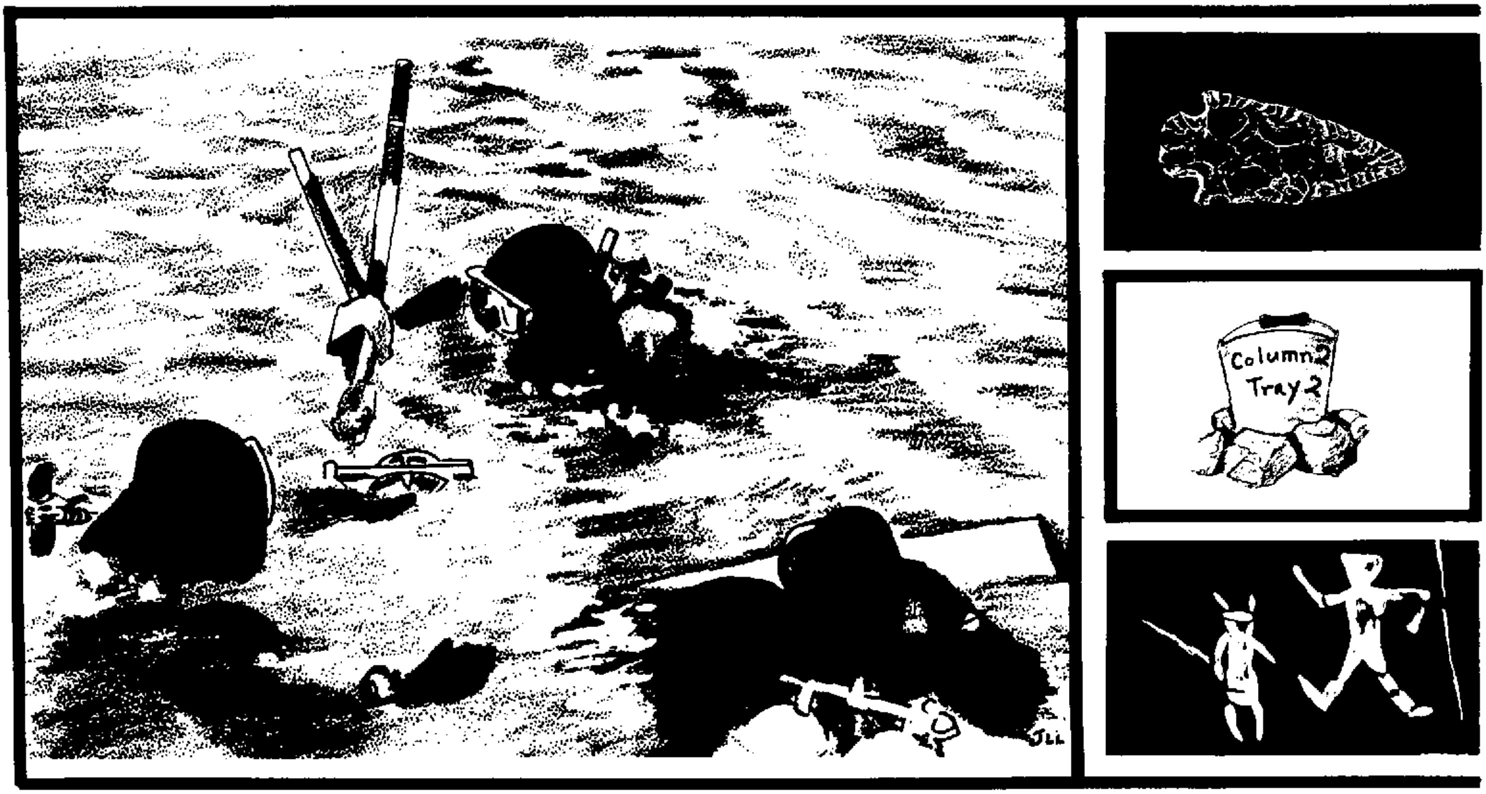
The Final Report of the

National Reservoir Inundation Study



Volume 2 · Technical Reports

THE FINAL REPORT
OF THE
NATIONAL RESERVOIR INUNDATION STUDY
VOLUME II

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INTRODUCTION TO VOLUME II

Volume II of the Final Report of the National Reservoir Inundation Study has two objectives. The first is to present detailed information on field and experimental research that provided most of the data that is summarized and synthesized in Volume I. Much of the data presented in that volume is the result of research conducted under contract to the National Reservoir Inundation Study by archeologists involved in mitigation research in proposed and existing reservoirs located throughout the country. Technical report No. 1 in Volume II provides a format for presenting summaries of the data and insights of these contributors within the context of their respective research efforts.

In the same category of contributions are several research projects that were designed in part by Inundation Study archeologists, but largely carried out by researchers from other scientific fields. The laboratory and field experiments on differential preservation of common cultural materials falls into this category, and details of the design, implementation and results of these experiments are included in this volume of technical reports.

The second objective of Volume II is to present information on reservoir cultural resource management, freshwater inundation effects, and archeological data retrieval and mitigation techniques that, because of their technical or specific nature, was judged to be beyond the scope of the summary volume (Volume I). An extensive annotated bibliography of freshwater inundation effects and related subjects is also included at the end of Volume II. This bibliography should provide an excellent starting point for future research on inundation impacts, freshwater differential preservation and reservoir cultural resource management, and is organized and cross-referenced in such a way that technical literature relevant to specific problems can be extracted with, we hope, a minimum of effort.

The organization of Volume II is similar to an appendix. Each of the contributions in this volume is a separate and independent report, and as such, stands alone (although many of the reports may refer to specific sections in Volume I, as well as other technical reports in Volume II). The only organization imposed in this volume involves the sequential ordering of reports that deal with similar research topics.

Technical Report 1 - Summary of Field Research of the National Reservoir Inundation Study (Carrell).

This report abstracts research results conducted by Inundation Study personnel and by various institutions and individuals under contract to the National Park Service. Field studies on inundation impacts were conducted at a number of reservoirs located throughout the U.S. The abstracts in this technical report are organized on a loose geographic basis and the research results relating to specific impacts and hypotheses are presented in an abbreviated form in order to facilitate data extraction.

Technical Report 2 - Techniques for Preinundation Site and Soil Stabilization (Ware)

State-of-the-art site and soil stabilization techniques are presented along with a discussion of their use and misuse in reservoir cultural resource mitigation programs.

Technical Report 3 - Laboratory Studies of Differential Preservation in Freshwater Environments (Ware and Rayl)

This report contains a detailed discussion of the laboratory research design and its implementation, emphasizing variable selection, control, and measurement procedures. The extensive results of the laboratory experiment are summarized in tabular form at the end of the report, and the report concludes with a brief discussion of the results, their implications, and suggestions for future research.

Technical Report 4 - Pollen Exine Deterioration and Preservation (Holloway)

A research program was conducted through the Departments of Antropology and Biology at Texas A & M University into the differential deterioration of pollen subjected to freshwater inundation. The report contains the results of the detailed quantitative analysis of biochemical impacts to pollen under controlled laboratory conditions and a field experiment.

Technical Report 5 - Seed Deterioration Under Inundation Conditions: An Experimental Study (Toll)

The specific emphasis of this report is the description and quantification of morphological changes in specific seed taxa under different inundation conditions in both the laboratory and field experiments over varying lengths of time. The goal was to isolate those factors which contribute to differential preservation and biological degradation of seeds.

Technical Report 6 - Field Studies of Differential Preservation in Freshwater Environments: Brady Creek Reservoir, Texas; Claytor Lake Reservoir, Virginia; and Virginia Polytechnic Institute and State University (Rayl, Simmons, and Benoit)

The design, implementation, and results of a field experiment into the differential preservation of a variety of cultural materials is presented. Materials used in the experiment included bone, ceramics, pollen, seeds, lithics, wood, shell, leather and paper.

Technical Report 7 - Preliminary Experiments in the Structural Preservation of Submerged Anasazi Units (Nordby)

The report concentrates upon a specific type of archeological site found in the Southwest. It details the nature of the impacts observed and presents a complete discussion of materials and approaches employed to protect and stabilize the sites from further destruction.

Technical Report 8 - An Experiment to Determine the Effects of Wet/Dry Cycling on Certain Common Cultural Materials (Murphy)

Technical report 8 complements reports 3 through 6 by offering insights into the impacts of wet/dry cycling on materials such as bone, shell, pollen and ceramics.

Technical Report 9 - The Applications and Limits of Underwater Archeology for Mitigating Impacts to Cultural Resources in Reservoirs (Murphy)

A summary of state-of-the-art underwater archeological data retrieval methods is provided to acquaint reservoir or cultural resource managers with the potential and limitations of these techniques. The application of underwater archeology to reservoir mitigation problems is also discussed.

Technical Report 10 - Guidelines for Data Collection and Site Preparation for Inundation (Carrell)

This report is a standardized set of guidelines for data retrieval and site preparation for inundation study research purposes. It serves not only to explicitly outline the techniques employed by most inundation study researchers thus far, but also permits future investigators to account for differences in data retrieval returns by using the same procedures in any future research.

Technical Report 11 - The Final Report of the National Reservoir Inundation Study: An Annotated Bibliography (Carrell)

This bibliography includes sections on: 1) effects of freshwater inundation research reports, 2) biochemical impact processes, 3) mechanical impact processes, 4) reservoir and nonreservoir freshwater impacts, 5) differential preservation of cultural materials, 6) dating and analysis techniques, 7) mitigation of reservoir impacts, 8) cultural resources management 9) underwater archeology and remote sensing, 10) legal aspects, vandalism, and antiquities violations along with miscellaneous publications relating to reservoir studies. Compiled over the 4½ year duration of the inundation study, it is intended to serve as a reference for the two volumes of the final report and to highlight areas of special interest in inundation impacts research.

SUMMARY OF FIELD RESEARCH
OF THE NATIONAL RESERVOIR INUNDATION STUDY

by
Toni L. Carrell

These reports resulted from the
National Reservoir Inundation Study
research and were prepared under contract
from the National Park Service

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INTRODUCTION

One of the major goals of the inundation study was to compile a data-bank containing information that would form a base for developing predictive models on inundation impacts and methods for site protection and preservation. This information was generated from field and laboratory research and was designed for use as primary references for the inundation study in the preparation of the final report of findings. Ultimately, this information should also be used by land managers and archeologists in order that reasoned decisions can be made in the interest of cultural resources management.

The selection of reservoir areas in which inundation research was conducted was based upon geographical, geological, and cultural diversity. Where possible, a consideration was also given to reservoir function, e.g., flood control, irrigation, etc. Not all of the reservoirs initially considered by the inundation study core team were ultimately used. Limitations of time, and money, prior documentation of sites in the case of previously flooded resources, accessibility of the site and logistical support, etc., eliminated many reservoir areas. Whenever possible, the inundation study employed the services of the archeologists who originally surveyed or excavated the site under consideration in an effort to get a better understanding of the impacts that could be attributed to inundation.

The primary references resulting from field work undertaken contain raw data which address a wide variety of hypotheses presented in the _Preliminary Report of the National Reservoir Inundation Study_ (Lenihan et al. 1977). These references may also be of interest on a regional level to cultural resource managers. The data was compiled in a variety of forms; i.e., field work undertaken by the core team, contracted reports and analyses, reservoir assessment trips, experiments initiated by the inundation study and carried out in cooperation with other agencies or institutions (discussed elsewhere in Volume II), and reports not contracted for by the inundation study but organized around the inundation study hypotheses on a voluntary basis by the principal investigator.

This section of the technical reports includes abstracts from reports received as a result of inundation study coordination and contracts and, where pertinent, a summary of findings resulting from field assessments. The results from each of the research efforts are emphasized. All are on file with the NRIS and are included in the annotated bibliography in this volume. (The abstracts are organized on a loose regional basis, by reservoir, to facilitate their use by the reader.)

Western States and Pacific Northwest:

- California
- Oregon
- Washington
- Nevada
- Idaho

Southwest and Rocky Mountains:

- Montana
- Utah
- Wyoming
- Colorado
- North Dakota
- South Dakota
- New Mexico
- Arizona
- Texas
- Oklahoma

Midwest and North Atlantic:

- Minnesota
- Wisconsin
- Iowa
- Nebraska
- Kansas
- Missouri
- Illinois
- Michigan
- Indiana
- Ohio
- Maine
- Vermont
- New York

Midwest and North Atlantic (Continued):

- New Hampshire
- Massachusetts
- Connecticut
- New Jersey
- Rhode Island

Mid-Atlantic and Southeast:

- Kentucky
- Tennessee
- North Carolina
- South Carolina
- Georgia
- Alabama
- Mississippi
- Arkansas
- Louisiana
- Delaware
- Pennsylvania
- Maryland
- West Virginia
- Virginia
- Florida
- Washington, D.C.

CHESBRO RESERVOIR, CALIFORNIA

ARCHEOLOGICAL RESOURCES OF CHESBRO RESERVOIR

INTRODUCTION

The Archeological Resources of Chesbro Reservoir (Winter 1977) was written in fulfillment of a contract between the Soil Conservation Service and Dr. Joseph C. Winter, an anthropologist affiliated with San Jose State University, California. The research undertaken at Chesbro was initiated as a result of plans to increase the height of the dam and raise the pool level by 11 feet. The report evaluates the research potential of the cultural resources within the reservoir and briefly outlines a program to mitigate, on a site-specific basis, the adverse mechanical impacts of inundation. Although the report was not contracted for by the National Reservoir Inundation Study, Dr. Winter coordinated on his own initiative with project personnel to ensure that some of the results of his investigations could be integrated into the overall research strategy of the Inundation Study.

As a result of consultation with the Inundation Study archeologists and a review of a draft copy of the Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977), Dr. Winter recommended that the Inundation Study be contracted to work with the Soil Conservation Service, and the archeological consultant contracted to direct the follow-up mitigation efforts, in the development of a two-part conservation/data-retrieval program. This program should be aimed at: (1) conducting limited testing to gather any additional baseline data needed to assess the impacts of inundation upon selected dating and analysis techniques as detailed in the research design of the Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977) and (2) implementing site-specific protective techniques in an effort to prevent further erosion of a significant archeological site located within the fluctuation zone of the reservoir.

The program suggested by Dr. Winter is a unique approach to the problem encountered by many individuals faced with mitigating inundation impacts. The overall conservation orientation, coupled with limited data retrieval to address specific inundation concerns and local research problems, urges site protection rather than total excavation of the resources. "A much more reasonable and productive alternative [to total excavation] is to protect and preserve [the sites] from continued inundation . . . . the Chesbro sites hold enormous value for generating experimental data about means of preserving sites . . . and provides a unique opportunity to develop a totally new and extremely necessary experimental archeology program" (Winter 1977:59).

RESULTS

Several categories of impact were noted at the five sites investigated by Winter. One site, CA-SCL-52, provided an ideal situation for the controlled examination of differential effects of inundation. It is a large, multicomponent site which is located at the edge of the maximum reservoir pool; during periods of increased pool levels, only half of the site is inundated.

Soil Chemistry Analysis

Preliminary analysis of four soil samples collected from both the inundated and noninundated areas of CA-SCL-52 revealed the following:

pH of soils: The pH values in the noninundated area of the site, 8.0 and 7.6, were higher than those values from the inundated area, which were 7.0 (Winter 1977:52). It appears that the pH of the inundated area of the site is being lowered, assuming that other independent variables are not involved. This supports the hypothesis of the NRIS (Lenihan et al. 1977:58) which states that "absolute pH values will be altered by the effects of inundation . . . [and that] In a loosely compacted soil stratum, pH values will approach the reservoir pH value if this loose stratum does not lie below a compact soil stratum."

Phosphate: The phosphate values at CA-SCL-52 exhibited great differences between the inundated and noninundated samples. Phosphorous levels of 200+ lbs/acre were found in the noninundated samples, whereas the inundated samples yielded levels of 100 lbs/acre and 50 lbs/acre (Winter 1977:51-52). The loss of phosphate as a result of inundation has been hypothesized by the NRIS (Lenihan et al. 1977:59).

Nitrates: The nitrate levels between the flooded and unflooded areas of the site were not noticeably altered. Values in both areas were 10 lbs/acre (Winter 1977:51). The hypothesis offered by Lenihan (1977:59) suggests the loss of the chemical will be proportional to the length of inundation. Winter does not discuss these results *vis a vis* the hypothesis, and no information was available on the duration of inundation at the nitrate sample collection area.

Potassium: The NRIS has hypothesized (Lenihan et al. 1977:60) that inundation would adversely affect potassium concentrations in the upper strata of a site but should not affect concentrations of potassium below the soil water saturation levels. Samples were collected from the upper 29 cm of CA-SCL-52, so only the first half of the NRIS hypothesis was tested. The potassium values in the unflooded areas were found to be 200 and 300 lbs/acre, whereas the flooded areas yielded values of 100 and 140 lbs/acre (Winter 1977:53). The potassium concentration in the periodically flooded upper 20 cm of the site appears to be dissolving at a rapid rate, adversely affecting potential returns from this type of soil chemistry analysis.

The soil chemistry conducted at Chesbro Reservoir was of the most preliminary nature. Due to the limited sample size and collection strategy, the results can only be suggestive rather than statistically significant. A follow-up study at Chesbro (see this section, Stafford and Edwards 1980) provides greater insight into differential impacts to soil chemistry analysis.

Mechanical Impacts

Mechanical impacts to the five sites included siltation, erosion, and slumping. Sites CA-SCL-223 and 246 were found to have up to a meter of silt covering portions of them (Winter 1977:49). Shoreline erosion at CA-SCL-52 had removed at least 5 cm of soil and cultural material. Redeposition of the mixed material in a lower area of the site was documented during the drawdown of the reservoir pool (Winter 1977:49).

Resistance of cultural remains to the effects of direct mechanical activity is a primary concern of the National Reservoir Inundation Study. A "Susceptibility to Mechanical Impact Chart" in the Preliminary Report of the National Reservoir Inundation Study (Lenihan 1977:19-20) assigns to various cultural manifestations relative predictive values related to their ability to withstand mechanical impacts. The scale used was broad -- 0 to 3 -- with 1 indicating lesser susceptibility and 3 greater susceptibility.

The Chesbro sites included soil midden; surface lithics, bone, and charcoal; historic house foundations; and subsurface features. A resistance value for each of these cultural features to mechanical activity, suggested by Lenihan et al. (1977:19-20), is given below, along with values assigned based upon observation of impacts at each site. These values were determined based upon written descriptions in Winter's report. Also provided is an educated guess as to the reason for impacts observed.

SUSCEPTIBILITY TO MECHANICAL IMPACTS

Site	Cultural Manifestation	Susceptibility Predicted/Observed	Reason
4-SCL-52	Soil Midden	2/2	Gentle slope, reduced impact of wave action
	Surface lithics, bone charcoal	1/2	Wave action, slope, periodic drawdown

SUSCEPTIBILITY TO MECHANICAL IMPACTS (Cont'd)

Site	Cultural Manifestation	Susceptibility Predicted/Observed	Reason
4-SCL-52	Subsurface features	1/0	Midden not becoming gelatinous, consistency helping to maintain feature integrity
4-SCL-246	Soil midden	2/2	Wave action during drawdown, result of drought
	Subsurface features (charcoal lens, fire-cracked rock)	1/0	Midden not becoming gelatinous, consistency helping to maintain feature integrity
4-SCL-245	Surface lithics	1/3	Human activity, direct disturbance
4-SCL-224	Surface lithics	1/1	Moderate human disturbance
	Subsurface features (firecracked rock, charcoal lens)	1/2	Erosion due to bank slumping/undercutting
4-SCL-223	Soil midden	2/2	Erosion due to drawdown and reestablishment of stream channel
	Subsurface foundation concrete	0/0	Site generally undergoing siltation, concrete maintaining integrity

Although assignment of susceptibilty values is entirely subjective, useful information can be obtained by this method. It appears that soil midden does not float away or become gelatinous as has been hypothesized by Johnson (1971) and others. Subsurface features are maintaining their integrity and not sinking into a more consolidated soil profile, even after 20 years of continuous inundation. Disturbance of surface lithics and other remains is tied directly to slope angle and human activity. The gentler the slope, the less impact wave action has on displacement of surface artifacts. The most severe impact to the surface features in Chesbro Reservoir was caused by direct human activity. Following that, bank slumping and shoreline erosion caused lesser impacts, the former causing the greater of the two.

Agreement with NRIS hypothesized impacts occurred in 5 cases; lesser impacts than predicted occurred in an additional 2 cases; greater impacts than hypothesized occurred in only 3 of the 10 features evaluated.

Other Impacts

Human Impacts: Other factors have influenced the preservation and/or deterioration of the Chesbro sites. As a result of a nearby boat landing, CA-SCL-245 has been severely impacted. Use of the area by boaters, campers, and fishermen has resulted in almost total destruction of the site (Winter 1977:49). During the 1975-77 drought episode in the western states, Chesbro Reservoir experienced unusually low water levels. The heavily silted flood plain provided an ideal location for off-road vehicles, and almost all of the sites were impacted (Winter 1977:49).

Faunal/Floral Impacts: An increase in ground squirrel activity in the periodically inundated areas of CA-SCL-52 was noted by Winter (1977:48). Differential vegetation patterns in the undisturbed, silted, and periodically inundated areas of the site were found (Winter 1977:46). The thick grasses and root matt, found in the undisturbed areas, did not become reestablished adequately for site protection during periods of fluctuating water levels. The erosion of the periodically inundated areas increased as a result of limited groundcover.

Resurvey Potential

Lenihan (1977:74) states that the two factors

> that will pose the greatest limitation in post-inundation survey are siltation and mechanical disturbances. . . . Standard archeological survey procedures conducted to relocate sites ...will not yield comparable pre- and post-inundation results ...[it] being most evident in sites that are buried beneath silt...

Resurvey in the lower areas of the reservoir was severely limited due to heavy siltation. Site CA-SCL-52 was partially buried by up to a meter of silt in some portions. Positive site identification from a former survey and determination of site boundaries were hampered by silt cover (Winter 1977:13-17). A similar situation occurred at CA-SCL-246 (Winter 1977:27-33).

Dating Techniques

Carbon-14 samples were collected from three sites in Chesbro Reservoir: CA-SCL-52, 223, and 224. The sites were roughly dated, based upon analysis of materials collected, to an occupation period between 1500 B.C. and 1800 A.D. Lenihan et al. (1977:84) hypothesized that "Carbon-14 samples taken... after inundation will yield dates similar to those... [taken] prior to immersion, within the limits of statistical confidence." Results of analysis dated the three sites as follows (Winter 1977 personal communication):

CA-SCL-52	-	AD 1320 ± 100 (UCR 537)
CA-SCL-223	-	AD 1520 ± 100 (UCR 538)
CA-SCL-224	-	AD 375 ± 100 (UCR 551)

The dates are well within the estimated occupation period given for the sites and are supportive of the NRIS hypothesis. It should be noted that CA-SCL-52 has undergone periodic inundation, 4-SCL-223 had been continuously inundated for over 20 years, and 4-SCL-224 has never been flooded.

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1977 "The Archaeological Resources of Chesbro Reservoir." Society for California Archaeology Occasional Papers in Cultural Resources Management No. 1.

A BASELINE DATA STUDY
OF THREE ARCHAEOLOGICAL SITES AT CHESBRO RESERVOIR

INTRODUCTION

The prolonged drought conditions in the Western states during 1976 and 1977 resulted in lowered water levels in numerous reservoir areas. Rivers were once again in their channels; bridges and foundations of dwellings were exposed. Numerous prehistoric sites, formerly inundated, were again accessible. The drought provided an ideal situation in which to gather data on the impacts of inundation on cultural remains.

Chesbro Reservoir was extremely low during the summer of 1977; several sites which had been continuously flooded since initial filling of the reservoir were exposed. It was within this milieu that field work was undertaken which would result in A Baseline Data Study of Three Archaeological Sites at Chesbro Reservoir by Jean Stafford and Robert Edwards (1979). This study was conducted under a contract between the National Park Service and Rob Edwards, an archeologist affiliated with Cabrillo College, who acted as principal investigator. Jean Stafford, an experienced and highly competent archeologist, assisted in all phases of the study, contributed to the organization of the research, and was the principal author of the final report.

> The main purpose of the field work was twofold. The short-term goal was to retrieve a maximum amount of base-line data while the reservoir was low--data which would provide the necessary background for generating future hypotheses and for testing those proposed by the Inundation Study Team. The long-term goal was to set up experimental conditions which would be rechecked in the future, after inundation and downdraw have again occurred. This study would help to quantify the impacts caused by inundation (Stafford and Edwards 1979:1).

Three sites were selected for investigation. CA-SCL-52 is a major habitation site which has been only partially inundated. The inundated areas are exposed on a seasonal basis. This site was ideal for intrasite comparisons of impacts of seasonal flooding and wave action. Site CA-SCL-223 was selected because it had been continuously flooded until the drought; it was hoped that data on long-term inundation impacts could be gleaned from study of this site. The last site, CA-SCL-224, is located in the upper reaches of the reservoir and has never been flooded. Erosion from stream channelization and wave action is adversely impacting the site (Stafford and Edwards 1979:2).

> Comparison of data from these three sites--one partially inundated, one constantly inundated, and one never inundated--should generate the greatest number of hypotheses and allow the widest range of testing techniques and data collection (Stafford and Edwards 1979:4).

BASELINE DATA COLLECTION

The major emphasis of the research was placed on gathering baseline information on selected areas of potential impacts. A critical means of quantifying physical changes in a site over time and exactly relocating sample collection areas or features is the establishment of a grid system.

Site Preparation

Datums and Grid Points: Primary and secondary datums were installed at all three sites according to National Reservoir Inundation Study guidelines (Lenihan et al. 1977:129-130). The site grid method used was based upon the cartesian system. Since the primary datum was located at the center of the grid, cardinal directions were added to numerical designations to eliminate negative numbers (Stafford and Edwards 1979: 42-43). Markers used for specific grid points were twelve-inch-long galvanized iron spikes with a zinc washer which had been die stamped with a grid point number. As grid points were located, the spikes were driven flush with the ground surface. Metal spikes were used in the hope that, should siltation cover them, a metal detector could be used for relocation. This grid formed the basis for all of the sample collection and contour mapping at the sites.

Contour Surveying: CA-SCL-52 and 223 were surveyed for contour elevations, and topographic maps of each site were produced. A ten centimeter contour interval map was produced for CA-SCL-52. This contour interval was selected in an effort to quantify the effects of erosion and deposition of soil at the site.

> Reference to printed materials produced... before inundation such as geological survey maps, reservoir maps and stereo pair aerial photographs are inadequate... contour intervals are ordinarily too great to be of much value, especially if an archeological site is very level. For example, erosion of the top ten centimeters of a site may be a significant loss of information on a very shallow site but this difference would be almost impossible to detect by comparing the twenty foot contour interval...maps made before and after inundation. In short, the scale of such photos and maps is such that it prevents determination of significant contour changes...which are relatively very small... (Stafford and Edwards 1979:53).

Coring and Soil Sample Preparation: The purpose of the subsurface examinations were, in addition to determining site limits and depths, to gain an understanding of the general stratigraphy and any impacts already resulting from inundation. Soil samples for chemical and textural analysis were also collected at this time. "Comparative analysis... between [the] three sites... would suggest the kinds of changes the inundated site had already undergone during...twenty years... [of inundation]" (Stafford and Edwards 1979:54).

A detailed explanation of the coring techniques and equipment used is provided by Stafford and Edwards (1979:64-75). Problems encountered and a comparison of sampling devices are also discussed.

Mechanical Impacts

Erosion, redeposition, and mixing of site soils, along with heavy sedimentation, are the primary factors affecting the sites in Chesbro Reservoir.

CA-SCL-52: The northeastern portion of the site appears to be eroding; an estimate of ten to twenty centimers of soil loss is based upon pedestalling of rock features on the surface (Stafford and Edwards 1979:84). Because 52 is a gently sloping site, terraces from wave action have not formed; however, the dark midden soils are "being eroded from the wave zone and spread in thin layers toward the north...and east...out-side the assumed original site limits" (Stafford and Edwards 1979:85).

A comparison of contour mapping data from the inundated and non-inundated areas of the site further suggest erosion of the northeast portion of the midden mound.

Depth of silt overburden was determined through coring. The fine texture and even color of the silt clearly contrasted with the dark midden soils. The north and west areas of the site exhibited silt deposition; greater quantities of silt are being deposited at lower site elevations (Stafford and Edwards 1979:87).

> The amount of positive or negative impact that this site is experiencing from siltation and deflation may not appear traumatic at this point. But maximum siltation over midden areas is 30 centimeters ... and estimates of deflation are at least 5 centimeters. This deflation ... represents about 1/20 of the depth of the midden--a negative impact in terms of irretrievable data loss (Stafford and Edwards 1979:90).

CA-SCL-223: Winter (1977) suggested earlier that this continuously inundated site had suffered from reservoir siltation. Coring at the site did not support this hypothesis. However, some areas of the site did have a thin 1-2 centimeter layer of sterile coarse, rocky compacted soil. Its gravelly texture suggests that it may have been deposited on a natural course alluvial deposit (Stafford and Edwards 1979:92).

Further evidence to suggest little or no sedimentation is the concrete walk and remaining house foundations which had no sediment deposits on them (Stafford and Edwards 1979:92).

Stereo pair aerial photographs taken in 1950, prior to flooding, show a distinct drop in elevation at the site. Erosion of the exposed midden by wave action is not suggested as an impact (Stafford and Edwards 1979:93). Minimal erosion and siltation of this site, to date, may be due to its location in a protected, leeward cove.

CA-SCL-224: This site has never been inundated; mechanical impacts here have been limited to the north face of the site where stream channelization is undercutting and eroding the site.

The charts on the following pages summarize the types of relative impacts and estimates of impact values on site soils and the relative mechanical impacts to cultural remains due to reservoir conditions (after Stafford and Edwards 1979:97-98).

Soil Chemistry Analysis

pH of Soils: At site SCL-52 it appears that pH is leaching out to depths of at least 1 meter in areas where wave action has occurred (Stafford and Edwards 1979:112). "Siltation over portions of the site, and redeposition of midden particles are causing misleading surface representations of true subsurface pH values rendering surface pH ineffective in determining subsurface areas of...cultural activity" (Stafford and Edwards 1979:112).

The continuously inundated site, SCL-223, also exhibited loss of pH content. "...Silt deposition, heavy periodic inundation, midden erosion and redeposition...render pH an ineffective tool for surface study" (Stafford and Edwards 1979:110).

Phosphorus: In contrast to the pH values, phosphorus appears to remain in surface midden located in the wave action zone and in the periodically inundated areas of SCL-52 (Stafford and Edwards 1979:124). Some slight leaching does occur at the 0-20 centimeter levels where there is no silt overburden; where silt was present it appears to have retarded surface alteration of this chemical.

SPECULATIONS ON RELATIVE MECHANICAL IMPACT
DUE TO GENERAL RESERVOIR CONDITIONS*

Site	Cultural Manifestations	Estimated Susceptibility Value	Comments
CA-SCL-52	Midden soil: Northeast portion	2	Wave action and erosion
	Northwest portion	0	Silted over
	Lithic surface scatter	1	
	Ground and heat-altered stone	1	
	Bone component of midden	2	
	Shell component of midden	2	
	Concrete structures	0	
	Brick rubble	1	
	Lithic scatter	1	
	Midden soils	1	
CA-SCL-224	Hearth features (currently)	3	Continued severe slumping of Llagas Creek bank and erosion
	Hearth features (when inundated)	3	
	Asphalt roadway	0	
	Lithic surface scatter	1	

Key:
0 = impact CA-SCL-223
1 = minimal impact
2 = moderate impact
3 = severe impact

*After Stafford and Edwards (1979:98)

Significant phosphorus values were still evident in the top 80 centimeters at site SCL-223, although these appeared to have been affected slightly, exhibiting lowered values. It is possible that "inundation... [may have] an effect on decreasing values of phosphorous ...in midden soils that are well aerated after long periods of inundation..." (Stafford and Edwards 1979:126).

Soil Textural Analysis: At site SCL-52 and SCL-223 there was no difference in the soil particle size in the inundated and noninundated areas of the sites; further, there were no distinct differences in the midden and nonmidden areas (Stafford and Edwards 1979:129-130). Clearly, soil textural analysis was not a useful tool in defining site limits and/or depths in this case. Inundation has not, apparently, affected the texture of the soils. This supports the hypothesis of Lenihan et al. (1977:191) that soil textures would not be impacted by inundation.

Dating Techniques

Carbon 14: Only one sample was collected from a rock feature at SCL-224. Results were inconclusive due to a number of factors, including a very small sample size. Rodent activity was also very pronounced at this site and contamination of the sample was a strong possibility (Stafford and Edwards 1979:136-137).

Thermoluminescence Dating: Sample analysis results tentatively suggest that periodic inundation does not impact TL analysis. Continuous inundation, however, does adversely impact the results of this dating technique (Stafford and Edwards 1979:138-146).

Other Impacts

Faunal: Site SCL-52 has been impacted in two very different ways. First, cattle were known to have pastured on and near the site in the past. Although the site is not presently used for grazing, the effect of pastactivity on the chemical content of surface soils is not clear (Stafford and Edwards 1979:83). Secondly, two species of rodents have impacted the midden area of the site. Ground squirrel activity has been much more destructive than gopher intrusions. "Rodent activity appears much more pronounced in these [inundated] areas than in never inundated areas..." (Stafford and Edwards 1979:83). It is suggested by Stafford that seasonally inundated soils are going to receive greater burrowing impacts from gophers and ground squirrels than noninundated areas (1980:83).

Human Impacts: During the drought episode, vast areas of the reservoir were exposed. Site SCL-52 was impacted by off-road vehicles being driven in circles around the site. In the lower areas of the reservoir, vehicle tracks were quite pronounced in the soft soils. These kinds of activities can cause considerable damage to surface features and can contribute to site erosion and deterioration (Stafford 1980:84).

THE EXPERIMENTS

Two experiments were set up as a part of the Chesbro study. These were designed to be longevity studies and therefore to be left undisturbed for future research.

Effects on Faunal Remains

Fifteen sets of identical faunal remains were placed in cores at each of the three sites studied. All cores were located within midden soils in areas that would undergo different rates of inundation. That is, one sample each was placed in a noninundated area, one in a continuously inundated area, and one in a seasonally inundated area (Stafford and Edwards 1979:165).

Sample cores included mammal, bird, fish and marine shell. All samples were treated in an identical manner; a complete discussion of preparation and placement in the cores is presented by Stafford and Edwards (1979:163-170). This study was designed to quantify rates of deterioration or preservation of these classes of artifactual remains.

Results of this experiment are discussed elsewhere in this section of the Technical Reports (Stafford and Edwards 1980).

Artifact Displacement Study

Removal and mixing of surface artifactual remains, coupled with deflation and redeposition of midden soils, constitute a major impact to site interpretation. The second Chesbro experiment was aimed at gathering detailed information on both the rate and depth of site deflation coupled with artifact displacement or removal.

Four two-meter-square units on CA-SCL-52 were carefully mapped and specific contour elevation information recorded. The units were placed at different elevations so that

> ...one unit (A) [was] well below the high water line and ...subjected to inundation for the greatest period of time; and two units (B and C) within the wave action zone, with Unit B just above high water line and Unit C just below the never-inundated portion of the site. A fourth unit (D) was placed in a never inundated area for comparative analysis. This latter will serve as a control unit (Stafford and Edwards 1979:174).

Information recorded for each unit included detailed descriptions of both natural and cultural material found on the surface, dimensions, weight, and identifying attributes; soil texture and color; rodent disturbance; vegetation; and so forth. Surface soil pH samples were also taken for each unit and the values recorded.

The table on the following two pages summarizes the predicted impacts to the test units (after Stafford and Edwards 1979:194-195).

The second half of this experiment consisted of placing selected items on the surface of the mapped units (A-D). "By placing the same item at the same location on all four units a comparison of differential displacement could be made between seasonally inundated, shoreline, and non-inundated zones" (Stafford and Edwards 1979:197).

SPECIFIC PREDICTIONS OF RELATIVE IMPACTS ON ARTIFACTS AND SOIL COLOR, TEXTURE, AND pH CONTENT ON SCL-52 MAPPED UNITS*

KEY TO NEGATIVE IMPACTS

4 = complete loss
3 = severe impact
2 = moderate impact
1 = slight impact
0 = no impact
+ = positive impact

UNIT DESCRIPTIONS

A Lowest elevation, 5% slope, seasonally inundated for longest period
B Lower wave zone (full reservoir), 2% slope, assumed longest wave impact period
C Upper wave zone (full reservoir), 4% slope, wave impact shortest period
D Never inundated, 2% slope, border of reservoir

AGENT OF DATA LOSS	PREDICTED IMPACT		RELATIVE IMPACT (by unit) A	B	C	D
Seasonal inundation (wet/dry cycles)	Soil color change		0	0	0	0
	Leaching of pH		3	2	2	0
	Soil texture change		0	0	0	0
	Artifact damage (cracking/deterioration) on	Wood	3	3	2	0
		Charcoal	1	1	1	0
		Bone	2	2	2	0
		Shell	2	2	2	0
		Metal	1	1	1	0
		Glass	1	1	1	0
		Stone	1	1	1	0
Wave and current action	Artifact damage (mechanical impact) on	Wood	2	2	2	0
		Charcoal	2	2	2	0
		Bone	1	2	2	0
		Shell	1	2	2	0
		Metal	0	0	0	0
		Glass	1	2	2	0
		Lithic scatters	1	1	1	0
		Ground Stone	1	1	1	0

*After Stafford and Edwards 1979

AGENT OF DATA LOSS	PREDICTED IMPACT	RELATIVE IMPACT (by unit) A	B	C	D
Wave and current action	Introduction of floated foreign materials	0	3	3	0
	Loss of horizontal artifact context: buoyant objects	4	3-4	3-4	0
	non-floating objects	1	2	2	0
	Loss of vertical context from deflation	2	1	1	0
Change in vegetation	Loss of vegetation, increased soil erosion, loss of provenience	2	0	0	0
	Increase in vegetation, deterrent to erosion and provenience loss	0	+	+	0
Increase in rodent activity	Disturbance of artifact context	1	3	2	1
Changes in use of full reservoir borders	Decrease in cattle grazing, no removal of vegetation	0	+	+	0
	Increase in police protection of basin area	+	+	+	+
	Increase in public use, vandalism or accidental damage to artifacts	0	0-1	0-1	2
Changes in use of full reservoir basin	Boating wave action increases	1	2	2	0
Changes in use of basin after drawdown	Increased public access: collection of artifacts	1	1	1	1
	destruction of artifacts	1	1	1	1
	unintentional damage	1	1	1	1
	Increased vehicle use: damage to stratigraphy and artifact provenience	1	0	0	1
	damage to artifacts	1	0	0	1

The objects selected for placement on the units varied in surface texture, density, porosity, weight, and shape. "Movement of these objects within one unit, where environmental conditions were assumed to be equal throughout... would suggest the [artifactual] attributes contributing to the greatest loss of provenience" (Stafford and Edwards 1979:197).

Forty-three different items were used in each unit; one piece each was placed in the four test units and a control piece retained for later comparisons of artifact deterioration. As far as reasonably possible, each class of artifact was the same size, age, and condition. Objects selected were generally small enough to be comparable to those typically found on prehistoric sites (Stafford and Edwards 1979:197). It was hoped that the objects were also small enough to avoid attraction when left unprotected on the units and to minimize the appearance of "trash" on the reservoir margins.

One class of material left on the units was removed immediately as a result of either casual or deliberate vandalism. Sears shotgun shells were placed on Unit A and mapped in; examination one week later revealed that all of the shells had been removed. This episode merely reinforces the selective nature of vandalism; artifacts that exhibit deliberate shaping or tool function, such as projectile points or mortars, are more often removed from sites than generalized lithic remains (Stafford and Edwards 1979:173).

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INUNDATION EFFECTS ON THERMOLUMINESCENCE RESPONSE OF ARCHAEOLOGICAL LITHICS FROM CHESBRO RESERVOIR

INTRODUCTION

"Inundation Effects on Thermoluminescence Response of Archaeological Lithics from Chesbro Reservoir" was written in partial fulfillment of an ongoing analysis contract between Dr. Ralph Rowlett, a researcher affiliated with the University of Missouri, and the National Reservoir Inundation Study. The analysis was designed to test the hypothesis:

> [Thermoluminescence] Samples that have been inundated for 20% or more of their archeological lives will be adversely affected, and will not yield data comparable to that yielded by samples that have not undergone such long-term immersion (Lenihan et al. 1977:103).

RESULTS

The samples submitted were selected from two sites in Chesbro Reservoir which have undergone continuous and periodic inundation for a period of 20 years. A third site, which had never been flooded, was also sampled.

> Initial results from this most limited study seem to imply that consistent inundation will upset burial context relationships enough to disturb TL dating....This implication should be accepted as not more than a working hypothesis, however, as the set of samples under study were lacking in certain vital characteristics to enable the reliable confirmation of the hypothesis that inundation has severely deleterious effects for TL response. The results do not disconfirm the hypothesis, but point weakly toward its confirmation. Periodically inundated sites, at least at the rate of seasonal inundation experienced in the Chesbro Reservoir, do not harm the samples (Rowlett and Bates 1979:5).

Rowlett concludes his report with the admonition that direct communication with the thermoluminescence laboratory on such matters as sample size, collection <u>vis-a-vis</u> stratigraphic levels, and independent dating information would have "provided a clearer evaluation of the main hypothesis" (Rowlett and Bates 1979:5).

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RESULTS OF TESTING INUNDATION IMPACTS ON SITE CA-SCL-52 AT CHESBRO RESERVOIR

INTRODUCTION

The "Results of Testing Inundation Impacts on Site CA-SCL-52 at Chesbro Reservoir" (Stafford and Edwards 1980) presents a discussion of several tests that were set up in the fall of 1977 to study the effects of inundation at site CA-SCL-52 in Chesbro Reservoir. Work was performed under a contract between the National Park Service and Rob Edwards, an archeologist affiliated with Cabrillo College, Aptos, California.

This study was designed as a follow-up on the baseline study by Stafford (1980) abstracted in this section of Volume II. The baseline study included placing a permanent grid over the site, collecting of detailed contour information, determining of site limits, and coring for subsurface chemical and textural analyses. Four experiments were set up to test selected hypotheses suggested by Lenihan et al. (1977).

This report addresses the short-term results of the following experiments:

1) effects of seasonal inundation on the provenience of surface artifacts;

2) effects of seasonal inundation on the preservation of artifacts;

3) effects of seasonal inundation on stratigraphy; and

4) effects of inundation on the subsurface faunal component of archaeological sites (Stafford and Edwards 1980:1).

RESULTS

Hydrodynamic Sorting or Removal of Artifacts

The purpose of this experiment was to identify and quantify the impacts of inundation which contribute to the redistribution of surface artifacts and other site constituents.

The test at CA-SCL-52 involved mapping existing surface material on four two-meter by two-meter surface units and the placement on these units of selected modern test materials. (See Stafford and Edwards 1980 for complete discussion of the setup of this experiment).

> The units differed in elevation, with Unit A at the lowest point below the wave zone, where it is seasonally inundated for the longest period; Unit B in the lower wave action zone when the reservoir is full; and Unit C in the upper wave action zone. Unit D, at the highest elevation, has never been inundated and was to serve as the control unit (Stafford & Edwards 1980:4).

After two seasons of inundation the units were reexamined. Changes in the location of the surface remains were of three kinds:

1) loss of objects from the unit surface,

2) change of provenience within the unit, and

3) introduction of new materials (Stafford and Edwards 1980:6).

Predictably, units B and C in the wave action zone exhibited a greater displacement of inventoried materials by way of complete loss and change of provenience. Comparatively, the loss of data was the least at Unit A. It should be noted, however, that units B and C were subjected to a good deal of rodent activity, whereas on Unit A there was no activity during the initial mapping in 1977 and only one hole in 1979. Of the items not remaining *in situ* on Units B and C, the degree to which rodent activity vs. reservoir hydraulics has been a contributing factor in their disappearance is not understood.

Further, assuming that there were little or no wood fragments and pieces of plastic on the surface of the test units prior to initial flooding, then all of the floatable materials found on Units A, B and C have been introduced as a result of water movement over these units. Control Unit D counts of floatable materials were used as the basis of comparison.

> If the relative amounts of surface materials found in 1977 and 1979 represents the pattern throughout the history of the reservoir, then the vast majority of items on [the surface of] Units B and C are being moved by reservoir agents (Stafford and Edwards 1980:11).

The implications for redistribution and missing surface remains are clear. The loss of floatable artifacts on all units was 88-100% (Stafford and Edwards 1980:13). Size appears not to be as significant an attribute in provenience loss for objects that float; rather density may be the key variable here (Stafford and Edwards 1980:14). A complete discussion of the nature and amount of displacement of all of the surface artifacts is provided by Stafford and Edwards (1980:18-27). The results were mixed, but tentative findings suggest that there is a tendency for objects that are "heavy or greater in density, smooth in texture and rectangular in shape to remain *in situ* more often" (Stafford and Edwards 1982:23).

Differential Preservation

Artifact Preservation: The same objects used in the test of hydrodynamic artifact sorting were examined prior to placement on the test units and after recovery to determine the nature of artifact deterioration sustained over the two-year period of exposure. Stafford and Edwards predicted two primary agents of data loss from seasonal inundation and the relative impacts by unit for each type of artifact class. Impacts were rated from 0 (no impact), 1 (minimal impact), 2 (moderate impact), to 3 (severe impact). The following table is a summary of their predicted/observed impacts.

Chesbro Relative Impact Chart

Agent of data loss	Predicted impact	Material	Relative Impact by Unit* Predicted/Observed			
			A	B	C	D
Seasonal inundation (wet/dry cycles)	Artifact damage from alternating waterlogging/ dessication cycles on:	Vegetable Matter	3/3	3/*	2/*	0/1
		Charcoal	1/*	1/*	1/*	0/2
		Bone	2/*	2/*	2/*	0/*
		Shell	2/2	2/*	2/*	0/1
		Metal	1/3	1/2	1/2	0/*
		Glass	1/*	1/1	1/*	0/0
		Stone	1/1	1/1	1/1	0/0
Wave and current action	Artifact damage from mechanical impact on:	Vegetable Matter	2/1	2/*	2/*	0/*
		Charcoal	2/*	2/*	2/*	0/*
		Bone	1/*	2/*	2/*	0/*
		Shell	1/0	2/*	2/*	0/0
		Metal	0/0	0/0	0/0	0/*
		Glass	1/*	2/2	2/*	0/1
		Stone	1/2	1/2	1/0	0/0
		Lithic Scatters	1/*	1/*	1/*	0/*

*After Stafford & Edwards 1980:28

*Prediction cannot be confirmed or denied due to lack of recoverable samples

The impacts resulting from wetting and drying appear to be generally more severe than those from mechanical impacts, at least in this limited test. "This is especially true of vegetable matter and tin metals... The most pronounced mechanical impact was that of abrasion. This was greatest on the side... placed against the soil..." (Stafford and Edwards 1980:4). Because of the limited sample size of recovered materials, all predictions and observations remain tentative.

Faunal Preservation: An experiment in the preservation of faunal remains (discussed in detail in Stafford 1980) was set up in October 1977 by Diane Gifford. The test cores were recovered in November 1979 and analysed in January 1980.

The two-year duration of this experimental study was determined to be insufficient to affect "striking changes in the condition of even the most delicate fish bones in the samples" (Gifford in Stafford and Edwards 1980:70). The Avian long bones displayed some surface degeneration; however, both porous ribs and dense naviculocuboids were essentially unchanged. Mollusc remains in the upper 60 cm of the seasonally inundated area of CA-SCL-52 exhibited a greater surface chalkiness than did those samples more deeply buried in the core (Gifford in Stafford and Edwards 1980:70), suggesting that this type of faunal remain may undergo a more rapid surface deterioration than vertebrate remains. Gifford suggests that experiments of this nature should be conducted over an extended period to quantify rates of faunal deterioration.

Other Impacts

Faunal: Stafford and Edwards developed a specific hypothesis regarding the impacts of rodent activity on archeological sites in Chesbro Reservoir. They suggest that:

> In a reservoir context, seasonally exposed sites located on the borders of reservoirs will experience a severe negative impact to stratigraphy from increased rodent activity in the zone just below the high water line... (Stafford and Edwards 1980:54).

This hypothesis could not be confirmed; rather, it appears that the seasonal inundation of the reservoir margins may have had an inhibiting effect on rodent activity. The increased rodent activity observed in 1977 just below the wave zone may have been due to the prolonged drought and the reexposure of previously unavailable areas.

Human: During the period of prolonged drought in 1977, vehicular traffic in Chesbro Reservoir constituted a major impact to exposed surface areas in the empty reservoir basin. Following two years of normal rainfall, however, vehicular traffic around the reservoir was greatly reduced, and no direct evidence of impacts from vehicles was observed or measured. It appears that periods of drought provide particularly good opportunities for direct impacts to sites by off-road vehicles.

Loss of Qualitative Data Relating to Strata and Features

The impacts of soil deflation and deposition were addressed by a third experiment. Site CA-SCL-52 was extensively surveyed and contour maps prepared in 1977. In 1979 contours on the units were again taken and comparisons made after two years of inundation.

Changes which occurred to each unit were profiled for ready comparison. The following three conclusions were drawn by the researchers:

1) Seasonal inundation has deflated soil in all inundated areas but deposition from unidentified agents has been greater than deflation on Units B and C.

2) Portions of the site inundated for the longest period have experienced the greatest amount of deflation.

3) Inundation has had a leveling effect on micro-contours and the degree of leveling correlates with the length of seasonal inundation (Stafford and Edwards 1980:53-54).

Based on the contouring data, the two researchers were able to predict an overall deflation rate for the seasonally inundated areas of CA-SCL-52 of 2.025 centimeters per year (Stafford and Edwards 1980:

57). This particular type of information is especially helpful for longterm management planning for the cultural resources along the pool margins in Chesbro.

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THE EFFECTS OF INUNDATION ON THE PEDERSEN SITE CA-ELD-201, FOLSOM LAKE, CALIFORNIA

INTRODUCTION

During the summer and fall of 1976, a group of archeologists under the direction of John W. Foster carried out preliminary data recovery at a large site in Folsom Reservoir, California. "The Effects of Inundation on the Pedersen Site, CA-ELD-201, Folsom Lake California" was written in partial fulfillment of a contract between Foster and the National Reservoir Inundation Study.

The Pedersen site was discovered during the drought episode in the Western states when the water level in Folsom Lake fell far below normal, exposing areas that had been continually inundated for 20 years. The draw-down and exposure of CA-ELD-201 provided an excellent opportunity to gather baseline data on inundation impacts.

RESULTS

The Pedersen Site was unique in that nearly all of the midden and top soil had been washed away, leaving a large number of artifacts deposited on exposed, decomposing bedrock (Foster et al. 1977:1).

Differential Preservation

Stone: An extensive surface collection, encompassing over 6,625 sq. meters of CA-ELD-201, was undertaken by Foster. Both chipped and groundstone artifacts were abundant; however, the effects of inundation were not uniform on either class (Foster et al. 1977:18).

Andesite, basalt, quartz, quartzite, slate, and shale were the primary materials from which the lithics were manufactured (Foster et al. 1977:18). Of these, the slate and shale exhibited extensive water damage; edges were ground smooth and many were fractured (Foster et al. 1977:18). Slate and shale are high in impurities and water-soluble chemicals; their deterioration as a result of inundation was hypothesized by Lenihan et al. (1977:37-38).

Artifacts manufactured from andesite, basalt, quartz, and quartzite, stone types high in silica and low in water-soluble impurities, were affected to a lesser degree. However, "careful examination of flake scars and edge ware on scrapers, choppers and utilized flakes indicates that potentially useful data have been compromised by water and sand" (Foster et al. 1977:18). This supports the National Reservoir Inundation Study hypothesis on differential preservation of stone (Lenihan et al. 1977:37-39).

Ground stone artifacts exhibited solution weathering, including roughening, pitting, and exfoliation (Foster et al. 1977:18). The affected specimens, approximately 25% of the sample, were primarily course-grained granites with feldspar matrix inclusions (Foster et al. 1977:18). A massive, seventy-pound mortar, which had apparently received extensive prehistoric use as evidenced by a mortar pit of 13 cm, was fractured laterally and badly deteriorated from solution weathering; continuous inundation precipitated structural failure (Foster et al. 1977:17). Finer-grained granite artifacts, primarily manos and pestles, were less affected by inundation, presumably due to grain texture.

The overall pattern of differential preservation of stone artifacts found at the Pedersen site supports the National Reservoir Inundation Study hypothesis for that artifact class (Lenihan et al. 1977:33-39).

Bone: Much less bone was recovered from CA-ELD-201 than would be expected from a site of its size and magnitude. Only five specimens were recovered from a surface collection of over 6,600 sq. meters (Foster et al. 1977:19). Inundation, wave action, and erosion have, presumably, acted together to displace or cause the deterioration of this class of material.

Wood: A great deal of charred wood was found at CA-ELD-201. During reservoir construction activities, extensive cutting and burning of vegetation occurred, the charcoal remains being highly visible on the dry lake bed during the drawdown (Foster et al. 1977:20). It appears that charred wood *per se* is not affected by continuous inundation. Further evidence to support this was found in the remnants of a house-pit depression where the remains of a burned post were found (Foster et al. 1977:1). These findings are in agreement with the National Reservoir Inundation Study hypothesis (Lenihan et al. 1977:49).

Shell: No shell artifacts were identified during the research; however, two specimens of a native freshwater mussel were collected. Both specimens appeared to have been adversely impacted as a result of prolonged inundation (Foster et al. 1977:19). This agrees with the hypothesis advanced by the National Reservoir Inundation Study (Lenihan et al. 1977:43).

Mechanical Impacts

The most significant feature of the Pedersen site was the presence of three housefloors in the remaining midden. They consisted of highly compact, dark, artifactually rich midden; erosional activity caused pedestalling of the remnants, and water movement across the depression has given them the appearance of being laminated (Foster et al. 1977:16-17).

The housefloors and remaining midden are located along the crest of a small ridge. "Over 80% of the surviving midden exists along this ridge, whether this results from elevation, slope, orientation to wave activity, current reflection, differential compactibility, or other factors, is unknown" (Foster et al. 1977:17). What was clear was the loss of an estimated one meter of soil over much of the site area (Foster et al. 1977:16).

Other Impacts

Faunal: The introduction of a nonnative burrowing clam into the American River valley and reservoir system has, at least in Folsom Reservoir, adversely impacted one archeological site. The midden remnants at CA-ELD-201 have been riddled by these clams (Foster et al. 1977:24). The remaining midden depth is estimated to be 20-30 cm; clam cavities average 5 cm in depth and approximately 4 cm in diameter (Foster et al. 1977:24). This is one of the few documented instances in which an aquatic species had been found to be an agent of destruction of an archeological site.

Compounding the burrowing activity of these clams, raccoons have found them to be an easily obtainable and abundant food source. As the lake waters receded and the clam-laden midden was exposed, the raccoons moved in and began excavation. The result of the clam-raccoon attack has been the destruction of large areas of the remaining midden (Foster 1977, personal communication).

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ARCHEOLOGY IN SOLUTION: TESTING INUNDATION'S EFFECTS AT FOLSOM RESERVOIR, CALIFORNIA

INTRODUCTION

"Archeology in Solution: Testing Inundation's Effects at Folsom Reservoir, California" (Foster and Bingham 1978) was written in partial fulfillment of a contract between John W. Foster, an archeologist affiliated with the State of California Parks and Recreation Department, and the National Park Service administered National Reservoir Inundation Study. The supplemental archeological field study at the Pedersen Site, CA-ELD-201, was undertaken between July 1977 and February 1978 to document and quantify reservoir impacts to the site.

The purpose of the research was to test specific hypotheses advanced, in part, in the Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977), concerning inundation effects and to record data for future comparative use at Folsom Lake. Five specific research goals were outlined in the report:

1. to test for evidence of lithic artifact redistribution due to hydraulic action.
2. to test excavate the surviving midden deposit and focus on identification of impacts not visible from the surface.
3. to gather soil samples from the midden surface, subsurface and off site areas for future comparative use.
4. to collect physical and hydrological data on Folsom Reservoir pertinent to inundation dynamics.
5. to examine the sandy slopes of the site area for evidence of seasonal impact from draw-down, wave action and refilling (Foster and Bingham 1978: 2-3).

Mechanical Impacts

Mechanical impacts to the Pedersen site (CA-ELD-201) included erosion and downslope sedimentation. Shoreline erosion has removed 80-95 cm of soil (Foster and Bingham 1978:37) in the site area. Soil loss was dramatically documented through aerial photography and through direct measurement of original soil level on oak and pine tree stumps which dot the peninsula upon which the site is located.

Downslope deposition of eroded soil has resulted in the development of two beaches in areas of former drainage. The depth of the redeposited material ranges from several centimeters to well over 2 meters (Foster and Bingham 1978:37). The severity of the erosional processes at CA-ELD-201 can be attributed to on-shore prevailing winds, exceeding 30 mph (Foster and Bingham 1978:9). Due to its location relative to the pool level, CA-ELD-201 is inundated for the majority of an average year. This period coincides with the maximum wind velocity over the site; surface waves and subsurface turbulance have combined for a direct assault on the site and the surrounding area (Foster and Bingham 1978:11). The resistance to erosion of the environmental matrix in which the Pedersen site is located, given a range of reservoir conditions, has been hypothesized by Lenihan et al. (1977:20). Foster selected four types of reservoir conditions that were applicable to the Pedersen site and ranked each according to predicted impacts and observed impacts. As can be seen below, on the following relative impact chart, in all four categories, the predicted impacts were in agreement with those observed by Foster.

Foster and Bingham (1978:4) hypothesized that, "inundated midden soil will be differentially eroded as a function of inherent soil compaction and degree of slope." The dense, more compacted areas in the midden, predominantly housepits, were found to be more resistant to erosional processes than the surrounding areas. Patches of midden and housepit remnants were pedestalled and depths did not exceed 25 cm (Foster and Bingham 1978:37).

The susceptibility of cultural remains to direct mechanical activity has been hypothesized by the NRIS (Lenihan et al. 1977:20). The Pedersen site included midden, housepit, subsurface features, and surface scatter including lithics, groundstone, and shell.

Relative Impact Chart

Environmental Matrix CA:ELD:201	Erosion Factors: Stream channel and Reservoir Dynamics	Water velocity in river over site dependent on such factors as slope and nature of water release	Periodic draw-down over site	Subject to wave actions, boats, wind, etc.	Liquefaction
Silty sands, poorly graded sand-silt mixture		3/3	2/2	3/3	3/3

Degree of impact rated from 1 (minimal) to 3 (severe) Susceptibility presented: predicted/observed (after Lenihan et al. 1977)

A predicted resistance value for each of these general areas is given below along with values assigned based upon observations of impacts at the site. Also provided is a suggested reason for the impacts observed.

Susceptibility to Mechanical Impacts

Cultural Manifestations	Predicted/Observed	Reason
Lithic and/or ceramic surface scatter	1/2	Subject to draw-down slope, wave action
Standing earthworks, prehistoric mounds military structures (surface features)	2/2	Wave action, Slope
Subsurface rock (features)	0/0	Midden integrity good, not becoming gelatinous (Foster 1978:31)
Soil midden	2/3	Slope, wave action
Subterranean rooms, house pits	3/2	Shallow floor, no slumping

Hydrodynamic Sorting of Artifacts

A test of a hypothesis, advanced by Foster and Bingham (1978:4), which suggested artifact redistribution as a result of hydraulic action, was undertaken by surface transect sampling and excavation. It was found that:

1. there was a significant difference (exceeding .001) in the quantity of all materials recovered between the surface collection and the excavation units (Foster and Bingham 1978:25 & 31);

2. there is a strong correlation between successive downslope substrate zones and an increase in average artifact weight (Foster and Bingham 1978:28); and

3. there appears to be quantitative differences between surface and subsurface collection of lighter weight lithics and bone (Foster and Bingham 1978:25).

The overall pattern of artifact redistribution and quantitative data gathered at CA-ELD-201 suggests confirmation of Foster's hypothesis. The two relevant variables affecting distribution appear to be weight and downslope substrate zone (Foster and Bingham 1978:29).

Dating Techniques

Carbon-14: Desert side-notched points are a reliable time marker for the Late Horizon, Phase 2, in Central California, which occurs from about 1500 to 1700 AD. Two desert side-notched points were found in association with a hearth at CA-ELD-201. The association of the points with the hearth permitted a reasonable test of Carbon-14 dating reliability in a periodically inundated site (Foster and Bingham 1978:31). Analysis of the hearth sample by Dicarb Laboratory resulted in a date of 1320-1770 AD (DIC 975) (Foster and Bingham 1978:37). The carbonized material does not appear to have been adversely impacted by inundation, arguing strongly for the usefulness of C-14 dating after inundation has occurred.

Differential Preservation

Bone: A total of 227 bones or bone fragments were recovered during surface collection and excavation at CA-ELD-201 (Foster and Bingham 1978:29). The condition of the large bone fragments recovered from excavation did not appear to have been adversely affected as a result of 20 years of periodic inundation. However, it is suspected that many of the smaller mammal bones were lost or deteriorated from the effects of periodic inundation (Foster and Bingham 1978:31). No information was provided on water pH and no discussion of preservation vis-a-vis this variable was undertaken.

Stone: Comparison of surface stone with that collected by excavation supports the NRIS hypothesis that inundation will increase the deterioration of stone materials (Lenihan et al. 1977:36). Exposed stone artifacts exhibited abrasion damage, pitting, fracturing, and exfoliation, while subsurface stone was well preserved (Foster and Bingham 1978:39). The stone most affected by inundation was that which was high in impurities and water-soluble chemicals.

Analysis Techniques

Analysis of bone fragments recovered through excavation revealed the presence of butchering scars after 20 years of periodic inundation (Foster and Bingham 1978:31). It appears that, at least in this circumstance, buried bone was not adversely affected.

Other Impacts

Floral: Plant growth in the midden areas was seen to accelerate the general rate of soil erosion. The process of soil desiccation combined with root penetration opened numerous fissures [in the midden] ... and root action became more damaging as the season progressed .... (Foster and Bingham 1978:38).

Faunal: Clam cavities, previously discussed in this section of the technical reports (see Foster et al. 1977:24), contributed to the deterioration of the remaining midden. Excavation confirmed that penetration was confined to the upper 10 cm of midden; however, the remaining intact midden did not exceed 30 cm (Foster and Bingham 1978:38) thus constituting a major impact. Rodents and cattle also impacted the site area by their burrowing and wallowing activities, respectively (Foster and Bingham 1978:38).

Human Vandalism: The exposure of CA-ELD-201 and the development of sand beaches as a result of erosional processes attracted boaters and picnickers to the area. "One campfire hearth, composed of several artifacts, was noted in the site area...." (Foster and Bingham 1978:38). Visitor impacts to the site were minimal due to the "paucity of historic materials (bottles, etc.)" (Foster and Bingham 1978:38) and due to the vigilance of the park rangers at Folsom Lake, who took an active interest in its protection.

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LAKE MENDOCINO RESERVOIR, CALIFORNIA

INTRODUCTION

Supplementary Investigations into the Effects of Freshwater Immersion on Cultural Resources of the Lake Mendocino Reservoir Basin, Mendocino County, California (Stoddard and Fredrickson 1978) was written in partial fulfillment of a cooperatively funded contract by the San Francisco District, U.S. Army Corps of Engineers, and the National Reservoir Inundation Study with the Foundation for Education Development, California State College, Sonoma. Dr. David A. Fredrickson acted as principal investigator, and Stephen E. Stoddard directed field operations. The report presents the results of archeological investigations into the mechanical impacts, differential preservation, and site preparation for reflooding of several prehistoric and historic sites that have been subjected to freshwater immersion between 1957 and 1976. These sites became available for research as a result of the 1975-77 prolonged drought in the west. Following the winter rains of 1977-1978, these sites were reinundated by Lake Mendocino.

RESULTS

Mechanical Impacts

Information gathered on mechanical impacts through field observation was compared to predicted impacts outlined in the Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977:19-21). The Relative Impact Chart (Lenihan et al. 1977:20), which outlines a matrix of soil type and erosional factors, was used in conjunction with information from specific sites located by the Sonoma researchers. Granting a certain subjectivity in judging the weight of impacts, when comparing the National Reservoir Inundation Study predicted impacts and 26 susceptibility values assigned by Stoddard and Fredrickson, it was found 14 were in agreement. An greater than predicted and 4 were less than predicted (Stoddard and Fredrickson 1978:38).

RELATIVE IMPACT CHART

SITE	Environmental Matrix	Stream Channel and Reservoir Dynamics	EROSION FACTORS							
			Site located on inside of meander of river	Site located on outside of meander of river	Water velocity in river over site dependent on such factors as slope and nature of water release	Water with high carrying capacity, e.g., in channel just below dam	Periodic drawdown over site	Subject to wave action, boats, wind, etc.	Flood plain inside river channel	Flood plain outside river channel
CA-MEN-544	Organic silts and organic silt-clays of low plasticity.			3/3	3/3		3/3	3/3		2/2
CA-MEN-547	Silty gravels, poorly graded gravel-sand silt mixtures.		1/1		2/3	2/3	1/1	1/1	2/3	
CA-MEN-561	Silty sands, poorly graded sand-silt mixtures.		2/2		3/2	3/3	2/2		3/2	
CA-MEN-1165	Clayey sands, poorly-graded sand-clay mixtures.		1/1				2/2	2/1	2/1	
CA-MEN-1166	Clayey sands, poorly-graded sandy clay mixtures.		1/1		2/3	2/3	2/3	2/3	2/3	

Degree of Impact is rated from 1 (minimal) to 3 (severe). Susceptibility is presented as predicted/observed.

Soil types are taken from Russian River Watershed Water Quality Investigation Bulletin 143-4, Department of Water Resources, Sacramento, California, 1968.

*After Stoddard and Fredrickson 1978.

The National Reservoir Inundation Study chart below hypothesizing the Susceptibility of cultural manifestations to mechanical impacts (Lenihan et al. 1977:21-22) was also used and Stoddard and Fredrickson compared predicted impacts to observed effects.

Site	Cultural Manifestations	Susceptibility (Predicted/Observed)	Reason for Disparity
CA-MEN-544	Lithic and/or ceramic surface scatter.	1/2	Slope, high current, and erosion
	Soil midden	2/3	High current and erosion
CA-MEN-561	Lithic and/or ceramic surface scatter.	1/2	High current
	Soil midden	2/1	Silted over
CA-MEN-1165	Standing structure of concrete	1/1	
	Standing structures of fixed stone; no mortar and/or plaster	1/1	
	Subsurface foundations of wood	3/1	Silted over, on clay
	Subsurface foundations of concrete	0/1	Consolidation of soil near edges of foundation undercuts slightly.
	Surface debris-dump	N.A./2	Current in creek cuts through silt
CA-MEN-1166	Standing structures of concrete	1/3	High current erosion
	Subsurface foundations of concrete	0/0	Silted
	Surface debris-dump	N.A./2	Current and erosion

After Stoddard and Fredrickson (1978:39)

Out of 12 observations, 3 were in agreement, 5 were greater, and 2 were less than predicted. One site type, a surface debris-dump not included in the Inundation Study chart, underwent moderate impact. The conclusions drawn by the Sonoma researchers were "that water velocity, the related silt carrying capacity of the water, and various kinds of drawdown were the primary determinants of mechanical effects ...." (Stoddard and Fredrickson 1978:37) in the deeper areas of the lake and that wave action and water fluctuations as a result of recreational use were major determinants of mechanical impact in the upper levels of the reservoir.

Soil Chemistry Analysis

pH of Soils: The National Reservoir Inundation Study hypothesized that in a loosely compacted soil stratum, pH values would approach reservoir values (Lenihan et al. 1977:58). Stoddard and Fredrickson found that the pH of soil samples from Lake Mendocino was less than that of the lake waters, suggesting that either the hypothesis is incorrect or that "other variables were operating to bring about the ... [disparity in] pH readings for the soil samples" (Stoddard and Fredrickson 1978:40).

Nitrogen Nitrates: The National Reservoir Inundation Study hypothesized that "the potential for soil nitrate analysis will be lost in direct proportion to the length of time immersed" (Lenihan et al. 1977:59). The low nitrate content for the soil samples tested lends support to this hypothesis and "may be a reflection of this process" (Stoddard and Fredrickson 1978:40).

Organic Matter in Soils: It has been hypothesized by the inundation study that organic content of subsurface soils would not be affected by inundation, while surface soils would be adversely affected (Lenihan et al. 1977:60).

> The generally low percentage of organic matter found in the soil samples from Lake Mendocino in both near-surface and subsurface samples suggests loss

> of organic matter may have occurred, contrary to the NRIS hypothesis. Lacking pre-inundation data, the possibility must be left open that the organic content of the sites was never high during the pre-inundation period (Stoddard and Fredrickson 1978:40).

In general the Sonoma researchers felt that "lacking pre-inundation baseline data, additional comment on the soil sample findings would not be fruitful. [The results] must stand ... as a baseline for future studies" (Stoddard and Fredrickson 1978:41).

Resurvey Potential

Lenihan states that the two factors

> that will pose the greatest limitation on post-inundation survey are siltation and mechanical disturbances . . . . Stoddard archeological survey procedures conducted to relocate sites . . . will not yield comparable pre- and post-inundation results .... (Lenihan et al. 1977:74).

During the 1977 investigations at Lake Mendocino it was found that standard survey techniques had to be "augmented by extensive augering and by more intensive analysis than usual of location data contained within archival materials, existing records, and maps" (Stoddard and Fredrickson 1977:42). Those areas within the reservoir, found to have minimal silting were most easily addressed by standard survey techniques. The Sonoma researchers felt that the "general hypothesis of the NRIS [was] sustained" (Stoddard and Fredrickson 1977:42).

Differential Preservation

Bone and Shell: None of the prehistoric sites tested at Lake Mendocino yielded bone or shell specimens (Stoddard and Fredrickson 1977:41). The water in Lake Mendocino is approximately pH 7 (Cox et al. 1977:158) and the pH of "soil samples is collectively lower than 7 ..." (Stoddard and Fredrickson 1977:40); that is, more acidic than the lake waters. The deterioration of bone under acid soil conditions has been discussed elsewhere (Dowman 1970) and the differential preservation of this class of material in an inundated context has been hypothesized. "... Osteological materials that are subjected to ... a pH change toward acidity (pH value below 7.0), will not be as well preserved following inundation as prior to inundation" (Lenihan et al. 1977:27).

The acidic, saturated soils found within Lake Mendocino may also have contributed to the deterioration of shell. Stoddard and Fredrickson found that there was a high calcium content in the soils tested and "this may be related to [the] dissolution of bone and shell" (1977:41), although the possibility does exist that preinundation quantities of these classes of material may have occurred only in small amounts.

Historic Cultural Material: The historic cultural materials such as ceramics, glass, metal, wood, bone, shell, and paper, among others, found at two sites within Lake Mendocino, were in a remarkably good state of preservation (Stoddard and Fredrickson 1977:26-28). Such preservation may have been a function of the fine-texture and anaerobic environment created by silt deposition on the sites (Stoddard and Fredrickson 1977:27). This supports the generalized hypothesis of the National Reservoir Inundation Study that anerobic environments will act to preserve cultural remains (Lenihan et al. 1977:24-55).

Analysis Techniques

X-Ray Flourescence: A total of 20 obsidian samples were collected from the sites within Lake Mendocino for source identification through the X-ray flourescence technique. Seventeen of the 20 specimens submitted were identified (Stoddard and Fredrickson Appendix F 1977:3), the source dating technique yielding useable results for obsidian hydration analysis. Three samples were not suitable for use due to small size. The ability to successfully employ X-ray flourescence as a source identification technique was not compromised as a result of inundation, lending support to the National Reservoir Inundation Study hypothesis for that analysis technique (Lenihan et al. 1977:65).

Dating Techniques

Obsidian Hydration: Hydration rim readings for the 17 samples submitted for this dating technique yielded dates which fell within the rage of site ages estimated by the Sonoma researchers. Hydration rim development, and therefore dating results, were not adversely affected by inundation. This may be due in part to the relatively short period of inundation, ca. 20 years, or may indicate that due to the high resistance to deterioration of obsidian, hydration dating of inundated samples is indeed viable. The National Reservoir Inundation Study hypothesized that obsidian hydration analysis would be compromised as a result of prolonged inundation (Lenihan et al. 1977:90-91).

Carbon-14 Analysis: Two charcoal samples were submitted for radiocarbon age determination (Stoddard and Fredrickson Appendix B 1977: 1). Dates of 735 ± 240 years and 320 ± 80 years were received for samples from sites CA-MEN-555 and CA-MEN-1137, respectively. Although the date from CA-MEN-1137 was earlier than anticipated, Fredrickson felt that there was no reason to reject the date and that "all data were consistent with expectations and there was no reason to believe that results were skewed by the effects of inundation" (Stoddard and Fredrickson Appendix B 1977:6). This is in agreement with the hypothesis presented by Lenihan et al. (1977:84-85).

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GRAND COULEE NATIONAL RECREATION AREA, WASHINGTON
LAKE ROOSEVELT - FIELD ASSESSMENT

INTRODUCTION

In May 1977, a trip was undertaken by National Reservoir Inundation Study personnel to determine the viability of including sites within Grand Coulee National Recreation Area in the nationwide research program of inundation impacts. Field assessments in the earliest stages of the inundation study were also undertaken to document impacts of flooding, both beneficial and detremental.

The following information on inundation effects at several sites in the Kettle Falls area of Lake Roosevelt was gathered during conversations with David H. Chance, field director in charge of a multiphase salvage effort, and during field observation by a study archeologist. All notes and slides compiled during the trip are on file at the National Park Service Southwest Regional Office, Southwest Cultural Resources Center in Santa Fe.

It should be noted that subsequent to the visit of an inundation study archeologist, a report documenting work undertaken in the Kettle Falls area was published by the University of Idaho entitled: "Kettle Falls: 1972 Salvage Excavations in Lake Roosevelt" (Chance, Chance and Fagan 1977). To the degree that inundation effects was discussed in that document and enhanced and/or verified information provided to the Inundation Study through personal communication, that report has been cited.

RESULTS

Differential Preservation

Wood: Fort Colvile, the site of a Hudson's Bay Company Post, has been seasonally inundated since 1940. Excavations have revealed the presence of great quantities of wood in the form of planks and posts from the historic structures. The site has a clearly defined sediment deposit which may be contributing to its overall preservation. The wood has been found to be in an excellent state of preservation.

Bone: The frequency of bone recovered from the Ksunku Site, which has been seasonally inundated since 1940, was low (Chance et al. 1977:120). The upper strata of the site, otherwise represented by heavy concentrations of cultural material and features, contained less bone than expected; acid soil conditions having influenced bone preservation (Chance et al. 1977:120). It should be noted, however, that depth below surface did influence amount and degree of preservation. Stratum 5, 228 cm to 243 cm below the surface, produced a great quantity of bone (Chance et al. 1977:121). Below stratum 5, much of the bone was heavily coated with a sandy ferro-manganese cement, contributing toward material preservation (Chance et al. 1977:121). All of the bone and antler specimens recovered were soft and disintegrated if jarred, necessitating special handling (Chance et al. 1977:121).

The deterioration of bone under acid soil conditions has been previously documented (Dowman 1970), and the differential preservation of this class of material in an inundated context has been hypothesized by Lenihan et al. (1977:24-28). The state of preservation of the bone specimens from Ksunku supports the generalized National Reservoir Inundation Study hypothesis.

The effects of periodic flooding do not appear to have adversely affected the deeply buried bone. No statement can be made, based on the limited data available from this particular example, regarding the specific effects seasonal flooding has had on the shallowly buried bone. Alternating wet and dry cycles, coupled with acid conditions, could have ultimately been the cause of bone deterioration and its noticeable absence in the upper strata.

Animal and Vegetable Fibers: At the Chaudiere Site (45-Fe-47), a multiple burial produced a few pieces of cedar and charred and abundant burnt pine bark (Chance et al. 1977:48). The burials have been tentatively dated as prior to 1780 AD; presumably the charred pine and cedar are of nearly the same antiquity. The Chaudiere Site, like the Ksunku Site, has been seasonally flooded for 40 years.

Feature 2 at Chaudiere, a pit house, produced large quantities of pine nuts, cherry pits, hazelnuts, and rye grass seeds. Serviceberry seeds were also recovered from a small daub-lined pit in the floor (Chance et al. 1977:49). A ceache of charred pine nuts, in a good state of preservation, was recovered from feature 3 (Chance et al. 1977:52) at the same site. The acidity of the soil, in this case, contributed to the preservation of the remains. This information supports the test implication presented by Lenihan et al. (1977:47) on differential preservation of this class of material remains.

Mechanical Impacts

Each spring Lake Roosevelt is drawn-down between 50 and 80 feet causing widespread erosion in the reservoir. As the pool level is lowered, and then refills, water flow over the sites is accelerated; the major sites at Kettle Falls experience water velocities in excess of 20 mph (Chance, personal communication). Erosion, deflation, slumping, and wave cut terraces have all acted together to damage and, in some cases, destroy sites within Roosevelt Lake.

Qualitative Data on Strata and Features

Excavations have been conducted at Fort Colvile, Ksunku, and Chaudiere, sites which have been flooded periodically for 40 years. In each case distinct soil horizons, stains, house floors, storage pits, hearths, etc., have been clearly in evidence. Some gleying of sediment colors may be occurring (Chance, personal communication) but generally both visual and tactile cues have been unaffected by inundation. The Kettle Falls report provides additional documentation of this preservation (Chance et al. 1977).

Dating Techniques

Carbon 14 Analysis: Samples were collected for analysis from both Chaudiere and Ksunku. Although some questions of contamination were raised on the results of samples from Ksunku, ultimately a Gakushuin University assay was believed to be correct (Chance et al. 1977:143). Dates from Chauiere also appear to be in accord with dates based from artifactual material (Chance et al. 1977:143). This data agrees with the National Reservoir Inundation Study hypothesis of no adverse impact to Carbon-14 dating analysis from inundation (Lenihan et al. 1977:84).

Obsidian Hydration: The results of hydration analysis were, for the most part, consistent and useful for general comparisons within and between sites in the Kettle Falls area. "Specimens from 45-Fe-45 (Ksunku), a deep midden suggesting a long occupation, shows a general progression through time in the widths of hydration bands" (Chance et al. 1977:144).

The results of this analysis are in some ways contrary to the hypothesis presented by Lenihan et al. (1977:90). Obsidian samples were collected from strata starting at 2 cm below the surface to 205 cm (Chance et al. 1977:145). The shallowly buried obsidian, 50 cm or less, did not exhibit markedly skewed hydration rim readings, as was anticipated in the Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977:90-91). This may be attributable to the seasonal nature of the inundation episodes at the sites, although there is no evidence to confirm or deny this. The overall length of time than inundation has been occurring at the sites may, in addition, be too short to affect changes in hydration rates.

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THE MECHANICAL AND CHEMICAL EFFECTS OF INUNDATION AT ABIQUIU RESERVOIR

INTRODUCTION

The School of American Research conducted archeological investigations in Abiquiu Reservoir between 1974 and 1978. All of the sites inundated as of 1977 had been excavated and/or carefully documented by the School of American Research. An _Evaluation of Abiquiu Reservoir Archaeological Materials for Inclusion in the National Park Service Inundation Study_ (Schaafsma 1977) was written prior to undertaking inundation-related research in the reservoir. This report discussed both the inundated sites as well as temporally and culturally similar sites not previously inundated which could serve as a base for comparison.

Initial inundation of many of the sites investigated by the School of American Research took place in 1960 and they have since been seasonally inundated. Inundation of the sites prior to excavation and sample collection is a reversal of the optimum research approach advocated by the Inundation Study. The generalized Inundation Study research strategy has been to excavate sites prior to immersion, prepare them for later examination, and then investigate the sites after flooding or during a drawdown. The situation in Abiquiu, therefore, posed certain limitations on the research utility of these sites but offered certain potentials.

> The fact that the materials have all been inundated provides a time frame for certain kinds of inundation conditions that would be impossible to check for within the time limitations of the study . . . since the Corps of Engineers maintains accurate records of water level, the exact amount of inundation can be specified for any sample. This can be computed both in terms of number of days total over the past 14 or 15 years, as well as the number of days per year. The water temperature and pH value of the water during immersion can also be

> obtained . . . . Finally, weather conditions during periods of exposure can be obtained from Corps records which have been maintained at Abiquiu Dam. . . . Thus the flooding would be a special class of immersion consisting of alternate periods of inundation and exposure. There is reason to believe that this type of inundation is more damaging to the physical nature of the sites than permanent, long term immersion . . . . The fact that the flood waters each year do not reach the same level means that sites at different contour levels have been differentially inundated. . . [providing] the study with the opportunity to evaluate different types of inundation conditions (Schaafsma 1977:3-5).

Following the evaluation by Schaafsma and a discussion with Inundation Study personnel of both the problems and potential value of the sites, field work was conducted during the summer of 1977.

RESULTS

__The Mechanical and Chemical Effects of Inundation at Abiquiu Reservoir__ (Schaafsma 1978) was written in partial fulfillment of a contract between the School of American Research and the National Reservoir Inundation Study. The focus of the study was the excavation and analysis of samples from a selected control site, a comparison with selected inundated sites excavated during drawdown, and the integration of data into the larger matrix of specialized analyses.

Soil Chemistry Analysis

Alf Sjoberg, a researcher with the American Archaeology Division, University of Missouri, Columbia, was contracted to analyze 160 soil samples and evaluate the data according to Schaafsma's research design (1978:56-68). Unfortunately, Sjoberg rejected Schaafsma's research approach, without consultation either with Schaafsma or the National Reservoir Inundation Study. The problem with Sjoberg's study was one of:

> misinterpretation of the intention of the research design, which mainly appeared due to a failure to . . .

[understand] the subjunctive mode in which . . .[the] various potential effects of inundation were offered. By no means was it assumed beforehand that the various effects definitley would occur (page 3 [Sjoberg 1978]).

The potential effects were merely reasonable to investigate, given the nature of the chemical remains and the preliminary results . . . .

. . . The result of comparing all the inundated samples with all the unindated samples . . . lumps such things as sheep manure . . . along with surface samples . . . . There was no stratification according to context. Simply put, there is little of value to his (Sjoberg's) substantive cnclusions.

. . . We are left with . . . a body of well-analyzed raw data that was not ordered or systematically addressed. . . . and generalizations drawn from previous studies rather than from this data base (Schaafsma 1978:70-71).

Given the nature of Sjoberg's report, Schaafsma was faced with ordering the data into the systematic approach outlined in his original research design. Schaafsma's results are discussed below:

pH: It has been suggested (Lenihan et al. 1977:58) that pH values would be affected by inundation. The pH values from across the inundated sites (AR-8 and AR-23) are nearly homogenous (Schaafsma 1978:83). However, the control site (AR-512) of the same type and temporal affiliation exhibited clear intrasite patterning of pH values, differences well in excess of .5, which is considered to be of archeological interpretive significance (Eddy and Dregne 1964:12). It appears then that the overall pH of the inundated sites, whose range of variation in values barely exceeded .5 (Schaafsma 1978:79), has been adversely impacted, presumably due to inundation.

Phosphorus: Woods (1977) suggests that phosphorus values in excess of 200 ppm could be suspected to be anthrosols; the control site values ranged from 5 to 345 (Schaafsma 1978:73). The intrasite concentrations of phosphorus, in excess of 200 ppm, corresponded to features and indicate that phosphorus could be used to define activity areas on the exposed control site (Schaafsma 1978:74).

The inundated sites, AR-8 and AR-23, also exhibited great internal variability of values, 145-445 ppm and 90-467 ppm, respectively (Schaafsma 1978:80). Sjoberg suggested (1978:21) that phosphorus values would increase with inundation; the higher overall values at AR-8 and AR23 tend to support this contention. Although internal variability at the inundated sites has not been affected, the clear patterning of concentrations found at the control site was not as great at either of the inundated sites (Schaafsma 1978:80), suggesting a homogenizing effect on values as a result of inundation (Sjoberg 1978:21).

Calcium and Magnesium: The overlapping pattern of concentrations of three independent chemicals (calcium, magnesium, and phosphorus) at the control site strongly suggests definable activity and disposal areas (Schaafsma 1978:77). The chemical concentrations also closely correspond to a lithic scatter.

The chemical concentrations at the two inundated sites (AR-B and AR-23) did not correpond as clearly as at AR-512 and the range of values were less at the inundated sites. Calcium and phosphorus were strongly linked at AR-512; this was not the case at AR-8. At AR-23 high phosphorus and calcium values were overlapping in one area (Schaafsma 1978: 81).

The magnesium values at the two inundated sites continued to form clear intrasite patterns (Schaafsma 1978:81). There is some indication, based upon this limited test, that magnesium might be a stable chemical after inundation and continue to reflect preinundation activity areas.

Dating Techniques

Trace Element Analysis: Data retrieved as a result of trace element analysis is an essential step in obsidian hydration dating. The effects of inundation upon trace element composition of obsidian are unknown. Potential problems in analysis results could stem from leaching or contamination through absorption of elements present in water. It was hypothesized by Lenihan et al. (1977:65) that data returns from x-ray fluorescence analysis, a technique used in most trace element studies, would not be adversely affected by inundation.

In order to test the above hypothesis trace element studies were conducted on never inundated obsidian artifacts collected from AR-512, samples collected from the prehistoric source quarry, and samples collected from AR-8 and AR-5, seasonally inundated since 1960. All obsidian samples used were from the Polvadera Peak quarry.

> The assumption underlying the test is that samples from the same quarry are chemically similar. Significant differences between the quarry samples (and presumably the uninundated samples) and the inundated samples could be the result of immersion (Schaafsma 1978:50).

David Laing, a geologist, was contracted to perform the analysis. The conclusion reached was that inundation had no effect on trace element analysis. "Within the limitations of the present sample and experimental design, no significant difference can be demonstrated between the element composition of inundated and non-inundated obsidian artifacts." (Laing 1978:6). It should be noted, however, that the determination of "no effect" may be invalid. Due to procedural errors, discussed fully by Schaafsma (1978:53-56), it is not possible to state with any certainty that trace element analysis is not affected by inundation.

Archeomagnetic Dating: A series of nine individually oriented samples were collected from the central hearth at AR-9 in Abiquiu Reservoir to test the effects of inundation on this dating technique (Wolfman 1971:1). This site was inundated in the spring of 1973 and 1975 and may have been inundated briefly at other times in the past as well.

It has been hypothesized by the NRIS(1977:93) that:

> Archeomagnetic samples removed from reservoir contexts will not exhibit adverse effects from inundation, except when exposed for periodic drawdown conditions (Lenihan et al. 1977:93).

Seven of the nine samples collected produced statistically reliable results indicating "that there is a 95% chance that the hearth dates between ca. A.D. 1800 and the present" (Wolfman 1977:3). AR-9 a Ute ramada structure, was tentatively dated by other means as ca. A.D. 1810-1878 (Schaafsma 1978:75). The results of this particular field test tend to support the first half of the Inundation Study hypothesis. The fact that AR-9 has been periodically inundated for 17 years would suggest that the physical integrity of the feature, rather than periodic inundation, is the critical factor in the usefulness of archeomagnetic dating.

Alpha Recoil Track Dating: It has been suggested by Lenihan et al. (1977:105-106) that fission track dating and alpha recoil track dating would not be adversely affected by inundation. In order to test this hypothesis a series of periodically inundated sherds from Abiquiu Reservoir were submitted to the Arkansas Archeological Survey for analysis. The possibility exists that skewing of results could occur as a result of depletion or contamination of the uranium content of the sherds, as uranium is water soluable (Wolfman and Rolniak 1977:1).

The sherds selected for analysis were from sites AR-513 an AR-3. They had been inundated for 38 days and 893 days, respectively (Wolfman and Rolniak 1977:3). Schaafsma assigned both sites to the Navajo occupation dating between A.D. 1650 and 1710 and classified the samples as Penasco micaceous (Wolfman and Rolniak 1977:3).

Wolfman and Rolniak found that the sample from AR-3 had an unusually high uranium content:

> It should be noted that the Chama Valley cuts through portions of the Morrison and Chinle formations in which uranium deposits have been discovered . . . the sediments on sites which have been covered by Chama River water probably have higher than normal uranium concentrations. The shallowly buried sample [from AR-3 collected just below the surface] with longer inundation in deep water seems to have been contaminated while the more deeply buried sample [from AR-513 collected at 8 inches below the surface] with shorter

inundation in shallow water does not appear to have been affected (Wolfman and Rolniak 1977:4).

The two researchers conclude, based on this limited test, that samples will be subject to uranium contamination in those situations where long inundation and shallow burial in enriched soils occurs rendering analysis results unusable (Wolfman and Rolniak 1977:5).

Mechanical Impacts

Mechanical impacts to the sites investigated by Schaafsma included siltation, wall collapse, spalling of rock surfaces, artifact redistribution, pedestalling of features, erosion, and redeposition of soil (Schaafsma 1978:19-44).

The relative susceptibility of a variety of cultural manifestations to direct mechanical activity has been hypothesized by Lenihan et al. (1977:19-20). The hypothesized impacts along with observed impacts at the sites examined in Abiquiu are given below. The values assigned to observed impacts were based upon Schaafsma's written descriptions and in some cases personal communication. A reason for the observed impacts is also given.

Site	Cultural Manifestation	Susceptibility Predicted/Observed	Reason
AR-32B	Standing structure of unshaped stone, no mortar or plaster	1/1	side canyon, heavy sediment build up, reduced wave action
AR-4	Standing structure of unshaped stone, no mortar or plaster	1/3	prolonged wave action, floating driftwood
AR-3	Standing structure of unshaped stone, no mortar or plaster	1/3	main basin of reservoir, no sediment build up, prolonged exposure to wave action, floating draftwood

AR-5	Subsurface feature of stone (hearths)	1/3	wave action, slope, pedestalling, compact soil
	Lithic surface scatter	1/1	gentle slope, minimal wave action
AR-2 slope,	Subsurface feature of stone (hearth)	1/3	wave action, redeposition of stone, friable soil
AR-26	Petroglyphs	1/3	rock face spalled provenience data lost
AR-111a	Standing structure of adobe	2/3	rapid sedimentation, deterioration of adobe bricks
AR-30	Standing structures of stone - no mortar and/or plaster	1/2	slumping and wall collapse, heavy siltation, possible heavy wave action
	Upright logs chinked with mud and plaster (Historic jacal)	2/1	rapid sedimentation to depth of 7 feet
	Standing structure of adobe	2/3	rapid sedimentation, deterioration of adobe bricks
AR-513	Standing structure unshaped stone, no mortar or plaster	1/3	prolonged wave action, floating debris

After Lenihan et al. 1977:19-20

The hearth features at AR-5 and AR-2, although culturally similar, have exhibited slightly different kinds of inundation impacts. The feature at AR-5 is located within a fairly stable, compacted, soil matrix, which, through gradual erosion, initially resulted in pedestalling of the feature and then eventually resulted in downslope redeposition when all of the soil matrix was removed (Schaafsma 1978:22-25). In contrast, the feature at AR-2 was located on an unstable gravel bench and subjected to direct mechanical impact by wave action. Feature remnants were located downslope of their original position (Schaafsma 1978:22-27).

The Navajo unshaped masonry structures at AR-32b and AR-3 survived initial flooding; however, AR-3 slumped badly. It appears that AR-32b was able to survive both initial inundation and subsequent drawdowns as a result of the rapid heavy sediment build up (25 to 50 cm). Wave action and the pounding of floating logs and other debris contributed to the rapid destruction of the structure at AR-3. Similar destructive conditions at AR-32b may have been somewhat mitigated by the sediment build up acting as a buffer against both the waves and debris (Schaafsma 1978:20-21). Floating driftwood combined with wind-driven waves to mount a frontal assault on freestanding masonry structures at AR-4 and AR-513, tausing extensive damage (Schaafsma 1978:21).

Although no obvious change to the glyphs themselves has occurred as a result of inundation, the shale matrix upon which the rock art at AR-26 was located has spalled off the cliff face, tumbling down the rocky slope (Schaafsma 1978:29). Loss of provenience data for this particular cultural resource was total.

Silt Deposition Impacts on Cultural Remains

The relative accessibility of the resource base to future researchers is another indirect impact of inundation. Burial of sites in Abiquiu through sediment build up has been of two types:

> One is the massive accumulation of silt in the sediment pool, which is planned to gradually rise higher. The other is the formation of a light layer of sediment on flat to gentle slopes on benches about the sediment pool. Both of these types of silt accumulation relate directly to the future accessibility of the cultural resources affected (Schaafsma 1978:27).

A silt layer varying from 2 to 5 cm covered several sites in the reservoir. When first observed in October 1974, they were covered by dense layers of surface lithics. Revisited in November 1975, the thin silt layer deposited in the interim, effectively covered the majority of lithic scatters, rendering it impossible to detailed, controlled surface collection (Schaafsma 1978:27-28). In the other extreme, silt deposition at AR-30 in excess of 8 feet made archeological investigation virtually impossible (Schaafsma 1978:27).

Other Impacts

Faunal: A not uncommon use of lands surrounding reservoir areas is grazing. Schaafsma observed:

> A special condition found at Abiquiu . . . is the persence of stock . . . as the water in a fluctuating reservoir . . . goes up and down, it forms a varying zone that is trampled by stock as they come to the water to drink. Their feet in the muddy soil can do extensive damage to archaeological remains in the upper foot or so. Because of the fluctuating water level, this zone passes back and forth over the landscape many times, affecting any sites that happen to be in the way. An archaic hearth was noted that had been stepped in by a cow at a time when it was muddy and soggy. Needless to say, there [was] not much left (Schaafsma 1978:28-29).

Lenihan et al. (1977:110) hypothesized that faunal impacts "will be no more severe than those imposed upon terrestrial sites." This hypothesis should be reconsidered in light of fluctuating water levels found in many reservoirs. Although Lenihan et al. (1977:110) address sites at the edge of the reservoir pool and state that these will show "more severe faunal impacts than those not subjected to such disturbance," the hypothesis does not reflect the potential severity of impacts resulting from fluctuating water levels.

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NAVAJO RESERVOIR, NEW MEXICO

EFFECTS OF INUNDATION ON ARCHAEOLOGICAL MATERIALS FROM NAVAJO RESERVOIR

INTRODUCTION

The "Effects of Inundation on Archaeological Materials from the Navajo Reservoir" was written in partial fulfillment of an ongoing analysis contract between Dr. Ralph Rowlett, a researcher affiliated with the University of Missouri, and the National Reservoir Inundation Study. The analysis was designed to test the hypothesis:

> [thermoluminescence] samples that have been inundated for 20% or more of their archeological lives will be adversely affected, and will not yield data comparable to that yielded by samples that have not undergone such long-term immersion (Lenihan et al. 1977:103).

RESULTS

The samples submitted were selected from six archaeological structures at the Albino Village site in Navajo Reservoir (Rowlett and Bates 1979b:1). These sites had undergone continuous inundation for a period of 20 years and were exposed during a drought episode in the western states. A total of 29 samples were submitted for TL analysis, 19 from the inundated structures and 10 control samples from material excavated in 1962, prior to flooding (Rowlett and Bates 1979b:1).

Although the samples collected "were not an ideal samples for this study . . . the basic research data was of a higher quality for this study than would have been easily obtainable elsewhere" (Rowlett and Bates 1979b:1).

> Results of the TL response of the non-inundated and the samples inundated for 20 years did show some differences in the TL response of such samples . . . the directionality [of the responses] was in the same direction -- the non-inundated samples gave more consistent

> responses . . . . The direction also agrees with the results on 8 samples from Chesbro Reservoir in California (Rowlett and Bates 1979a). While the small number of samples from Chesbro did not provide the close matches of inundated and non-inundated as those from Navaho [sic] Reservoir Albino Village, they too showed . . . responses as more consistent from the non-inundated samples. (Rowlett and Bates 1979b:7).

Improved sampling strategy, i.e., inundated samples collected from the same features and with the same collection methods as the noninundated control samples, would have enhanced the results.

It does appear that continuous inundation has a deleterious effect on TL response, "making it both less consistent as well as generally diminishing the amount of response. This interferes drastically with TL dating and makes interpretive assays less definite." (Rowlett and Bates 1979b:9).

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LAKE POWELL, UTAH

GLEN CANYON REVISTED: THE EFFECT OF RESERVOIR INUNDATION ON SUBMERGED CULTURAL RESOURCES

INTRODUCTION

During the month of April, 1978, National Reservoir Inundation Study archeologists conducted field work at nine prehistoric sites within the boundaries of the Glen Canyon National Recreation Area, Utah. The sites, inundated by Lake Powell for less than ten years in most cases, were selected primarily on the basis of good documentation prior to inundation and accessibility by the research team.

"Glen Canyon Revisited: The Effects of Reservoir Inundation on Submerged Cultural Resources" (Rayl, Fosberg, Lenihan, Nordby and Ware 1978) documents the impacts resulting from relatively short-term inundation and discusses two experiments undertaken by the National Reservoir Inundation Study.

RESULTS

Mechanical Impacts

All of the sites selected for study had been excavated and/or 1978:18). Preinundation photographs, base maps, and detailed discussion of site condition prior to initial flooding provided the Inundation Study with baseline data for assessing the impacts of flooding. Low lake levels in the spring of 1978 reexposed six of the nine sites.

> [D]uring the initial field reconnaissance on Lake Powell... it became apparent [how] dramatic impacts of reservoir mechanical processes [were] on the submerged sites... In several cases entire sites were obliterated, presumably by wave action and other related near-shore mechanical impacts. In those rare instances, only the bottom-most courses of walls

> intact, and the interiors of rooms were typically scoured out by wave action and filled with a thin mantle of redeposited silt (Rayl et al. 1978:20).

The susceptibility of cultural manifestations to mechanical activity has been hypothesized by the inundation study (Lenihan et al. 1977:19-20). The following table compares the predicted to observed impacts and presents a reason for impacts observed (after Rayl et al. 1978:54-55).

Site	Cultural Manifestation	Susceptibility Predicted/Observed	Reason for Impact
42Sa533 (Steury Ledge)	Standing structures of stone, mortar or plaster	2/2	moderate wave action, stone shape (slab) contributing to wall stability
42Sa583 (Echo Cave)	Standing structures of stone-no mortar or plaster	2/1	under 50 feet of water; low-lying walls in structures with dry laid masonry more resistant to mechanical impact
42Sa584	Surface scatter-lithics or ceramics	1/3	no cultural materials remaining on surface, collected by visitors; popular alcove for picnicking
42Sa585 (Doll Ruin)	Area 1: Standing structure of stone mortar or plaster	2/2	under 35 feet of water; high sand content in mortar causing deterioration of bonding agents
	Area 2: Standing structure of stone mortar or plaster	2/2	in 45 feet of water; high sand content in mortar contributing to deterioration; wave action during initial flooding
	Area 3: Standing structure of stone-no mortar or plaster	2/3	direct wave action, complete destruction of rooms

Site	Cultural Manifestation	Susceptibility Predicted/Observed	Reason for Impact
	Area 4: Standing structure of stone-no mortar or plaster	1/2	moderate wave action, under-cutting of talus
	Abraded bedrock features (hand and toe holds), abrading grooves, bedrock mortars, metates	1/0	no apparent deterioration
42Sa590	Standing structure of stone - no martar or plaster	2/3	only north wall standing, all others collapsed due to wave action and erosion
42Sa615 (Mouse Alcove)	Upright logs chinked with mud or plaster (jacal)	2/3	under 25 feet of water; built on unstable trash fill; only foundation remains
42Sa616	Standing structure of stone - mortar or plaster	2/3	wave action; only remaining evidence course of sandstone; sandy mortar
42Sa619 (Gourd House)	Standing structure of stone - mortar or plaster	2/3	wave action and poor quality mortar combined for near total destruction of site
42Sa689	Surface scatter-lithic or ceramics	1/2	slope wave action, erosion, deflation, artifact re-distribution or removal

As can be readily seen, wave action and erosion are the primary variables affecting site preservation and deterioration in Lake Powell.

Adapted from the National Reservoir Inundation Study Relative Impact Chart (Lenihan et al. 1977:22), the chart on the following page summarizes the impacts predicted for each site examined. It is based upon the susceptibility of the environmental matrix to various erosional factors. Rayl et al. (1978:53) rated the sites with predicted/observed impacts.

RELATIVE IMPACT CHART

Site	Environmental Matrix (Soil Types)	Erosion Factors: Stream Channel and Reservoir Dynamics — Site located on inside of meander of river	Site located on outside of meander of river	Water velocity in river over dependent on such factors as slope and nature of water release	Periodic drawdown over site	Subject to wave action, boats, wind, etc.	Site on terrace above river channel	Site located in alcove
42Sa533	Sandy silt, moderately well-sorted sediment cover (undeveloped soil)		2/2	1/1	2/2	2/2	1/1	
42Sa583	Hardpan surface in sandstone alcove	1/1		1/1	2/1	2/1		2/1
42Sa584	Sandy silt, moderately well-sorted sediment cover (undeveloped soil)		2/2	1/1	2/1	2/1		2/1
42Sa585	Sandy silt, moderately well-sorted sediment cover (undeveloped soil)		2/2	1/1	2/2	2/3	1/2	
42Sa590	Sandy silt, moderately well-sorted sediment cover (undeveloped soil)		2/2	1/1	2/2	2/3		2/2
42Sa615	Sandstone bedrock in sheltered alcove		2/3	1/1	2/2	2/3		2/3
42Sa616	Sandstone bedrock in sheltered alcove		2/3	1/1	2/2	2/3		2/3
42Sa619	Sandstone bedrock in sheltered alcove		2/3	1/1	2/2	2/3		2/3
42Sa689	Sandy silt, moderately well-sorted sediment cover (undeveloped soil)		2/2	1/1	2/2	2/2	1/2	

* 1 = minimal impact; 2 = moderate impact; 3 = severe impact
impact expressed as predicted/observed.

Out of 45 predicted susceptibility values, 26 are in agreement, 13 are greater, and 6 are less than predicted by the Inundation Study.

Differential Preservation

Pictographs: Two anthropomorphic figures were relocated on the cliff wall above Doll Ruin in about 30 feet of water. As a result of inundation the pictographs were obscured by a layer of silt and algae. Team archeologists were able to reexpose the art work by rubbing the algae. All of the figures examined were still intact and in good condition (Rayl et al. 1978:23).

Analysis of two pigment samples, one collected prior to inundation in 1959 and a second collected in 1978 after flooding, by X-ray diffraction and atomic absorption revealed increased percentages of calcite in the inundated sample (Rayl et al. 1978:25). Although not proven, it was assumed that the increase in calcite in the pigment was a result of the formation of the calcium rich "bath-tub ring" during periods of reservoir pool level drawdown.

Structural Stabilization Experiment

Doll Ruin and Steury Ledge were selected to test methods of structural preservation after inundation had occurred. Larry V. Nordby, archeologist and ruins stabilization expert with the National Park Service, Southwest Cultural Resources Center, directed the precedent setting stabilization experiment and follow-up evaluation.

The west wall of Structure 4 at Doll Ruin, the only wall in Area 2 which retained any structural integrity, was grouted with an epoxy mortar while inundated by 50 feet of water (Nordby 1978:79). The major problem encountered during the stabilization efforts was the rapid increase in mortar viscosity due to the cold (51°F) water temperature (Nordby 1978:79). A step-by-step discussion of the mortar preparation process and wall cleaning and application of the mixture underwater is provided (Nordby 1978:77-81).

At Steury Ledge only structures 1 and 2 were used for the stabilization tests. The site's inundation history indicated that when flooded it was in the high energy beach zone, that is, in less than 10 feet of water where wave action and surge could do the most potential damage. Unlike Doll Ruin, which had never been excavated, Steury Ledge was excavated after flooding and drawdown and not backfilled (Nordby 1978:82).

The stabilization test conducted at Steury Ledge was designed to determine the efficacy of three different materials: an unamended mud mortar, a soil cement mixture, and a soil-epoxy mixture (Nordby 1978:88). Not all areas within the structures were treated, "the remaining sections of the walls were left untreated to function as control sections for comparability" (Nordby 1978:88). Each test area was marked and photographed prior to and after stabilization.

The follow-up study, conducted in 1979, is discussed and expanded upon in "Preliminary Experiments in the Structural Preservation of Submerged Anasazi Masonry Units" (Nordby 1980). An abstract of that report is provided elsewhere in this section of the technical reports.

Field Experiment in Differential Preservation of Cultural Materials

Several days of field work at Lake Powell were devoted to setting up an experiment to gather additional baseline data on the impacts of short-term immersion on selected cultural remains. The field experiment involved placing buckets containing artifacts in the reservoir at 25-foot-deep intervals to a maximum of 100 feet (Fosberg 1978:63). A total of eight buckets was placed, four each in two different locations, a tributary and the main channel of the Colorado River (Fosberg 1978:64).

Ten pieces of each class of material were used: bone, obsidian, chalcedony, chert, basalt, pottery, and perishables, including twigs and reeds. Samples from each piece were retained for comparative purposes (Fosberg 1978:62). The materials remained immersed for one year, at which time they were retrieved and subjected to a variety of analyses. The results of this testing have been incorporated into the Results Section in Volume I and were not reported on separately. The microbiological experiments at Brady Reservoir, Texas, presented elsewhere in Volume II of the technical reports, were a corollary field experiment. The interested reader may want to peruse that report for data on the impacts of microorganisms on cultural remains.

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PRELIMINARY EXPERIMENTS IN THE STRUCTURAL STABILIZATION OF SUBMERGED ANASAZI UNITS

INTRODUCTION

Larry V. Nordby, supervisory archeologist and ruins stabilization expert with the National Park Service, Southwest Cultural Resources Center, worked with the Inundation Study on two occasions documenting and assessing the impacts of freshwater inundation on prehistoric southwestern structures. During the month of April 1978, and again in May 1979, efforts were made to stabilize Anasazi structures both underwater and prior to initial flooding. "Preliminary Experiments in the Structural Preservation of Submerged Anasazi Masonry Units" (Nordby 1980) discusses the success and failure of the stabilization experiments at Glen Canyon National Recreation Area.

THE EXPERIMENTS

Preservation of Anasazi structures must include an understanding of two broad concerns:

> First, the materials from which they were constructed are relatively durable when left undisturbed by moisture, but proceed quickly down the path toward entropy once violated by water from any source . . . . [and second] aboriginal building technology, which although often surprisingly sophisticated, was not designed to produce buildings which would last forever (Nordby 1980:9-11).

The poor mortar quality found in many of the structures in Lake Powell, although lasting hundreds of years in the dry desert environment, contributed to the rapid deterioration of the structures once inundated.

> Simply stated, inundation results in complete mortar dissipation by softening and separation of the component soil particles. As the plastic and liquid limits of these mortars are reached and exceeded, the weight

of wall stones causes the wall to topple, even in the absence of current or wave activity (Nordby 1980:11).

Other factors which contribute to the problems of structural preservation include lack of vertically plumb walls, lack of solid foundations, unbonded or abutted corners, and walls which are thicker at the top than at their base (Nordby 1980:11).

Other natural and human forces act to increase the rate of deterioration of these structures. Wind-generated waves and boat wakes "are the single most devastating environmental concern" (Nordby 1980:12). The rate of water impoundment and the fluctuation of water levels each increase the rate of site destruction; both create high energy beach zones as they pass over the sites. Casual vandalism by picnickers and deliberate destruction by pothunters and the insensitive can completely obliterate the last vestiges of an already fragile resource (Nordby 1980:12-13).

The general testing format for the work conducted was to leave a section of the wall untreated and stabilize other segments of walls with various materials to determine the efficacy of each material and for comparison both with each other and the untreated section. All work involved mortar repointing and filling voids behind the wall facade (Nordby 1980:17). The three materials tested were: unamended mud mortar, soil cement mixture, and a soil epoxy mixture.

Stabilization efforts were undertaken at three sites prior to flooding. After being immersed, examination of the test panels at Steury Ledge revealed that:

> (1) The unamended mortars . . . have been eroded;
>
> (2) the calcium aluminate-soil cement panels remain intact, although one or two stones atop the wall are loose...;
>
> (3) the soil-epoxy mixture panel is completely intact (Nordby 1980:24).

In-and-Out House (42Ka595) was inundated within 10 to 15 days of treatment. Both calcium-aluminate soil cement and epoxy were used and, in addition, the stones were impregnated with methyl methacrylate (Nordby 1980:26). Stabilization efforts failed here, perhaps due to a number of factors:

> (1) Possible vandalism. This is the site from which the sandbags were removed, and it is possible that the walls were destroyed by vandals. The absence of much [of the] fallen wall stone in areas up to a depth of 10-15 meters below the site makes one wonder where it went.
>
> (2) The few pieces of rubble that we found retained mortar between several stones which fell as a monolith ... the methyl methacrylate did not effectively bond the stone to prevent dissolution of the iron oxide cement...
>
> (3) Lack of solid footing, with the site situated atop a sandy fill soil, probably contributed significantly to the failure of this attempt... (Nordby 1980:26).

Calcium-aluminate soil cement, soil epoxy grout, and methyl methacrylate were also used at 42Sa231. The lake level, as of the stabilization efforts, was 1 to 2 meters below the basal course of stone. The large boulders, upon which the structure sits, had dropped 15 to 30 cm (Norbdy 1980:26). Apparently, the only thing which had prevented further deterioration of the site was the preservation work. Nordby feels that when the site is inundated in the spring of 1980, this too will fall and the site will be destroyed.

Doll Ruin, stabilized with soil epoxy mortar while underwater at a depth of ca. 17 meters, is now close to a depth of 30 meters. Reexamination of the walls revealed that the mortar remains tightly packed between the stones (Nordby 1980:30).

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PALMETTO BEND RESERVOIR, TEXAS

PREHISTORIC AND HISTORIC ARCHAEOLOGICAL SITE MAGNETOMETER SURVEYS IN THE PALMETTO BEND RESERVOIR AREA

INTRODUCTION

The usefulness of the magnetometer in detecting subsurface cultural features is widely accepted (Arnold and Kegley 1974; Breiner 1973; Weymouth 1976; and others). Its application to both the marine and riverine environments for survey is also well documented (Arnold 1976; Murphy in preparation; and others). However, the efficacy of magnetometer survey in locating prehistoric sites in reservoirs, after an inundation event has occurred, has not been determined.

In an effort to gather baseline data for later comparative testing, the National Reservoir Inundation Study contracted with J. Barto Arnold, marine archeologist with the Texas Antiquities Committee, to undertake a magnetometer survey of two archeological sites in Palmetto Bend, prior to initial flooding. Prehistoric and Historic Archeological Site Magnetometer Surveys in the Palmetto Bend Reservoir Area (Arnold and Prokopetz 1976) was written in partial fulfillment of that contract.

RESULTS

This study was designed to test the hypothesis that results of a magnetometer survey conducted after flooding would not be substantially altered and would yield data comparable to that obtained prior to inundation (Lenihan et al. 1977).

Two sites were selected for study, the Chytka Site (41JK66), a prehistoric site, and the Sutherland Site (41JK33), a historic plantation site reported to contain remnants of slave quarters. The surveys were conducted in a similar manner, readings were taken at 1-meter intervals at the Sutherland Site and at 0.5-meter intervals at the Chytka Site. "A Varian M-50 proton precession magnetometer was utilized for this survey with the sensor held at a constant 0.5 meters above the ground surface" (Arnold and Prokopetz 1977:2). A 1 m by 1 m grid of magnetometer readings was completed at the Sutherland Site, while a 0.5 m by 1 m grid of readings was established for the Chytka Site.

Baseline results from the Chytka Site were not astounding. The cultural features were limited to a few small hearths, characterized by the presence of burned calcite rocks. "Unfortunately the hearths were small, and... could not be expected to produce a large anomoly... a very subtle anomoly was all that could be reasonably expected... not much greater than the background noise level" (Arnold and Prokopetz 1977:3).

A large anomoly complex at the Sutherland site was postulated to be a structure by Arnold (1977:6). A 100-gamma difference was noted in this area.

The degree to which comparative readings can be obtained from these two sites after flooding will be determined in the future. The baseline information gathered by Arnold and Prokopetz will go a long way toward addressing the problem of impacts to this type of data-gathering tool in reservoir areas.

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LIBBY RESERVOIR, MONTANA

FIELD ASSESSMENT

INTRODUCTION

In May 1977, National Reservoir Inundation Study personnel were sent to Montana to determine the viability of including sites within Libby Reservoir and Re-Regulating dam in the nationwide research program on inundation impacts. This trip included a field assessment to document mechanical impacts of flooding to cultural remains.

The following information on inundation effects was gathered during conversations with David Munsell, U.S. Army Corps of Engineers Seattle District Archeologist, and during field observation by a study archeologist. Field notes and photos are on file with the National Park Service, Southwest Region, Southwest Cultural Resources Center, Santa Fe, New Mexico.

RESULTS

Mechanical Impacts

Each spring Libby Reservoir undergoes a drawdown between 100 and 150 vertical feet, exposing numerous prehistoric and historic sites. Wind-driven waves and terracing during the drawdown and refilling periods are the primary impacts. The thin soil horizon does not provide an adequate buffer to protect sites from destruction. Clear-cutting, water level fluctuation, and a lack of vegetative regeneration have all contributed to soil deflation and site destruction through direct frontal assault on the sites. Wind erosion, although not usually noted, has contributed to site destruction in many areas of the reservoir; after inundation, the thin, friable soils are especially vulnerable to this type of impact.

The differential resistance of cultural remains to direct mechanical activity has been hypothesized by Lenihan et al. (1977:19-20). Sites within Libby Reservoir have a diverse range of cultural manifestations from paleo-Indian to protohistoric (Munsell, personal communication). Erosion has left lithic scatters and hearths on deflated soil surfaces and wave action is causing some redistribution of lighter materials.

SAYLORVILLE RESERVOIR, IOWA

EYEING THE GATHERING WATERS WHILST BUILDING THE ARK: PREPARATION OF ARCHAEOLOGICAL SITE 13PK183 SAYLORVILLE RESERVOIR IOWA, FOR POST-INUNDATION STUDY

INTRODUCTION

The Iowa State University Archaeogical Laboratory has been involved in investigations within the Saylorville Reservoir region since 1967. In May 1975, there was a possibility that Saylorville Reservoir would begin to fill late in the year or during the spring of 1976. For a variety of reasons initial impoundment was delayed until 1977. It was the opinion of the Iowa State Archaeological Laboratory (I.S.U.A.L.) personnel, the Rock Island Corps of Engineers, and the National Reservoir Inundation study that a site or sites within Saylorville would be good target areas for testing the effects of inundation on archeological remains.

Representatives from the Corps of Engineers, I.S.U.A.L., and the National Reservoir Inundation Study met in November 1976, for an on-site field inspection and evaluation of possible sites for inclusion in the inundation study. At that time, a deeply stratified prehistoric habitation site offered the best overall conditions for assessing inundation-related impacts (Gradwohl and Osborn 1977:2). Plans for preparing site 13PK149 had to be abandoned when an unexpected heavy rainstorm in early May caused the lowest portion of the reservoir to fill, cutting off access to the area and flooding major portions of the site (Gradwohl and Osborn 1977:4).

A second site, Bennett Bend, located in the upper portion of the reservoir, was then selected for preparation. This site will be permanently inundated by 3 to 8 feet of water by the conservation pool and will be "subject to scouring and wave action as the reservoir fills and during periods of reservoir draw-down" (Gradwohl and Osborn 1977:4). Eyeing the Gathering Waters Whilst Building the Ark: Preparation of

Archaeological Site 13PK183 Saylorville Reservoir, Iowa, for Post-Inundation Study was written in partial fulfillment of a contract between the Iowa State Archaeological Laboratory and the National Reservoir Inundation Study.

PREPARATION OF 13PK183 FOR POST-INUNDATION STUDY

Preparation of this site for later study was undertaken in order to provide the type of controlled data and information needed to more accurately assess inundation impacts. Further, the condition of the site prior to flooding was well documented by the Iowa State Archaeological Laboratory personnel and relocational primary and secondary datums carefully plotted and mapped in.

The general strategy for site preparation included the following activities to stabilize portions of the site for later investigation:

1) setting a permanent primary datum and ancillary grid datum points at the site,

2) setting two permanent secondary datum points above the flood control pool,

3) preparation of selected vertical profiles for future study,

4) collection of additional selected data to be analysed and/or replicated by underwater archaeologists in the future, and

5) backfilling selected portions of the site (Gradwohl and Osborn 1977:28).

The specific preparatory procedures undertaken at 13PK183 are outlined below.

Permanent Primary, Secondary and Grid Datum Points

The area of the site selected for preparation was the south block excavation unit. Permanent secondary PVC datums were established above the 890-foot elevation on upland hillslopes to the east and north of the site. Specific relocational data is provided in the report by Gradwohl and Osborn (1977:32-34). One permanent primary datum was set up, supplemented by several permanent grid points established throughout the site. These were constructed and placed according to inundation study guidelines (Lenihan et al. 1977:123-182) in a pattern that should assist underwater archeologists in locating the site and specific site features (Gradwohl and Osborn 1977:33).

Preparation of Vertical Profiles

Two areas within the south block excavation unit were prepared for examination of vertical stratigraphic changes after inundation. The maximum depth of the north profile was 6.2 feet; within this, seven stratigraphic levels were identified, not including an overlying plow zone and historic deposits (Gradwohl and Osborn 1977:35).

A sheet of plexiglass, 4'x 6' x 3/8" thick, was placed against the north profile and engraved with the stratigraphic levels. After installation, the entire north profile was covered with clear polyethylene sheeting, 16 feet wide, "flagged at intervals along the borders with white plastic contact paper squares. It is hoped the flagging will help National Park Service divers to relocate the buried sheeting" (Gradwohl and Osborn 1977:35-40). Fill dirt, originally removed from the profile, was replaced against the covered profile and packed down. A second east-west trending stratigraphic profile was also prepared and covered with plastic sheeting; this profile did not have a plexiglass profile sheet placed against it. Backfilling was completed in a similar manner to the northern profile.

Additional Data Collection

In addition to the site preparation outlined above, a limited number of specific samples were collected from the two vertical profiles, especially for postinundation comparative analysis.

Soil Samples: Prehistoric stratigraphic levels I-a through I-e, as well as the overlying plow zone and historic deposits, Ap and Ap', were sampled for later analysis.

> Mechanical analysis of the soil column in the field included soil type, color, and composition noted from moist samples. All descriptions used are standard soils nomenclature and include thickness and depth, color, and texture. Colors reported are ...from the Munsell soil chart... (Gradwohl and Osborn 1977:43-44).

Pollen Samples: Pollen samples were collected from each of the stratigraphic levels "on the same profile and adjoining the soil sample collection area" (Gradwohl and Osborn 1977:45).

Snail Samples: "Samples were also collected for the purpose of snail analysis since [in this area] the presence or absence of certain gastropod species often can be used as indications of climatic variation" (Gradwohl and Osborn 1977:46).

These samples were collected from each of the stratigraphic levels present.

This site is one of a number that have been incorporated into the ongoing study of inundation impacts. Results of this study await follow-up investigation when the effects of time and flooding have had an opportunity to show marked changes in the site.

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A FINAL REPORT ON THE EFFECTS OF INUNDATION ON CULTURAL RESOURCES: TABLE ROCK RESERVOIR, MISSOURI

INTRODUCTION

A two-year study, conducted by the American Archaeology Division of the Department of Anthropology, University of Missouri-Columbia, was undertaken to assess impacts relating to freshwater inundation of four sites located in the upper reaches of Table Rock Reservoir. A Final Report on the Effects of Inundation on Cultural Resources: Table Rock Reservoir, Missouri (Garrison, May, Marquart, and Sjoberg 1979) was written in partial fulfillment of a research contract between the University and the National Reservoir Inundation Study.

RESULTS

Two general types of sites are found within Table Rock Reservoir, rock shelters and thinly deposited open sites; examples of both site types were relocated and examined during the study (Garrison et al. 1979:4).

Differential Preservation

Stone: In an effort to test the hypotheses concerning differential preservation of stone, i.e., stone artifacts that are inundated will deteriorate faster than similar stone artifacts that are not inundated and the differences in the rate of deterioration will be proportionate to the amount of water-soluble chemicals within the stone (Lenihan et al. 1977:36-37), lithic materials were collected from both an inundated and noninundated site.

Five physical attributes were measured to quantify changes in the specimens due to inundation: leaching, friability, reactivity to HCl, patina development, and edge damage (Garrison et al. 1979:15-23).

> Both limestone and sandstone artifacts exhibited differences in leaching, friability and reactivity between inundated and uninundated samples. Chert was relatively unaffected... [it is] only when patina and edge damage are compared that differences are noted... those samples with the greatest amount of edge damage were from beach environments... (Garrison et al. 1979:23).

The analysis conducted generally supported the hypothesis offered by Lenihan et al. (1977:37) that stone with a high proportion of carbonate compounds will deteriorate at a faster rate than artifacts with a low proportion, under periodic or continuous inundation. Further, differing rates of deterioration could not be detected between periodically and continuously inundated samples (Garrison et al. 1979:27, after Lenihan et al. 1977:38).

Scouring, tumbling, and other mechanical effects were most pronounced on materials collected from the beach zone (periodically inundated); very little of these impacts were found on the noninundated or completely inundated samples. This supports the test implication offered by Lenihan et al. (1977:39).

Three general conclusions can be drawn from the analysis of patination impacts:

> 1. Glossy patination is present on artifacts from [all] three contents: inundated, beach and non-inundated;
>
> 2. dull patina is more prevalent on artifacts from the beach environment... most probably related to abrasion <u>and</u> exposure to ultraviolet light; and
>
> 3. brownish, glossy patina and dark oxide stains occur only on samples from inundated contexts (Garrison et al. 1979:28).

<u>Analysis Techniques</u>

<u>Microscopic Analysis of Stone Artifacts</u>: A comparison of materials from both an inundated and non-inundated context was undertaken to test the effects of inundation on microscopic analysis results.

> The microscopic analysis of selected stone artifacts from inundated and uninundated contexts were... inconclusive... Only sandstone was seen to be altered enough by mechanical action, scouring and abrasion, to obscure edge wear (Garrison et al. 1979:41).

The authors suggest that the negative results may be due to a relatively short period of inundation (ca. 20 years); the effects of inundation on chert may not be as great as initially hypothesized; microscopy used may have been inadequate to detect changes; the researchers may have been unable to discriminate between natural weathering and inundation (Garrison et al. 1979:41).

Neither plant nor animal residues could be detected for either group of artifacts under low to medium magnification. Apparently inundation did not affect this category of analysis; poor preservation of organic materials is common in these sites (Garrison et al. 1979:41).

<u>Soil Chemistry Analysis</u>

<u>Phosphorous</u>: Lenihan et al. (1977:59) suggest that phosphate concentrations will be adversely impacted as a result of inundation. Garrison et al. take this basic hypothesis further and suggest:

> 1) sites located in relatively shallow water, where wind-generated processes occur constantly will... decrease in phosphate content due to leaching and erosion...
>
> 2) sites located on beaches are affected by erosional movement of soil particles, but also by leaching of chemical compounds such as phosphate... The repeated but not permanent presence of water... increases the possibilities of leaching.
>
> 3) sites deeply buried below the water surface and located where wind-generated processes seldom occur and soil transport or erosion is minimal will show little or no chemical alteration (Garrison et al. 1979:44).

Analysis results tended to support all of the above hypotheses. A statistically significant difference in the levels of phosphate was found between the inundated and noninundated areas (Garrison et al. 1979:62-66).

Site 23BY8, permanently inundated by 7.6 m of water, exhibited phosphate concentrations significantly higher than those obtained in shallow water contents (Garrison et al. 1979:62). On the surface this would tend to support the third hypothesis above; however, this rock shelter site was used as a cattle shade prior to inundation (Garrison et al. 1979:62). This may have a direct bearing on the high phosphate values; verification of hypothesis three must be considered tentative.

Other Impacts

Loss of Qualitative Data Relating to Strata and Features: Three features exhibiting differential soil colors, textures, soil remains, and vegetation were located above the water level at site 23BY162. Approximately one year later, when the area was under nearly 3 meters of water, these features were relocated and examined (Garrison et al. 1979:73).

The reddish color of the soil at Feature 1 was still recognizable, and associated lithics did not appear to have been significantly altered. Feature 2, an area characterized by thick vegetation and red-brown silt-clay prior to inundation was relocated after flooding by the soil color; no original or replacement aquatic vegetation was present. Feature 3 was never relocated; the thick vegetation, readily apparent when the area was dry, had died as a result of flooding, and no aquatic replacement species were present (Garrison et al. 1979:73-77).

Whereas soil colors and textures, i.e., feature or stratigraphic indicators, do not appear to have been adversely affected as a result of inundation, vegetational indicators of features have been severely impacted, at least under conditions of periodic inundation (Garrison et al. 1979:78). It is not known how continuous inundation would affect the formation of stable biotic communities on culturally modified soils.

Impacts on Soil Strata: Garrison et al. suggested that soil strata would be impacted by inundation and "that the extent of this alteration will depend... [on] soil type, mechanical effects, and vegetational cover" (1979:82). Lenihan et al. have suggested a range of predicted impacts to standard soil types as a result of selected reservoir variables, i.e., mechanical impacts (1977:18-20).

Of those soils subjected to wind-driven waves, boat wakes, and periodic drawdown, gravels, silty gravels, and inorganic clays are the most resistant to erosion. Sands, organic silts, and other highly organic soils are the least resistant to mechanical action (Lenihan et al. 1977:20). All soils, to some degree, are affected.

The site examined at Table Rock was at the water's edge, an area considered to be the highest energy zone and therefore potentially in the most destructive zone of impact. As expected, the shoreline and littoral zone transect areas were the most severely impacted. A transect starting at the beach line to a depth of 12 meters was also examined. Evidence from the transect at 23SN562 indicates a loss of the upper soil horizons to a water depth of 3 meters. Exposure to prevailing winds and to periodic water level fluctuations may account for the loss of the A and B horizons. A slope angle of 11° may have also contributed to soil loss.

Faunal Impacts: The National Reservoir Inundation study has hypothesized that faunal impacts would be greater at sites in shallow water, but these impacts may not be any more severe than those found on terrestrial sites (Lenihan et al. 1977:110). Data gathered from seven transects sampled over a 23-month period at Table Rock Lake indicates that "95% of the mussel disturbances occur [at water depths] between 1 and 3 meters" (Garrison et al. 1979:105). There was a noticeable lack of mussel disturbance in less than 1 meter of water and greater than 6.5 meters of water (Garrison et al. 1979:106).

An examination of survey results reveals some interesting general trends relating to bottom matrix and mussel activity. Those soils which are predominantly medium/fine silt over clay exhibited the greatest total number of mussels, 218. Gravel and silt over clay had a total of 73, and a bottom matrix of gravel/pebbles over clay exhibited no mussel activity (after Garrison et al. 1979:102). This strongly suggests that, in addition to shallow depths, 1 to 3 meters, bottom matrix plays a role in where mussel activity will occur. Shallow sites on deflated rocky soils could be expected to be impacted to a lesser degree than a site with a more humic soil matrix. This data has further implications for site protection; a layer of medium-sized anomalous gravels could be placed over a site prior to inundation to retard the invasion of burrowing mussels and reduce the subsequent impacts that their activities produce.

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AN INUNDATION STUDY OF THREE SITES IN THE BLUESTONE RESERVOIR SUMMERS COUNTY, WEST VIRGINIA

INTRODUCTION

The excavation and analysis of sites 46Su3, 46Su9, and 46Su22 were conducted under the auspices of the Cultural Resource Management Program of the Department of Anthropology, University of Pittsburg and the U.S. Army Corps of Engineers, Huntington District. Selected analyses were conducted under separate contract through the National Reservoir Inundation Study. "An Inundation Study of Three Sites in the Bluestone Reservoir, Summers County, West Virginia" (Adovasio et al. 1980) was written in partial fulfillment of the analysis agreement between the University of Pittsburg and the National Reservoir Inundation Study.

This testing was conducted to: "(1) gauge the effects of more or less constant inundation on site 46Su3; (2) to delineate the extent and character of the archaeological deposits; and (3) gather artifacts and data on the prehistoric inhabitants of the Bluestone Lake area for a newly constructed interpretive center" (Adovasio et al. 1980: 47). The additional controlled collections at 46Su9 and 46Su22 were conducted with the same objectives stated above.

RESULTS

The three sites selected for study represented an excellent situation for testing the relative effects of inundation. Three factors concerning the Bluestone sites should be emphasized:

1. All three localities are open sites that apparently represent semi-permanent, stable villages.

2. All three sites are believed to be representative of the same cultural phase or tradition. Two of them (46Su3 and 46Su9) are partially contemporaneous while the third (46Su22) is only slightly later in age.

> 3. The sites represent an inundation gradient with 46Su3 almost permanently covered by water, 46Su22 aperiodically covered and 46Su9 never covered by floods (Adovasio et al. 1980:47).

Five sediment columns were collected for soil chemistry and grain size analysis. One column each was taken from 46Su9 and 46Su22, while three sample columns were taken from 46Su3.

> The sample locations at 46Su3 were selected to reflect a gradation in inundation conditions between short-term and long-term or continuous submergence. Thus, unit 30L179 at the highest elevation is not subject to constant inundation. Unit 28L234 occupies an intermediate position ... and 38L326 at the lowest elevation is continuously submerged (Adovasio et al. 1980:98).

Grain Size Analysis

Standard grain size analysis was performed on the samples collected. A consistent difference occurred between the sediments collected from 46Su3 and the other two sites. The greatest percentage of sediment for these samples occurs in the fine sand to coarse silt range. Soil deposition at this site occurred predominantly as a result of repeated flooding, both prior to and after inundation (Adovasio et al. 1980:106). Within site 46Su3 there are postinundation depositional differences. The mean grain size for the 0-10 cm samples was "consistently finer than that seen in the underlying strata of all three excavation units . . . this change is to be expected, as after inundation, 46Su3 was submerged in relatively quiet water conditions" (Adovasio et al. 1980:107). This deposition was due entirely to inundation.

Soil Chemistry Analysis

pH of Soils: The National Reservoir Inundation Study hypothesized that although absolute pH values would be altered by the effects of flooding, results should still yield relative intrasite pH values that are useful for archeological research purposes (Lenihan et al. 1977:58).

An overall comparison of pH from the inundated sites and the non-inundated sites revealed a general trend toward a more acidic soil. The mean values of the 46Su3 test units were 6.9 at 38L326, the continuously inundated unit; 7.34 at 28L234, the moderately inundated unit; and 8.4 at 30L179 at the rarely inundated unit. Site 46Su22, only intermittently inundated, had a pH value of 7.92; while 7.96 was the mean pH value of the never inundated site (Adovasio et al. 1980: 112-116). The discrepancy at unit 30L179, the rarely inundated site, may be due to the high quantities of shell material found at this locus (Adovasio et al. 1980:112).

Both the continuously and moderately inundated units at 46Su3 exhibited a shift toward acid, increasing with depth below surface of the sample. The continuously inundated unit, 38L326, ranged from 7.9 to 6.7, while the moderately inundated unit, 28L234, ranged from 7.5 to 6.8 (Adovasio et al. 1980:113-115).

It appears that although inundation has moderately affected the pH results, the intra- and intersite patterning has not been adversely impacted, relative results still being useful for interpretive purposes.

Organic Matter in Soils: Both sites which have undergone either continuous or aperiodic inundation (46Su3 and 46Su22, respectively) exhibited reduced total organic matter. "The inundated loci have lower values ... generally ranging 0.5 to 1.5% below the non-inundated loci" (Adovasio et al. 1980:117). Stratum III, soils deposited on the sites during flooding, appear to have an increased organic content. These sediments, deposited during quiet water conditions, may contain increased organic matter resulting from soil erosion and upstream runoff.

The NRIS hypothesized that flooding would not affect the percentage of organic matter in subsurface soil samples; however, surface soils would experience a reduced organic content (Lenihan et al. 1977:60). The reduced organic content of sites 46Su3 and 22 may be related to cultural variables at the sampling locales; however, this possibility was not discussed by Adovasio et al. (1980). The preliminary data returns tend to nullify the hypothesis of no effect.

Potassium: The mean values for potassium are lower for the inundated areas. "The difference in potassium values between inundated and exposed sites is not great but may be due to leaching caused by submergence..." (Adovasio et al. 1980:117).

This supports the NRIS hypothesis that inundation would have an adverse effect on potassium concentrations in archeological soils (Lenihan et al. 1977:60).

Sodium: Sodium concentrations were relatively consistent between the sediment columns at each test locale. "Values are slightly higher (3ppm) at the inundated loci, suggesting that sodium actually may be added to the sediments with submergence. The difference may not be significant however" (Adovasio et al. 1980:117).

Calcium: "Calcium shows significantly lower values at the submerged loci. This element probably has been leached and removed to some extent by inundation ... Examination of molluscan remains ... supports this interpretation" (Adovasio et al. 1980:117).

Magnesium: The mean values for magnesium at the inundated and noninundated loci suggests that this chemical is being added to the sediment by submergence. This is in direct contrast to calcium values at the same loci (Adovasio et al. 1980:118).

Phosphorus: These values were reasonably uniform at all five test locations; however, 38L326, the continuously inundated unit, did exhibit significantly lower values (Adovasio et al. 1980:118). The NRIS hypothesized that phosphate values would be lowered as a result of inundation (Lenihan et al. 1977:59).

Sulfate: "Sulfate values are significantly higher for the inundated loci" (Adovasio et al. 1980:118). Examination of the ppm concentrations of the continuously inundated unit at 46Su3 reveals a dramatic difference between the upper strata (0-30 cm) with values from 37.5 ppm to 30.0 ppm, and the lower strata (30-90 cm) with values from 6.25 ppm to 9.62 ppm. Unit 28L234, moderately inundated, exhibits similarly dramatic shifts, as does the intermittently inundated unit, 30L179. The aperiodically inundated site, 46Su22, and the never inundated site, 46Su9, do not have such dramatic changes. The ranges for all strata at both sites are 17.50 ppm to 2.50 ppm (Adovasio et al. 1980:113-116). The data suggests that the sediments being deposited on the inundated sites are abnormally high in sulfate compounds. It is not known what the long-term effects of increased sulfates are on cultural resources.

Nitrates: It has been tentatively hypothesized by the NRIS that the potential for nitrogen analysis will be adversely affected in direct proportion to the length of immersion (Lenihan et al. 1977:59). The striking differences in the total nitrogen content of the inundated versus noninundated sites support this hypothesis (Adovasio et al. 1980: 118).

Impacts on Analytical Techniques

Bone: Faunal remains from 46Su3 and 46Su9 were analysed to determine the relative differences in water absorption of the bone, calcium concentrations, and tensile strength (Adovasio et al. 1980:121).

The results of the water absorption study indicate that little or no differences exist between bone specimens subjected to prolonged inundation and those exposed to intermittent flooding. That is, "deposition of bone in a subsequently inundated environment does not appreciably affect the water absorption capability of the faunal materials" (Adovasio et al. 1980:128). There is no discussion here of any deleterious effects to the preservation of the samples from repeated wetting/drying. For information on this phenomenon, the reader should refer to the Technical Report No. 8 in this volume.

The tensile strength of various specimens from both sites was analysed. "The results show that the stress coefficients of the samples from 46Su3 and those of bones from 46Su9 are significantly different" (Adovasio et al. 1980:129). There was a 3- to 4-fold difference in strength between the sample groups.

Calcium content of the bone specimens was also analysed. It was felt by the Bluestone researchers that "any drastic alteration in the chemical composition of the bone due to different environments (alteration of pH, for example) would become evident in the analysis of calcium content" (Adovasio et al. 1980:128). There were no significant differences from specimen to specimen either within or between sites (Adovasio et al. 1980:128).

Differential Preservation

Shell: It has been hypothesized that flooding will accelerate the rate of deterioration of shell remains and, therefore, these specimens will not be as well preserved as similar shells from a noninundated site (Lenihan et al. 1980:43).

Nearly 16,000 molluscan shells or shell fragments were examined by the Bluestone researchers. Twenty-nine taxa were recognizable and identified (Adovasio et al. 1980:130). Overall, specimens were better preserved at 46Su9 than at 46Su3. This site ". . . has experienced the greatest amount of taphonomic and diagenetic modification... [as evidenced by] the greater deterioration of nacreous shell material in the mussel Cyclonaias tuberculata" (Adovasio et al. 1980:149).

Pollen: "The list of botanical taxa and quantities represented indicates no significant differences [in pollen preservation] among 46Su3 (inundated for approximately 30 years), 46Su9 (never inundated) and 46Su22 (major though intermittent flooding)" (Adovasio et al. 1980:150).

The percentage of samples having no pollen preserved was greatest at 46Su3. It should be noted that all samples contained moderate amounts of fungal spores, suggesting that destruction by fungi was at least a possibility (Adovasio et al. 1980:150).

Ceramics: The shell-tempered ceramics from 46Su3, 46Su9, and 46Su22, are "essentially uniform in gross metric and technological attributes ... differences do occur in relative amounts ... of the mixed shell and various guilt tempered wares ... [however this may be due] to the degree of Fort Ancient acculturation within each assemblage" (Adovasio et al. 1980:159).

Preliminary analysis of materials collected in the fall of 1979 indicates that continued inundation may have an adverse effect on the Bluestone ceramics, especially those which contain tempering material of mussel shell, limestone, or other calcareous grit. The sherds, from two continously inundated units, are of the shell-temper variety; their surfaces have been completely leached as a result of inundation (Adovasio et al. 1980:160). The authors further state that "Although no physical tests have been performed on these sherds, a subjective assessment indicates that the clay matrix appears to be softer than is that of the unleached shell-tempered wares ..." (Adovasio et al. 1980:163).

An additional piece of information on inundation impacts to ceramics was also provided in this report. One of the contributing authors (Johnson) has had experience excavating and analyzing ceramics from the Allegheny Reservoir impoundment area in Pennsylvania and New York. The sites, late Woodland proto-Erie hamlets, yielded ceramics of two pottery traditions: the Ontario Iroquois, tempered and baked with pulverized igneous grit; and the McFate-Chautauqua phase of the Glaciated Allegheny Plateau, tempered with pulverized baked shell. Occupied between ca. A.D. 900 to 1450, these sites have been subjected to annual early spring flooding and heavy rains from snowmelt runoff.

> The adverse effects of periodic, fluctuating inundation on even grit-tempered proto-Erie ceramics is severe.

> [While] the presence of the shell-tempered Chautauqua ware is often revealed in excavation only by a tell-tale off-color smear in the subsoil matrix. The grit-tempered wares are often in such a poor state of preservation that it is necessary to 'refire' them with a propane torch in order to remove them intact from their midden matrix (Adovasio et al. 1980:163-164).

Bone: Although not discussed specifically in the report, there are numerous references to quantities of bone recovered from the excavations. "The surface of [46Su3] ... is literally covered with ... vast quantities of lithic, bone and ceramic artifacts as well as abundant non-artifactual bone and shell remains" (Adovasio et al. 1980:77). Unfortunately, there is no discussion here of the general state of preservation of these materials. Indeed, there were enough bone specimens recovered from the continuously inundated site for a variety of analyses, discussed elsewhere in this abstract. Their condition was such that species identification was possible, as well as the selection out of only deer metapodials for use in tensile strength testing (Adovasio et al. 1980:124).

The soils of 46Su3 were generally more alkaline than acidic ranging from a mean pH of 6.9 to 8.4 (Adovasio et al. 1980:116). Dowman (1970) and others have demonstrated that alkaline soils tend to aid in the preservation of bone. It is assumed that the overall preservation of bone specimens was not adversely affected by inundation.

Stone: The preservation of stone artifacts at 46Su3 was not discussed directly. References to "vast quantities of lithic... and ground stone items whose sheer mass militates against ready transport" (Adovasio et al. 1980:77) suggests that inundation has not adversely impacted this category of cultural materials at Bluestone.

Other Impacts

Human Impacts: The protection of site 46Su3 from vandalism is partially due to the site's inaccessibility during most of the year.

However, the determined efforts of a park ranger have played the major role in keeping the amount of vandalism that has occurred from 1948 to 1977 at a minimum (Adovasio et al. 1980:47). It cannot be stressed enough that a program that is active and obvious in its protection of the resource will be the most effective deterrent to vandalism and pot hunting.

Faunal Impacts: The Asian clam, *Corbicula manilensis*, found in many Western reservoirs, was also found in the upper strata of the Bluestone site 46Su3 (Adovasio et al. 1980:140). A similar species has contributed to the deterioration of housepit floors in Folsom Reservoir in California and apparently this species is burrowing and mixing into the cultural strata at 46Su3. This "may have created some serious problems for the interpretation of recovered archaeological data" (Adovasio et al. 1980:140).

Loss of Qualitative Data Relating to Strata and Features: Lenihan et al. (1977:108) have hypothesized that in certain soil types, such as sands and sandy loams, soil silhouettes may be adversely impacted by inundation, whereas in compacted soils, such as clays and clayey loams, soil stains are not altered by periodic flooding.

The soils of site 46Su3 are predominantly clay and compact clay loams. Colors, textures, as well as discontinuities, are readily discernable throughout the profile (Adovasio et al. 1980:50-51). Continuous inundation has not affected the ability to determine soil profiles at this site.

The aperiodically inundated site, 46Su22, also exhibits distinct soil profiles, although the soils here have much less clay content and are more a sandy loam (Adovasio et al. 1980:54-55). The ability to detect soil profiles at this site may be due to the limited flooding that the site has experienced.

Dating Techniques

Carbon 14 Analysis: Nine samples were submitted for C14 analysis; 4 from the continuously inundated site, 46Su3; 2 from the never inundated site, 46Su9; and 3 from the aperiodically inundated site, 46Su22.

> It should be stressed that, according to Stuckenrath [Smithsonian Institute] and Stehli [Dicarb Labs], the radiocarbon samples from Bluestone were essentially 'similar' in laboratory 'behavior'; that is, there were no apparent differences in the physio-chemical attributes of the samples from any of the Bluestone Lake sites (Adovasio et al. 1980:75-77).

The dates provided by analysis appear to accurately reflect chronological and cultural factors at each site under investigation and, therefore, were not adversely impacted by either continuous or aperiodic inundation.

Thermoluminescence Dating: Analysis of ceramics by this technique was undertaken by Dr. Ralph Rowlett at the University of Missouri, Columbia. The results of this analysis are reported separately in this section of the Technical Reports.

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INUNDATION EFFECTS ON THERMOLUMINESCENCE RESPONSE OF ARCHAEOLOGICAL REMIANS FROM BLUESTONE RESERVOIR, SUMMERS COUNTY, WEST VIRGINIA

INTRODUCTION

"Inundation Effects on Thermoluminescence Response of Archaeological Remains from Bluestone Lake Reservoir, Summers County, West Virginia" was written in partial fulfillment of an ongoing analysis contract between Dr. Ralph Rowlett, a researcher affiliated with the University of Missouri, and the National Park Service, National Reservoir Inundation Study. The analysis was designed to test the hypothesis:

> [Thermoluminescence] samples that have been inundated for 20% or more of their archeological lives will be adversely affected, and will not yield data comparable to that yielded by samples that have not undergone such long-term immersion (Lenihan et al. 1977:103).

RESULTS

The samples submitted were selected from three sites which had experienced varying amounts of inundation since 1949. Samples from site 46Su22 were used as the baseline for this study. It had suffered only rare inundation from 1949 to 1979. Site 46Su9 has an intermittent inundation history and 46Su3 has been annually inundated each summer for the past 30 years (Rowlett and Bates 1980:1). Both shell- and lithic-tempered ceramic samples were analysed. Eight samples came from the baseline or control site, 46Su9, and 9 each from site 46Su22, only moderately inundated, and 46Su3, annually flooded; "...these three sites provide a good basis for comparison, especially since they are thought to all date from AD 1100-1300" (Rowlett and Bates 1980:1).

Site 46Su22

The rarely inundated material from this site was consistent in the absolute date response; the mean date for the 6 shell-tempered sherds was A.D. 1210 ± 134 years (17.4%) (Rowlett and Bates 1980:4).

> This date falls squarely within the radiocarbon estimated age and demonstrates not only the efficacy of the laboratory techniques and the validity of the shell derived age determinations, but more importantly for this study, that the shell tempered pottery is largely unaffected by the rare flooding to which this site is subjected (Rowlett and Bates 1980:5).

Site 46Su9

This periodically flooded site was harder to evaluate; the dates clumped into two groups which are either in the early 18th or early 13th century (Rowlett and Bates 1980:5). These somewhat conform to strata F3 and F4;

> In any case F3 and F4 come out with rather different dates. If one assumes that F3 must date from 1100 to 1300 AD, then its mean date is AD 1282 ± 344, or a 49.3% range of variation, quite in contrast to the 17.4% range of variation for site 46Su22. Interestingly, the apparent younger age for site 9 would be consistent with other inundation studies we have done; inundation reduces TL response, creating thus an illusion of reduced age ... the end result is that the F3 and F4 dates present greater margins of error, i.e., less consistent readings than the little inundated site 46Su22 (Rowlett and Bates 1980:6).

Site 46Su3

> This seasonally flooded site clearly produces the greatest variation even if there is a consistency for the readings to be, on the average, seriatable as to stratum. Sample 3-1, though, is clearly too late. Indeed the mean age . . . is AD 1693 ± 109 or a 39% range of error, not an impossible date but one considerably different from the predicted AD 1100 - 1300 date. Like most other flooded sites, the date comes out too young, i.e., there is a decreased thermoluminescence (Rowlett and Bates 1980:7).

Summary of Lithic Tempers

Only one of the lithic temper types, a fine grained grey-black stone, provided good material for dating. The results of the TL analysis of these samples suggests that inundation affects TL response and produces a reduced TL response and apparent TL age (Rowlett and Bates 1980:9).

Rowlett and Bates conclude:

> This set of samples, while not quite perfect, provided a very good test of the effects of TL on archaeological material inundated for a different periodicity and for varying amounts of time. It would have been helpful if (a) more radiocarbon dates had been available to assist as a control, and (b) there was not a hint that site 46Su9 had not been occupied at two different reprises. . .
>
> The hypotheses that prolonged and recurrent inundation distorts TL response and thus TL dating is supported once again by a particular study. The progressively more flooded sites also show more reduced TL response. This is true of the shell temper dates, as well as for the grey-black temper. This joins other evidence from the West that TL response of burnt limestone, flint, chert and even basalt. . . is distorted if these rocks are heavily inundated. While this distortion is quite severe and would render the absolute TL dating of flooded sites extremely difficult, seriation of responses would still be possible . . . "(Rowlett and Bates 1980:11).

While the detrimental effects of inundation are pronounced,

> . . . the feasibility of using mollusc shell tempers from pottery for TL dating seems assured from this study. The apparent accuracy of such TL dates has been a gratifying spin-off" (Rowlett and Bates 1980:11).

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BLUE MOUNTAIN LAKE, ARKANSAS

BLUE MOUNTAIN LAKE: AN ARCHEOLOGICAL SURVEY AND AN EXPERIMENTAL STUDY OF INUNDATION IMPACTS

INTRODUCTION

In August 1977, the Arkansas Archeological Survey conducted a survey of Blue Mountain Lake in West Central Arkansas. Thirty-nine archeological sites were recorded during the reservoir drawdown; in addition, an experimental study designed to test the effects of inundation upon selected archeological remains was established. Blue Mountain Lake: An Archeological Survey and an Experimental Study of Inundation Impacts (Padgett 1978) was written in partial fulfillment of a contract between the Arkansas Archeological Survey and the National Reservoir Inundation Study.

THE EXPERIMENTS

The experimental study involved construction of archeological features in an area of the lake which, normally, is underwater. Blue Mountain Lake was selected for this experiment for several reasons:

1) the lake is relatively shallow, less than 4m deep in most sections;

2) there was easy access to the exposed lake bottom during the draw down, and

3) the lake is drawn down periodically to improve water conditions, which will allow monitoring at 7 to 10 year intervals" (Padgett 1978:43).

Experimental archeology, a useful approach in understanding archeological data, has been predominantly employed in imitative experiments of various types (Lowie 1937; Ahen 1970; Ascher 1961; among others). The Blue Mountain experiments, however, were designed to be simulative rather than imitative.

> The focus of the experiment is not the function of particular features or artifacts, but the effects of a particular environment (fresh water immersion) upon features and artifacts (Padgett 1978:44).

The specific tests established were based upon hypotheses taken from The Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977). All of the experiments listed below involve pre- and postinundation comparisons. Wherever feasible, the tests were established to provide "matched pair comparisons between different types of materials in the inundation site... or between inundated materials and non-inundated control groups" (Padgett 1978:46). This 'matching' or control method should facilitate comparative and statistical testing of the results.

An attempt was made by the researchers to keep the experimental site as realistic as possible in terms of the materials used and the features created. All of the materials used, with the exception of some obsidian and Southwestern ceramics, were similar to cultural remains that have been found in archeological sites in and around Blue Mountain Lake (Padgett 1978:46).

Equal weight was not given to each of the tests established. In some cases larger sample sizes and more rigorous measurements were used on those materials, such as stone and ceramics, whose deterioration/preservation processes "are, if not more complex, at least less known" (Padgett 1978:46). Water temperature and chemical composition along with pool level fluctuations will, presumably, affect the materials in a variety of ways. Accurate records of these variables is kept by the U.S. Army Corps of Engineers office; these data will be available for use during the follow-up testing and analysis of the experimental test materials.

The following is an overview of the experimental tests established at Blue Mountain Lake.

Differential Preservation

Ceramics: This experiment was designed to test the hypothesis that the basic ceramic structure of materials from an inundated context will be adversely impacted by water saturation in a ratio proportional to its porosity, permeability, and strength (Lenihan et al. 1977:32). Ceramics of both the shell-tempered and grit-tempered variety were used; the tests performed on the control group were porosity and strength analysis. The specific testing procedures used are outlined in detail in the Blue Mountain Lake report (Padgett 1978:47).

Also included in the experiment on differential preservation of ceramics was a test of the hypothesis on the durability of fugitive (painted on after firing) decoration on ceramics subjected to inundation. Matched pairs of decorated ceramics were used; one half of the samples were placed in the experimental site, the other half in museum storage (Padgett 1978:49).

Stone: Materials used in the test of differential preservation of stone included Peoria chert, Boone chert, and Arkansas novaculite (Padgett 1977:50). The Boone and Peoria cherts are high in carbonate mineral composition while the Novaculite is high in silicates. It is hypothesized by Lenihan (et al. 1978:34) that those stone samples high in carbonates would deteriorate at a faster rate than similar samples high in silicates.

Bone: Cranial, rib bones, long bones, mandibles, and teeth were used in this test. One half of each sample was placed in the inundation test site; the others were placed in museum storage with no chemical preservation. When samples are recovered from the test site, both sets of samples will undergo trace element analysis (Padgett 1978:51).

Ferrous Metals: One half of a metal artifact was cleaned and painted with a corrosive inhibitor; the other half was left untreated. The test sample was then buried in the experimental site (Padgett 1978:52).

Shell: Freshwater mussels were used in an effort to quantify the deterioration of shell in an inundated context. Each sample was numbered and weighed; similar samples were placed in museum storage for post-inundation comparison (Padgett 1978:53).

Impacts Upon Qualitative Data Relating to Strata and Features

In this experiment a soil profile was created. A trench was dug and soils of different types (local and from other sources) were used to simulate natural and cultural stratigraphy. The profiles were placed at right angles to each other; a plexiglass sheet was placed against each profile and inscribed with profile data (Padgett 1978:60).

As a part of the stratigraphy test, some cultural materials were placed in the profile. These included ceramic, lithic, and osteological material placed below a layer of compact clay. This was done to test the hypothesis that:

> Cultural materials and organic matter will be better preserved when located in relationship to a cultural feature that acts as a barrier to water saturation than cultural materials and organic matter that are not located in such a relationship to a cultural feature (Padgett 1978:60).

Impacts on Analytical Techniques

Soil Chemistry Analysis: A range of soil chemical analyses were performed on samples collected at the site prior to inundation. Both the natural and created soil profiles were tested for pH, phosphate, nitrate, potassium, and trace elements (Padgett 1978:54).

Flotation: Samples of plant seeds and nut fragments were partially carbonized by roasting. One half of the samples (by weight) were placed in the inundation test site in a loose sand matrix, while the remaining portion was placed in the site in a silt-clay matrix with a hard clay cap. Both test units were of the same dimension and depth (Padgett 1978:55).

Impacts on Standard Survey Techniques

Samples of lithics and ceramics were placed on the ground surface within a 2-meter square and plotted in as to their exact location within the unit. The ability of the researchers to relocate the test unit and artifacts will be dependent upon the amount of silt cover and/or surface disturbance that the unit undergoes during flooding. To the degree that the unit and artifacts can be relocated, an understanding of the limitations of standard survey techniques prior to and after inundation will be enhanced (Padgett 1978:56).

Impacts on Dating Techniques

Archeomagnetic Dating: Two clay hearths were prepared at the test site, one at 50 cm below the surface and a second at 10 cm below the surface. It was hoped that pre- and postinundation samples could be taken from the hearths. Unfortunately, during firing the hearths were doused with water during a severe rainstorm, resulting in insufficient firing for archeomagnetic sampling (Padgett 1978:57). It will be interesting to note the relative condition of these hearths after inundation.

Obsidian Hydration Dating: Samples of obsidian were buried at the test site at different depths as well as above the level of water immersion (Padgett 1978:59). If depth below surface is a factor affecting the hydration rate of obsidian in an inundated context, and the time is sufficient to show a change, this test could answer many questions regarding inundation impacts to this dating technique.

The Blue Mountain Lake experiment was "conceived as a broad range study to test effects of inundation upon archeological sites" (Padgett 1978:79). As with all studies of this genre, the results will not be known for some time. However, it is this type of controlled experimentation that may, ultimately, provide the data needed to understand the impacts of inundation.

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EXPERIMENTS FOR MONITORING THE EFFECTS OF INUNDATION ON THE TOQUA SITE (40MR6), TELLICO RESERVOIR, MONROE COUNTY, TENNESSEE

INTRODUCTION

The University of Tennessee completed the majority of the field work at several sites within Tellico Reservoir prior to December 1976. The Tellico archeological project, in cooperation with the National Park Service, set up a series of inundation test situations at the Toqua site, which was to be permanently inundated by the reservoir waters. Experiments for Monitoring the Effects of Inundation on the Toqua Site (40MR6), Tellico Reservoir, Monroe County, Tennessee (Schroedl 1977) was written in partial fulfillment of a contract between the National Reservoir Inundation Study and the Department of Anthropology, University of Tennessee.

Toqua is situated on a river terrace, stretching approximately 1100 feet and being 600 feet in width. The site consists of two mounds and a large surrounding village confined between the 799-foot and 801-foot contours (Schroedl 1977:1). When Tellico Reservoir closes, Toqua will be permanently flooded by seven to thirteen feet of water.

THE EXPERIMENTS

The area selected for the inundation study experiments was between the 800- and 801-foot contours; the location was chosen on the basis of three factors:

> 1. It was undisturbed by the bulldozer and self-loading pan used to strip the plow zone. . .
>
> 2. Nearby excavations suggested that backhoe trenches here probably would reveal undisturbed village deposits including structure, floors, post-molds and burial pits.

> 3. Because of inclement weather during November and December, this was one of the few areas that access with a backhoe and Melroe Bobcat were comparatively easy (Schroedl 1977:7).

Four backhoe trenches were excavated on December 11 and 12, 1976. Each was marked with PVC subdatums in accordance with National Reservoir Inundation Study site preparation guidelines (Lenihan et al. 1977). Sufficient distance was maintained between trenches to prevent wall collapse. Each trench was treated in a similar manner; a complete sequence of soil samples was recovered, including samples from pits cross-sectioned by the excavations. Bone samples were collected where half or more of the remains could be left in the profile. Unfortunately, there were insufficient quantities of charcoal to collect samples for dating purposes (Schroedl 1977:11).

The east profiles were trowelled, drawn and described; these followed standard soil terminology and Munsell color designations.

> The accuracy and detail of the descriptions and drawings are tempered by the conditions under which they were made. At times there was a steady, moderate to heavy rain with temperatures ranging from the middle 30's to the middle 40's (Schroedl 1977:11).

Backfilling of the trenches was completed using a Melroe Bobcat. Trench 1 was backfilled with the soil removed from it. After each bucket load, the soil was tamped down firmly. Once filled to the top, the Bobcat was driven across the length and width of the trench numerous times (Schroedl 1977:15).

Trench 2 was also backfilled with the soil removed from it; however, the soil in this trench was not packed down and care was taken not to drive any machinery across the test trench at any time. Test trench 3 was not backfilled; all dirt piles which could potentially wash into the unit before or during flooding were removed from the immediate vicinity (Schroedl 1977:17). Trenches 1 through 3 were handled in the above described manner to test the efficacy of various backfilling/no backfilling options.

Prior to backfilling trench 4, a 4- by 8-foot sheet of 1/2-inch thick plexiglass was installed against the east profile.

> Stratigraphic lines were engraved in the plexiglass with a router using a 1/8-veining bit set about 1/8-inch deep. Labeling the plexiglass was done with a 3/16-inch veining bit set 1/8-inch deep. Labels included descriptive names for each strata (plow zone, midden, and sterile alluvium), Munsell colors, and the location of bone samples. Abbreviations for the participating institutions (UT and NPS), the site name and number, the date (12 December 1976) and the names of participating individuals were routed near the base of the plexiglass (Schroedl 1977:19).

The nonplexiglass half of the trench was filled with soil that had previously been removed from the unit. The remainder of the trench was filled with grayish brown sand, purchased for this purpose. Special care was taken to prevent sand from falling between the plexiglass and the profile, and to insure that the wood shoring was not displaced or crushed by the weight of the sand (Schroedl 1977:19).

A second series of inundation experiments was also conducted at Toqua. Two hearths, from which archeomagnetic samples had been taken, were covered with a thin mantle of concrete. "Other protective materials were considered, but the consensus was that concrete might withstand inundation better ... and that it could be broken apart with a geologist's hammer when necessary" (Schroedl 1977:23). Inclement weather including freezing, intermittent rain, snow, and thawing prevented proper curing of the concrete cap, resulting in early signs of it breaking apart.

PREINUNDATION DAMAGE TO THE EXPERIMENTS

The Tellico Reservoir was scheduled to inundate the Toqua site in January 1977. A federal court injunction indefinitely delayed closure. The impact on the inundation experiments resulted from two factors: weathering and vandalism.

An unusually severe winter in East Tennessee resulted in extensive frost heaving and slumping of the site sediments. "During the spring, moderate to heavy rains flooded, saturated, and eroded the experiment area" (Schroedl 1977:24).

In late March or early April 1977, backhoe Trench 3 was severely damaged by relic collectors. Feature 638, one of the concrete-capped hearths, was completely destroyed at about the same time (Schroedl 1977:24). Subsequently, the plexiglass sheet in Trench 4 was completely removed and the unit destroyed. Trenches 1 and 2 have also suffered from vandalism and relic collecting (Schroedl 1977, personal communication).

The cumulative effect of these activities was total destruction of the inundation study experiments, coupled with a frontal assault on the remaining resources at Toqua.

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OZARK NATIONAL SCENIC RIVERWAYS, MISSOURI

NATIONAL RESERVOIR INUNDATION STUDY RESEARCH AT ROUND SPRING AND ALLEY SPRING, OZARK NATIONAL SCENIC RIVERWAYS, MISSOURI

INTRODUCTION

The Ozark National Scenic Riverways in Southeast Missouri was the location chosen for a combined research effort between personnel from the American Archeology Division, University of Missouri-Columbia and the National Reservoir Inundation Study. Alley Spring and Round Spring were the two areas examined between September 18 and September 21, 1978. National Reservoir Inundation Study Research at Round Spring and Alley Spring, Ozarks National Scenic Riverways, Missouri (Carrell, May and Garrison 1980) presents a discussion and preliminary results of this joint field effort.

THE RESEARCH

A major area of emphasis of the Inundation Study includes comparisons between pre- and postinundation cultural remains to determine changes in data-retrieval and analytic potential. The Inundation Study has contracted with individuals and institutions across the U.S. to prepare sites in reservoirs undergoing excavation for postinundation study and evaluation. These contracted situations will only be able to provide information on relatively short periods of inundation; however, the karst areas of the U.S. have been included in the study in an effort to assess the long-term effects of freshwater inundation. Numerous springs in the Southeast, particularly in Florida, have yielded cultural and noncultural organic materials which have been submerged for thousands of years and are in excellent states of preservation.

The selection of Round Spring and Alley Spring for inclusion in the inundation research was based upon four factors:

1) Round Spring was used both historically and prehistorically by local inhabitants...

2) Alley and Round Springs have relatively constant [water] temperatures which vary seasonally only slightly; a phenomenon shared by the springs in Florida which have yielded well preserved cultural material...

3) Alley and Round Springs have water chemistry values suitable for comparison to an on-going laboratory experiment being conducted at the University of New Mexico.

4) The Alley Spring area has experienced a long historic occupation period. Prehistoric use of the spring area has been substantiated... (Bonn and Chapman 1972) and there exists the possibility of prehistoric use of the basin and cave area as well (Carrell, May and Garrison 1980:9).

The specific research objectives of the field effort at the two springs were:

1) preliminary examination of the Alley Spring cave features and Round Spring basin for cultural remains;

2) placement of buckets containing archeological materials in both sinks for the field phase of the [comparative] water chemistry laboratory experiment; and

3) general environmental survey and mapping of Round Spring basin (Carrell et al. 1980:10).

<u>The Field Experiment</u>

One of the stated research goals of the Inundation Study is to address the problems of chemical and biological impacts (Lenihan et al. 1977:1). Questions regarding water chemistry and biological impacts have been addressed through two avenues of research: a water-chemistry laboratory experiment and associated comparative field phases. Round Spring and Alley Spring were selected for inclusion in the field experiment because: their water chemistry values closely correlated with those values used in the laboratory experiment; their water temperatures are relatively constant; and both had areas where buckets of materials could be placed in total darkness to factor out certain biological impacts (Carrell et al. 1980:22-23).

Two buckets of experimental materials were placed in Alley Spring and one placed in Round Spring. In order to provide a statistical sample and permit integration into the laboratory experiment, a minimum of 10 samples of each artifact class used (i.e., bone, lithics, and pottery) was placed in each of the buckets.

One bucket was placed in an area of high light penetration at 25 feet in Alley Spring where there is a diversity of vegetation and associated freshwater animal life. It was suspected that materials in this area would undergo quantitatively greater attack from macro- and micro-biological activity than similar materials placed in a second bucket in the total darkness of Alley Spring cave. A single bucket of materials was placed at a depth of 50 feet in a small room in the deepest area of Round Spring basin.

These buckets were left in place for a period of one year. After that time they were removed and the materials analysed for inundation impacts. The results of these analyses have been incorporated into the research results section in Volume I of this final report.

Data Collection at Alley Spring and Round Spring

Archeological surface collections were made in three areas in and adjacent to Alley Spring basin. Several historic period samples were recovered along with a conglomerate containing what appears to be a Jakie Stemmed point (Carrell et al. 1980:29).

The results of analysis of a limited floral collection was the identification of a specimen as Potomogeton Zosterifolius Schum or P. epihydrus. If correctly identified, this species is several hundred miles south of its previously known range of the Michigan-Minnesota area.

During a survey of the Alley Spring cave for possible archeological remains, a species of crayfish was noted which appeared to have adapted to the total darkness of the cave environment by losing all pigmentation. "These troglobitiec crayfish were seen beginning at a depth of 100 feet in an area 150 to approximately 200 feet from the entrance" (Carrell et al. 1980:32).

During subsequent examinations of the cave by the research team, some discrepancies were noted between the plan drawing found in Springs of Missouri (Vineyard and Feder 1974:80) and the information gathered by the Inundation Study team. The differences noted were:

> 1) the tubular channel [did] not appear to curve as abruptly to the west as indicated by [Vineyard and Feder]... and,
>
> 2) the area beyond the slope opened up into what appears to be a large room rather than continuing as a narrow channel or tube (Carrell et al. 1980:34).

During the mapping of Round Spring basin and grotto an archeological site was discovered in the grotto under 10 feet of water. This previously unknown site [23SH96] produced three categories of cultural materials: bone, ceramics, and lithics. No prehistoric artifacts were found in Round Spring basin.

The ceramics recovered were in an excellent state of preservation and were tentatively identified as Meramec Spring cord marked ca. 400-900 AD (Carrell et al. 1980:37). Examination of the lithic materials revealed utilization of six of the seven tools collected and the identification of a large intact point or knife form as Late Woodland (ca. 400-900 AD).

The discovery of the Round Spring Grotto Site (23SH96) has implications for the rethinking of hydrogeological and paleoclimatological changes which have occurred in the Riverways area. Study of the variables indicative of spring level fluctuations and a search for other early sites underwater would contribute to an understanding of the nature and role of large freshwater spring features in Southeast Missouri.

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TECHNIQUES FOR PRE-INUNDATION SITE AND SOIL STABILIZATION

by
John Ware

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INTRODUCTION

During the five-year course of the National Reservoir Inundation Study, Park Service archeologists traveled extensively and consulted on a number of reservoir mitigation projects in many parts of the country. During the course of these contacts a number of problems were addressed and two questions were nearly always asked: "Are there mitigation alternatives to excavation on reservoir projects?" ...and, "What, if anything, can be done to protect sites that can't be excavated?"

A systematic approach to answering questions of this type is provided in Volume I, Chapter 5, which summarizes approaches to mitigating adverse impacts to cultural resources in reservoirs. A review of mitigation approaches and alternatives discussed in Chapter 5 suggests that the answer to the first question is a qualified "yes," depending on the nature of the cultural resource and its location within the impoundment, particularly its location with respect to the fluctuating reservoir shoreline. The answer to the second question is that many protection alternatives exist, ranging from periodic monitoring to construction of protective facilities whose initial construction and long-term maintenance costs may exceed even the most ambitious of mitigative excavation programs.

There are a number of protection and stabilization methods that hold considerable promise for archeological and historic site preservation in a reservoir environment. Some of these methods have been employed in hydraulic engineering applications for years, and their construction, design specifications, and long-term performance characteristics are well documented. Other methods are in the advanced stage of laboratory testing but have not been subjected to long-term field tests, and consequently, detailed design and construction--application procedures have yet to be formulated.

This technical report is aimed at summarizing the most promising of these methods. Its goal is to acquaint archeologists with some of the protection and mitigation options that may exist; not to provide archeologists with a technical manual for how and when to implement these options. The majority of methods and techniques outlined below have not been tested on archeological sites, and until these tests are conducted and the utility of the methods evaluated, specific recommendations for implementation would be premature.

RESERVOIR IMPACTS

Dam construction, water impoundment, and reservoir use generate a variety of adverse impacts on cultural resources. The first step in selecting methods of resource protection involves predicting the nature and intensity of those impacts.

Some of the most devastating impacts to cultural resources occur during dam construction prior to water impoundment. In earth and earth-rock dam construction, large quantities of soil and rock borrow material are routinely excavated from the reservoir basin and transported to the dam site for use in embankment construction. Obviously, unless borrow pits can be located so as to avoid cultural resources, excavation is the only realistic mitigation option in such direct construction impacts.

Aside from direct construction impacts, wave action along the fluctuating reservoir shoreline is probably the most destructive form of erosive impact associated with a reservoir. In addition to water waves, the shoreline may also be periodically subjected to water-borne ice and floating debris impacts. In large reservoirs, ice sheets up to 12 inches thick and 100 acres across may be driven across the lake and into the shore following the spring breakup (Sherard 1963:16). During spring runoff, large trees and other floating debris may accumulate in a reservoir impoundment and wash against the shore, causing substantial impacts to sites that might otherwise have survived the impacts of repeated wave blows.

In general, the intensity of wave and wave-related impacts will be directly proportional to the size of the reservoir and the frequency and intensity of wave-generating storms. However, reservoir function may also influence the intensity of wave impacts. For example, wakes from high-speed motor boats may constitute a major source of wave impacts, especially in small recreational reservoirs that are incapable of producing large wind-generated waves. Reservoir function also determines the frequency and intensity of water level drawdowns which, in turn, may influence the extent and intensity of wave erosion on the fluctuating shoreline.

There are a number of established methods of wave protection on shorelines and shoreline hydraulic facilities. Because of the erosive potential of breaking waves and floating debris, wave protection structures must be strong and extremely durable. Consequently, effective wave protection tends to be relatively expensive. It has been estimated that on large earth dams, 10 to 30% of total construction costs may be devoted to upstream embankment protection; and on small dams with large reservoirs, the total cost of embankment protection may exceed 50% of total construction costs (Sherard et al. 1963:450). Several techniques currently employed by the U.S. Water and Power Resources Service (WPRS) and the U.S. Army Corps of Engineers for earth dam and shoreline protection are summarized below under the heading <u>Wave Protection</u>.

In addition to the mechanical impacts of breaking waves and water currents, the biochemical effects of long-term fresh water inundation may adversely affect certain classes of cultural resources in a reservoir. In light of the long-term consequences of fresh water inundation, methods that would prevent or limit water saturation of submerged resources may have considerable utility for cultural resource management.

Technologies for waterproofing archeological sites may be available in the form of materials and techniques used in the lining of canals and reservoirs. These same techniques may also have some utility in protecting sites from water current action and for temporary wave impact protection. Several of these methods are discussed below under the heading <u>Canal and Reservoir Linings</u>.

The process of inundation is not the only aspect of dam construction and reservoir impoundment that may result in adverse impacts. Most reservoirs are designed to serve multiple functions. A common secondary function of fresh water reservoirs in the United States is recreation, and recreational activities may cause substantial impacts to cultural resources that are never or only rarely submerged. Direct impacts may result from the construction of recreational facilities such as access roads, campgrounds, boat ramps, and so on; while indirect impacts are almost certainly to occur as a result of increased visitor access to hundreds of miles of reservoir shoreline.

Unless a direct impact is involved, or unless the cultural resource is highly visible and, therefore, susceptible to vandalism, perhaps the best management strategy is to leave the site alone and periodically monitor its condition. If direct impacts are imminent or in progress, however, a variety of protective measures are available, and some of these are summarized in the concluding sections of this report entitled Soil Stabilization and Vegetation Stabilization.

WAVE PROTECTION

The design of wave protection facilities is generally based on estimates of shoreline erosion intensity, and wave height is usually employed as an estimate of this potential. In general, wave height will vary with the magnitude of wind velocity, the duration of that velocity, and the size of the reservoir fetch or the water surface area over which the wind blows.

Experience has shown that maximum wave heights for a given wind velocity are usually not achieved unless the duration of the velocity is on the order of one hour. Consequently, standard wave height equations usually employ the average wind velocity calculated over a sixty-minute period. In calculating fetch length, experience has also shown that the use of the greatest straight line distance over open water often results in overestimations of maximum wave height. As a result, an "effective fetch" is frequently computed for wave height predictions. An effective fetch is obtained by dividing the 45° angle on either side of the maximum fetch (the greatest straight line distance) into 15 equal segments. The fetch length of each of these segments is then multiplied by the cosine of the angle of deviation from the maximum fetch line, and the sum of these products is then divided by the sum of the cosines (Davis and Sorensen 1969:4-18).

Once wind velocity and effective fetch have been estimated, their values are entered in a standard formula for estimating wave height. Two of the more popular formulas used by the WPRS and the Army Corps of Engineers are the Molitar and Craeger formula (Davis et al. 1973:3):

<u>Molitar formula</u>: $h = 0.17 \quad VD + 2.5 - 4 \quad D$

where:
h = wave height
V = wind velocity
D = reservoir fetch

<u>Craeger formula</u>: h =

where:
c = 2.08 (arbitrary constant)

Once maximum wave height for a given reservoir is determined, there are additional formulas available for computing wind setup, wave run-up, and freeboard requirements, which may be useful in determining size and configuration requirements for various wave protection structures (see Davis and Sorensen 1969:18-53).

Most of the wave protection technology that may have utility in cultural resource protection has been developed over the years for use in stabilizing the upstream slopes of earth dam embankments. In decreasing order of frequency, earth dam facings are protected by: 1) dumped rock riprap, 2) hand-placed rock riprap, 3) articulated concrete pavement, 4) monolithic concrete pavement (Sherard et al. 1963:171), and

5) in recent years, compacted soil-cement and asphaltic-concrete. These and several other embankment protection methods are briefly summarized below.

Riprap

Rock riprap, consisting of a blanket of well-graded rock fragments on a gravel and sand filter, is the most common form of upstream earth dam protection. The advantages of rock riprap include: 1) low cost, 2) resistance to post-construction embankment settlement, 3) resistance to frost heave and floating debris impacts, and 4) effective dissipation of wave energy.

Rock riprap may be either dumped or hand placed. In general, dumped riprap is considered a more effective wave barrier than equivalent thicknesses of hand-placed riprap, since the movement of individual rocks has little effect on the strength and integrity of the dumped blanket, whereas rock displacement in a hand-placed blanket may expose the underlying filter to erosion and result in one of the most common causes of riprap failure (Sherard 1963:175). Experience has shown that hand-placed riprap tends to be particularly susceptible to ice and floating debris impacts which have the potential for dislodging individual rock from their matrix.

The first step in constructing a rock riprap blanket involves grading the underlying slope and spreading a thin layer or filter of crushed rock or gravel, which serves to prevent erosion and undercutting of the underlying embankment soil. Filters consist of well-graded mixtures of gravel (3-4 inches in diameter) and course sand, and vary in thickness depending on predicted wave height (Table 1), gradation of riprap, the plasticity and gradation of the underlying soil, and material costs (Sherard 1963:459). To aid in the placing of the filter and rock blanket, a horizontal berm of graded soil and gravel is normally constructed along the lower edge of the embankment. The berm not only provides a horizontal working surface for construction equipment but also helps to prevent undermining of the riprap blanket in the event of reservoir drawdown.

Once the filter is in place, the rock fragments are laid directly on the filter. Riprap fragments should be well-graded and placed in a uniform layer without grade segregation. Large riprap is usually emplaced with the aid of heavy equipment; if individual rock fragments are small, however, hand labor... placement may be cost efficient (Sherard et al. 1963:663).

According to WPRS specifications, rock riprap should satisfy two primary requirements: 1) rocks should be of suitable size and shape for the intended use, and 2) they should be tough and durable enough to withstand predicted erosion and weathering agents at the site of placement (Earth Manual 1974:115). Size, shape, and gradation requirements are governed primarily by estimates of wave intensity (see Table 2) and slope steepness. Upstream dam facings usually vary in steepness between 2:1 and 4:1; for slopes within this range there are standard formulas for estimating rock size, gradation, and blanket thickness. For slopes greater than 4:1, these variables must be adjusted upward if maximum protection is to be achieved. The size and angularity of the rock fragments will also vary relative to slope steepness and angle of repose. In theory, rock selected for riprap applications should meet the quality specifications of concrete aggregate. In reality, however, much softer rocks are often used if they constitute the best available source. Igneous, metamorphic rocks, and limestones are generally preferred for riprap applications; shaly sedimentary rocks are usually avoided. If the only available riprap source contains rocks with high clay contents, laboratory freeze-thaw tests are usually required in order to determine weathering characteristics.

In a recent review of embankment protection on 50 earth-riprap dams in the United States by WPRS, two types of significant riprap deterioration were noted: 1) slope erosion from wind, wave, and ice action was indicated by slope abrasion, beaching, washing of fines, displacement, plucking of stones from the slope, and slumping; and 2) rock fragment disintegration was noted due to weathering, decomposition resulting from temperature variation, water absorption, decrepitation, ice, fire, and plant root impacts (Davis et al. 1973:2).

Most instances of riprap erosion were traced in poorly graded beds, as when large rocks of uniform size were used without a sufficient quantity of small rocks to fill the interstices between the larger rock fragments. The use of well-graded blankets not only helps to keep the larger rocks in place but also protects the underlying gravel filter. In most cases, rock disintegration due to weathering was minimal, and in no cases did weathering compromise the effectiveness of the riprap blanket.

On the basis of their survey, WPRS made the following recommendations for riprap design specifications on earth dam facings:

1) All dams with fetches larger than 2.5 miles should be protected by riprap with a 36 inch normal thickness and rock sizes graded up to one cubic yard.

2) Riprap gradation limits should be revised to include more large size rocks (see Table 2).

3) More attention should be devoted to rock placement so that a well-keyed, dense blanket is obtained.

4) Higher quality borrow areas should be selected, and greater control over quarry blasting should be employed so that rocks of suitable graded size are obtained (Davis et al. 1973:4).

In addition to reservoir slopes and dam embankments, rock riprap is often used to protect a variety of hydraulic features such as bridge abutments, roadway beds, groins and breakwaters, and as reservoir and canal linings. Several of these applications may have utility for archeological site protection. The U.S. Army Corps of Engineers has conducted laboratory tests of riprap stability on embankments subjected to periodic overflow by rising reservoir waters (U.S.A.C.E. 1964), a situation that might be analogous to an archeological site located on an isolated rise within the drawdown zone of a reservoir. The experients indicate that for any form of overflow embankment, riprap size and gradation should be determined on the basis of expected wave heights <u>and</u> overflow current velocities. It was found that the most effective stone size for a particular gradation is that which represents 60 to 65% of the average stone weight in the protective blanket. Considering the two forces involved, upstream slopes of 1:3 and downstream slopes of 1:4 are considered optimal for overflow embankments.

Another common use of riprap is in protective blankets for impervious reservoir linings. Linings may be composed of a variety of impermeable materials; well-graded gravels with plastic fines are often used since they have the advantage of impermeability and erosion resistence. Design specifications for riprap blankets are similar to embankment protection structures. Rocks should be well-graded, equidimensional, and angular, and well-rounded cobbles and boulders should be avoided except on very flat slopes.

Concrete Slabs

Concrete slabs and pavements were once used second only to rock riprap in wave embankment protection structures, but in recent years concrete structures have largely been replaced by lower cost alternatives, such as asphaltic-concrete pavement and soil-cement. The most common form of concrete protection consists of articulated pavements composed of individual slabs varying from 5 to 50 feet across, and 4 to 12 inches thick (Sherard et al. 1963:178). The individual slabs are usually reinforced with wire mesh or steel rebar. Another less common application is the monolithic reinforced concrete slab.

The primary advantage of multiple independent slabs lies in their ability to adjust to differential embankment settling without severe cracking. In general, however, articulated concrete slabs have not been particularly successful due to high construction and long-term maintenance costs. Most failures of articulated slabs are attributable to erosion of the underlying filter through the slab joints, resulting in differential settlement and cracking of the slabs. Cracking of the slabs permits additional erosion of the filter, which may result in additional fracturing and settlement. The extent of fracturing can usually be controlled by the use of bidirectional steel reinforcement of individual concrete slabs. The embankment under the slabs should also be highly compacted to reduce the occurrence of differential settling.

Monolithic concrete slabs have been very successful in wave protection applications; however, the cost of monolithic slab construction is often prohibitive. The primary disadvantage of a monolithic slab is its smooth surface, which encourages wave run-up. During high intensity storms, excessive storm surge may overtop the embankment and erode any unprotected section of the embankment above the slab. To discourage wave run-up, wave breakers or steps are often incorporated into the slab (Sherard et al. 1963:178-184).

Soil-Cement

The Earth Manual (1974) defines two varieties of soil cement: 1) compacted soil-cement is a "cement stabilized soil consisting of a controlled mixture of soil, cement, and water compacted to a uniform, dense mass" (1974:120); 2) plastic soil-cement is a "cement stabilized soil consisting of a mixture of soil and cement with sufficient water to form a fluid consistency which will flow easily and can be pumped without segregation" (1974:121).

In the last 20 years, compacted soil-cement has been used on a number of WPRS earth dam embankments as a substitute for rock riprap. Many of these dams are located in the Great Plains where rock sources suitable for riprap are located a considerable distance from the construction sites. In general, compacted soil-cement is considered a viable and cost-effective alternative to riprap if the haul distance to a suitable rock source exceeds approximately 20 miles (Degroot 1971:1). As a general riprap substitute, compacted soil-cement is often used in protective blankets, excavation linings, and other applications where unconsolidated soils require protection from water wave and current erosion.

The most desirable soil aggregate for soil-cement applications is a well-graded silty sand with a fines content of between 15 and 25%. Uniformity of soil in texture, grading, and moisture content is critical to successful bonding. Of these criteria, aggregate gradation is perhaps the most important (see Table 3). Soils with high percentages of gravel are difficult to work and apply in a uniform level, while high percentages of fines make the soil-cement difficult to mix and tends to inhibit thorough bonding.

Soil aggregate is usually quarried near the construction site, and if the source is not homogeneous, it is usually screened and graded before use. Laboratory tests are generally required to determine soil-cement ratios, cement type, and moisture and compaction requirements. Typical soil-cement mixtures average around ten parts aggregate to one part cement but will vary according to cement type and aggregate quality. In general, the lower the percentage of fines in the aggregate, the higher the percentage of cement required for adequate bonding. However, because of problems in mixing, an excess of fines tends to be more detrimental than a deficiency of fines (DeGroot 1971:4).

In large-scale applications such as upstream dam facings, soil-cement is usually mixed in a continuous flow mixing system and deposited at the construction site with the aid of heavy equipment. The soil-cement is normally deposited in a series of horizontal layers or lifts and compacted with a combination of sheepsfoot and pneumatic rollers. Erosion on the edges of the lifts where the soil-cement is poorly compacted results in a stair-step configuration to the slope, which ultimately functions to reduce wave run-up.

Asphaltic-Concrete

Asphaltic-concrete, a "controlled mixture of asphalt cement and graded aggregates mixed and placed under elevated temperature" (Hickey 1971:1), has many potential hydraulic construction applications. In recent years, asphaltic-concrete has been applied as a protective cover on upstream dam facings where it has proved to be an acceptable substitute for rock riprap. It is also frequently used for canal and reservoir linings.

Asphaltic-concrete aggregate requirements are comparable to those of soil-cement. Aggregate should consist of a well-graded sand-gravel mixture, with maximum particle size ranging from Number 4 standard sieve size to 1½ inches; nonplastic fines should not exceed 15% of total aggregate dry weight (Earth Manual 1974:121).

Asphaltic-concrete is usually applied as a "hot-mix" using standard highway-type pavers and compactors. Early experimental installations of asphaltic-concrete on WPRS facilities have provided poor to good service, with the majority of failures apparently resulting from poor initial compaction. With proper compaction, the durability of asphaltic-concrete approaches that of concrete, and long-term maintenance costs for both are roughly equivalent (Hickey 1971:2).

The advantages of asphaltic-concrete are that it is less expensive than concrete and steel, more flexible than concrete slabs, and can be applied more rapidly than most other riprap substitutes. Perhaps the most important disadvantage of asphaltic concrete is its compaction requirements. With improper compaction, asphaltic-concrete tends to be soft and is easily damaged by impacts from ice and other floating debris.

Failures in asphaltic-concrete blankets typically consist of transverse cracking and surface erosion, both of which are mitigated by proper compaction during initial application. Other failures have been attributed to frost heaving and plant growth. In warmer climates, it is recommended that the soil base be treated with a sterilant before the application of the hot-mix.

Metal Plates

Welded steel plates have been used for upstream dam protection on several earth dams in the United States, and other types of rigid metal plates and mats have been tested as possible riprap substitutes (Styron 1979). Steel plates have two major advantages over articulated and monolithic concrete slabs: 1) they are water-tight and 2) they are relatively flexible and readily conform without rupture to differential embankment settlement. Experience has shown that steel plates last at least as long as reinforced concrete, that maintenance costs are very low, and that corrosion of the steel is minimal--although it is recommended that clay filters be avoided because of the potential for corrosion (Sherard et al. 1963:480).

The primary disadvantage of steel and other metal riprap substitutes is their high cost. A cost that may range from 5 to 10 dollars per square foot tends to limit the use of metal plate wave protection to very special applications where the advantages of metal plates outweigh the costs (Styron 1979).

Summary

In summary, a variety of wave protection technologies exist which have potential application for archeological site protection. From the standpoint of both cost and effectiveness, rock riprap is probably the method of choice in most applications. A major advantage of riprap over the various riprap substitutes is that it can be placed on irregular slopes of variable steepness, whereas soil-cement and asphaltic-concrete require fairly even slopes and a high degree of compaction. Both of these requirements are often incompatible with archeological site preservation.

The primary disadvantage of all the methods discussed above is their relatively high cost. Rock riprap is often the least expensive of the various alternatives; however, riprap costs are extremely variable depending on the costs of quarrying suitable rock and the haul distance between the rock source and the construction site. If haul distances exceed approximately thirty miles, then several riprap alternatives become cost competitive.

With the exception of steel plates, none of the technologies outlined above are designed to exclude water. Virtually all, however, can be combined with impermeable membranes or filters to provide not only protection from wave and current action but also water seepage. Impermeable membranes will be presented in more detail below in a brief discussion of canal linings.

CANAL AND RESERVOIR LININGS

In addition to wave protection structures, there are a number of techniques currently in use for protecting canal banks and reservoir slopes from current action and water seepage. The application of these techniques may have some utility for archeological preservation in instances where an archeological site must be protected from water saturation or sustained current flows.

With the possible exception of wave-generated nearshore currents, water current impacts on archeological sites in reservoirs are negligible when compared with the erosive impact of breaking waves. However, in upstream portions of a water impoundment where wave action is negligible due to small fetch areas, strong currents associated with river inflow may pose periodic threats to archeological sites during periods of high reservoir water levels. Under these circumstances, various canal and reservoir lining materials might help to stabilize the endangered site. None of the methods described in this section are designed for wave protection, however, so if wave impacts are anticipated, it would be advisable to forego linings in favor of a more durable protective cover except, that is, in a temporary or emergency situation when long-term stabilization is not required.

Linings may be water permeable or impermeable, and the latter may have special utility in protecting resources that are adversely affected by saturation. Once again, if the site that is being sealed against water is subject to wave action or other erosive agents, the impermeable lining should be covered by an appropriate thickness of durable protection.

Exposed Linings

Canal and reservoir linings may be either exposed or buried. Exposed linings include many of the materials and applications used in wave protection structures, such as concrete, soil-cement, and asphaltic-concrete. Although compaction and aggregate requirements are somewhat different for canal linings, application procedures for these materials are comparable to procedures outlined above for dam facings and shore protection blankets. In general, rigid linings of cement and asphalt are preferred when structures must accommodate high velocity water flows.

Another form of rigid canal lining not generally used in wave protection facilities is pneumatically-applied liquid concrete, commonly known as shotcrete or by the trademark name of gunite. The primary advantage of shotcrete is that it can be easily applied over rough surfaces, and when steel reinforced, shotcrete linings 1 to 1½ inches thick can be applied at approximately the same cost as unreinforced concrete that is twice as thick (USBR 1963:8). The principal disadvantage of shotcrete is that it is thinner than concrete and therefore more susceptible to cracking as a result of soil and hydrostatic pressures. It is also very difficult to control the thickness of shotcrete linings, and failure due to localized weakness is common.

Other forms of pneumatically-applied linings include plastic soil-cement and sprayed-on asphaltic membranes. Plastic soil-cement has properties similar to shotcrete, except that locally-derived soils are used for aggregate. The performance characteristics of plastic soil-cement are essentially identical to those of shotcrete. Sprayed-on asphaltic membranes have been tested, but with only limited success due to their high susceptibility to mechanical injury (USBR 1963).

In addition to exposed rigid linings, flexible membranes of synthetic rubber are occasionally used to line canals and reservoirs and to waterproof spillways and outlet structures (Hickey 1971). Rubber membranes are available in large sheets and a variety of thicknesses, ranging from 1/32 to 1/8 inch, and are commonly reinforced with cotton or nylon. Splicing is accomplished in the field with rubber cement and gum tape. The primary advantage of synthetic rubber linings is that they are impermeable and easy to apply; disadvantages include high cost, poor weathering characteristics, and susceptibility to vandalism and injury. It is recommended that exposed rubber membranes be restricted to structures that continually contain or carry water, in order to inhibit ozone deterioration and to protect the lining from vandalism and physical forces (Hickey 1971).

Buried Membrane Linings

Buried canal linings may consist of hot-applied asphalts, prefabricated asphaltic materials, graded layers of impermeable clay soils such as bentonite, and plastic membranes. In recent years plastic membranes have become the material of choice because of their low cost, long-term durability, and ease of application. According to Timblin (1977), over 48,000 square meters of plastic canal linings have been implaced in WPRS facilities since they were first introduced in 1953. The long-term performance history of these buried linings is excellent.

Although a variety of different plastic membranes have been used (i.e., polyethylene, chlorinated polyethylene, ethylene vinyl acetate copolymer), polyvinylchloride (PVC) has been used most extensively. PVC is more expensive than many other polyethylene membranes; however, it has greater puncture resistance, is more widely available in large sheets, and is more easily spliced and repaired in the field. The method of application involves preparing a suitable foundation free of any sharp objects that might tear the membrane. Once the foundation is prepared, the plastic is laid down in large rectangular sheets which are sealed in the field with either solvent, heat, or by electronic seam sealing methods. Once the membrane is laid down, sealed, and anchored, a layer of earth at least one foot deep is placed on top of the membrane and compacted. The layer of earth is necessary to protect the membrane from physical injury and weathering.

Advantages of buried plastic membranes are low initial cost, rapid application, and relatively long effective use life, which may exceed ten years. Plastic membranes are particularly useful in cold climates where freeze-thaw action discourages the use of concrete and asphalt linings. The major drawback to plastic linings is their low resistance to mechanical erosion and abrasion. Erosion of the soil cover that exposes the membrane to weathering significantly reduces the use life and effectiveness of the lining. Consequently, buried membranes can only be used in channels with limited water flow velocities. Maintenance usually includes periodic repair and replenishment of the soil cover. Plant growth on the cover must also be actively discouraged.

SOIL STABILIZATION

In geology, "soil" is defined as the unconsolidated mantle of climatically-conditioned, disintegrated, and decomposed rock, soluble salts, and decomposed organic matter on the outermost layer of the solid earth crust that provides a suitable medium for plant growth (Winterkorn et al. 1968:6). To the engineer, who is concerned with the foundation and construction properties of soils, the term "soil" is applied to any "material in the surface layer of the earth crust which is loose enough to be moved with spade and shovel" (Winterkorn et al. 1968:5).

Engineers are primarily concerned with the physical properties of soils, such as unit weight, permeability, compressibility, sheer strength, and interaction characteristics with water. To aid in the determination of engineering properties of various soil groups, engineers have devised a "Unified Soil Classification System" that is based on such physical properties as particle size, particle size range and relative proportions, and characteristics of the very fine grain components of soils (Earth Manual 1974:2).

Particle sizes in the "Unified Soil Classification System" range from gravel (3 inches to No. 4 standard sieve size-4.76mm), to sand (No. 4 to No. 200 sieve size-.074mm), to fine-grained silts and clays smaller than No. 4 sieve. Gravels and sands have essentially the same engineering properties; when well-graded, they are very stable; when devoid of fines, they are relatively pervious, easily compacted, and little affected by moisture and frost action (Earth Manual 1974:10-11).

The presence of fines has a major influence on the engineering properties of soils. Gravel-sand soils with only 10% fines may be virtually impervious, and if well-graded, may be severely affected by frost heaving. On the other hand, small amounts of clay and silt may improve the engineering properties of soils by helping to bind together course grain soil components. Soils with large amounts of fines pose the greatest problems in engineering applications because their structural properties are adversely affected when their moisture content is altered.

The primary soil groups of the "Unified Soil Classification System" are presented in Table 4 below, along with a tabular summary of their most important engineering properties and desirability for various construction uses (after Earth Manual 1974:20-21).

When a soil is deficient in certain physical properties that are required for an intended use, there are various methods available for altering those properties so that the soil can still be used. These methods are known collectively under the term soil stabilization, which is defined as "any physical, chemical, biological or any other method or combination of such methods employed to improve certain properties of a specific soil in a particular environment, enabling the soil to serve as a better foundation or construction material" (Winterkorn 1968:7).

The previous sections on wave protection structures and canal and reservoir linings discussed a variety of "physical" soil stabilization methods. In this and the following sections, we will focus on chemical and vegetation stabilization of soils.

During the decade following the enactment of the National Environmental Policy Act in 1969 there was a significant increase in the technology of soil stabilization in order to reduce rates of soil erosion, air pollution, and sedimentation of lakes and rivers. The petrochemical industry generated much of this new technology. In recent years a number of chemical soil stabilizers have been developed, tested, and marketed for a variety of stabilization applications, including: 1) erosion control, 2) soil stabilization prior to revegetation, 3) protection of earthworks during construction delays, 4) waterproofing problem soils, 5) dust control, 6) secondary road stabilization, and 7) permanent stabilization of soils poorly adapted to vegetation stabilization (Timblin 1977:4-5). In addition, the Corps of Engineers and WPRS are conducting ongoing tests of a number of chemical stabilizers for hydraulic engineering applications, and the results published to date are promising (Morrison and Simmons 1977).

WPRS tests of chemical soil stabilizers have focused on the family of petrochemical polymers including water-based vinyl polymer and acrylic copolymer, water-based epoxized-silicone, several varieties of liquid asphalt, several petroleum-base resins, neoprene-asphalt and liquid asphalt with mineral and fiber fillers, and synthetic resin emulsions. The results of these tests are described by Morrison (1971) and Morrison and Simmons (1977) and can be summarized as follows: 1) Water-based vinyl polymers and acrylic copolymers proved very effective in increasing the bearing strength and erosion-weathering resistance of sandy soils and are currently being tested for use in temporary beach stabilization. The high cost of acrylic copolymer, however, may restrict its use to very small areas. 2) Epoxized silicone proved to be an ineffective soil stabilizer. 3) The liquid asphalts were generally effective as soil stabilizers, but each variety tested failed to meet specifications on one or more of the the tests conducted. 4) The petroleum-based resins were effective, but their slow curing time tends to limit their utility. In terms of archeological preservation applications, the most promising chemical stabilizers appear to be two solvent-based materials, an elastomeric emulsion and a liquid urethane product, both of which appear to have some merit for long-term erosion control, soil stabilization, and as gravel and sand binders for riprap substitute. Screening tests of these stabilizers were conducted over a period of several years and included tests of compressive strength, penetration, wind and wave erosion, and outdoor weathering.

Tests conducted on elastomeric emulsion were designed to evaluate its effectiveness as a rock-gravel binder for riprap substitute. Treated gravel samples containing approximately 2 parts binder to 100 parts gravel were subjected to wave action, freeze-thaw, and outdoor weathering resistence tests. The treated samples exhibited excellent sheer strength properties, with very little strength loss after a year of outdoor exposure. Freeze-thaw tests in water resulted in some strength loss but no visible deterioration of the samples. The samples also showed excellent resistance to wave impacts. Wave tank tests resulted in very little aggregate loss after three years and approximately 63.2 million wave "blows". Additional outdoor weathering tests over a four-year period, however, resulted in a slow but progressive deterioration of the binder, with a total aggregate weight loss of 37.3% over the four-year period. Because of these long-term weathering characteristics, WPRS recommends that the use of elastomeric emulsion be limited to temporary stabilization of dikes and beach belt areas (Morrison and Simmons 1977:30-31).

Field application of elastomeric emulsion uses conventional equipment and involves three steps: 1) a gravel or gravel-sand blanket is first washed with water to rinse off any adhering dust and dirt and then is allowed to drain for at least 30 minutes; 2) a 1% ammonia-water solution, which aids in the eventual setting of the liquid stabilizer, is applied to the gravel blanket at a rate of 1.8 liters per meter square (0.4 gal/yd^2) and allowed to dry for 15 minutes; and 3) the emulsion is applied with a conventional sprayer at a rate of 2.3 to 4.5 liters per meter square (0.5 to 1.0 gal/yd^2), depending on the type of gravel and the desired depth of stabilization (Morrison and Simmons 1977:29).

Tests conducted on a urethane liquid stabilizer were designed to evaluate its effectiveness for long-term soil stabilization and as a riprap substitute. Tests included compressive strength, penetration, wave action, freeze-thaw, and long-term outdoor exposure. Gravel samples treated with the liquid exhibited excellent strength properties, with no measurable loss of compressive strength following repeated freeze-thaw and wetting and drying tests. After two years and approximately 42 million wave "blows" in the laboratory wave tank, no appreciable deterioration of the treated samples was noted. And after 26 months of continuous outdoor exposure, very little aggregate weight loss was noted, and the samples were described as in good condition. In addition to the laboratory tests, samples of urethane-treated sand were field tested for three years under conditions of multiple wet-dry cycles and light foot traffic. None of these field test samples exhibited any visual evidence of deterioration (Morrison 1977:4).

Another soil stabilization treatment that is particularly effective for stabilizing heavy clay and granular soils is lime. Treatment with quicklime or hydrated lime has proved effective in improving the engineering properties of soils that lack a granular skeleton due to the high water affinity of their silt and clay fractions (Winterkorn 1968: 27). Physical and structural changes resulting from soil-lime treatment include: 1) a drop in the placticity index, 2) a marked decrease in the plastic and liquid limit, 3) a decrease in soil binder content, 4) a decrease in lineal shrinkage and swell, 5) improvements in soil workability due to disintegration of clay clods, 6) a significant increase in compressive strength and load-bearing potential, and 7) a significant decrease in the moisture content of saturated clay soils. As a result of its success in stabilizing problem soils, lime treatment has been used extensively in the pretreatment of clay soils prior to the application of cement and waterproofing agents, as an inhibitor of capillary water action in soils underlying protective pavements and blankets, and as a soil stabilizer under all types of pavements and construction foundations (Winterkorn et al. 1968:30).

The WPRS used lime stabilization of the Friant-Kern Canal in the first large-scale application of soil-lime techniques in hydraulic construction. Mixing 3.2% quicklime with the highly expansive native clays that line the banks of the canal produced a highly stable foundation in which the unstable clay was transformed to a hard, stable, rock-like material. Tests performed on the bank materials before and after the quicklime application recorded an increase in the unconfined compressive strength of the bank material from 2 lb/in^2 before lime treatment to more than 200 lb/in^2 after treatment (Morrison and Simmons 1977:82-83). Prior to the Friant-Kern experiments, lime stabilization was used mostly in highway construction and related applications. The results of these tests, however, suggest a broad range of hydraulic applications, particularly in the stabilization of soils with high proportions of silt and clay fines.

VEGETATION STABILIZATION

A great deal of recent research has been conducted on the use of vegetation for both temporary and permanent erosion control. Most of this research has been conducted in highway construction and surface mining contexts, where revegetation has become the primary method of stabilizing disturbed soils. Unfortunately, hydraulic applications of vegetation stabilization are limited by the fact that few plant species are adaptable to environments that are permanently or even periodically inundated. On the other hand, inundation is not the only adverse impact associated with fresh water reservoirs, and vegetation stabilization may be the method of choice in minimizing impacts associated with recreation activities and construction in the backshore zone above the fluctuation shoreline.

Revegetation of disturbed soils is a complex undertaking, requiring consideration of many interacting factors ranging from soil quality and variability to species compatibility and local climatic variability. Unfortunately, we can only review some of the more salient aspects of the multivariate decisions that must be made if revegetation is to be successful.

Successful revegetation begins with soil preparation and extensive soil sampling of various chemical and physical factors relating to plant growth. Key soil variables include pH, fertility, texture, depth, permeability, presence of toxic materials, soil moisture, and water retention capacity. Determining these soil variables will aid in selecting plant species, plant placement, seeding and planting procedures, fertilization and long-term maintenance requirements, and any soil amendments that must be made to support long-term plant growth and succession. Topsoil is usually ideal for revegetation, and any topsoil removed as overburden during reservoir construction should be stockpiled for later use. With proper fertilization, however, subsoils may also be used and may even be preferable to local topsoils (USDA 1979:14).

In addition to soil variability, the physiographic nature of the site must be considered. Local temperature variation, including daily minimums, maximums, and averages, must be computed, and local climatological records consulted for longer-term temperature variability and trends. Other key physiographic variables include amounts and distribution of precipitation; elevation and length of growing season; the slope and aspect of the proposed site, which influence such things as soil stability, length of day, solar radiation loads, and growing season length; maximum local wind velocities; and so on. Depending on the locality, fire risks and impacts associated with weed and animal invaders must also be taken into account.

All of these considerations are important to plant species selection, a decision that must take into account a number of interacting variables. For example, species compatability must be determined. Mixtures of adapted grasses and forbs are ideal because they provide faster and more efficient protection against erosion than trees and shrubs. Introduced species should also be on the low end of the successional scale in order to insure active colonization of the disturbed site. And finally, species selection is influenced by the availability and cost of seeds, container-grown plants, root stock, cuttings, and wildings (USDA 1979:15).

Regardless of the method of plant introduction, the disturbed locality is usually stabilized before planting, and a variety of mulches are commonly used for this purpose. Straw, hay, woodchips, gravel, and cotton gin trash are often used as mulches in areas of low relief. On steep slopes, mulches are often anchored by means of mechanical disking or the use of a soil tankifier, such as asphalt emulsion. A variety of soil retention mats have also been used (Morrison and Simmons 1977:87). Until the vegetation blanket is fully established and the disturbed locality stabilized, frequent maintenance in the form of supplemental watering, refertilization, reseeding, and weed and insect control, is often required.

CONCLUSIONS

The goal of cultural resource management is the assessment, protection, and long-term preservation of significant archeological and historic cultural resources. In recent years the traditional methods of achieving these goals have been scrutinized and reevaluated, and the result has been a major reordering of management and research priorities and goals. The traditional approach of "salvaging" endangered resources by extensive excavation has been criticized, in part because excavation is itself a form of destructive impact. That is, regardless of the quality of excavation procedures and the scope of the excavation design, excavation nearly always results in the loss of potentially valuable information. It is this realization that has generated the modern emphasis on "preservation" in cultural resource management, and it is in the spirit of this new preservation ethic that we have summarized a number of approaches to cultural resource protection in a reservoir environment that may provide mitigation alternatives to excavation.

The question of preservation versus excavation in a reservoir impact zone is, however, far from being resolved. There is the question, first of all, of comparative costs. A number of protection alternatives presented above, particularly those designed for high energy wave protection, are comparatively expensive, and unless the costs of these long-term protection methods compare favorably with excavation costs, their utility is questionable.

The question of comparative costs can be resolved only on a reservoir-by-reservoir basis, since the costs of excavation and protection will vary from one reservoir to the next depending on the nature of the cultural resources and the availability of suitable raw materials for constructing protective facilities. There is also a hidden cost built in to the protection alternative that must be taken into account. If protection is to last for the life of the reservoir, total protection costs must include the costs of long-term monitoring and maintenance.

A second unresolved question of excavation versus long-term protection is the effectiveness of the various protection methods outlined above. In only a few instances have these methods been tested for their effectiveness in archeological and historic site protection, and until comprehensive tests are conducted and their results evaluated, large-scale application of these methods would be premature. It is recommended that before any of these methods are attempted, except on a preliminary or trial basis, a comprehensive testing program be conducted to evaluate the long-term effectiveness of various protection alternatives. This testing program could be greatly accelerated if an extensive program of field testing were combined with a program of laboratory experiments using scale models to simulate a variety of cultural resource preservation problems.

TABLE 1

THICKNESS AND GRADATION LIMITS OF RIPRAP ON 3:1 SLOPES*

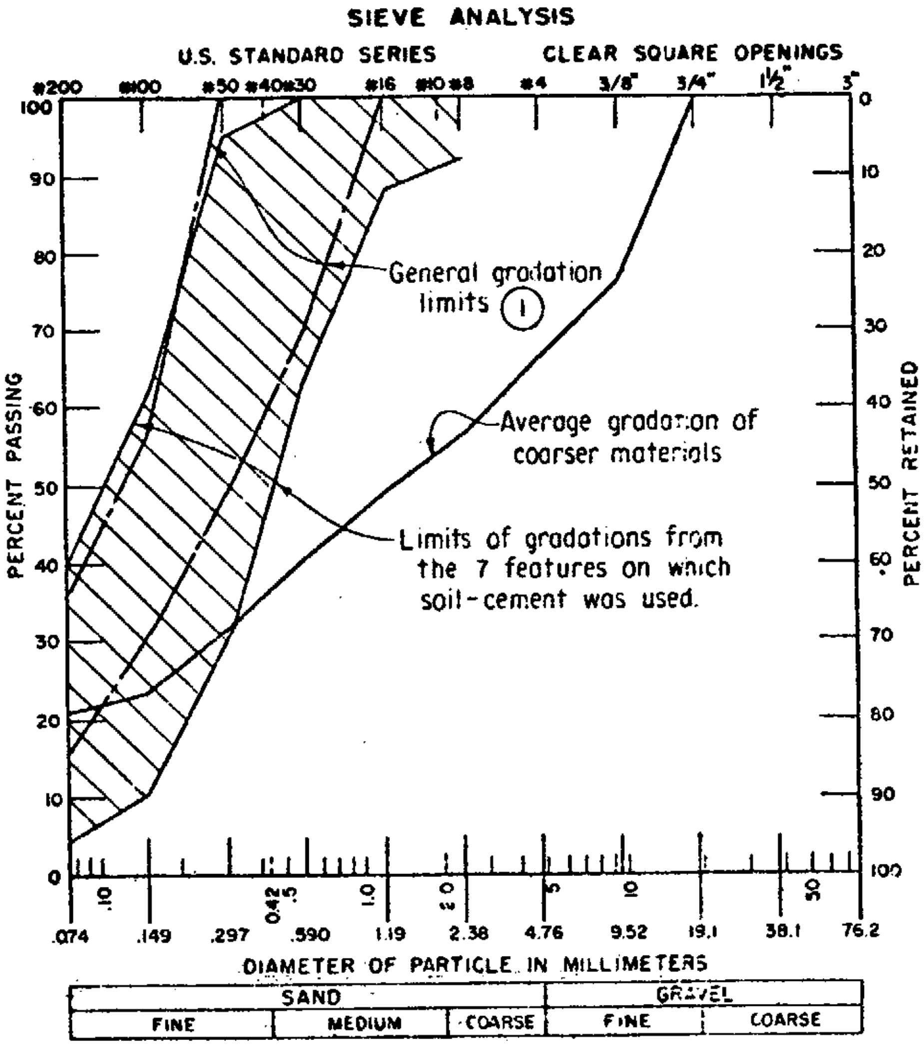
Reservoir fetch, miles	Nominal thickness, inches	Maximum size	Gradation, percentage of stones of various weights (pounds): At least 25 percent greater than	45 to 75 percent from--to--	Not more than 25 percent less than-[1]
1 and less	18	1,000	300	10-300	10
2.5	24	1,500	600	30-600	30
5	30	2,500	1,000	50-1,000	50
10	36	5,000	2,000	100-2,000	100

[1]Sand and rock dust less than 5 percent.

Nominal thickness of riprap inches	Gradation, percent by weight — Size of rock fragments: 1/2 cu yd to 1 cu yd	1/2 cu ft to 1/2 cu yd	Less than 1/2 cu ft	Sand and rock dust
24		More than 75	Only enough to fill voids in larger rock	Less than 5
30		More than 75		Less than 5
36	40-50	50-60		Less than 5

*(with permission of the Bureau of Reclamation)

TABLE 2



SUMMARY OF GRADATION TEST RESULTS ON SOIL-CEMENT MATERIAL

(DeGroot 1971:3)
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TABLE 3

IMPORTANT ENGINEERING PROPERTIES & RELATIVE DESIRABILITY FOR USE OF TYPICAL SOIL GROUPS

Typical Names of Soil Groups	Group Symbols	Important Engineering Properties			Workability as a Construction Material
		Permeability When Compacted	Shear Strength When Compacted and Saturated	Compressibility When Compacted and Saturated	
Well-Graded Gravels, Gravel-Sand Mixtures, Little or No Fines.	GW	Pervious	Excellent	Negligible	Excellent
Poorly-Graded Gravels, Gravel-Sand Mixtures, Little or No Fines	GP	Very Pervious	Good	Negligible	Good
Silty Gravels, Poorly-Graded Gravel-Sand-Silt Mixtures	GM	Semipervious to Impervious	Good	Negligible	Good
Clayey Gravels, Poorly-Graded Gravel-Sand-Clay Mixtures	GC	Impervious	Good to Fair	Very Low	Good
Well-Graded Sands, Gravelly Sands, Little or No Fines	SW	Pervious	Excellent	Negligible	Excellent
Poorly-Graded Sands, Gravelly Sands, Little or No Fines	SP	Pervious	Good	Very Low	Fair
Silty Sands, Poorly-Graded Sand-Silt Mixtures	SM	Semipervious to Impervious	Good	Low	Fair

(After Bureau of Reclamation Earth Manual 1974:20-21)

TABLE 3 (cont.)

Typical Names of Soil Groups	Group Symbols	Important Engineering Properties			
		Permeability When Compacted	Shear Strength When Compacted and Saturated	Compressibility When Compacted and Saturated	Workability as a Construction Material
Clayey Sands, Poorly-Graded Sand-Clay Mixtures	SC	Impervious	Good to Fair	Low	Good
Inorganic Silts and Very Fine Sands, Rock Flour, Silty or Clayey Fine Sands with Slight Plasticity	ML	Semipervious to Impervious	Fair	Medium	Fair
Inorganic Clays of Low to Medium Plasticity. Gravelly Clays, Sandy Clays, Silty Clays, Lean Clays	GL	Impervious	Fair	Medium	Good to Fair
Organic Salts and Organic Silt-Clays of Low Plasticity	OL	Semipervious to Impervious	Poor	Medium	Fair
Inorganic Silts, Micaceous or Diatomaceous Fine Sandy or Silty Soils, Elastic Silts	MH	Semipervious to Impervious	Fair to Poor	High	Poor
Inorganic Clays of High Plasticity, Fat, Clays	CH	Impervious	Poor	High	Poor
Organic Clays of Medium to High Plasticity	OH	Impervious	Poor	High	Poor
Peat and Other Highly Organic Soils	PT	---	---	---	---

TABLE 3 (cont.)

Relative Desirability for Various Uses
(No. 1 is Considered the Best)

Rolled Earthfill Dams						
Homogeneous Embankment	Core	Shell	Erosion Resistance	Compacted Earth Lining	Seepage Important	Seepage not Important
---	---	1	1	---	---	1
---	---	2	2	---	---	3
2	4	---	4	4	1	4
1	1	---	3	1	2	6
---	---	3 if gravelly	6	---	---	2
---	---	4 if gravelly	7 if gravelly	---	---	5
4	5	---	8 if gravelly	5 erosion critical	3	7
3	2	---	5	2	4	8
6	6	---	---	6 erosion critical	6	9
5	3	---	9	3	5	10
8	8	---	---	7 erosion critical	7	11
9	9	---	---	---	8	12
7	7	---	10	8 volume change critical	9	13
10	10	---	---	---	10	14
---	---	---	---	---	---	---

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LABORATORY STUDIES OF DIFFERENTIAL PRESERVATION IN FRESHWATER ENVIRONMENTS

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INTRODUCTION

In the fall of 1978 an experiment was initiated to investigate the relationships between freshwater biochemical variability and the deterioration rates of common cultural materials. In order to discriminate between the water chemical and microbiological effects of inundation, a two-stage experiment was designed. The first stage was conducted in the laboratory and was designed to isolate and measure water chemical impacts. This stage involved immersing various classes of cultural materials in buckets containing water chemical solutions of varying concentrations. At four-month intervals for one calendar year, the materials were removed from the solutions in order to measure rates of physical and chemical deterioration.

The second stage of the experiment involved immersing duplicate samples of cultural materials in an actual reservoir in order to assess the impacts of macroinvertebrates and microorganisms. In addition to measuring deterioration rates on the field samples and comparing these rates with the laboratory samples, biological sampling stations were established in the reservoir to determine the kinds of organisms present and their predation patterns.

This first in a series of four technical reports dealing with the experiment presents the design and results of the laboratory phase of the water chemical experiments. The results of field studies of differential preservation are presented in Technical Report six; detailed reports of pollen and seed preservation studies are presented in Technical Reports four and five, in this volume.

The Problem

Since its inception, the National Reservoir Inundation Study has been concerned with the problem of a reservoir's chemical impacts upon submerged cultural resources. One of the first questions raised by the study was: "...will chemical or other environmental changes that occur as a result of immersion cause differential preservation of those classes of cultural remains that are usually subjected to attribute analysis by archeologists (ceramics, bone, wood, glass, shell, etc.)?" (Lenihan et al. 1977:11). While water chemistry was taken into consideration in the formulation of the hypotheses presented in The Preliminary Report of the National Reservoir Inundation Study, it was acknowledged at that time that a detailed investigation into the impacts caused by water chemistry "should (eventually) receive special attention due to its subtle and complex nature" (Lenihan et al. 1977:12). The formulation of a laboratory experiment, designed to isolate the effects of water chemicals on archeological materials, came about as a direct response to these concerns.

The experiment was designed to address two fundamental questions: first, what are the effects of specific cations and anions on specific classes of cultural materials, and second, within physiographic regions of the country characterized by similar water chemistry environments, what variables within a class of cultural materials determine whether one group or another will survive inundation?

Answers to the first question would allow the identification of those bodies of water across the United States that would have the greatest impacts upon certain classes of archeological data. Answers to the second question would allow archeologists to predict which types of ceramics, bones, lithics, and so on would most likely be adversely affected by flooding in their region, and which types might be preserved.

Background research on these problems was conducted at the research library of the Water and Power Resources Service's (formerly the U.S. Bureau of Reclamation) Engineering and Research Center in Denver, Colorado. With the aid of the research library staff and a computer-based bibliographic retrieval system, nearly a dozen data bases were searched for references that might be relevant to the questions posed. The results of the literature search can be summarized briefly. A great deal of basic research has been conducted on the general topic of material preservation in an aqueous ennvironment;

however, the great majority of this research has focused on degradation rates for modern synthetic construction materials (i.e., concrete, metal alloys, treated wood, etc.) in salt water marine environments. Very few studies have addressed the nature of freshwater impacts on materials commonly found in an archeological context; materials such as bone, ceramics, stone, botanical remains, and so on.

Studies of differential preservation of submerged wood and fossil plant pollen are the two most notable exceptions to this statement. Although the vast majority of wood preservation studies have focused on marine impacts, several freshwater studies have also been conducted (Greaves and Levy 1968; Croes 1976). In addition, several studies have addressed the question of differential pollen preservation in freshwater lake and bog deposits (Sangster and Dale 1961; 1964).

Virtually all of the freshwater preservation studies accomplished to date have been conducted at field stations where only minimal water chemical controls could be maintained. No examples of laboratory-staged freshwater experiments were found in the published literature, and so the experiment described below had to be designed essentially from the ground up. A major consideration in the design of the experiment was the selection and control of archeological material samples, as well as the preparation and maintenance of freshwater chemical environments and the control of cation /anion distributions and concentrations between laboratory environments.

The first half of this technical report presents a detailed outline of this experimental design, with a discussion of archeological material selection criteria and sample preparation procedures, solution preparation and maintenance procedures, and analytical techniques. The second half of the report presents and discusses the results of the experiment. These results are summarized at the end of the report, and implications for future research are discussed and evaluated.

EXPERIMENTAL DESIGN

The first step in both the laboratory and field phases of the experiment was the selection of representative samples of cultural materials for immersion. Two primary considerations influenced this selection process. One of the primary goals of the experiment was to investigate biochemical impacts on a broad range of cultural materials to insure that the results of the experiment would have the greatest possible utility for the greatest number of researchers. An additional goal was to identify, within each material category, material states or depositional conditions that influence differential preservation rates in a submerged environment.

With these goals in mind, seven general categories of material were selected, including: ceramics, lithics, wood, shell, seeds, bone, and pollen. Within each of these categories, most of the normal variability that occurs in the real world was strictly controlled so that chemical factors influencing deterioration rates could be isolated and distinguished from internal variables of manufacture and design that might influence deterioration rates.

For example, instead of using prehistoric ceramics in the experiment, ceramic chips were manufactured in the laboratory so that such variables as clay type, temper-paste ratio, construction technique, sherd thickness and shape, firing atmosphere, etc., could be held constant, while such variables as firing temperature and tempering material, variables that most directly influence sherd strength (Shepard 1956), could be systematically varied.

In general, the variables that were allowed to vary in each of the material categories were those that were judged most significant in terms of material preservation within a reservoir environment. A second major consideration was whether or not the variability was similarly reflected in real artifact types across the United States. And a third factor conditioning the variability introduced was the basic consideration of what types of materials could be obtained within the time and fiscal constraints of the experiment.

Materials and Procedures

The test materials used in both the laboratory and field phases of the experiment consisted of both aboriginal and simulated archeological specimens. Samples of ceramics, lithics, wood, seeds, and bone were made from contemporary source materials, while samples of shell and rabbit bone were obtained from archeological contexts.

Ceramics: It was felt that testing prehistoric ceramics would introduce too many unknowns into the experiment, since variation in source material, manufacture, firing temperature and atmosphere, tempering material, and so on, could not be strictly controlled in a prehistoric ceramic assemblage. Consequently, the Inundation Study contracted with a ceramicist from the University of New Mexico for the production of ceramic tiles.

Four firing temperatures were selected on the assumption that they represent typical low (600°C), medium (750° - 900°C), and high (1050°C) firing temperatures for prehistoric ceramics (Shepard 1956). Tempering materials used included organic plant fiber and crushed sandstone. While other examples of organic temper (such as shell) and mineral temper (such as basalt) were considered, straw and sandstone were both used prehistorically and were readily available for use in the experiment. All of the laboratory ceramics were decorated with a simple bar design composed of either mineral or organic paint. The organic paint consisted of dandelion extract, while the mineral paint was derived from crushed manganese dioxide (MnO_2). Both of these paint preparations were utilized by prehistoric potters (Helene Warren, personal communication).

Ceramics were manufactured from clay obtained from a fine-grained, iron-saturated clay member of the Morrison Formation, located at the foot of La Bajada Hill, approximately forty miles north of Albuquerque, New Mexico. Sandstone temper was obtained from sandstone outcrops adjacent to the Rio Puerco, northeast of the Pueblo Indian village of Laguna, New Mexico. Sandstone slabs collected on the

Rio Puerco were reduced on a Braun "Chipmunk" assay grinder to coarse sand-size chunks measuring .3 to .7 mm in diameter, ideal for tempering the fine-grained La Bajada clay. Plant fiber temper was obtained from grasses found on the University of New Mexico campus.

The ceramic tiles were prepared as follows: The La Bajada clay was broken into small chunks and soaked in water for 24 hours, or until saturated. The clay was then kneaded and wedged to form a homogeneous clay body. While the clay was being wedged, tempering materials were added to the clay body. The prescribed proportion of temper to clay was 15% of total clay volume. Once the clay-temper mixture reached a smooth, homogeneous consistency, large clay slabs were rolled out by hand to the desired thickness of 6 mm, and each slab was cut into square tiles measuring 5 cm on a side. The tiles were then allowed to dry at room temperature to minimize warpage.

Once dry, 900 tiles containing crushed rock temper and 300 tiles containing organic temper were selected for firing. Two groups of three-hundred rock-tempered tiles were then fired at 600° and 900°C, respectively, for twelve hours. After cooling, dandelion extract was applied with a medium water color brush, creating two parallel stripes across the top of each tile. Both groups of tiles were then refired to approximately 350°C in order to set the paint. Mineral paint and slip solutions were then applied to the remaining 600 tiles while they were still in an unfired state. Slips were applied in two coats to create a stronger bond with the unfired clay, and the double parallel line pattern was then repeated in mineral paint on all of the tiles. After the paint had dried, the 300 organic-tempered tiles were fired to 750°C for twelve hours, and the remaining 300 rock-tempered tiles were fired to 1050°C for the same length of time. Thus, four groups of tiles reflecting variability in temper type, paint type, and firing temperature were produced:

Group IA = Mineral paint/organic temper/750°C
Group IIA = Organic paint/rock temper 600°C
Group IB = Organic paint/rock temper 900°C
Group IIB = Mineral paint/rock temper/1050°C

Initially, nine tiles of each firing/temper group were to be immersed in each of thirty controlled water chemical solutions, with one tile per group, per container, to be set aside as a baseline time zero standard. Measurement intervals were planned at the end of four, eight, and twelve months of immersion. Since the various tests planned at each measurement interval included destructive break-strength tests, there could be no replacement of samples after they were tested. Consequently, test sample size became a major concern. In order to enlarge the number of ceramic samples that could be tested at each measurement interval, each of the tiles was cut into equal thirds with a diamond saw, thereby tripling the number of ceramic specimens.

Each of the samples was labeled by ceramic type and assigned an identification number corresponding with the original tile sample number, which ranged from 1 to 300 for each ceramic group. Because of sample degradation due to handling, the effects of wetting and drying, and undoubtedly other unknown factors, total test sample numbers decreased with each sampling interval, especially in group IIA (600°C), where many of the samples completely disintegrated after only four months of immersion. In most cases, however, there were sufficient samples to carry out all of the tests.

<u>Lithics:</u> Because ground stone material would have been too bulky to include in the experimental containers, only chipped stone material was investigated. Chert and obsidian were selected because of their common occurrence in prehistoric lithic assemblages. The primary variable held constant was that of source area. Each type of lithic was obtained from a restricted and known source.

Chert nodules were obtained from an exposed vein of Edwards Plateau Flint in the Cretaceous Georgetown formation, near Georgetown, Texas, and consisted of a homogeneous, medium-to-dark gray cryptocrystalline material. Obsidian was obtained from the vicinity of "Obsidian Ridge" in the Tertiary volcanic Jemez Caldera, located in north central New Mexico. The obsidian is internally fractured and exhibits a "foamy" cortex.

Chert flakes were manufactured by the direct-percussion method using a ball-peen hammer to strike blades off a prepared core. Flakes varying from 1.5 to 2.0 inches in length were selected for immersion. The chert and obsidian flakes were numbered consecutively from 1 to 150, and five samples of each type were immersed in each of the water chemical solutions.

In order to determine whether inundation obscures lithic wear patterns, a worked surface was produced on each of the lithic flakes. Each flake was held for 3-5 seconds on a belt sander with 80-grit garnet paper. Grinding was performed on acute edges and dorsal surfaces, when possible. Each experimental group was then enclosed in a small, perforated plastic bag, tied off with nylon monofilament, and immersed in the solutions for the entire twelve months of the experiment. No interval measurements were made on the whole lithic flakes. At the conclusion of the experiment, array and close-up photographs were taken and compared with preinundation photographs in order to detect any changes in artifact wear patterns or visual changes in the flakes that may have resulted from inundation.

In order to maximize reactions between the chemical solutions and lithic materials, additional samples of chert and obsidian were ground on a Braun "Chipmunk" assay grinder and immersed along with the whole lithic flakes. Samples of the ground lithics were screened by hand for 20-30 seconds using an upper mesh of .5 mm and a bottom mesh of .124 mm, and thirty 13g samples of each lithic type were weighed and put into test tubes containing solutions drawn from the thirty water chemical containers.

These ground lithic samples were weighed at four-, eight-, and twelve-month intervals, in order to detect differential leaching across water chemical environments. The procedure was as follows: The first step involved separating the ground material from the chemical solution by filtration (the filtered chemical solution was diluted to 50 ml with deionized water and retained for atomic absorption analysis). After filtration, the ground material was allowed to dry under a fume hood. Once dried, the material was poured through a Pyrex funnel with a 1 cm exit hole and allowed to free-fall into a glass vial measuring 1.7 cm in diameter by 3.8 cm in depth. The excess ground material was then carefully scraped off, level with the top of the vial, using a flat-edged metal blade. The vial and its contents were then weighed on a top-loading, 1200 series Mettler balance. This procedure was repeated ten times for each sample, and the average of the ten measurements was recorded.

Shell: Samples of clam (*Rangia cuneata*) and oyster (*Crossostrea virginica*) obtained from prehistoric shell midden sites in the Matagorda Bay region of the central Texas Gulf Coast were used in the experiment. Shells varying in size from 3 cm to 10 cm were selected, and five shells of each type were immersed in each of the thirty water chemical solutions. In order to avoid contamination, both shell types were rinsed in a primary and secondary bath of deionized water, and particles adhering to the surface of the shells were removed with a soft nylon brush and a "water pik". In addition, samples of each shell type were ground and periodically weighed in a manner identical to the lithic samples.

Wood: Obtaining sufficient numbers of archeological wood samples of the same provenience, age, species, and so on, proved impossible. Therefore, wood samples were procured from a local Albuquerque lumber yard that obtains their wood from the same source. Two types of wood were selected for analysis: white oak, a hardwood, and ponderosa pine, a softwood. Samples of both types were selected from heartwood so as to minimize chemical and physical variability within the samples. Samples were purchased in 6 foot by 1 inch by 1 inch lengths and then cut to a dimension of one-inch square on a radial arm saw with a general purpose carbide-tipped blade.

Three hundred one-inch cubes of each wood were prepared, and ten samples of each type were immersed in each of the thirty water chemical solutions. Testing of the wood was initially planned at four-, eight-, and twelve-month intervals. However, at the four-month interval, sample degradation was so extensive due largely to the effects of drying that the eight-month testing interval was omitted. Following twelve months of immersion, all of the wood samples were photographed and subjected to shear strength tests on an Instron durometer.

Bone: Three types of bones were used in the experiment: cow, deer, and rabbit. Fresh cow bones were obtained from a local Albuquerque butcher shop. Care was taken to select animals grown in the same geographic area, of the same variety, sex, and age at slaughter. Only tibia bones were utilized.

Fresh deer tibiae were secured from the New Mexico State Game and Fish Department, from road kills obtained in the southern portion of New Mexico. All deer bones were from adult male mule deer.

The majority of rabbit bones used in the experiment were obtained from a single prehistoric archeological site in northwestern New Mexico. Since all rabbit bones shared the same archeological context, such variables as geochemical conditions of burial, archeological age, and rabbit species could be held essentially constant. All of the rabbit selected were adult cottontail (*Sylvilagus*). Unfortunately, because the total number of rabbit bones required for the experiment could not be obtained from one site, several additional bones were taken from collections of unknown provenience from several sites in northern New Mexico. For these few samples, only age, health, and species could be held constant. In both cases, only rabbit tibiae were used in the experiment.

In order to simulate the charred condition in which bones are often preserved in an archeological site, as well as to remove the soft tissue adhering to the specimens, all of the fresh cow and deer bones were baked in a kiln at low temperature until nearly all of the innermost soft tissues were charred and could be easily removed. Before the bones were charred they were cut to a standard dimension.

The epiphyses were first sawn off the whole bones, and only the relatively uniform diaphysis was used for the test samples. Each shaft was cut down the midline, exposing the medullary cavity, and each half shaft was then cut perpendicular to the shaft midline at 2 cm intervals, producing half shaft bone arches which were used as the test samples. Both cow and deer bones were prepared in identical fashion, and five bones of each type were placed in perforated plastic bags and immersed in the test solutions.

Because of the paucity of rabbit bone available for the experiment, only two small uncharred bone fragments were placed in each chemical container. Rabbit bone samples were prepared using a small radial blade on a Dremel tool to cut 1 cm. long sections from the shaft portion of each femur. On each of the samples a portion of the surface was marked with an inert marking pen, and the bone surface adjacent to the mark was photographed at 5X magnification.

All of the bone samples remained in solution until the final twelve-month sampling interval, at which time all bone samples were removed from solution, weighed, and photographed.

Seeds: Seven categories of seeds were investigated, including blue corn, popcorn, navy beans, kidney beans, oats, rye, and wheat. Technical Report Five (Toll) in this volume contains a detailed discussion of seed selection and preparation procedures.

Pollen: Fourteen varieties of fresh and fossil pollen were investigated, including corn, Douglas fir, white poplar, Colorado blue spruce, pinyon pine, Virginia live oak, common sagebrush, one-seed juniper, black willow, August marshelder, pecan, careless weed, cattail, and sunflower. A detailed report of pollen selection and preparation procedures is contained in Technical Report Four (Holloway) in this volume.

Water Chemistry Design

Once material categories were selected and experimental samples manufactured or obtained, the next step in the design was the selection of relevant water chemical variables. The chemistry of freshwater lakes and streams is determined by complex interactions among geologic, biological, climatic, and human land use variables, and a survey of reservoirs throughout North America suggests a great deal of regional variability in each of these dimensions. The first step, therefore, in selecting water chemical variables for the experiment involved determining the range and concentrations of chemicals generally occurring in reservoirs from various regions throughout North America. Contacts with water quality experts from the U.S. Army Corps of Engineers, the Water and Power Resources Service, and the U.S. Geological Survey yielded an initial list of 25 common chemicals. On the basis of chemical concentration data supplied by the Water and Power Resources Service and the Water Quality Branch of the U.S. Geological Survey, this list was eventually reduced to nine constituents, including pH, calcium (Ca), magnesium (Mg), sodium (Na), carbonate (CO_3), bicarbonate (HCO_3), chlorine (Cl), sulphate (SO_4), and iron (Fe).

Since these chemicals occur in nature only as compounds, the list of nine elements was expanded to 14 compounds in such a way that cross-comparisons between experimental containers could isolate the impacts associated with individual ions. The 14 compounds included: $CaCO_3$, $MgCO_3$, Na_2CO_3, $NaHCO_3$, $KHCO_3$, HCl, NaCl, $MgCl_2.6H_2O$, $CaCl_2$, $FeCl_3.6H_2O$, $Na_2SiO_3.9H_2O$, $CaSO_4.2H_2O$, $MgSO_4$, and H_2SO_4.

Once the minimum number of 14 compounds was determined, each compound was dissolved in two separate containers of deionized water; in the first container at a parts-per-million concentration approximating the median value for that compound in North American reservoirs, and in the second, at a concentration twenty times greater than the median value in order to simulate the effects of long-term immersion. An additional bucket containing five of the most common chemicals in solution ($CaSO_4.2H_2O$, $MgCl_2$, $NaHCO_3$, $FeCl_3$, and $Na_2SiO_3.9H_2O$) was established to measure interactive chemical effects in a complex reservoir environment. And finally, cultural materials were immersed in a container of deionized water to serve as a control for the chemical solutions.

The contents and vat numbers of each solution prepared for the experiment are listed in Table 1. The analyses performed on each solution are listed in Table 2. In addition to the analyses in Table 2, spot checks on vats to which particular ions were not purposely added were made to help determine levels of contamination, adsorption, or precipitation.

The basis for the ionic concentrations in each vat, as noted in Table 3, was as follows: Vats Nos. 2 through 14 were prepared such that the concentration of at least one cation or one anion would approximate that of a "typical" freshwater reservoir. Vat No. 15 was a control, containing pure deionized water from the same tank which was used to prepare the chemical solutions. Vat 15 was also used to obtain background levels for pH and dissolved oxygen. Vat No. 16 was prepared to contain median freshwater values of a combination of species, namely calcium, magnesium, bicarbonate, iron, and silica.

Vat Nos. 1, and 1A through 14A, contained 20 times the median freshwater concentration of at least one of the cations or anions under consideration. Since the laboratory experiment was limited to approximately one year, it was hoped that study of ion concentrations of 20 times the nominal values would provide an accelerated view of the effects of these ions on submerged archeological materials. Combinations of cations and anions were chosen to provide the optimum amount of data and cross checking of cation-anion effects.

Since the laboratory phase of the experiment was designed to isolate and measure only water chemical impacts on cultural materials, attempts were made to exclude biological activity within the experimental containers. One option considered was the use of organic and/or inorganic compounds to limit the growth of bacteria, algae, etc. This approach was discarded in favor of periodic preparation of fresh solutions for two major reasons: 1) addition of compounds such as phenol, tincture of merthiolate, or silver nitrate would possibly have had more effect on the specimens than would the ions under study, and 2) addition of the specimens would possibly add, from surface contamination, etc., more of the ions under study than would be present in the prepared solutions--hence, the need to periodically monitor and change solution concentration.

Since the various specimen types were added to the solution in stages, it was decided to change the solutions after each sample addition. In most cases, aliquots from each vat were taken to determine amounts of contamination. Over the course of the study, the solutions were changed twenty times, and in thirteen of these changes, aliquots were collected for analysis (Tables 4-16). The dates on which the laboratory sample solutions were prepared, and the dates on which aliquots were taken for analysis, are presented in Table 17. A final visual observation of the condition of the vats after removal of the last specimens is recorded in Table 18.

ANALYTICAL PROCEDURES

Water chemical solutions were prepared in five-gallon Nalgene vats, each vat containing 12 liters of solution (Tables 1-3). Initial solution preparation took place in September 1978, and solutions were monitored for approximately two weeks prior to artifact immersion to allow ion concentrations to stabilize. On September 28, 1978, the ceramic tile samples were immersed in the controlled solutions, followed approximately two weeks later by the lithic samples, and so on, until all of the material samples were immersed (see Table 17).

Adding material categories in stages allowed adequate time during subsequent testing intervals to measure changes in each of the artifact categories, without subjecting any one category to extended periods of noninundation during the testing intervals. Staged immersion also permitted the collection of periodic water samples from the control vats in order to measure the extent of leaching associated with each artifact category during the first two weeks following initial immersion.

Measurements of artifact deterioration were scheduled at four-month intervals for one calendar year. Four months after initial immersion, all artifacts in a given category were removed from solution and subjected to a variety of qualitative observations and quantitative measurements designed to measure changes in artifact physical-chemical characteristics. These measurements were repeated after eight months of immersion, and again after twelve months, yielding a series of observations and measurements that could then be compared with noninundated control standards in order to assess deterioration rates through time.

Qualitative observations, focusing on changes in material attribute states, were made at each of the time measurement intervals and were supplemented at Time 0 and Time 3 with black-and-white array and closeup photographs. All of the artifacts in a class were photographed in array plates with 2¼ X 2¼ Panatomic-X film, and closeup photographs were taken of representative samples of artifacts using a 35 mm camera with bellows attachment set at approximately 10X magnification.

Quantitative measurements varied according to artifact group. All artifacts were weighed on a top-loading Mettler P 1200 balance before, during, and after inundation in order to detect artifact weight loss through leaching. Comparisons of artifact wet and dry weights were also used to derive an index of porosity, and changes in this index were then correlated with weight loss as an additional measure of chemical leaching.

Compression Tests

In addition to weight change measurements, ceramic and wood samples were periodically subjected to compression tests on an Instron Universal Testing Machine in order to ascertain structural changes in the samples that might influence the mechanical weathering properties of the materials. The Instron is a flexible machine which is adaptable to various modes in order to measure tensile strength properties on a wide variety of materials. It consists of a bottom stage which contains a servo-unit designed to measure the compression load, and positioned over it, a movable head which can be adjusted to descend on the servo-unit at varying speeds. The descent of the compression head is controlled by an automatic motor switch and by rotating a positive-movement fine control adjustment knob. Normally, the fine adjustment knob is used for setting the compression head position immediately above the sample to be tested, and the automatic motor is used for lowering the head during the test.

Two contact heads were specially manufactured for the experiment and fitted to the movable compression head. A blade-like structure was designed for testing the ceramics. The blade, manufactured from "1018" steel and measuring 1/8-inch thick, 1-inch deep, and 4-inches long, was fitted into a grooved piece of solid aluminum bar stock, measuring two inches in diameter and two inches thick. For ceramic testing, two four-inch lengths of one-by-one-inch "1018" steel bars were placed directly on the servo-unit, parallel to the compression blade, and spaced one inch apart. The ceramic tile was then placed lengthwise across the bars, and the blade was lowered manually to a position directly over the sample. The automatic lowering motor was then activated, causing the blade to descend at a preadjusted rate of .02 feet per minute. When the sample failed, the load pressure at failure was automatically recorded on a graduated chart which was calibrated at 1 inch per minute.

The contact head for testing wood samples was constructed from a "1080" steel cylinder measuring 1.5 inches in diameter and two inches thick. Compression testing of the wood differed somewhat from the ceramic breakstrength tests. The 1-inch by 1-inch wood sample blocks were placed on the servo-unit directly under the round compression head, with the wood grain perpendicular to the platform. The test was then performed in essentially the same manner as with the ceramics; however, different load positions were required for the pine and oak specimens. (The pine was tested in the 10,000-pound load position, while the oak blocks were tested in the 20,000-pound position). In both load positions, the compression head was lowered at a speed of 0.5 feet per minute, and the load pressure at failure was automatically recorded on a graduated chart.

In addition to the above tests, fine-grained mineralogical, petrographic, and trace element chemical changes in artifact populations were measured by a wide variety of assay techniques, including optical petrographic analysis, X-ray diffraction analysis, electron microprobe analysis, neutron activation analysis, and atomic absorption spectrophotometry.

X-ray Diffraction Analysis

X-ray diffraction spectra of ceramic and shell samples were analyzed on a Phillip-Norelco X-ray diffractometer utilizing Ni-filtered Cu_K radiation. X-ray diffraction is a unique analytical tool which allows the identification of chemical compounds, minerals, and in general, any crystalline material. It can be used to identify crystal phases such as calcite/aragonite, and it can also approximate compositions within a solid solution series. The technique is based on the fact that crystalline materials have atoms arranged in a regular and periodic pattern whose spacing is of the same order of magnitude as the wavelength of X-rays. The crystalline material acts as a three-dimensional diffraction grating, scattering the X-rays in directions characteristic of the grating space of the particular crystal. The diffracted X-rays are recorded either on film or electronically by means of a radiation detector and a diffractometer. Once recorded, the diffraction angle is measured, the set of interplanar spacings (d) are calculated, and the relative intensities of the diffracted X-rays are measured or estimated. A catalog of diffraction patterns may then be consulted, or a standard pattern may be compared in order to determine the mineralogy of the sample.

One of the principal advantages of X-ray diffraction is that it is nondestructive. It can also be used to tell how certain elements are bound chemically, i.e., calcium may be determined as being present as carbonate - either calcite or aragonite - or as a chloride, silicate, etc. The disadvantages of X-ray diffraction are that complex mixtures are difficult to interpret, and the limit of detectability for poorly crystallized materials is relatively high. Furthermore, the limit of detection for even well crystallized phases is on the order of one to five percent, with an accuracy of plus or minus 5 to 10 percent of the amount present. Consequently, X-ray diffraction can only approximate the amounts of various elements comprising a heterogeneous mixture.

Two methods of sample preparation were used in the X-ray diffraction analysis of ceramics and shell: an unoriented packed powder aliquot and an oriented clay separate. Scans from 7° to 65° two-theta for all unoriented specimens and 4° to 30° two-theta for all oriented specimens were made at a rate of 2° two-theta per minute. Diffraction spectra were compared to those listed in the Joint Committee on Powder Diffraction Standards reference literature (1974). For clay mineral identification, extensive use was made of Carroll (1970). All abundances noted were rough estimates, based solely on diffraction maxima intensities.

Electron Microprobe Analysis

Samples of ceramics and lithics were subjected to electron microprobe analysis. The electron microprobe is an instrument capable of determining the chemical composition of substances on a microscopic scale (resolution is typically about 2 microns). It accomplishes this by bombarding a sample (nearly always a polished specimen) with a beam of electromagnetic lenses. When the electron beam strikes the sample, X-rays are generated for every element in the path of the beam. Since these X-rays have wavelengths and energies characteristic of the elements that generated them, analysis of the wavelengths generated by the beam yields proportional counts for elements present in the sample.

The number of X-rays from a given element in a fixed length of time is proportional to the abundance of that element in the sample. Therefore, by comparing the number of X-rays of a given element counted on a standard mineral of known composition, it is possible to quantitatively determine the concentration of the element in the sample.

A few complications make the actual measurement of element proportions somewhat more problematical than described above. The raw data must be corrected for instrument drift, backscattering of electrons, and fluorescence (the production of X-rays of one element by the X-rays of another, heavier element). The correction procedures are well established, however, and the magnitudes of the corrections are usually small (5% of the amount present).

Electron microprobe analyses of lithic and ceramic samples were done on an ARL EMX-SM automated microprobe using both focused and broad-beam techniques. All data were corrected for background and instrument drift and for directional matrix effects by the method developed by Bence and Albee (1968). (These corrections take into account such effects as the backscattering of electrons and X-ray fluorescence). The following mineral standards were used in the microprobe analysis: Augite A 209 for Si, Fe, Mg, and Ti; Amelia albite for Na; orthoclase OR-1 for K; Lindsley anorthite for Ca and Al; doped diopside for Mn and Cr; and apatite for P. Prior to microprobe analysis, thin-sections of the sherd and lithic samples were analyzed for petrographic composition on a Zeiss petrographic microscope equipped with both reflected and transmitted light.

Atomic Absorption Analysis

Samples of ceramics, lithics, bone, and shell were analyzed by Atomic Absorption Spectrophotometry (A.A.). Atomic Absorption is an analytical technique developed by Alan Walsh in 1955. Since then, A.A. has become widely used for the accurate analysis of trace elements in virtually any matrix.

In flame A.A., a solid sample is dissolved in acids or mixed acids or by fusion with an appropriate flux. The solution is then aspirated into a flame of air-acetylene or nitrous oxide-acetylene. (In the latter oxidant-fuel combination, cesium equivalent to 1000 mg/liter was added to each solution to minimize the ionization interference which occurs in the hotter flame.) The flame dissociates complexes or compounds, thereby producing free neutral atoms of the element of interest. These atoms are capable of absorbing light at discrete wavelengths. Light generated by a hollow cathode tube specific for a given element is passed through the flame and isolated by means of a diffraction grating. Specific wavelengths are then detected with a photomultiplier tube and amplifier and recorded on graduated chart paper.

Atomic Absorption was used for analyzing Na, K, Ca, Mg, Fe, Mn, Al, Si, and Sr because of its sensitivity, accuracy, and speed in determining these elements. Although atomic absorption can be used to accurately measure the quantity of a given element, e.g., iron, it cannot be used to discern whether the iron was originally present in the samples as ferrous or ferric iron, or whether it was present as a sulfide, oxide, silicate, etc. For this reason, X-ray diffraction was used to supplement A.A. wherever possible.

Neutron Activation Analysis

Samples of obsidian and chert flakes were subjected to neutron activation analysis in order to measure changes in certain trace elements beyond the detection range of atomic absorption.

Instrument neutron activation analysis (INAA) is one of the most sensitive techniques for the determination of the average abundance of elements in geological materials. Gordon and others (1968) showed the destructive analysis of standard rocks for 23 elements. Many other elements cannot be analyzed because of interfering reactions with Mn, La, Na, Sc, and Co.

The most commonly used source of neutrons for activation analysis is the nuclear reactor. The lithic samples from the inundation experiment were irradiated at the Omega West reactor, a thermal, heterogeneous, tank-type reactor operated by the Los Alamos Scientific Laboratory. The reactor is light water moderated and cooled. At the eight-megawatt level the reactor provides fluxes of up to $8 \times 10_{13}$ neutrons / cm_2 - sec in the experimental facilities.

Lithic samples subjected to INAA were crushed in an agate mortar and pestle by hand and passed through a nylon sieve to less than 100 mesh. The agate mortar and pestle and sieve set were thoroughly washed in dilute acids and distilled water between samples to minimize contamination.

RESULTS

The laboratory experiment outlined above was designed to assess the impact of various water chemical environments and immersion times on seven general classes of archeological materials. In order to make an assessment of impact, it was necessary to measure changes in artifact populations through time and across chemical solutions. This was accomplished by a variety of different methods.

Most of the analytic techniques employed were designed to directly measure changes in the mineralogical and/or chemical constituency of the inundated artifacts. Samples of ceramics, lithics, bone, wood, and shell were analyzed by atomic absorption spectrophotometry to determine changes in ionic composition resulting from inundation. In addition, selected ceramic samples were subjected to X-ray diffraction analysis to determine gross changes in mineralogical composition following inundation; samples of ceramics and lithics were analyzed optically for petrographic changes; and thin section of ceramics and lithics were analyzed under the electron microprobe in order to isolate fine-grained changes in chemical composition. Lithic samples were also subjected to neutron activation analysis to determine changes in trace element composition.

In addition to direct measurements of whole specimens, water samples from the experimental vats were periodically analyzed by atomic absorption and other chemical assay methods in order to detect fractions of dissolved ions added to the solution as a result of artifact breakdown. This procedure provided an indirect measure of material decay, and the only measure of artifact decay during the first two weeks following initial immersion.

Finally, all of the artifact populations were analyzed before and after inundation for observable or qualitative changes, changes in size and weight, and for ceramic and wood categories, changes in tensile strength measured on an Instron durometer.

The results of these analyses are summarized below for five of the seven archeological material categories (the results of the seed and pollen analyses are presented in Technical Reports Three and Four, in this volume). The implications of these results and suggestions for future research will be discussed at the conclusion of this report.

Ceramics

Four categories of ceramics reflecting variability in firing temperature and tempering material (see page 6) were submerged in controlled water chemical solutions for twelve months in order to evaluate factors that influence ceramic deterioration rates in a reservoir environment. At four-month intervals through the twelve-month immersion period, nine samples of each ceramic type from each of the controlled solutions were removed from the water, measured, weighed, and subjected to tensile strength tests. At the end of twelve months, samples of each ceramic type were selected at random for X-ray diffraction, electron microprobe, and atomic absorption analysis. These analyses were designed to address the following general questions:

1. What chemical and mineralogical changes in fired clay ceramics can be expected following brief immersion episodes, and can these changes be predicted on the basis of observed chemical and chemical interaction properties?
2. Do chemical and mineralogical changes resulting from inundation affect the resistance of ceramics to various mechanical and chemical weathering processes?
3. What are the effects of firing temperature and tempering material on chemical/mineralogical interactions and resistence to weathering?

The analyses presented below address these and other questions from a number of independent, yet complementary approaches. X-ray diffraction and petrographic analyses were performed on unfired clay, noninundated ceramics, and inundated ceramic samples in order to assess and distinguish mineralogical and petrographic changes resulting from ceramic firing and inundation. Electron microprobe and atomic absorption analyses on unfired clay, noninundated, and inundated ceramics were designed to detect changes in ionic concentration resulting from inundation. Instron tensile strength tests on inundated and noninundated control samples were designed to assess the effects of observed chemical, mineralogical, and petrographic changes on the ceramic's ability to withstand mechanical weathering processes. The results of these analyses are presented below and in Tables 19-31.

<u>Visual Analysis:</u> Visual observations of ceramic samples from each of the four ceramic groups were conducted in order to assess the impacts of chemical immersion on ceramic attribute data. The variable clay type was held constant, while the variables of firing temperature,

temper type, and pigment type were systematically varied in order to determine whether these factors are differentially affected by inundation. The attributes selected for analysis include hardness, color, surface texture, and pigment properties. These attributes were qualitatively assessed using control standards. No attempt was made to quantify the observations.

With the exception of vat 14A (H_2SO_4), few visible changes were observed between samples submerged in different chemical environments. All four ceramic groups exhibit evidence of degradation due to immersion in the H_2SO_4 solution. The IA group exhibits severe surface pitting; and the mineral paint is faded and in some instances is obliterated. No IIA ceramics survived the year-long immersion in vat 14A. Group IB ceramics are extensively cracked and the pigment is faded and is exfoliating, though to a lesser degree than noted in group IA. The group IIB ceramics were also affected by the sulfuric acid, although to a lesser extent than the other three groups. The mineral pigment is faded but remains intact. The clay body is also somewhat softer than the control sherds, a feature noted in all of the ceramic groups.

The most notable effect of inundation was the consistency of change between ceramics of the same group regardless of the chemical environment. These observations can be summarized as follows:

1) Group IA (750°, mineral paint, organic temper) ceramics exhibit a high incidence of surface pitting probably attributable to the greater porosity of the ceramics after firing. In addition, the mineral paint is faded but for the most part remains intact. In all instances, the clay body is softer than the noninundated control samples and is lighter in color. The La Bajada clay fires to a deep reddish-orange. Following immersion the clay faded to a dull reddish-orange. On the whole, ceramic group IA withstood the impacts of the chemical environments better than groups IIA and IB, but not as well as IIB.

2) Group IIA (600°, organic paint, sandstone temper) ceramics were the most dramatically affected by immersion. Very few IIA samples survived the year-long immersion intact. Those that did are extremely soft and friable and are generally in poor condition. The organic pigment failed to adhere in most instances and is extremely faded where present. The majority of sherds in this group were retrieved in a crumbly, friable state.

3) Group IB (900° C, organic paint, sandstone temper) ceramics are generally noted in poorer condition than group IA despite having been fired at a higher temperature. In addition, the organic pigments applied as surface decoration have faded, though to a lesser degree than the mineral paints. The organic pigments appear to be subject to greater degrees of exfoliation than the mineral pigments. As observed in ceramic groups IA and IIA, the IB ceramics have also faded to a reddish-orange color, though the color change is not quite as distinctive. Additionally, the clay body of the IB ceramics is softer than their noninundated counterparts.

4) Group IIB (1050° C, mineral paint, sandstone temper) ceramics sustained the impacts of immersion far better than the other three ceramic groups. This is undoubtedly attributed to the higher firing temperature and apparent vitrification of the clay minerals. The mineral pigment applied as surface decoration has faded in similar fashion to the IA group but for the most part remains intact. The clay color is slightly faded from its reddish-brown hue, but the color difference is not as pronounced as in groups IA and IIA. In addition, the softness of the clay observed in the other three ceramic groups is not as apparent in the IIB ceramics.

Some general statements can be made in an attempt to explain some of the observed changes in the ceramic categories. Firing temperature is an important variable in ceramic deterioration. As expected, the IIA group fired at the lowest temperature (600°C) exhibited the greatest deterioration. The least amount of deterioration was observed in the IIB group fired to 1050° C. The disparity between the deterioration of groups IA and IB may be partially attributed to temper type, since there is suggested evidence of inadequate firing of the clays. Shepard (1956) notes that the use of aeolian or waterworn sand as tempering material tends to weaken the paste since it does not form as rigid a bond with the clay as does angular, rough-surfaced grains. Furthermore, tempered ceramics are generally weaker than untempered ones and clays with high percentages of temper are weaker than clays with low temper percentages. The IA ceramic group was tempered with organic grasses, which oxidized during firing, leaving voids in the clay body. Perhaps these voids did not contribute to the structural frailty of the clay as much as the sandstone temper. In fact, the clay may have been strengthened by the addition of the carbonaceous temper. Shepard (1956) observes that carbonaceous matter in the clay combines with oxygen to produce volatile gases such as carbon dioxide or carbon monoxide. The oxidation reaction produces heat which raises the internal temperature of the ware. The hardness and density of the carbon, the duration and temperature of firing, and the density of the paste all affect the rate of combustion, which is most effective between 700° and 800° C, precisely the range in which the IA ceramic group was fired.

However, other variables also affect strength. These include clay composition, texture, workmanship, and firing atmosphere. Despite the attempt to control these variables in the laboratory, the effort was not entirely successful. The problems and suggestions for future research will be addressed in the conclusion section.

The differential preservation of the pigments was qualitatively assessed through visual observation. In general, despite the difference in firing temperatures between the IA and IIB (mineral paint) ceramic groups and the IIA and IB (organic paint) groups, similarities in the degree and nature of fading and disappearance of the painted decorations were observed. In general, the mineral pigment faded more consistently than the organic pigment, in some cases almost to the point of obliteration. However, for the most part, the design elements are still discernible even after fading. The organic pigments tend to fade differentially within the same bucket and even within the same artifact. When moist, the organic pigments can be rubbed off during handling. Much of the attrition and exfoliation observed on the organic painted ceramics can probably be attributed to the mechanics of handling rather than to the effects of particular chemical solutions, since variability between chemical solutions was not observed. Where present, the organic pigments are generally darker and more pronounced than the mineral pigments, suggesting that organic pigments may sustain the impacts of inundation better than mineral pigments. This observation is quite subjective, however. Other factors such as firing temperature, bonding capacity, and variables of manufacture must be considered as well.

Analysis of Ceramic Breakstrengths: Ceramic samples from each of the four firing-temper categories were subjected to Instron tensile strength tests at each of the four measurement intervals. The results of these tests are presented graphically in Table 19.

Due to systematic errors resulting from improper machine calibration at Time 3, only the Time 1 - Time 2 results are presented. Nevertheless, several definite patterns in ceramic deterioration are suggested by the graphs. As predicted, there is an overall decrease in ceramic breakstrength through time for each of the ceramic categories, with the greatest decrease occurring in the IIA group (600°C - rock temper), and the smallest overall decrease occurring in the IIB group (1150°C - rock temper). There is also a great deal of variation in breakstrength trajectories between chemical environments, suggesting differential deterioration rates across water chemical solutions.

To test the significance of these observed changes, the ceramic breakstrength data were subjected to a multivariate analysis of covariance (Proc-GLM; Barr, et al. 1979). The purpose of the analysis was to isolate and assess the statistical significance of the three primary treatment effects, i.e., chemical, time, and ceramic type, and the interactions among these effects. The covariance model was selected in order to assess and control for the effects of two potentially significant covariates, sherd thickness and weight. The results of the analysis of covariance are presented in Table 20 and can be summarized as follows:

Each of the three primary treatment effects, chemical, time and ceramic type, as well as the interactive effect of chemical and ceramic type, were highly significant at the .0001 level. In addition, sherd thickness proved to be a significant covariate, also at the .0001 level, while sherd width was insignificant. Of the three primary treatment effects, the variable ceramic type, with an F-value of 863.24 (3 d.f.), exerted by far the strongest effect, followed by time (F=143.18, 1 d.f.) and water chemistry (F=2.53, 29 d.f.).

We may conclude that ceramic firing temperature is by far the most important factor in determining ceramic breakstrengths among the experimental ceramic groups. Firing temperature not only influences initial tensile strengths, but also largely determines inundation effects on breakstrength change through time. Note in Table 19 the effect of firing temperature on initial tensile strength, as well as its effect on the range of tensile strength changes within each firing temperature group. The three rock-tempered ceramic categories illustrate this relationship. For the concentrated solutions in Table 19, the mean decrease in breakstrength for the IIA ceramic group (600°C) from Time 1 to Time 2 is 40.44 units, with a standard deviation of 24.9 units (one unit is equal to approximately 5 lbs. of compression force). For the IB group (900°C), the mean decrease is 29.63 units, with a S.D. of 26.39 units. (When the outlying effects of vats 8a ($MgCl_2.6H_2O$) and 11a ($Na_2SiO_3.9H_2O$) are omitted from the sample, the mean decrease for IB ceramics is reduced to 22.21 units, with an S.D. of 17.27 units.) For the IIB ceramic group (1050°C), the mean decrease drops to 16.75 units, with a S.D. of 13.66. Thus, high firing temperatures not only increase ceramic tensile strengths but also reduce the variability in tensile strength change across different water chemical environments.

Turning to the IA ceramic group (750°C-organic temper), we find a significant departure from the pattern established by the rock-tempered ceramics. For the IA group, the mean breakstrength decrease from Time 1 to Time 2 is only 7.13 units, with an S.D. of 9.34, a magnitude of change and internal variability substantially less than the hottest fired rock-tempered ceramics. This is almost certainly a consequence of internal oxidation of the organic temper resulting in higher internal firing temperatures for the organic-tempered ceramics.

Immersion time is also a significant factor in ceramic deterioration. Despite the absence of Time 3 breakstrength data, certain trends in breakstrength change through time are apparent. The most significant change in ceramic breakstrength across all four ceramic firing categories occurred during the first four months of immersion, and that rate decreased substantially after eight months of immersion. We can perhaps assume that rates would have decreased even further after twelve months of immersion, but unfortunately, this cannot be verified.

The interpretation of water chemical effects on ceramic breakstrengths proved extremely difficult. Although the water chemistry factor was highly significant in the analysis of covariance, attempts to rank-order specific ionic solutions by the degree of their effect failed. Each of the concentrated solutions in Table 19 was assigned a rank within each ceramic group on the basis of the magnitude of tensile strength change from Time 1 to Time 2. These rank-orders were then compared across each of the ceramic groups using Spearman's Rank-Order Coefficient (R). The results are summarized in Table 21.

The lack of correspondence between solution rank-orderings for the four ceramic groups makes it impossible to evaluate chemical effects on the basis of the Instron breakstrength data alone. Furthermore, there are few significant differences in breakstrengths between the normal and concentrated solutions, and no apparent systematic differences between the chemical solutions and the deionized water control (vat 15). It would appear, therefore, that immersion in an aqueous solution alters ceramic tensile strength, but that water chemical variability in concentrations normally found in freshwater reservoirs exerts a minimal effect on ceramic breakstrengths--at least over the short-term.

Another possibility, of course, is that the testing method used was not sensitive enough to detect subtle differences in water chemistry effect.

Water Chemistry Analysis:* Atomic absorption analyses of the thirty chemical solutions were conducted periodically in order to detect subtle changes in the chemical composition of the various artifacts in solution. By extracting solution samples prior to the addition of new materials, it was hoped that the analysis would provide a measure

*Water Chemical analyses were conducted by John Husler, Department of Geology, University of New Mexico.

of the extent of ionic leaching for each class of material in each bucket.

The results of the analyses are summarized in Tables 15-17. Analysis of the chemical solutions two weeks after the ceramic samples were immersed revealed a significant amount of calcium release. After the initial sampling period (10/9/78), the control vat containing deionized water (vat 15) contained 58 mg/l of calcium in the 12 liters of deionized water, corresponding to a weight loss of 0.70 g of calcium from the ceramics. The solution also contained 25 mg/l potassium, 2.1 mg/l magnesium, 9 mg/l silica and 25 mg/l sodium (see Table 15). Vat 16 contained 83 mg/l calcium and 27 mg/l potassium. The increased sodium concentration (19 mg/l) may indicate possible sodium contamination as a result of improper handling of the material (i.e., not wearing gloves at all times and/or letting dust come in contact with thmaterials during initial sample preparation).

Vats 1A, 3, 4, 7, 11 and 11A all reveal increased potassium levels after the addition of the ceramics (Table 6). Since potassium is an extremely soluble ion, it would continue to be released until stability was achieved, generally within a few days following immersion. The sodium levels in vats 1A, 3, 11A and 12A also increased following the addition of the ceramics (Table 8). These values probably reflect a combination of improper handling, as well as some variation in the composition of the ceramics.

The results of the ceramic water chemical analyses indicate significant leaching of calcium and trace amounts of potassium, magnesium, and silica leaching during the first two weeks of ceramic immersion. Sodium was also detected; however, the presence of sodium may have been due to contamination rather than artifact leaching. One of the limitations of the water chemistry analysis was that it could detect leaching of specific artifact classes only during the first two weeks of immersion. After the initial two weeks, additional artifacts were added to the vats, making it difficult to distinguish the individual contributions of different material classes.

The analyses did, however, demonstrate short-term chemical reactions that could then be verified by constituent analyses of the artifacts themselves.

X-Ray Diffraction Analysis:* Thirty-three powdered ceramic samples and one raw clay control sample were subjected to X-ray diffraction analysis to determine their mineralogies. Two methods of analysis were employed. First, an unoriented packed powder aliquot was analyzed. Analysis of unoriented samples allows the detection and identification of mineral phases present in concentrations exceeding approximately five percent of the total sample. The second method employed an oriented clay separate. Analysis of oriented samples allows identification of mineral species in concentrations approaching approximately one percent of the total sample.

The results of the analysis are summarized in Table 22. The raw clay control contains abundant quartz, chlorite, illite, and kaolinite, with traces of orthoclase, microcline, and calcite. All of these minerals are common constituents of "potters clay" obtained near fluvial sandstone outcrops.

Samples of IA and IIA ceramics (fired at 750° and 600°C, respectively) are mineralogically similar and tend to approximate the mineralogy of the raw clay material. Both ceramic groups contain abundant quartz, chlorite, and illite, with accessory orthoclase, microcline, and hematite. The primary differences between the IA and IIA groups, and between both groups and the raw clay sample, seem to reflect mineralogical changes induced by firing. For example, since the crystal structure of kaolinite is destroyed upon heating, kaolinite is not represented in the IA group and was detected in abundance in only half of the IIA group. In addition, both ceramic groups exhibited better defined illite crystallinity (exemplified by the sharpening of its diffraction maxima) than the raw clay control.

*X-ray diffraction analyses were conducted by Joe Register, Department of Geology, University of New Mexico.

Since illite is a high temperature mineralogical phase, this appears to be an artifact of firing as well.

The IB ceramic samples (fired at 900°C) contain large amounts of quartz and chlorite with varying concentrations of orthoclase, microcline, illite, and hematite. Calcite and kaolinite were largely absent from the diffraction spectra. Spinel was tenuously identified in one sample. The IIB samples (fired at 1050°C) contain abundant quartz and chlorite with minor amounts of orthoclase, microcline, and hematite; illite is present in one sample. Spinel, mullite, and fayalite occur in varying amounts in some samples.

The X-ray diffraction analysis of fired clay ceramics demonstrates considerable mineralogical variability among the various ceramic groups and between the fired ceramics and the unfired clay control. Most of this variability, however, can be attributed to the effects of firing temperature on mineralogical phase expression, rather than the effects of inundation. For example, kaolinite should not be detectable in ceramics fired at temperatures above 470° (Grimshaw 1971), and illite should be transformed into spinel in ceramics fired at or above 900° (Brownell 1976). Furthermore, olivine and spinel should replace chlorite at firing temperatures above 860° and mullite should be the dominant mineralogical phase in material fired at 1050°C (Grimshaw 1971).

These predictable changes in mineralogical expression account for the vast majority of changes between the ceramic groups. The problem of isolating inundation effects on the basis of X-ray diffraction is further compounded by the mineralogical variability observed within ceramic firing groups. For example, although all of the ceramics were fired to at least 600°C, kaolinite is abundant in half of the IIA ceramics. In addition, illite was detected in some samples from both the IB and IIB groups, while very small amounts of spinel, fayalite, mullite, and other high temperature phases were detected in these same groups.

At least some of this variability is probably attributable to sampling error, small sample size, and inherent imprecisions in the measurement technique. Differences in mineralogy among samples fired at the same temperature also suggest some lack of quality control during the firing process.

Electron Microprobe Analysis:* Ceramic samples from each of the four firing temperature categories were subjected to electron microprobe analysis to determine compositional changes in the fine-grained matrix of the samples. Because time and cost constraints did not permit the study of all ceramic samples in all chemical solutions, samples were analyzed from four solutions judged most likely to exhibit chemical effects ($MgSO_4$; NaCl; $FeCl_3$; KCl).

The samples were made into standard polished thin sections, 30 mm thick. Prior to microprobe analysis, the samples were examined under a Zeiss petrographic microscope equipped with both reflected and transmitted light. Petrographic analysis of the raw clay from which the ceramics were fired detected kaolinite (up to 10 u across), quartz (10 to 80 u across), chlorite and hematite (1 u to 10 u), trace amounts of K-feldspar and plagioclase, and many grains 1 u across which could not be identified optically. Analysis of the fired clay ceramics yielded only a few compositional differences between the fired and unfired clay. One exception was the presence of muscovite in all of the fired ceramics. Muscovite, a hydrated, layer-lattice silicate, occurs in the fired clay as elongated crystals ranging in size from 10 x 50 u to 25 x 200 u. These grains undoubtedly formed when the clay was fired.

*Electron microprobe analyses were conducted by Jeff Taylor, Department of Geology, University of New Mexico.

Silt-size crystals of quartz and K-feldspar were also detected in the fired clay (as they were in the unfired clay). These minerals are distributed throughout a fine-grained matrix in which the crystal size is approximately 1-2 u. Although these small grains could not be identified in this section, qualitative microprobe analyses suggest they are vaguely like muscovite, while a few (usually equant grains) are composed of mullite, consisting mostly of SiO_2 and Al_2O_3. No petrographic differences could be discerned between uninundated and inundated ceramic samples.

Electron microprobe analyses were performed on an ARL EMX-SM automated microprobe using both focused and broad-beam techniques. All data were corrected for background and instrument drift and for differential matrix effects by the method developed by Bence and Albee (1968). Because of instrument resolution problems, measurement of the compositions of the matrix of each ceramic type were analyzed using a beam size of approximately 25 u and averaging at least 15 points per sample. This analysis avoided all silt-sized quartz and K-feldspar grains and, therefore, analyzed only the fired-clay matrix.

The results of the broad-beam analyses are summarized in Tables 23-31. Note that the totals in Tables 23-27 are less than 100%. Two factors are responsible for this. First, all of the major minerals analyzed contain some water (e.g., pure muscovite sums to only 94%, with six% attributable to water volume). Second, the matrices of the fired ceramics were porous, so that some of the volume analyzed was actually void of material. These less than 100% totals should not be considered significant since the totals on all analyses of a given ceramic type are essentially comparable and reflect porosity and recrystallization effects of different firing temperatures. There is, in fact, a rough correlation between percent total and firing temperature: IIA ceramics (600°C) have the lowest totals (ca. 83%), whereas IA (750°C) and IB (900°C) exhibit the highest percent totals (ca. 90%).

Tables 28-31 present the ratios of the concentration of each element in the inundated samples to the concentration in the control samples (noninundated ceramics) for each ceramic type. When the concentration of an element is the same in both the inundated and noninundated samples, this ratio is 1.0 (i.e., no change during inundation). Since a set of individual analyses often varied between inundated samples and noninundated controls, samples were assessed on the basis of the statistical uncertainties associated with the measurement of each oxide. These uncertainties were determined by combining the standard deviations of the means for a set of 15 individual analyses with the student's t-distribution (95% confidence intervals). On average, these uncertainties are as follows (in weight percentages): SiO_2, ± 0.4; TiO_2, ± 0.05; Al_2O_3, ± 0.3; FeO, ± 0.2; MgO, ± 0.05; CaO, ± 0.15; Na_2O, ± 0.01; and K_2O, ± 0.04. For convenience in interpretation, Tables 28-31 display the average range expected (plus or minus approximately 10%) in the ratio of the concentration of each element in an inundated sample to that in the noninundated control population. Consequently, values that fall outside the dashed lines in Tables 28-31 are significantly different from a value of 1.0 and demonstrate that a chemical change took place during inundation.

The data (Tables 23-31) indicate that SiO_2, Al_2O_3, TiO_2, and FeO contents were not affected significantly by inundation. The other oxides, however, were affected to varying degrees. MgO is enriched in all ceramic samples inundated in the $MgSO_4$ solution (2A), except in ceramic IIB (Table 31). CaO is markedly depleted in all samples, with the $MgSO_4$ solution apparently causing the greatest dissolution of CaO. Na_2O tends to be enriched in those samples inundated in solution 7A (NaCl), but also in solution 12A (KCl) in ceramic class IIA (Table 29), and solution 2A ($MgSO_4$) in ceramic class IA (Table 28). K_2O is enriched in those ceramic samples inundated in solution 12A (KCl). All these effects are much less obvious in the IIB samples (Table 31). This is consistent with their more recrystallized, coarser, and less porous nature.

The details of the chemical reactions that took place to produce these changes are obscure. Reactions involving muscovite (and probably illite as well) can be ruled out, however. As the data in Table 27 demonstrate, there are no systematic differences in muscovite compositions in ceramics immersed in different solutions. Perhaps the observed changes in matrix compositions are caused by reactions involving fine-grained (approximately 2 mm) mullite or kaolinite grains.

Atomic Absorption Spectroscopy:* Over 1,000 ceramic samples were analyzed by atomic absorption analysis for changes in trace element fractions resulting from inundation. Trace elements measured included calcium (CaO), sodium (Na_2O), potassium (K_2O), magnesium (MgO), manganese (MnO), and Iron (Fe_2O_3).

Calcium (CaO) is the only element showing a significant and consistent decrease across all four ceramic firing categories. Atomic absorption analyses thus tend to confirm the results obtained from the water chemical and electron microprobe analyses, which indicate a substantial amount of calcium leaching from the ceramics during the course of the 12 months of immersion.

Most other trends observed in the AA analysis appear to be due to factors other than inundation. For example, a significant increase in calcium (CaO) percentages from the IA to the IIB ceramic groups appears to be an artifact of firing temperature. The percentage of Ca (or any other nonvolatile element) will tend to increase when a sample is heated, by an amount proportional to the weight of the volatile elements driven off. In the case of calcium, the weight of volatiles ($H_2O(-)$, $H_2O(+)$, and CO_2) decreases from an average of 4.8% of total weight by volume in the IIA ceramics (600°C) to an average of 0.74% in the IIB ceramics (1050°C). This would appear to be a sufficient volatile element loss to account for the apparent increase in CaO percentage between the four firing groups.

*Atomic Absorption Spectroscopy analyses were performed by John Husler, Department of Geology, University of New Mexico.

This same factor probably accounts for a significant increase in sodium percentage across firing categories, with the exception that the extreme temperatures associated with the IIB ceramic firing appear to have volatilized some sodium ions and resulted, therefore, in a decrease in sodium percentage in the IIB ceramic group. A decrease in K_2O across firing categories also appears to be a result of firing temperature, since potassium will invariably volatilize at high temperatures.

The only other significant trend in the elements measured was exhibited by manganese (MnO), where IA (750°C) and IIB (1050°C) ceramics displayed inflated manganese percentages. These inflated values are almost certainly the result of the use of manganese oxide paint and slips on all IA and IIB ceramic tiles.

In order to measure the effects of water chemical environment on calcium leaching rates, atomic absorption data from the 15 concentrated solutions were subjected to an analysis of variance (Barr et al. 1979). The results of the analysis indicate that chemical environment, firing temperature and the interaction between chemical and firing temperature, are all significant at the .0001 level.

Lithics

Two categories of lithic flakes (obsidian and chert) were immersed in the experimental vats for twelve months in order to evaluate water chemical effects. In addition, samples of ground obsidian and chert were immersed in separate vials containing identical water chemical solutions in order to enhance any chemical reactions that might occur over extended periods of immersion.

After twelve months of immersion, the lithic flakes were removed from solution, observed for qualitative changes in attribute states, and subjected to electron microprobe, atomic absorption, and neutron activation analysis in order to measure quantitative changes in lithic composition. At four-month intervals for one calendar year the ground lithic samples were removed from solution, dried, weighed, and water samples were collected for atomic absorption analysis of leaching effects. The results of these analyses are summarized below and in Tables 32 through 37.

Visual Analysis: Qualitative analyses of lithic flakes were conducted in order to detect any obvious changes in lithic attribute states following twelve months of immersion. Of particular concern were changes in microscopic wear-pattern recognition resulting from chemical weathering of the abraded edges of the lithic samples. After 12 months of immersion, no obvious qualitative changes in wear patterns were observed on the flakes, and no other impacts to flake attributes were recorded. This is not surprising in view of the fact that the species of minerals typically comprising chert and obsidian are very resistant to chemical weathering processes.

Since no qualitative changes in lithic flakes were observed, samples of whole flakes were subjected to a variety of fine-grained chemical assay tests to determine any changes in chemical or mineralogical constituency following inundation.

Electron Microprobe Analysis:* The electron microprobe is capable of measuring on a microscopic scale the abundances of elements heavier than carbon. One of its most common applications in petrographic analysis is the determination of how the chemical composition of a single crystal larger than 10 mm varies from its center to its edge. This attribute allowed us to analyze the edges and centers of chert and obsidian flakes to see if compositional changes occurred on the edges of the flakes during inundation.

Chert and obsidian samples from two concentrated water chemical solutions ($CaCl_2$ and KCl) were analyzed for edge compositional

*Electron Microprobe Analysis was performed by Jeff Taylor, Department of Geology, University of New Mexico.

changes and compared with samples from the deionized water control. The results are summarized in Tables 32 and 33.

Petrographic analysis of the obsidian samples revealed a homogeneous, colorless (in thin section) glass with occasional aligned crystallites (1 x 5 u in size) and small (5 u) clasts comprising less than one percent of each sample. All of the obsidian samples are rich in SiO_2, typical of obsidian from the Jemez Mountains of New Mexico, and three samples are compositionally indistinguishable from one another. Significantly, the edges of all the samples examined by the microprobe exhibited identical compositions as the centers, demonstrating that no measurable chemical reactions occurred between the obsidian samples and the solutions in which they were inundated.

The chert samples examined are typical of cherts found in limestones, consisting of colorless, equant, microcrystalline quartz (5-10 u grain size) that grades into a brownish material consisting of microcrystalline quartz interspersed with fibrous crystals. Microprobe analyses indicate that the areas containing fibrous crystals have the same chemical composition as those containing the more equant, microcrystalline quartz. The fibrous crystals probably represent a devitrified, amorphous silica gel. A few fractures criss-cross the chert samples, but with the exception of one chert flake immersed in KCl which exhibits extensive fracturing, these cracks are usually not so numerous as to affect comparisons between edge and center compositions.

All of the chert samples are nearly pure SiO_2, with trace amounts of Al_2O_3, CaO, Na_2O, and K_2O. Microprobe analyses revealed no significant compositional differences between edges and centers of specimens and no systematic differences between inundated and noninundated samples. The one exception was the heavily fractured chert flake from the KCl solution, which was enriched in K_2O in both its interior and on its edges. It is not clear whether this enrichment resulted from inundation, perhaps aided by the pervasive fracturing, or is the result of the specimen having higher than normal concentrations of K_2O to begin with (the sample was not analyzed prior to inundation). In any case, the enrichment is relatively modest.

<u>Neutron Activation Analysis:*</u> Twenty obsidian and twenty-four chert samples, including four control samples of each material type, were subjected to neutron activation analysis to determine changes in the trace element composition resulting from exposure to different water chemical environments. The mean, standard deviation, and sample size for each observational group are summarized in Tables 34 and 35.

The results of the neutron activation analysis for the obsidian samples show no significant differences between the samples immersed in the chemical and/or deionized water solutions and the noninundated control samples. The results of the analysis for various trace elements in the obsidian samples are summarized in Table 34. Eleven elements, including cesium (Cs), scandium (Sc), tantalum (Ta), rubidium (Rb), uranium (U), thorium (Th), and five rare earth elements (REE), lanthanum (La), cerium (Ce), samarium (Sm), terbium (Tb) and ytterbium (Yb), exhibited gamma spectra considered strong enough for accurate detection (Table 36). Although additional elements were also detected, they occurred in concentrations at or below accurate lower limits of detection and were therefore not included in the analysis.

Most of the elements analyzed exhibit similar chemical and physical properties. Experiments on adsorption and cation exchange have demonstrated that these elements exhibit high sorptive capacities due to their high ionic potentials. As a result, they behave as typical hydrolysate elements, combining to form insoluble hydroxides

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*Neutron activation analyses were conducted by Rich della Valle, Department of Geology, University of New Mexico.

that are readily precipitated or adsorbed onto the material surface. Consequently, the removal of these elements through leaching may be hindered by the adsorptive properties of the material. A combination of factors including the brief immersion period (12 months) and the small percentage of surface area exposed to the chemical reagents may have restricted the capacity for leaching or adsorption. An exception to this tendency toward adsorption is uranium, a highly mobile element.

Uranium mobility has been well documented by Bullwinkel (1954), Hostetler and Garrels (1962), Lisitsin (1962, 1971), Muto et al. (1968), Rich et al. (1977), and Langmuir (1978). Uranium is easily oxidized to the soluble uranium dicarbonate (UDC) and uranium tricarbonate (UTC) complexes (Hostetler and Garrels 1962). Because uranium is easily oxidized and its complex ions are soluble (Garrels and Christ 1965), the thorium/uranium (Th/U) ratio can be a valuable indicator of chemical change. In natural (fresh) obsidian, the Th/U ratio is generally between 3.5 to 4.0 ppm. The data presented in Table 34 indicate no significant change in the Th/U ratio resulting from immersion in the various chemical environments. The constant Th/U ratios are indicative of the stability (in the given time) of the obsidian. However, over extended periods of time the obsidian would eventually devitrify due to its inherent metastability under normal conditions of temperature and pressure.

The results of neutron activation analysis on the chert samples revealed anomalous behavior in some of the chemical solutions. The results of the analysis for various trace elements in the chert samples are summarized in Table 35. Six elements were detected in the chert samples. Included are sodium (Na), iron (Fe), chromium (Cr), uranium (U), samarium (Sm), and the rare earth elements (REE). Other elements detected were considered below the accurate detection limits (Table 36) and consequently were not included in the analysis.

Since the majority of chemical solutions did not have an adverse impact on the trace element composition of the chert samples, these values were averaged in the tabulations (Table 35). The anomalous values were not included in the mean computations, but rather were isolated for comparative purposes. As Table 35 indicates, no significant differences were noted between the samples immersed in the deionized water solution (Vat 15) and the noninundated controls. A brief summary of the results of neutron activation analysis of the chert samples is presented below.

Anomalously high values of sodium (Na), 0.18%, were measured in those samples immersed in vats 4A ($NaHCO_3$) and 11A (Na_2SiO_3). This is most likely attributed to sodium contamination by the leaching solution. Conversely, anomalously low values of iron were detected in vats 3A, 4A, and 10A. These solutions ($CaCl_2$, $NaHCO_3$ and $FeCl_3$) exhibited values of .39%, .28% and .39% Fe_2O_3 (as total iron), respectively. A partial explanation for the low values is the slight amount of leaching occurring in the solutions since iron chlorides and certain forms of the iron and carbonate moiety are soluble in nature. However, in order to confirm this observation, a larger sample size and additional experimentation are required. Lower values may represent a dilution effect resulting from the precipitation of a $CaCl_2$ or $NaHCO_3$ weathering rind.

Similarly, anomalously low values of chromium (Cr) were recorded for these same three chemical solutions ($CaCl_2$, $NaHCO_3$ and $FeCl_3$), 33.9, 22.2 and 26.8 ppm, respectively. As in the case of iron, the slightly lower values may be explained by slight amounts of leaching by these solutions. While some leaching is indicated, these values may also represent a dilution effect resulting from the precipitation of a thin crust.

In cherts, uranium values are generally less than 1 ppm; however, the high mean values (6.37 ppm) of uranium exhibited by the chert samples included in the water chemical experiment may indicate a thin crust of uranium associated with colloidal silica. If this were the case, any leaching of uranium would involve a chemical attack of the colloidal silica. This may be indicated in the samples immersed in vats 4A and 10A ($NaHCO_3$ and $FeCl_3$), for which anomalously low values of 2.77 and 3.25 ppm uranium were recorded.

Samarium carbonates have been reported in nature, but only at elevated temperatures. However, this may only be a kinetic effect. Given sufficient time samarium carbonates can also form under conditions of low temperature. Additionally, the compound can form at the same pH conditions reported for the water chemical experiment. Figure 3 represents an Eh - pH diagram for samarium. Anomalously low values of samarium were recorded for the Na_2CO_3 (vat 1A) and Na_2SiO_3 (vat 11A) solutions, 0.89 and 0.68 ppm, respectively. While the low samarium values for the sodium carbonate solution (Na_2CO_3) may be due to the leaching of samarium, the low values recorded for sodium silicate (Na_2SiO_3) may simply indicate a dilution effect caused by the precipitation of ionic silica.

These results indicate that while some leaching of trace elements from the chert samples may have occurred, it is more likely that a dilution effect is indicated, since many of the chert samples developed weathering rinds. Examples of ionic species which can precipitate a weathering rind include sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), and sodium silicate (Na_2SiO_3). It must be emphasized, however, that all of the above observations are based on a statistically invalid population (one sample per chemical environment). In order to assure analytical quality, more samples must be analyzed from the anomalous solutions.

Atomic Absorption Analysis:* Samples of chert and obsidian flakes from the fourteen concentrated vats and the deionized water control were subjected to atomic absorption analysis in order to detect differential changes in trace elements across the water chemical solutions. Elements measured included calcium (CaO), potassium

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*Atomic Absorption Spectroscopy analyses were performed by John Husler, Department of Geology, University of New Mexico.

(K_2O), sodium (Na_2O), magnesium (MgO), manganese (MnO), and iron (Fe_2O_3).

Percent data obtained from the atomic absorption analysis were subjected to an analysis of variance (Barr et al. 1979), and the results indicate that there is no significant difference in trace element fractions across water chemical environments. Nor is there significant variation in trace elements measured between inundated lithics and noninundated controls.

Ground Lithic Analysis: The results of the whole rock assays indicate little if any change in lithic composition after one year of inundation. These results were anticipated during the design phase of the experiment, and an attempt was made to maximize chemical reactions by immersing samples of finely-ground lithics in the hopes that by increasing lithic surface area in direct contact with the chemical solutions, any chemical reactions that might occur would be easier to detect.

At four-month intervals for one calendar year the ground lithic samples were removed from solution, dried, and weighed, and aliquots were taken for atomic absorption analysis of mineral leaching. Significant weight loss was noted for both ground lithic types at each of the time measurement intervals, and atomic absorption analyses at Time 1 and Time 2 indicate that several constituent elements were in fact leaching into the water solutions. The results of the atomic absorption analyses are presented in Table 37.

The results indicate that ground chert samples immersed in deionized water (vat 15) contributed significant amounts of calcium, sodium, and silica to solution after only four months of inundation. After eight months of immersion, in addition to the elements noted at Time 1, significant traces of potassium and magnesium were also recorded. The same leaching trends occur in Vat 16, the combined water chemical vat, with the exception that leaching effects appear to be somewhat accelerated in Vat 16.

Ground obsidian samples exhibited leaching trends similar to the chert, with the exception that only trace amounts of calcium were detected from the obsidian solutions (see Table 37).

Shell

Two categories of shell, clam and oyster, were included in the water chemical experiment in order to assess the impacts of water chemical variability on artifactual shell. Five samples each of clam and oyster shells were immersed in thirty chemical environments for a period of one year. At the end of the twelve-month interval, selected samples were removed and subjected to chemical tests, including X-ray diffraction and atomic absorption analyses. Visual observations were also made in order to detect changes between chemical environments over time. These analyses were designed to address two fundamental questions: 1) what chemical and mineralogical changes can be expected following brief periods of inundation and can these changes be predicted on the basis of the observed chemical interactions? and 2) do these changes resulting from inundation influence the differential preservation of shell?

Visual Analysis: The clam and oyster shells were subjected to visual examination to assess impacts to attribute data used for identification and classification. The attributes selected for study included morphology, surface texture, color, and nacre (sheen). These attributes were qualitatively assessed using preinundation photographs and representative control standards.

The results of the observations can be summarized as follows. Visual changes were noted in only three vats, 6A (HCl), 7A (NaCl), and 14A (H_2SO_4). Vats 6A and 14A contain concentrated acid solutions which would predictably leach the calcium carbonate component of the shell. The clam shells were more noticeably affected by the acids than the oyster shells. Perhaps it is the result of the difference in chemical composition between the two genera. The effects included dissolution of a large part of the shell, extreme chalkiness of the preserved portion, and an overall bleaching effect. The only other observed differences in inundated shell were noted in vat 7A, which contains a concentrated NaCl solution. The effect of the chemical environment is confined to an overall bleaching effect. The samples continued to exhibit their former morphological and textural characteristics.

X-Ray Diffraction Analysis:* One hundred twenty-two powdered clam and oyster shells (including three noninundated control samples) were subjected to X-ray diffraction analysis to determine changes in their mineralogies resulting from immersion in various chemical environments. The experimental procedure for these analyses are identical to those described in the section concerning the mineralogy of the ceramic samples (see page 31).

The results of the analysis are presented in Table 38. The majority of the shells are monomineralogic. The principal component of clam shells is aragonite, while the oyster shells are predominantly calcite. Trace amounts of calcite and quartz were observed in a few of the clam shells. Similarly, small amounts of aragonite and quartz were detected in a few of the oyster shells. However, since no other phases were detected in any of the shell samples, it is concluded that inundation had very little effect on the mineralogy of these specimens.

Water Chemical Analysis:* In spite of the absence of gross mineralogical changes in the inundated shell, the majority of shell samples exhibited significant weight loss during the twelve-month immersion period. Tables 9 and 10 summarize clam and oyster weight loss averages from time 1 to time 3 for each of the thirty water chemical environments. Predictably, the most significant shell dissolution occurred in the acidic vats (6A, and 14A), but virtually all of the experimental containers exhibit some evidence of shell deterioration.

*X-ray diffraction analyses were conducted by Joe Register, Department of Geology, University of New Mexico.

Atomic absorption analyses of water samples from the thirty experimental containers were conducted to determine what elements were being added to solution as a result of shell dissolution. The results of these analyses are summarized in Tables 5-16. It was observed from the study of ions leached from shells (as well as ceramics and bone) in the high acidity vats 6, 6A (HCl), and 14 and 14A (H_2SO_4) that large amounts of calcium were released (Table 9). After the addition of the shell, vat 6A contained 178 mg/l of calcium, while vat 14A contained 210 mg/l calcium. Of the non-acidic vats, 15, 16 and 7A exhibited the greatest calcium release (Table 9), with values of 12.1, 46.0 and 51.3 mg/l registering, respectively. Potassium release occurred in vats 3, 4, 7, 11, and 16 (Table 6). Sodium was detected in vats 15, 1A, and 12A (Table 8). These latter values for potassium and sodium could reflect continued ionic release from the ceramics and/or contamination as a result of handling or contact with dust. The amount of leaching is dependent upon the initial concentration of the ion either in solution or in the material and the solubility of the ion in a particular solution. Generally, the leaching will continue until the concentration of a particular ion approaches a saturation level in the solution or the ionic concentration in a sample exceeds the saturation level in the surrounding water.

We may conclude that acidic water solutions may be highly destructive of artifactual shell after only short periods of inundation, but that other water chemical variables probably have a minimal effect on shell deterioration rates. This conclusion is supported by the fact that shell dissolution rates in the deionized water control vat (Vat 15) equalled or exceeded rates measured in many of the ionic solutions (see Table 15).

Ground Shell Analysis: In order to accelerate chemical reactions and enhance the measurement of leaching effects, samples of finely - ground clam and oyster shell were prepared and immersed in a fashion

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*Water Chemical analyses were conducted by John Husler, Department of Geology, University of New Mexico.

identical to the ground lithic samples. At four-month intervals for one calendar year the ground shell samples were removed from solution, dried, and weighed, and aliquots were taken for atomic absorption analysis of mineral leaching. The results of these analyses are summarized in Table 39.

The results suggest that both oyster and clam shells are subject to considerable calcium leaching during relatively brief immersion periods, and this process will undoubtedly be accelerated in acid pH environments. Whereas calcium leaching rates appear relatively constant in the ground oyster shell, leaching rates for clam tend to decline from four to eight months after immersion.

Wood

Two categories of wood, Ponderosa pine and Red oak, representing the general classes of softwood and hardwood, were immersed in the thirty chemical environments for a twelve-month period of time. Ten samples of each type of wood were immersed. At the four- and twelve-month sampling intervals, the specimens were removed from the solutions and allowed to dry. Qualitative measurements consisting of photographs and Munsell color determinations were conducted along with quantitative measurements of sample dry weights. In addition to the qualitative measurement of color change, visual observations were conducted at the twelve-month interval to detect changes within specific wood categories and chemical environments which might not be expressed through mechanical means. Chemical tests were not performed on any of the wood samples.

The analyses were designed to address two basic questions: 1) what structural changes can be expected following brief episodes of inundation, and can these changes be predicted on the basis of the observed chemical interactions? and 2) do these changes that result from inundation influence the differential preservation of wood? The results of the analyses presented below address these questions in an independent, yet complementary, mode.

Visual Analysis: The pine and oak samples were subjected to visual examination to assess the impacts resulting from exposure to a series of thirty cationic solutions. The variables selected for study include morphology, color, and surface texture. These variables were qualitatively assessed using Munsell color determination, color photographs, and representative control standards.

The results of the observations can be summarized as follows. The primary visual changes observed between buckets are color differences. This variability is difficult to evaluate since variation in color seems to be a function of staining from the solutions. Within the individual buckets, oak stained a consistently darker color than the pine. Pine samples from buckets 3A, 6A, 9A, and 14A were generally darker than the samples from the other buckets. This may be attributed either to the effect of the chemical solutions or to the interactions with the other materials in the buckets. The oak shows somewhat less variability between buckets than the pine; however, the oak from 6A and 11A is somewhat lighter than the other buckets.

In general, few changes were observed which could be attributed to the effects of any specific chemical environment with the notable exception of vat 11A. The oak samples in vat 11A exhibit an effect which is clearly the result of the chemical environment. The oak exhibits numerous linear splits along the end grain, which run parallel to the grain of the wood (Fig. 5). No cracking is apparent in the pine. This difference may be a function of the structural difference between the two types of wood. The other feature noted in Vat 11A is the bleached appearance of both the pine and oak. None of the wood from any of the buckets exhibited warping or distortion, a feature frequently associated with alternate wetting and drying. This is surprising since the wood was subjected to alternate periods of wetting and drying after each sampling interval and during the porosity tests.

Water Chemical Analysis: Atomic absorption analyses of solution aliquots collected two weeks after initial wood submersion yielded no conclusive evidence of chemical leaching. An increase in calcium detected in Vats 15 and 16 (Tables 15 and 16) may be related to the immersion of the wood, but continued leaching from the ceramics and shell samples may also account for this increase. No other significant chemical changes were noted during this testing interval.

Wood Dry Weights

At the end of four months, and again at the end of 12 months of immersion, all uncharred pine and oak samples were removed from solution, allowed to dry at room temperature (68°) for a minimum of three weeks, and weighed on a Mettler P1200 balance. The differences in dry weights between Time 1 (4 months) and Time 2 (12 months) were then assessed by means of the paired-t statistic. The results of the paired-t test are presented in table 40.

Bone

Three categories of bone -- rabbit, cow, and deer -- were represented in the laboratory cultural material assemblage. Five samples each of the cow and deer bone and two samples of rabbit bone were immersed in thirty water chemical solutions for a period of twelve months. Two weeks after the initial immersion of the bone samples, water aliquots were collected from each of the ionic solutions and subjected to atomic absorption analysis in order to determine fractions of dissolved ions attributable to bone dissolution. In addition, visual and qualitative observations were made at the end of 12 months of immersion in order to detect gross changes in bone morphology resulting from short-term inundation.

These analyses were designed to address two basic questions: 1) what chemical changes in archeological bone can be expected following brief periods of inundation, and can these changes be predicted on the basis of observed chemical interactions? and 2) do chemical changes in bone that result from inundation influence the differential preservation of bone in a submerged, freshwater environment?

Visual Analysis: Both charred and uncharred bone samples were subjected to visual analysis to assess the impacts resulting from exposure to a series of thirty cationic solutions. The variables selected for study include morphology, color, and surface texture. These variables were qualitatively assessed using preinundation photographs and representative control standards.

The results of the observations can be summarized as follows: Few visual changes were noted between buckets. For the most part, the pattern of bone degradation is consistent within each category of bone. The deer bone appears to be the least affected by the chemical solutions. The bone mass is extremely dense and contains little cancellous tissue. The cow bone similarly was little affected by the chemical interactions. Although the cancellous tissue was rendered friable and showed a tendency to slough off, the dense bone matrix was preserved intact. The rabbit bone was affected to the greatest degree; however, observed impacts were minimal. Slight alteration of surface texture was observed within the rabbit bone group as a whole.

The most dramatic effects of chemical degradation occurred in the acidic vats 6A and 14A. Within these vats, the bone was severely modified. The texture of the bone was transformed into a porous, laminar jet black material (Fig. 6) that is extremely friable. A white precipitate was observed on the surface of the deer bone from Vat 6A. In general, the deer bone withstood the effect of immersion better than did the cow bone, presumably because of the extreme density of the bone and the reduced amount of surface area that was exposed to the chemical solutions. The uncharred rabbit bone, however, completely dissolved in both acidic solutions. This suggests that under extreme conditions of acidity, bone probably will not withstand the impacts of prolonged inundation.

Water Chemical Analysis: The results of water chemical analyses performed after the addition of the bone materials (1/25/79) indicate an increase in calcium in vats 12 and 15. Sodium increases were detected in vats 1A, 11, 15, and 12A; while potassium increased in vat 16. Magnesium also increased in the control vat 15. These leached ions are consistent with the chemical composition of bone, which is primarily composed of calcium phosphate. The results of the atomic absorption analyses are summarized in Tables 5, 6, 8, and 9.

CONCLUSIONS, IMPLICATIONS, AND SUGGESTIONS FOR FUTURE RESEARCH

The experiments on differential preservation conducted at the University of New Mexico in 1978-79 were designed to address a number of basic questions relating to the differential preservation of common archeological materials in freshwater environments. The laboratory phase of the experiment was specifically designed to isolate and measure water chemical effects on artifact degradation rates. The design of the experiment was simple: samples of common archeological materials (ceramics, lithics, shell, wood, bone, seeds, and pollen) were immersed in vats containing a number of common cation and anion species dissolved in distilled water at solution concentrations approximating those found in "typical" freshwater reservoirs, and in concentrations approximating twenty times normal reservoir levels, in order to simulate the effects of long-term immersion. At four-month intervals for one calendar year, samples of artifacts were removed from solution and measurements of change and deterioration were made.

The experiment was designed and executed with two ultimate goals in mind: 1) to conduct basic research on the relationship between water chemical variability and artifact deterioration rates in order to enable more accurate predictions of inundation impacts on cultural resources and 2) to conduct basic research that may serve as a comparative baseline for future studies of material differential preservation.

With these goals in mind, we will conclude this study by summarizing the relevant results of the laboratory experiment and suggesting directions for the design of future research.

Ceramics

The most important results of the ceramic experiments can be summarized as follows:

1) Ceramic tensile strength decreased through time for nearly all tiles and across all chemical environments; however, individual chemical effects proved difficult to distinguish and impossible to rank-order on the basis of magnitude of effect. Furthermore, there were few significant differences in tensile strength between normal and concentrated solutions, and in general, tensile strength changes in the deionized control solution were of the same order of magnitude as those from the ionic solutions. It would appear, therefore, that submersion in an aqueous environment is sufficient to alter the tensile strength of fired clay, but that chemical variability, in solution concentrations normally found in freshwater reservoirs, has a minimal effect on ceramic tensile strength.

2) The most important factor determining ceramic tensile strength, and the effects of immersion on ceramic tensile strength, is ceramic firing temperature. The majority of ceramic tiles fired at 600°C virtually disintegrated during the first four months of immersion. Ceramics tempered with combustible plant fiber were generally more resistant to chemical attack than ceramics tempered with crushed rock. This is probably due to the higher internal firing temperatures that are achieved as a result of the combustion of the organic fiber temper.

3) Organic carbon paints survived the chemical attacks of inundation better than the manganese oxide paints due to the greater solubility of mineral pigment.

4) By a process of differential leaching of soluble ions, inundation may be expected to significantly alter ratios of trace elements in fired clay, an effect which may skew source identification and other studies which are based on trace element ratio analysis.

5) The only element analyzed that showed consistent and significant leaching across all ceramic firing temperatures and across all water chemical environments was calcium (CaO). Calcium leaching rates were highest in the acid pH water environments. The loss of calcium, which is a potential bonding agent of fired clay, may account for at least a portion of the tensile strength variability through time exhibited by all four ceramic firing categories. This interpretation is suggested but by no means confirmed by the experimental data.

There were a number of problems with the ceramic design, many of which are correctable. Ceramic tiles within each firing category exhibited a great deal of variability due to clay heterogeneity and, apparently, some lack of quality control during the firing process. These problems should be easy to correct in future experiments. Clay heterogeneity can be minimized by thorough mixing of the clay body prior to firing. Firing controls should focus on firing consistency, which can be monitored by X-ray diffraction prior to selection of experimental sample sets. These controls are essential if the treatment effects of firing and inundation are to be differentiated.

Ceramic tile shape and size, and especially thickness, must be carefully standardized in future experiments so that the contribution of these variables to ceramic tensile strength can be unambiguously distinguished from the primary treatment effects.

Instron tensile strength measures were the only measures used in the experiment to assess weathering resistence in ceramic tile groups. Additional independent measures of weathering resistence would have been extremely useful as a means of evaluating the utility of tensile strength as a measure of weathering resistence. Perhaps a more accurate simulation of reservoir chemical and mechanical weathering processes would be to subject tile samples to mechanical stress in a "drum-style" tumbler. Abrasion resistance tests could also be employed. The multiplication of independent tests to measure mechanical weathering resistance would greatly strengthen this aspect of the experiment.

Lithics

Although certain rare trace element proportions may have been slightly altered by inundation, no other measurable changes resulting from inundation were noted in the whole lithic flakes. No qualitative changes in lithic morphological states or artificially-induced wear patterns were detected on any of the inundated flake samples. Electron microprobe analyses of whole flakes failed to detect any systematic chemical or mineralogical differences between inundated flakes and noninundated control samples and failed to detect any evidence of ion leaching from the inundated lithics.

The electron microprobe succeeded in isolating a single obsidian flake which was slightly enriched with KCl but this enrichment is probably the result of extensive internal fracturing exhibited by the enriched specimen.

Analysis of ground chert and obsidian samples revealed leaching of trace amounts of calcium, sodium, silica, potassium, and magnesium, and there is some evidence to indicate that ground lithic leaching rates were higher in the solution vats than in the deionized water control vat.

The results of the ground lithic experiments should be interpreted with caution, however. Although the results clearly demonstrate the kinds of chemical reactions that occur at the lithic-water interface, it must be stressed that the implication of these results for whole lithic preservation in an aqueous environment is difficult to assess. In the case of whole lithics, the development of a superficial weathering rind tends to inhibit the rate of chemical reactions, and so the use of ground samples may yield spurious predictions about weathering rates for whole lithic flakes and artifacts. Consequently, the results of the ground lithic analysis may be useful as a guide to the kinds of chemical reactions that might be expected to occur during long periods of immersion, but the results cannot be used as a basis for predicting rates of lithic artifact deterioration in an aqueous environment.

The greatest drawback to the lithic design was the short duration of the experiment. An attempt was made to accelerate the primary treatment effect by immersing finely-ground samples of chert and obsidian, thereby increasing by a large factor the lithic surface area in direct contact with water. Although this procedure provided valuable insights into the kinds of chemical weathering processes that might be expected to occur over the long term, there are obvious problems in extrapolation between the ground lithic samples and the unground lithic flakes.

Neutron activation analysis was the only analytical procedure sensitive enough to detect chemical changes in whole lithics after only a year of immersion. Unfortunately, our analysis employed sample sizes too small to reach statistically valid conclusions. It is recommended that future studies of lithic degradation commit more resources to neutron activation analysis.

Bone

Bone degradation patterns were similar to those observed for shell. Predictably, the most destructive water environments for bone were the concentrated acid pH solutions (Vats 6A and 14A). Trace amounts of leaching occurred, however, in all solutions, and involved such elements as calcium, sodium, potassium, and magnesium.

Of the three bone types examined, deer bone appeared to be the least affected by inundation, followed by cow and rabbit bone. The rabbit bone samples totally disintegrated in the concentrated acid solutions (Vats 6A and 14A).

The design of the bone experiment has to be judged inadequate on the basis of these results. Some of these inadequacies can be traced to sample procurement and preparation problems, which, in turn, affected sampling and testing procedures. The experiment was initially designed to examine degradation processes in "archeological" bone. However, it proved to be impossible to obtain sufficient quantities of archeological bone to conduct the experiment. Another problem with archeological bone is its variability. Our goal was to control for variation attributable to species, sex, age, and health of individual, so that normal variation on these dimensions would not obscure variability introduced by the primary treatment effect of inundation. Unfortunately, these sources of variation are difficult to measure, let alone control, in most archeological bone populations. Add to this the problem of variability introduced by differential burial and preservation conditions - conditions that may vary dramatically between sites and even within different depositional units of the same archeological site - and the advantages of using archeological bone were soon outweighed by the disadvantages of the uncontrolled variability.

To correct for these problems, modern cow and deer bone were used. The use of modern bone permitted control over age, sex, and health variability (and absolute control over species variability), but the use of modern bone introduced its own unique set of problems.

First, the fresh bone had to be cleaned to remove all traces of soft tissue, a potential source of contamination in the experimental vats. Attempts at boiling and burying the fresh bone were only partially sucessful due to insufficient preparation time. Eventually, all of the fresh cow and deer bone had to be slowly baked in a kiln to remove all adhering remnants of fat and other soft tissue. Consequently, all of the large bone samples used in the experiment were partially carbonized, and this precluded the comparison of charred and uncharred bone which was part of the initial design.

In addition, although attempts were made at standardizing variability within the fresh bone samples, it became apparent after the bone samples were cleaned that considerable variability, especially in size and robusticity, existed within the cow, and to a lesser extent within the deer population.

This unforeseen variability eventually made it difficult to isolate and measure the effect of water chemical variability on bone degradation.

The solution to these problems lies in budgeting sufficient lead time to select and prepare bone samples to conform to experimental design standards.

Shell

Significant visual changes in shell morphology were noted in only three vats, the concentrated acids, HCL (Vat 6a) and H_2SO_4 (Vat 14a), and concentrated NaCl (Vat 7a). The concentrated acids attacked the surfaces of the shells and left a distinct, chalky residue. Shell dissolution was advanced in both of the concentrated acid solutions, although, in general, the clam shells were more visibly degraded than the oyster. Shell degradation resulting in measureable weight loss was pronounced in the concentrated NaCl solution--the primary visible effect being a pronounced "bleaching" of the surfaces of the shells.

Atomic absorption analyses of water aliquots confirmed the results of the visual analysis. Leaching rates were predictably high in the acid solutions, but evidence of shell dissolution was noted in virtually all of the chemical solutions, even in the deionized water control (Vat 15). We may conclude that inundation constitutes an adverse impact on shell artifacts and that this adverse impact is accelerated in acid pH environments.

The results of the shell degradation experiments are relatively unambiguous due, in part, to the magnitude of the observed changes. Interpretation of the results could have been enhanced, however, by more careful attention to initial shell variability. Whole shell samples employed in the experiment exhibited a large amount of variability in size and shape. Attempts to standardize this variability by immersing ground shell samples provided results that are difficult to extrapolate to problems of whole shell preservation. This aspect of the experiment could have been strengthened if whole shells had been modified to eliminate size-shape variation without resorting to grinding procedures that resulted in the drastic alteration of shell morphology.

Wood

The wood experiments were designed to measure inundation impacts on two species of wood, pine and oak, that are common in archeological contexts in North America. Visual analysis of wood specimens following twelve months of immersion indicated only minor alteration in specimen structure or composition. The majority of visual changes consisted of surface stains and color alterations, but these changes are probably attributable to interactions between the wood samples and other materials immersed in the experimental vats. The notable exceptions were the oak samples immersed in concentrated $Na_2SiO_3.9H_2O$ (Vat 11a). Long-term immersion in Vat 11a resulted in extensive cracking of the surface of the oak samples. This characteristic form of degradation was not noted in any of the other chemical environments, nor were the pine samples in Vat 11a similarly affected; we may conclude, therefore, that the observed alteration is a result of unique water chemical interactions which have implications for long-term oak preservation in water environments rich in sodium silicate.

Measurements of weight loss on both wood species from Time 1 to Time 3 (eight months) indicated significant changes in the majority of concentrated solution vats. However, only three solutions ($MgCl_2.6H_2$, $CaCl_2$, and $MgSO_4$) exhibited weight losses that were significantly greater than those observed for the deionized water control. In general, the pine samples survived the effects of inundation better than the oak samples, which corresponds with the results obtained by Dimbleby and Jewell (1964).

TABLE 1

SOLUTION PREPARATION

VAT #	ADDITION	AMOUNT	VOLUME (LITERS)
1A	Na_2CO_3	0.0127 g	12.0
2A	$MgSO_4$	12.96 g	12.0
3A	$CaCl_2$	26.51 g	12.6
4A	$NaHCO_3$	47.61 g	13.2
5A	$KHCO_3$	54.17 g	12.6
6A	HCl	18.4 ml 1:1(6N)	12.6
7A	NaCl	12.17 g	12.6
8A	$MgCl_2$ $6H_2O$	24.29 g	13.2
9A	$CaCl_2$	6.31 g	12.6
10A	$FeCl_3.6H_2O$	0.287 g	13.2
11A	$Na_2SiO_3.9H_2O$	23.51 g	13.2
12A	KCl	40.34 g	12.6
13A	$MgSO_4$	12.32	12.6
14A	H_2SO_4	10.9 ml 1:1 (9N)	12.6

TABLE 1 (cont'd)

VAT #	ADDITION	AMOUNT	VOLUME (LITERS)
1	$Fe_2(SO_4)_3 \cdot nH_2O$	0.246 g	All Diluted to 12.0 liters
2	$MgCO_3$	0.458 g	
3	600 ml of 3A		
4	600 ml of 4A		
5	600 ml of 5A		
6	600 ml of 6A		
7	600 ml of 7A		
8	600 ml of 8A		
9	600 ml of 9A		
10	600 ml of 10A		
11	600 ml of 11A		
12	600 ml of 12A		
13	600 ml of 13A		
14	600 ml of 14A		
15	NONE		
16	600 ml of 4A + 600 ml of 8A + 600 ml of 10A + 600 ml of 11A + 1.96 g $CaSO_4 \cdot 2H_2O$		

TABLE 2

VAT #	ADDITION	ANALYSES
1	$Fe_2(SO_4)_3 \cdot nH_2O$	Fe, $SO_{4=}^{=}$, diss. O_2
2	$MgCO_3$	Mg, CO_3, HCO_3^-, pH, diss. O_2
3	$CaCl_2$	Ca, Cl, K, Na, diss. O_2
4	$NaHCO_3$	Na, $CO_3^=$, HCO_3^-, K, Ca, pH, diss. O_2
5	$KHCO_3$	$CO_3^=$, HCO_3^-, K, Na, Ca, pH, diss. O_2
6	HCl	Cl^-, diss. O_2
7	NaCl	Na, Cl^-, K, Ca, diss. O_2
8	$MaCl_2 \cdot 6H_2O$	Mg, Cl^-, diss. O_2
9	$CaCl_2$	Ca, Cl^-, diss. O_2
10	$FeCl_3 \cdot 6H_2O$	Fe, Cl^-, diss. O_2
11	$Na_2SiO_3 \cdot 9H_2O$	Na, Si, K, Ca, diss. O_2
12	KCl	K, Cl^-, Na, Ca, diss. O_2
13	$MgSO_4$	Mg, $SO_4^=$, diss. O_2
14	H_2SO_4	$SO_4^=$, diss. O_2
15	Blank	Ca, Mg, Na, Fe, Si, $CO_3^=$, HCO_3^-, Cl^-, $SO_4^=$, pH, diss. O_2
16	$CaSO_4 \cdot 2H_2O$	Ca, Mg, Na, Fe, Si, $CO_3^=$, HCO_3^-, Cl^-
	$MgCl_2 \cdot 6H_2O$	$SO_4^=$, pH, diss. O_2
	$NaHCO_3$	
	$FeCl_3 \cdot 6H_2O$	
	$Na_2SiO_3 \cdot 9H_2O$	
1A	Na_2CO_3	Na, $CO_3^=$, HCO_3^-, K, Ca, pH, diss. O_2
2A	$MgSO_4$	Mg, $SO_4^=$, diss. O_2

TABLE 2 (cont'd)

VAT #	ADDITION	ANALYSES
3A	$CaCl_2$	Ca, Cl^-, diss. O_2
4A	$NaHCO_3$	Na, $CO_3^=$, HCO_3^-, K, Si, Ca, pH, diss. O_2
5A	$KHCO_3$	K, $CO_3^=$, HCO_3^-, Na, Ca, pH, diss. O_2
6A	HCl	Cl^-, diss. O_2
7A	NaCl	Na, Cl^-, K, Si, Ca, diss. O_2
8A	$MgCl_2 \cdot 6H_2O$	Mg, Cl^-, diss. O_2
9A	$CaCl_2$	Ca, Cl^-, diss. O_2
10A	$FeCl_3 \cdot 6H_2O$	Fe, Cl^-, diss. O_2
11A	$Na_2SiO_3 \cdot 9H_2O$	Na, Si, K, Ca, diss. O_2
12A	KCl	K, Cl^-, Si, Na, Ca, diss. O_2
13A	$MgSO_4$	Mg, $SO_4^=$, diss. O_2
14A	H_2SO_4	$SO_4^=$, diss. O_2

TABLE 3

VAT #	ION	ION CONCENTRATION Mg/l	COMPOUND	AMOUNT (g) REQUIRED FOR 12 l	VAT #	(g) 20X
1	Fe	4.5=12.01 SO_4	$Fe_2(SO_4)_3 \cdot nH_2O$	--	1	0.246
1A	CO_3	0.6	Na_2CO_3	--	1A	0.0127
2	Mg	11	$MgCO_3$	0.458	--	--
2A	Mg	220	$MgSO_4$=899.8 SO_4	--	--	12.96
3	Ca	38	$CaCl_2$	1.263	3A	25.25
4	HCO_3	131	$NaHCO_3$	2.164	4A	43.28
5	HCO_3	131	$KHCO_3$	2.580	5A	51.59
6	Cl	16	HCl	0.437 ml	6A	8.74 ml
7	Na	19=29.26 Cl	NaCl	0.580	7A	11.59
8	Mg	11	$MgCl_2 \cdot 6H_2O$	1.104	8A	22.08
9	Cl	16	$CaCl_2$	0.300	9A	6.01
10	Fe	0.225	$FeCl_3 \cdot 6H_2O$	0.013	10A	0.261
11	Si	8.8	$Na_2SiO_3 \cdot 9H_2O$	1.069	11A	21.37
12	K	80.1	KCl	1.83	12A	40.34
13	SO_4	39	$MgSO_4$	0.586	13A	11.73
14	SO_4	39	H_2SO_4	0.26 ml	14A	5.19 ml
15	pH, diss. O_2	--	--	--	--	No sample
16	$CaSO_4 \cdot 2H_2O$	38 Ca		1.959		
	$MgCl_2 \cdot 6H_2O$	11 Mg		1.104		
	$NaHCO_3$	131 HCO_3		2.164		
	$FeCl_3$	0.225 Fe		0.013		
	$Na_2SiO_3 \cdot 9H_2O$	8.8 Si		1.069		

TABLE 4

Ca (mg/1)

DATE	16	15	12A	12	11A	11	7A	7	5A	5	4A	4	1A
9-25-78	26.9, 27.0	<0.1			<0.1								
10-9	>50.8	>50, 58						>50					
10-17	29.8,23	2.4	33.3	4.7		1.8	2.9	2.2					
11-1	46.0	12.1					51.3	14.3	4.5	23.9	4.8		
12-6	54.9,41	10.9				7.9		10.8	5.1				10.3
12-15	57.4,42.5	23.5										20.0	
1-25-79	53.0,39	26.2		39.9									
2-13	57.9,58.4	12.8	43.0		1.2								
2-28	53.1,38	24.0,18.0											
3-13	45.0,31	9,7	27.8		0.7								
4-20	>50, 60.1	16.4		33.7							15.2		27.2
5-17	45.9	13.4,9.5			(1:20)					15.1		12.7	
6-19	43.3,31	15.9			<0.1	13.6	31.1						

TABLE 5

ALIQUOT ANALYSES

Mg (mg/1)

	Vat					(1:20)	(1:20)	(1:20)
DATE	16	15	2	8	13	2A	8A	13A
9-25-78	12	<0.5	9.9, 9.8	11.9, 12.9	9.6	11.1	11.2	10.2
10-9	10.3	2.1	8.9	10.1	9.4	9.1	9.1	8.2
10-17	10.3	0.1	6.1	9.7	8.7	10.4	10.6	11.
11-1	--	0.6	3.9	4.7	3.5	8.5	8.7	9.4
12-6	7.5	0.5	4.8	7.7	6.4	10.5	10.4,10.2	9.1
12-15	7.3	0.7	5.0	7.5	5.8	10.0	10.2	8.5
1-25-79	10.6	2.4, 2.3	7.1	8.9	8.2	10.4	10.5	8.9
2-13	10.7	0.8	5.9	9.1	8.1	10.5	10.7	9.3
2-28	9.7	1.2	5.4	7.0	6.7	10.5	10.4	9.5
3-13	10.0	0.5	5.7	7.4	6.7	10.5	10.9	9.4
4-20	11.1	0.8	6.3	8.4	8.3	10.8	10.7	9.6
5-17	10.0	0.7	6.7	8.6	8.3	10.6	10.7	9.5
6-19	10.4	0.9	6.8	9.2	8.4	10.5	10.7	9.3

TABLE 6

ALIQUOT ANALYSES

K (mg/l)		(1:20)		(1:20)		(1:20)		
Date	5	5A	12	12A	11	11A	11A	1A
9-25-78	103	99.8	< 0.5	105	< 0.50		0.30	< 0.50
10-9	105	86.2	24.8	94	21.5		20.8	25.3
10-17	94.5	102	98, 100	103	2.4	1.2	11.0	4.4
11-1	69, 68.9	99.0	67.5	95	8.3	1.2	10.8	10.3
12-6	93.5, 87.5	103	90.6	102	6.6		8.5	6.7
12-15	108	100	89.5	102	8.7	1.3	8.5	8.3
1-25-79	97.5	103	102	104	6.1		7.3	8.7
2-13	100	102	104	102	4.6		5.5	6.4
2-28	90.6	103	105, 102	103	4.7		5.0	4.6
3-13	95.5	98.9	94.5	103	2.9		4.5	2.8
4-20	102	100	105, 104, 109	103		0.8		3.7
5-17	102	99.8	104	101	3.6		4.2	3.0
6-19	103	100	106, 102	100	3.5		3.8	2.5

TABLE 6 (cont'd)

ALIQUOT ANALYSES

Date	(1:10)* 16	16	15	(1:20) 4	4A	7	(1:20) 7A	3
9-25-78	0.8	< 0.50	≤ 0.50	0.50		< 0.50		< 0.50
10-9	3.1	27.7		23.3		25.3		27.7
10-17	0.9	6.7	3.4	5.4		2.6		4.0
11-1	2.1	15.6	8.7 10	12.4		8.7		12.7
12-6			6.4	8.7	1.6			8.4
12-15			8.0			9.8		11.3
1-25-79		9.8	7.0	8.1		8.7		8.7
2-13			6.2	6.1		5.5		5.4
2-28	1.2	6.7	5.9	5.6		5.4		
3-13	1.0	4.8	3.4	3.5		4.4		
4-20	1.3	5.6	3.8	4.2		4.9		4.4
5-17			3.1	3.5		4.4		3.8
6-19		4.2	3.5	3.5		3.8	0.9	3.8
Blank	0.6							

*Cesium added.

TABLE 7

ALIQUOT ANALYSES

Si (mg/l)

Date	16	16†	15	12A	11	11A	4A	7A
9-25-78	*>16.1	6.4	<1	<0.5	5.84	148	<0.1	
10-9	>16.1	7.75	9.24		8.83	125		
10-17	>16.1	6.12			6.35	162		
11-1	>16.1	6.35	9.27		9.06	166		<0.1
12-6	>16.1	6.86	7.2		7.84	147		
12-15	>16.1	7.52			8.64	142		
1-25-79	>16.1	6.21			6.77	145		
2-13	>16.1	6.54		4.7	7.47	139		
2-28	>16.1	6.91			8.31	159		
3-13	>16.1	6.44		1.42	6.16	162		
4-20	>16.1	7.10			10.5	151, 156		<0.1
5-17	>16.1	6.54			6.96	145, 147	<0.1	<0.1
6-19	>16.1	6.77	10.95		8.41	154		

* >= greater than

<= less than

† = SiO_2 Si

TABLE 8

ALIQUOT ANALYSES

Na (mg/1)					(1:20)						(1:20)	(1:20)		
Date	16	16*	15	11	11A	12	12A	5	5A	4	4A	7A	1A	3
9-25-78	75	8.4	<0.1	16.3	14.8		0.5		0.7	56.3	50	20.0	0.2	0.3, 0.7
10-9	94	9.6	25	37.3	14.4		42.4			>50	44	21.0	29	6
10-17	69	7.8	1.4	16.3	13.3	1.2	0.5			>50	49	20.4	2.3	
11-1	71	7.7	5.8	18.7	12.2		3.8			>50	48	250+ 19.3	7.2	
12-6	73	7.8	1.2	16	13.1		1.0			56	51	20.0	1.6	
12-15	75	7.8	1.7	16.7	13.6	1.4				54.5	50	20.4	2.2	
1-25-79	79	8.4	4.7	22	14.7	6.6	6.7			58.2	50	20.4	6.2	
2-13	72	7.8	27	20	13.4		2.6			54.8	48	20.4	2.7	2.7
2-28	73	7.7	5.4	16.7	13.6	1.6	2.6	1.9	2.0	52.6	52	21	1.9	
3-13	71	7.7	1.7	15.3	215+ 13.6	0.7	0.7			49.1	50	21	0.9	
4-20	76	7.7	2.4	25	15.1	1.8	1.4	1.5		52.8	52	21	1.6	
5-17	73	7.7	1.1	18.0	14.6		1.2			52.6	50	21	1.1	
6-19	74	7.8	1.1	18.5	14.7	1.4	1.3		1.2	56	52	21.0	1.1	
Blank		1.3												

* 1:10 + cesium

\+ undiluted

TABLE 9

CHEMICAL ANALYSES

CO_3^{2-}, HCO_3^{-1} (ug/ml)

	1A		2		4A				5A		5	
	CO_3^{2-}	HCO_3^-	CO_3^{2-}	HCO_3^-	CO_3^{2-}	HCO_3^-	CO_3^{2-}	HCO_2^-	CO_3^{2-}	HCO_3^-	CO_3^{2-}	HCO_3^-
9/25/78	0	1.0	0	50.5	0.74	127.0	0	131	1.23	119	0	132
10/09/78	0	28.5	0	62.5	1.97	93.0	0	129	1.72	88	0	129
10/17/78	0	13.5	1.97	31.5	0.98	125.0	3.44	240	1.23	122	0	134
11/01/78	0	34.0	1.72	47.0	1.97	112.0	5.16	212	2.21	117	0.24	124
12/06/78	0	45.0	0	64.5	5.16	109.0	0	166	4.18	114	0	172
12/14/78	0	80.0	0	73.0	9.34	92.0	0.74	183	4.92	109	0	182
01/25/79	0	161.0	0	165.0	7.38	99.5	0	257	3.44	115	0	149
02/12/79	0	74.0	0	100.0	4.18	108.0	4.67	157	5.41	108	0	184
02/28/79	0	50.5	0	75.5	1.48	122.0	0	160	0.98	126	0	151
03/13/79	0	41.0	0	63.0	1.72	120.0	0	150	3.20	116	0	150
04/20/79	0	61.0	0	83.5	2.21	121.0	0	162	2.46	119	0	160
05/19/79	0	61.5	0	84.0	2.21	120.0	0	168	0.98	123	0	164

	15		16	
	CO_3^{2-}	HCO_3^-	$CO_3^=$	HCO_3^-
09/25/78	0	2.0	0	120
10/09/78	0	21.0	0	117
10/17/78	0	9.0	0.24	124
11/01/78	0	25.0	0.49	118
12/06/78	0	42.0	1.72	170
12/14/78	0	61.5	0	187
01/25/79	0	145.0	0	253
02/12/79	0	82.0	0	174
02/28/79	0	51.5	0	153
03/13/79	0	39.0	0	145
04/20/79	0	59.5	0	136
05/19/79	0	49.5	0	159

TABLE 10

ALIQUOT ANALYSES

Fe (mg/1)

DATE	15	16	1	1*	10	10A	10A*
9-25-78	<0.2	<0.2	1.84	1.74	<0.2	0.43	1.95
10-9	<0.2	<0.2	<0.2	0.83	<0.2	<0.2	O.S.+
10-17	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
11-1	<0.2	<0.2	<0.43	<2.07	<0.2	O.S.+	1.78
12-6	<0.2	<0.2	0.27		<0.2	<0.2	
12-15	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2
1-25-79	<0.2	<0.2	<0.2		<0.2	<0.2	
2-13	<0.2	<0.2	<0.2		<0.2	<0.2	0.52
2-28	<0.2	<0.2	<0.2		<0.2	<0.2	
3-13	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
4-20	<0.2	<0.2	<0.2		<0.2	<0.2	
5-17	<0.2	<0.2	<0.2		<0.2	<0.2	
6-19	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2

* Shaken vigorously before analysis

+ Off Scale

TABLE 11

ALIQUOT ANALYSES

SO_4^- (mg/1)

Date	1	2A	13	13A	14	14A	15	16
9-25-78	10	910	34.2	776	28	980	<0.1	118
10-9-79	143	450	199	698	204	946	178	240
10-17-78	16	1020	6.1	10.2	64	686	7.2	130
11-1-78	20	730	20.8	296	54	1460	23.4	122
12-6-78	14.2	990	43	1164	50	666	0.6	141
12-14-78	15.3	970	25.4	1400	38	920	<0.1	86
1-25-79	0.20	1040	2.0	1256	91	1458	<0.1	104
2-12-79	14.1	1010	10	804	105	708	3.2	80
2-28-79	17.9	1000	31.7	1180	96	1220	0.4	125
3-13-79	21	1090	41.1	1030	27	734	0.2	121
4-20-79	22	1090	52	1460	64	846	0.3	57.8
5-19-79	19.5	920	4	1196	71	816	0.8	107

TABLE 12

ALIQUOT ANALYSES

Cl^-

Date	3	3A	6	6A	7	7A	8	8A
9-25-78	35.9	1277	13.2	352	13.6	593	13.0	675
10-9-78	92.2	1315	35.9	390	49.3	654	57.0	713
10-17-78	40.0	1264	15.5	321	20.0	612	21.0	673
11-1-78	47.1	1256	19.0	352	21.1	613	22.2	679
12-6-78	40.2	1252	12.7	300	18.0	607	19.0	653
12-14-78	42.7	1261	10.2	329	19.0	605	22.8	653
1-25-79	31.8	1217	10.3	340	14.1	607	14.6	657
2/12/79	34.9	1205	16.0	329	14.9	627	20.9	666
2-28-79	43.8	1286	23.4	357	14.9	681	22.1	641
3-13-79	41.2	1295	> .9	276	14.1	625	19.0	714
4-20-79	45.4	1318	6.0	326	11.3	618	20.9	682
5-19-79	42.9	1293	13.0	310	16.0	612	16.5	653
6-19-79	43.8	1267	9.2	313	21.0	624	16.8	650

Date	9	9A	10	10A	12	12A	15	16
9-25-78	3.7	302		6.0	< 0.1	1537	< 0.1	16.5
10-9-78	37.0	340		28.1	21.0	1557	20.8	47.0
10-17-78	15.0	298		5.3	64.9	1537	< 0.1	27.2
11-1-78	17.4	299		14.4	70.0	1543	5.0	20.1
12-6-78	13.0	294		1.9	60.0	1535	< 0.1	18.7
12-14-78	7.0	294		5.5	59.0	1519	< 0.1	16.7
1-25-79	9.8	289		2.8	51.4	1562	< 0.1	18.3
2-12-79	20.8	310		9.6	53.8	1555	0.9	17.2
2-28-79	11.5	308		10.2	70.0	1568	14.4	25.2
3-13-79	9.6	313		9.9	51.7	1435	< 0.1	16.8
4-20-79	14.9	309		1.1	70.0	1213	2.9	80.8
5-19-79	11.5	303		7.9	59.2	1489	< 0.1	13.0
6-19-79	15.0	307		7.6	57.8	1476	< 0.1	16.3

TABLE 13

Dissolved Oxygen

Vat #	D.O. mg/1
1	4.01
2	3.79
3	3.72
4	3.62
5	3.48
6	4.08
7	4.02
8	4.09
9	4.22
10	3.97
11	4.19
12	4.12
13	3.98
14	4.90
15	4.10
16	3.53
1A	4.01
2A	3.77
3A	3.51
4A	3.29
5A	2.73
6A	5.82
7A	3.54
8A	3.92
9A	3.25
10A	4.06
11A	4.22
12A	4.11
13A	4.12
14A	4.98
8/15 Deionized H_2O	5.07 final

Temp:	21.8°C
BP:	6352mm.
Scale:	0-10
Calibrate	-7.32

TABLE 14

pH

Date	VAT	pH
9/25/78	1A	4.87
	2	7.5
	4	8.07
	5	8.24
	4A	8.54
	5A	8.65
	15	5.19
	16	8.32
	deionized H_2O (Spout)	5.52
	deionized H_2O (Jug)	5.03
10/9/78	1A	6.95
	2	7.71
	4	8.28
	5	8.19
	4A	8.61
	5A	8.65
	15	7.10
	16	8.17
10/17/78	1A	6.85
	2	9.05
	4	8.65
	5	8.31
	4A	8.59
	5A	8.66
	15	6.62
	16	8.38
11/1/78	1A	8.25
	2	8.65
	4	8.82
	5	8.39
	4A	8.64
	5A	8.71
	15	7.36
	16	8.52

TABLE 14 (cont'd)

pH

DATE	VAT	pH
12/6/78	1A	6.78
	2	6.68
	4	6.89
	5	7.90
	4A	8.83
	5A	8.87
	15	6.93
	16	8.14
12/14/78	1A	7.01
	2	7.24
	4	8.26
	5	7.79
	4A	9.20
	deionized H_2O (Spout)	5.26
	5A	8.80
	15	6.90
	16	7.99
1/25/79	1A	7.71
	2	7.90
	4	8.21
	5	8.55
	4A	9.05
	5A	8.70
	15	7.99
	16	8.08
2/13/79	1A	7.38
	2	7.49
	4	8.64
	5	8.05
	4A	8.26
	5A	9.00
	15	7.39
	16	8.09

TABLE 14 (cont'd)

pH

DATE	VAT	pH
2/28/79	1A	6.81
	2	6.70
	4	7.15
	5	7.44
	4A	8.37
	5A	8.34
	15	6.70
	16	7.40
3/13/79	1A	7.16
	2	6.64
	4	7.54
	5	7.58
	4A	8.48
	5A	8.58
	15	6.96
	16	7.97
4/20/79	1A	6.53
	2	7.07
	4	7.58
	5	7.08
	4A	8.32
	5A	8.73
	15	6.70
	16	6.98
5/19/79	1A	6.75
	2	6.89
	4	7.36
	5	7.32
	4A	8.64
	5A	8.27
	15	6.76
	16	7.15

TABLE 15

ALIQUOT ANALYSES

Vat 15: Blank

(mg/1)

DATE	Ca	Fe	K	Mg	Na	Si	CO_3	HCO_3	Cl^-	SO_4
9-25-78	< 0.1	< 0.2	<0.50	< 0.5	< 0.1	<1.0	0	2.0	< 0.1	< 0.1
10-9-78	>50, 58	< 0.2	25	2.1	25	9.24	0	21.0	20.8	178
10-17-78	2.4	< 0.2	3.4	0.1	1.4		0	9.0	< 0.1	7.2
11-1-78	12.1	<0.2	8, 7, 10	0.6	5.8	9.27	0	25.0	5.0	23.4
12-6-78	10.9	<0.2	6.4	0.5	1.2	7.2	0	42.0	<0.1	0.6
12-14-78	23.5	<0.2	8.0	0.7	1.7		0	61.5	<0.1	0.1
1-25-79	26.2	< 0.2	7.0	2, 4, 2.3	4.7		0	145	<0.1	0.1
2-13-79	12.8	< 0.2	6.2	0.8	27		0	82	0.9	3.2
2-28-79	24.0, 18.0	<0.2	5.9	1.2	5.4		0	51.5	14.4	0.4
3-13-79	9.7	<0.2	3.4	0.5	1.7		0	39.0	<0.1	0.2
4-20-79	16.4	<0.2	3.8	0.8	2.4		0	59.5	2.9	0.3
5-17-79	13.4, 9.5, 12.7	< 0.2	3.1	0.7	1.1		0	49.5	< 0.1	0.8
6-19-79	15.9	<0.2	3.5	0.9	1.1	10.9			< 0.1	
1-16-80	2.0	<0.01	<0.2	0.24	0.50	0.7				

TABLE 16

ALIQUOT ANALYSES

VAT 16: $CaSO_4 \cdot 2H_2O$, $MgCl_2 \cdot 6H_2O$, $NaHCO_3$, $FeCl_3 \cdot 6H_2O$, $Na_2SiO_2 \cdot 9H_2O$

(mg/l)

DATE	Ca	Fe	K	Mg	Na	Si+	CO_3	HCO^-	Cl^-	SO^-
9-25-78	26.9, 27.0	<0.2	<0.5, 8.0*	12	75, 84*	6.4	0	120	16.5	118
10-9_78	50, 83	<0.2	27.7, 31*	10.3	94, 96*	7.75	0	117	47.0	240
10-17-78	29.8, 23	<0.2	6.7, 9.0*	10.3	69, 78*	6.12	0.24	124	27.2	130
11-1-78	46.0	<0.2	15.6, 21*	3.84	71, 77*	6.35	0.49	118	20.1	122
12-6-78	54.9, 41	<0.2		7.5	73, 78*	6.86	1.72	170	18.7	141
12-14-78	57.4, 42.5	<0.2		7.3	75, 78*	7.52	0	187	16.7	86
1-25-79	53.0, 39	<0.2	9.8	10.6	79, 84*	6.21	0	253	18.3	104
2-13-79	57.9, 58.4, 41.0	<0.2		10.7	72, 78*	6.54	0	174	17.2	80
2-28-79	53.1, 38	<0.2	6.7, 12*	9.7	73, 77*	6.91	0	153	25.2	125
3-13-79	45.0, 31	<0.2	4.8, 10*	10.0	71, 77*	6.44	0	145	16.8	121
4-20-79	50, 60.1	<0.2	5.6, 13*	11.1	76, 77*	7.10	0	136	80.8	57.8
5-17-79	45.9	<0.2		10.0	73, 77*	6.54	0	159	13.0	107
6-19-79	43.3, 31	<0.2	4.2	10.4	74, 78*	6.77			16.3	
1-16-80	24.8	<0.01	<0.2	10.3	60.4	42.7				
Blank			0/6*		1.3*					

* cesium added

+ SiO_2 si

TABLE 17

DATES OF ALIQUOT ANALYSES

DATE	Experimental Procedure
9/25/78	Sample removed from each vat.
9/28/78	Ceramics immersed in vats.
10/6/78	Ground lithics and shells (in test tubes) filled with solution from each vat
10/9/78	Sample removed from each vat.
10/12/78	New solutions prepared
10/17/78	Samples removed from each vat before addition of shells.
11/1/78	Sample removed from each vat before addition of wood.
11/8/78	New solutions prepared.
11/22/78	New solutions prepared.
11/27/78	100 ml. solution from each vat added to charred seeds.
11/29/78	100 ml. solution from each vat added to raw seeds.
12/6/78	Sample removed from each vat.
12/14/78	Sample removed from each vat.
12/15/78	New solutions prepared.
12/27/78	New solutions prepared.
1/25/79	Sample removed from each vat.
1/25/79	New solutions prepared.
2/13/79	Sample removed from each vat.
2/13/79	New solutions prepared.
2/28/79	Sample removed from each vat.

TABLE 17 (cont'd)

DATES OF ALIQUOT ANALYSES

Date	Experimental Procedure
2/28/79	New solutions prepared.
3/13/79	Sample removed from each vat.
3/15/79	New solutions prepared.
4/20/79	Sample removed from each vat.
4/20/79	New solutions prepared.
5/17/79	Sample removed from each vat.
5/19/79	New solutions prepared.
6/19/79	Sample removed from each vat.
6/19/79	New solutions prepared.
7/19/79	New solutions prepared.
8/8/79	New solutions prepared.
8/8/79	Ground lithics and shells (in test tubes) filled with fresh solution from each vat.
9/13/79	New solutions prepared.
10/19/79	New solutions prepared.
12/18/79	New solutions prepared.
1/16/80	Final sample removed from each vat.

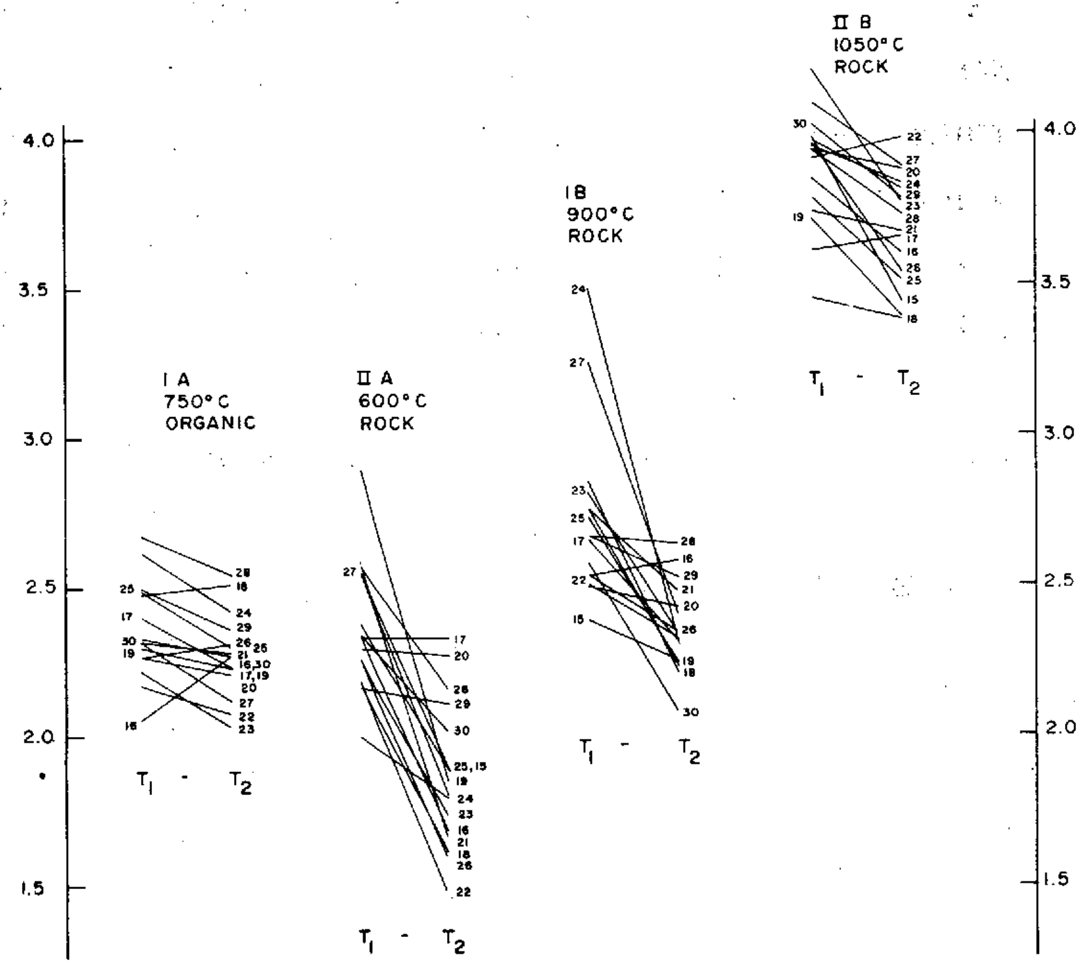
Table 18

VISUAL OBSERVATION OF VAT CONDITIONS

Condition of Vats 1-14A (final check; final sample). 1-16-80

1	clear - Fe ppt out
2	clear - some $MgCO_3$ undissolved
3	clear
4	clear - slightly yellow
5	clear - slightly yellow
6	clear - slightly yellow
7	clear
8	clear - slight color change
9	clear
10	clear - slightly yellow - some algae present
11	clear - slight green - algae present
12	clear - no color change
13	clear
14	clear - some algae present
15	clear - with green algae
16	green - biological growth
1A	clear - biological growth
2A	yellow - green - some algae
3A	clear - with some green algae
4A	clear - light yellow
5A	clear - light yellow
6A	yellow - biological growth
7A	clear - no color change
8A	clear - with green algae (slight)
9A	clear
10A	semi clear - Fe ppt out
11A	clear brown - charred wood present
12A	clear - slight yellow
13A	clear - slight color change
14A	clear - biological growth

TABLE 19



Log of Instron Breakstrength

TABLE 20

ANOVA FOR CERAMIC BREAKSTRENGTHS

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
CHEMICAL	29	17.14598781	2.53	0.0001
TIME	1	33.50661256	143.18	0.0001
IDNUM	3	863.24195659	1229.56	0.0001
CHEMICAL*IDNUM	90	42.29738682	2.01	0.0001
CHEMICAL*TIME	29	12.75101569	1.88	0.0032
THICK	1	151.66432840	648.07	0.0001
WIDTH	1	0.17208169	0.74	0.3913
ERROR	2093	489.81324589		
CORRECTED TOTAL	2248	1831.86212281		

TABLE 21

CHANGES IN CERAMIC BREAKSTRENGTH FROM TIME 1 TO TIME 2

	Unit* Breakstrength Change from $T_1 - T_2$		
Vat #	IIA 600°C rank	IB 900°C rank	IIB 1050°C rank
15	-54 (5)	-10 (13)	-44 (1)
16	-52 (7)	+4 (16)	-20 (6)
1A	-1 (16)	-27 (8)	+3 (15)
2A	-51 (8)	-51 (3)	-7 (12)
3A	-83 (1)	-42 (4)	-26 (4)
4A	-2 (15)	-5 (14)	-5 (14)
5A	-74 (2)	-21 (9)	-6 (13)
6A	-56 (4)	-14 (11)	+5 (16)
7A	-42 (9)	-39 (7)	-36 (2)
8A	-17 (13)	-96 (1)	-11 (11)
9A	-39 (10)	-39 (6)	-21 (5)
10A	-53 (6)	-15 (10)	-34 (3)
11A	-60 (3)	-67 (2)	-17 (9)
12A	-33 (11)	-2 (15)	-18 (8)
13A	-4 (14)	-11 (12)	-12 (10)
14A	-26 (12)	-40 (5)	-19 (7)
Total	-647	-474	-268
x	-40.44	-29.63**	-16.75
S	24.94	26.93	13.66

Spearman's Rank-Order Correlation Between Ceramic Firing Temperature Groups:

IIA (600°C) + IB (900°C): R = 0.13
IIA (600°C) + IIB (1050°C): R = 0.29
IB (900°C) + IIB (1050°C): R = -0.074

* 1 unit equal to approximately 5 lbs. of compression force, i.e., between Time 1 and Time 2. The IIA ceramics lost approximately 270 lbs. of compression strength.

** When we omit outlier vats 8A and IIA (see Table 19) from the population, the average breakstrength loss in the 1B (900°C) group is substantially reduced ($\bar{x}$ = 22.21, s = 17.27).

TABLE 22

Ceramic Group	Quartz	Orthoclase	Microcline	Calcite	Chlorite	Illite	Kaolinite	Hematite	Spinel	Fayalite	Mullite
Raw Clay	A	P	P	P	A	A	A	?	N	N	N
Control IA	A	P	P	P	A	P	N	P	N	N	N
IA	A	P	P	?	A	A	N	P	N	N	N
IA	A	P	P	P	A	P	N	P	N	N	N
IA	A	P	P	?	A	A	N	P	N	N	N
IA	A	P	P	?	A	A	N	P	N	N	N
IA	A	P	P	N	A	P	N	P	N	N	N
Control IIA	A	P	P	P	A	A	A	P	N	N	N
IIA	A	P	P	P	A	A	N	P	N	N	N
IIA	A	P	P	A	A	A	P	A	N	N	N
IIA	A	P	P	A	A	A	A	P	N	N	N
IIA	A	P	P	P	A	P	P	P	N	N	N
IB	A	P	P	N	A	P	N	A	N	N	N
IB	A	P	P	N	A	P	N	P	N	N	N
IB	A	P	P	P	A	P	N	P	N	N	N
IB	A	P	P	P	A	P	N	P	N	N	N
IB	A	P	P	A	A	P	N	P	N	N	N
IB	A	P	P	N	A	P	N	P	?	N	N
IB	A	P	P	P	A	P	N	P	N	N	N
Control IIB	A	P	P	N	A	N	N	P	P	?	P

TABLE 22 (cont'd)

Ceramic Group	Quartz	Orthoclase	Microcline	Calcite	Chlorite	Illite	Kaolinite	Hematite	Spinel	Fayalite	Mullite
IIB	A	P	P	N	A	A	N	P	P	N	P
IIB	A	P	P	N	A	N	N	P	?	P	P
IIB	A	P	P	N	A	N	N	P	?	N	P
IIB	A	P	P	?	A	N	N	P	?	P	?
IIB	A	P	P	N	A	N	N	A	P	?	N
IIB	A	P	P	N	A	N	N	P	P	?	P

A = Abundant

P = Present

? = Possibly present

N = Not detected

TABLE 23

BROAD-BEAM MICROPROBE ANALYSES (WEIGHT PERCENTAGE) OF MATRICES OF IA CERAMICS[1]

	Non-Inundated CONTROL	Mg SO4	NaCl	$FeCl_3$	KCl
SiO_2	52.1	52.0	50.7	52.5	49.2
TiO_2	0.79	0.81	0.84	0.88	0.73
Al_2O_3	19.3	19.0	18.9	18.6	18.6
FeO	7.2	7.6	7.6	7.4	7.2
MgO	1.6	2.1	1.8	1.7	1.7
CaO	1.8	0.69	1.0	1.0	1.5
Na_2O	0.36	0.44	0.51	0.36	0.32
K_2O	3.3	3.4	3.3	3.4	4.2
TOTAL	86.45	86.04	84.65	85.84	83.45

1. Mn below detection limit (< .06 weight percentage). All analyses listed are averages of 15 individual analyses.

TABLE 24

BROAD-BEAM MICROPROBE ANALYSES (WEIGHT PERCENTAGE) OF MATRICES OF IIA CERAMICS[1]

	Non-Inundated CONTROL	KCl
SiO_2	49.6	48.6
TiO_2	0.70	0.81
Al_2O_3	19.4	18.5
FeO	6.7	7.2
MgO	1.6	1.6
CaO	1.6	0.43
Na_2O	0.39	0.56
K_2O	3.3	4.0
Total	83.29	81.7

1. Each analysis listed is the average of 15 individual analyses.

TABLE 25

BROAD-BEAM MICROPROBE ANALYSIS (WEIGHT PERCENTAGE) OF MATRICES OF IB CERAMICS[1]

	Non-Inundated CONTROL	Mg SO4	NaCl	$FeCl_3$	KCl
SiO_2	51.1	50.6	49.5	49.4	49.7
TiO_2	0.84	0.83	0.90	0.88	0.91
Al_2O_3	19.0	19.2	18.6	18.1	18.2
FeO	7.0	7.8	7.1	7.4	7.2
MgO	1.7	2.2	1.7	1.7	1.7
CaO	2.2	0.70	1.4	2.1	1.6
Na_2O	0.36	0.39	0.63	0.39	0.35
K_2O	3.3	3.3	3.3	3.2	4.0
Total	85.5	85.02	83.13	83.17	83.66

1. Mn $\leq$ 0.06 weight percentage. All analyses listed are averages of $<$ 15 individual analyses.

TABLE 26

BROAD-BEAM MICROPROBE ANALYSIS (WEIGHT PERCENTAGE) OF MATRICES OF II B CERAMICS[1]

	Non-Inundated CONTROL	$MgSO_4$	NaCl	$FeCl_3$	KCl
SiO_2	58.6	60.4	59.3	58.2	57.8
TiO_2	0.72	0.73	0.82	0.77	0.67
Al_2O_3	17.8	17.2	17.5	17.2	18.2
FeO	6.6	6.4	6.6	6.9	6.7
MgO	1.4	1.5	1.5	1.6	1.5
CaO	1.6	1.0	1.4	1.4	1.5
Na_2O	C.50	0.44	0.51	0.39	0.47
K_2O	3.2	3.5	3.2	3.3	3.5
Total	90.42	91.17	90.83	89.76	90.34

1. Mn $\leq$ 0.06 weight percentage. All analyses listed are averages of $<$ 15 individual analyses.

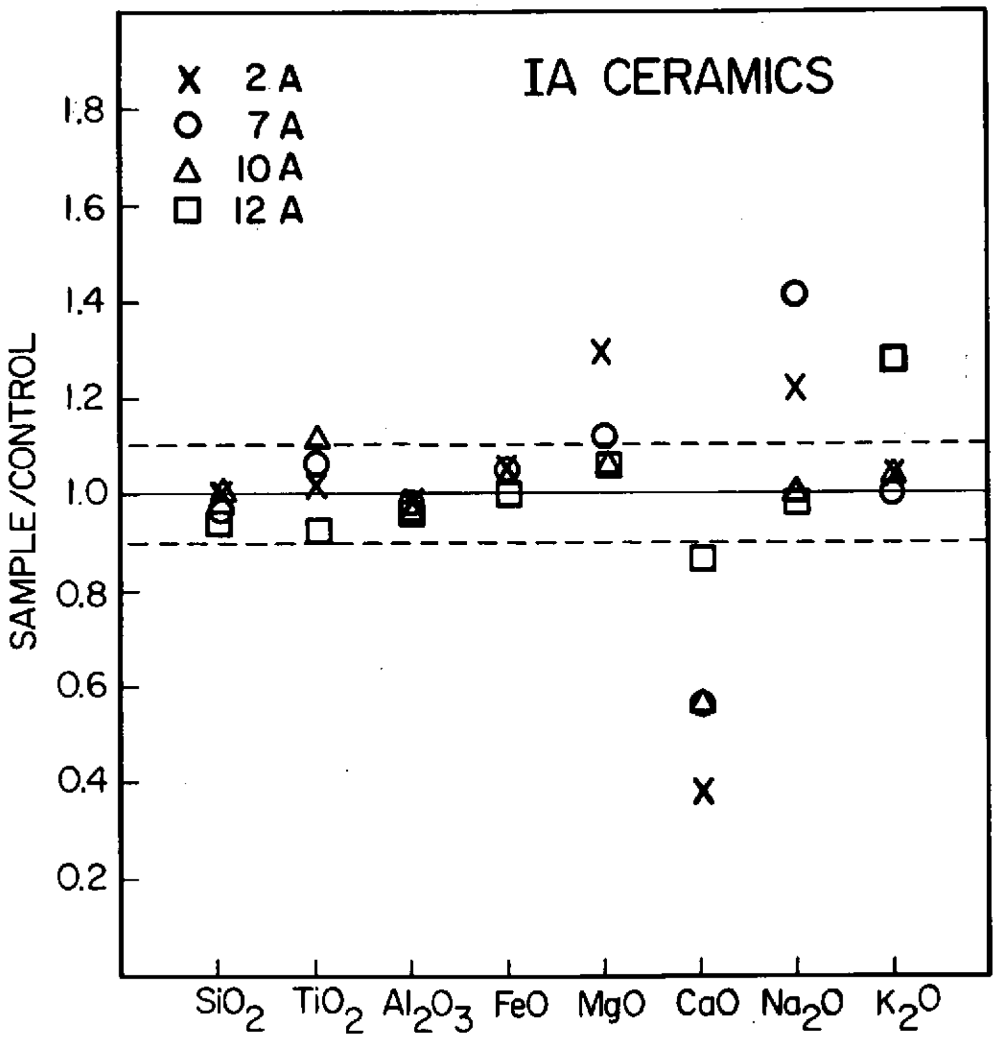
TABLE 27

COMPOSITIONS (WEIGHT PERCENTAGE) OF MUSCOVITES IN IA CERAMICS[1]

	Non-Inundated CONTROL	$MgSO_4$	NaCl	$FeCl_3$	KCl
SiO_2	46.1	46.6	44.5	46.1	45.9
TiO_2	0.69	0.79	0.69	0.79	0.67
Al_2O_3	30.5	30.7	30.5	28.5	30.8
FeO	4.7	4.4	5.0	5.0	4.8
MgO	1.4	1.3	0.70	1.9	1.2
Na_2O	0.44	0.55	0.40	0.47	0.47
K_2O	10.1	10.1	10.2	10.0	10.2
Total	93.93	94.44	91.99	92.76	93.64

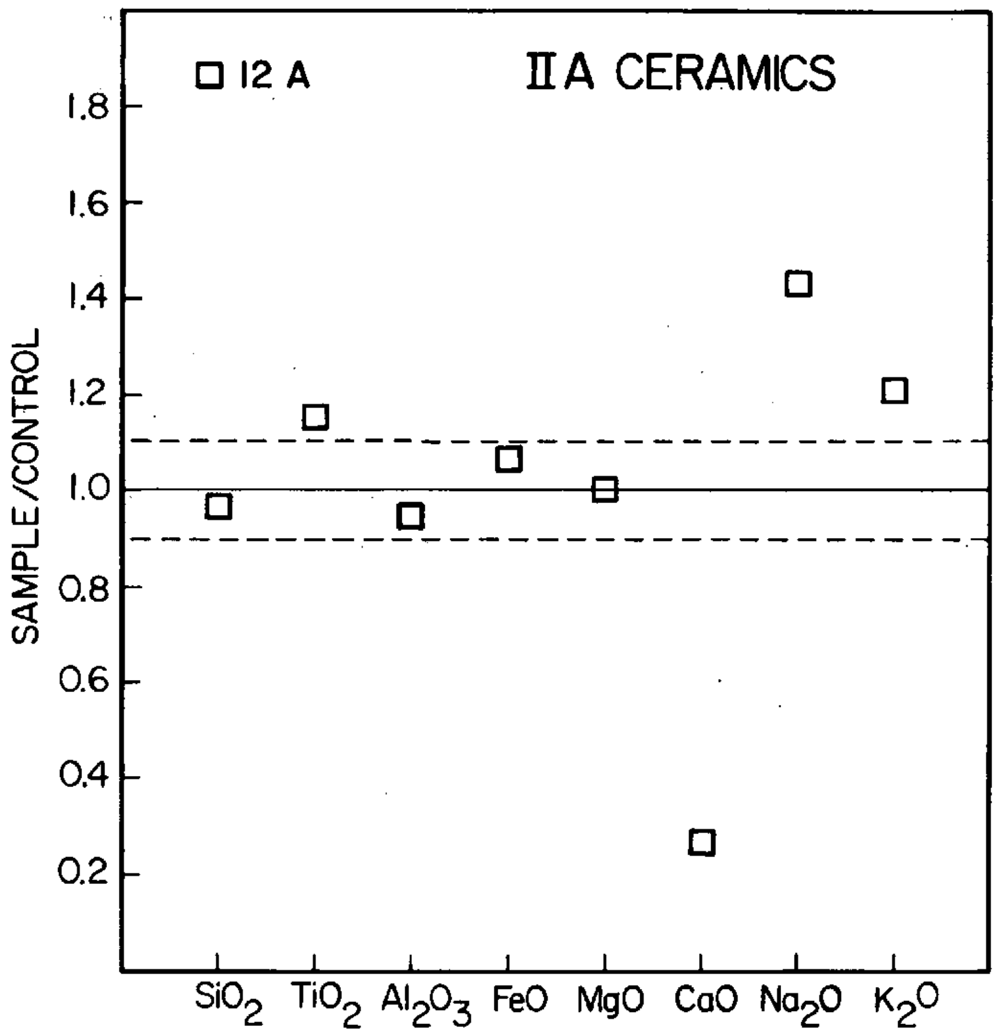
1. Averages of $\gtrsim$ 4 analyses.

TABLE 28



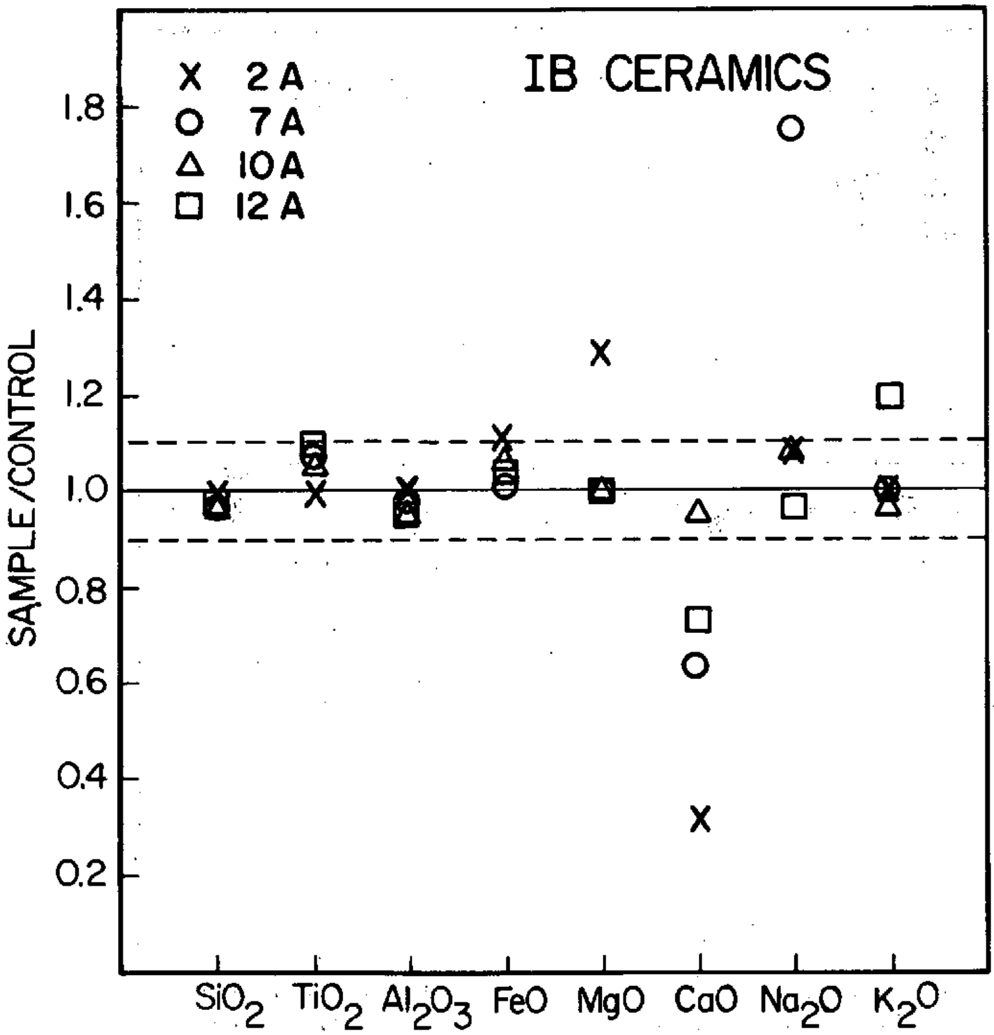
BROAD-BEAM MICROPROBE ANALYSES OF CERAMICS

TABLE 29



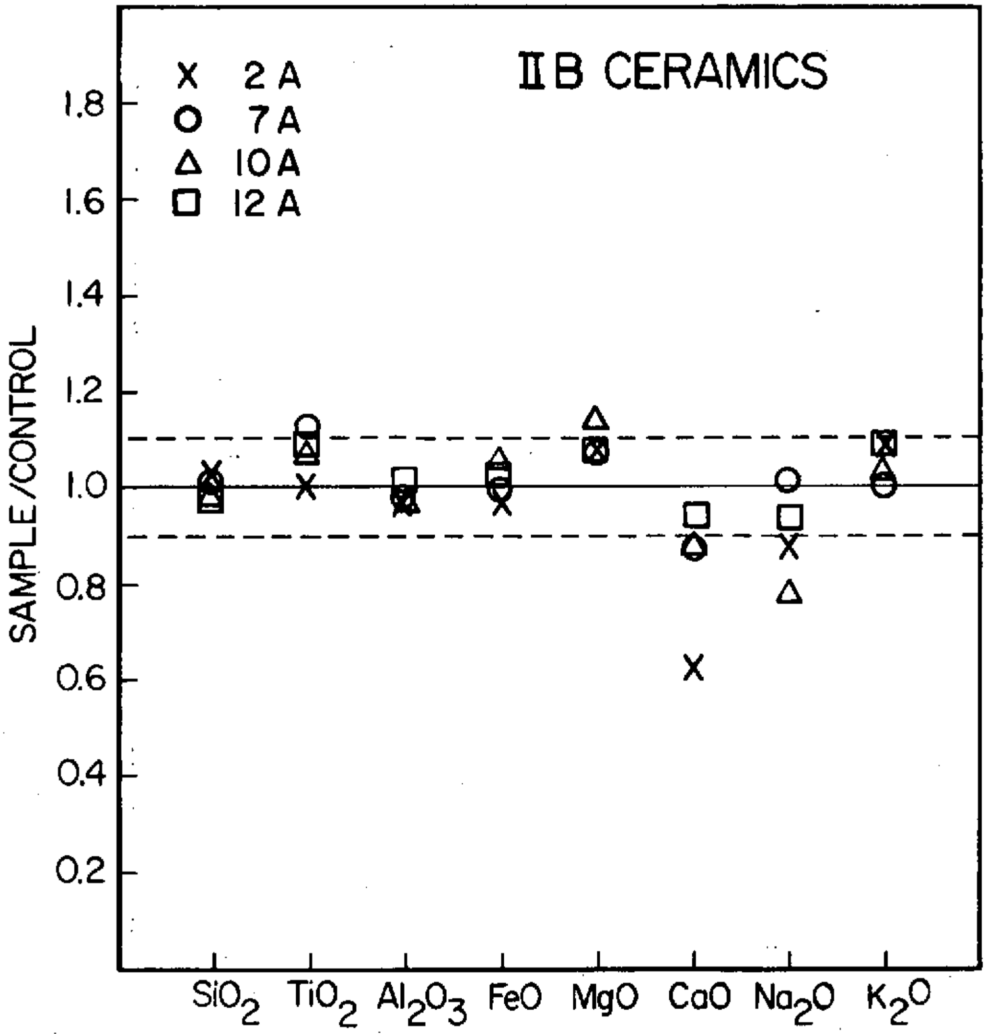
BROAD-BEAM MICROPROBE ANALYSES OF CERAMICS

TABLE 30



BROAD-BEAM MICROPROBE ANALYSES OF CERAMICS

TABLE 31



BROAD-BEAM MICROPROBE ANALYSES OF CERAMICS

TABLE 32

COMPOSITIONS (WEIGHT PERCENTAGE) OF CENTERS AND EDGES OF OBSIDIANS[1]

	CaCl		KCl		Deionized H_2O	
	Center	Edge	Center	Edge	Center	Edge
SiO_2	77.4	77.6	77.5	77.5	77.7	77.6
TiO	.05	0.07	0.05	.05	0.08	0.07
Al_2O_3	11.9	11.9	11.9	12.1	12.3	12.2
FeO	0.99	0.98	1.0	0.99	0.92	0.87
MnO	0.06	0.07	.06	0.09	.06	0.07
CaO	0.25	0.24	0.25	0.24	0.25	0.28
Na_2O	4.5	4.7	4.7	4.8	4.5	4.5
K_2O	4.3	4.3	4.3	4.3	4.3	4.3
Total	99.44	99.86	99.74	99.97	100.05	99.89

1. Abundances of the following oxides were lower than the detection limits: Cr_2O_3 (< .07), MgO (< .05), and P_2O_5 (< .06).

TABLE 33

COMPOSITIONS (WEIGHT PERCENTAGE) OF CENTERS AND EDGES OF CHERT SAMPLES[1]

	Ca Cl		KCl		Deionized Water		Non-Inundated
	Center	Edge	Center	Edge	Center	Edge	Control
SiO_2	99.6	99.2	99.0	100.3	99.2	99.0	100.0
Al_2O_3	0.34	0.39	0.19	0.13	0.16	0.16	0.15
CaO	0.11	0.66	0.04	0.04	0.10	0.11	0.08
Na_2O	.04	0.05	.04	0.05	0.06	0.09	0.07
K_2O	0.05	0.06	0.11	0.10	0.05	0.07	0.04
Total	100.10	99.76	99.34	100.62	99.57	99.43	100.34

1. Abundances of the following oxides were lower than the detection limits: TiO_2 (< .05), Cr_2O_3 (<.07), FeO (<.06), MnO (< .06), MgO (< .05), and P_2O_5 (< .06).

Table 34

RESULTS OF INAA OF OBSIDIAN

Obsidian Element	-Solutions- Mean	S	n	-Control- Mean	S	n	-Distilled H_2O- One obs.	n
Cs	9.30	1.03	15	7.91	1.28	4	8.05	1
Sc	1.52	.04	15	1.43	.16	4	1.54	
Ta	6.49	.38	15	5.65	.65	4	6.69	
Rb	208.	12.7	15	197.	43.8	4	224.	
U	6.69	.57	15	5.64	.74	4	6.33	
Th	23.7	.44	15	21.0	3.58	4	23.8	
La	37.1	.86	15	32.7	4.99	4	37.4	
Ce	75.2	4.83	15	68.6	11.8	4	74.0	
Sm	7.93	.96	15	8.05	1.27	4	8.67	
Tb	1.45	.14	15	1.35	.13	4	1.43	
Yb	6.19	.25	15	5.48	.62	4	6.36	
Th/U	3.57	.34	15	3.64	.33	4	3.76	

TABLE 35

RESULTS OF INAA OF CHERT

Chert Element		-Solutions-			-Control-			-Distilled H_2O-
		Mean	S	n	Mean	S	n	Mean n = 1
Na	A	.15[B]	.005	14	.15	0	4	.15
Fe	A	.75[C]	.16	14	.73	.22	4	
Cr	A	55.0[D]	25.6	15	64.3	16.4	4	
U	A	6.37[E]	1.55	15	6.60	.49	4	6.16
Sm	A	1.25[F]	.12	14	1.16	.04	4	1.24

Note:

A. Anomalous values not included in averages.

B. $NaHCO_3$ and $Na_2SiO_3 \cdot 9H_2O$ yielded anomalous values of .18% Na_2O.

C. $FeCl_3 \cdot 6H_2O$, $CaCl_2$ and $NaHCO_3$ yielded anomalous values of .33%, .39%, and .28% Fe_2O_3 (as total Fe) respectively.

D. $CaCl_2$ and $FeCl_3 \cdot 6H_2O$ yielded anomalous values of 33.9 and 26.8 ppm Cr respectively.

E. $Na_2SiO_3 \cdot 9H_2O$ and $FeCl_3$ yielded anomalous values of 2.77 and 3.25 ppm U respectively.

F. Na_2CO_3 and $Na_2SiO_3 \cdot 9H_2O$ yielded anomalous values of .89 and .68 ppm Sm respectively.

TABLE 36

INNA DETECTION LIMITS

Element	Precision	Accuracy	Lower Limit of Detection LLD
Na	±5%	±5%	.01%
Fe(Total as Fe_2O_3)	±5%	±5%	.05%
Cr	±10%	±10%	5 ppm
U	±10%	±20%	1.5 ppm
Cs	±15%	±15%	1.0 ppm
Sc	±5%	±5%	.1 ppm
Ta	±10%	±10%	.5 ppm
Rb	±10%	±10%	50 ppm
Th	±5%	±5%	.1 ppm
La	±10%	±10%	1 ppm
Ce	±10%	±10%	5 ppm
Sm	±10%	±10%	.25ppm
Tb	±10%	±10%	.5 ppm
Yb	±10%	±10%	.5 ppm

TABLE 37

ATOMIC ABSORPTION ANALYSIS OF GROUND LITHIC WATER SOLUTIONS

(Mg/1)

Sample	Vat	Time	Ca	Fe	K	Mg	Na	Si
Chert	15	1	68	0.2	2.1	2.0	10	29
Chert	15	2	249	0.1	9.9	10.7	11	22.9
Chert	16	1	68	0.1	4.8	6.7	57	17
Chert	16	2	274	0.1	12.6	19	67	26.8
Obsidian	15	1	11	0.4	8.4	2.0	29	27
Obsidian	15	2	10	0.8	6.1	2.0	11	23
Obsidian	16	1	18	0.1	5.7	6.5	89	24.2
Obsidian	16	2	11	0.2	4.7	4.2	56	10

TABLE 38

X-RAY DIFFRACTION ANALYSIS OF GROUND SHELL

Shell Type	Vat	Calcite	Aragonite	Other Minerals
Clam	Control	N	A	N
Clam	Control	N	A	N
Clam	1A	N	A	N
Clam	1A	N	A	N
Clam	2A	P	A	N
Clam	2A	N	A	N
Clam	3A	P	A	N
Clam	3A	P	A	N
Clam	4A	N	A	N
Clam	4A	N-	A	N
Clam	5A	N	A	N
Clam	5A	N	A	N
Clam	6A	P	A	N
Clam	6A	P	A	N
Clam	7A	N	A	N
Clam	7A	N	A	N
Clam	8A	P	A	Quartz
Clam	8A	N	A	N
Clam	9A	?	A	N
Clam	9A	N	A	N
Clam	10 A	N	A	N
Clam	10A	N	A	N
Clam	11A	P	A	N
Clam	11A	N	A	N
Clam	12A	P	A	N
Clam	12A	N	A	N
Clam	13A	P	A	N
Clam	13A	P	A	N
Clam	14A	N	A	N
Clam	14A	N	A	Quartz
Clam	15	N	A	Quartz
Clam	15	P		N
Clam	15	P	A	N
Clam	16	P	A	N
Clam	16	N	A	N
Clam	1	P	A	N
Clam	1	N	A	N
Clam	2	N	A	N
Clam	2	N	A	N
Clam	3	P	A	Quartz
Clam	3	P	A	N
Clam	4	N	A	N
Clam	4	P	A	Quartz
Clam	5	N	A	N

TABLE 38 (cont.)

Shell Type	Vat	Calite	Argonite	Other Minerals
Clam	5	P	A	Quartz
Clam	6	P	A	Quartz
Clam	6	P	A	N
Clam	7	P	A	N
Clam	7	N	A	N
Clam	8	P	A	N
Clam	8	N	A	N
Clam	9	P	A	N
Clam	9	P	A	N
Clam	10	N	A	N
Clam	10	N		N
Clam	11	P	A	N
Clam	11	N	A	N
Clam	12	P	A	N
Clam	12	N	A	N
Clam	13	N	A	N (possible gypsum)
Clam	13	P	A	N
Clam	14	P	A	N
Clam	14	N	A	N
Oyster	Control			
Oyster	1A	A	N	N
Oyster	1A	A	N	N
Oyster	2A	A	N	Quartz
Oyster	2A	A	N	N
Oyster	3A	A	N	N
Oyster	3A	A	N	N
Oyster	4A	A	N	N
Oyster	4A	A	N	N
Oyster	5A	A	N	N
Oyster	5A	A	N	N
Oyster	6A	A	N	Quartz
Oyster	6A	A	N	N
Oyster	7A	A	N	N
Oyster	7A	A	N	N
Oyster	8A	A	N	N
Oyster	8A	A	N	N
Oyster	9A	A	N	N
Oyster	9A	A	P	N
Oyster	10A	A	N	N
Oyster	10A	A	N	N
Oyster	11A	A	N	N
Oyster	11A	A	N	N
Oyster	12A	A	N	N
Oyster	12A	A	N	N

TABLE 38 (cont.)

Shell Type	Vat	Calite	Aragonite	Other Minerals
Oyster	13A	A	N	Quartz
Oyster	13A	A	N	N
Oyster	14A	A	N	N
Oyster	14A	A	N	Quartz
Oyster	15	A	N	Quartz
Oyster	15	A	N	Quartz
Oyster	16	A	N	N
Oyster	16	A	N	N
Oyster	1	A	N	Quartz
Oyster	1	A	N	Quartz
Oyster	2	A	N	Quartz
Oyster	2	A	N	Quartz
Oyster	3	A	N	N
Oyster	3	A	N	Quartz
Oyster	4	A	N	N
Oyster	4	A	N	N
Oyster	5	A	N	Quartz
Oyster	5	A	N	N
Oyster	6	A	N	Quartz
Oyster	6	A	N	Quartz
Oyster	7	A	N	Quartz
Oyster	7	A	N	N
Oyster	8	A	N	N
Oyster	9	A	N	N
Oyster	9	A	P	Quartz
Oyster	10	A	N	N
Oyster	10	A	N	Quartz
Oyster	11	A	N	Quartz
Oyster	11	A	N	N
Oyster	12	A	N	N
Oyster	12	A	N	N
Oyster	13	A	N	N
Oyster	13	A	N	N
Oyster	14	A	N	N

A = Abundant
P = Present
N = Not detected

TABLE 39

(Mg/)

Sample	Vat	Time	Ca	Fe	K	Mg	Na	Si
Clam	15	1	188	<0.1	15.1	19.2	173	19
Clam	15	2	33	0.3	2.2	<2.0	10	25
Clam	16	1	183	<0.1	19.8	20.2	256	34.5
Clam	16	2	50	0.1	3.9	4.0	52	18.3
Oyster	15	1	212	<0.1	13.3	11	39	23
Oyster	15	2	202	0.1	5.8	6	21	11
Oyster	16	1	191	0.2	15.5	13.5	92	31.6
Oyster	16	2	241	0.2	6.5	14.9	73	20.5

TABLE 40

Changes in Wood Sample Dry Weights from Time 1 to Time 3

Paired t scores, 9 degrees of freedom

Vat	Oak	Pr.	Pine	Pr.
15	Weight Increase	--	4.74	.001*
16	8.42	.001	5.42	.001
1A	5.00	.001	5.31	.001
2A	Weight Increase	--	Weight Increase	--
3A	2.32	.025	3.24	.010
4A	Weight Increase	--	Weight Increase	--
5A	Weight Increase	--	Weight Increase	--
6A	7.22	.001	3.87	.005
7A	8.91	.001	6.95	.001
8A	6.40	.001	9.07	.001
9A	6.35	.001	7.71	.001
10A	7.83	.001	1.15	.250
11A	6.72	.001	3.08	.010
12A	1.69	.100	4.32	.001
13A	8.37	.001	7.16	.001
14A	Weight Increase	--	Weight Increase	--

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POLLEN EXINE DETERIORATION AND PRESERVATION

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INTRODUCTION

The National Park Service Inundation Study is designed as an attempt to assess accurately the impact of water impoundment projects on cultural resources (Lenihan et al. 1977). This project, by implication, is quite extensive and attempts to integrate data obtained from a variety of researchers and studies in an archeological context. Because this is an ambitious undertaking, an attempt has been made to provide data on the broadest spectrum of recoverable cultural artifacts and environmental data. This report examines the experimental design and results obtained from the palynological portion of this project.

Palynology is an extremely important research tool of growing importance used in archeological investigations. The analysis of fossil pollen preserved in prehistoric human feces (coprolites) has been widely used in developing inferences concerning both the diet and the nutritional requirements of prehistoric human populations (Bryant 1974a, 1974b; Williams-Dean 1979). Pollen from floor sediments in pueblo sites in the American Southwest have been useful in inferring room utilization (Hill 1973; Hill and Hevly 1968). Pollen recovered from an archeological context in addition to adjacent, undisturbed areas have also been useful in reconstructing the vegetation present during the occupation of the archeological sites (Schoenwetter 1962; Martin 1970). Thus, it is evident that palynology can contribute an immense quantity of data for use by the archeologist.

In fossil pollen studies, however, the paleoecologist is forced to draw his conclusions not from the pollen grains which were originally deposited, but rather from those grains which remain after exposure to various forces or weathering agents. Paleoecologists have found certain types of hydric environments (lakes and bogs) most suitable for their studies. While preservation in these types of environments is generally good to excellent, there is still some deterioration of pollen which occurs. Few studies to this date have focused their attention on factors which affect pollen preservation and the subsequent interpretation of such records. A major goal of this study then, is to provide new data to help fill this void and perhaps obtain a more nearly precise understanding of agents involved with pollen deterioration.

In order to test specific cause and effect relationships in pollen preservation, it was necessary to establish a series of testable hypotheses. The underlying assumption to any such test, as observed by Lenihan et al. (1977), is that all samples are handled properly in the field and in the laboratory.

HYPOTHESIS I:

Some loss of pollen in palynological samples will result from the chemical and biological composition of the sampling location.

TEST IMPLICATION I: The distribution of deteriorated pollen within any sample will have a nonrandom distribution but will correlate with the sample locations.

HYPOTHESIS II:

Pollen will be better preserved in a water column than pollen located in the sediment-water interface.

TEST IMPLICATION I: The percentage of deteriorated pollen will be much lower in samples from the water column than from the sediment-water interface due primarily to the major effect of biological organisms present in the sediment.

HYPOTHESIS III:

There is a strong positive correlation between the amount of pollen deterioration and the length of time the samples have been exposed to the elements.

TEST IMPLICATION I: There will be a nonrandom distribution of pollen percentages of deteriorated pollen determined by the sampling intervals. The longer the pollen remains in the reservoir, the more highly degraded will be the pollen in each sample.

HYPOTHESIS IV:

Acetylated pollen, which lacked cytoplasm, will show a significantly less amount of deterioration than will unacetylated pollen.

TEST IMPLICATION I: Effects of microorganisms on pollen exines will have a nonrandom distribution. The organisms attack the pollen to obtain the internal cytoplasm and thus will attack those grains more severely that contain this substance.

HYPOTHESIS V:

Pollen will show a marked difference in preservation when exposed to different chemical compounds.

TEST IMPLICATION I: There will either be a strong positive or a negative correlation between pollen preservation and specific chemical compounds.

TEST IMPLICATION II: By changing the strength of the chemical solutions, the degree of pollen preservation will be likewise changed.

The null hypothesis is perhaps the easiest to test for. In all cases the null hypothesis states "there is no relation between the degree of pollen deterioration and any of the variables, and therefore a random distribution is expected." The Null Hypothesis will be rejected if statistically there is less than 0.001 probability of the distribution occurring by chance.

Pollen grains are the male gametophytes of the more advanced members of the plant kingdom consisting of members of the Coniferophyta and Anthophyta (Gymnosperms and Angiosperms). These gametophyte plants (pollen grains) carry the genetic information which is transferred during fertilization. The pollen grain (Figure 1) is composed of a multilayered outer covering and a cellulose interior surrounding the binucleate internal cytoplasm which comprises the male gametophyte (Foster and Gifford 1974). The outer covering, or "exine," of a pollen grain is composed of cellulose, hemicellulose, lignin, and a compound called sporopollenin. Sporopollenin, as defined by Shaw (1971), is composed of oxidative polymers of carotenoids and carotenoid esters and is responsible for the preservability of pollen under adverse conditions. Thus, the outer covering is a durable organic compound, yet it is susceptiable to deterioration as is any other biological agent.

Bryant (1978) has recently synthesized many of the current investigations involved with pollen preservation. He has grouped the types of deterioration into three classes: mechanical, biological, and chemical. Mechanical deterioration of pollen exines involves natural forces inherent in the weathering process which affect all naturally occurring materials. This process is initiated as soon as the pollen grains are released from their anthers and may be caused by collision or abrasion with each other or with other objects, such as clay particles, sand grains, etc. (Bryant 1978).

Chemical deterioration is a more complex problem and contains more variables than does mechanical deterioration. Dimbleby (1957) indicated that soil pH appears to be a major determinant in the preservation of pollen. His experiments have shown that in certain soil types having a pH greater than 6.0, pollen was not preserved in sufficient quantities to analyze. However, in alkaline soils such as those found in the American Southwest and Texas, Martin (1970) and Bryant (1969) have demonstrated that fossil pollen can be extracted from soils ranging in pH from 6.6 to 8.9. On the other hand, both authors also noted the highly deteriorated condition of pollen recovered from these types of highly alkaline sediments.

Havinga (1966, 1971) has ably demonstrated that soil type and composition have a major effect on the preservability of pollen grains. The more acid type soils (histosols) generally preserve pollen much better than more alkaline type soils (aridosols, molosols) tested, such as leaf mold and riverine clay soils. This same correlation with pH was also reached independently by Sangster and Dale (1961, 1964).

Related to these studies of the effects of soil pH is Tschudy's (1969) work on the oxidation-reduction potential of soils (Eh), which he feels may be more important than pH in the preservability of pollen. He noted that sediments with a low Eh are reducing environments and thus tend to be more favorable for pollen preservation.

Likewise, pollen is often destroyed or decayed in soils with a high Eh due to the rapid rate of oxidation which accompanies this condition.

The third major group of causative agents is biological and is perhaps the most important of the three in the eventual preservation or destruction of pollen grains. Although our knowledge on this particular aspect is still incomplete, it is thought that certain types of biological agents such as the fungi and bacteria (Elsik 1971) feed on the internal cytoplasm and organelles of pollen and thus weaken the exines during their entry into the grain. Elsik (1966) contains an excellent review of the research on this question. Goldstein (1960) investigated the effects of certain fungi such as the Phycomycetes on pollen and found them to be positively correlated with the destruction of certain pollen types. He found that the Chytrids (Chytridiomycetes) were especially responsible for the weakening of the exine. In later studies, Elsik (1966, 1971) noted that bacterial deterioration by bacteria such as the Actinomycetes occurs in a definite pattern and that this can occur not only in fresh pollen containing cytoplasm but also in grains which have been fossilized for millions of years.

Several recent attempts have been made to study the effects of pollen preservation as it relates to the physical environment. Sangster and Dale (1961, 1964) attempted to show the rate of pollen preservation in: a) a weakly acidic peat bog; b) a strongly acidic peat bog; and c) an alkaline pond. Their results showed that the best preservation of pollen occurred in the highly acidic environments (correlated with the lowest pH) of the peat bogs. The pollen was most deteriorated in the alkaline pond. Their data also showed that some pollen types (e.g. Populus) do not preserve well under any conditions yet were present in the greatest quantity in the acid environment.

Cushing (1967) has demonstrated the desirability of including what he refers to as indeterminate pollen in the calculation of statistical pollen sums. In this way, at least some of the differences in pollen preservation varied directly with the pH and the type of sediments involved.

Likewise, Hall (personal communication, 1979) views deteriorated pollen as forming increasingly more deteriorated classes, each class being more severely degraded and thus more unrecognizable in the fossil record. The more seriously the pollen is degraded, the more drastic the effect on the interpretaton.

Finally, recent investigations by Bryant (1977a, 1977b) have attempted to correlate the degree of pollen preservation with the percentage of organic matter in the sediment. These investigations suggest that fossil pollen is potentially recoverable from sediments containing more than 1.0-1.6% organic matter.

METHODS AND MATERIALS

Fresh pollen of thirteen taxa (Table 1) were obtained from the Hollister-Stier Laboratories and were mixed together to obtain a uniform mixture. This uniformity was achieved when all thirteen pollen taxa were present in a subsample of this mixture when examined. These thirteen specific taxa were chosen for a variety of reasons. First, several of the taxa are representative of economic plants used by aboriginal groups in the United States (Zea, Amaranthus). Secondly, several of the taxa are common plants which are indicative of major plant biomes in the United States and these are extremely important in interpreting fossil vegetational communities (Pseudotsuga, Picea, Pinus, Quercus, Carya, Artemisia, Salix, and Iva). Third, some of these taxa have been studied previously by other researchers and are known to preserve rather poorly in different sediments (Populus, Pseudotsuga, Juniperus) while others are known to preserve extremely well (Artemisia, Iva, Quercus). A final consideration which perhaps was more important than the others was the ease of recognition of these taxa once degradation had started. For this reason, only one species of each genera was included. All the pollen taxa included can be very easily distinguished from each other. This would also insure that relatively few misidentifications of degraded pollen would occur.

The construction of the packets which would hold the pollen during the testing posed the greatest problem. Each packet had to be porous enough to allow access by microorganisms while restricting the loss of pollen. A NYTEX screen with openings of 15 mm was used. Two 2-inch squares of NYTEX were cut to form each packet. Three edges were sealed with Castolite, a liquid plastic resin. In order to readily identify the packets containing fresh and acetylyzed pollen, colored dye was mixed with the castolite. Blue dye was used with packets containing unacetylated pollen and red dye for those containing acetylated pollen. The packets were then allowed to dry.

TABLE 1: POLLEN TAXA USED IN INUNDATION STUDY

Zea mays	Corn
Pseudotsuga sp.	Douglas Fir
Populus alba	White Poplar
Picea pungens	Colorado Blue Spruce
Pinus edulis	Pinyon Pine
Quercus virginiana	Virginia Live Oak
Artemisia sp.	Common Sagebrush
Juniperus monosperma	One-Seeded Juniper
Salix nigra	Black Willow
Iva sp.	August Marshelder
Carya Illinoiensis	Pecan
Amaranthus sp.	Careless Weed
Tapha latifolia	Cattail

Prior to the construction of these packets, one-half of the fresh pollen mixture was acetylyzed in order to simulate the effect of natural fossilization. The fresh material was treated with a solution of 9 parts acetic anhydride and one (1) part sulfuric acid (H_2SO_4) (Eardtman 1960). This mixture was heated in a heating block for a period of about 15 min. This treatment removes the cellulose and hemicellulose components of the pollen grains including the cytoplasm, organelles, and the intine (FIG 1). The resulting grains, therefore, are very similar to naturally occurring fossil pollen which have likewise lost these components.

Two mixtures were made of the pollen, one each for the laboratory and the field phases of the study. For the laboratory phase, the pollen was added to the packets by two methods. Dry, unacetylated pollen was placed in small gelatin capsules. These capsules were then inserted into the NYTEX packets along with a drop of marker pollen (*Helianthus*) to be used for quantification, and the fourth edge was sealed. The gelatin capsules were useful for two reasons. First, placing the pollen in the capsules protected the pollen mixture from the castolite while it dried. Second, once in the water, the gelatin dissolved completely and passed through the pores of the packets allowing the pollen to be released inside.

The acetylated pollen was suspended in 56 ml of distilled water. To this was added 4 ml of concentrated *Helianthus* pollen. The entire mixture was kept in suspension to allow for uniform sampling. A 0.5-ml subsample was removed and again placed in gelatin capsules. The capsules were placed in the NYTEX packets and the fourth edge sealed.

Packets prepared for the field phase were prepared as described above. Pollen for these packets was first suspended in 100 ml of distilled water. Again, a 0.5 ml subsample was removed and placed in a 000 gelatin capsule. This capsule was then placed in a 003 gelatin capsule. These were then inserted into the prepared NYTEX packets and the fourth edge sealed. This procedure was used on both acetylated and nonacetylated pollen.

The sampling stations for the polleniferous material used in the field phase were distributed throughout Brady Reservoir, McCulloch County, Texas, differently than for other categories of materials under investigation, due to the form of data retrieval desired. Different sampling locations within the reservoir were used in order to control, as much as possible, different chemical and biological regimes operating at different locations within the reservoir. Three sampling locations were chosen within the reservoir for attaching the prepared pollen samples. The method described by Voschell and Simmons (1977) was used for anchoring the sample packets to upright wooded posts which had been inserted into the sediment. The packets were then placed at the water-sediment interface beneath these posts. It was hoped that these suspended packets would record the effect of water on the exines. I feel that these packets (suspended by line) are crucial since they would reveal any deterioration which would normally occur in the water prior to and during the settling of pollen to the floor of the lake.

The pollen samples were collected from Brady Reservoir at 5-, 10-, 20-, 90-, and 240-day intervals (Table 2). Four packets each of the acetylated and unacetylated pollen were removed from the sediment at each sampling location. Two packets each of acetylated and non-acetylated pollen were removed from the water column at each sampling location at the same time.

The packets containing the pollen were immediately transferred to small jars containing a 1% solution of formalin. This acted as a preservative and also insured that no further biological deterioration would occur to the pollen after the collection date. The jars were then sent to the Texas A&M University Pollen Laboratory for analysis. The packets were stored in this solution of formalin for a period of 1-3 months and upon opening it was found that the edges of many of the packets had become very brittle and cracked. During the collection of the packets at time interval 5, it was noted (Sandra Rayl, personal communication, 1980) that the packets exhibited this same condition when removed from the reservoir. Apparently the water has in some

TABLE 2: SAMPLING TIME INTERVALS

TIME 1	5 days	removed May 7, 1979
TIME 2	10 days	removed May 12, 1979
TIME 3	20 days	removed May 22, 1979
TIME 4	90 days	removed July 31, 1979
TIME 5	240 days	removed January 16, 1980

way affected the castolite. However, the majority of the packets still contained pollen, yet others did not. This may be a factor in assessing those few samples which reported no pollen recovered (Appendix I). If these packets are used in the future for additional studies, perhaps a silicon-based resin would better withstand the effects of an inundated environment.

In the laboratory, the packets were opened and the contents were carefully washed into a 100 ml beaker with 100% ETOH. Since small fragments of the castolite were present after this initial wash, the material was screened through a 200-mm mesh screen. This procedure eliminated all traces of the castolite. The pollen residue was then concentrated into 12-ml centrifuge tubes and washed thoroughly with 100% ETOH. Nigrosin B, a biological stain, was added to each sample and allowed to stand for a period of 5 minutes before further washing. This procedure produced the most acceptable color stain for photography of the samples. Excess stain was removed using 100% ETOH.

Multiple samples were removed from each sampling location as previously mentioned. Half of these samples were prepared for examination using Transmitted Light Microscopy (TLM) and the others for examination using Scanning Electron Microscopy (SEM). The material for TLM was washed with acetone and then transferred to a mounting media of 1,000 cs silicon oil. The silicon oil containing the pollen residue was then mounted on microscope slides following the method of Andersen (1965). The material for viewing with SEM was stored in vials in a solution of 100% ETOH until they could be processed using the Critical Point Drying Technique (Lewis and Nemanic 1973).

Pollen examined on the light microscope was identified by scanning across a slide using transect intervals of 1 mm until at least 200 grains were counted. Two hundred grains were used as a minimum based on the recommendations of Barkley (1934).

During the analysis, the deterioration categories of Cushing (1967) were generally utilized. These categories were: 1) non-affected for normal; 2) crumpled; 3) broken; 4) corroded; and 5) degraded. These classes form what Blalock (1972) defines as an ordinal scale with each successive class showing increased deterioration.

Normal grains were defined as those having no observable forms of deterioration. These grains are easily recognizable since they are in very good shape and are structurally intact. Category 2 (crumpled) included those grains which were either folded or crumpled. Grains which had only one fold as well as those that were completely crumpled were included in this category.

Broken pollen grains, Category 3, included those grains in which the outer wall (exine) of the grain had been ruptured. Included in this category were those grains with small tears or perforations as well as those with almost continuous splits along the exine surface.

Corroded and degraded grains, categories 4 and 5, are very similar in the type of deterioration exhibited. However, corroded grains can be distinguished since they refer to grains which have a noticeable thinning of the exine so that the pore or colpus (apertures of the pollen grain) structure is less distinct yet still intact. Cushing (1967) included within this category grains which had been pitted. However, I felt that this phenomena would be better treated by placing them in the group with the broken grains. Degraded grains, on the other hand, show an advanced stage of corrosion in which the grains are severely thinned and in many cases remain only as ghost images.

FIELD PHASE

The analysis of the pollen samples consisted of classifying and categorizing the thirteen pollen taxa into one of the five (5) categories previously described. Originally, I had intended to analyze this data by individual taxa and category. This type of approach would have resulted in the most useful form of data analysis. However, in order to use computer manipulation to analyze the data in this form, it would have been necessary to compare a number of 13 X 5 matrices (13 pollen taxa by 5 degradation categories). Many of the individual cells of these matrices would have been empty because of the nature of the problem. For example, after only 5 days' immersion, it is improbable that grains from all 13 taxa would show a complete ordinal series (Blalock 1972). Earlier investigations (Sangster and Dale 1961, 1964) have ably demonstrated that some pollen taxa are more resistant to deterioration than others.

Based on these considerations, I decided to collapse these matrices into a more usable format. I collapsed the matrix into a comparison between grains showing some form of deterioration (categories 3-5) and those showing none (categories 1 and 2), without regard to the individual taxa involved. This form of data was more amenable to computer manipulation. SAS package computer programs using the FUNCAT procedure were utilized (SAS, 1979). This procedure allowed the use of categorical data without substantial modification of the results. Normal and crumpled categories were both considered to show no modification because it is impossible to distinguish between crumpling which occurred naturally under field conditions and crumpling which was induced in the palynology lab during the preparation procedure prior to examining the samples using TLM. While admittedly this introduces a small amount of error into the calculations, I believe it is minimal in comparison to including the crumpled category with deteriorated grains.

TABLE 3: PERCENT DETERIORATED POLLEN

	SEDIMENT		WATER	
TIME	ACETYLATED	NOT ACETYLATED	ACETYLATED	NOT ACETYLATED
STATION 1				
1.	14.29	11.36	4.18	2.02
2.	13.65	4.03	8.78	12.16
3.	7.43	9.80	9.82	9.96
4.	10.26	7.30	13.27	15.41
5.			27.97	51.93
STATION II				
1.	17.32	22.73	11.73	14.98
2.	20.61	25.93		10.92
3.	15.75	17.74	13.00	14.53
4.	14.15	15.73	14.62	15.20
5.	28.22		17.60	

Table 3 Continued

STATION III

1.	25.34	14.82	12.27	8.61
2.	14.41	15.77	24.11	14.86
3.	12.75	17.98	14.15	23.94
4.	13.44	22.76	13.87	
5.			24.68	64.32

TABLE 4: CHI-SQUARE VALUES, MAIN EFFECTS ONLY

VARIABLE	DF	CHI-SQUARE	PROBABILITY
Location	2	73.16	0.0001
Time	4	492.38	0.0001
Position	1	6.35	0.0117
Treatment	1	62.06	0.0001
Residual	43	432.16	0.0001

Table 3 gives the percentages of deteriorated and nondeteriorated grains per sample station. These same data are presented graphically in Figures 2, 3, and 4, with each figure representing a separate sampling station.

Using the FUNCAT procedure, the total number of pollen grains counted per sample and the sum of the pollen grains included in categories 3, 4, and 5 were entered into the computer. Each sample also consisted of four variables which were used to identify the sample: 1) location; 2) time; 3) position; and 4) treatment. Location was defined as the sampling stations and consisted of three levels. Time referred to the sampling interval and consisted of 5 levels. Position was based on the location of the sample within each sampling location, either in the water column or in the sediment-water interface, and thus consisted of two levels. The fourth variable, treatment, likewise consisted of two levels, referring to acetylated or unacetylated pollen.

The FUNCAT procedure is designed to test specific hypotheses or models. The initial model stated that the condition of the grains is a function of the main effects of location, time, position, and treatment, where condition is defined as the percentage of grains which were deteriorated. Results of this model are presented in Table 4. Location, time, and treatment were all shown to be significant at the chi-square test. In other words, there is only one chance out of 10,000 that this distribution occurred at random. The variable position is somewhat less significant at only the 0.0117 level. This still indicates that in only 1 chance out of 100 would the distribution have occurred at random.

The results of these analyses have shown that percentages of pollen deterioration vary directly with the four parameters under investigation: location, time, position, and treatment. The residual effects, defined as those not accounted for by the model, likewise yielded a chi-square value which was significant at the 0.0001 level. The next step was to saturate the model by testing for every possible

TABLE 5: CHI-SQUARE VALUES, VARIABLE INTERACTIONS

VARIABLES	DF	CHI-SQUARE	PROBABILITY
Location	2	37.89	0.0001
Time	4	28.79	0.0001
Position	1	4.17	0.0001
Treatment	1	3.09	0.0411
Location + Time	8	34.19	0.0001
Location + Position	2	6.51	0.0385
Location + Treatment	2	0.18	0.9138
Time + Position	4	64.79	0.0001
Time + Treatment	4	22.19	0.0002
Position + Treatment	1	0.09	0.7631
Location + Time + Position	6*	43.25	0.0001
Time + Position + Treatment	3*	3.73	0.2917
Location + Time + Position	7*	28.98	0.0001
Location + Time + Position + Treatment	6*	26.31	0.0002
Residual	0	-0.00	1.0000

Effects marked with * did not test to the degree of freedom in the design.

combination of variables which could affect the outcome of the number of deteriorated grains and thereby reducing the residual effects to zero. The results of this section analysis are presented in Table 5.

In all combinations in which time was included as a factor, the chi-square values were significant at least at the 0.0002 level (the exception to this being the combination of time, position, and treatment). Location was significant at the 0.0001 level when considered independently but in conjunction with other variables was decidedly not significant.

In general the levels of significance as indicated by chi-square values show that the variable of time most affects the number of deteriorated grains within each sample. A secondary influence, but to a lesser extent, is location. The obvious conclusion, therefore, is that the longer the sample remains in the water, the greater the amount of deterioration which will occur to the sample. Location plays an important role which may be due in part to the different microfloral and microfaunal communities present at each sampling locale.

Bennoit and Simmons (1979) have provided an assessment of biological and physical-chemical water quality properties from the sampling locations at Brady Reservoir. In their analysis it was shown that pH varied significantly between stations 1 and 3, and station 2. Likewise the anaerobic and aerobic counts differed between sampling stations 1 and 2. No data on this particular parameter was supplied for station 3. This type of variation may be enough to account for the differences in pollen deterioration between these sampling locales.

Sampling station 2 (Figure 3) shows the overall highest percentages of pollen deterioration. The substrate at this locale is mostly a limestone with a somewhat shallower water level than at the other two sampling stations (Sandra Rayl, personal communication, 1980).

Sampling intervals showed the most dramatic changes in the percentages of deteriorated pollen, which correlates with the results of the chi-square values (Table 4 and 5). The initial sample (5 days, Table III) showed at least a 10% frequency of deteriorated pollen. This indicates that agents acted on the pollen exine immediately after deposition. The results from later sampling intervals (Table III) show that after this initial attack the rate of pollen deterioration tends to slow down. These are precisely the results obtained by Sangster and Dale (1961, 1964) and corroborates their findings.

The chi-square values also indicated that the variables, position and treatment had little overall effect on the deterioration rates, even in conjunction with other variables. In general, pollen which had been acetylated prior to the study suffered less biological attack than untreated pollen. These results tend to substantiate Elsik's (1971) view that microorganisms do attack grains in a fossilized condition. However, the indications from the present study suggest that fossilized grains are attacked much less frequently than are fresh, untreated pollen. Ample evidence of fungal attack on unacetylated pollen was observed from this study, as can be seen in Plate I D and Plate II B, C, D. The factors involved with this seeming difference in fungal attack are still undetermined. The method of artificial fossilization (acetolysis) may be partially the cause. It cannot yet be determined if these chemicals are causing an inhibitory effect on the microorganisms or rather some other factor is involved. If these chemicals are causing some form of inhibition, it cannot be too great or a more noticeable difference between the two treatments would have been observed.

As mentioned earlier, the position of the pollen at each location appears to have less of an effect than any of the other variables. This may be due in part to keeping the pollen in suspension much longer than it would be under natural conditions. The earlier sampling intervals all show markedly less deterioration than that observed in samples which had been placed in the sediment. Possibly this is due to an effect of the original hypothesis, which stated that pollen will be attacked only minimally before being incorporated into the sediment. The evidence presented in Appendix I appears to support this position. However, the later samples show a large increase in the amount of deterioration. This later increase could be due in part to: a) the effect of the water or b) attack by living organisms inhabiting the particular depth at which the samples were located. This would be a function of the experiment and not necessarily reflect natural conditions. In addition, the water column is aerobic, according to Bennoit and Simmons (1979), and while at this stage no definite conclusions can be reached, the possibility exists that differences in ion concentration between the water and sediment could account (in part) for variations observed in the rates of deterioration.

Up to this point I have been discussing the trends revealed by using only deteriorated or nondeteriorated classes of pollen. It is necessary now to examine the individual taxa involved. Appendix I presents the frequency distribution of samples by taxa and by deterioration classes. Evaluation of these particular sets of data will be subjective, as these data were not subjected to computer manipulation because of constraints explained earlier.

These data tend to support observations of earlier researchers (Sangster and Dale 1961, 1964; Havinga 1966, 1971; Cushing 1967) that pollen deterioration affects different pollen taxa at vastly different rates. Many pollen taxa shown to be resistant to deterioration by earlier studies likewise are more resistant according to my results.

Picea and Pinus, while exhibiting some crumpling, only rarely and in only isolated cases are found to have deteriorated sufficiently to be included in deterioration categories 3-5 (Plate I A). The same condition is found in grains of Quercus, Artemisia, Salix, Iva, and even Zea, though to a slightly less extent.

Other pollen taxa revealed a more significant degree of deterioration. Pseudotsuga pollen was almost always deteriorated in some form or another. Usually the grain was broken and was usually ruptured along an entire side (Plate I B). Likewise Populus also severely deteriorated over time. While many of the Populus grains were only crumpled, a far higher percentage were present in a degraded condition, especially in the later sampling intervals. In time periods 4 and 5, Populus consistently showed relatively high frequencies of both corroded and degraded pollen.

The most surprising effect was that of Amaranthus. In both the fossil and modern pollen, Amaranthus is indistinguishable from Chenopodium pollen and therefore these two taxa are usually included together as Cheno-Am (Martin 1970; Bohrer 1968; Hill 1973; Hill and Hevly 1968). Amaranthus pollen deteriorated rather quickly in these samples, a rather high percentage being included in the corroded category (#4). The general appearance of these grains showed a noticeable thinning of the exine with a removal of very small surface sculpturing (Plate I C, II A). A fresh Amaranthus grain is characterized by the conspicuous presence of small verrucae (projections on the surface generally greater than 1 mm) evenly distributed over the entire surface. In these corroded grains the verrucae have been completely eroded off, with the surface taking on an almost psilate (smooth) appearance. Previous researchers, especially in the American Southwest, have used Cheno-Am pollen to interpret disturbances such as found in archeological sites (Bohrer 1968; Hill and Hevly 1968) and have also interpreted the presence of this group as sometimes representing an economically useful plant to various prehistoric populations (Bohrer 1968). Thus the apparent susceptibility of grains of this taxa to deterioration assumes paramount importance in these interpretations. In many archeological sites, Cheno-Am pollen has been noted to occur in a degraded condition (Bryant, personal communication, 1980). However, given the general morphology of Cheno-Am pollen (periporate which is defined as having more than 5 pores) these grains can usually be recognized even in a highly degraded condition.

Based on the above discussion, we can return briefly to the hypotheses set out in the introduction. The chi-square values obtained earlier clearly call for the rejection of the Null Hypothesis in at least two instances. Hypothesis III, which states that there is a positive correlation between time and pollen deterioration, and Hypothesis I concerning sample location cannot be rejected. While these two hypotheses cannot be proven, the Null Hypothesis for these two clearly must be rejected.

Based on the data contained in Appendix I, I am also inclined to reject the Null Hypothesis for Hypothesis IV concerning the treatment of the pollen. In main effects, this variable was shown to be significant at the 0.0001 level (Table 4). However, in Table 5 it was significant only at the 0.07 level. While this would certainly not allow a rejection of the Null Hypothesis using the parameters established earlier, these data in conjunction with the frequency distribution contained in Appendix I allows for a tentative rejection of the Null Hypothesis and at best a weak correlation between deterioration and treatment.

The last hypothesis to be considered, Hypothesis II, concerning the position of the samples, clearly must be rejected. No correlation was noted either in the frequency distribution or by chi-square values. In no case could the Null Hypothesis be rejected, and therefore we are obligated to reject the hypothesis.

LABORATORY PHASE

In conjunction with the field phase of this project, a series of controlled experiments were carried out under laboratory conditions with the ultimate aim of determining effects on both perishable and nonperishable archeological remains. It was realized early in the planning stage that all chemicals normally present in the reservoir could not be used in the laboratory study since they were often present in minimal amounts. Accordingly, only selected combinations of cation/anion pairs were to be used in this study. The solutions were made in consultation with Dr. John Husler (University of New Mexico).

Each sample was subjected to a low concentration of the chemical and also to a concentrated solution. Because of time constraints on the study, it was felt that these concentrated solutions would approximate long-term exposure to the chemicals.

The pollen samples were immersed in open vats containing the solution and other artifactual material included in this study. The solutions were changed at periodic intervals and samples removed at 6-month and 51-week intervals. The data was again compared using deteriorated and nondeteriorated categories, and the results are shown in Tables 6 and 7. The percentage calculations by taxa are presented in Appendix II and III. Only 1 sample was lost (11A, $NaSiO_3$ $9H_2O$, 20%) during the experiment. This packet was opened in the laboratory and, after washing with 100% ETOH, it was noted that no pollen was present. Upon earlier examination of the packet, no obvious breaks or splits had been observed. I assume that some microscopic "leaks" in the castolite had occurred which allowed the pollen sample to be lost.

In general, the acetylated pollen showed consistently less dete rioration than did the unacetylated pollen, although a few exceptions to this can be seen in Tables VI and VII. This may be due at least in part to the chemical pretreatment given the acetylated pollen. The most surprising results were yielded from samples 14 and 14A (H_2SO_4). Sulphuric Acid is a major constituent of the acetylation mixture, yet this chemical revealed relatively little deterioration compared to other chemicals tested.

From the samples collected at the end of 6 months, only the 20% solution of HCl and NaCl produced less than 20% deteriorated pollen from unacetylated samples. The acetylated pollen had less than 20% deterioration in solutions of $KHCO_3$, deionized water, and the 20% solution of NaCl. Several samples produced greater than 30% deteriorated pollen. Samples in solutions of $NaHCO_3$ HCl, $CaCl_2$, KCl, $MgSO_4$, and number 16 (a combination of chemicals) and concentrated solutions

TABLE 6: PERCENTAGE FREQUENCY DISTRIBUTION OF DETERIORATED POLLEN IN LAB PHASE, 6-MONTH STAGE EACH SAMPLE

	UNACETYLATED	COMPOUND	ACETYLATED
1	26.8%	Fe2(SO4)3 nH2O	26.4%
1A	25.8	Na2CO3	25.7
2	27.2	MgCO3	24.6
2A	35.4	MgSO4	33.9
3	29.0	CaCl2	20.0
3A	22.3	CaCl2	20.0
4	38.9	NaHCO3	28.9
4A	35.5	NaHCO3	25.8
5	29.3	KHCO3	17.8
5A	36.2	KHCO3	29.3
6	36.6	HCl	27.9
6A	17.6	HCl	25.0
7	29.0	NaCl	25.6
7A	17.8	NaCl	18.1
8	25.9	MgCl2 6H2O	20.5
8A	28.3	MgCl2 6H2O	24.2
9	37.0	CaCl2	24.4
9A	29.4	CaCl2	20.1
10	24.3	FeCl2 6H2O	29.1
10A	30.3	FeCl2 6H2O	25.4
11	29.4	NaSiO3 9H2O	32.4
11A	NO SAMPLE		
12	30.5	KCl	21.4
12A	35.3	KCl	25.6
13	35.3	MgSO4	27.7
13A	34.6	MgSO4	28.6
14	21.3	H2SO4	25.8
14A	28.0	H2SO4	29.8
15	26.8	deionized water	19.3
16	34.9	NaHCO3 + MgCl2 6H2O + FeCl2 6H2O + NaSiO3 9H2O	28.6

TABLE 7: PERCENTAGE FREQUENCY DISTRIBUTION OF DETERIORATED POLLEN IN LAB PHASE, 51-WEEK STAGE EACH SAMPLE

	UNACETYLATED	COMPOUND	ACETYLATED
1	23.7	Fe2(SO4)3 nH2O	23.5
1A	24.2	NaCO3	27.8
2	28.2	MgCO3	19.1
2A	25.8	MgSO4	23.2
3	24.6	CaCl2	20.7
3A	31.9	CaCl2	19.3
4	27.4	NaHCO3	23.3
4A	28.9	NaHCO3	20.7
5	26.8	KHCO3	25.7
5A	24.0	KHCO3	25.7
6	22.5	HCl	20.2
6A	15.7	HCl	23.3
7	36.8	NaCl	22.6
7A	28.0	NaCl	25.7
8	46.7	MgCl2 6H2O	31.8
8A	21.9	MgCl2 6H2O	20.1
9	33.5	CaCl2	27.5
9A	30.8	CaCl2	27.3
10	24.3	FeCl2 6H2O	21.9
10A	23.2	FeCl2 6H2O	21.3
11	28.6	NaSiO3 9H2O	18.6
11A	61.0	NaSiO3 9H2O	24.8
12	33.9	KCl	23.0
12A	28.4	KCl	28.3
13	32.0	MgSO4	23.1
13A	26.3	MgSO4	25.6
14	26.3	H2SO4	24.8
14A	28.5	H2SO4	22.6
15	24.7	deionized water	24.6
16	25.3	MaHCO3 + MgCl2 6H2O + FECl2 6H2O + NaSiO3 9H2O	24.2

of $NaHCO_3$, $KHCO_3$, $FeCl_2$, KCl, and $MgSO_4$ all evidenced deterioration in excess of 30%. It should be noted that three of the four chemicals from sample #16 evidenced large amounts of deterioration when used separately. In acetylated pollen, only $NaSiO_3$ $9H_2$ had greater than 30% deteriorated pollen.

The samples removed at the end of 51 weeks showed much greater deterioration of pollen. This corroborates the findings of the field phase in which it was noted that time was probably the dominant factor involving breakdown of the pollen exine. Only the concentrated solutions of HCl of unacetylated pollen and samples of $MgCO_3$ and $NaSiO_3$ $9H_2O$ and a concentrated solution of $CaCl_2$ of acetylated pollen samples had less than 20% deterioration. Of the unacetylated pollen, those in solutions of NaCl, $CaCl_2$, KCl, $MgSO_4$, and concentrated solutions of $CaCl_2$ and $NaSiO_3$ $9H_2O$ had greater than 30% pollen deterioration. $MgCl_2O$ and $NaSiO_3$ $9H_2O$ had greater than 40% deteriorated pollen. Acetylated pollen showed percentages of deterioration greater than 30% in only $MgCl_2$ $6H_2O$.

While all samples contained deteriorated pollen, it is clear that some chemicals apparently exerted a somewhat stronger influence than did others. In all, nine compounds produced pollen deterioration in excess of 30%. These compounds include:

$CaCl_2$	BASE
KCl	BASE
NaCl	BASE
$FeCl_2$ $6H_2O$	BASE
$MgCl_2$	BASE
$MgSO_4$	BASE
$KHCO_3$	BASE
$NaHCO_3$	BASE
$NaSiO_3$ $9H_2O$	BASE

Of the above nine compounds, five contained chlorine (Cl); two contained magnesium (Mg); two contained potassium (K); and two contained sodium (Na). All nine compounds are basic in pH. Sodium silicate ($NaSiO_3$ $9H_2O$) produced the most dramatic effect (16% deterioration), but compounds containing chlorine produced the most consistently high percentages of deteriorated pollen. Apparently these types of compounds were responsible for the greatest amount of deterioration. Therefore, I suspect that their presence would adversely affect pollen preservation and may be quite valuable as predictors for adequate pollen preservation, especially in archeological sites.

During the analysis of samples from this laboratory phase, the presence of fungal hyphae was noted. As outlined in the research design for this phase of the study (NPS 1980), it was decided not to add compounds of organic or inorganic origin to the samples for the purpose of controlling the growth of biological organisms, in order not to affect the results of these chemical solutions on these samples. If the above-mentioned fungi were actually growing during the course of the experiment, then the results might be seriously called into question.

Of the total of 30 samples investigated, eleven showed evidence of some form of biological growth at the completion of the laboratory phase (Table 8). In order to assess and possibly distinguish the effects of the biological organisms from those of the initial chemical environment, samples of the water in which the pollen samples were immersed were sent to a microbiologist (Dr. Barton) at the University of New Mexico.

Barton (1980) has cultured bacterial colonies from this sample water and observed that both fungi and algae were not present and "the bacterial flora of the water samples was really quite limited" (Barton 1980:6). Selected samples of the pollen mixtures were also examined using SEM and likewise revealed little biological contamination of the samples (Barton 1980). Thus, the conclusion that relatively little biological contamination has occurred appears somewhat justified.

TABLE 8: VAT CONDITION AS OF JANUARY 16, 1980*

1	Clear	Fe ppt out	$Fe_2(SO_4)_3$
2	Clear	Some $MgCO_3$ Undissolved	$MgCO_3$
3	Clear		$CaCl_2$
4	Clear	Slightly Yellow	$NaHCO_3$
5	Clear	Slightly Yellow	$KHCO_3$
6	Clear	Slightly Yellow	HCl
7	Clear		NaCl
8	Clear	Slight Color Change	$MgCl_2$ $6H_2O$
9	Clear		$CaCl_2$
10	Clear	Slightly Yellow Algae Present	$FeCl_2$ $6H_2O$
11	Clear	Slight Green Algae Present	$NaSiO_3$ $9H_2O$
12	Clear	No Color Change	KCl
13	Clear		$MgSO_4$
14	Clear	Algae Present	H_2S04
15	Clear	Algae	deionized H_2O
16	Green	Biological Growth	$NaHCO_3$ + $MgCl_2$ $6H_2O$ + $FeCl_2$ $6H_2O$ + $NaSiO_3$ $9H_2O$
1A	Clear	Biological Growth	Na_2CO_3
2A	Yellow	Green Algae	$MgSO_4$
3A	Clear	Some Algae	$CaCl_2$
4A	Clear	Light Yellow	$NaHCO_3$
5A	Clear	Light Yellow	$KHCO_3$
6A	Yellow	Biological Growth	HCl
7A	Clear	No Color Change	NaCl
8A	Clear	Some Algae	$MgCl_2$ $6H_2O$
9a	Clear		$CaCl_2$
10A	Semi-Clear	Fe ppt out	$FeCl_2$ $6H_2O$
11A	Clear Brown	Charred Wood Present	$NaSiO_3$ $9H_2O$
12A	Clear	Slight Yellow	KCl
13A	Clear	Slight Color Change	$MgSO_4$
14A	Clear	Biological Growth	H_2SO_4

*From National Park Service Inundation Study, Chemical Laboratory Progress Report, January 3, 1980. Unpublished manuscript.

While using some of the pollen obtained for this study for another type of experiment, I noticed the appearance of fungal hyphae in the samples after they were left in distilled water for several days. Therefore, it is possible that the origin of some fungal contamination noted in the lab phase of this project could have come from the fresh pollen commercial sources. It is equally likely that the source of these fungi is aerobic, and that they were deposited during the preparation of the pollen packets. Whatever the immediate source of these microorganisms, based on the data supplied by Barton (1980), it would appear unlikely that these organisms caused much deterioration to the pollen exines. The evidence from Barton's (1980) study also suggests that the chemical solutions altered the pH of the water sufficiently to retard or inhibit a large amount of biological growth. This suggests that at least a majority of the observed deterioration of pollen exines was chemically related or perhaps induced.

As discussed earlier, there is a trend in the amount of deteriorated pollen when subjected to differing chemical elements. Based on the recent microbiological studies, the chemical environment of the samples appears to be directly affecting the preservability of the pollen exine, with little effects being caused by the observed microorganisms. There apparently is a strong correlation between several alkaline compounds and pollen deterioration. Based strictly on these present observations, the Null Hypothesis for Hypothesis V must be rejected. Test Implication I for Hypothesis V is not falsified or rejected. At this time it would be premature to accept this test implication as being verified. Test Implication II, on the other hand, is not supported by these data and must be rejected, at least for the time being. No significant increase in the percentages of deteriorated pollen could be correlated with the increased concentrations of these chemicals.

CONCLUSIONS

The present investigation has demonstrated several key points relevant to the destruction or loss of information from inundated archeological sites by selective loss of pollen taxa. In almost any situation, whether in terrestrial or inundated archeological sites, a certain percentage of frequency of palynonmorphs will be acted upon by various chemical and biological agents. This action apparently starts immediately upon deposition of fresh pollen into the study area. The major controlling factors appear to be time and the condition of the substrate. The biological and chemical action most likely will not cease upon "fossilization" but rather, once fossilization has started, in all likelihood will slow down.

The results of earlier investigations, such as those by Sangster and Dale (1961, 1964), which demonstrated selective destruction of pollen exines, is supported. Thin-walled grains are broken and otherwise deteriorated much more rapidly and completely than most pollen taxa with thicker walls.

The chemical data suggests the possibly faster deterioration rates operating under differing chemical regimes. Under long-term conditions these chemicals typically present in reservoir systems may have a more detrimental effect on pollen than originally hypothesized, but this data was inconclusive.

The overall indications of this study are that in inundated archeological sites, while pollen deterioration will occur, there will be selective deterioration of certain taxa. Since pollen of some economic plants consist of exines which are extremely thin, if selective deterioration occurs, it will most likely affect this class of pollen.

FUTURE DIRECTIONS

The present study has indicated the feasibility of determining differential pollen preservation under varying environmental conditions. Once the process of pollen deterioration and preservation is more clearly understood, the value of pollen both as an interpretive tool and as a predictor will be greatly enhanced. The most pressing need in subsequent studies is to reexamine the effects of the chemical compounds under rigorously controlled laboratory conditions. Extreme care must be taken to avoid any hint of contamination. The use of autoclaving devices will reduce the possibility of contamination greatly. While not affecting the pollen, this procedure will kill any organisms present in either the chemical solutions or adhering to the pollen. By keeping the solutions in sealed containers, no atmospheric contamination should occur.

In addition to the ions involved in the above study, the effects of chemicals routinely used in pollen extraction procedures need to be investigated. To this date, no specific data is available to document the effects of standard laboratory chemicals such as nitric acid, hydrofluoric acid, and the acetolysis mixture, to cite a few.

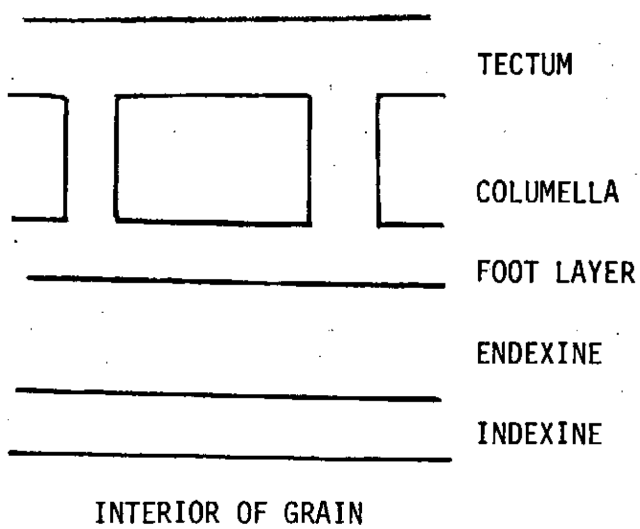
Results from the field phase of this study provided good evidence for biological attack on pollen exines. The next step is therefore to isolate particular microorganisms, such as fungi or bacteria, in pure cultures and determine the effects of particular species on the pollen grains. If specific organisms can be related to specific pollen taxa or to specific methods of exine penetration, perhaps we may be able to say a little more concerning soil conditions, etc., of the sampling site. This particular study could also be combined very easily with an additional investigation concerning the role of pH. A controlled series of experiments relating pH of the solution in both short- and long-term effects could help elucidate the impact of this, as well as Eh on the pollen and the microorganisms investigated.

One of the most important aspects of palynological investigations from archaeological sites involves the deterioration of pollen from plants used economically by the prehistoric inhabitants. A more complete study of the effects of weathering agents on economic pollen is strongly indicated. Before being able to assess the interpretations of room use, diet, and nutrition, to name a few, the susceptibility of pollen from these taxa must be completely understood.

Finally, the role and mechanism of mechanical deterioration of pollen exines must be more thoroughly investigated. In the study we have focused on the biological and chemical modes of deterioration. The types of mechanical degradation, especially when correlated with specific soil types from a variety of archeological site locales throughout the United States, would yield much information concerning the feasibility of obtaining palynological data from particular site areas prior to excavation. This would provide the archeologist with more insight during the early planning stages, specifically regarding the construction of the research design and the budget.

FIGURE I.

CROSS-SECTION OF TECTATE POLLEN WALL
PRIOR TO ACETOLYSIS*



*From Faegri and Iversen (1975)

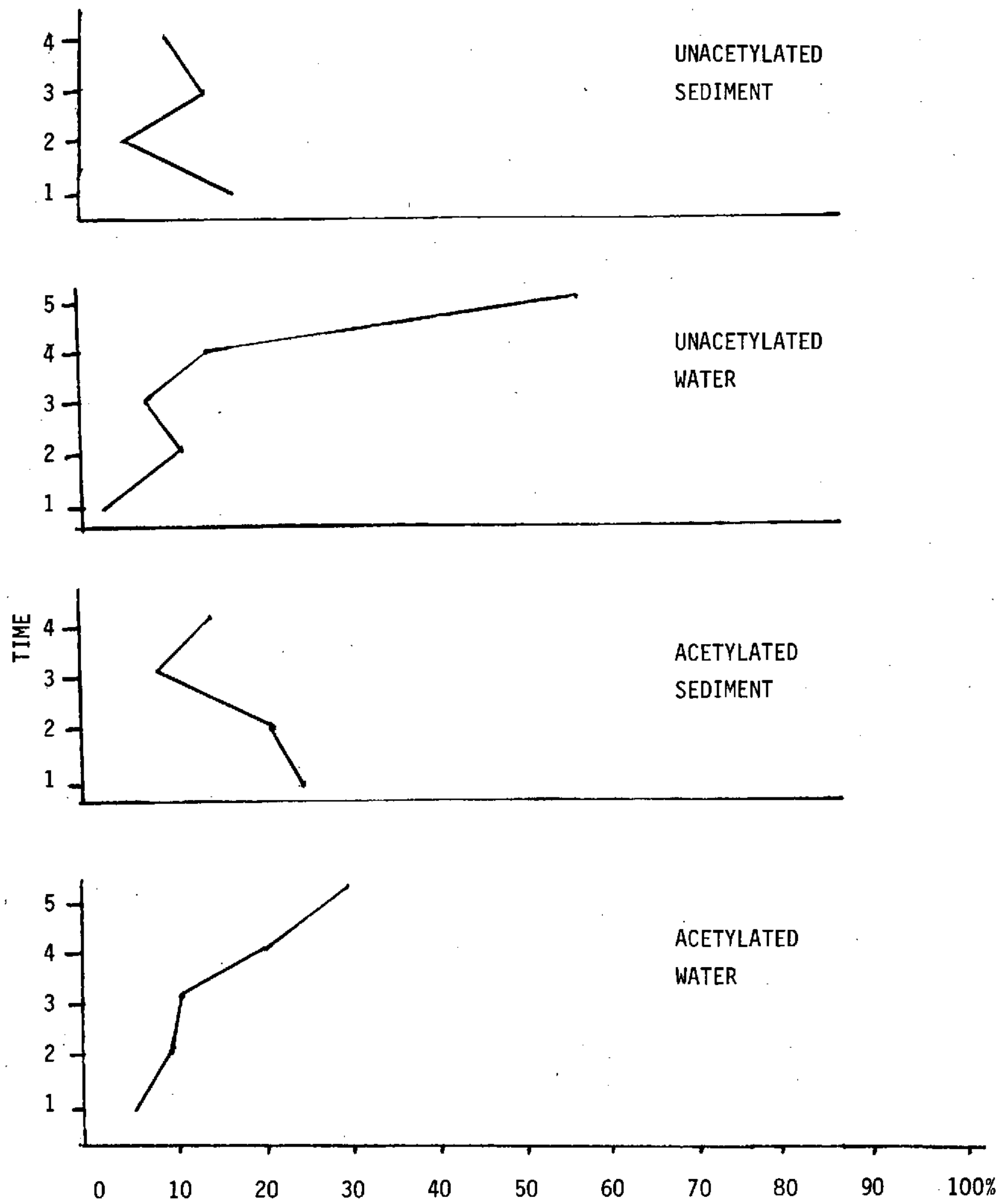


FIGURE 2 SAMPLE STATION 1

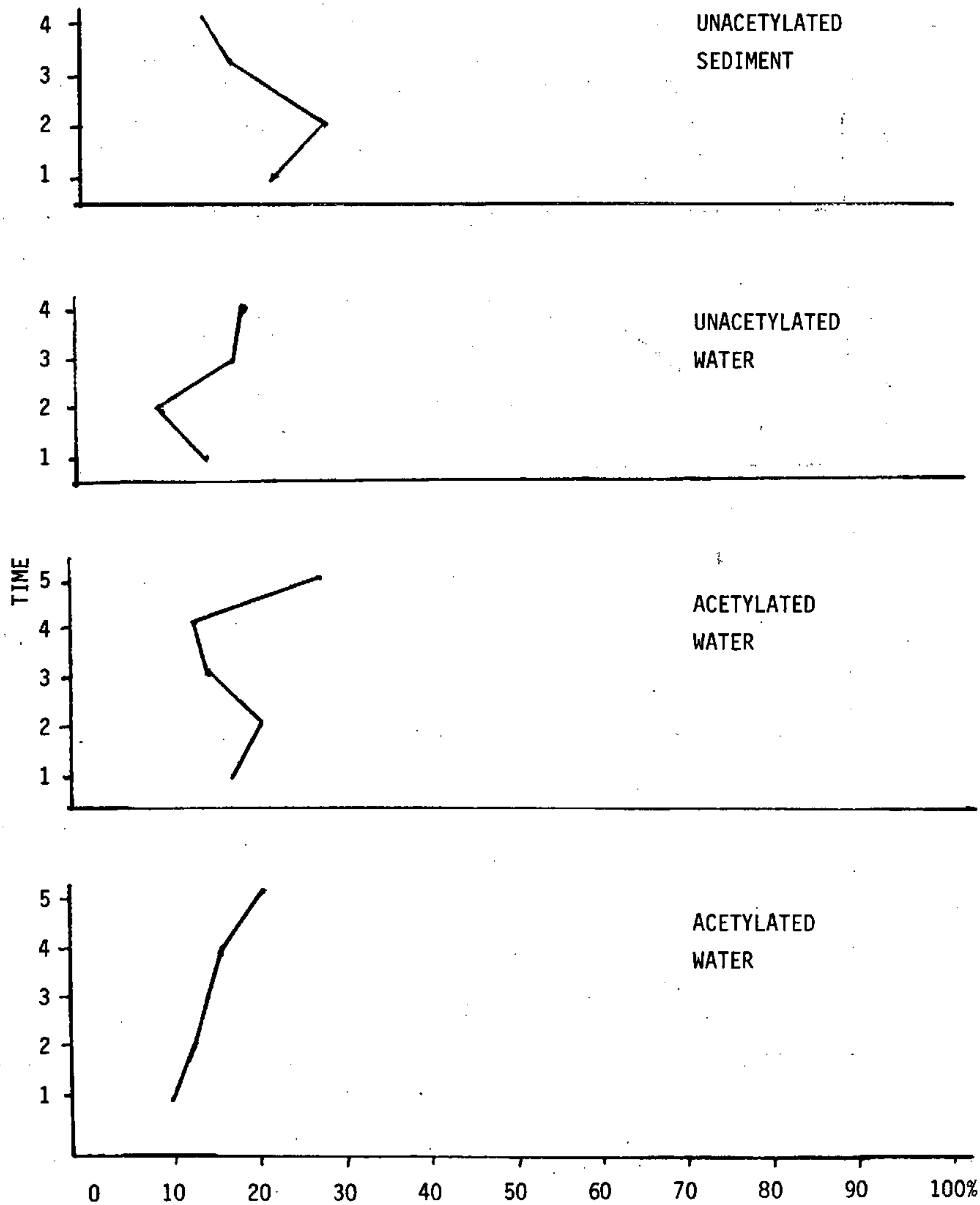


FIGURE 3 SAMPLE STATION 2

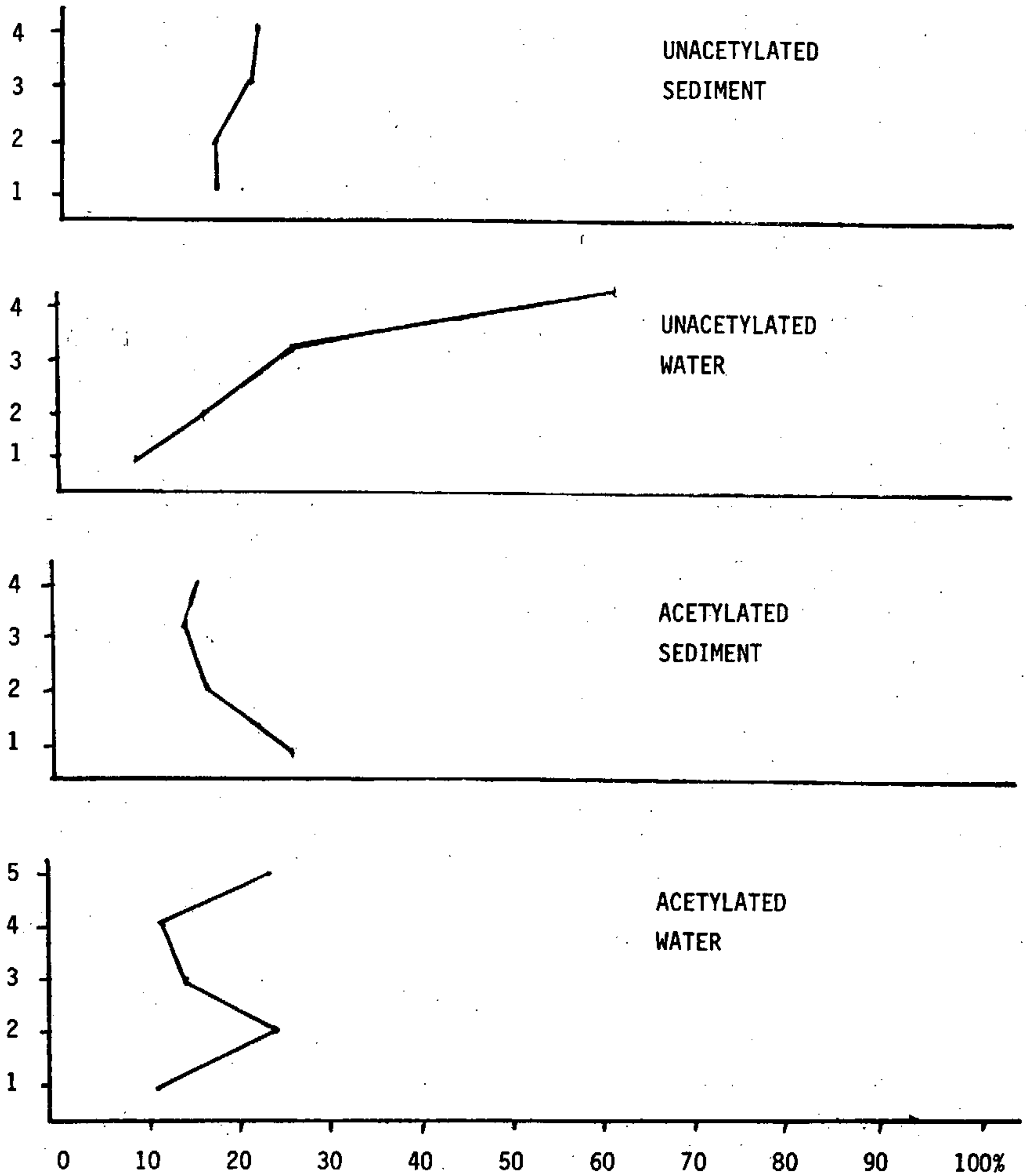
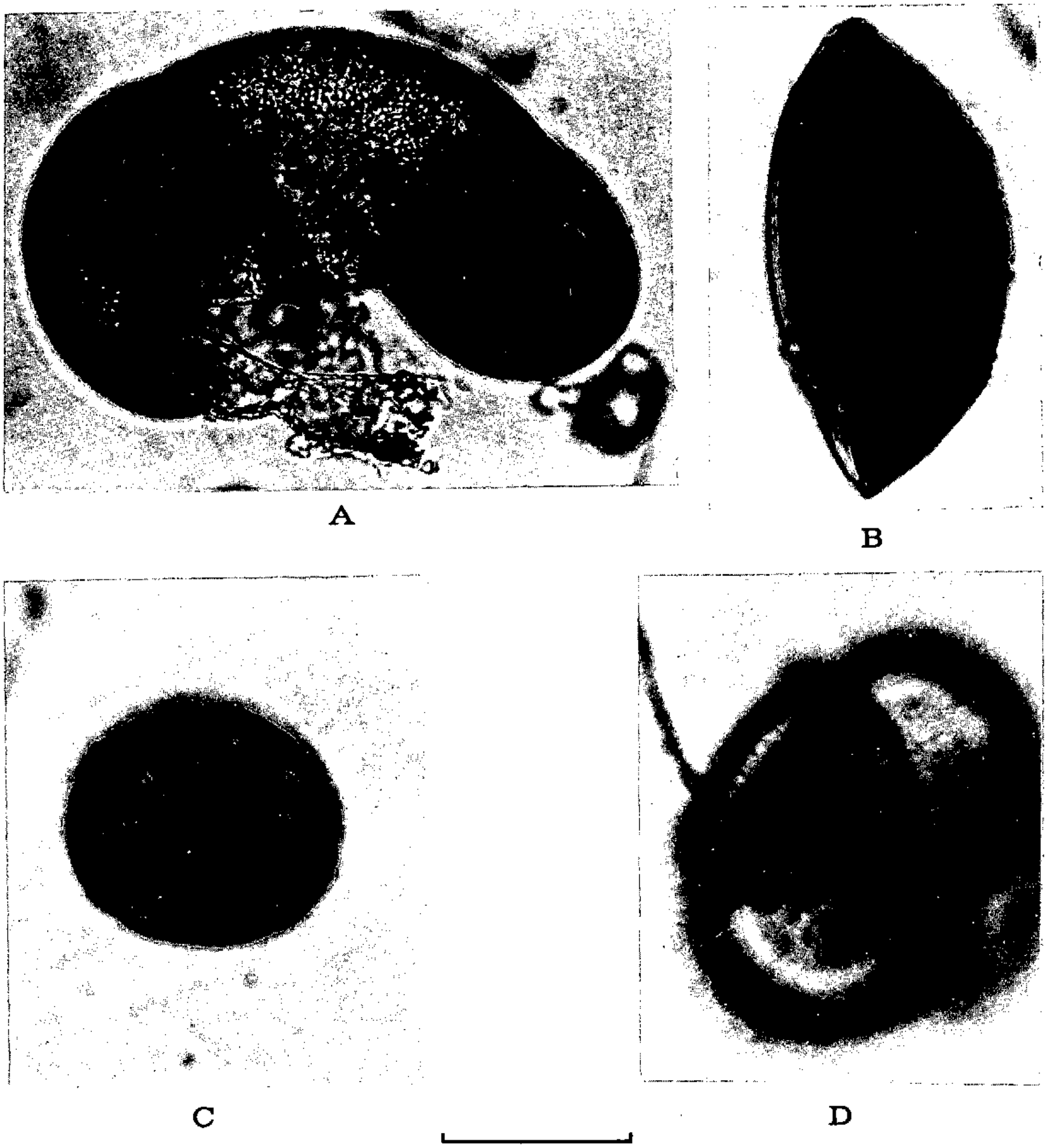


FIGURE 4 SAMPLE STATION 3



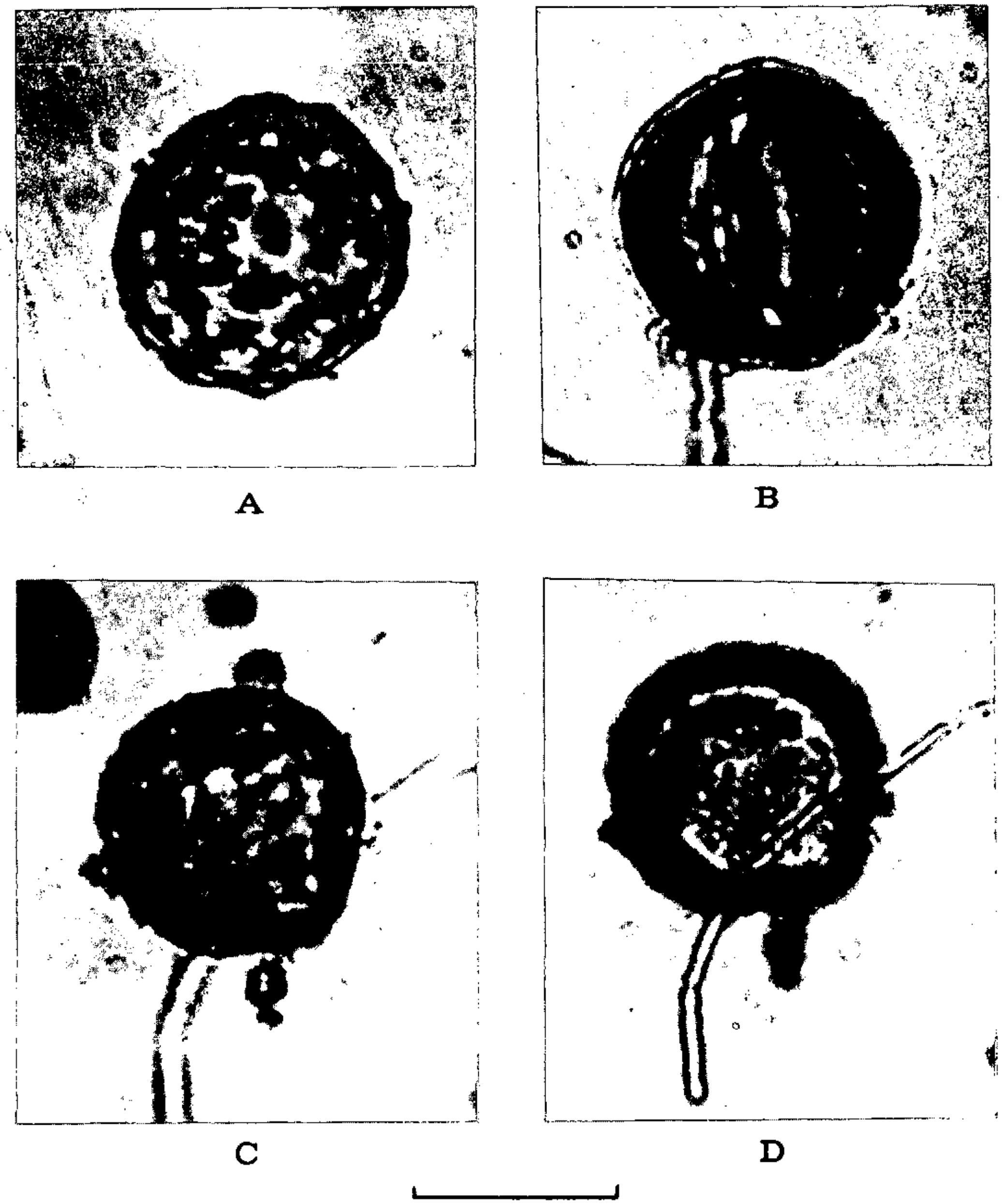
I A: <u>Picea</u> pollen grain, broken

I B: <u>Pseudotsuga</u> pollen grain broken

I C: <u>Amaranthus</u> pollen grain, corroded

I D: <u>Typha</u> pollen grain with fungal hyphae

LINE SCALE = 20 um ALL MICROGRAPHS



II A: Amaranthus pollen grain, degraded
II B: Artemisia pollen grain with fungal hyphae
II C: Quercus pollen grain with fungal hyphae
II D: Quercus pollen grain with fungal hyphae

LINE SCALE = 20 um   ALL MICROGRAPHS

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APPENDIX I

POLLEN FREQUENCY DISTRIBUTIONS FOR FIELD PHASE

I-1-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	4.0	1.5	1.0		12.0	6.0	16.0	1.5	4.5	16.0	6.5	3.5	8.5
	CRUMPLED	0.5	1.0			1.0								1.0
UNACETYLATED	BROKEN			2.5	0.5				7.0					
	CORRODED												5.0	
	DEGRADED			0.5										
	NORMAL	0.6		3.1	0.3	5.5	13.8	18.0	2.7	7.9	9.3	3.1	6.2	13.1
	CRUMPLED	1.3	0.6	1.0		1.3							0.6	1.3
ACETYLATED	BROKEN						0.3		2.4					
	CORRODED												6.2	
	DEGRADED													

I-1-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						18.4	12.6		21.5	9.5	2.3	1.7	8.5
	CRUMPLED	2.0	0.3	5.4	1.3	4.7						0.3		1.0
UNACETYLATED	BROKEN	0.3	0.6						3.7					
	CORRODED			1.0			0.3						2.3	
	DEGRADED													
	NORMAL						12.3	16.3	0.3	13.6	9.0	2.6	2.6	8.6
	CRUMPLED	1.6		0.3	0.6	6.3								6.0
ACETYLATED	BROKEN		0.6						5.6					0.3
	CORRODED			3.3				1.6					7.6	
	DEGRADED													

I-2-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	3.6		4.8		0.4	6.8	15.3	2.4	11.6	7.6	4.4	8.0	16.5
	CRUMPLED				2.4	5.6			1.6				4.0	0.4
UNACETYLATED	BROKEN					0.4			2.8					
	CORRODED												0.8	
	DEGRADED													
	NORMAL	1.8		2.1	0.3	1.5	11.1	17.9	0.9	13.2	8.9	2.1	3.3	10.8
	CRUMPLED	0.6	0.9	0.9		4.6		0.9	1.5	0.3			1.8	3.7
ACETYLATED	BROKEN			1.5					2.7					
	CORRODED									0.9			4.9	
	DEGRADED													

I-2-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL													
	CRUMPLED													
UNACETYLATED	BROKEN			NO POLLEN RECOVERED										
	CORRODED													
	DEGRADED													
	NORMAL	1.7		0.3			15.1	16.5	0.3	14.4	8.8	3.5	2.1	5.9
	CRUMPLED	2.1		0.7	1.0	4.2				0.3		0.7		4.2
ACETYLATED	BROKEN		1.0				0.7		4.9					
	CORRODED			2.4						0.7			7.7	
	DEGRADED													

I-3-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	2.3		7.0	0.6	1.0	6.7	18.5	2.0	11.8	9.7	2.3	5.7	16.5
	CRUMPLED		0.6	1.0		2.7							1.0	
UNACETYLATED	BROKEN		0.3	0.3					6.0					
	CORRODED					0.3				0.3			2.3	
	DEGRADED													
	NORMAL	0.3		3.0			14.5	20.5	1.3	12.5	7.4	2.7	5.0	13.5
	CRUMPLED	1.3		2.3	0.6	3.3						0.3	0.3	3.3
ACETYLATED	BROKEN			1.3			1.0		1.6					0.3
	CORRODED												2.3	
	DEGRADED			0.6										

I-4-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	1.2		4.7	0.8	5.1	8.5	21.5	1.2	9.4	9.0	4.3	5.1	14.5
	CRUMPLED	3.0				2.5								1.2
UNACETYLATED	BROKEN	0.4			0.4	0.8			3.8					0.4
	CORRODED												1.2	
	DEGRADED													
	NORMAL	1.8	0.3	2.1	0.3		12.0	19.0	0.3	19.4	8.7	1.4	5.8	8.7
	CRUMPLED	0.3		0.3		4.0								2.5
ACETYLATED	BROKEN								5.4					1.0
	CORRODED			0.3						0.3			2.5	
	DEGRADED					0.3								

I-1-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	2.0	0.8	2.0	0.4	7.6	6.4	11.7	16.5	8.4	8.8	4.0	10.0	16.9
	CRUMPLED	0.4				0.4							1.6	
UNACETYLATED	BROKEN		0.4						1.6					
	CORRODED													
	DEGRADED													
	NORMAL	2.3	1.0	2.8	0.5	4.9	11.7	23.7	2.3	10.1	13.5	1.5	6.5	12.5
	CRUMPLED		0.2	0.2									1.0	0.2
ACETYLATED	BROKEN			0.5		0.5			1.8					
	CORRODED												1.0	
	DEGRADED								0.2					

I-2-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.7	0.3	3.9	0.3	1.5	7.4	20.3	0.3	22.3	9.0	3.1	3.5	6.6
	CRUMPLED	0.7	0.3	1.9		0.7	1.9		0.3			0.3	0.3	1.1
UNACETYLATED	BROKEN			1.5			0.3		6.6					
	CORRODED												3.1	
	DEGRADED			0.3										
	NORMAL	1.0		1.2	0.2	1.2	11.7	18.4	1.2	13.9	14.5	1.7	4.7	11.7
	CRUMPLED	0.4	0.2	1.0		4.0			0.4					2.9
ACETYLATED	BROKEN		0.4	0.6					3.4				0.4	
	CORRODED												3.8	
	DEGRADED													

I-3-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	3.4		4.9	1.1	0.7	13.0	17.2	1.5	13.0	9.9	4.5	1.5	9.9
	CRUMPLED	0.7		1.9	0.3	4.5							0.3	0.7
UNACETYLATED	BROKEN		0.3						2.6					
	CORRODED												6.8	
	DEGRADED													
	NORMAL	0.8	0.4	4.9	0.8	0.4	16.9	12.5	0.8	21.8	10.7	0.8	4.9	7.5
	CRUMPLED	0.4		1.7	0.4	2.6								0.8
ACETYLATED	BROKEN	0.4	0.4						1.7					
	CORRODED												6.6	
	DEGRADED								0.4					

I-4-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL			1.7		2.5	12.1	15.0	2.1	11.1	13.2	5.3	4.3	6.4
	CRUMPLED	1.7	0.3	1.0	0.3	3.9								2.8
UNACETYLATED	BROKEN			0.7		0.3			6.4					0.7
	CORRODED			1.0			0.3		0.7				5.0	
	NORMAL	0.9	0.4	0.4		0.9	13.2	18.9	0.4	13.7	13.2	1.8	2.3	6.6
	CRUMPLED	1.8	0.4	1.4	0.4	2.8						0.4	0.9	3.7
ACETYLATED	BROKEN								3.3				0.4	0.9
	CORRODED	0.4		3.3			0.9						2.8	0.9
	DEGRADED			0.9										

I-5-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						2.1	2.1		8.5	3.4	0.8		9.8
	CRUMPLED				1.2	10.3	0.8			0.4		1.2		5.5
UNACETYLATED	BROKEN						0.4		3.4			0.4		
	CORRODED					1.2	6.0	0.4		4.7	2.5		10.3	3.0
	DEGRADED	0.4		4.7	0.4		4.2			1.7	2.1	2.1	3.0	1.7
	NORMAL	0.3				0.3	5.7	20.6		16.8	9.9	1.9	0.6	4.5
	CRUMPLED	1.5			0.3	4.2	0.6							3.8
ACETYLATED	BROKEN		1.5				1.5	0.3	3.0			0.3		
	CORRODED				0.6	0.3	4.9		0.3	2.6	0.3		7.2	
	DEGRADED			2.2					0.3				1.5	

I-5-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	4.0	1.5	1.0		12.0	6.0	16.0	1.5	4.5	16.0	6.5	3.5	8.5
	CRUMPLED	0.5	1.0			1.0								1.0
UNACETYLATED	BROKEN			2.5	0.5				7.0					
	CORRODED												5.0	
	DEGRADED			0.5										
	NORMAL													
	CRUMPLED													
ACETYLATED	BROKEN		NO POLLEN RECOVERED											
	CORRODED													
	DEGRADED													

II-1-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.7		0.3		0.7	8.4	13.1	1.5	13.5	10.8	3.4	3.8	6.9
	CRUMPLED	1.5	1.1	10.4	1.1	3.0	0.3						0.3	0.3
UNACETYLATED	BROKEN	0.3				0.3			4.2					
	CORRODED	0.3					2.7	1.1		6.5			1.5	
	DEGRADED									0.3				
	NORMAL	0.3					9.6	16.1		10.3	10.6	2.4	1.7	10.6
	CRUMPLED	2.0	1.3	0.3	0.6	9.6			0.3					3.4
ACETYLATED	BROKEN		2.0				0.3	0.3	4.8					
	CORRODED			0.6		1.3		2.4					6.5	0.3
	DEGRADED			1.3										

II-1-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL			0.3			6.0	17.8		15.9	8.9	2.2	2.8	9.5
	CRUMPLED	2.2	0.3		0.3	2.5						0.3		3.5
UNACETYLATED	BROKEN		0.3			0.3	0.6	0.3	6.7					
	CORRODED			9.9		0.3	1.5	0.6					3.8	
	DEGRADED			2.2										
	NORMAL				0.2	0.5	13.4	15.5	0.5	21.4	12.0	1.3	1.6	4.2
	CRUMPLED	1.3	0.5	2.1	0.2	1.6		0.2	0.2				0.5	6.9
ACETYLATED	BROKEN	0.2					0.5		4.2	0.2				0.2
	CORRODED			0.5			0.2	1.8		0.5			5.6	0.2
	DEGRADED												-.2	

II-2-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.4	4.1	18.5		11.5	9.4	4.5	4.9	4.5
	CRUMPLED	3.2	0.8	0.4	2.4	6.1		0.4				0.8		1.6
UNACETYLATED	BROKEN						0.8		6.5					
	CORRODED		0.4			2.0	1.2	0.8			0.4		6.1	
	DEGRADED			6.9		0.4								
	NORMAL	0.4			0.2	0.2	8.2	20.2		13.1	12.9	2.1	1.4	4.4
	CRUMPLED	3.0			0.9	2.3		0.7			0.2	0.4		6.8
ACETYLATED	BROKEN		0.4				1.1		5.8	0.4		0.2		
	CORRODED			0.2		2.5	0.4	2.8					6.1	
	DEGRADED			1.8		0.4	0.2						1.4	

II-2-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL													
	CRUMPLED													
UNACETYLATED	BROKEN			NO POLLEN RECOVERED										
	CORRODED													
	DEGRADED													
	NORMAL			0.2			14.1	14.3		19.4	10.7	2.0	1.7	9.7
	CRUMPLED	1.0	0.5	2.8	0.5	3.8								2.8
ACETYLATED	BROKEN		0.2				0.2		4.8					
	CORRODED					0.5		2.0					7.9	0.5
	DEGRADED													

II-3-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.2	6.2	18.4		15.0	12.4	3.6	5.0	8.2
	CRUMPLED	3.1	0.2	0.2	0.5	3.9								2.5
UNACETYLATED	BROKEN			0.2					9.6					
	CORRODED			3.3				0.5		1.6			4.2	
	DEGRADED													
	NORMAL	0.4					12.1	18.5		12.1	9.7	3.6	1.7	6.0
	CRUMPLED	2.6	0.2	0.9	0.7	4.1		0.2				0.4		7.8
ACETYLATED	BROKEN		1.4	0.2			0.7		4.8					
	CORRODED			1.2		0.9		1.7					5.3	
	DEGRADED			0.9									0.4	

II-3-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						10.9	14.5		13.0	12.4	4.2	2.4	8.5
	CRUMPLED	3.3	0.3	-.6	0.9	6.3						0.6		6.0
UNACETYLATED	BROKEN		0.6						6.0					
	CORRODED			3.3		0.9					0.3		2.7	0.9
	DEGRADED			0.3									0.3	
	NORMAL			0.2	0.2	0.4	13.4	16.8	0.7	18.5	13.2	0.9	4.4	7.3
	CRUMPLED	1.2		0.7	0.7	2.2	0.2	0.7						2.9
ACETYLATED	BROKEN		1.7	0.2			0.2		3.9					0.7
	CORRODED			2.4		0.2							4.1	
	DEGRADED			0.2				0.7						

II-4-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL				0.2		10.5	15.8		15.3	13.6	3.6	5.5	5.8
	CRUMPLED	1.6			0.8	2.7	0.2				0.2	0.2		3.6
UNACETYLATED	BROKEN		0.5						7.2					
	CORRODED			2.5			0.8	1.1		0.8			5.2	
	DEGRADED			0.8									0.2	
	NORMAL						12.8	15.8		18.8	9.6	2.2	6.1	4.2
	CRUMPLED	0.9		0.2	0.2	3.2				0.2		0.4		6.1
ACETYLATED	BROKEN		0.9				0.9		5.6	0.4				
	CORRODED			1.2		0.4	0.2	1.2			0.2		5.6	
	DEGRADED			1.2										

II-4-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL			0.3	0.3		6.5	18.4	0.3	25.0	10.7	2.0	2.4	7.6
	CRUMPLED	1.3		3.4	1.0	4.8	0.3					0.3	1.3	2.4
UNACETYLATED	BROKEN		0.6						5.2					
	CORRODED									0.3			4.1	
	DEGRADED								0.3					
	NORMAL	0.2			0.2	0.4	14.4	19.4		18.5	12.6	1.0	4.3	6.9
	CRUMPLED	1.0		2.1	0.4	4.3								3.2
ACETYLATED	BROKEN		0.2						5.4					
	CORRODED						0.2	0.8					3.4	
	DEGRADED													

II-5-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.5	6.0	15.5		12.7	8.8	2.2	1.9	7.4
	CRUMPLED	4.1			0.8	3.0	0.2	0.2			0.2	0.2		5.2
UNACETYLATED	BROKEN		0.5				1.1		4.7					
	CORRODED				0.2	1.6	5.2	0.8		1.3	0.8		5.2	1.6
	DEGRADED			4.4		1.3	0.8						0.5	0.8
	NORMAL	0.3					3.9	16.6		12.7	10.6	1.5	2.4	7.5
	CRUMPLED	0.9			0.3	0.6	0.9					0.6		8.7
ACETYLATED	BROKEN		0.6				1.5		6.6			0.3		0.3
	CORRODED	0.6			0.3	0.9	7.2						5.7	0.6
	DEGRADED			3.0		1.8								8.7

II-1-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	1.0				0.3	11.4	21.2		13.9	11.1	1.7	0.3	12.5
	CRUMPLED	2.4	0.3	2.4	0.6	4.5				0.3				0.3
UNACETYLATED	BROKEN								5.9					
	CORRODED			0.3			1.3	0.3		1.7			4.5	
	DEGRADED												0.6	
	NORMAL	1.1				0.5	15.0	20.3		13.4	10.6	2.2	1.3	11.1
	CRUMPLED	1.9		3.3	0.2	3.9								2.7
ACETYLATED	BROKEN			0.5					4.4				0.5	
	CORRODED						0.8	0.5		0.2			4.4	
	DEGRADED													

II-2-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL					0.4	14.7	20.5		14.2	10.5	3.7	2.5	14.7
	CRUMPLED	1.6	0.4	2.1	0.8	2.1			0.4					
	BROKEN		0.4						2.9					
	CORRODED		2.1					0.4					5.0	
	DEGRADED													
ACETYLATED	NORMAL						11.6	20.3		22.6	8.0	1.3	3.3	7.0
	CRUMPLED	0.6	0.3	2.3	0.3	4.0	0.3	0.3			0.3	0.3	0.3	3.6
	BROKEN		0.6	0.3			0.6		4.0			0.3		
	CORRODED							0.3			0.3		5.6	0.6

II-3-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL			0.4	0.4	0.8	10.6	17.9		20.0	10.6	4.7	0.8	6.4
	CRUMPLED	0.8		4.2		6.4						0.4		0.4
	BROKEN		0.4	1.2	0.4		0.4		5.9					
	CORRODED						0.4			0.4			3.8	
	DEGRADED			1.2										
ACETYLATED	NORMAL	NO POLLEN RECOVERED												
	CRUMPLED													
	BROKEN													
	CORRODED													
	DEGRADED													

II-4-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL			0.3	0.6	1.2	8.8	12.4	1.2	24.0	11.2	2.7	3.0	8.8
	CRUMPLED	1.8		5.1	0.3	0.6								2.4
	BROKEN		0.3	2.1					7.2					
	CORRODED							0.9					4.5	
	DEGRADED													
ACETYLATED	NORMAL	0.2				0.8	10.5	19.0	1.1	21.6	10.8	0.5	2.6	9.3
	CRUMPLED	1.1		0.2	0.8	3.0			0.2		0.5			1.4
	BROKEN		0.5	0.2					5.2					
	CORRODED			2.3		1.4		0.2					4.3	

II-5-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL													
	CRUMPLED													
	BROKEN			NO POLLEN RECOVERED										
	CORRODED													
	DEGRADED													
ACETYLATED	NORMAL	0.3			0.7	0.3	11.6	12.7		14.6	8.6	3.3	2.6	12.7
	CRUMPLED	1.4	1.8			5.2	0.3							5.6
	BROKEN					0.3	1.1		4.1					
	CORRODED	0.3					2.2	0.3		0.7			6.7	
	DEGRADED			0.7			0.3						0.3	

III-1-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	2.2			0.3		11.1	23.7	1.1	8.9	10.7	4.0	1.4	10.4
	CRUMPLED			8.5	0.7	1.4							1.8	2.2
UNACETYLATED	BROKEN		0.3	0.7		0.3			2.2					0.7
	CORRODED			0.3						1.8			4.0	
	DEGRADED													
	NORMAL	1.0		0.3	1.0	0.6	10.8	15.5	1.0	10.8	8.2	1.9	3.3	8.2
	CRUMPLED	1.6	1.3	3.3	0.3	3.6			0.3		0.3		1.0	6.6
ACETYLATED	BROKEN			1.0					6.6				0.3	0.6
	CORRODED					0.6	0.3			1.0			7.5	
	DEGRADED			0.3										

III-1-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						6.6	19.1		9.7	13.5	3.1	4.7	10.3
	CRUMPLED	3.4	0.6		1.2	7.5		0.3						1.2
UNACETYLATED	BROKEN		0.3				0.3		3.1					
	CORRODED			9.1			0.3	1.2					3.7	
	DEGRADED													
	NORMAL	1.1					9.8	14.6		14.6	11.2	2.5	4.2	7.3
	CRUMPLED	3.3			0.5	6.4		0.8						3.3
ACETYLATED	BROKEN		1.1	0.5					6.4					
	CORRODED			3.3				0.8		0.2			6.4	
	DEGRADED							0.5		0.2				

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL						10.0	18.4		9.6	9.2	5.6	3.6	17.6
	CRUMPLED	3.6	0.4	1.2	0.8	2.8								
	BROKEN		0.4						4.8					
	CORRODED			3.6				1.2		0.4			6.4	
	DEGRADED													
ACETYLATED	NORMAL	2.1	0.3	0.3	0.3	0.3	11.3	17.5	1.8	12.0	14.2	1.4	2.9	10.9
	CRUMPLED			3.6		2.9							0.7	3.6
	BROKEN						0.3		4.0					0.7
	CORRODED									0.3	0.3		5.1	
	DEGRADED							1.0		1.3				

III-2-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.6		6.2		0.3	8.2	21.3		4.1	10.3	4.4	3.7	14.1
	CRUMPLED		0.3	4.4	1.0	3.7			0.3				0.3	1.0
	BROKEN					0.3			5.1					0.6
	CORRODED									4.4			4.1	
	DEGRADED													
ACETYLATED	NORMAL						11.7	23.0		12.7	13.0	1.7	2.9	8.1
	CRUMPLED	2.4	0.2		0.7	2.9		0.9	0.2					3.1
	BROKEN		0.7				0.7	0.2	2.9			0.2		
	CORRODED			2.4		0.2		1.2					6.8	
	DEGRADED													

III-3-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.5		1.0			5.7	23.4	0.5	10.3	10.3	2.4	3.5	5.9
	CRUMPLED	1.9		6.2	0.2	4.3							2.7	2.4
	BROKEN	0.2	0.2	0.2					6.8					
	CORRODED						2.1	0.8		2.4			4.9	
	DEGRADED													
ACETYLATED	NORMAL			0.3		0.6	12.9	22.0		8.0	9.7	2.9	3.2	13.9
	CRUMPLED	3.8		0.6	0.9	4.8				0.3				0.3
	BROKEN		0.6				0.3	0.3	3.5					
	CORRODED			0.6		0.6	0.3	1.6		0.3			6.7	
	DEGRADED													

III-3-S

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL			0.3		0.6	12.9	22.0		8.0	9.7	2.9	3.2	13.9
	CRUMPLED	3.8		0.6	0.9	4.8				0.3				0.3
	BROKEN		0.6				0.3	0.3	3.5					
	CORRODED			0.6		0.6	0.3	1.6		0.3			6.7	
	DEGRADED													
ACETYLATED	NORMAL	0.8		0.2			12.0	19.7	1.1	13.1	11.7	2.2	5.1	6.5
	CRUMPLED	1.4	0.8	1.4	0.2	4.2		1.4				0.5	2.5	3.7
	BROKEN						0.2		3.1					
	CORRODED							0.8		0.2			5.4	
	DEGRADED					0.5								

III-4-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.6	0.3	3.4	0.6	1.0	6.9	3.8	1.0	9.7	10.4	3.8	1.0	7.9
	CRUMPLED	0.6		4.5	0.3	8.6							0.6	11.4
UNACETYLATED	BROKEN			2.0			0.3		7.9					
	CORRODED			1.3							0.3		6.2	
	DEGRADED				0.3	0.3	0.3	2.4					0.3	0.3
	NORMAL						11.7	18.0		20.6	10.4	2.8	4.3	9.5
	CRUMPLED	1.7	0.2		0.6	3.0								2.1
ACETYLATED	BROKEN		0.4				0.8		3.7					0.2
	CORRODED			1.7		0.2		1.0					5.8	0.2
	DEGRADED													

III-4-S

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.4	5.3	13.2		20.5	9.8	1.9	.9	14.7
	CRUMPLED	2.9			0.9	1.9								1.9
UNACETYLATED	BROKEN						0.4		6.3					
	CORRODED			3.9		0.9	0.4	0.9	0.4	0.9	0.9		4.4	
	DEGRADED			2.4							0.4			
	NORMAL					0.5	11.5	16.4	1.0	22.8	10.7	1.2	4.1	6.1
	CRUMPLED	1.0	0.7	3.0	0.2	2.5								5.1
ACETYLATED	BROKEN		0.2						3.8					
	CORRODED						0.5	0.7		0.2			5.9	
	DEGRADED							0.2					0.5	

III-1-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.8		0.8	0.4	1.6	14.7	15.5	0.8	11.0	13.9	2.0	2.4	14.3
	CRUMPLED		2.0	4.5		2.4							1.2	2.0
	BROKEN		0.4			0.8			2.0				0.4	1.2
	CORRODED							0.4	0.4				2.8	
	DEGRADED													
ACETYLATED	NORMAL	1.6				1.3	17.0	21.8	1.0	9.0	8.5	1.8	1.6	5.6
	CRUMPLED	0.5	0.2	3.7	0.2	4.0		0.5	0.5				1.0	7.2
	BROKEN		0.2			0.2			3.2					-.5
	CORRODED							0.2		0.5	0.2		6.9	
	DEGRADED													

III-2-W

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	2.4				0.8	12.4	16.4	1.2	10.4	12.8	2.8	2.4	6.8
	CRUMPLED	0.4	1.2	7.2		7.6								2.0
	BROKEN					0.4			3.6					
	CORRODED						0.4			4.8			7.6	
	DEGRADED													
ACETYLATED	NORMAL	0.7		0.7		0.3	13.8	18.9	0.3	16.6	8.3	1.5	1.1	5.9
	CRUMPLED	0.7	0.3	1.1		2.7								1.9
	BROKEN		0.3						7.9					
	CORRODED						1.5	2.7					7.1	
	DEGRADED			1.5		2.7								

III-3-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3					9.2	15.8		8.8	13.5	4.2	1.1	5.0
	CRUMPLED	2.3		2.3	0.3	5.0							1.1	6.5
UNACETYLATED	BROKEN		0.3						5.0					
	CORRODED			1.1		0.3	5.4	0.3		3.0			7.3	
	DEGRADED			0.7										
	NORMAL	1.2	0.3	0.9		0.3	9.1	17.2	0.6	15.0	8.8	2.5	4.7	8.1
	CRUMPLED	0.3		0.9	0.6	4.4		0.6				0.3	0.6	8.8
ACETYLATED	BROKEN			0.6			0.6		4.7					
	CORRODED							0.6		0.3			6.9	
	DEGRADED					0.3								

III-4-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL													
	CRUMPLED													
UNACTYLATED	BROKEN			NO POLLEN RECOVERED										
	CORRODED													
	DEGRADED													
	NORMAL	0.4					17.2	18.9		12.1	10.5	1.6	2.5	10.5
	CRUMPLED			2.1	0.4	2.9	0.4				0.4		0.4	5.4
ACETYLATED	BROKEN	0.4							4.6					
	CORRODED							2.1		1.6			5.0	
	DEGRADED													

III-5-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL				0.5		3.3	3.7		10.3	2.3	0.5		
	CRUMPLED	0.5				4.2	0.5					1.0	1.4	6.6
UNACETYLATED	BROKEN								5.1		0.5			
	CORRODED	0.5				1.0	9.4	2.8		9.4	3.3	3.7	9.9	2.3
	DEGRADED			6.1	0.5	0.5	1.0	0.5	1.0	1.4	1.8	2.3	1.8	
	NORMAL						11.1	19.4		15.8	10.3	1.1	0.3	7.9
	CRUMPLED	0.7			0.3	3.9						0.7		5.5
ACETYLATED	BROKEN		1.1		0.7		1.5		1.9			0.3		
	CORRODED					0.3	5.5	0.3		0.3		0.3	9.5	0.7
	DEGRADED			1.1			0.7						0.7	

III-5-W

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL				0.5	3.2	1.6	1.6		16.6	1.6		1.6	3.2
	CRUMPLED	0.5				2.6						0.5		2.1
UNACETYLATED	BROKEN		1.0				0.5		2.6				0.5	
	CORRODED					3.2	7.5			5.9	1.0		9.1	8.0
	DEGRADED		0.5	5.9		6.9	1.0			1.6	0.5	0.5	1.6	4.8
	NORMAL		0.3		0.3		10.7	22.7		9.6	11.0	1.6	1.0	4.3
	CRUMPLED	1.6				4.3	1.0							7.6
ACETYLATED	BROKEN		0.3			0.3			3.0				0.3	
	CORRODED	0.3			0.3	1.0	5.6	1.6					6.3	1.3
	DEGRADED			2.3									0.3	

APPENDIX II

POLLEN FREQUENCY DISTRIBUTION

LABORATORY PHASE

6 MONTHS

$Fe(SO_4)_3nH_2O$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.4	14.8	11.2		13.2	7.2	1.6	7.6	0.8
	CRUMPLED	2.0	0.4		0.8	8.0								5.2
UNACETYLATED	BROKEN		0.4	0.4				10.4			0.4			
	CORRODED			4.0				0.8			9.6			
	DEGRADED			0.8										
	NORMAL	0.3	0.3			2.1	17.4	10.5	0.9	8.7	11.4	1.8	10.2	4.5
	CRUMPLED	1.2	0.2	0.6	0.3	1.5	0.3					0.3		0.9
ACETYLATED	BROKEN		3.6				0.9		4.2					0.3
	CORRODED			3.0		0.3	1.2			0.3		0.6	11.4	0.3
	DEGRADED				0.3									

Na_2CO_3

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL				0.3	0.3	11.4	12.5		15.2	9.1	2.2	5.3	3.8
	CRUMPLED	5.7			0.7	6.4								0.7
	BROKEN		1.5					8.7						
	CORRODED					0.3							6.4	
	DEGRADED			7.0									6.4	
ACETYLATED	NORMAL				0.4	1.2	26.5	8.0		6.0	11.6	3.2	3.2	3.2
	CRUMPLED	1.2				4.0	0.8	0.4						4.4
	BROKEN	0.4	2.0			0.8	0.4		3.2					
	CORRODED	0.4						0.4					12.8	0.4
	DEGRADED	1.2		2.0		1.6								

$MgCO_3$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL					0.3	12.0	8.4		12.0	7.0	1.4	7.4	4.2
	CRUMPLED	2.8			0.3	6.3	0.3					0.7	1.0	6.3
	BROKEN		1.0			0.3		11.6			0.7			
	CORRODED	0.4				0.3					0.7		6.3	1.4
	DEGRADED			4.2										
ACETYLATED	NORMAL					0.4	18.4	11.2		10.4	10.4	2.0	4.6	5.8
	CRUMPLED	3.7			0.4	4.1	2.0		0.4			0.8	1.6	0.4
	BROKEN	1.2	4.6					3.7		0.4				
	CORRODED												11.2	
	DEGRADED			3.3										

$MgSO_4$ 20%

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3				0.6	5.5	9.0		11.8	9.7	3.1	1.7	2.7
	CRUMPLED	4.5			1.7	7.2							0.3	5.5
UNACETYLATED	BROKEN		1.7						10.4	0.3				
	CORRODED					0.3							14.2	0.3
	DEGRADED			7.2									1.0	
	NORMAL	1.3				1.7	20.0	12.1		3.0	15.6	2.1	4.3	6.0
	CRUMPLED	4.3			0.8	4.7	0.4							0.8
ACETYLATED	BROKEN	0.9	6.0						3.4					
	CORRODED					0.8	1.3						16.9	
	DEGRADED			3.0									1.3	

$CaCL_2$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						14.3	10.0		12.0	8.1	2.7	2.7	3.1
	CRUMPLED	2.7	1.1			6.9	0.7						1.9	4.6
UNACETYLATED	BROKEN		0.7		0.3	0.3			9.3			0.3		
	CORRODED						0.3	0.3		0.3			7.7	0.2
	DEGRADED			1.1									3.4	
	NORMAL				0.4	0.4	22.1	10.8		5.0	17.1	0.8	3.3	1.2
	CRUMPLED	2.5				4.6	1.6		3.7	0.4		0.4	0.8	2.0
ACETYLATED	BROKEN		3.7						0.4				0.4	
	CORRODED						1.6						11.7	
	DEGRADED			1.6									0.4	

$CaCl_2$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.7	7.4	8.6		7.4	9.8	2.3	1.9	10.1
	CRUMPLED	6.6	1.1		1.1	9.8	0.3					0.3	0.3	9.0
UNACETYLATED	BROKEN		0.3						4.7			0.3		
	CORRODED			0.3		0.7	0.7						5.3	0.7
	DEGRADED			5.4									3.1	
	NORMAL				1.2	0.8	18.7	12.6		6.5	13.4	5.3	7.3	5.7
	CRUMPLED	2.0				3.2				0.4				2.4
ACETYLATED	BROKEN		6.5				0.4		1.6				0.4	
	CORRODED						0.4						6.1	
	DEGRADED			4.4										

$NaHCO_3$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL				0.3		9.5	8.8		7.3	9.1	3.3	1.8	4.4
	CRUMPLED	3.3			0.3	8.4						0.3	0.3	3.3
UNACETYLATED	BROKEN	0.7	1.8						9.9					
	CORRODED					1.8							16.5	0.7
	DEGRADED			4.4		0.3							2.2	0.3
	NORMAL	0.4			0.4	0.8	19.8	8.6		8.6	12.3	0.8	5.3	3.7
	CRUMPLED	1.2				6.6	0.8							1.2
ACETYLATED	BROKEN		1.2						1.6					
	CORRODED					0.4							19.4	2.0
	DEGRADED			3.3			0.8							

$NaHCO_3$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NOMRAL	0.3					9.8	10.5		6.1	10.8	2.7	0.3	9.8
	CRUMPLED	2.7			0.3	6.1	0.6					1.6		2.3
UNACETYLATED	BROKEN	0.3	1.0						7.1					
	CORRODED					1.3	1.0	0.3					12.8	1.0
	DEGRADED			8.1									2.3	
	NORMAL				0.4	1.3	21.1	10.1		7.3	13.8	0.9	7.3	4.6
	CRUMPLED	1.8	0.9			3.6						0.4		
ACETYLATED	BROKEN		1.3						5.0					
	CORRODED										0.4		12.4	
	DEGRADED			5.9									0.4	

$KHCO_3$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						12.6	9.8		7.1	9.8	2.3	5.8	3.4
	CRUMPLED	4.7			0.6	8.1	0.3					0.3	0.3	4.7
UNACETYLATED	BROKEN		1.3						9.8					0.3
	CORRODED						0.3						8.1	
	DEGRADED			6.1		0.3				0.3			1.3	1.0
	NORMAL	0.3			0.3	2.5	20.3	12.8		8.9	12.8	3.2	5.7	1.7
	CRUMPLED	1.4		1.4	0.3	3.5	0.3		2.1	0.3		0.3		1.4
ACETYLATED	BROKEN		2.8						0.7					
	CORRODED			2.1			0.7						12.8	
	DEGRADED												0.3	

$KHCO_3$ 20%

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.3	8.3	7.0		8.3	11.4	1.3	1.6	4.3
	CRUMPLED	4.6	0.6		0.6	8.3						1.3	0.3	4.6
UNACETYLATED	BROKEN	0.3	0.3						13.4			0.6		
	CORRODED						1.0				1.3		9.3	2.0
	DEGRADED			5.7									2.0	
	NORMAL					0.8	20.2	13.2		2.0	15.7	1.6	4.9	2.8
	CRUMPLED	2.4				3.3	0.8					0.4		2.0
ACETYLATED	BROKEN		2.8		0.4		0.4		4.5					
	CORRODED					0.8	0.8						15.2	
	DEGRADED			3.3									0.8	

HCl

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.7	12.7	7.9		9.5	11.5	0.4	0.7	4.7
	CRUMPLED	2.7			0.4	4.3	0.4							6.7
UNACETYLATED	BROKEN		2.3						11.9					
	CORRODED					0.4							13.5	
	DEGRADED			7.5									0.7	
	NORMAL					1.2	21.7	8.1		7.1	12.0	3.5	4.2	4.8
	CRUMPLED	1.9				3.5	1.2						0.3	1.9
ACETYLATED	BROKEN		1.6						4.8	0.3				
	CORRODED						1.2						13.3	1.2
	DEGRADED			3.8			0.3						0.9	

HCl 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						10.6	10.2		6.5	17.2	1.2	8.1	6.6
	CRUMPLED	1.6	0.4		0.4	11.0						0.4	1.2	6.5
UNACETYLATED	BROKEN		0.8						2.4					
	CORRODED						0.8	0.4					4.9	
	DEGRADED			6.9									0.8	0.4
	NORMAL					0.4	21.9	10.0	0.8	5.2	12.2	1.3	8.7	2.1
	CRUMPLED	1.7			0.8	4.3	0.8		1.3			0.4	0.4	1.7
ACETYLATED	BROKEN		2.6				1.3		5.2			0.4		0.4
	CORRODED			1.3		0.8	0.8						8.7	
	DEGRADED			1.7									1.3	

NaCl

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.3	8.3	9.3		7.9	7.9	1.3	9.3	2.7
	CRUMPLED	2.4			0.3	9.3	1.0					1.7		8.6
UNACETYLATED	BROKEN		1.0			0.3		0.3	10.7	0.3				2.0
	CORRODED					1.3	0.3					0.3	3.4	0.6
	DEGRADED			6.9									1.0	
	NORMAL				0.3	0.7	18.4	11.6		4.5	10.9	1.5	8.6	3.7
	CRUMPLED	6.0				5.6						0.3		1.8
ACETYLATED	BROKEN		4.1						2.6			0.3		0.3
	CORRODED					0.7							13.5	0.3
	DEGRADED			2.6									0.7	

NaCl 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.7				0.7	9.4	8.7	0.3	12.1	7.9	3.0	5.2	14.3
	CRUMPLED	2.6	1.8	0.7	1.1	9.8							0.3	3.0
	BROKEN		0.3	0.7					8.3					
	CORRODED		2.2			0.7							5.3	
	DEGRADED													
ACETYLATED	NORMAL	0.8	0.4		0.4	0.8	27.9	10.2	1.6	5.3	11.1	3.2	6.9	4.5
	CRUMPLED	2.0				0.4	2.8					0.8		2.0
	BROKEN		2.0	0.4					0.8					
	CORRODED			1.6				0.4					11.5	
	DEGRADED			0.4									0.8	

$MgCl_2$ $6H_2O$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.2			0.2	1.4	9.3	10.4		5.6	8.4	1.9	11.2	4.5
	CRUMPLED	5.3	0.8	1.1		7.9							0.2	5.0
	BROKEN	0.2	0.5	0.2	0.2				13.8			0.2		
	CORRODED			1.6	0.2	0.5	0.2						7.0	0.5
	DEGRADED													
ACETYLATED	NORMAL	0.5	0.8			1.0	18.4	12.3	1.7	9.3	11.1	2.0	5.8	4.1
	CRUMPLED	2.0	1.7	2.3		3.5	0.2							1.7
	BROKEN		0.8						3.5		0.2		0.2	
	CORRODED												15.5	
	DEGRADED													

$MgCl_2\ 6H_2O$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	1.0	0.3		0.3		14.8	8.6		3.1	12.4	2.0	5.1	3.4
	CRUMPLED	5.1	1.7		0.3	7.2	0.3			0.6		1.0		3.4
UNACETYLATED	BROKEN		1.0	0.3					12.8					
	CORRODED			4.8				0.3					8.9	
	DEGRADED													
	NORMAL	0.2			0.2	1.6	21.5	9.4	0.5	7.2	11.0	1.6	5.3	3.6
	CRUMPLED	1.6	0.2	2.6		4.0	1.8							1.0
ACETYLATED	BROKEN		3.7	0.5					3.2			0.8	0.5	
	CORRODED							0.2					14.5	
	DEGRADED			0.2										0.2

$CaCl_2$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.3	13.5	7.7		7.7	7.7	2.7	4.6	1.5
	CRUMPLED	1.9		0.3	0.7	9.2						0.3		4.6
UNACETYLATED	BROKEN		3.0			0.3			10.4					
	CORRODED												15.8	
	DEGRADED			6.0			0.3							
	NORMAL	0.3				3.1	16.0	18.5	0.6	12.5	9.7	2.0	2.0	3.1
	CRUMPLED	1.3		0.6	0.3	3.1								1.3
ACETYLATED	BROKEN		3.4			0.3		0.3	4.1					
	CORRODED		0.3					0.3					15.0	
	DEGRADED			0.3										

$CaCl_2$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.8		0.4		0.2	9.0	7.2	0.4	8.0	10.0	1.8	4.4	9.8
	CRUMPLED	2.4	1.3	0.2	0.6	8.4				0.2				5.2
UNACETYLATED	BROKEN	0.2	0.6		0.2				10.8					
	CORRODED			6.4		0.2							11.2	
	DEGRADED													
	NORMAL	0.6	0.3		0.3	0.9	19.8	13.8	0.9	7.8	9.7	3.7	5.9	4.4
	CRUMPLED	0.9		0.6		4.0	0.9		2.8			0.3		1.5
ACETYLATED	BROKEN		1.8	0.6										
	CORRODED			0.9		0.3	0.6						14.1	
	DEGRADED			0.9									0.6	

$FeCl_2$ $6H_2O$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						11.6	8.9		6.5	7.6	4.4	6.5	12.3
	CRUMPLED	4.1	0.6		0.6	8.9								3.0
UNACETYLATED	BROKEN		1.0						7.9					
	CORRODED					0.3							8.2	
	DEGRADED			5.8									1.0	
	NORMAL					1.1	18.0	12.5		5.9	11.8	1.1	5.1	6.6
	CRUMPLED	1.4			1.1	3.3	0.3					0.7		1.4
ACETYLATED	BROKEN		3.3				0.3		5.9	0.3		1.8		
	CORRODED						0.7						13.6	0.3
	DEGRADED			2.5										

$FeCl_2\ 6H_2O$ 20%

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3		0.3			10.2	6.8		9.8	0.8	3.0	8.3	6.0
	CRUMPLED	4.5	1.5		0.7	7.1								0.7
UNACETYLATED	BROKEN		1.1						9.8					
	CORRODED		7.5			0.3		0.7					10.6	
	DEGRADED													
	NORMAL				0.9	0.3	14.7	12.7	1.3	7.5	13.3	2.9	5.2	4.5
	CRUMPLED	1.9	0.3		0.3	2.9	1.9					0.9		2.2
ACETYLATED	BROKEN		3.9		0.3				0.9					
	CORRODED			2.9			0.3	0.3					16.0	
	DEGRADED			0.3									0.2	

$NaSiO_3\ 9H_2O$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.8	10.3	4.1		8.2	7.4	2.4	0.8	9.6
	CRUMPLED	3.7			0.8	4.9						0.8		16.1
UNACETYLATED	BROKEN		2.4						4.1			0.4		
	CORRODED					1.6	0.4			1.2			8.2	1.2
	DEGRADED			8.2				0.4					0.8	
	NORMAL				0.7	2.6	15.4	11.6		7.9	11.3	3.0	4.0	1.8
	CRUMPLED	3.3				3.3						0.3		0.7
ACETYLATED	BROKEN	0.3	6.0				0.3		6.4					0.3
	CORRODED					0.3	1.1						12.8	0.7
	DEGRADED			3.7										

$NaSiO_3 \; 9H_2O$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL													
	CRUMPLED													
UNACETYLATED	BROKEN			NO POLLEN SAMPLE RECOVERED										
	CORRODED													
	DEGRADED													
	NORMAL													
	CRUMPLED													
ACETYLATED	BROKEN			NO POLLEN SAMPLE RECOVERED										
	CORRODED													
	DEGRADED													

KCl

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.6	14.5	10.0		9.0	9.0	5.2	3.4	1.0
	CRUMPLED	2.4			0.6	7.6						1.0		4.5
UNACETYLATED	BROKEN		2.4						9.3					
	CORRODED					1.7							9.7	
	DEGRADED			5.2						0.6			1.3	
	NORMAL					1.2	20.2	9.5		8.2	15.2	2.0	4.5	3.7
	CRUMPLED	2.4			0.4	6.6	2.0					0.4		1.6
ACETYLATED	BROKEN		4.1			0.4			5.3					
	CORRODED						0.8						6.6	0.4
	DEGRADED			2.0									1.2	0.4

KCl 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.2			0.2	0.5	8.1	11.6		7.3	9.2	1.0	2.4	5.1
	CRUMPLED	4.6	0.5		0.8	7.3				0.8		0.2	0.2	3.8
UNACETYLATED	BROKEN	0.2	1.3						12.2					
	CORRODED	1.3		1.0								0.2	11.6	0.5
	DEGRADED			5.1		0.2							1.0	
	NORMAL	0.3	0.3		0.7	2.5	18.6	13.1	0.3	7.6	10.2	1.8	2.9	4.7
	CRUMPLED	1.0	0.3			5.4	1.0		0.3					1.8
ACETYLATED	BROKEN		5.1			0.3			2.9					
	CORRODED			1.0				1.0					15.3	
	DEGRADED													

$MgSO_4$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3					9.5	11.6		10.6	9.8	0.3	1.4	4.5
	CRUMPLED	5.6			0.3	4.9						1.4		3.8
UNACETYLATED	BROKEN		2.8			0.3			10.6	0.3				
	CORRODED					0.7	1.4				0.7		10.9	
	DEGRADED			6.0									1.4	
	NORMAL	0.6				1.7	20.5	13.3		4.7	9.2	4.1	3.4	4.4
	CRUMPLED	2.3			0.3	3.0	0.3	0.3						3.4
ACETYLATED	BROKEN		6.8						3.0					0.3
	CORRODED												12.3	1.3
	DEGRADED			2.7									1.0	

$MgSO_4$ 20%

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.2			0.8	0.2	10.0	11.5		5.0	10.0	1.1	3.2	7.3
	CRUMPLED	4.4			0.5	5.9							0.2	4.1
UNACETYLATED	BROKEN		0.2			0.2			9.1					0.2
	CORRODED					0.5	0.8						9.4	
	DEGRADED			10.3									1.4	
	NORMAL	0.6				0.9	17.9	13.6		3.2	12.0	1.6	4.5	8.4
	CRUMPLED	2.2			0.3	4.5	0.3							0.6
ACETYLATED	BROKEN	0.3	4.3				0.3		2.2					
	CORRODED						1.6						16.2	
	DEGRADED			2.2			0.6						0.6	

H_2SO_4

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3				1.1	8.6	7.5		5.1	8.3	3.9	8.3	13.8
	CRUMPLED	1.1	0.3	3.5	1.9	11.4			0.3			0.3		1.9
UNACETYLATED	BROKEN		3.9						7.5					
	CORRODED			5.9		0.3							3.5	
	DEGRADED													
	NORMAL				0.3	0.3	24.0	10.5	0.7	5.8	8.0	2.5	8.3	4.7
	CRUMPLED	1.4				5.0	1.0							1.0
ACETYLATED	BROKEN	0.3	2.5			0.3	1.4		1.8	0.3		0.3	0.3	0.7
	CORRODED			2.5			0.3						12.0	0.3
	DEGRADED			0.7					0.7				0.7	

H_2SO_4 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL					0.7	15.1	11.8		9.9	12.5	1.8	3.3	6.6
	CRUMPLED	2.5			1.1	5.1						0.3		0.7
	BROKEN		1.4		0.3	0.3			4.0					
	CORRODED					0.3							7.3	
	DEGRADED			9.5									4.4	
ACETYLATED	NORMAL				0.3	0.3	19.2	7.8		6.2	16.8	1.1	4.7	3.1
	CRUMPLED	0.7				5.0	6.1					0.3	0.3	2.3
	BROKEN		2.7						4.3					0.7
	CORRODED						2.3						16.0	
	DEGRADED			3.1										

DEIONIZED H_2O

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.3					7.8	9.3		10.4	7.8	2.9	5.2	7.8
	CRUMPLED	3.7	1.4	0.7	0.7	10.0						0.7		3.7
	BROKEN								14.1					
	CORRODED			4.8									7.8	
	DEGRADED													
ACETYLATED	NORMAL				0.7	1.4	20.0	8.9	1.1	11.1	11.8	2.6	4.8	4.0
	CRUMPLED	4.8		1.4		5.5	0.7		0.3					0.7
	BROKEN		4.0						1.8					0.3
	CORRODED			1.8			0.7						10.4	
	DEGRADED													

$NaHCO_3 + MgCl_2\ 6H_2O + F3Cl_2\ 6H_2O + NaSiO_3\ 9H_2O$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3					11.7	10.1		6.6	11.3	3.1	2.7	2.7
	CRUMPLED	1.5			1.9	8.6	0.3			0.3				3.1
UNACETYLATED	BROKEN		1.1						10.5					
	CORRODED												14.1	
	DEGRADED			8.6									0.3	
	NORMAL	1.0			0.3		19.2	17.4		3.4	12.5	3.1	3.8	2.7
	CRUMPLED	1.7		0.3		2.4	0.6							2.0
ACETYLATED	BROKEN		4.1			0.6	0.3		2.7			0.3		1.0
	CORRODED					0.6							15.0	0.3
	DEGRADED			3.1										

APPENDIX III

POLLEN FREQUENCY DISTRIBUTION

LABORATORY PHASE

51 WEEKS

$Fe(SO_4)_3\ nH_2O$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						16.7	9.2		12.2	8.5	3.7	9.2	3.3
	CRUMPLED	2.2	0.3		0.3	7.8						0.7	0.3	1.1
UNACETYLATED	BROKEN		1.8		0.3				10.0			0.7		0.3
	CORRODED					0.7							2.2	
	DEGRADED			5.9									2.2	
	NORMAL					0.6	16.2	8.6		8.3	11.4	1.7	10.7	4.1
	CRUMPLED	3.8			0.6	5.1	1.0		1.0				0.6	2.0
ACETYLATED	BROKEN		3.8				0.3		3.4		0.3			
	CORRODED					0.6	0.6	1.0					9.3	
	DEGRADED			3.4									0.3	

Na_2CO_3

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.3	11.5	8.7		8.7	11.5	3.5	5.9	6.3
	CRUMPLED	2.8			0.3	10.5	0.3					1.0		3.8
UNACETYLATED	BROKEN		1.0						9.1					
	CORRODED					0.3	0.3						7.3	
	DEGRADED		0.3	4.5									1.0	
	NORMAL	0.3				1.9	16.2	7.9		7.6	10.2	1.9	4.6	4.6
	CRUMPLED	4.3			0.3	6.2	1.6		0.3				0.3	3.3
ACETYLATED	BROKEN		5.6			0.3			5.6			0.3	0.3	
	CORRODED				0.3								9.6	
	DEGRADED			5.6	0.3									

$MgCO_3$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.3	8.1	10.0		8.1	9.6	2.7	2.7	5.4
	CRUMPLED	5.4	0.3		0.7	11.6	0.7					1.9	0.3	3.1
UNACETYLATED	BROKEN		1.0	0.3		0.3	0.7		4.2			0.3		
	CORRODED					1.9	1.9		3.8	0.7			4.2	
	DEGRADED			5.4			0.7						1.9	
	NORMAL				0.4	0.8	16.6	10.5		10.1	14.2	2.8	4.4	3.2
	CRUMPLED	2.8	0.4		0.4	5.2	2.8	0.4	0.8	0.4			2.0	2.0
ACETYLATED	BROKEN		2.0				0.4		2.0					0.4
	CORRODED						0.8						9.3	
	DEGRADED			1.2									2.8	

$MgSO_4$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.7					7.4	5.6		4.4	8.9	3.3	7.4	20.9
	CRUMPLED	2.9			0.7	8.2						0.7		2.2
UNACETYLATED	BROKEN		4.1				0.3		9.3					
	CORRODED			5.2									6.3	
	DEGRADED												0.3	
	NORMAL	0.6			0.3		20.0	9.5		5.5	10.4	3.6	9.5	5.2
	CRUMPLED	2.9				3.9	1.3					0.3		1.3
ACETYLATED	BROKEN	0.6	3.9				0.6		1.9					
	CORRODED					0.3	0.6						11.8	
	DEGRADED			3.2										

$CaCl_2$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.3				1.0	11.3	12.3		7.5	6.8	1.3	1.0	8.5
	CRUMPLED	2.3			0.3	2.0						0.3	0.3	10.6
	BROKEN	0.3	2.0				0.6		11.9					
	CORRODED					3.7	1.0						5.4	1.3
	DEGRADED			4.7									2.0	
ACETYLATED	NORMAL	0.2				0.8	17.7	11.8		10.0	11.8	1.7	4.4	3.2
	CRUMPLED	2.3			0.5	4.7					0.2	1.1		1.1
	BROKEN		3.2				0.8		2.9					
	CORRODED					0.8	0.2						16.2	0.5
	DEGRADED			1.4									0.8	

$CaCl_2$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL					0.3	12.7	10.4		9.5	10.4	1.6	4.5	5.5
	CRUMPLED	4.2	1.6		0.6	3.6	1.3						0.3	1.9
	BROKEN		0.9			0.6	0.6		12.4			0.6		
	CORRODED					2.2							6.8	
	DEGRADED			5.9									0.3	
ACETYLATED	NORMAL	0.7	0.3	1.5	1.1	1.5	17.4	6.0		8.3	12.5	2.2	7.9	3.8
	CRUMPLED	3.0				2.2								3.4
	BROKEN	0.3	4.1	1.5		0.3	0.3		4.1					
	CORRODED			0.3			0.7						15.2	
	DEGRADED													

$NaHCO_3$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.3	10.7	10.4		9.7	7.6	1.7	8.6	5.5
	CRUMPLED	3.4	0.6			7.6	0.6		0.3			0.6	2.4	1.7
UNACETYLATED	BROKEN		1.7	0.3	0.3				10.4					0.3
	CORRODED			0.6			0.3		0.3	0.3			3.8	0.3
	DEGRADED			4.5									3.8	
	NORMAL					1.3	23.3	13.0		12.3	8.2	1.7	3.4	2.0
	CRUMPLED	1.7				3.4	3.0		1.3					1.3
ACETYLATED	BROKEN	0.3	2.7		0.3	0.3	1.0		3.4				0.3	
	CORRODED			0.6				0.6		0.6			8.9	0.3
	DEGRADED												3.4	

$NaHcO_3$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL				0.3	0.3	10.1	6.3		9.4	11.7	4.0	7.4	5.7
	CRUMPLED	2.6			0.6	4.7			0.6			0.6		6.0
UNACETYLATED	BROKEN	0.3	1.3						11.7					
	CORRODED					0.3							9.0	0.6
	DEGRADED			5.3										
	NORMAL	0.3				1.1	19.1	11.7		6.2	10.9	2.7	7.4	3.9
	CRUMPLED	2.7				5.4	0.3	0.3	3.5	0.3		0.7		1.9
ACETYLATED	BROKEN	0.3	2.7		0.3				2.3				0.3	
	CORRODED												9.7	0.7
	DEGRADED			3.9										

$KHCO_3$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.6	15.3	10.5		14.9	12.9	2.3	6.8	1.7
	CRUMPLED	2.7				3.7						0.6	0.6	
UNACETYLATED	BROKEN		1.3		0.3	0.3	0.3		12.2	0.3				
	CORRODED			0.3									6.8	
	DEGRADED			4.4									0.3	
	NORMAL					1.0	14.9	8.3		10.0	13.1	3.1	7.2	4.5
	CRUMPLED	2.7	0.3		0.6	2.4	1.7		1.7			0.3		2.7
ACETYLATED	BROKEN	0.3	4.5						1.3			0.3		0.3
	CORRODED					0.3							12.8	
	DEGRADED			3.8									0.6	

$KHCO_3$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3			0.3		12.2	13.7		13.7	11.1	1.4	6.2	2.2
	CRUMPLED	4.0			-.7	7.7						0.3		1.4
UNACETYLATED	BROKEN		2.2						8.8				0.3	
	CORRODED			3.3						0.3			8.8	
	NORMAL					1.8	15.9	13.0	1.0	4.7	11.2	2.8	5.7	3.9
	CRUMPLED	1.0	0.6	1.0	1.0	3.9			1.8			0.3	0.6	2.8
ACETYLATED	BROKEN	0.6	1.8						3.6					
	CORRODED			2.1									17.3	
	DEGRADED													

HCl

		ZEA	PSEDUDOTSUGA	POPULUS	PIGEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					1.1	14.0	11.2		10.5	6.2	1.9	7.0	10.8
	CRUMPLED	1.9			0.7	6.2						0.3		5.0
UNACETYLATED	BROKEN		1.1		0.3	0.3			9.7					
	CORRODED												4.6	
	DEGRADED			5.4									0.7	
	NORMAL					1.6	17.9	10.9		10.6	15.2	2.3	5.6	3.9
	CRUMPLED	2.6			0.6	3.6	0.9		2.6					0.6
ACETYLATED	BROKEN		0.9						0.3					
	CORRODED					0.3	0.6						13.9	
	DEGRADED			2.9									0.9	

HCl 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3	0.3		0.7	1.0	11.7	9.8		5.4	10.9	2.9	9.5	13.5
	CRUMPLED	3.2	2.9			8.0	0.3					0.3	1.0	1.4
UNACETYLATED	BROKEN		0.3						7.3					
	CORRODED			4.3		0.7	0.7						1.0	
	DEGRADED			1.0										
	NORMAL	0.9				1.2	18.4	10.7		6.1	12.6	1.2	4.9	7.0
	CRUMPLED	2.4	0.3	0.3	0.3	5.8	2.4		0.3			0.3		0.9
ACETYLATED	BROKEN	0.6	4.0	0.9		0.3	0.9		3.6					0.3
	CORRODED						0.3						12.3	
	DEGRADED													

NaCl

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.9	9.9	9.9		9.9	9.9	1.3		1.6
	CRUMPLED	3.6			0.6	8.3	1.3	0.3						4.9
UNACETYLATED	BROKEN		2.6				1.3	0.3	12.2					
	CORRODED					0.9	1.6					12.2		
	DEGRADED			4.9								0.3		
	NORMAL				0.3	0.7	16.0	14.4		10.5	12.1	1.9	2.3	4.2
	CRUMPLED	1.9		1.9		6.2	2.7					0.3		1.1
ACETYLATED	BROKEN	0.3	3.5			0.3	0.3		2.3					0.3
	CORRODED												15.2	
	DEGRADED													

NaCl 20%

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3				0.7	6.7	6.7		4.9	8.5	2.4	4.2	14.1
	CRUMPLED	5.3	2.4		0.3	10.2	1.0			0.3				3.1
UNACETYLATED	BROKEN	0.3					1.4		7.8		0.3	0.7		
	CORRODED			1.4									7.0	
	DEGRADED			7.0			0.3						1.4	
	NORMAL					0.3	18.5	8.9		7.5	12.5	3.5	6.7	4.2
	CRUMPLED	1.8		0.3	0.3	3.2	3.2						0.7	2.1
ACETYLATED	BROKEN		3.5		0.3	0.7	0.3		5.0					
	CORRODED			1.4									13.5	0.3
	DEGRADED			0.3										

$MgCl_2$ $6H_2O$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.6				0.6	8.2	13.0		11.3	5.1	2.0		2.4
	CRUMPLED	2.4			1.0	2.0						2.4	0.3	1.3
UNACETYLATED	BROKEN		2.7		0.3		0.6		13.4					
	CORRODED	0.3				7.9	2.4					0.3	8.5	
	DEGRADED			6.1									3.7	
	NORMAL					1.5	18.7	8.7		8.1	10.9	1.2	4.3	4.0
	CRUMPLED	3.1				2.8	1.5					0.3		2.5
ACETYLATED	BROKEN		2.5		0.3				4.3			0.3		
	CORRODED			0.6			1.5			0.3			15.3	0.6
	DEGRADED			4.0		0.9							0.9	

$MgCl_2$ $6H_2O$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.8	0.4		0.4	0.4	8.2	7.0		3.0	8.6	3.7	6.1	16.5
	CRUMPLED	3.7			0.4	10.3						0.4		7.0
UNACETYLATED	BROKEN		0.4						11.1					
	CORRODED			2.4									6.6	
	DEGRADED												1.2	
	NORMAL	1.4	1.8	0.7		0.7	20.1	10.2		10.6	13.1	1.0	5.4	3.2
	CRUMPLED	2.5	0.7	1.4	0.3	5.4	0.3	0.3	0.3					1.4
ACETYLATED	BROKEN	0.3	2.1						1.8					
	CORRODED						0.3						15.3	
	DEGRADED													

$CaCl_2$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						13.0	9.3		11.6	7.6	3.3	7.9	2.5
	CRUMPLED	3.3	0.2		0.2	12.1	1.4		0.2	0.2			0.5	1.1
UNACETYLATED	BROKEN	0.2	1.7			0.8			11.0			0.5	0.2	
	CORRODED												6.2	
	DEGRADED			3.6										
	NORMAL	0.3				0.7	16.5	9.5		9.5	9.8	4.9	9.8	4.5
	CRUMPLED	2.8		0.7	0.3	4.9	1.7	0.3	2.4					
ACETYLATED	BROKEN		4.2			0.3	0.7		2.4				0.3	0.3
	CORRODED			0.3		0.3	0.3						7.3	
	DEGRADED			1.7									2.1	

$CaCl_2$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						11.9	9.2		10.3	4.2	1.1	3.0	5.7
	CRUMPLED	4.2			0.3	5.7	0.3							11.5
UNACETYLATED	BROKEN		1.5			0.3			8.4					
	CORRODED			0.3		0.3		0.3					9.2	0.3
	DEGRADED			6.9									3.8	
	NORMAL	1.9				2.4	20.4	9.3		6.6	12.4	2.7	8.5	3.3
	CRUMPLED	2.2	1.1	0.5	0.2	4.1	0.5				0.2	0.5	0.8	2.2
ACETYLATED	BROKEN		2.7				0.2		3.0					
	CORRODED			2.4			0.2						10.4	
	DEGRADED													

$FeCl_2 \ 6H_2O$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.9			0.3	1.3	11.8	9.2	0.3	5.5	12.5	1.3	5.9	6.2
	CRUMPLED	4.6	2.3		0.9	8.8	0.3							3.2
UNACETYLATED	BROKEN		0.9						10.5					
	CORRODED									0.3			4.9	0.3
	DEGRADED			6.9									0.3	
	NORMAL	0.4			0.4	1.6	13.0	9.2		10.1	13.9	2.1	8.0	3.7
	CRUMPLED	2.5				5.4	2.1		4.2					0.8
ACETYLATED	BROKEN	0.4	4.2				0.8		1.6					0.4
	CORRODED												10.5	0.4
	DEGRADED			3.3										

$FeCl_2 \ 6H_2O$ 20%

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	1.3	1.3	0.3	0.6	1.9	9.5	9.8		11.1	9.1	1.6	7.2	11.8
	CRUMPLED	1.6	0.3	0.6	0.3	6.8				0.3			0.3	0.3
UNACETYLATED	BROKEN	0.3	2.9	0.3					11.4					
	CORRODED			3.9									4.2	
	DEGRADED													
	NORMAL		0.6			1.2	16.9	14.4		5.9	12.8	2.5	7.2	4.7
	CRUMPLED	1.8		1.5	0.3	6.2	0.6							1.5
ACETYLATED	BROKEN		2.5	0.6					2.8			0.3		0.3
	CORRODED			1.5									13.1	
DEGRADED														

$NaSiO_3\ 9H_2O$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.3					11.1	6.9		8.7	8.3	1.3	7.3	2.0
	CRUMPLED	8.0	2.0		0.6	11.5	0.3					1.0	0.3	0.6
UNACETYLATED	BROKEN			0.3	0.3		0.3		6.6			0.6	0.6	
	CORRODED												8.0	3.1
	DEGRADED			5.5		0.3							2.4	
	NORMAL					1.9	14.6	13.8		6.7	15.4	3.9	7.1	2.7
	CRUMPLED	3.9	0.3		0.3	1.5	2.7		0.3			1.1	1.5	2.7
ACETYLATED	BROKEN		2.3				0.7		0.7					
	CORRODED			0.3			1.5						5.1	
	DEGRADED			1.5	0.7									

$NaSiO_3\ 9H_2O$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL						0.7	6.8		1.4	9.0	1.4	2.1	1.8
	CRUMPLED	2.1			0.7	6.8				0.7		0.7		4.3
UNACETYLATED	BROKEN	0.3	2.1		0.3				19.8	0.7				
	CORRODED			0.3			0.7	1.4		1.0	1.0		9.7	
	DEGRADED		0.3	9.0			7.5			6.1				
	NORMAL	1.6				1.9	19.6	11.1		7.8	10.1	5.2	6.8	1.9
	CRUMPLED	1.3	0.6	0.9		4.9	0.6							0.3
ACETYLATED	BROKEN		4.5		0.3		0.6		4.5				0.3	
	CORRODED			0.6									12.0	
	DEGRADED			1.6										

KC1

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL					0.7	10.2	8.8		8.8	10.6	2.8	5.3	3.5
	CRUMPLED	2.8	1.0	0.3	0.3	9.5						0.3		0.7
UNACETYLATED	BROKEN		1.4	0.3		0.3			10.9					
	CORRODED			3.1						0.3			11.6	
	DEGRADED			5.3									0.3	
	NORMAL	0.6				2.0	20.6	8.7		5.5	16.4	1.3	3.8	5.9
	CRUMPLED	1.0		1.7		4.8	0.3		1.0			0.6		1.7
ACETYLATED	BROKEN		4.8	0.6					1.0					
	CORRODED												16.4	
	DEGRADED													

KC1 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
	NORMAL	0.4				0.4	10.9	10.5		12.6	10.5	0.8	7.7	2.8
	CRUMPLED	1.6		1.2	0.4	7.3							0.4	3.6
UNACETYLATED	BROKEN		1.2	0.4					15.4					
	CORRODED						0.4						8.9	
	DEGRADED			0.8							0.4		0.8	
	NORMAL	2.0				2.0	16.0	10.2		9.0	10.2	3.0	5.2	3.7
	CRUMPLED	1.7	0.2	0.7	0.2	4.5	0.7						0.5	1.2
ACETYLATED	BROKEN		5.7						5.2					
	CORRODED			3.2			0.7						13.2	
	DEGRADED													

$MgSO_4$

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL				0.3	1.3	9.4	14.5		6.0	11.4	3.3	3.7	4.3
	CRUMPLED	2.7	2.0			6.4	0.3					1.0		0.6
	BROKEN	0.6	3.7	0.3					9.1					
	CORRODED					0.3							11.8	
	DEGRADED			2.3									3.3	0.3
ACETYLATED	NORMAL					1.5	17.7	11.5		8.4	11.1	0.3	9.6	3.4
	CRUMPLED	2.7		0.7	0.3	2.3	1.9		3.4					1.1
	BROKEN		4.6	0.3					1.9					
	CORRODED			0.7		0.3	0.7						13.1	0.3
	DEGRADED			0.7										

$MgSO_4$ 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL					0.7	12.7	8.5		11.2	9.6	4.2	6.5	1.1
	CRUMPLED	5.0	0.3		0.7	10.4				0.3				1.5
	BROKEN		0.3				0.3		11.2					
	CORRODED					0.3							5.8	
	DEGRADED			6.5									1.5	
ACETYLATED	NORMAL	0.3				0.3	20.0	8.9		8.3	9.6	1.7	5.8	4.8
	CRUMPLED	4.4	0.3			5.2	1.7					1.0		1.3
	BROKEN	0.6	3.1		0.3		1.3	0.3	2.7				0.6	0.3
	CORRODED												12.1	0.6
	DEGRADED			3.1										

H_2SO_4

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	3.0	0.3		1.5	3.0	8.3	10.6		6.4	7.5	3.7	9.0	6.4
	CRUMPLED	0.3		0.7		9.8	0.3							0.7
	BROKEN								12.8					
	CORRODED												4.5	0.3
	DEGRADED		0.3	7.5										
ACETYLATED	NORMAL	1.4			0.2	2.8	15.0	14.4		6.6	11.2	2.6	6.6	5.4
	CRUMPLED	2.6				2.6	1.1						0.2	1.7
	BROKEN		4.6						3.7					
	CORRODED			0.2		0.5							13.0	
	DEGRADED			2.0									0.2	0.2

H_2SO_4 20%

		ZEA	PSEDUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL					0.3	7.6	12.8		5.4	16.4	1.8	5.1	2.5
	CRUMPLED	3.6	0.3		0.7	10.6	0.3					0.3		2.9
	BROKEN	0.3	1.8						2.9		0.3			
	CORRODED			1.4		1.0	0.3						4.7	0.3
	DEGRADED			9.1							0.3		5.4	
ACETYLATED	NORMAL	0.3			0.3	0.3	20.1	13.7		2.4	12.2	3.6	5.5	5.1
	CRUMPLED	0.9				4.5	2.7		3.3			0.6	0.3	0.9
	BROKEN		5.5				0.3		1.2					
	CORRODED			1.2			0.9						13.4	
	DEGRADED													

DIONIZED H_2O

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL			0.3	0.3		13.7	9.9		10.9	9.6	1.7	6.8	2.7
	CRUMPLED	4.1	1.0	4.1	0.6	8.5								0.3
	BROKEN		2.4	0.3					9.9					
	CORRODED			5.4		0.6							5.4	
	DEGRADED												0.3	
ACETYLATED	NORMAL				0.3	1.8	18.9	12.0		5.3	7.9	3.1	6.6	6.3
	CRUMPLED	2.5	0.3		0.3	5.6	0.3		1.5					2.2
	BROKEN	0.3	6.3		0.3				2.2					
	CORRODED			2.2			0.3						12.0	
	DEGRADED			0.3									0.3	

$NaHCO_3 + MgCl_2 + FeCl_2\ 6H_2O + NaSiO_3\ 9H_2O$

		ZEA	PSEUDOTSUGA	POPULUS	PICEA	PINUS	QUERCUS	ARTEMISIA	JUNIPERUS	SALIX	IVA	CARYA	AMARANTHUS	TYPHA
UNACETYLATED	NORMAL	0.7			0.3	2.5	9.6	8.5		20.7	12.1	1.4	7.1	2.8
	CRUMPLED	2.8	0.3		0.3	2.5	0.3							0.7
	BROKEN		1.0			0.3			7.8					
	CORRODED			0.7			0.3			0.3			7.8	0.3
	DEGRADED		0.3	5.0									1.0	
ACETYLATED	NORMAL					1.4	16.1	10.8		8.4	12.6	5.2	5.2	4.5
	CRUMPLED	3.1	0.3		0.3	4.5	1.7					0.3	0.3	3.5
	BROKEN		5.2				0.7		3.1			0.7	0.3	
	CORRODED			3.1			0.3						10.5	
	DEGRADED													

SEED DETERIORATION UNDER INUNDATION CONDITIONS
An Experimental Study

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Albuquerque, New Mexico

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INTRODUCTION

As a segment of the National Park Service Inundation Project, this study constitutes an exploratory investigation into parameters of deterioration of submerged botanical materials. The preservation of archeological plant remains is of interest because they may provide information both about past environment and prehistoric subsistence and economy. This study is really a specialized case of a much wider concern, namely the estimation of quantitative and qualitative relationships between plant assemblages as recovered from an archeological site and as originally deposited. Clearly, both selective and general deterioration will cause skewing or misrepresentation of the botanical record of climate and diet. Our ability to infer deterioration effects may thus allow a more realistic evaluation of the archeological record.

The specific emphasis of this study involved the description and quantification of morphological change in specific seed taxa, under different ambient conditions in both lab and field, and over varying lengths of time. A major goal was to isolate the action of specific factors that relate to rate and types of biological degradation.

While an extensive literature of seed-related studies exists (see Barton 1967), unfortunately, very little of the research done to date in seed biochemistry (and related fields) is of direct application to this project. For economic reasons, most studies involving seed deterioration have been geared towards estimating and measuring seed quality (seed viability and seedling vigor) over relatively short periods of time (Abdul-Baki and Anderson 1972). In such studies, for obvious reasons, less-than-optimal conditions are avoided as test variables, and morphological alteration is only of indirect (if any) interest. While available data on seed respiration, temperature, and moisture content is voluminous, research interest in seed condition wanes once the seed is dead (Harrington 1972). Agribusiness wants to know whether a seed will grow--not what it looks like. The chemical and structural characteristics of seeds are of interest only in so far as they affect germination rate. There is, however, an economic need (in construction and manufacturing industries) for information detailing the physical deterioration of wood under various conditions. Thus it has been determined that biological degradation of wood is "primarily a process of removal of cellulose," with the rate of cellulose loss correlating well with the degree of lignification and presence in the cell wall of protective substances such as resins, terpenes, and tannin (Barghoorn 1949:13). Equivalent information, detailed for different seed taxa, has simply not been pursued systematically. Data from nonagricultural seed species is especially scanty.

Factors affecting seed deterioration are not well known but may include mechanical breakdown (abrasion, crushing), chemical breakdown (oxidation), microbiological predation (indirect chemical breakdown), and macrobiological predation. In this study, similar seeds were immersed in various chemical environments (representing mean ionic constituents of a cross-section of North American lakes and reservoirs) in order to isolate the specific effects of individual chemical components. Seeds were also submerged in Brady Reservoir, McCulloch Co., Texas under varying conditions of location, time, and exclusion of size classes of predators. Since there is reason to believe that seed type and condition may significantly affect the rate and type of deterioration, seven different seed taxa, both burned and unburned, were immersed in each chemical environment and in each field test case.

Based on the expected patterns of results, a series of hypotheses were devised:

Hypothesis 1: There is a difference in seed preservation correlated with exposure to specific chemical compounds.

> Test Implication: There is a strong positive or negative correlation between the percentage of damaged seeds and specific chemical environments.

Hypothesis 2: Burned seeds will show significantly less deterioration than unburned seeds.

Test Implication (Lab Seeds): Fewer burned seeds will show evidence of deterioration than unburned.

Test Implication (Brady Seeds): Fewer burned seeds will be completely deteriorated (gone) than unburned.

Hypothesis 3: Some seed deterioration will result from the chemical and biological composition of sampling locations in the reservoir.

Test Implication: Survival rate of Brady seeds will be nonrandomly distributed with regard to sample location (Stations I, II, and III).

Hypothesis 4: There is a positive correlation between the extent of seed deterioration and the length of time the samples were exposed.

Test Implication: T2 seeds (exposed eight months) at Brady will be more highly deteriorated than T1 seeds (exposed four months).

Hypothesis 5: Considerably more seed loss will occur when macroorganisms have access to seeds.

Test Implication: Survival of Brady Filter C seeds will be considerably less than in Filters A and B.

Hypothesis 6: There will be significant differences in deterioration rates between specific taxa or between taxonomic groups (beans vs. corn vs. grains).

Test Implication: Attributes of deterioration will have a nonrandom distribution with respect to taxa.

In all cases the null hypothesis implies a random distribution of attributes of deterioration with respect to the variable being tested.

METHODS AND MATERIALS

EXPERIMENTAL DESIGN

In 1978, experiments for the study of seed deterioration were set up by Steve Fosberg to parallel studies of other artifact categories (bone, shell, wood, lithics, and ceramics) in the Inundation Project. As with the other material classes, seeds were immersed for specific time intervals under a series of laboratory and field conditions. Once the seeds were removed and dried, a series of observations and measurements were taken to determine the nature and extent of seed deterioration under the various conditions.

Laboratory Phase

In the laboratory phase of the study, Fosberg planned to control for chemical environment in order to isolate deterioration effects of various ionic components of reservoir water. A series of 14 chemical solutions, representing average concentrations of cations and anions in typical North American freshwater reservoirs or lakes (Fosberg 1978), were prepared by John Husler, Department of Geology, University of New Mexico (Table 1). Two series of solutions were prepared, a concentrated series numbered 17 through 30 in this study and a series diluted 1:20 (numbered 1 through 14). The assumption was that the more highly concentrated solutions would escalate any effects due to the action of the chemical environment and, therefore, simulate a longer passage of time. Such a measure was necessary since long-term change is clearly of interest here, and the study was limited to one year. Two control solutions were also prepared: #15 (deionized water) controlled for the effect of immersion alone versus the effects of chemical compounds in solution, and #16, a mixture of four of the chemical compounds ($NaHCO_3 + MgCl_2.6H_2O + FeCl_2.6H_2O + NaSiO_3.9H_2O$), allowed interaction of the ionic components, such as would occur in an actual reservoir or lake.

In order to isolate the deterioration effects of specific chemical compounds, other factors that might contribute to deterioration must be controlled. Thus, it was hoped that biological predators would be omitted during the laboratory phase of this study. Macroorganisms, common in a natural lake or reservoir, were of course absent, but a means for controlling the effect of microorganisms was not included in the experimental design. In fact, microorganisms appeared to have been a major contributing cause of seed deterioration. Larry Barton has noted that soil bacteria common on the surface of seeds could easily contaminate the test vats and account for the flourishing cultures present at the close of the experiment (personal communication). Barton has suggested that autoclaving or chemical sterilization (either of which may possibly affect seed condition and susceptibility to deterioration) would have precluded microbiological activity (algal, fungal, and bacterial growth).

Field Phase

The field phase of the seed study was conducted by Sandra Rayl and John Ware in order to observe deterioration of seeds and other artifact categories in an actual reservoir. Samples were placed at three different locations in Brady Reservoir (see Table 2) to test whether there was variability in deterioration that correlated with variability in biological or chemical composition throughout the reservoir. At each location, seed specimens were placed in three containers, each designed to allow entry (and hence predation) of a different size classification of organisms. Finally, the effect of time on rate or extent of deterioration was studied by means of equivalent data sets immersed (at all three stations and all three filter systems) for two four-month time intervals.

SEED TAXA STUDIED

Beans

Beans have a particularly poor record of appearance in archeological sites (remains occur rarely and are usually charred and fragile).

There are several conditions which determine bean preservation in archeological contexts. In their experiments on deterioration of botanical remains, Gasser and Adams noted that beans degenerated more rapidly than the other materials tested. Beans have a thin, fragile seed coat which breaks rapidly, leaving the interior immediately susceptible to external factors. When the seed coat breaks, the bean splits into its two cotyledons, facilitating deterioration. This process can be accelerated by seed germination, with the seedlings soon dying. Beans are also vulnerable to attack by mold (Gasser and Adams 1979:3). Aside from the problems of survival, beans are also less likely to be deposited in the site in the first place. "Beans, unlike corn, seldom yield a waste or by-product which can accumulate in the debris of a cave or dwelling over a period of years. Threshing of dry beans, as described in historic times among Indians in the Southwest (Whiting 1939; Castetter and Bell 1942), is carried out in flat areas well removed from habitations. "The beans arrive at the habitation site ready for the pot or storage with nothing to be discarded except, perhaps, the culls. The practice of threshing beans in the field from the dry picked pods or from piles of the harvested whole plant is widespread in Indian America" (Kaplan 1956: 199-200). Unlike small seeds of annual weeds, such as Chenopodium or Amaranthus, or even slightly larger seeds of Oryzopsis, the larger size and often bright or distinctive coloring of beans enhances their visibility, and reduces the likelihood of their going unnoticed on habitation, roof, or plaza surfaces.

All three bean types tested here (pinto, kidney, and navy) are varieties of the common bean, Phaseolus vulgaris, domesticated in the New World. Kaplan points to the highlands of Mexico and Central America as centers of present-day diversity and probable origin of domestication (1956:191-2). While numerous variations on the kidney bean have long history in the Southwest and Mexico, pinto beans are a relative newcomer to North America. The only known prehistoric collection of pintos in the Southwest comes from the Verde Valley, indicating a distribution limited to a single variety of the Garrapata [or tick bean] group as well as a rather restricted range of cultivation (op. cit. 222). I cannot find any reference to beans corresponding to the navy bean type, appearing in southwestern archeological sites.

Corn

Remains of Zea mays are by far the most common botanical debris of domesticates found in archeological sites. For instance, corn comprised 57% by weight of the nonwood vegetal assemblage collected during stabilization of Sliding Rock Ruin, Canyon de Chelly National Monument (Struever n.d.:24). Examination of a well-preserved assemblage from a "dry" site, such as Sliding Rock, provides insight into the range of corn plant parts deposited in archeological contexts, many of which are missing (presumably due to selective deterioration) in assemblages from open sites. These include parts brought to the site for storage (cobs with kernels, or loose kernels) and nonfood uses (cobs without kernels for fuel, and stalks and leaves for thatch, padding, etc.). Tassels, which may have ceremonial significance, and roots were also retrieved. Factors of both deposition (food processing techniques, disposal patterns) and preservation (including probable durability of charred specimens) are expected to contribute to the high proportion of corn specimens in archeological assemblages.

Corn types used in the Inundation Project include a modern popcorn variety and Hopi Blue Corn.

Grains

The cereals include annual grasses "grown chiefly for their large 'grains' which provide a concentrated food source." (Renfrew 1973:30). Triticum (wheat) and Secale (rye), both of Old World origin, are among the earliest domesticates of man (see Renfrew, Ibid., for a detailed discussion of the origin and distributions of these genera).

The grains of wheat and rye are similar in morphology, being ovoid in form, and "pointed at the . . . base where they were attached to the floret, and blunt at the apex . . . rounded on the dorsal surface, and [with] a deep, longitudinal groove on the ventral side" (Ibid.:31).

Using characteristics outlined by Renfrew (Ibid.:60-1, 85), untreated specimens of these two genera could be distinguished reliably in most cases. Submerged and/or charred grains were often difficult or impossible to tell apart.

CONDITIONS

Controls

Because the laboratory seed specimens were not measured before immersion, 30 specimens of each taxon, both burned and unburned, were analyzed to determine a range of pretreatment variability for each taxon.

Laboratory Phase

In December of 1978, a grab collection of specimens of each taxon (both burned and unburned) was immersed in each chemical solution. For each chemical environment, all burned seeds were stored in one 125 ml plastic bottle with screw cap and all unburned seeds in another. The solutions were replaced after the initial 4-month interval, then left undisturbed for the remainder of the experiment. This is in contrast to other artifact categories, where chemical solutions were poured off and replaced at more frequent intervals (Sandra Rayl, personal communication).

On December 13, 1979, contents of each bottle were poured through a fine screen (0.35-mm mesh). The liquid portion was returned to the bottle immediately and retained for later water and microbiological analysis. The seeds were spread on paper toweling to dry, with an additional sheet of toweling as a dust cover.

Field Phase

In contrast to the lab phase, a known number of seeds (10 burned and unburned of each of the seven taxa) were placed in each of the test situations at Brady. In April of 1978, two full sets of specimens, one to be retrieved at four months and one at eight months, were placed at each of the three stations.

Measurements and Observations

After a thorough air drying, each seed was measured and checked for a series of damage attributes. Measurements included length, width, and thickness, as a means of determining size and shape changes. Vernier dial calipers were used, and measurements were made to the nearest 0.1 mm. Ten burned and unburned seeds of a single taxon were weighed on a top-loading balance accurate to the nearest 0.01 g. Combined weights were used in order to avoid compounded rounding errors on the lighter specimens (i.e., wheat and rye). Condition attributes observed included: presence of nonsuperficial cracks extending into the endosperm; occurrence of severe seed coat damage, in which less than approximately 80% of the seed coat was remaining; occurrence of partial or complete separation of the two cotyledons in beans; and absence of endosperm in the grains and corn (in this latter instance only the tough seed coat remains).

RESULTS

DESCRIPTION OF SEED CONDITION

Laboratory Phase

Cracked endosperm occurs more commonly in burned seeds than unburned (Table 3). Among unimmersed seeds the burned specimens exhibit more cracking than unburned, and immersion of burned seeds seems to considerably increase the incidence of cracking. Unburned seeds do not appreciably increase in cracking after immersion. Thus, it would appear that burning itself is initially responsible for much of the endosperm cracking and that cracking is exacerbated by soaking. Differences between solutions appear to be less than between taxa. As a group, beans [1] are subject to the most cracking, with the smaller navy beans less so. Burned corn is also subject to considerable cracking, while unburned corn is not. Wheat and rye are generally least subject to cracking.

As with cracked endosperm, it appears that burning by itself is responsible for some degree of seed coat damage (Table 4). Soaking increases coat damage greatly for burned seeds and only slightly for unburned seeds. The "thin, fragile seed coat" of beans (Gasser and Adams 1979:3) no doubt influences the susceptibility of both burned and unburned beans to coat damage. Burned corn exhibited some coat damage, while unburned corn did not. Rye seems to be slightly more subject to coat damage than wheat.

Splitting of cotyledons occurs naturally in the course of bean germination, as the result of physical and chemical processes initiated by water absorption. In this experiment, cotyledon separation was clearly related to water uptake, and splitting was a much greater problem in burned specimens than in unburned (Table 5). Note that some split unburned seeds may have subsequently deteriorated totally, and hence would not be available for counting. In fact, comparison of the characteristics of the same seeds after wetting and drying indicated that much cotyledon separation took place after the seeds were removed from solution and dried.

Missing endosperm did not occur in beans[1] or unburned corn (Table 6). The chief occurrence of this characteristic was in unburned rye.

Field Phase

The most obvious trend noted in the data from the field phase of this study is not the percentage occurrence of particular damage attributes, but simply survival of seed specimens. In the field phase,

[1]Beans technically do not have endosperm tissue. Characteristics of the cotyledons (which have the analgous role of food storage) were observed for beans.

a known number (ten) of seeds of each taxon was subjected to each test condition, making it possible to determine the number of seeds that were totally deteriorated. There was a dramatic difference between the number of burned seeds surviving all conditions in the reservoir, compared with unburned seeds (see Table 7). In many cases, <u>all</u> specimens of unburned seeds were entirely missing, while under the same test conditions, at least some burned specimens of every taxon were still present. Because the total number of observable unburned seed specimens was so low, it was difficult to compare the field and lab results.

As in the laboratory experiment, cracked endosperm (Table 7) was observed more frequently in burned specimens at Brady (35% of surviving burned seeds) than in unburned specimens (24%). Among the burned seeds, at least, differences between the test conditions are overshadowed by differences between taxa. For example, within the three classes of beans included in the experiment, the kidney and pinto beans tended to crack more frequently than the navy beans. While burned corn and beans seem to exhibit a similar propensity for cracking, cracking was considerably less common in wheat and rye.

Seed coat damage (Table 8) occurred in 28% of the burned seeds at Brady, compared to 15% of the unburned seeds. In both burned and unburned seeds, coat damage occurred far more frequently in all three bean types than in corn and grains. Burned rye exhibited more coat damage than burned wheat. All three of these trends in the distribution and frequency of seed coat damage in the reservoir samples are similar to trends observed in the laboratory data.

Splitting of cotyledons (Table 9) occurred more commonly in burned beans (55% of surviving specimens) than unburned beans (26%). Again, this parallels the laboratory results.

As observed in the lab, missing endosperm did not occur in beans or unburned corn (Table 10). Among burned specimens, absence of endosperm was recorded with similar frequencies in corn and grains. However, the highest percentage of this trait occurred in unburned rye.

Application of Data to Hypotheses

Laboratory data was reviewed in order to determine whether seed preservation varied significantly with respect to chemical environment (Hypothesis 1). Categorical deterioration effects (Tables 3-6) show subtle, if any, differences between chemical environments. Ordinal data (length, width, and thickness measurements) for beans were analyzed for each chemical environment, using the FUNCAT procedure, an SAS package computer program (SAS 1979). All tests produced low R-square values, indicating greater variability measurements within chemical environments than between chemical environments. Thus, chemical environment could not be shown to be a significant determinant of deterioration effects.

It was expected that burned seeds would show less evidence of deterioration than unburned seeds (Hypothesis 2). Fewer burned than unburned seeds in the Brady Reservoir experiment were completely deteriorated (missing). However, in both the lab and field experiments, the charred seeds showed an unexpected higher rate of physical damage. While this is partially attributable to the burning process (see Table 3-6), the combination of burning plus inundation compounded the damage. When laboratory seed weights were examined, it was apparent that, in general, burned seeds lost less weight after immersion in both the control environment and the various chemical solutions (Table 11). Popcorn, however, proved anomalous. Unlike the other taxa, the burned popcorn tended to weigh more than the unburned, despite the fact that weight loss in the burned popcorn was particularly high. After submersion, weight loss for unburned popcorn was less than for the other unburned taxa, and also less than burned popcorn.

While it is clearly possible to discount the null hypothesis that there is no relationship between charring and seed damage, addressing

Hypothesis 2 proved more complex than originally expected. Although burned seeds appear to be more susceptible to greater variety of damage attributes, they are less likely to totally deteriorate (at least as shown by the field experiment).

Hypothesis 3 concerned the relationship between degree of preservation and sampling location in Brady Reservoir. Comparable data were available for Time 1, Filters A and C at Stations I, II, and III. When the survival rate of all seeds was compared using a chi-square one-sample test for goodness of fit, there was not a statistically significant difference between the three sample locations (0.95 p 0.90).

It was presumed that seed deterioration would progress as a function of the length of time the samples were exposed (Hypothesis 4). No comparison of laboratory data could be made since the seeds were all immersed for the same time interval. Comparable data available from the Brady experiment included Station I (Filters A and C) and Station III (Filters A, B, and C). A chi-square one-sample test indicated no significant difference in survival of seeds of all taxa between time periods (0.05 p 0.10). In the pollen portion of the Inundation Study, however, Holloway found time to be the most significant factor in determining extent of pollen degradation (1980:23).

In the Brady experiment, three filters allowed access of three different size classes of predators. It was expected that the amount of seed deterioration would correlate with mesh size of the filters (Hypothesis 5). At Station III, data were lumped for all taxa and time intervals within each filter size. Survival of seeds followed the expected pattern, with the highest survival rates in the smallest filter (Filter A, 67 seeds), intermediate survival rate in the intermediate filter (Filter B, 52 seeds), and lowest survival rate in the largest filter (Filter C, 31 seeds). A chi-square one-sample test showed this distribution to be nonrandom (0.05 p* 0.001). Survival data from Filters A and C, at Stations I and III were also compared, and as expected, produced even more significant results (p* p.001).

Holloway found that deterioration "affects different pollen taxa at vastly different rates" (1979:27); similar results were expected for seeds. In terms of survival of seeds (known only from the field experiment), there were no significant differences between taxa for the uncharred seeds. There were, however, significant differences observed in burned seeds. For example, burned beans showed extensive seed coat damage more often than other taxa (p* 0.001, using a chi-square one-sample test on burned lab seeds). Burned beans also showed significantly higher rates of "endosperm" (cotyledon) cracking, compared to other taxa. Unburned seeds showed a consistent, general pattern in both the laboratory and field results. Chi-square one-sample tests for survival of seeds at Brady, and for frequency of seed coat damage in the lab experiment, both showed highly significant values (p* 0.001), indicating nonrandom distributions with respect to taxon. Survival of wheat and rye in the field was much greater than other taxa. These same taxa showed low frequencies of damage in the lab. Both burned and unburned beans showed the highest indices of various damage attributes in both the lab and field. Popcorn behaved very differently from blue corn and from all of the other taxa (see discussion of Hypothesis 2).

DISCUSSION

Significance of Results

Several aspects of the design and implementation of this study allowed some insight into aspects of seed deterioration not originally envisaged when the study was planned. For instance, charcoal is known to be a very durable substance, and since nearly all prehistoric plant remains recovered in open archeological sites are charred, it has long been assumed that charred botanical materials were more resistant to biological decay and other forms of deterioration than uncharred materials. This experiment produced some interesting results concerning this assumption. Much more deterioration was observed in charred seeds than was expected. As Jewell and Dimbleby (1966) noted in their experimental study of archeological materials buried for specific time intervals in a chalk bank in southern England, fungal attack of wood (resulting in measurable weight loss) was similar for both charred and uncharred specimens. An important point is that the wood in this experiment was not charred throughout, and as Dimbleby has noted elsewhere (1967:97), "surface charring does nothing to preserve the wood beneath." This may well be the case with some of the seed specimens used in the Inundation Project: seeds that are incompletely carbonized, that is, converted to elemental carbon, are susceptible to anaerobic fungal attack and possibly other forms of microfloral and faunal consumption. Even though seeds were charred for the experiment under "controlled" conditions, there may be significant variability in the degree of carbonization. Clearly, such variability is even more likely to occur in the very uncontrolled conditions of a prehistoric hearth, or the accidental burning of a habitation.

The availability of survival data in the field experiment presents an entirely different perspective on deterioration of submerged seeds than that gained from the laboratory phase alone. Since the initial number of experimental subjects was unknown in the lab phase, observations were necessarily limited to the percentage occurrence of a particular attribute and as "seed coat damage" among surviving seeds. Measurements used in the lab phase were thus analogous to those used in Holloway's study of pollen deterioration under inundation conditions (Holloway, this volume). While damage is more prevalent among surviving burned seeds in the laboratory experiment, it is certainly clear that burned seeds are more resistant to total destruction in the long run, when observed under field conditions. Factors, such as the presence of larger classes of predators or naturally-occurring microfloral or microfaunal populations, may have a critical bearing on the composition and condition of plant assemblages preserved in submerged archeological sites.

Variation in the preservation of different taxa in this experiment may be tentatively attributed to the physical and chemical composition of the seed types. For instance, several aspects of bean seed coats contribute to their being relatively hydrophilic. The outer, water-resistant cuticle layer is relatively thin; permeability of seed coat cell walls is high; and the presence of glutinous materials increases the hydroscopic effect. Beans react very readily to available moisture in several irreversible physical and chemical processes. Once the seed coat has swollen and burst, the inner parts are exposed to attack. In the presence of water, the characteristics of bean seed coats probably account for bean degradation. Popcorn differs fundamentally from the six other taxa in attributes of both the external covering and the makeup of food reserves and embryo. Whereas beans, flour-corn types such as blue corn, and cereal grains are composed largely of soft starch, popcorn contains a small proportion of hard starch ("horny endosperm") and a relatively large complement of oils and proteins. The outer cover of the kernel is hard, rigid, and nearly impermeable to water; these characteristics allow a tremendous build-up of pressure under heat, culminating in an explosion when the kernel finally "pops". These characteristics of popcorn may be linked to its unusual behavior under experimental inundation conditions (see page 12). As long as the highly resistive outer covering of popcorn remains intact, morphological change is minimized. Eventually, highly acidic surroundings or microbial action, might eat away at this tough coating. Since burned popcorn in this experiment experienced a consistently high weight loss with submersion, an interesting possibility is that burning may alter the composition of the integument or the internal parts and make some constituent of the kernel more soluble or otherwise susceptible to leaching.

Implications for Archeological Research

Results of this study relate directly to predicting inundation impacts on archeological sites and to evaluating deterioration effects on paleobotanical assemblages. Inundation introduces special problems for the taxonomic identification of deteriorated specimens. Saturation and subsequent drying are particularly damaging to charred seeds. Some of the more prevalent effects of immersion may occur also from normal fluctuations in soil moisture in uninundated sites. For instance, it is easy to see how cracking and exfoliation of bean seed coats and splitting of cotyledons can lead to the most commonly encountered form of archeological bean specimen, a single charred cotyledon, lacking seed coat and identifying hilum characteristics.

It is evident from this study that several factors affect selective deterioration and lead to alteration of the species composition of a botanical assemblage. Two factors are particularly significant: charring and access of predators. The extent to which an assemblage is burned, and the conditions under which any burning occurred, will affect both presence and recognizability of taxa. For instance, inundation under conditions similar to those tested at Brady could result in an assemblage skewed heavily towards indistinguishable cereal grains (ignoring for the moment the fact that the cultivated cereals were not present in the New World before European contact). The same collection, under similar conditions, could vary considerably in representativeness, depending simply on which botanical materials were charred. Similarly, the depth of archeological deposits and differences between the microfloral and faunal communities in inundated soil and the water column could significantly affect the survival of unburned seeds.

It should be apparent that it is difficult to pinpoint either quantitative or qualitative deterioration effects due specifically to inundation, since equivalent information is not available for noninundated plant materials. Survival of any unburned botanical remains under inundation conditions may be a moot point, since these remains may be entirely deteriorated long before the building of a reservoir is contemplated. A preliminary step in quantifying deterioration by inundation involves investigating conditions of preservation under nonsaturated conditions. For example, the impact of inundating a dry cave or rockshelter will be detrimental simply because the plant assemblage that was preserved in the site prior to inundation is likely to contain more unburned materials that are more susceptible to decomposition.

Suggestions for Future Research

There are several difficulties with the experimental design which interfere substantially with the quality of the results and which diminish the ability to make clear and meaningful descriptions and explanations. To benefit those planning future studies, these problems are discussed below. One of the major problems is the large number of variables and small number of replicates. Naturally-occurring variability within a given seed taxon masks the subtle differences between the actions of the numerous chemical solutions in the lab. While there were 30 different chemical environments (16 of which are discussed in this report), only ten seeds of any given taxon were consistently available for measurement. At Brady Reservoir there were 18 test conditions and again, ten replicates. It is recommended that 1) the experiment be simplified to include a smaller number of questions, 2) factors such as microbiological destruction in the lab should be controlled, and 3) a larger number of seeds (e.g., 30) should be observed for each test condition.

Another problem involves the lack of important information on attributes of seed specimens before they were subjected to test conditions in the field and in the lab. It is not known how many seeds of any given taxon were placed in each laboratory test solution; therefore, rate of loss or damage cannot be determined. Since measurements of the actual seeds subjected to specific experimental conditions are not known, change can only be estimated and not quantified as actual loss of size, shape, change, weight, etc.

Further studies of deterioration of archeological plant assemblages should investigate the behavior of taxa more representative of prehistoric subsistence. As noted above, grains such as wheat and rye were not available to prehistoric peoples, and their preservation is not relevant to a study of the composition of assemblages in North American sites. Taxa which represent a range of types encountered archeologically under good preservation conditions (such as in a dry shelter) or known from historic ethnobotanical accounts should be used. In the Southwest, for instance, such a range of taxa should include a variety of wild plant types. Larger, lignified materials such as pinyon shells, cactus seeds, and ricegrass (*Oryzopsis*) caryopses should be investigated, as well as smaller, annual weed seeds. Many of the annual weeds were exploited extensively for both seed and green crops. The archeological record of these tiny (ca. 1 mm) seeds varies considerably from site to site, and it is difficult to determine to what extent this variability reflects differences in subsistence strategy or preservation. In future studies weed seed should include such taxa as *Chenopodium* and *Portulaca*, which occur frequently in archeological sites and are often charred, as well as taxa with thinner seed coats (presumably containing less lignin or cutinous materials), such as *Descurainia* or *Mentzelia*, which are prominent in the ethnobotanical literature but are far less common in archeological sites and rarely survive charring. Representative domesticated plants should include the cucurbits (squash and gourd rind, peduncles, and seeds), and corn parts other than kernels (cobs and shanks, in particular).

SUMMARY

Several patterns in the deterioration of seeds were observed in this study. An unexpected result was that immersed charred seeds showed more signs of damage than uncharred seeds. Although more burned seeds survived the reservoir experiment, the proportion of burned seeds showing damage was higher than for unburned seeds, suggesting that some unburned seeds may have totally disintegrated in the lab as well. Access of predators (as controlled in the field by different mesh filters) was a significant determinant of seed damage for unburned seeds. This may account for some differences between lab and field results. Chemical environment (in the lab) and time interval and sample location (in the field) could not be shown to account for significant amounts of variability in the data. The experimental design may be responsible for the appearance of these latter factors as insignificant. Subtle differences between chemical environments, time intervals, or locations may have been masked by variability within the very small number of replicates. It is suggested that future research should address fewer questions and use larger sample sizes.

Taxa varied significantly in amounts and types of degradation. Among the burned seed taxa, beans suffered the most attrition. Damage to beans could obscure identifying characteristics linked to the seed coat (as in the hilum area). Unburned beans and corn were more deteriorated and are, therefore, less likely to survive inundation conditions. By affecting the species composition of archeological assemblages, selective deterioration can result in misrepresentation of the botanical record of climate and diet.

Before the impact of inundation of the preservation of archeological plant materials can be quantified, the extent of deterioration before inundation must be better understood. Future research should encompass the degradation of botanical materials under various physical and chemical soil conditions (different soil particle composition, drainage, pH), and under various conditions of deposition and erosion. The spectrum of plants investigated should more nearly reflect those likely to have been deposited by hunter/gatherer or agriculturalist populations in the New World. For example, cultivars should include cucurbits and corn remains other than kernels. Wild plants should include heavily lignified materials such as nutshells and the larger, harder seeds, as well as small annual weed seeds.

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TABLE 1

Chemical Environments and Seed Specimens Analyzed, UNM Laboratory Phase

	Chemical Environment	# of Seeds Analyzed, Each Taxon[1] Burned	Unburned
0	Unimmersed (dry control)	30	30
15	Deionized water (immersion control)	10	10
16	$NaHCO_3$ + $MgCl_2.6H_2O$ + $FeCl_2.6H_2O$ + $NaSiO_3.9H_2O$	10	10
17	$NaCO_3$	10	10
18	$MgSO_4$	10	10
19	$CaCl_2$	10[2]	10[3]
20	$NaHCO_3$	10	10[4]
21	$KHCO_3$	10	10
22	HCl	10	10
23	NaCl	10	10
24	$MgCl_2.6H_2O$	10	10
25	$CaCl_2$	10	10
26	$FeCl_2.6H_2O$	10	10
27	$NaSiO_3.9H_2O$	10	10
28	KCl	10	10
29	$MgSO_4$	10	10
30	H_2SO_4	10	10

[1]Taxa: pinto beans, kidney beans, navy beans, popcorn, blue corn, wheat, & rye.
[2]Only 8 blue corn specimens survived and were available for measurement.
[3]Only 4 kidney bean specimens survived and were available for measurement.
[4]Only 7 kidney bean specimens survived and were available for measurement.

TABLE 2
Brady Reservoir Phase Experimental Varibles

Variable	Cases	
Location in reservoir[1]	Station I	1/2 mile west of dam
	Station II	1-1/2 mile west of dam
	Station III	3 miles west of dam
Exclusion of biological predators	Filter A	0.2 micron mesh (excluded micro- and macroorganisms)
	Filter B	2.0 micron mesh (excluded macro-organisms only)
	Filter C	2.5 cm openings
Time	Time Interval I	Four months
	Time Interval II	Eight months

[1]All sample locations were near the north shore of Brady Reservoir.

TABLE 3
Percentage Occurrence of Cracked Endosperm in Unimmersed and UNM Lab Experiment Seeds

	Unimmersed Seeds[1]	Seeds Immersed in deionized water	Seeds Immersed in Chemical Environments[2]															Combined[3]
			16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Burned																		
Pinto Bean	20	80	80	30	30	60	60	60	80	50	60	20	40	70	70	90	70	54
Kidney Bean	23	100	80	80	50	40	50	50	40	50	60	70	50	90	50	70	70	60
Navy Bean	3	50	60	30	10	30	40	20	30	50	0	40	10	50	30	10	0	33
Popcorn	23	60	0	50	60	0	50	40	10	60	60	60	80	80	80	70	70	51
Blue Corn	70	20	0	60	50	0	80	20	0	40	50	30	60	30	50	50	10	35
Wheat	10	10	0	20	0	0	0	20	10	10	20	20	10	10	0	0	0	8
Rye	10	0	40	30	0	0	20	10	10	0	20	20	30	40	0	10	10	16
All Burned Seeds	23	46	37	43	29	17	43	31	26	37	39	37	40	53	40	43	33	37
Unburned																		
Pinto Bean	0	0	0	10	10	0	30	30	20	10	0	0	0	0	0	0	0	7
Kidney Bean	0	0	0	0	10	0	10	10	10	0	0	0	0	0	0	10	0	3
Navy Bean	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	1
Popcorn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue Corn	7	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Wheat	3	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	1
Rye	3	0	0	0	0	40	0	20	0	0	0	0	10	0	0	0	0	5
All Unburned Seeds	2	0	0	3	4	6	6	9	3	4	0	1	0	0	0	1	0	3

[1] n-30 for individual taxa; n=210 for "all burned seeds" and "all unburned seeds."
[2] n-10 for individual taxa; n=70 for "all burned seeds" and "all unburned seeds."
[3] n=150 for individual taxa; n=1050 for "all burned seeds" and "all unburned seeds."

TABLE 4
Percentage of Occurrence of Extensive Seed Coat
Damage in Unimmersed and UNM Lab Experiment Seeds

	Unimmersed Seeds[1]	Seeds Immersed in deionized water	Seeds Immersed in Chemical Environments[2]															
			16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Combined[3]
Burned																		
Pinto Bean	17	60	100	50	50	70	60	100	100	0	80	20	10	50	0	90	100	59
Kidney Bean	17	90	100	70	30	100	100	100	100	0	0	30	30	60	0	90	100	61
Navy Bean	43	80	80	70	90	100	40	80	90	0	0	100	100	80	0	90	90	67
Popcorn	0	0	20	30	0	10	50	10	0	0	10	0	0	20	80	40	20	19
Blue Corn	17	10	10	10	0	10	60	40	0	20	10	0	0	0	50	50	10	18
Wheat	0	0	10	10	10	0	20	0	0	10	0	0	100	100	60	0	0	21
Rye	3	40	10	80	0	10	60	0	100	0	0	0	60	50	100	0	0	31
All Burned Seeds	14	40	47	22	26	43	56	47	56	4	14	21	43	51	41	51	46	39
Unburned																		
Pinto Bean	0	0	0	20	0	0	10	100	90	0	10	0	20	0	30	0	50	22
Kidney Bean	0	0	10	10	0	0	10	90	60	0	0	0	0	10	30	10	0	15
Navy Bean	0	30	0	0	0	0	10	100	90	0	0	0	50	20	20	0	0	19
Popcorn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rye	0	0	0	0	10	0	10	10	0	10	0	0	0	0	0	0	0	3
All Unburned Seeds	0	4	1	4	1	0	6	43	34	1	1	1	10	4	11	1	7	8

[1] n=30 for individual taxa; n=210 for "all burned seeds" and "all unburned seeds."
[2] n=10 for individual taxa; n=70 for "all burned seeds" and "all unburned seeds."
[3] n=150 for individual taxa; n=1050 for "all burned seeds" and "all unburned seeds."

Table 5
Percentage of Cotyledon Separation in Unimmersed and UNM LAB Experiment Beans

	Unimmersed Seeds[1]	Seeds Immersed in deionized water[2]	Seeds Immersed in Chemical Environment[2] 16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	All Chemical Environments Combined[3]
Burned																		
Pinto Bean	27	100	90	70	60	90	90	90	100	80	80	50	40	90	60	100	100	79
Kidney Bean	13	100	90	60	70	60	50	80	80	80	60	90	100	80	90	80	80	77
Navy Bean	3	100	50	90	80	60	40	40	80	90	40	90	50	80	40	60	60	63
All Burned Beans	14	100	77	73	70	70	60	70	87	83	60	77	63	83	63	80	80	73
Unburned																		
Pinto Bean	0	0	0	0	0	40	0	30	40	0	0	0	0	0	0	0	0	7
Kidney Bean	0	10	10	10	20	04[5]	14[6]	10	30	20	0	0	10	10	20	10	0	11
Navy Bean	0	60	0	0	0	0	0	60	80	0	0	0	0	0	0	0	0	9
All Unburned Seeds	0	23	3	3	7	17[5]	4[7]	33	50	7	0	0	3	3	7	3	0	9

[1] n=30 for individual taxa; n=90 for "all burned seeds" and "all unburned seeds."
[2] n=10 for individual taxa; n=30 for "all burned seeds" and "all unburned seeds."
[3] n=150 for individual taxa; n=441 for "all burned seeds" and "all unburned seeds."
[4] n=4
[5] n=24
[6] n=7
[7] n=27

TABLE 6
Percentage of Absence of Endosperm in Unimmersed and UNM Lab Experiment Corn and Grains

	Unimmersed Seeds	Seeds Immersed in deionized water[2]	Seeds Immersed in Chemical Environments[2]															Environments Combined[3]
				16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Burned																		
Popcorn	0	10	0	10	0	0	10	0	0	0	10	0	10	10	0	0	0		3
Blue Corn	0	20	0	20	0	0	0	0	0	0	0	0	20	10	0	0	0		3
Wheat	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Rye	0	30	0	10	0	20	0	10	0	0	0	0	0	0	0	0	0		3
All Burned Seeds	0	18	0	10	0	5	3	3	0	0	3	0	8	5	0	0	0		2
Unburned																			
Popcorn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Blue Corn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Wheat	0	10	0	0	10	0	0	0	0	10	0	0	30	70	10	0	0		9
Rye	0	100	100	10	80	0	70	60	20	60	20	10	70	30	30	0	30		39
All Unburned Seeds	0	28	25	3	23	0	18	15	5	18	5	3	25	25	10	0	8		12

[1]=30 for individual taxa; n=120 for "all burned seeds" and "all unburned seeds."
[2]n=10 for individual taxa; n=40 for "all burned seeds" and "all unburned seeds."
[3]n=150 for individual taxa; n=600 for "all burned seeds" and "all unburned seeds."

TABLE 7

Occurrence[1] of Cracked Endosperm in Brady Reservoir Seeds

	Station I						Station II						Station III						
	Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		All
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	Combined
Burned																			
Pinto Bean	6/10	8/10	---	4/10	6/10	5/10	6/10	---	3/10	---	2/10	---	5/10	4/9	1/9	5/8	0/6	0	55/122
Kidney Bean	3/10	6/10	---	8/10	3/10	2/7	3/10	---	4/6	---	1/9	---	6/10	6/10	4/7	5/8	3/10	4/6	58/123
Navy Bean	0/10	4/10	---	2/10	1/10	6/10	1/10	---	3/8	---	0/10	---	0/9	6/10	0/7	3/7	2/9	0	28/120
Popcorn	4/10	5/10	---	5/10	5/10	4/8	6/10	---	5/8	---	5/8	---	4/10	3/10	7/9	5/7	4/9	1/1	63/120
Blue Corn	5/10	2/10	---	6/9	1/8	2/8	4/10	---	4/7	---	2/5	---	1/7	5/10	3/6	5/10	0/7	1/1	41/108
Wheat	0/10	4/10	---	2/10	1/10	1/7	0/10	---	3/10	---	2/10	---	4/9	0/10	1/6	1/9	0/10	1/2	20/123
Rye	2/10	2/10	---	3/10	1/8	3/8	0/10	---	1/7	---	1/9	---	0/9	5/10	0/8	1/8	5/9	1/3	25/119
All Burned Seeds	20/70	31/70	---	30/69	18/66	23/58	20/70	---	23/56	---	13/61	---	20/64	29/69	16/52	25/27	14/60	8/13	290/835
Unburned																			
Pinto Bean	0	0	---	1/1	0	0	0	---	0	---	0	---	0	3/3	0/1	0	0	0	4/5
Kidney Bean	0	0	---	3/3	0	0	0	---	0	---	0	---	0	3/3	0/3	0	0	0	6/9
Navy Bean	0	0	---	0	0	0	0	---	0	---	0	---	0	3/3	0/2	0	0	0	3/5
Popcorn	0	2/2	---	4/6	0	0	0	---	0	---	0	---	0	0	0	0	0	0	6/8
Blue Corn	0	1/2	---	2/3	0	0	1/1	---	0	---	0	---	0	0	1/4	0	0	0	5/10
Wheat	0	0/8	---	0/7	0	0	0/1	---	0/4	---	0/1	---	1/6	0/5	0/5	0	0	0	1/37
Rye	0	0/7	---	0/5	0	0	0/5	---	0/3	---	0/1	---	0/3	0	0/7	0	0	0	0/31
All Unburned Seeds	0	3/19	---	10/25	0	0	1/7	---	0/7	---	0/2	---	1/9	9/14	1/22	0	0	0	25/105

[1]Occurrence expressed as a fraction, with numerator equal to # of seeds with cracked endosperm, and denominator equal to # of seeds surviving.

---missing data

0 no survivors (with measurable or identifiable characteristics)

TABLE 8

Occurrence[1] of Extensive Seed Coat Damage in Brady Reservoir Seeds

	Station I						Station II						Station III						
	Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		All
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	Combined
Burned																			
Pinto Bean	4/10	8/10	---	6/10	0/10	9/10	2/10	---	3/10	---	7/10	---	3/10	3/9	1/9	3/8	2/6	0	51/122
Kidney Bean	3/10	7/10	---	2/10	7/10	7/7	2/10	---	3/6	---	8/9	---	1/10	2/10	0/7	3/8	10/10	3/6	58/123
Navy Bean	5/10	3/10	---	9/10	7/10	10/10	4/10	---	3/8	---	7/10	---	1/9	5/10	1/7	5/7	5/9	0	65/120
Popcorn	0/10	3/10	---	2/10	0/10	4/8	0/10	---	0/8	---	1/8	---	0/9	0/10	0/9	0/7	0/9	0/1	10/119
Blue Corn	0/10	0/10	---	0/9	2/10	3/8	2/10	---	0/7	---	1/5	---	0/7	2/10	0/6	1/10	0/7	1/1	12/110
Wheat	0/10	0/10	---	0/10	0/10	0/7	0/10	---	0/10	---	0/10	---	0/9	4/10	0/6	0/9	0/10	0/2	4/123
Rye	7/10	1/10	---	0/10	0/10	2/8	7/10	---	0/7	---	1/9	---	7/9	3/10	4/8	0/8	1/9	0/3	33/121
All Burned Seeds	19/70	22/70	---	19/69	16/70	35/58	17/70	---	9/56	---	25/61	---	12/63	19/69	6/52	12/57	18/60	4/13	233/838
Unburned																			
Pinto Bean	0	0	---	0/1	0	0	0	---	0	---	0	---	0	3/3	1/1	0	0	0	4/5
Kidney Bean	0	0	---	0/3	0	0	0	---	0	---	0	---	0	3/3	0/3	0	0	0	3/9
Navy Bean	0	0	---	0	0	0	0	---	0	---	0	---	0	3/3	2/2	0	0	0	5/5
Popcorn	0	2/2	---	1/7	0	0	0	---	0	---	0	---	0	0	0	0	0	0	3/9
Blue Corn	0	1/2	---	0/3	0	0	1/1	---	0	---	0	---	0	0	0/4	0	0	0	2/10
Wheat	0/4	0/8	---	0/7	0	0	0/1	---	0/4	---	0/1	---	0/6	0/5	0/5	0	0	0	0/41
Rye	0/3	0/7	---	0/5	0	0	0/5	---	0/3	---	0/1	---	0/3	0	0/7	0	0	0	0/34
All Unburned Seeds	0/7	3/19	---	1/26	0	0	1/7	---	0/7	---	0/2	---	0/9	9/14	3/22	0	0	0	17/113

[1]Occurrence expressed as a fraction, with numerator equal to # of seeds with seed coat damage, and denominator equal to # of seeds surviving.

---missing data

0 no survivors (with measurable or identifiable characteristics)

TABLE 9

Occurrence[1] of Cotyledon Separation in Brady Reservoir Beans

	Station I						Station II						Station III						
	Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		All
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	Combined
Burned																			
Pinto Bean	5/10	3/10	---	5/10	7/10	8/10	3/10	---	3/10	---	2/10	---	6/10	6/9	4/9	7/8	5/6	0	64/122
Kidney Bean	4/10	6/10	---	9/10	5/8	7/7	6/10	---	2/6	---	6/9	---	6/10	8/10	2/7	7/8	9/10	5/6	82/121
Navy Bean	4/10	6/10	---	6/10	1/10	7/10	1/10	---	3/6	---	3/10	---	3/9	8/10	0/7	3/7	8/9	0	53/118
All Burned Beans	13/30	15/30	---	20/30	13/28	22/27	10/30	---	7/22	---	12/29	---	15/29	22/29	6/23	17/23	22/25	5/6	199/361
Unburned																			
Pinto Bean	0	0	---	0/1	0	0	0	---	0	---	0	---	0	0/3	1/1	0	0	0	1/5
Kidney Bean	0	0	---	0/3	0	0	0	---	0	---	0	---	0	0/3	2/3	0	0	0	2/9
Navy Bean	0	0	---	0	0	0	0	---	0	---	0	---	0	1/3	1/2	0	0	0	2/5
All Unburned Beans	0	0	---	0/4	0	0	0	---	0	---	0	---	0	1/9	4/6	0	0	0	5/19

[1]Occurrence expressed as a fraction, with numerator equal to # of seeds with separated cotyledons, and denominator equal to # of seeds surviving.

---missing data

0 no survivors (with measurable or identifiable characteristics)

TABLE 10

Absence[1] of Endosperm in Brady Reservoir Corn and Grains

	Station I						Station II						Station III						
	Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		Filter A		Filter B		Filter C		All
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	Combined
Burned																			
Popcorn	0/10	2/10	---	3/10	0/10	4/8	1/10	---	2/8	---	3/8	---	0/10	0/10	0/9	0/7	5/9	1/1	21/120
Blue Corn	1/10	0/10	---	0/9	5/8	5/8	2/10	---	0/7	---	3/5	---	0/7	1/10	0/6	0/10	2/7	0/1	19/108
Wheat	0/10	0/10	---	2/10	0/9	1/7	0/10	---	0/10	---	0/10	---	0/9	5/10	0/6	0/9	1/10	0/2	9/122
Rye	0/10	1/10	---	1/10	2/8	3/8	1/10	---	3/7	---	2/9	---	2/9	3/10	0/8	3/8	2/9	1/3	24/119
All Burned Seeds	1/40	3/40	---	6/39	7/35	13/31	4/40	---	5/32	---	8/32	---	2/35	9/40	0/29	3/34	10/35	2/7	73/469
Unburned																			
Popcorn	0	0/2	---	0/6	0	0	0	---	0	---	0	---	0	0	0	0	0	0	0/8
Blue Corn	0	0/2	---	0/3	0	0	0/1	---	0	---	0	---	0	0	0/4	0	0	0	0/10
Wheat	4/4	1/8	---	7/7	0	0	1/1	---	4/4	---	1/1	---	5/6	5/5	2/5	0	0	0	30/41
Rye	3/3	6/7	---	5/5	0	0	5/5	---	3/3	---	1/1	---	3/3	0	6/7	0	0	0	32/34
All Unburned Seeds	7/7	7/19	---	12/21	0	0	6/7	---	7/7	---	2/2	---	8/9	5/5	8/16	0	0	0	62/93

[1]Absence expressed as a fraction, with numerator equal to # of seeds with no endosperm, and denominator equal to # of seeds surviving.

---missing data

0 no survivors (with measurable or identifiable characteristics)

Table 11. Weight Loss of Burned and Unburned Lab Seeds After Immersion

	Average Weight[1] in gm (Unimmersed)		% Weight Loss[2] after immersion in deionized water		% Weight Loss[3] after immersion-all chemical environments combined	
	Burned	Unburned	Burned	Unburned	Burned	Unburned
Pinto Bean	.249	.363	4%	28%	10%	20%
Kidney Bean	.377	.477	36%	37%	27%	34%
Navy Bean	.094	.116	14%	18%	10%	18%
Popcorn	.122	.111	62%	9%	55%	+12%[4]
Blue Corn	.163	.281	34%	48%	36%	41%
Wheat	.029	.033	48%	67%	45%	39%[5]
Rye	.020	.026	40%	85%	35%	58%

[1] n=30

[2] n=10

[3] n=140

[4] net weight gain

[5] sampling error?

FIELD STUDIES OF DIFFERENTIAL PRESERVATION IN FRESHWATER ENVIRONMENTS: BRADY CREEK RESERVOIR, TEXAS; CLAYTOR LAKE RESERVOIR, VIRGINIA; AND VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

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INTRODUCTION

A principal goal of the Inundation Study is to provide Federal land managers and cultural resource managers with a comprehensive body of data that can be used to formulate realistic guidelines for the management of submerged cultural resources. Toward this end, a variety of questions is being addressed that relate the differential preservation of cultural materials submerged in a freshwater environment to water chemical, microbiological, reservoir dynamics, and other processes which influence rates of differential preservation.

In response to these questions, a two-pronged experiment was developed to identify water chemical and microbiological impacts on various categories of cultural materials. The field phase of the experiment developed as a correlate to the laboratory water chemical experiment conducted at the University of New Mexico, Albuquerque. The twofold purpose was: 1) to evaluate the decomposition rates of selected materials in a given reservoir and compare these rates with the controlled laboratory experiments, and 2) to separate the relative contributions of the chemical, microbiological, and macroinvertebrate decomposition processes on a variety of cultural materials placed in reservoir sediments. The field phase is specifically designed to address the problem of biological impacts to common cultural materials and evaluate the interactions between biological and chemical processes. The task of separating biological from chemical impacts is an extremely difficult one, especially since most degradation is the result of a synergistic combination of biochemical reactions. The experimental design outlined in this report reflects the complexity of the problem.

EXPERIMENTAL DESIGN

The experiments conducted at Brady Creek Reservoir, Claytor Lake Reservoir and Virginia Polytechnic Institute and State University were designed to determine decomposition rates of cultural materials in different environments under controlled conditions. Each of the three aspects of the field experiment will be discussed individually within this section.

Phase 1: Brady Creek Reservoir

Brady Creek Reservoir is situated in McCulloch County, Texas in the geographical center of the state. The 5290-acre storage reservoir was constructed in 1961 by the city of Brady in cooperation with the Soil Conservation Service and Farmers Home Administration for flood control and municipal and industrial water supply. The original purpose for the reservoir has not been realized, as the water supply is derived from local wells. The primary use for the reservoir is recreation, while the adjacent land is used for livestock grazing and agriculture.

The selection of Brady Reservoir as the test reservoir was based on the following criteria: 1) geographical proximity to Santa Fe, New Mexico, headquarters for the Inundation Study, 2) water chemical values approximating a "typical" reservoir (i.e., limited variability in water chemistry conditions), and 3) water chemical values falling within one standard deviation of the mean concentrations prepared for the laboratory water chemical experiment at the University of New Mexico.

In order to evaluate the selective criteria for reservoir selection, two independent sources of raw chemical data were consulted: NASQUAN and U.S. Geological Survey. Of the eight chemical variables selected for the laboratory experiment, seven variables from Brady Reservoir are within one standard deviation of the mean. The eighth falls just outside the range. The data are presented in Table 1.

Brady Reservoir is a typical "hard" water reservoir in that anions such as carbonate and cations such as sodium, potassium and magnesium occur in above average concentrations. The variation of ions in "average" natural waters is listed in Table 2. These data are compared with the water quality data collected by the Texas Geological Survey in Brady Reservoir. A spectral analysis of the major cations and the anion carbonate was conducted on water samples collected during the four- and eight-month sampling intervals in order to evaluate chemical variability within the reservoir and to establish a data base from which to compare water chemistries within the microbiological samplers (Tables 3 and 4).

One factor which would affect biological productivity is thermal stratification. The degree to which Brady Reservoir would thermally stratify would depend upon the severity and frequency of summer thunderstorms which would tend to mix the water mass. The shallowness of Brady Reservoir (maximum depth 50 ft.) indicated the probability that thermal stratification would be lacking. Observed edaphic properties indicated the reservoir would be fairly eutrophic in nature and hence become anaerobic near the bottom at the mud-water interface. The degree of anaerobiosis would depend upon the development of thermal stratification and the subsequent formation of a hypolimnion.

For the Brady Reservoir phase of the experiment, six categories of cultural materials (lithics, ceramics, shell, bone, wood, and seeds) were immersed in three samplers at three sampling stations for a period of eight months. The three sampling locations were selected on the basis of geographic and edaphic variability (Figure 1), all at a depth of approximately 20 feet. Because the reservoir does not stratify thermally, a factor which influences biological activity, the transects were not stratified according to depth. The procedures for establishing the transects and placing the samplers are described by Voshell and Simmons (1977).

In an attempt to isolate water chemical impacts from biological ones, a series of five-gallon Nalgene containers fitted with specialized membranes were prepared. Two types of membranes were employed. Type A is a dual membrane system designed to exclude microorganisms, while permitting the diffusion of water molecules. It consists of a sterile millipore membrane filter with 0.2 micron sieve openings superimposed over a glass filter with 0.3 micron sieve openings. The second, Type B, is a nonbiodegradable membrane filter with 1 mm sieve openings which excludes macroinvertebrates. A third type of container, a 1-liter plastic bucket with snap-on lid and numerous holes, 2.5 cm in diameter, was utilized to permit the interaction between the lake water, micro and macroorganisms, and the artifact materials. At four-month intervals, the materials were removed for analysis. At the same time, water samples were extracted to measure properties such as temperature, oxygen, conductivity, pH, alkalinity and hardness.

In addition to placing common archeological materials in the reservoir, packets of fresh and fossilized (acetylized) pollen, some suspended in the water column and others buried in the sediments, were included in order to derive rates of deterioration for varieties of pollen often encountered in archeological contexts. Due to the fragile nature of the pollen and its susceptibility to chemical and biological degradation, the sampling intervals were more frequent than for the other materials. The pollen was extracted according to the following schedule: 5 days, 10 days, 20 days, 90 days, 180 days, and 365 days following the initial placement of pollen in the reservoir. The results of the pollen degradation study are presented in Technical Report 4 in this volume.

<u>Phase 2:</u> <u>Claytor Lake Reservoir</u>

Claytor Lake Reservoir, situated in Pulaski County, Virginia was selected because of its geographical proximity to Virginia Polytechnic Institute and State University, the location selected for the biological analyses and laboratory phases of the field experiment. Waters feeding into Claytor Lake drain rich carbonate and dolomite formations in the Ridge and Valley province of Virginia. The mean values for the principal ions are presented for both Brady Creek Reservoir and Claytor Lake in Table 5.

A series of artifacts (Table 11) were placed in closed samplers fitted with filters implanted in the rubber-stoppered ends. The sampler units were constructed of cast acrylic tubes, selected to be nonbiodegradable. The small volume of the tubes would serve to increase the rate of decomposition taking place. The tubes, measuring 8.5 cm in diameter and 60.8 cm in length, were sealed with number 15 rubber stoppers. One inch wide rubber straps were used to secure the stoppers. The filter units were installed in a 1/8 inch hole drilled through the stopper. The Nuclepore 47 mm filter holder units had plastic grids on each side of the filter paper to prevent rupture, such as occurred in the Brady samplers (see discussion of microbiological results, this volume). At each end of one set of tubes, a 45 mm millipore 0.2 micron filter was implaced to exclude microorganisms. The second set of tubes was fitted with filter units, minus the filters, to exclude macroinvertebrates.

The artifacts, including pine and oak cubes, cultivated seeds, paper strips, and leather, were placed in each tube. The wood and seeds were placed in bags made from nylon stockings, an inert substance which would not contribute to microbial growth. The bags were tied using dental floss, also selected for its nonbiodegradable properties. Whatman filter paper was cut into strips, rolled, and inserted through the holes of a nylon mesh bag to prevent matting and to allow the water to be in contact with the entire surface area (Figure 2).

Once the materials were in place, the tubes were filled with distilled water and autoclaved at 148°C for 15 minutes at 15 PSI. The autoclaving technique proved too destructive for the materials used in the experiment. The acrylic tubes were slightly warped by the heat and some loss of water was noted. In addition, the leather strips placed in the tubes were completely destroyed by the sterilization process (Figure 3). In spite of these problems, the sterile samplers were placed in Claytor Reservoir at various depths (Table 12) along transect lines and allowed to fill with lake water through the process of diffusion. At the end of the four-month sampling interval, the samplers were removed from the lake and the contents were subjected to water chemical and metric analyses.

Phase 3: Virginia Polytechnic Institute Laboratory Experiments

The laboratory experiments consisted of two related parts: a water chemical experiment and a mud column study. Each segment was conducted over a three-month period of time from February to May, 1980.

The first part, the water chemical experiment, was designed to determine rates of deterioration under controlled laboratory conditions. The results were to be compared with the Claytor Lake data in an attempt to predict factors contributing to the decomposition of various organic materials. In order to compare the two sets of data, the experiment was further subdivided into two segments. One series of samplers containing seeds and paper was filled with sterilized Claytor Lake water and maintained at a constant temperature (30°C) for three months. A second series of comparable samplers was filled with sterilized distilled water and maintained under the same conditions for the same period of time.

The samplers for the water chemical phase of the experiment differed slightly from the Claytor Lake samplers (Figure 3). The acrylic tubes were shorter, measuring 8.5 cm in diameter by 30 cm in length, and only had filters placed in one end. Seeds and paper (prepared as above) were placed in the tubes, which were filled with the appropriate aqueous solution (Claytor Lake water or distilled water); 25 mm filter holders were used which had a grid only on one side of the filter paper. The entire unit was then sterilized using slightly modified techniques to avoid the problems encountered previously. The seeds were surface sterilized with Clorox, a technique suggested by the Plant Pathology Department at Virginia Polytechnic Institute. The water and paper strips were autoclaved in the tubes, after which the filters were aseptically added. The sterilized units were placed in an aquarium, weighted to keep them submerged, and maintained at a constant 30°C temperature for three months (Figure 4).

The second part of the laboratory experiment, a mud column study, was designed to assess the interaction between biological organisims and organic materials at various depths in a soil profile. The conditions would approximate the soil matrix of a submerged archeological site. Three soil matrices were selected for the study: fine silt, mud, and gravel. The cores for the mud substrate were removed from Claytor Lake at an approximate depth of 34 meters. The gravel was obtained from a shallow location, about 60 cm below the surface of the water. The samples were placed in white plastic buckets to exclude light. Artifacts consisting of leather and paper strips were placed at the water-substrate interface and at depths of 2 and 4 inches below the interface. The sediment was then covered by three inches of Claytor Lake water. The experimental units were maintained at 30° for three months.

ARTIFACT VARIABILITY

In order to ensure consistency in sample variability and testing procedures, the artifact classes, preparation procedures, and measurements were identical to those included in the water chemical phase of the experiment conducted at the University of New Mexico (see Technical Report 3, this volume). The major difference between the Brady Reservoir and the laboratory assemblages was the reduced number of artifact subcategories in the former. Due to the difficulty of acquiring additional samples and the brief amount of time allotted for sample preparation, categories such as clam shell, obsidian, deer, and rabbit bone were eliminated. The seed category, oats, was also eliminated since it became empirically obvious that the oats would be too unconsolidated to effectively measure at the end of the experiment.

The Claytor Lake and Virginia Polytechnic Institute assemblages differed from the other assemblages in that the only categories included were seeds, wood, leather, and paper. Emphasis was placed on evaluating the short term effects of decomposition on organic materials, since these phases were of such short duration (four and three months, respectively), and preliminary results from the water chemical experiment conducted at the University of New Mexico indicated little change in the inorganic material categories of ceramics, lithics and shell.

The discussion of artifact variability will be limited to those materials not included in the water chemical phase of the experiment, namely leather and paper. For a description of the variability within the categories of ceramics, lithics, bone, shell, wood, seeds and pollen, consult the discussion presented in Technical Report 3 of this volume.

Leather

Strips of 6.5 x 5 cm untreated 1/16-inch thick soft leather were included in the Claytor Lake phase of the experiment in order to measure weight and dimensional changes resulting from immersion and/or microbial degradation.

Paper

Strips of 2.5 x 6.5 cm Whatman 1 qualitative filter paper were rolled and placed into nylon mesh bags to prevent matting and to allow complete contact between the water and surface area of the paper samples (Figure 2).

MEASUREMENT PROCEDURES

Measurement procedures for the Brady Reservoir phase of the experiment were conducted according to the guidelines established for the water chemical phase in order to insure consistency and to provide a baseline with which to compare results between the two bodies of data. Since the measurements performed are identical with those of the water chemical experiment, the information will not be duplicated in this report (see Technical Report 3, this volume).

Measurements on the materials included in the Claytor Reservoir and Virginia Polytechnic Institute experiment were limited to dry weight comparisons between pre- and postinundated wood, seed, and leather samples.

While most emphasis was placed on measuring various properties of the artifactual materials in order to detect evidence of change, measurements of water quality and biological activity were also performed in order to identify the relationships between the observations and the environmental variables. The physical and chemical methods employed to measure water chemical variability follow standard limnological procedures as outlined in Table 13. The identification of microbiological and macrobiological organisms follow standard biological methods for separation (macrobenthos), isolation (microbiological), and enumeration. These procedures are also outlined in Table 13. The results of the analyses performed within the scope of the experimental design are presented in the following section.

RESULTS

The field phase of the experiment was designed to assess the effect of biological activity on the decomposition rates of various classes of archeological materials in different environments under controlled conditions and to evaluate the biochemical interactions responsible for the observed or predicted degradation. In order to assess these impacts, selected categories of artifacts were subjected to a series of controlled environmental situations for varying periods of time. At the conclusion of the experiment and at predetermined sampling intervals, the artifacts and components of their environments were subjected to a series of chemical, mechanical, and visual analyses in order to determine changes which resulted from temporal and/or environmental factors of exposure.

Analytical techniques such as atomic absorption, X-ray diffraction and neutron activation were employed to directly measure changes in the mineralogical and/or chemical composition of the immersed artifacts resulting from inundation. Samples of ceramics, lithics, bone, and shell were subjected to atomic absorption spectrophotometry analysis in order to measure changes in ionic concentrations due to leaching, adsorption, or precipitation. In addition, selected ceramic samples were analyzed using X-ray diffraction techniques to determine gross changes in mineralogical composition attributed to inundation. Lithic samples were also subjected to neutron activation analysis to determine changes in trace element composition.

Water chemical analyses were performed using atomic absorption techniques to determine and evaluate the general variation in the major cations and anions of the reservoir waters and to provide a data base for comparing the water chemistries within the sampling units (Tables 2-10).

Lastly, all of the artifact categories were subjected to qualitative measurements involving visual assessments of color change, changes in dimensional properties and weight, and changes in tensile strength (wood, ceramics and paper).

The results of these analyses are summarized below for each of the three field phases. The material categories, pollen and seeds (except the Claytor Reservoir and VPI laboratory data), are not included in this discussion. The results are presented in Technical Reports 4 and 5 of this volume. The implications of the results and suggestions for future research will be discussed at the conclusion of the report.

Ceramics

Four categories of ceramics, reflecting variability in firing temperature, temper type, and pigment type, were submerged in three locations in Brady Creek Reservoir in order to determine natural factors of degradation within a reservoir environment. During the eight-month submersion period, ten samples of each type were extracted from each of the samplers per station at four month intervals, weighed, measured, and subjected to breakstrength tests. At the final eight-month interval, atomic absorption and X-ray diffraction analyses were conducted on randomly selected samples.

These analyses were designed to address the same questions presented in the water chemical phase of the experiment.

1) What chemical and mineralogical changes in fired clay ceramics can be expected following brief periods of immersion, and can these changes be predicted on the basis of observed chemical and chemical interaction properties?

2) Do chemical and mineralogical changes resulting from inundation affect the resistance of ceramics to various mechanical and chemical weathering processes?

3) What are the effects of firing temperature and tempering material on chemical/mineralogical interactions and resistance to weathering?

4) What are the relationships between material decomposition and the loss of analytical information for this class of archeological data?

The analyses presented below address these and other questions from a number of independent, yet complementary approaches. The results of these analyses are presented below and in Tables 14-17.

Analysis of Ceramic Breakstrength: Ten ceramic samples from each of the four ceramic groups were subjected to Instron tensile strength tests at four-month intervals for a period of eight months to assess the effects of the observed chemical and physical changes on the ability of the experimental ceramics to withstand mechanical weathering processes.

The breakstrength data from Brady Reservoir suggest many of the same patterns of deterioration as the laboratory experimental data (see Technical Report 3, this volume). Within each of the ceramic groups, there is a predictable decrease in ceramic breakstrength through time with the greatest decrease occuring in the IIA ceramic group (600°C, crushed rock temper) and the least decrease occurring in the IIB ceramic group (1050°C, crushed rock temper). Variation in breakstrength trajectories through time suggests a pattern of differential deterioration across biochemical environments.

In order to assess the statistical significance of the three variables measured -- time, mesh size, and ceramic type -- and the interactions between these variables, the ceramic breakstrength data were subjected to a multivariate analysis of covariance. This statistical model was selected in order to control for two potentially significant covariates, sherd thickness and weight. The results of the covariance analysis are summarized in Table 14.

Two variables, ceramic type and dry weight, were highly significant at the .0001 level. Of these, ceramic type exerted the greatest effect on breakstrength with an F value of 119.76 (3 d.f.), followed by dry weight with an F value of 25.94 (1 d.f.). The variables time and the interaction between mesh size and time were significant at the .0002 (F value 13.83, 1 d.f.) and .0006 (F value 4.98, 4 d.f.) levels, respectively.

The data suggest that the relationship between firing temperature and breakstrength is far more significant than the effects of other variables such as immersion time, dry weight, and the interaction between time and the biochemical environment. This relationship is illustrated in Figure 6, in which ceramic breakstrengths (transformed to logs) from Time 1 to Time 2 are plotted for all of the reservoir samplers. The mean decrease in breakstrength for each ceramic group from Time 1 to Time 2 are presented in Table 15 and can be summarized as follows: A consistent decrease in mean breakstrength, corresponding to decreasing firing temperature, is noted for the rock-tempered ceramic groups. The greatest amount of decrease, 66 units (one unit corresponds to 5 psi), was observed in the IIA group fired at 600°C. Group IIB, fired at 1050°C, exhibited the least change, 6 units, among the rock-tempered ceramics. A 12-unit decrease was observed in group IB, fired at 90°C. The organic tempered group, IA, fired at 750°C, exhibited the least overall amount of change, 4 units. This is probably the result of the higher internal temperature attained by the oxidation of the organic temper (see Technical Report 3, this volume).

Immersion time and the interaction between immersion time and mesh size are both significant factors in ceramic deterioration. In all of the ceramic categories, the most significant change in breakstrength occurred during the first four months of immersion. At the eight-month testing interval, this rate had decreased substantially, corroborating the results obtained in the laboratory water chemical experiment (Technical Report 3, this volume).

The interaction between the biochemical environment and the ceramic materials was difficult to assess, however some significant trends relating to ceramic deterioration are apparent. The least amount of overall change in breakstrength is observed in the microbiological samplers (mesh sizes A and B). The most significant change is observed in those ceramics placed in the open (mesh C) containers, exposed to the sediment. It would appear, therefore, that the combined chemical and biological interactions occurring at the mud-water interface are far more significant than either of these variables in isolation. Additional testing using larger sample sizes and a longer immersion time is needed to determine more precisely the rates and mechanics of ceramic deterioration over the long term.

Visual Analysis: Visual observations from each of the four ceramic groups were conducted in order to assess the impacts of chemical immersion on ceramic attributes. During ceramic preparation, the variables of firing temperature, temper type, and pigment type were systematically varied in order to determine whether these variables are differentially affected by inundation. The attributes selected for analysis include hardness, color, surface texture, and pigment properties. Each attribute was subjectively assessed by comparing inundated samples with non-inundated control standards. No attempt was made to quantify the observations.

At the end of the eight-month sampling interval, ceramic samples were retrieved from Stations 1 and 3 at Brady Reservoir. It was not possible to retrieve any of the samplers from Station 2 because the set line had been cut sometime between the four- and eight-month sampling intervals. A 100 ft. survey of the area failed to produce any of the remaining samplers with the exception of the pollen. Additionally, one of the macrobenthic containers could not be relocated at Station 1 at the eight-month period.

Although there appears to be a relationship between ceramic deterioration and environment of deposition as indicated by the breakstrength data, consistent differences in deterioration probably reflect compositional variability between the four ceramic groups. As noted in the water chemical experiment, ceramic group IIA, fired at 600°C, is the least preserved. All samples are in poor condition and share the characteristic of a soft, friable clay body. The organic pigment is slightly to moderately faded on the few remaining sherds. Predictably, the IIB ceramic group, fired at 1050°C, is the best preserved. These samples have suffered only minimal impacts from inundation, suggesting that firing temperature is a critical variable in ceramic preservation. The observed impacts resulting from inundation were limited to slight changes in sherd color and mineral paint fading. Ceramic groups IA and IB, fired at 750°C and 900°C, respectively, exhibited similar responses to inundation. A general softening of the clay body was noted in both groups, with slightly greater deterioration noted in the IB group. Several factors may be contributing to the observed deterioration. There is evidence that suggests the firing temperatures of the IB group may not have been adequate, since many of the mineral phase changes expected in ceramics fired to 900°C were not observed in the experimental ceramics (see Technical Report 3, this volume). Additionally, the organic tempered IA group may have attained higher internal temperatures than the 750°C value indicates as a result of the oxidation of the organic tempering material (Technical Report 3, this volume).

As observed in the laboratory samples, the organic pigments appear to be in a better state of preservation than the mineral pigments. In general, despite the difference in firing temperature between the mineral paint groups (IA and IIB) and the organic paint groups (IIA and IB), similarities in the degree and nature of fading and disappearance of the painted decorations were observed. In general, the mineral pigments faded more consistently than the organic pigments, in some cases almost to the point of obliteration. However, for the most part, even after fading, the design elements are still discernible. As noted in the laboratory ceramics, the organic pigments are subject to differential fading within the same bucket and even within the same artifact. When moist, the organic pigments can be rubbed off during handling. Therefore, much of the attrition and exfoliation observed on the organic paint ceramics is likely attributed to the mechanics of handling rather than to the effects of a particular environment, since variability between environments was not observed. Where present, the organic pigments are generally darker and more pronounced than the mineral pigments, suggesting that organic pigments may sustain the impacts of inundation better than their mineral counterparts. This observation is quite subjective, however. Other factors such as firing temperature, bonding capacity, and variables of manufacture must be assessed as well.

X-Ray Diffraction Analysis:* Thirteen powdered ceramic samples, including four fired and one raw clay control sample, were subjected to X-ray diffraction analysis to determine differences in their mineralogies which are attributable to inundation. Two methods of analysis were employed. The first, an analysis of an unoriented packed powder sample, allows the detection and identification of mineral phases present in concentrations exceeding approximately 5% of the total sample. The second procedure involves the analysis of an oriented sample in order to identify mineral species occurring in concentrations approaching approximately 1% of the total sample.

The results of the analysis are presented in Table 16. The raw clay control contains abundant quartz, chlorite, illite, and kaolinite, with trace amounts of orthoclase, microcline, and calcite present. All of these minerals are common constituents of "potters clay" obtained near fluvial sandstone outcrops.

Samples of IA and IIA ceramics (fired at 600° and 750°C, respectively) are mineralogically similar and tend to approximate the mineralogy of the raw clay material. Both groups contain abundant quartz and chlorite, with trace quantities of orthoclase, microcline and hematite. The primary differences between groups IA and IIA and between both groups and the raw clay control samples seem to reflect mineralogical changes induced by firing. For example, the crystalline

*X-ray diffraction analyses were conducted by Joe Register, Department of Geology, University of New Mexico.

structure of kaolinite is generally destroyed upon heating. In the IA ceramic group kaolinite was not detected in one of the two samples; in the IIA group kaolinite was abundant in both. In addition, both ceramic groups exhibited better defined illite crystallinity (exemplified by the sharpening of its diffraction maxima) than the raw clay control. Since illite represents a high temperature mineralogical phase, this appears to be an attribute of firing as well.

The IB ceramic samples (fired at 900°C) contain abundant amounts of quartz and chlorite with varying concentrations of orthoclase, microcline, illite and hematite. Calcite and kaolinite were absent from the diffraction spectra. The IIB samples (fired at 1050°C) contain abundant quartz and chlorite as well as trace amounts of orthoclase, microcline, hematite and spinel. Fayalite was tenuously identified in the control sample and in the two inundated samples.

The X-ray diffraction analysis of fired clay ceramics demonstrates considerable mineralogical variability among the various ceramic groups and between the fired ceramics and the unfired clay control. Most of this variability, however, can be attributed to the effects of firing temperature on mineralogical phase expression, rather than the effects of inundation. For example, kaolinite should be transformed into spinel at temperatures above 900° (Brownell 1976). Furthermore, olivine and spinel should replace chlorite at firing temperatures above 860°, and mullite should be the dominant mineralogical phase in material fired at 1050°C (Grimshaw 1971).

These predictable changes in mineralogical expression account for the vast majority of changes between the ceramic groups. The problem of isolating inundation effects on the basis of X-ray diffraction is further compounded by the mineralogical variability observed within ceramic firing groups. For example, although all of the ceramics were fired to at least 600°C, kaolinite is abundant in both of the IIA ceramics analyzed. In the IB ceramics illite was present in two of the samples and abundant in one other. In addition, small amounts of spinel and fayalite, indicating high temperature phases, were detected in some of the IIB samples.

At least some of this variability is probably attributable to sampling error, small sample size and inherent imprecisions in the measurement technique. Differences in mineralogy among samples fired at the same temperature also suggests some lack of quality control during the firing process.

Atomic Absorption Analysis:* Ceramic samples from each of the four ceramic groups, including fired and unfired raw clay control samples, were subjected to atomic absorption analysis to determine changes in chemical composition attributable to reservoir inundation. Five ionic compounds were analyzed: K_2O, MgO, Na_2O, Fe_2O_3, and MnO. The results of the analysis summarized in Table 17 indicate few significant differences between inundated and noninundated samples. Because of the small sample size of ceramics analyzed, particularly the control samples, it is difficult to evaluate the statistical significance of these results. Some leaching of potassium and sodium is evident in the IA, IB, and IIB ceramics, however, the amount is not significant. Iron (Fe_2O_3) exhibits the most significant loss due to leaching. In addition, MnO applied as a surface decoration in ceramic groups IA and IIB appears to be leached from the IIB ceramics and precipitated onto the IIA and IB ceramics which were painted with organic pigments. Some precipitation of MnO is noted in the IA ceramics as well, however, this observation is based on comparison with a single control sample, and is statistically invalid.

Water Chemical Analysis:** Atomic absorption analyses of natural water and microbiological samplers were conducted at the four- and eight-month sampling intervals at Brady Creek Reservoir. The results of the analyses are summarized in Tables 2-4. The most important difference was in selected ionic concentrations between the natural water and the filtered microbiological samples. An approximate threefold decrease in

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*Atomic absorption analyses were conducted by John Husler, Department of Geology, University of New Mexico

**Water chemical analyses were performed by George M. Simmons, Jr. Department of Biology, Virginia Polytechnic Institute and State University sodium and 2.5-fold increase in calcium and potassium was observed in the microbiological samplers from Station 1. The decrease in sodium is undoubtedly due to chemical erosion of the archeological substrates. The increased levels of potassium and manganese are also presumably due to chemical erosion of the substrates.

Corresponding to the increased calcium levels is an increase in the carbonate ion. The alkalinity value for the microbiological samplers is approximately four times the level measured in the natural lake water (635.3 and 165.2 mg/l $CaCO_3$, respectively). Ironically, the conductivity levels showed appreciable change and pH values were very similar (Table 2).

The degree to which the ceramics contributed to the observed chemical impacts cannot be determined since all of the materials were continually interacting with one another. It is expected, however, following the results of the laboratory water chemical experiment, that calcium and potassium ions are being contributed by the material categories of ceramics, bone, and shell.

Lithics

One lithic category, chert, was included in the Brady artifact assemblage. Two samples were immersed in each sampler per station for a period of eight months. Following the eight-month interval, the samples were removed and subjected to neutron activation analysis to determine whether inundation had affected the trace element composition of the chert. Visual examinations were conducted to evaluate changes in attributes relating to morphology and wear patterns. The results of these analyses are presented below.

Neutron Activation Analysis:* Five powdered chert samples from Stations I and III at Brady Reservoir were subjected to instrument neutron acti-

*Neutron activation analyses were conducted by Rich della Valle, Department of Geology, University of New Mexico vation analysis (I.N.A.A.) to determine whether inundation had altered the trace element composition of the samples. Of the 20 elements selected for analysis, only five including sodium, iron, chromium, uranium, and samarium occurred in detectable quantities. The remaining 15 were below the lower limits of detection (Table 18).

The results of the analysis, summarized in Table 19, show no significant differences between inundated and noninundated samples. Similarly, no significant differences were observed between samples immersed in the different chemical and/or biological environments. These data indicate that short term immersion will not adversely impact impact flaked chert artifacts. However, in order to evaluate the statistical significance of these results, a larger sample should be analyzed.

Atomic Absorption Analysis:* Chert samples were subjected to atomic absorption analysis to detect changes in ionic concentrations resulting from inundation. Six elemental compounds were analyzed, Na_2O, K2O, CaO, MgO, MnO, and Fe_2O_3. The results, summarized in Table 20, indicate little significant change resulting from inundation. The slightly higher values for MnO and Fe_2O_3 probably reflect a precipitation of manganese and iron leached from the ceramic samples. However, a larger sample size is required to evaluate the statistical significance of the results. These results concur with the results of the neutron activation analysis in which it was demonstrated that short periods of immersion do not adversely affect the trace element composition of chert and obsidian.

Visual Analysis: The lithic artifacts were subjected to visual examination to determine changes in morphological attributes and mechanically reproduced wear patterns. Gross visual examination of the artifacts aided by light microscopy did not reveal any significant changes resulting from inundation. Some attrition of the artifact margins (both on utilized and unutilized edges) was noted, but this is largely the result

*Atomic absorption analyses were conducted by John Husler, Department of Geology, University of New Mexico of handling and mechanical breakdown caused by collision between the artifacts placed together in the sampling containers. The visual observations are reinforced by the atomic absorption and neutron activation analyses conducted on the laboratory samples (see Technical Report 3, this volume), as well as by similar tests conducted on the Brady materials.

Shell

One category of shell, oyster, was included in the Brady Reservoir artifact assemblage. Five samples were immersed in each of the three samplers per station. At the four- and eight-month intervals, the samples were removed and weighed. At the eight month interval, randomly selected samples were subjected to atomic absorption analysis to determine changes in ionic concentrations resulting from inundation. Visual observations were also made to detect changes in morphological attributes over time and between sampling environments.

Atomic Absorption Analysis:* Nine powdered shell samples, including two noninundated control samples were subjected to atomic absorption analysis to detect changes in ionic concentrations attributable to inundation. The results of the analyses are summarized in Table 21. Five ionic compounds were selected for analysis: K_2O, MnO, MgO, Fe_2O_3, and Na_2O. No significant differences were noted between the inundated and noninundated control samples, thus corroborating the results of the atomic absorption and X-ray diffraction analyses conducted on the laboratory samples (see Technical Report 3, this volume). The slightly higher magnesium values noted in the control samples may simply reflect the normal range of variability of this element. The range measured for the seven inundated samples varied between .199% and .032% magnesium, while the two control samples contained .428% and .231% magnesium. Larger sample sizes are required to determine the significance of these differences. The most significant

*Atomic absorption analyses were conducted by John Husler, Department of Geology, University of New Mexico.

impact to shell is the leaching of calcium which was determined by atomic absorption of the natural lake water and the water contained in the microbiological samplers (Table 4). The calcium was presumably leached from the shell, bone, and ceramic samples. A comparison of dry weights conducted prior to and following inundation support the chemical data.

Statistical Analysis of Dry Weights: In order to assess the statistical significance of the variable time as a factor in deterioration, the dry weight data were subjected to a paired t-test to compare mean dry weights from T_0 to T_2, a period of eight months. The results of the paired t-test, presented in Table 22, can be summarized as follows: The data indicate that immersion time is a highly significant factor in weight loss both at the .05 and .001 levels of significance. The shell samples placed in the open samplers (Mesh C) at the sediment-water interface yielded the highest t-ratio (29.11, 11 d.f.) compared with Mesh B (9.29, 11 d.f), and Mesh A (7.68, 11 d.f.). In all cases, the null hypothesis which states that the means are equivalent must be rejected. Larger sample sizes are required to evaluate the interactive effects of mesh, time, and environment.

Visual Analysis: The oyster shells were subjected to visual examination to determine impacts to attribute data used for identification and classification. The attributes selected for study include morphology, surface texture, color and nacre (sheen). These attributes were qualitatively assessed using pre-inundation photographs and representative noninundated control standards.

The results of the analyses are summarized as follows. No detectable morphological or textural changes occurred during the eight-month episode of inundation. The only observable difference was a slight discoloration (darkening) of the shells contained in the macrobenthic samplers, which were in contact with the reservoir sediments. Similar effects were not observed in either of the two water chemical samplers, as the materials were not in contact with sediments, but were essentially "suspended" in the water column.

Wood

Two types of wood were included in the Brady and Claytor Reservoir assemblages: ponderosa pine and red oak, representing typical softwoods and hardwoods occasionally encountered in archeological contexts. Ten samples of each type were immersed in each sampling unit for a period of eight months in Brady Reservoir and four months in Claytor Reservoir. At the end of the respective four- and eight-month intervals, the samples were analyzed. Dry weights were measured in both the Brady and Claytor samples to determine weight loss. In addition, tensile strength (compression) tests were performed on the Brady samples to measure the change in internal strength resulting from deterioration of the cellular structure.

Compression Strength Analysis: Compression tests using the Instron Universal Testing machine were performed on all pine and oak samples at four-month sampling intervals in order to assess the effects of inundation on the mechanical and physical properties of wood. The extent to which inundation affects the structural integrity of the wood will depend upon the type and condition of the wood and the environmental conditions to which it is subjected. For example, in cold water (4-25° C) wood is generally resistant to chemical attack (Browning 1963). However, given sufficient time, even wood submerged in cold water will slowly degrade through chemical decomposition. The rate of deterioration will depend upon the temperature and the diffusion processes which govern the transfer of soluble extractives (e.g., polysaccharides). Laboratory experiments conducted on pine samples immersed in cold water indicated only a 1% loss of extractives, with little additional material loss noted when the immersion interval was extended to 72 hours (Browning 1963).

In watersaturated wood, the entire capillary structure, including the pores, fills with water. As adsorption takes place, only the non-crystalline structure of the wood swells. The extent of internal surface area and the density of the wood determines the amount of swelling which can take place. In time, swelling will lead to a decrease in strength properties as the cell wall components (e.g., cellulose) are chemically leached out. Once the saturated wood begins to dry (e.g., during drawdown) high surface tension stresses cause the cell walls to collapse inward resulting in the characteristic shrinking and cracking of differentially dried wood (Barkman et al. 1976).

The results of the compression tests on the pine and oak samples immersed in Brady Reservoir are summarized in Table 23. Unfortunately, due to the problems in calibration between the oak and pine samples, the results are tenuous. In addition, comparable T_0 samples from the population as that sampled for immersion were not available. Samples from an independent population did not produce consistent values, and therefore were excluded from analysis. Despite these shortcomings, certain trends are apparent from the data between sampling intervals T_1 and T_2. These can be summarized as follows.

As predicted, there was an overall decrease in wood compression strength through time for both categories of wood. The variation in compression trajectories between the different mesh sizes indicates differential deterioration within the samplers. The most significant factor affecting wood compression is wood type. Predictably, the compression values for the softwood (pine) category are lower than those for the hardwood (oak) category.

To test the significance of these results, the data were subjected to a Student t-test to test the null hypothesis of no difference between the population means. The variable mesh size was held constant, while the variables location and time were systematically varied. The data indicate that immersion time is a highly significant factor in both pine and oak samples subjected to an intense anaerobic environment. The highest t-ratios were consistently observed in the microbiological (mesh B) samplers, with oak exhibiting a value of 5.850 (38 d.f.) and pine exhibiting a value of 5.722 (37 d.f.). In only one instance, pine samples immersed in mesh A samplers, was there a failure to reject the null hypothesis, suggesting that some mechanism of differential preservation may have been operant. Longer immersion time and larger sample sizes are required to evaluate the question of differential preservation, and to evaluate the interaction effects of mesh, time and environment.

Visual Analysis: The wood samples were subjected to visual analysis to detect changes in morphological and textural characteristics of the specimens. An additional attribute selected for study was color. The variables were qualitatively assessed using Munsell color determinations, color photographs and representative noninundated control standards.

The results of the observations are summarized as follows. There were no observable differences in degree of weathering or color changes between the sampling stations. The variability noted occurred within the two general categories of wood and is not related to their spatial distribution within the reservoir. In general, the oak is much darker than the pine, a trend observed in the laboratory samples as well. The pine, however, while not as discolored as the oak, is consistently darker in color than the control standards. The oak samples also tend to be much more weathered in appearance than the pine. The form of weathering is a cracking and splitting of the exposed external surfaces. Little weathering was noted on the interior surfaces (i.e., the surface not directly exposed to the water). The unifacial character of the weathering pattern may be the result of the relative position of the artifacts within the samplers. In addition, the wood samples (both pine and oak) from the macrobenthic samplers appeared more weathered and darker in appearance than the water samplers, probably as a result of their exposure to the sediment.

Apart from these relatively minor changes, the oak and pine samples place in Brady and Claytor Reservoirs are in remarkably good condition. There is no obvious evidence of biological attack and degradation commonly observed in marine environments.

Dry Weight Analysis: The wood samples from Claytor Reservoir were subjected to dry weight analyses at the end of the four-month immersion period to determine loss due to decomposition. The data are summarized in Table 24. Although neither filter treatment nor depth appears to be a significant factor in weight loss, consistent weight loss was observed within the two categories of wood. However, because of the methods employed to dry the samples following immersion, it cannot be determined if weight loss is due to active processes of degradation or to the loss of natural water weight during the drying process. All of the artifacts removed from Claytor Lake were dried in a hot air oven at 80°F for 24 hours, and retained in a dessicator until weighed.

Bone

One variety of bone, charred cow, was included in the Brady Reservoir experiment. Five samples were immersed in each of the samplers for a period of eight months. At the end of the eight-month period, randomly selected samples were subjected to atomic absorption analyses to determine differences in ionic concentrations resulting from inundation. Visual analyses were performed to detect changes due to chemical or biological degradation. The results of these analysis are presented below.

Atomic Absorption Analysis:* Six powdered cow bone samples, including one noninundated control sample, were subjected to atomic absorption analysis. The results of the analysis are summarized in Table 25. Five ionic compounds were selected for analysis: K_2O, MnO, MgO, Na_2O and Fe_2O_3. Few significant differences attributed to inundation were noted in the test samples. There appears to be a slight leaching of potassium and a greater amount of magnesium leaching. As noted in the lithic samples, the primary effect is the precipitation of manganese and iron leached from the ceramics. Additional analyses using larger sample sizes are required to evaluate the significance of the results.

Visual Analysis: The Brady Reservoir cow bone samples were subjected to a series of visual analyses to determine if inundation had adversely

* Atomic absorption analyses were conducted by John Husler, Department of Geology, University of New Mexico

impacted those morphological attributes useful for identification and classification. The attributes selected for study, including color, morphology and surface texture were qualitatively assessed using pre-inundation photographs and representative control standards. The observations are consistent with those noted in the water chemical phase of the experiment. No significant differences were observed between the inundated and control samples, nor between samples exposed to different chemical or biological environments. The only observable factor related to inundation was the mechanical breakage that occurred as a result of handling and contact between the various materials. Table 26 summarizes the relative frequencies of broken versus unbroken bone samples. This attrition is not the direct result of biochemical activity, however, as noninundated samples stored on a laboratory shelf exhibited similar patterns and frequencies of breakage.

Seeds

Seven varieties of charred and uncharred cultivated seeds, including kidney beans, pinto beans, navy beans, popcorn, blue corn, wheat and rye, were immersed in Claytor Reservoir and in the controlled aqueous environments maintained at Virginia Polytechnic Institute. At the end of the four- and three-month immersion periods, respectively, the samples were removed for dry weight analysis. The results are summarized in Tables 27 and 29. Bulk dry weight measurements of the seeds were taken at the onset and conclusion of the experiments in order to provide an index for assessing biological and chemical impacts.

Two different methods were employed to dry the seeds after removal from the solutions. The first technique, applied to the Claytor Reservoir materials, involved drying the seeds in a hot air oven at 80°F for 24 hours, and placing them in a dessicator until they could be weighed. During the subsequent laboratory phase, this technique was abandoned in favor of a process which employed the use of forced air at room temperature for drying. This latter procedure was adopted to avoid an increase in weight loss due to excessive drying.

Analysis of the seeds in both the Claytor Lake and VPI laboratory solutions produced consistent results. In each instance the uncharred seeds exhibited a significantly higher weight loss than the charred seeds. This was supported through visual analyses of the seeds which showed more pronounced degradation in the uncharred varieties. In the Claytor Lake experiment, the variables of depth and sampler type (i.e., the presence or absence of filters) were not significant in terms of seed degradation. In the laboratory experiment, however, chemical environment was a significant factor in seed decomposition. The uncharred seeds immersed in sterilized distilled water exhibited a weight loss in excess of 2 g more than the uncharred seeds immersed in sterilized Claytor Lake water. The charred seeds, however, were not significantly affected by environmental differences. The reduction in weight loss values for the charred seeds is probably a function of nutrient unavailability.

A comparison of weight loss between the reservoir and laboratory samples indicates greater loss in the laboratory samples, presumably due to the higher temperature maintained in the laboratory (30°C versus a range of 6-16°C for Claytor Lake). On the basis of these results and those obtained from the Brady Reservoir and water chemical phases of the experiment, we may conclude that nutrient availability and temperature are important factors that influence decomposition rates.

Leather

Leather was one of the material categories not included in the water chemical experiments. It was included in the Claytor Lake and Virginia Polytechnic Institute phases in order to assess its susceptibility to biodegradability following a short term period of immersion. Unfortunately, the leather samples to be placed in Claytor Lake were completely destroyed by the sterilization (autoclaving) process prior to its immersion (Figure 3). Therefore, the only data available concerning the impacts of immersion of leather are derived from the mud column study conducted in the laboratory at Virginia Polytechnic Institute.

The results are summarized in Table 28. Samples of leather were placed on the sediment surface and at a depth of four inches below the substrate in each of the three samplers. At the end of three months, the samples were retrieved, dried and weighed. The results demonstrate that weight loss of the leather on the sediment surface is consistently higher than for the buried samples. In general, the leather from the mud matrix exhibited greater weight loss than the leather from either the fine silt or gravel matrix. Furthermore, the leather strips placed in fine silt, both at the surface and in a buried context, exhibited a greater weight loss than the samples in the gravel.

Paper

Paper was the second category of material not included in the water chemical experiment conducted at the University of New Mexico. Prepared strips of Whatman 1 qualitative filter paper were immersed in the Claytor Reservoir and Virginia Polytechnic Institute laboratory experiments. In general, the paper strips placed in the sediments (mud column experiment) were in a much poorer state of preservation than those samples placed in the two aqueous environments. Only small paper fragments were recovered from the silt and mud columns. While no fragments could be recovered from within the gravel column, the paper at the surface of the column was preserved intact. Apparently, the microenvironment at the surface was not conducive to microbial colonization and/or an inadequate amount of surface area was directly in contact with the gravel surface. Conversely, the loss of paper within the column may be attributed to uncontrolled bacterial activity. These assumptions, however, cannot be confirmed since neither water chemical analyses of the water covering the sediments nor bacterial studies were conducted.

Water Chemical Analyses:* A spectral analysis of major cations and the anion carbonate was conducted to evaluate general variation in the reservoir and to provide a data base from which to compare differences in the water chemistries of the microbiological samplers. The data are summarized in Tables 2-4. At the end of the first four-month sampling interval, September, 1979, water chemical data from Brady Reservoir indicated that the water column was aerobic (e.g., dissolved oxygen values between 6.8 to 8.5 mg/l (Table 3). At the mud-water interface, however, the oxygen readings fell to 1.0 mg/l or less, suggesting that the materials were in an anaerobic environment. This was confirmed by the stench of H_2S present when removing the materials from the macrobenthic samplers. During this time, the ionic composition of the water column was similar to that analyzed earlier by the U.S. Geological Survey in 1977 and 1978 (Tables 2 and 3). Four months later, the chemical composition of the water column had changed slightly (Table 5).

A comparison of chemical compositions between the Brady and Claytor Reservoirs produced the following results (Table 5). Of the four major cations in the natural water (Na, Ca, Mg and K), sodium was the most abundant ion in Brady Reservoir, and approximately 10 times the level found in Claytor Lake. Calcium, the next most abundant ion, was nearly six times as abundant in Brady Reservoir. The mean magnesium level in Brady Reservoir was 33.0 mg/l, slightly less than the value for Claytor Lake Reservoir. The elevated magnesium levels in the latter reservoir probably reflect the dolomite in the surrounding basin. Potassium averaged 15.3 mg/l in Brady, nearly three times the value observed in Claytor Lake. In comparison to the September values for Brady Creek Reservoir, the level of sodium had almost doubled by January (X = 93.6 vs. 161.3 mg/l, respectively). The reason for this is unclear unless the elevated levels in January were due to increased surface run-off and increased turbidity in the water column due to wind action. Other values were similar in order of magnitude to the September samples, but were also slightly elevated.

Tables 6 and 7 compare the general physical water properties at Claytor Lake in January when the samples were placed in the water and

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*Water chemical analyses were performed by George M. Simmons, Department of Biology, Virginia Polytechnic Institute and State University in April when the samples were removed. The major difference noted was the 10°C increase in temperature. Conductivity, alkalinity and pH values were all slightly lower in the April samples. Tables 7 and 8 summarize the water properties within the samplers. The results show no correlation between depth and/or presence or absence of filters. The physical changes noted were consistent between the samplers and included a reduction of pH and an increase in conductivity. Likewise, there did not appear to be a correlation between filter type or depth with regard to chemical changes, except in the cases of sodium and zinc. A slight increase in sodium was noted in the tubes with filters. The dramatic difference in zinc values can be attributed to the galvanized metal tags used to label the artifacts. All samples exhibited a higher concentration of cations inside the tubes than in the surrounding water outside the tubes.

The chemical and physical properties of the Virginia Polytechnic Institute laboratory water chemical experiments are summarized in Tables 9 and 10. In all cases, the concentration of the chemicals tested were much higher in the tubes than in the surrounding water. The dissolved oxygen and alkalinity values all measured zero; pH indicated an acidic environment and conductivity was very high. These results were nearly uniform for all tubes.

Biological Analyses:* Biological analyses of macroinvertebrates and bacterial organisms were conducted in order to identify and quantify the organisms participating in the degradation activites. The results of the analyses are presented in Tables 30-35.

Macrobenthic organisms collected from the macrobenthic samplers during the four- and eight-month sampling intervals at Brady Reservoir are summarized in Tables 30 and 31. The most notable difference between the stations was the slightly greater number of taxa and general

*Macroinvertebrate and microbiological identifications were performed by George M. Simmons, Jr. and Robert E. Benoit at the Virginia Polytechnic Institute and State University, Blacksburg, Virginia abundance of organisms at station 3 during both sampling periods. One explanation is the characteristic mud bottom in the upper reservoir area and the tendency for these environments to support a larger natural population. As Reed and Simmons (1976) reported, populations on bucket samplers closely represent natural populations. Therefore, one would expect greater colonization on the samplers located in more desirable habitats.

Most of the organisms identified include filter feeders, predators and detritivores. The other major category of "scrappers" included snails (Gastropoda). The family Physidae was abundant at all stations and <u>may</u> have been feeding on exposed surfaces of the cultural substrates. As a result of their feeding habits, they could have assisted in maintaining an actively growing fungal colony on any exposed substrate by periodically removing fungal mycelia. The surprising lack of amphipods, organisms usually associated with decaying organic material (e.g., seeds, wood, etc.) (Webster and Simmons 1979), may represent a general absence of these organisms in the local benthic community.

The bacterial populations of the water and sediment from Brady Reservoir reflect a "typical" decomposer population (Table 32). The bacteria observed in the water samples were members of the genera *Pseudomonas*, *Flavobacterium*, *Achrobacter* and *Arthrobacter*. Slide cultures of bacteria grown at the Virginia Polytechnic Institute microbiological laboratory indicate that several different types of budding and prostecate bacteria were also present. The sediment contained a diverse and abundant bacterial population which included anaerobic and facultative bacteria. There was a greater proportion of gram-positive versus gram-negative bacteria in the sediment as contrasted with the surface water. The higher bacterial count in the water during January may reflect a greater amount of organic matter entering the lake from runoff, or decomposition of emergent vegetation in the lake, or decreased activity of predators in the colder water (Table 33).

The bacterial populations which were observed in the decomposition chambers were greater than expected (Figure 8). After inspection of the samplers, it was obvious that gas pressure within the chambers caused the rupture. No significant difference between types of microorganisms in the different containers was observed, perhaps indicating the membrane ruptured shortly after placement in the reservoir. The rupture did not permit the entry of any macroinvertebrates into the chambers.

All of the decomposition chambers contained large quantities of gas (Figure 9). Based upon laboratory examination of water samples returned to the laboratory using a gas partitioner, the gas was identified as methane with significant amounts of CO_2 and H_2, and traces of H_2S. The appearance of these products indicates the artifacts were exposed to an intense anaerobic environment. Based upon the oxygen values of the water and sediment, the chamber environment was less oxygenated than the surface 2 cm of sediment. The chambers were not only anaerobic but the bacterial populations were still in an active state of metabolism. The bacterial populations were determined in terms of viable counts, microscopic counts, and adenosive triphosphate (ATP) concentrations of the cells. The ATP values indicate the bacterial cells were probably entering the declining growth phase. Therefore, the artifacts in the chambers were being exposed to the end products of anaerobic metabolism.

The bacterial numbers observed in the chambers represent many diffirent physiological types. Most of the bacteria probably grew initially using the soluble organics from the artifacts. However, there was little evidence based upon visible inspection of the artifacts that the microorganisms, which are capable of metabolizing cellulose and lignin, had become established in the chambers at that time. There were small numbers of bacteria present which have the potential to degrade wood in the chambers, however, the most likely source of energy needed to maintain the metabolism of the organisms was probably provided by the seeds, since the starch, monosaccharides, protein, etc. are more easily decomposed. Visual inspection of the seeds in the chamber indicated that these artifacts had lost some weight. Additionally, a bacterial slime layer covered the objects.

A comparison between the bacterial populations observed in the four- and eight-month sampling intervals indicates a marked decrease in the number of variable bacteria in the chambers. This was reflected in the decrease of gas production and the apparent quantity of methane. Some decrease in activity was expected because of the decrease in water temperature. However, it is likely that the decrease also reflects a trend toward a steady state in contrast to the flurry of anaerobic activity observed at the four-month interval. Decomposition of the artifacts should in theory parallel microbial activity. Since the chambers were designed to permit chemical and microbial activity on all sides of the artifacts, decomposition of the artifacts may be faster in the chambers during the initial period than it would have been had the artifacts been in direct contact with the sediment. In either case a steady state of decay is likely. The factors which regulate this decay can best be illustrated under laboratory conditions. Some preliminary laboratory data are shown in Table 34. This experiment demonstrated that decomposition is a function of nutrient concentrations, temperature, and dynamic condition of the environment. The dynamic factor simply reflects the idea that stagnation induced by microbial end products will reduce biological activity. The most important stagnation factors are pH, sulfide concentration, organic acid concentration and depletion of nutrients. Some of these stagnation factors, such as organic acids, will permit a slow weathering of some artifacts. The laboratory data indicate that it will be possible to make some reasonable predictions about the fate of certain artifacts in sediments if certain parameters are known.

The data from the chemical and microbiological analysis of the water in the artifact chambers are in general agreement. The microbial activity in the chambers clearly affected the chemistry of the chamber water. The increase in alkalinity and decrease of pH is evidence of CO_2 production and possible organic acid production. The decrease in conductivity and sodium indicates possible uptake of sodium by the microorganisms in the containers. The calcium may reflect a net influx of calcium into the chambers and subsequent use by microorganisms before floculation or precipitation. On the other hand, the calcium may represent release of calcium from the artifacts in the aquatic milieu. The decrease in iron should reflect uptake by bacteria for use in synthesis of cell components or the precipitation of insoluble iron compounds on the artifacts.

Microbiological analyses of the Virginia Polytechnic Institute water chemical phase of the experiment produced similar results to the Brady phase. All of the tubes exhibited varying degrees of gas production, reflected in the amount of water remaining in the tubes. Two tubes contained no water at all (Figures 6 and 7). In addition, the nylon bags containing the seeds were swollen due to gas production (Figure 6). Examination of the filters indicated that they were all intact. The volume of gas produced was not enough to rupture the filters, though the amount was sufficient to displace the water in the tubes. Bacterial data collected from the water in the aquarium and from each tube are summarized in Table 35. Dilutions of the water samples were grown aerobically on standard plate count media. No attempt was made to identify colony types or to plate anaerobic cultures.

CONCLUSIONS, IMPLICATIONS, AND SUGGESTIONS FOR FUTURE RESEARCH

The results of an eight-month experiment designed to study the effects of chemical and biological variability on seven classes of cultural materials within an actual reservoir were presented in this report. The Brady Reservoir study was designed as a corollary to the laboratory water chemical experiment conducted at the University of New Mexico (see Technical Report 3). Its purpose was to analyze the cause and effect relationships between the chemical and biological components of a typical reservoir and the differential preservation of the various artifact classes. The seven material categories selected, ceramics, lithics, bone, shell, wood, seeds, and pollen, are representative of materials frequently preserved in archeological sites.

The main purpose of the experiment was to isolate the water chemical and biological variables in order to identify the major factors contributing to material deterioration and assess their impacts. This was achieved through the design of samplers fitted with special filters. One filter system was designed to exclude microorganisms, thus isolating the water chemical effects; the second system was designed to include microorganisms, but exclude macro-invertebrates. A third system, consisting of an open container placed at the mud water interface, permitted the interaction of all of the variables, water chemical, biological, and edaphic. Unfortunately, rupture of the two filter systems precluded isolating water chemical from microbial effects.

Additional experiments conducted at Claytor Lake Reservoir and Virginia Polytechnic Institute and State University were designed to determine the decomposition rates of various perishable materials not included in the Brady Creek Reservoir and water chemical experiments. It was felt that rates of deterioration over the short term could best be measured in biologically degradable materials such as leather and paper. Wood and seeds, comparable to those included in the aforementioned experiment, were also included to determine rates of deterioration. The results of these experiments are summarized as follows for each material category:

Ceramics

Several effects attributed to inundation were observed in the ceramic samples.

1) Despite the failure to isolate water chemical from biological impacts, significant differences were noted between ceramic samples placed in the microbiological samplers (mesh sizes A and B) and those placed at the sediment water interface (mesh C). In general, all of the ceramic groups placed in the open samplers (mesh C) were in

a poorer state of preservation than those in the microbiological samplers, suggesting that the interactive biochemical and edaphic effects are much greater than either of these in isolation. These differences in deterioration were detected both visually and analytically through breakstrength and chemical analyses.

2) Within all four ceramic categories, there is a consistent decrease in ceramic breakstrength through time. The most significant change occurred during the initial four-month period of inundation. Following this period, the rate of change diminished. Those factors that may alter ceramic breakstrength include alteration of the trace element composition, primarily through leaching, absorption of water, and alternate wetting and drying.

3) Firing temperature appears to be a dominant factor influencing ceramic deterioration. This corroborates the findings of the laboratory water chemical experiment in which it was observed that firing temperature is the principal factor responsible for the deterioration. The least amount of deterioration was observed in the IIB ceramics, fired to 1050°C, while the greatest deterioration was noted in the IIA ceramic group, fired to 600°C. The similar states of degradation noted in those ceramics fired in the midrange (IA, 750°C and IB, 900°C) probably reflect a combination of differing tempering materials (organic versus crushed rock), ceramic variability, and inadequate firing.

4) The results of visual analysis indicate an overall deterioration in all ceramic categories resulting from inundation. The most obvious effects are a general softening of the clay body and differential fading of the surface decoration. The slightly better preservation of the organic (beeweed) pigment versus the mineral (MnO) pigment may be partially accounted for by the difference in solubility of the C and Mn ions.

5) Another effect which has not been fully explored or tested, but which has significant potential for degradation in an inundated context, is the effect of biologically produced organic acids. The presence of the organic acids could effectively reduce the pH of the environment enough to induce leaching of cations such as Ca and other ions which function as binding elements.

The implications that these effects have for archeological ceramics submerged in an aqueous environment are as follows:

1) Because archeological remains occur in both temporal and spatial contexts, their deterioration may affect archeological interpretation at all levels. For example, the elimination or differential destruction of ceramics fired at low temperatures may skew the representativeness of the cultural record. The deterioration of ceramic types frequently used as diagnostic temporal markers (e.g., seriation dating) likewise skew the cultural interpretation.

2) The dissolution or leaching of trace elements from the ceramics has a twofold effect. If the elements being leached are binding elements, the ceramics will crumble and lose their structural integrity. Since most ceramic analysis is based upon the survival of attributes such as surface treatment, paste, temper type, etc., the ability to perform the analyses will be impaired. Second, leaching of key trace elements may preclude the kinds of analyses required for clay and/or temper source identification. These analyses are useful for identifying indigenous versus trade wares and for identifying local source materials.

3) A third implication concerns the interactive effects of the biochemical and edaphic environment. Because archeological remains are interred in a soil matrix, it is significant that the greatest impacts occurred in the biological samplers exposed to the sediments, suggesting that burial does not necessarily ensure preservation. Biochemical and mechanical factors must be assessed as well.

Lithics

No adverse impacts attributable to inundation were noted in the lithic samples, suggesting that short term immersion (e.g., eight months) is insufficient to effect a change in the trace element composition and exposed to normal chemical concentrations. Cursory examination of chert and obsidian samples subjected to 20 times normal chemical concentrations in the water chemical experiment (see Technical Report 3) indicate that short term interaction with concentrated chemical solutions, such as occur at the sediment-water interface of a reservoir did not affect the trace element composition. Additional research is recommended in order to test the effects of prolonged immersion on materials submerged at depths greater than 50 feet. It is possible that leaching of trace elements may have been inhibited by the presence of a natural weathering rind on these samples.

The implications of these data are restricted in that the main purpose of the analysis was to measure chemical change resulting from inundation and to evaluate the potential for conducting trace element analyses following immersion. Toward this end, the experiment was successful, however, due to time and fiscal constraints, other types of analyses which would have been beneficial for archeological applications (e.g., assessing impacts to hydration rates) were not conducted. Therefore, it is recommended that future research be directed toward this problem as well as that of long term immersion.

Shell

As noted in the lithic samples, few changes were observed that can be attributed to the effects of inundation. Atomic absorption and X-ray diffraction analyses failed to detect any significant changes in ionic concentrations other than a predictable decrease in calcium. The leaching of calcium was corroborated both by water chemical data and by weight loss measurements conducted at periodic time intervals.

The results of the statistical analysis of shell dry weights indicate a greater proportional weight loss in those shells placed at the sediment-water interface than those placed in the microbiological samplers. The data suggest that the combined chemical and biological interactions occurring at the mud-water interface may exert a greater influence than either water chemical or microbiological impacts in isolation. However, caution must be exercised in evaluating the results of these experiments since these observations are based on critically small sample sizes.

The implications that these results may have for archeological shell submerged in a reservoir are outlined as follows:

1) Predictably there will be a leaching of calcium from the shells as a result of the chemical and biochemical reactions occurring within a reservoir. The major factors determining the rate of the reactions include pH, cation concentration, and edaphic properties of the reservoir which influence the rate of diffusion.

2) Two major effects may result for the chemical leaching of calcium. The first and most devastating effect is the elimination of shell from the archeological record. It is conceivable that localized production of organic acids and a concomitant lowering of pH could dissolve the shell and, as a result, skew the archeological record. The second allied effect is that severely leached shell will eventually lose its structural integrity, therefore increasing its susceptibility to both chemical and mechanical impacts, which would eventually result in the total destruction of the shell and/or loss of attributes useful for identification and analysis. While neither of these effects were specifically observed in the Brady Reservoir samples, they may be inferred from the results obtained from the water chemical experiment (see Technical Report 3, this volume). Obviously, future research should address the question of long term inundation effects.

<u>Wood</u>

All measurements of the wood samples yielded tenuous results. Some resulted from calibration problems (compression analysis); others resulted from measurement and procedural problems (dry weight measurements). It is not our intention to apologize for these shortcomings, but rather to provide guidance to future researchers interested in the problem of differential preservation of wood. Like many other categories of archeological materials included in these experiments, wood is a highly variable material in terms of its structural and physical properties. As a result, it tends to react to physical and chemical stimuli in a variable manner, which could not be controlled within the context of the present research design. Thus, although the results presented below are highly generalized, we feel they adequately

reflect the major impacts resulting from short-term immersion.
1) The most obvious change which could be detected visually is that of surficial weathering (e.g., surficial discoloration). Generally, this type of weathering does not penetrate beyond 0.1 in. below the surface of the wood and, therefore, does not interfere with its structural properties (Browning 1963). In addition to the darkened surface, small stress-related cracks were observed which probably resulted from the drying process. While various degrees of discoloration and cracking were observed in all of the samples, the most pronounced effects were observed in the wood samples in contact with the mud-water interface.
2) A second result attributable to inundation is the loss of compression strength. This is probably the result of a combination of factors, including incipient solubilization of the extractive portion of the wood, which would lead to structural weakening and loss of strength as a result of the drying process. The experimental design did not permit the independent testing of these factors, however, it is recommended that these factors be isolated in the future. One way to achieve this is to perform the compression tests on samples which have been dried under carefully controlled conditions. For example, the moisture content of waterlogged wood is a useful index for measuring deterioration. It is determined by weighing the wet wood, then drying it at 110°C (230°F) until a constant weight is achieved. The moisture content is then calculated as a percentage less than 100, based on the wet weight of the wood, or as a percentage greater than 100, based on the dry weight. The amount of cell wall material remaining can also be calculated from these figures by subtracting the moisture calculated on wet weight from 100 (Blackshaw 1976).

Since these results are not substantiated by rigorous testing or measurement procedures, the implications for archeological wood are based upon observable trends apparent from these data and from data presented in the literature (Levy 1970, Florian n.d., Croes 1976).
1) Given sufficient time, archeological wood will degrade in a submerged anaerobic environment, even in the absence of biological organisms. The rate of degradation will depend upon the type of wood,

the condition of the wood, and the edaphic, chemical, and biological components of the environment.

2) That portion of the wood most susceptible to degradation is the soluble extractive component contained within the cell body. Over the long term, chemical attack of the more resistant components comprising the cell wall (e.g., cellulose and lignin) will contribute to the structural weakening of the wood, causing it to lose its resiliency.

3) Perhaps the most destructive effect of inundation is alternate wetting and drying, such as would occur during periodic drawdown. Wood is extremely susceptible to changes in volume and form in the presence of moisture. In the absence of moisture (e.g., the drying phase), moisture that is extracted from the cellular structure sets up internal stresses which causes the collapse of the cell wall and results in the characteristic cracking of dried wood. Over the long term, as more cracks develop and existing cracks enlarge, the wood will eventually succumb to mechanical, chemical, and biological processes of degradation. One result is the total elimination of the wood from the archeological record; a second result is the loss of attribute data useful for identification and functional analysis.

Bone

Few significant differences attributed to inundation were observed in the bone samples. The main reason for the notable lack of inundation impacts, despite the perishable nature of bone, is that charred bone was selected. Charred bone, like charred wood, is a chemically inert substance which is generally not affected by external factors. The only observable chemical impacts were a slight leaching of potassium and a slightly greater amount of magnesium leaching. These results may simply reflect the natural variability of these ionic concentrations in bone, rather than effects of inundation. Since so few samples were analyzed, the significance of these results cannot be assessed. The greatest impacts resulting from inundation will undoubtedly result from mechanical processes, which will break the bone into fragments too small for identification. The severity of the impact will ultimately depend upon the nature of the mechanical process, the nature of the bone, and its contextual relationship.

Seeds

Consistent weight loss was observed in both the uncharred and charred seeds, with greater weight loss observed in the uncharred seeds. This observation was supported both through visual observations and laboratory experimentation, which suggested that nutrient availability and temperature may have been the primary factors influencing the decomposition rates.

The implications of these results are important in terms of archeologically preserved seeds subjected to reservoir environments. Many of the seeds preserved in archeological contexts have survived because special environmental factors (e.g., exclusion of oxygen, absence of microorganisms) have ensured their survival. Under some conditions, inundation may continue to preserve the seeds, however, it is felt that under most situations, inundation will destroy preserved seeds. For example, aeration of the soil, which results during initial inundation and during seasonal turnover, may initiate the process of aerobic degradation in materials that are buried within 30 cm of the surface. Additionally, chemical changes in the soil may contribute to chemical degradation of seeds in contact with that soil. Likewise, swelling of the seed may contribute to its mechanical destruction. Charred seeds are not exempt from the processes of degradation, particularly mechanical processes which may remove the seed coat or fragment the seed making identification difficult, if not impossible.

Any change in environmental status will have its impact on the materials preserved within that environment, and it has been the purpose of this experiment and the laboratory water chemical experiment to identify those variables that influence differential preservation of common cultural materials.

SUMMARY

Obviously, the complexity of the problem of differential preservation of common cultural materials far exceeds the research designs implemented in these experiments. However, a few general statements can be made to summarize the data presented in this report.

1) In general, decomposition of organic materials parallels microbial activity. Those factors that regulate the rate of decomposition include nutrient concentrations, temperature, and the dynamic condition of the environment. Therefore, it is assumed that once certain parameters are known, it should be possible to predict rates of degradation.

2) The decomposition of any material, organic or inorganic, will ultimately depend upon the dynamic interaction of that material with its environment. The most important factors which influence preservation are the chemical and physical properties of an object and its immediate environment and the dynamic aspects of that interaction.

3) The water chemical and biological data support the fact that a reservoir is a dynamic, open, natural system which is subject to any number of physical and chemical fluxes. Therefore, the prediction of biochemical impacts on submerged cultural materials has to take into consideration the complexity of the systemic reactions and the tremendous amount of uncontrolled variability inherent within any natural system.

Future Directions

The following recommendations for future research into the problem of differential preservation of common cultural materials submerged in a reservoir environment are based on the problems encountered during the course of this project. They reflect shortcomings in the design as well as recommendations for collecting needed baseline data that were not collected during the course of the experiment.

The primary focus of future research should be the identification of those variables that influence differential preservation. Particular emphasis should be placed on analyzing the chemical and physical properties of the various materials commonly preserved in archeological contexts before any attempt is made to evaluate the environmental variables. Once the chemical and physical properties are known and isolated, then one can begin to effectively deal with the environmental variables, adding them one at a time to assess their impacts. The final step should be the analysis of the interaction between the material and the complex environmental matrix.

In addition, an attempt should be made to control the amount of variability within each material category. Despite our attempt to accomplish this, the control standards employed in this research design were not rigorous enough to isolate the effects of inundation from the effects of internal variability. This point cannot be overemphasized, as it quickly became apparent that in some instances it was not possible to distinguish subtle chemical changes resulting from inundation from those resulting from artifact variability (see ceramic discussion, Technical Report 3, this volume). While it is true that archeological materials exhibit a tremendous amount of internal and external variability, it is the purpose of this kind of experiment to reduce the amount of variability in order to measure very subtle effects of inundation on representative classes of archeological materials and to predict what those impacts are in real archeological sites. The only way to control the amount of variability is to reproduce a series of representative materials, such that the amount and degree of variability is a carefully controlled and measurable quantity.

It is further recommended that the materials be studied in isolation. A shortcoming of both the field and laboratory phases of the experiment was the fact that all of the materials were interacting in the same containers. This compounds the problem of studying the isolated effects of certain variables on a single material category. The first step in any decomposition study should be the establishment of a baseline for eventually studying the interactive effects. Without this baseline, it is impossible to determine rates or processes of degradation.

Lastly, it is recommended that such experiments be conducted over much longer periods of time. While it is agreed that fiscal constraints often determine the length of time that can be committed to any research endeavor, there is no real substitute for the variable time. Therefore, in conclusion, it is recommended that long term monitoring of laboratory experiments and selected archeological sites be undertaken to realistically assess the effects of prolonged immersion on archeological sites and the contextual relationships of the materials and features within these sites. In an age where so many nonrenewable cultural resources are being destroyed at an alarming rate, the archeological community must take a firm stand to protect the cultural resource base from such rapid destruction. The results of the water chemical and field phases of these experiments indicate that immersion has a definite adverse impact on most classes of archeological materials. These data are further corroborated by data collected from archeological sites in various reservoirs throughout the country over the past five years, in which it has been clearly demonstrated that processes of reservoir inundation adversely impact archeological resources at all levels within the archeological value hierarchy.

TABLE 1

Mean Concentration of Selected Water Quality Constituents (mg/1)

Constituent	NASQUAN Data X	Brady Reservoir Data (3/5/78) X	s	range
Calcium	57	48	9	57 - 39
Magnesium	11	13	10	23 - 3
Sodium	129	51	45	96 - 6
Carbonate	0.5	0.9	2	2.9 - 1.1
Bicarbonate	136	155	23	178 - 132
Chloride	180	87	80	167 - 7
Silica	11	7	3	10 - 4
Sulfate	129	87	79	166 - 6
Dissolved Oxygen	9.7	7	.3	10 - 4

TABLE 2

Mean Concentrations of Selected Water Quality Parameters (mg/1)

Property	1(1)	2(2)	3(3)	4(4)
Carbonate (includes bicarbonate)	136 mg/1	58.4 mg/1	184 mg/1	160 mg/1
Magnesium	19 mg/1	4.1 mg/1	31 mg/1	32 mg/1
Sodium	129 mg/1	6.3 mg/1	140 mg/1	180 mg/1
Calcium	57 mg/1	15.0 mg/1	65 mg/1	51 mg/1
Iron	—	—	—	—
pH	—	—	8.2	7.8
Conductivity	—	—	1250	1360

1. NASQUAN Data Base
2. Cole (1979, p. 301)
3. Brady Reservoir, February 28, 1979
4. Brady Reservoir, October 10, 1978

TABLE 3

General Physical and Chemical Water Quality Properties of Brady Reservoir, September 9, 1979

	Station 1	Station 2	Station 3
Temp.	28°C/26.8°C @ 5.5 m	28°/C27°C @ 7 m	28°C
Conductivity	900	900	950 umohs
Oxygen	6.8	6.8	8.5
pH	8.2	7.5	8.1
Bicarbonate	142.0	136.0	136.0
Sodium	95.2	95.2	92.8
Manganese	0.5	0.4	0.8
Magnesium	27.86	27.12	28.25
Iron	0.10	0.19	0.11
Calcium	51.1	50.1	51.0

TABLE 4

General Water Chemistry Properties
from Brady Reservoir, Texas
January 11-12, 1980

Sample Station	Oxygen (mg/l)	Alkalinity (mg/l $CaCo_3$)	Conductivity (umohs)	pH
1	10.0	166.0	900	7.1
2	10.0	167.5	800	7.1
3	10.0	162.0	800	7.1
Claytor Lake Reservoir (Va.)		35.0	63	7.1
Water Parameter - Filtered Microbiological Sampler				
IA2		680	800	7.5
IIIA2		656	900	6.9
IIIB2		570	800	7.1

TABLE 5

Chemical Analysis of Water Samples
from Microbiological Containers and Natural
Reservoir Water in Brady Reservoir,
Texas and Claytor Lake Reservoir
Pulaski County, Virginia

Sample Element (mg/1)												
					Natural Water							
Station 1 (Brady R.)	166	67.5	33	16.5	.32	.06	.04	.02	.5	.5	.1	.1
Station 2 (Brady R.)	158	68.5	33	14.5	.35	.04	.02	.01	.5	.5	.1	.1
Station 3 (Brady R.)	160	73.5	34	15.0	.50	.09	.13	.03	.5	.5	.1	.1
Claytor Lake R., Va.	17	12.5	50	5.0	.35	.03	.01	.01	.5	.5	.1	.1
					Water from Microbiological Samplers							
IA2 (Station 1)	53.5	164.5	36.5	55	.37	2.5	.005	.04	.03	0	.06	.025
3A2 (Station 3)	32.4	230.5	29.0	49	.70	1.5	.005	.07	.01	0	.02	.025
3B2 (Station 3)	52.5	167.5	35.0	41	.40	0.7	.005	.00	.00	0	0	.025

TABLE 6

General Physical Water Quality Properties of Claytor Lake
January 26, 1980

	Surface
Temp	6°C
Dissolved oxygen	12.0 mg/l
pH	7.13
Alkalinity	35.0
Conductivity	63 mohs

TABLE 7

General Physical Water Properties of Claytor Lake Reservoir
and Water in Sampling Tubes, April 27, 1980

	Sta I	Sta II
Temperature	16	16
Conductivity	51	48
Dissolved oxygen	7.998	8.084
Alkalinity	29	31
pH	6.60	6.62

Tubes

	1A4	IIIA4	IB4	IIB4	IIIB4
Conductivity	310	230	240	240	180
Dissolved oxygen	.86	0	0	.516	0
Alkalinity	0	0	0	0	0
pH	4.30	4.28	4.22	4.25	4.20

TABLE 8

Chemical Water Quality Properties of Claytor Lake
and Water in Tubes on April 27, 1980
(mg/l)

	IA4	IIIA4	IB4	IIB4	IIIB4	Sta. 1	Sta. 2
Cu	.02	.01	.00	.00	.01	.00	.00
Cd	.03	.00	.02	.05	.00	.01	.02
Cr	.00	.02	.02	.03	.00	.00	.00
Fe	6.25	6.0	5.0	6.75	5.5	.20	.18
K	44.5	17.0	19.25	28.0	4.75	.96	.91
Mg	13.0	11.25	11.25	11.25	8.5	3.5	3.0
Mn	2.46	2.18	1.70	2.0	.93	.10	.11
Na	10.79	9.0	6.75	6.75	6.25	5.5	4.5
Zu	38.5	62.5	61.0	48.5	37.0	.00	.00
Ca	24.25	25.0	26.25	23.75	25.75	10.	9.0

TABLE 9

Chemical Water Quality Properties of Tubes
and Aquarium in Laboratory Studies

	BIA	BIIA	BIIIA	BIB	BIIB	BIIIB	Aquarium
Cu	.02	.05	.04	.08	.02	.01	.00
Cd	.01	.00	.01	.02	.01	.01	.00
Cv	.03	.03	.02	.09	.02	.02	.00
Fc	2.63	15.5	3.96	2.31	8.5	8.5	.26
K	103.5	133.5	134.0	55.0	121.0	135.5	21.5
Mg	19.5	15.0	29.5	20.0	19.5	22.5	3.0
Mn	.05	.39	.23	.56	1.57	1.88	.04
Na	15.0	28.0	26.0	20.5	24.5	21.5	7.0
Zn	8.0	8.5	14.0	19.0	4.0	5.0	.04
Ca	48.0	50.0	45.5	38.5	56.0	71.0	8.5

	LIA	LIIA	LIIIA	LIB	LIIB	LIIIB
Cu	.10	.03	.02	.11	.00	.03
Cd	.02	.00	.01	.03	.01	.00
Cr	.05	.01	.02	.08	.01	.02
Fe	2.33	3.95	4.05	7.0	3.67	3.65
K	121.5	129.0	121.0	41.0	89.5	127.5
Mg	31.0	31.0	26.0	33.0	18.0	23.5
Mn	.37	.35	.15	2.07	.11	.09
Na	25.0	25.0	23.5	14.5	16.5	17.5
Zn	30.0	9.5	11.0	78.0	6.5	9.5
Ca	81.0	40.0	53.5	51.5	48.5	25.0

TABLE 10

Physical Properties of Water in Tubes and Water Outside Tubes in Aquarium

		Temp	D.O*	Alk.	pH	Cond.
	Outside Tubes	30°C	1.118	166	7.28	180
Lab	LIA	30°C	---	0	---	---
	LIIA	30°	0	0	4.71	900
	LIIIA	30°	---	0	4.51	900
	LIB	30°	---	0	---	---
	LIIB	30°	---	0	4.39	890
	LIIIB	30°	---	0	4.61	900
Brady	BIA	30°	0	0	4.36	700
	BIIA	30°	---	0	4.58	1300
	BIIIA	30°	---	0	4.41	800
	BIB	30°	---	0	---	---
	BIIB	30°	---	0	5.02	900
	BIIIB	30°	0	0	5.00	800

*Only enough water in BIA, LIIA, BIIIB to do D.O. In other tubes not enough water was left in tubes to do a Winkeler test.

TABLE 11

List of Materials Included in Claytor Lake Samples

Wood:	2 species: white oak and ponderosa pine 10 species ponderosa pine per tube 7 pieces white oak per tube
Seeds:	7 varieties (kidney beans, pinto beans, blue corn, popcorn, navy beans, wheat, and rye charred: variety of each seed type per tube uncharred: variety of each seed type per tube
Paper:	15 strips 2.5 x 6.5 cm. per tube Whatman 1 qualitative filter paper
Leather:	strips of 6.5 x 5 cm untreated 1/16-inch thick soft leather

TABLE 12

Location of Tubes in Claytor Lake

Tube	Filter	Sta. 1 (10 ft.)	Sta 2 (20 ft.)
IA4	x	x	
IIIA4	x		x
IB4		x	
IIB4			x
IIIB4			x

TABLE 13

Analytical Methods

Parameter	Method
Temperature (°C)	YSI (Model 33) temperature/conductivity meter, Yellow Springs Instrument Company
Specific Conductance (umoh/cm)	Same instrument as listed above
Dissolved Oxygen (mg/l)	Azide modifications of the Winkler technique (Amer. Publ. Health Assoc., et al., 1973)
Total Alkalinity (Mg/l $CaCO_3$)	Titrimetric method using methyl purple as indicator (Amer. Publ. Health Assoc., et al., 1973)
Hydrogen Ion Concentration (pH)	Beckman Electromate Meter (Model 1009), Beckman Instrument Corporation
Cations (mg/l)	Atomic Absorption (Norelco Model SP-90A)
Macrobenthos	Washing in a No. 35 mesh sieve, (500 mm openings) preserving with 5% formalin (Amer. Publ. Health Assoc., et al., 1973)
Anaerobic Bacteria	Holdeman, L.V. and W.E.C. Moore Ed. Anaerobe Laboratory Manual, V.P.I. Anaerobe Laboratory, 1972
Aerobic Bacteria	Amer. Publ. Health Assoc., et al., 1973
Bacterial Identification	Buchanan R.E. and N.E. Gibbons Ed., Bergey's Manual of Determinative Bacteriology, 8th Ed. Williams and Wilkins Co., Baltimore, 1974

TABLE 13 (cont'd)

Property	Method
Temperature (°C)	standard laboratory thermometer
Specific conductance (umoh/cm)	Thomas Model 275 Linear conductance/resistance meter
dissolved oxygen (mg/l)	Winkler technique
Total alkalinity $CaCo_3$ mg/l	Titration using phenolphthalein and methyl purple indicator
Hydrogen ion (pH)	Fisher accument Model 310
cations (mg/l)	Atomic absorption Norelco Model Sp-90A
weight gms.	Sartorius balance

TABLE 14

Analysis of Covariance

SOURCE	DF	Type IV SS	F Value	PR F
Mesh size	8	4.39891202	2.38	0.0160
Time	1	3.19797749	13.83	0.0002
Ceramic type	3	83.08068185	119.76	0.0001
Mesh size/ Ceramic type	24	8.87421298	1.60	0.0362
Mesh size/time	4	4.60729394	4.98	0.0006
Thickness	1	0.13756761	0.59	0.4409
Dry weight	1	5.99873273	25.94	0.0001
ERROR	533	123.25461793		
CORRECTED TOTAL	575	354.10236128		

TABLE 15

Mean Decrease in Breakstrength

Ceramic Type	Firing Temperature (°C)	Temper Type	Mean Breakstrength Change (Log Units)
IA	750	Organic	4
IIA	600	Crushed rock	66
IB	900	Crushed rock	12
IIB	1050	Crushed rock	6

TABLE 16

X-ray Diffraction Analysis of Clay Constituents

Provenience	Ceramic Group	Quartz	Orthoclase	Microcline	Calcite	Chlorite	Illite	Kaolinite	Hematite	Spinel	Fayalite	Mullite
Raw Clay	------	A	P	P	P	A	A	A	?	N	N	N
Control	IA	A	P	P	P	A	P	N	P	N	N	N
IA	IA	A	P	P	P	A	P	?	P	N	N	N
IB	IA	A	P	P	?	A	P	N	?	N	N	N
Control	IIA	A	P	P	P	A	A	A	P	N	N	N
IA	IIA	A	P	P	A	A	A	A	P	N	N	N
IIIB	IIA	A	P	P	A	A	A	A	P	N	N	N
Control	IB	A	P	P	N	A	P	N	A	N	N	N
IIIA	IB	A	P	P	N	A	P	N	P	?	N	N
IIIC	IB	A	P	P	N	A	A	N	P	N	N	N
Control	IIB	A	P	P	N	A	N	N	P	P	?	P
IB	IIB	A	P	P	N	A	N	N	P	?	?	N
IIIC	IIB	A	P	P	N	A	N	N	P	P	?	N

A = Abundant

P = Present

? = Possibly Present

N = Not Detected

TABLE 17

Results of Atomic Absorption Analysis of Ceramics

Ceramic Group	K_2O			Na_2O			MgO			Fe_2O_3			MnO		
	X	s	n	X	s	n	X	s	n	X	s	n	X	s	n
IA	3.48	.121	14	.31	.02	20	1.63	.046	10	7.95	.413	11	.048	.004	10
Control	3.61	.007	2	.442	.112	5	1.67	----	1	7.84	.304	2	.037	----	1
IIA	3.18	.126	12	.504	.10	12	1.59	.10	10	7.14	.263	10	.044	.005	11
Control	3.19	.00	2	.435	.08	2	1.60	.028	2	7.38	.167	2	.039	.001	2
IB	3.14	.242	20	.50	.135	23	1.54	.08	16	7.13	.413	13	.069	.098	17
Control	3.34	----	1	.514	.044	5	1.61	.007	2	7.50	.028	2	.040	.000	2
IIB	3.23	.163	14	.589	.066	15	1.58	.03	12	7.07	.745	14	.047	.004	8
Contol	3.27	----	1	.638	.059	6	1.59	.014	2	7.39	.014	2	.060	.021	2

TABLE 18

Elemental Sensitivities of Neutron Activation Analysis

Element	Precision	Accuracy	Lower Limit of Detection (LLD)
Na	+ 5%	+ 5%	.01%
Fe(Total as Fe_2O_3)	+ 5%	+ 5%	.05%
Cr	+10%	+10%	.5 ppm
U	+10%	+20%	1.5 ppm
Cs	+15%	+15%	1.0 ppm
Sc	+ 5%	+ 5%	.1 ppm
Ta	+10%	+10%	.5 ppm
Rb	+10%	+10%	50 ppm
Th	+ 5%	+ 5%	.1 ppm
La	+10%	+10%	1 ppm
Ce	+10%	+10%	5 ppm
Sm	+10%	+10%	.25ppm
Tb	+10%	+10%	.5 ppm
Yb	+10%	+10%	.5 ppm

TABLE 19

Results of Neutron Activation Analysis of Chert

Element	Control			Mesh A			Mesh B			Mesh C		
	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$	s	n	$\bar{X}$	s	n
Na	.15	0	4	.16	.007	2	.15	.007	2	.16	.006	3
Fe	.73	.22	4	.7	.06	2	.60	.09	2	.69	.10	2
Cr	64.3	16.4	4	59.7	3.18	2	49.6	5.94	2	50.2	.99	2
U	6.60	.49	4	5.99	1.15	2	6.24	.88	2	6.70	.43	2
Sm	1.16	.04	4	1.13	.18	2	1.14	.13	2	1.18	.08	2

TABLE 20

Results of Atomic Absorption Analysis of Chert

Element	Control Sample $\bar{X}$	s	n	Inundated Sample $\bar{X}$	s	n
K_2O	.023	---	1	.023	.01	7
Na_2O	.10	---	1	.123	.015	4
MgO	$<$.01	---	1	.007	.004	7
Fe_2O_3	.637	---	1	.833	.251	7
MnO	.002	---	1	.007	.003	7
CaO	.046	.004	2	.044	.026	7

TABLE 21

Results of Atomic Absorption Analysis of Shell

Element	Control Sample X	s	n	Inundated Sample X	s	n
K_2O	.055	.04	2	.021	.012	7
Na_2O	.405	.02	2	.397	.052	7
MgO	.330	.139	2	.254	.042	7
Fe_2O_3	.040	.028	2	.045	.019	7
MnO	.007	.002	2	.008	.002	7

TABLE 22

Paired t-test Results of Whole Shell Dry Weights, T_0 to T_2

Provenience	t-ratio	d.f.	X_1 / s_1	X_2 / s_2	Region of Rejection at α level .05 at α level .001 (two-tailed test)	Reject Null Hypothesis* of No Difference
IA, IIIA	7.68	11	12.87 3.11	11.70 2.92	2.201 4.437	yes
IB, IIIB	9.29	11	14.04 6.65	13.05 6.40	2.201 4.437	yes
IC, IIIC	29.11	11	14.34 4.78	13.77 4.75	2.201 4.437	yes

* H_0: $u_1 = u_2$

TABLE 23

Results of Compression Tests on Brady Wood Samples, $T_1 - T_2$

Provenience	t-ratio	d.f.	X_1 s_1	X_2 s_2	Region of Rejection at level .05 (two-tailed test)	Reject Null Hypothesis* of No Difference
Oak						
IA, IIIA	4.363	37	14469.32 271.63	14075.0 327.21	2.042	yes
IB,IIIB	5.850	38	14647.5 269.5	14190.5 222.32	2.042	yes
IC, IIIC	2.432	58	14501.0 261.26	14338.0 227.71	2.021	yes
Pine						
IA, IIIA	1.803	38	3384.0 254.71	3254.5 195.73	2.042	no
IB, IIIB	5.722	37	3558.9 221.71	3172.5 199.92	2.042	yes
IC, IIIC	2.4022	58	3429.0 129.20	3257.67 217.74	2.021	yes

*H_0: $u_1 - u_2 = 0$

TABLE 24

Wood Dry Weight Measurements, Claytor Lake Reservoir
(Weights are in grams)

Softwood				Hardwood			
IA4	Wt. Before	Wt. After	Wt. Loss		Wt. Before	Wt. After	Wt. Loss
361	5.4150 g.	4.9900 g.	0.4250 g.	343	8.5796 g.	7.7576 g.	0.8220 g.
362	4.8738	4.3128	0.5610	344	8.6848	7.7112	0.9736
363	5.6016	5.0961	0.5055	345	9.4352	8.4834	0.9548
364	5.6013	5.1156	0.4857	346	9.8739	8.8970	0.9769
365	5.4977	4.9893	0.5044	347	9.8417	8.7872	1.0585
366	5.1461	4.6604	0.4857	348	9.0131	8.1118	0.9013
367	5.2801	4.7424	0.5377	349	9.8750	8.7965	1.0785
368	5.1411	4.6445	0.4966				
369	5.3321	4.7766	0.5555				
370	5.4664	4.9700	0.4964				
X	5.3355	4.8297	0.5053		9.3294	8.3629	0.9665

TABLE 24 (cont'd)

	Softwood				Hardwood		
IIIA4	Wt. Before	Wt. After	Wt. Loss		Wt. Before	Wt. After	Wt. Loss
401	4.6524 g.	4.0581 g.	0.5943 g.	371	8.9037 g.	7.8246 g.	1.0791 g.
402	5.4177	4.8142	0.6035	372	9.8868	8.7918	1.0950
403	5.4962	4.8743	0.6219	373	9.8369	8.6630	1.1739
404	4.7193	4.1515	0.5678	374	9.5657	8.4434	1.1223
405	5.9502	5.3330	0.6172	375	8.3827	7.3619	1.0208
406	5.0741	4.4746	0.5995	376	7.7695	6.8326	0.9369
407	5.1273	4.5260	0.6013	377	9.5644	8.4730	1.0914
408	5.4495	4.8590	0.5905				
409	5.2650	4.6899	0.5751				
410	4.7351	4.1540	0.5811				
X	5.1887	4.5934	0.5952		9.1299	8.0557	1.0742

TABLE 24 (cont'd)

Softwood				Hardwood			
IB4	Wt. Before	Wt. After	Wt. Loss		Wt. Before	Wt. After	Wt. Loss
371	5.1965 g.	4.6176 g.	0.5789 g.	350	9.6984 g.	7.6798 g.	1.0186 g.
372	5.4003	4.8121	0.5882	351	9.7936	9.6952	1.0974
373	4.8454	4.2373	0.6081	352	9.8566	8.7271	1.1295
374	5.2825	4.6761	0.6965	353	9.7411	9.6444	1.0967
375	5.7005	5.0971	0.6034	354	9.8276	8.7080	1.1196
376	4.9120	4.3282	0.5838	355	9.0411	8.0466	0.9945
377	5.3545	4.7777	0.5768	352	8.6602	7.6208	1.0394
378	5.1432	4.5285	0.6057				
379	5.2920	4.6789	0.6131				
380	5.3694	4.9786	0.3908				
X	5.2487	4.6732	0.5236		9.3739	8.3031	1.0708

TABLE 24 (cont'd)

	Softwood				Hardwood		
IIB4	Wt. Before	Wt. After	Wt. Loss		Wt. Before	Wt. After	Wt. Loss
391	5.4743 g.	4.9018 g.	0.5725 g.	364	8.516 g.	7.5850 g.	0.9314 g.
392	5.6397	5.0486	0.5911	365	9.7357	8.7916	0.9441
393	4.8233	4.2582	0.5651	366	9.6380	8.6915	0.9465
394	4.8866	4.3409	0.5457	367	9.8656	8.7819	1.0831
395	5.4958	4.8936	0.6022	368	9.5632	8.8202	0.9430
396	5.6589	5.2074	0.4515	369	8.9007	7.9417	0.9590
397	5.2679	4.7048	0.5631	370	9.6216	8.6563	0.9653
398	5.5055	4.9295	0.5760				
399	5.5574	5.0507	0.5067				
400	4.9372	4.4469	0.4903				
X	5.3246	4.7782	0.5464		9.4058	8.4383	0.9674

TABLE 24 (cont'd)

Softwood IIIB4	Wt. Before	Wt. After	Wt. Loss	Hardwood	Wt. Before	Wt. After	Wt. Loss
411	5.1656 g.	4.5778 g.	0.5878 g.	378	9.5432 g.	8.4872 g.	1.0560
412	5.0477	4.4714	0.5763	379	9.1361	8.1634	0.9727
413	5.4864	4.9392	0.5472	380	9.3874	8.3953	0.9921
414	5.5007	4.9488	0.5519	381	8.6953	7.6729	1.0224
415	4.9169	4.4189	0.4980	382	9.7301	8.6624	1.0677
416	5.4148	4.9350	0.4798	383	9.5132	8.5260	0.9872
417	4.7506	4.2893	0.4613	384	9.8845	9.7965	1.0880
418	5.1694	4.6819	0.4875				
419	5.0648	4.5386	0.5262				
420	4.0854	4.5586	0.5268				
X	5.1602	4.6359	0.5243		9.4128	8.3862	1.0266

TABLE 25

Results of Atomic Absorption Analysis of Bone

	Control Sample			Inundated Sample		
Element	$\bar{X}$	s	n	$\bar{X}$	s	n
K_2O	.031	---	1	.012	.001	5
Na_2O	.464	---	1	.431	.01	5
MgO	.935	.001	2	.503	.174	5
Fe_2O_3	.017	---	1	.052	.023	5
MnO	$<$.001	---	1	.060	.023	6

TABLE 26

Brady Reservoir Bone Breakage Frequencies

Provenience	Sampling Interval	Fragment/whole ratio	N
IA2	T_2	18/2	10
IA3	T_1	4/8	10
IIIA2	T_2	11/5	10
IIIB2	T_2	4/8	10
IIIC1	T_1	4/8	10
IIIC2	T_2	8/6	10

TABLE 27

Weights of Seeds Placed in Claytor Lake
(Weights are in grams)

	Charred				Uncharred		
	Before	After	Diff.		Before	After	Diff.
IA4	10.8594	5.4048	5.4546	IA4	13.9961	9.9064	4.0897
IIIA4	10.6226	4.5662	6.0564	IIIA4	13.3806	4.3800	9.0006
IB4	10.8930	6.8320	4.0610	IB4	14.4793	8.0990	6.3803
IIB4	10.6963	6.0106	4.6857	IIB4	14.4020	8.7745	6.3803
IIIB4	10.6886	5.2222	5.4664	IIIB4	13.9493	5.9177	8.0316
$\overline{X}$	10.7519	5.6071	5.1448		14.0414	7.4155	6.7765

TABLE 28

Weights of Leatber Strips Placed in Mud Columns under Controlled Laboratory Conditions, at 30°C (gms)

	Surface			4" Depth		
	Before	After	Loss	Before	After	Loss
Fine Silt	3.27	2.91	0.36	2.27	1.99	0.28
Mud	2.51	2.07	0.44	2.51	2.17	0.34
Gravel	2.22	1.88	0.34	2.40	2.17	0.23

TABLE 29

Seed Weights: Controlled Laboratory Experiment, VPI
(Weights are in grams)

	Charred			Uncharred		
Lab	Before	After	Diff	Before	After	Diff
LIA	10.0595	7.4239	2.6356	14.0397	3.6904	10.3493
LIIA	10.8296	7.8748	2.9548	13.9197	4.7778	9.1419
LIIIA	9.7612	6.5207	3.2405	14.4002	3.7397	10.6605
LIB	10.9443	7.7250	3.2193	14.5320	6.7956	7.7364
LIIB	10.267	6.7425	3.5232	13.9094	3.4970	10.5031
LIIIB	10.0878	7.0945	2.9933	14.6320	3.5897	10.9735
X	10.3246	7.3202	3.09445	14.2388	4.3483	9.8941

	Charred			Uncharred		
Brady	Before	After	Diff	Before	After	Diff
BIA	10.0174	7.7017	2.3157	14.1620	7.1154	7.0466
BII	10.6063	7.8748	2.7315	14.2800	4.6884	9.5916
BIII	10.8901	6.9541	3.9360	14.2491	4.9234	9.3257

TABLE 30

Macrobenthic Organisms Collected
From Brady Reservoir, Texas
September 9, 1979

*	INSECTA	STA 1	STA 2	STA 3
	DIPTERA			
	Chaoboridae			1
	Chironomidae (1)	83	76	66
	Chironomidae p	10	1	
	EPHEMEROPTERA			
	Caenidae: Caenis	1		
	Ephemeridae: Hexagenia	2		12
	MAGALOPTERA			
	Sialidae: Sialis			1
	ODONATA			
	Coenagrionidae: Argia			24
	Corduildae:			
	Epicordula		1	
	Tetragonenria			1
	Neurocordulia			3
	Libellulidae			1
	TRICHOPTERA			
	Polycentropodidae: Cyrnellus	1		10
	Leptoceridae			1
*	ANNELIDA			
	Oligochaeta	17	1	
	Hirudinea	13	35	1
*	TURBELLARIA			
	Tricladida	121	118	3
*	GASTROPODA			
	Ancylidae		6	2
	Physidae	91	25	62

TABLE 30 (cont'd)

	Planorbidae	1	5	
*	PELECYPODA			
	Sphaeriidae	36	38	169
	Unionidae: Quadrula			1
	Corbinculidae: Corbicula	6	3	30
non-living	Trichop. cases (prob. polycentropodida)	13		11
	MKS?	16	29	
	Total # specimens	192	338	400
	# taxa	13	11	19

TABLE 31

Macrobenthic Organisms Collected From Brady Reservoir, Texas January 11-12, 1980

Taxa	Number of Organisms	
	Station 1	Stations 2 & 3
Pelecypoda		
Corbicula fluminea	12	21
Sphaerium, sp	25	261
Anodonta (?) (immature)		1
Undet. sp. (immature)	1	
Gastropoda		
Physa, sp.	5	
Planorbidae	1	
Annelida		
Oligochaera	1	
Hirudinea	1	
Platyhelminthes		
Tricladida	6	
Anthropada		
Ostracoda	19	
Amphipoda	1	
Copepoda	1	
Insecta		
Ephemeroptera		
Caenis	2	9
Hexagenia		1
Odonata		
Argia	1	40

TABLE 31 (cont'd)

<u>Nehalennia</u>	3	15
<u>Neurocordulia</u>		4
Trichopetera		
<u>Oecetis</u>		2
<u>Cyrnellus</u>	2	
Megaloptera		
Sialis		1
Diptera		
Tanypodinae	4	9
Chronominae	49	496
Chaoboridae		1
Total Number	134	962
Total Taxa	17	14

TABLE 32

BACTERIAL COUNTS OF LAKE WATER, SEDIMENT AND WATER FROM INSIDE OF CHAMBERS CONTAINING ARTIFACTS (SEPTEMBER 9, 1979), BRADY RESERVOIR, TEXAS

Station	Surface Water Aerobic Count of Colony Forming Units/ml[1]	Sediment-Colony Forming Units/g dry	
		Anaerobic Count[2]	Aerobic Count[1]
1	$5.2 \times 10^2 \pm 0.4$	$1.6 \times 10^6 \pm 0.6$	$7.3 \times 10^5 \pm 0.4$
2	$1.3 \times 10^3 \pm 0.3$	$4.9 \times 10^6 \pm 0.8$	$5.0 \times 10^5 \pm 0.8$
3	$1.1 \times 10^2 \pm 0.4$		

Chamber	Water from Chamber Colony Forming Units/ml	
	Anaerobic Count	Aerobic Count
1 w/membrane	$9.3 \times 10^7 \pm 0.5$	$4.4 \times 10^6 \pm 0.3$
1 w/o membrane	$2.8 \times 10^8 \pm 0.6$	$7.1 \times 10^5 \pm 0.5$
3 w/membrane	$1.9 \times 10^8 \pm 0.7$	$9.4 \times 10^6 \pm 0.7$
3 w/o membrane	$7.8 \times 10^8 \pm 0.3$	$6.0 \times 10^5 \pm 0.4$
2 w/membrane	$6.6 \times 10^7 \pm 0.4$	$8.4 \times 10^5 \pm 0.6$
2 w/o membrane	$1.1 \times 10^8 \pm 0.6$	$2.9 \times 10^5 \pm 0.3$

1 Growth on Plate Count Agar medium for 7 days at 25°C.

2 Growth on Yeast extract - soil extract - peptone Agar Medium. VPI-Hungate Roll Tube anaerobic culture technique. Incubation for 7 days at 25°C.

TABLE 33

BACTERIAL COUNTS OF LAKE WATER, SEDIMENT AND WATER FROM INSIDE OF CHAMBER CONTAINING ARTIFACTS (JANUARY 11-12, 1980), BRADY RESERVOIR, TEXAS

Station	Surface Water Aerobic Count of Colony Forming Units/ml[1]	Sediment-Colony Forming Units/g dry	
		Anaerobic Count[2]	Aerobic Count[1]
1	$6.6 \times 10^3 \pm 0.5$	$1.8 \times 10^8 \pm 7$	2.9×10^6 1g. dry wt.
3	$3.0 \times 10^3 \pm$		

Chamber	Water from Chamber Colony Forming Units/ml	
	Anaerobic Count	Aerobic Count
1 w/membrane	$5.2 \times 10^6 \pm 0.6$	$1.8 \times 10^5 \pm 0.8$
2 w/o membrane	$5.8 \times 10^6 \pm 0.5$	$7.2 \times 10^4 \pm 0.7$
3 w/membrane	$9.6 \times 10^6 \pm 0.4$	$1.9 \times 10^4 \pm 0.6$
3 w/o membrane	$1.2 \times 10^7 \pm 0.6$	$7.7 \times 10^4 \pm 0.9$

1 Growth on Plate Count agar medium for 7 days at 25°C.

2 Growth on Yeast extract - sediment extract - peptone agar medium. VIP Hungate Roll Tube anaerobic culture technique. Incubation at 7 days 25°C.

TABLE 34

Decomposition of cellulose strips under laboratory conditions (Brady Simulation). Decomposition is measured as loss of tensile strength using control strips incubated under sterile conditions. Anaerobic treatment represent media maintained at less than -100mN. Low nitrogen and phosphorous represent a level of nitrogen and phosphorous found in sediment (Claytor Lake) whereas, high nitrogen and phosphorus represent optimum levels for decomposition. Dynamic aerobic conditions represent media subject to mechanical organization whereas dynamic anaerobic conditions were maintained by 20% change of liquid volume each week.

	Low nitrogen and phosphorous Treatment				High nitrogen and phosphorous Treatment			
	Static		Dynamic		Static		Dynamic	
	2 mo.	6 mo.	2 mo.	6 mo.	2 mo.	6 mo.	2 mo.	6 mo.
35° incubation								
anaerobic system	4%	13%	13%	25%	10%	19%	36%	
aerobic system			15%	36%			20%	
15°C incubation								
anaerobic system	1%	5%	3%	7%	2%	5%	8%	26%
aerobic system			5%	8%			4%	31%
2°C incubation								
anaerobic system	1%	2%	1%	3%	1%	3%	1%	5%
aerobic system			1%	3%			1%	4%

TABLE 35

Bacteria Counts from Laboratory Studies - Aerobic[1]

	Aquarium Water	--- 5.3×10^6 (colony forming units/ml)
Lab	LIA	--- 2.4×10^3
	LIIA	--- $>$300 on dilutions 10^1 thru 10^5
	LIIIA	--- 3.0×10^6
	LIB	--- not enough water in tubes
	LIIB	--- 4.0×10^6
	LIIIB	--- $>$300 on 10^2 dilutions; 0 on all other dilutions
Brady	BIA	--- $>$300 on 10^1 and 10^2 dilutions; 0 on all other dilutions
	BIIA	--- 1.78×10^4
	BIIIA	--- $>$300 on 10^4 dilution; 0 on all other dilutions
	BIB	--- not enough water in tubes
	BIIB	--- $>$300 on 10^5, 10^4 and 10^3; 0 on 10^2 and 10^1 dilutions
	BIIIB	--- $>$300 on 10^5, 10^3, 10^2, 10^1 dilutions; 2 colony forming units on 10^4 dilution

1 = growth on plate count algal medium for 3 days at $30^{o}C$

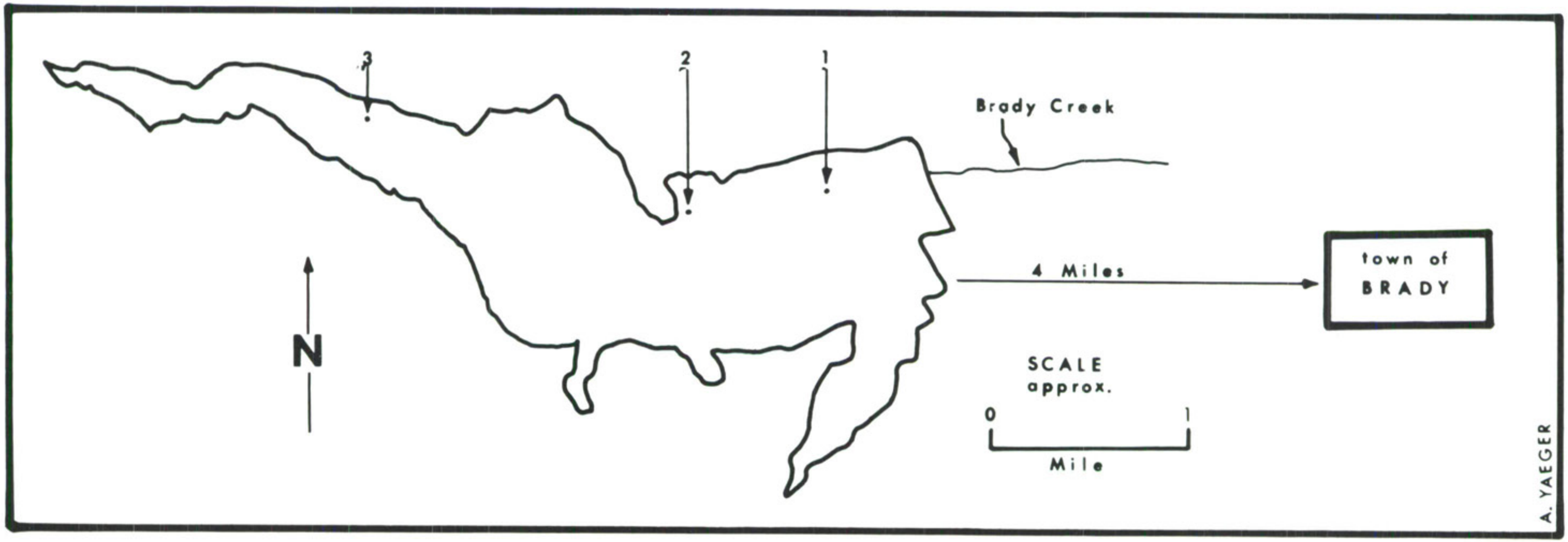

FIGURE 1. Numerals 1 - 3 indicate the location of experimental stations in Brady Reservoir, Texas.

Schematic diagram based upon smaller figure from Geological Survey, U.S.D.I., Austin, Texas.

Fig. 2. Claytor Reservoir sampler tubes showing placement of materials.

Fig. 3. Condition of leather samples after sterilization.

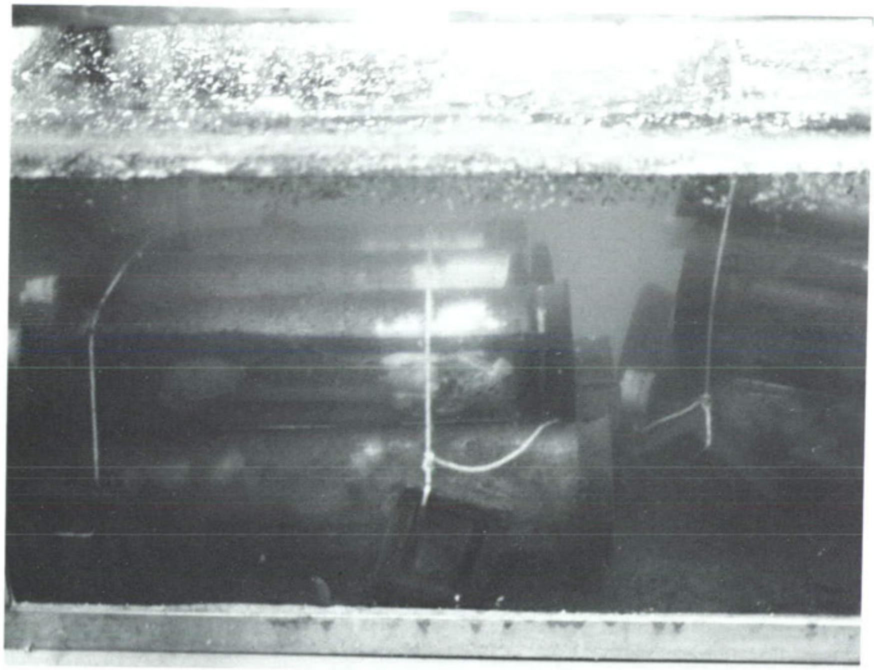

Fig. 4. Weighted samplers in aquarium at VPI.

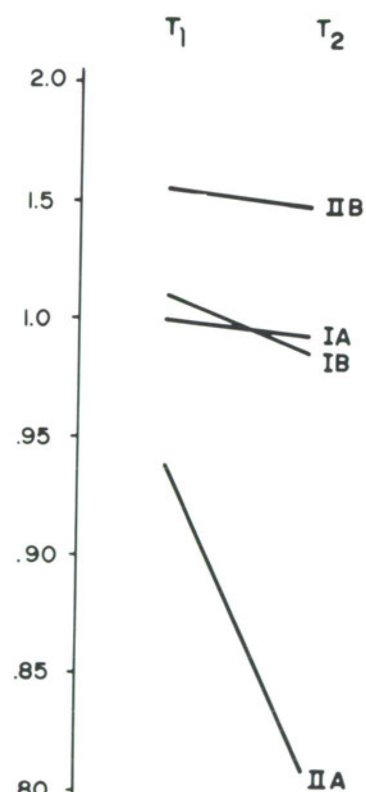

Fig. 5. Logarithmic transformation of ceramic break-strength, T_0 - T_2.

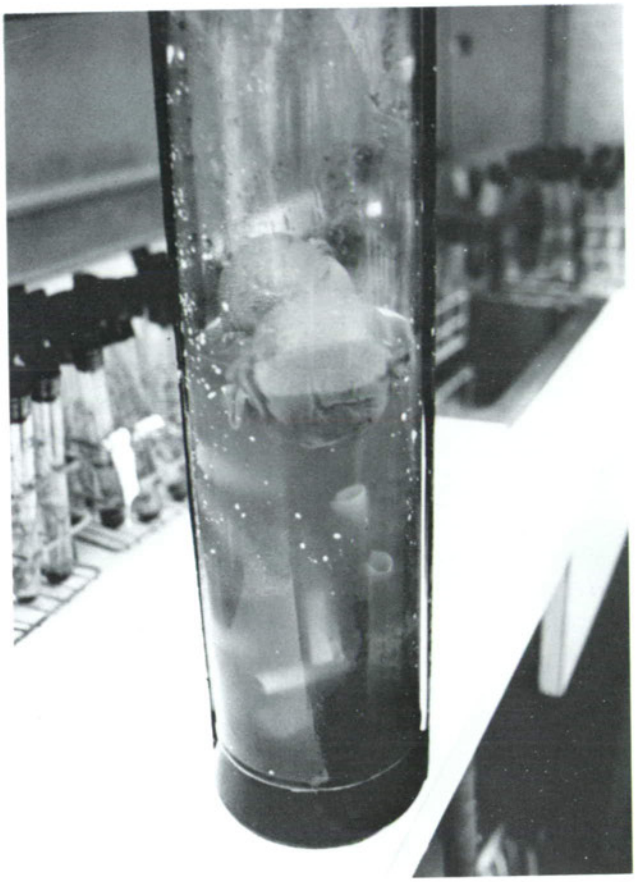

Fig. 6. VPI samples containing seeds and paper (Note swollen condition of seed bags due to gas production).

Fig. 7. VPI samples showing displacement of water due to gas production.

Fig. 8. Water from microbiological and chemical units. The turbidity generally reflects the density of microbial populations.

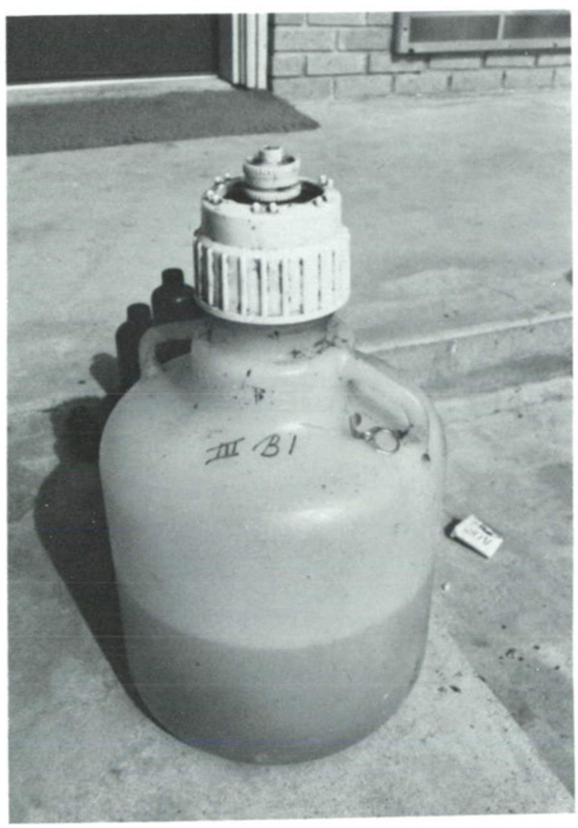

Fig. 9. Microbiological sampling unit with filter apparatus in place at top of chamber. The displaced water is due to production of gas by the microbial community inside. The primary gas was methane.

Fig. 10. Another microbiological sampling unit in which nearly all the water was expelled by gas production.

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PRELIMINARY EXPERIMENTS IN THE STRUCTURAL PRESERVATION OF SUBMERGED ANASAZI UNITS

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INTRODUCTION

In 1976, a study of the effects of freshwater inundation on various kinds of cultural resources was initiated under the auspices of the National Park Service. This multi-agency endeavor has been funded by the U.S. Army Corps of Engineers, the Bureau of Reclamation (now the Water and Power Resources Service), and the Soil Conservation Service, in addition to the National Park Service. One segment of this research has been involved with impacts resulting from reservoir impoundments in the Southwestern United States. This report concentrates upon a specific type of archeological site found in the Southwest, and presents a few thoughts regarding the scope of the impacts and the National Park Service attempts to ameliorate them and preserve the resource for posterity.

Many archeological sites located in Southwestern reservoir basins are situated in alcoves formed by erosional processes operant on the towering cliffs defining spectacular canyons (Figures 1 and 2). A large number of these sites consists of rooms built by the Anasazi, prehistoric ancestors of the modern day Hopi and other puebloan groups. The dessicated, protected environment of these ruins has resulted in remarkable natural preservation of the aboriginal stone masonry mortar and roofing timbers, not to mention archeological deposits containing perishable remains (Figures 3 and 4). These structures were occupied between A.D. 1000 and 1300 at the various reservoirs which form the locus of our experiments. Most of these tests were conducted at Glen Canyon National Recreation Area in Utah and Arizona.

THE NATURE OF THE ARCHEOLOGICAL SITES

Between 1957 and 1964, an extensive survey and excavation program was conducted by the Museum of Northern Arizona and the University of Utah to salvage data from sites which would be adversely impacted by the rising waters of Lake Powell (Rayl et al. 1978:2). Approximately 900 sites were recorded by crews traversing the rugged canyons of the Colorado River and its tributaries. Large numbers of the several site classes were situated in the aforementioned alcoves, and many of these remain characterized by still-standing, wet-laid masonry walls, and intact roofs. The latter are composed either of the alcove ceiling or logs, sticks, and other fibrous packing covered with mud.

The structures with exposed standing walls receive neither protection nor support upon submergence, a situation unlike most archeological or historic structures which are left unexcavated. The earth that remains in situ around most sites forms a protective mantle that prevents rapid degradation by natural agents. The lack of this protection may occur in two basic situations. If a site has been excavated and is not backfilled, the newly exposed walls will begin to deteriorate. A second situation may actually have nothing to do with archeological work. Cliff houses were frequently subjected to only limited activity during their use or occupation and only small amounts of the debris so ubiquitous to the human species accumulates within and nearby the confines of the structures (Rayl et al. 1978:67). Furthermore, post-occupational deposition usually is also minimal, since the structures are generally in protected locations, precluding the settlement of either wind- or water-borne particles. Of the sites which were subjected to experiments described here, several were excavated but left unbackfilled. Even had they not been dug, upper portions of the walls would still have been exposed because of minimal occupational and postoccupational deposition.

A brief digression into the preservation characteristics of these sites is necessary here. Preserving Anasazi sites must consider two broad concerns. First, the materials of which they were constructed are relatively durable when left undisturbed by moisture, but proceed quickly down the path toward entropy once violated by water from any source. For example, once inundated, the Navajo sandstone of the Glen Canyon area is affected chemically, producing a bathtub ring which identifies the prior high water mark when the waters recede (Figure 2) (Rayl et al. 1978:8). This "ring" is a calcium carbonate rich deposit containing quantities of such organic materials as blue-green and green algae in a flocculated silt matrix (Potter and Pattison 1976). Exposed surfaces of this ring are extremely friable, a condition exacerbated by dissolution of most of the iron oxide cement of the stone. Thin-section analysis reveals that mechanical interlocking of quartz grains composing the stone is all that remains to hold the stone together. Compressive strength tests show substantial mechanical strength loss after inundation (See Appendix A). For example, compare Figures 5 and 6.

The mortar of many aboriginal structures is frequently of poor quality, containing a clay percentage which is lower than that required to make the most durable mortar, however, mortar composition is probably a moot issue for fully inundated sites. Simply stated, inundation results in complete mortar dissipation by softening and separating the component soil particles. As the plastic and liquid limits of these mortars are reached and exceeded, the weight of the wall stones causes the wall to topple, even in the absence of current or wave activity.

A second preservation concern deals with aboriginal building technology which, although often surprisingly sophisticated, was not designed to produce buildings which would last forever. Some inherent faults make preservation of the structures more difficult. They include:

(1) Failure to build vertically plumb walls;

(2) The lack of solid foundation, or construction atop boulders which are themselves supported only by unconsolidants;

(3) Unbonded or abutted corners; and

(4) Building walls which are thicker at the top than they are at the base.

Other Forces Detrimental to Structural Preservation in Reservoir Contexts

Numerous forces deleterious to site preservation originate from natural as well as human sources. Summarizing some of these which operate on alcove sites, and which are all due to the presence of Glen Canyon Dam and the impoundment of Lake Powell, produces a short list:

Natural forces include:

(1) Wind generated wave activity, coupled with boat wakes, is the single most devastating environmental concern. The amount of damage that any one site will receive is related to canyon width and local wind patterns, plus the amount of boat traffic.

(2) The rate of water impoundment is probably important. Thus far, sites which have been inundated by rapidly rising waters have been less severely impacted because their presence in a high energy beach zone at the air-water interface does not last as long as some others. By a rapid rate of impoundment, I refer to Lake Powell's rise of 15 to 30 cm per day during months characterized by spring runoff.

(3) The fluctuating water level of such reservoirs as Lake Powell is another factor, and is one important reason for conducting this kind of research. Every time a site is placed into the aforementioned beach zone, it falls apart a little more. During runoff, water accrues in the reservoir, however water is released at variable times to meet irrigation agreements farther downriver. Thirty meters of depth fluctuation is not unusual throughout the course of a single year. Whenever sites come out from beneath

the water there is less there than previously: less for interpretation and the enhancement of cultural values to the public and less structure with data-bearing potential for archeologists.

Human forces incorporate:

(1) Casual invasion of alcoves by picnickers and other users of the recreation area, who often are genuinely interested in the archeology of the site. These people are usually oblivious to their own impact because of the lack of a strong formal educational program at marinas where boaters enter the water.

(2) Vandalism. Inveterate pothunting occurs occasionally in the area, however, vandalism usually consists of wall displacement and etching graffiti into wall plaster or rock art panels. One example involves a sandbagging experiment which we hoped to carry out to determine if sandbagging along the interiors of structures would help them to withstand inundation. The sandbags were first emptied, and then carried off.

The interplay between these various forces, coupled with the inherent weaknesses and building practices of the sites, produce the kinds of results graphically portrayed in Figures 7-10.

PRESERVATION EXPERIMENTS

Experiments in preservation were oriented towards mitigating the effects of adverse natural impacts and structural problems inherent in aboriginal buildings summarized previously. They were enacted at four sites with standing walls. Three of these were above the water at the time that the experiments were conducted. One was at a depth of about 17 meters, and was worked on underwater using diving technology. I must stress that these attempts are preliminary in scope. More work is needed to develop a technology which best does the job, in the event that this kind of research is pursued. In 1978, emphasis was placed upon mortar alteration or amendment as a means of preserving the structure, and in 1979 a more broadly based plan of stone and mortar stabilization was attempted. These endeavors involved the use of different kinds of mortars and the application of chemicals to the building stones of sites which we knew were shortly going to be devastated by impoundment. The time frame and funding levels for this work were compromisingly short in both cases.

Testing At Sites Above The Water Which Are Slated For Inundation

Experimental work was conducted at three sites prior to immersion and was designed to determine the degree to which effective preservation can be done to sites before their ultimate immersion and also to try and save the sites. For this reason, the tests share much in common with other tests traditionally conducted on the fabric of prehistoric ruins. Generally speaking, the format for these tests is:

(1) Permitting a section of wall to remain untreated, for observation of weathering rates and processes.

(2) Stabilizing segments of walls with various materials for comparative purposes, both with the control (untreated) section and with each other. This allows a relative assessment as to the viability of each material as a preservation agent during future monitoring of the ruin.

(3) Superimposing cost-effectiveness and other logistical considerations on the findings.

Many such treatment materials have appeared on the market in recent years as "snake oils" purported to cure the complete gamut of preservation ills. Unfortunately, these materials frequently increase the rate of original fabric deterioration rather than reduce it. A corollary is frequent, unaesthetic applications which impair the appearance of the resource, limiting visitor enjoyment. As a result, tests using original fabrics have been curtailed in recent years. After viewing the amount of damage to the physical integrity of ruins following submergence, it was decided that the testing was justified in view of certain destruction which attends lengthy immersion. In short, without added strength, the walls at Steury Ledge and the other two sites would soon deteriorate after submergence.

Testing a comprehensive series of materials was beyond the scope or financial ability of the Inundation Study. As a result, only three different material applications involving repointing and filling of voids behind the wall facade were made. A fourth method, direct application of a stone preservation, was also tested. The four methods were:

(1) Sections of wall were repointed with an unamended mud mortar, and voids were similarly filled. For the most part, components of the aboriginal mortar were not adequate to insure a durable mixture, so clay was added.

(2) Sections of wall were repointed with soil cement using soil from the site, clay, and calcium aluminate cement. Voids were also filled.

(3) Sections of wall were repointed with a soil-epoxy mixture using soil from the site, clay, and epoxy.

(4) Sections of wall were treated with methyl methacrylate.

The remaining sections of the walls were left untreated to function as control sections for comparability.

For all of the repointing work, certain standards were used. These included thorough cleaning of any wall joints to be treated by removing all mortar to a minimum depth of 2.5 cm, a procedure which was expedited by the absence of mortar over much of the wall. Only the inner faces of walls were treated, because of stone and back dirt piled against the structure exteriors. One test section of each material was done in each room. Backfilling was to be done at one site to determine any potentially beneficial effect of that practice, but time did not permit adding this variable to the test.

Structures 1 and 2 at Steury Ledge were the most visible of the three or four architectural features present, and preservation tests at this site were limited to them. Both structures are rectangular rooms built against the cliff wall. Sandstone slabs set vertically form the foundation of either single-stone thick (Structure 1) or double-stone masonry (Structure 2) of tabular semi-ashlar stones (Figs. 11 and 12). The walls enclosing Structure 1 range from 78 to 100 cm. high; Structure 2's walls are between 150 and 225 cm. high. A doorway cuts through the south wall of Structure 1, and a ventilator shaft marks Structure 2. Floor features in both rooms are limited to hearths, with bedrock composing the floor (Schroedl 1978).

The Museum of Northern Arizona survey file for 1957 (Foster et al. 1957) indicates dry laid wall construction, with "no mortar visible anywhere." The nature of the mortar which might have been used in the walls is not described in the University of Utah survey file (Anderson 1959, Schroedl 1977), but the National Park Service Ruins Stabilization Unit's assessment of condition (Mayer and Sudderth 1977) offers:

> The mortar has weathered from the top foot of all wall tops due to exposure to the weather, inundating by and emerging from the waters of Lake Powell. The excavated portions of the walls retain most of their original mortar.

On-site observations by the Inundation Study team indicate that most of the mortar present only one year earlier is now absent, with the basal vertical slabs and two to three courses above them remaining mortared. Mortar samples were taken from each wall and subjected to field tests to determine the particulate composition of the mortar, based upon the Unified Soil Classification System (Bureau of Reclamation 1974).

The tests consisted of a sieve analysis and a crude, but useful sedimentation test performed in a graduated cylinder (Fig. 13) with the results shown in Table 1. Munsell color was also recorded (Fig. 14). As is evident from Table 1, much of the mortar that remained in the wall has a high sand component. Only one sample, from the east wall of Structure 2, falls into the realm of a durable mortar (Clifton 1977). The others may have been mechanically altered by immersion or chemically altered by inclusion in the "bathtub ring" zone. At any rate, they are of poor quality when compared with other Anasazi mortars.

The calcareous sandstone ledge formed by its greater resistance to erosion seems less severely impacted by inclusion in this zone; however, no tests have been run on any of this kind of stone to determine relative unconfined compressive or shear strengths. The walls of both structures are largely composed of this more resistant material.

Specific information on the mortar application for each material used at Steury Ledge and two other sites follows. The procedures employed were similar at each site.

Unamended Mud Mortar: This mixture was applied to test sections on the south wall of Structure 1 and the east wall of Structure 2 at Steury Ledge (Figures 15, 16 and 17). The materials used include two parts of the sandy fill soil excavated from the ruin, mixed with one part clay (Fig. 18). The fill soil was screened through 1/16 inch mesh screen before mixing.

The disclosure that only minimal amounts of clay were present in the available soil prompted a search for any that was locally available. The closest that was found was located at the parking lot uphill from the Halls Crossing Marina (Fig. 19). A sedimentation test run on this material revealed that it was almost exclusively composed of clay/silt, and the addition of nitric acid indicated that only a small proportion of expansive montmorillonite clays were present. Munsell color is 2.5 YR 5/4. A load of clay was returned to Steury Ledge, where it was pulverized and screened through 1/4 inch mesh prior to mixing. After combining the dry components, water from the lake was used to create a plastic mud.

Joints were thoroughly dampened prior to the mud application. After repointing, the new mortar was periodically tamped to reduce shrinkage cracks. Three such tampings were done one hour after application, 2 1/2 hours after application, and three hours after application.

Soil-Calcium Aluminate Cement Mortar: The locations of this application were limited to sections of the west walls of Structure 1 and 2 (Figs. 20, 21, 22 and 23). The materials consisted of four parts excavated fill soil, two parts of the previously described clay, and one part calcium aluminate cement. Once again, the fill soil was screened through 1/16 inch mesh, and the clay was pulverized and screened through 1/4 inch mesh.

Calcium aluminate cement is available from several manufacturers. Each brand has unique properties and a specific color. Earthy color tones are a property of Lumnite, one of these products, which was selected for these tests. Some of its advantageous properties in a soil cement are:

(1) It is aesthetically compatible with aboriginal mortars.

(2) Its capillary potential exceeds that of most stone, which prevents forcing inordinate amounts of moisture through adjacent stones.

(3) Its compressive strength is lower than that of most stone. Under stress loading, the soil cement will break before the stones do.

(4) It can be removed without damage to the original stones

Disadvantages include:

(1) Possible strength loss through time at a rate more rapid than portland cement mortars.

(2) Most masons are unfamiliar with the correct application method.

(3) Slight color discrepancies must be dealt with.

Step-by-step, the application method for soil-calcium aluminate mortars follows:

(1) Mix the dry components together into a completely homogeneous mass.

(2) Add small amounts of water. A much dryer mixture than is ordinarily used with other mortars provides the greatest strength. The optimal mixture forms small balls less than 2 cm in diameter, and only slightly sticks to the palm of the hand.

(3) After complete dampening of the joints, pack the mortar tightly into them.

(4) Upon curing, alter the surface finish as needed by treatment with a muriatic acid wash or other weakly acidic liquid. This step was not completed at Steury Ledge because of low amounts of visitation and the impending resubmergence of the site.

Soil Epoxy Mortar: Small segments of the east wall of Structure 1 and the south wall of Structure 2 were repointed using a mixture of sandy fill and fine grained white silica sand imported by the team, combined in equal parts (Figs. 24 and 25). The white sand was added in a vain attempt to lighten the color when the epoxy was added. The procedures employed, replicated for use underwater at Doll Ruin, are discussed elsewhere. Application simply consisted of troweling the mixture into the joints after cleaning out any old mortar. The joints need not be dampened for the application.

Stone Preservation: This topic had only recently been the subject of field applications, and even then only on an emergency basis. The chemical selected was methyl methacrylate, developed principally by Dr. William J. Burke of Arizona State University, and used successfully on pictographs at Davis Gulch (Turner and Burke 1976), and at Snake House, a small ruin near Inscription House at Navajo National Monument (Burke 1979). Both these areas are composed of Navajo Sandstone, the same geological formation comprising Glen Canyon. Regarding prior results on test specimens from Snake House, Burke (1979:70) noted, "It was found that the cohesive strength of the sandstone could be increased several fold with only a modest change in the intensity of the reddish color of the sandstone."

The chemical consists of a small molecular acrylic monomer which penetrates the stone and polymerizes in situ. The treatment method consists of mixing the chemicals in the field, and pouring it over the wall surface in an attempt to impregnate the stone (Figures 26 and 27). Two sites, 42Ka595 and 42Sa231, were treated with the chemical. At one site, the treatment was performed by Dr. Burke prior to mortar repointing, and at another, applications were made afterwards.

Experiments Conducted At A Submerged Site

Our research was also interested in the feasibility of preserving a site which had been inundated, but which might again be exposed following reservoir drawdown. Unfortunately, the effects of undergoing even a single episode of submergence are devastating to any site's structural integrity. Consequently, it was difficult to find sufficient standing wall to permit a preservation effort. A small site, Doll Ruin, was found which still had up to three courses of masonry remaining, albeit only along a single wall of a single structure.

The state of the art for preserving archeological sites which are already underwater is extremely limited. In fact, as far as could be determined, no one had ever made such an attempt previously. Two problems must be addressed:

(1) What does current technology offer in the way of materials?

(2) What techniques can be implemented underwater?

These concerns will each be discussed in turn while also proceeding with a description of what was actually done at Doll Ruin.

Materials: The suitability of materials relies upon several properties. Initially, the substance must retain its workability in a completely aqueous environment. It must retain its bulk, and not become diluted or unconsolidated. Secondly, it must cure or harden underwater and be capable of preserving ruins thrust into an extremely detrimental environment. Finally, it must require simple enough techniques to utilize the material in remote field areas where logistics problems exist.

An exhaustive search for the material which would best satisfy all of the aforementioned criteria was not undertaken; discussions with various consultants were made on informal bases. The most suitable material for conducting these small-scale field tests, given certain logistical constraints, was a polyamide epoxy resin and hardener mixed with soil. Various resins are available on the market, and those selected for the test were from Ciba-Geigy Corporation of Ardsley, New York: The resin is Polyamide 825, and the hardener is Lancast A. It is noteworthy that other polyamide resins and hardeners can be purchased, both from Ciba-Geigy and its competitors, and that their working properties, such as viscosity and temperature range, vary considerably. The possibility that comparable resins would be better suited to this kind of work should be explored if these tests prove to be successful.

Consultants indicated that polyamide epoxies have been used successfully as a protective coating applied to the legs of off-shore drilling rigs. Their purpose in this context is to prevent saltwater corrosion of metal parts and retard wave action. Above water uses are myriad, ranging from construction to recreational epoxy mouldings. Properties relevant to test purposes include:

(1) They exhibit extreme durability and strength when combined with an aggregate.

(2) Polyamide epoxies harden underwater, within certain temperature limits. They are exothermic, generating their own heat, and permitting a drop in environmental temperature

(i.e., land-to-water), without significant alteration of the resin-hardener reaction.

(3) Virtually any texture and color match is possible for cosmetic purposes. Either powdered or liquid pigments can be used without a loss in other desirable properties. The texture approximates that of the original fabric if the aggregate is selected with care.

(4) Epoxies have extreme adhesive properties. For terrestrial preservation work, this characteristic could have mixed advantages and disadvantages, however, in submerged environments, it is unusual in the strength that it can impart to the walls. Individual stones can be bonded as part of a monolithic wall in order to avoid displacement.

(5) It is non-toxic, and will not harm underwater wildlife.

Experimentation by the author indicates that soil added to the resin-hardener mixture forms a fairly suitable aggregate. Since it is important to match an aboriginal soil mortar in terms of color and texture, soil is a suitable and logical additive. The cosmetic appearance of finished tests was not addressed as completely as the structural problem, however, and more work is needed.

Techniques: The development of application methods has been centered upon two operations. The first aspect involves above-water preparation of the mixture, and the second is the actual application of the resin-hardener-soil mix to the test wall.

Preparing the mixture essentially follows applications manuals (Anonymous 1976) which have been disseminated for use with various epoxies, and consists of the several steps listed:

(1) Mix thoroughly any soil and pigment which are to be added as aggregate or for coloration.

(2) Mix the 825 resin and Lancast A hardener in the following ratio by weight: seven pounds resin: four pounds hardener (Fig. 28). Considerable variation from this specification

is possible and a durable result will still be attained. The temperature of the mixture should be recorded.

(3) Mix the dry component (soil/pigment) and the wet component (resin/hardener) together in any desired consistency. The exact amount of resin and hardener that can be absorbed into the soil varies based on the viscosity of the former. The viscosity is in turn largely dependent upon the air temperature. The field test indicated that the viscosity will increase when the mixture is submerged and the temperature drops.

(4) Wait until the temperature of the mixture rises 20°F above that taken in Step 2, and then load it into a transporting container.

Two kinds of containers were used during the tests. The most crude was a polyethylene bucket with a snap-on lid. This bucket was not completely full upon descent,and the lid had to be opened to negate its positive buoyancy. As expected, the water introduced to displace the air did not dilute the mixture, although it may have increased the viscosity.

A second more successful container consisted of a two-quart bulk hand grout gun which had been similarly used for preserving dry land ruins. A large nozzle was screwed onto the gun for this particular application, and the nozzle was sealed.

(5) Submerge the containers with the mixture to retard the reaction while donning dive gear and preparing for underwater application.

Like the mixing, the underwater application is best described as a step-by-step process, augmented by experiences occurring in the field. These steps are:

(1) Using a compressed air blowing nozzle attached by an armored hose to the low pressure port of the regulator first stage, dislodge from the wall any particulate matter. Silt and algae may interfere with the bond between the new mortar and the stones, but they are easily removed with the device. Alternately,

a stiff brush may be used if employed carefully. This entire procedure is best done during a separate dive.

(2) Apply the mortar to voids in the wall as well as to the unmortared joints (Fig. 29).

First, the grout gun was used. Despite the largest available nozzle being used, the gun plugged almost immediately from increased viscosity. The water temperature was only 51°F, and although this was anticipated, it was hoped that the mortar would still pump through the nozzle. The end of the barrel was then unscrewed and the gun easily pumped the mortar out into lumps that could be pinched off and worked back into the joints between stones with the fingers.

After depleting the mortar in the grout gun, the lid of the bucket was snapped off and the mortar scraped out with a putty knife. It was then packed into the joints with the fingers. After a while the mixture in the bucket became so viscous that it was non-plastic and could not be scraped from the bucket. The dive ended, and the bucket was returned to the surface. After a few minutes at air temperature, the mortar returned to its less viscous state before curing.

(3) Clean the tools using an acetone solvent immediately. Once final curing occurs, tools cannot be cleaned.

As far as is known, there are no previous attempts at this kind of work. Therefore, only the results of this effort can be used to judge the capacity of the state of the art to deal with the preservation of submerged structures. Ongoing monitoring of the west wall of Structure 4 is needed to assess the success of this venture. Hopefully, there will be little perceptible change through time.

RESEARCH RESULTS

Although the use of specific site names has been generally avoided thus far, I will now use them in order to summarize both our endeavors and their results. First are the terrestrial sites, all of which have been submerged since work was done:

Steury Ledge

This site was used to test different mortar applications, including a control panel of unamended mud. Subsequent monitoring of the site, which is now underwater, showed that:

(1) The unamended mortars, in spite of having been made from a durable mixture by dryland standards, have been eroded;

(2) The calcium aluminate-soil cement panels remain intact, although one or two stones atop the wall are loose, having been broken from the mortar matrix;

(3) The soil-epoxy mixture panel is completely intact.

In-and-out House (42Sa231)

This site was repointed with both calcium aluminate soil cement and epoxy, and stones were impregnated with methyl methacrylate. It was inundated within 10 to 15 days of treatment. The attempt to stabilize the site was an abysmal failure, perhaps because of a number of factors. These are:

(1) Possible vandalism. This is the site from which sandbags were removed, and it is possible that the walls were destroyed by vandals. The absence of much fallen wall stone in areas up to a depth of 10-15 meters below the site makes one wonder where it went.

(2) The few pieces of rubble that we found retained mortar between several stones which fell as a monolith. Breakage was not along the stone-mortar interface in most cases. This suggests that the methyl methacrylate did not effectively bond the stone to prevent dissolution of iron oxide cement. We are awaiting comment from Dr. Burke, who is analyzing the stone samples in detail.

(3) Lack of solid footing, with the site situated atop a sandy fill soil, probably contributed significantly to the failure of this attempt. Stabilizing the entire slope was not feasible and will not be feasible in the future, and it is likely that these sites will simply be lost, unless some other management strategy is implemented.

Figures 30-32 show various aspects of the structure's destruction.

In and out House (42Ka595).

This site was treated with calcium alternate soil cement, soil-epoxy grout, and methyl methacrylate, and went under water in spring, 1980. While the lake level currently was between 1 and 2 meters below the basal course, the large boulders upon which it sat dropped between 15 and 30 cm. The only thing which still held it together was the epoxied wall cracks (Figures 33 and 34). This attempt failed in spring, 1980, although the site lasted an extra year because of the preservation work. If water level projections had not been met, and the site had not gone under, we would have saved it for some indefinite period. The failure to prevent site destruction was caused by massive slope subsidence of unconsolidated material below the site's foundation level. Short of a massive slope stabilization endeavor costing tens or hundreds of thousands of dollars, the only means of preserving this site would have been to prevent reservoir levels from rising to the critical point.

Doll Ruin.

A portion of one wall of this site was stabilized with soil epoxy mortar, at a depth of ca. 17 meters with a water temperature of about 50°F. This site is now at a depth of close to 30 meters, but the new mortar remains tightly packed between the stones (Fig. 35 and 36). Thus, this experiment has met with success, however, only continued monitoring, preferably both before and after another emersion, will permit a full assessment of the worth of this attempt.

MANAGEMENT ACTIONS AND ALTERNATIVES

The experiments described herein are rudimentary in nature and of limited scope, but they do provide another alternative to an arsenal of cultural resource management strategies under certain conditions. When it becomes apparent that an Anasazi structure with exposed wall is going to be inundated, it is equally obvious from this discussion that the site will be severely impacted by that action. What is forgotten is that these sites will frequently become exposed again during reservoir drawdown. When this happens, the unstabilized site will have probably been destroyed. If preserved by some of the means described here, that site may still have value, both in terms of data-bearing potential for archeologists who are continually asking new questions not anticipated by their predecessors, and in terms of cultural heritage values for the enjoyment and understanding of tomorrow's public.

These investigations are but the first step towards fulfilling the obligations of governmental agencies and professional archeologists. Underwater preservation is only in its nascent stage. Consequently, the efforts are not only partially successful, but expensive. In my opinion, they will probably never provide the most cost-effective management strategy to accomplish the aforementioned goals. As a result, I consider them to be a last-gasp management method, employed after the aspects of resource importance have been assessed.

If one considers that conservation equates to the wise use of the resource, it then follows that conservation is in the best interest of the public, professional archeologists, and managers. The preservation of terrestrial sites is a frequent strategy utilized in this vein, conjoined with the interpretation of those features to reservoir users. This practice is certain to be continued and the costs are ongoing and moderate.

A few supplementary strategies are worth noting. Each is implicitly predicated upon the responsibilities of concerned groups, i.e., researchers, academicians, and managers, to provide something worthwhile to the general public. They also assume that once inundated, sites may again emerge. These include:

(1) Complete inventory of cultural manifestations which will be impacted by the reservoir upon impoundment, or by visitors. In terms of architectural features, this may require data recovery methodology in addition to that normally used as part of an archeological survey. This is a duty of the professional community, and may involve test excavations geared towards an understanding of differential reservoir impacts (Rayl et al. 1978: 105).

(2) Backfilling of any excavations, if at all possible. This practice will aid in maintaining site architectural integrity, and is actually a preservation method. Again, this is an obligation of the researcher, both toward the public welfare and the future development of his or her discipline.

(3) Since water levels in southwestern reservoirs fluctuate, "attempts should be made to protect the most important sites from the mechanical impacts that occur in the high-energy beach zone (i.e., wave action, erosion, scour, etc.). Temporary or permanent breakwaters absorb some of the force of wind and boat generated waves" (Rayl et al. 1978: 105). This is primarily an agency responsibility.

(4) Establishing no-wake zones in certain areas to protect fragile architectural resources. This endeavor would involve the temporary designation of such areas until the water surface has exceeded or decreased beyond the critically destructive level of the beach zone (Rayl et al. 1978:105). This is a managerial problem which often requires increased agency liaison for those areas which are co-jurisdictional.

(5) Increasing a public information program to reduce overt acts of vandalism and increase user sensitivity to the fragility of many of these interesting and archeologically valuable sites. Although most reseachers envision this as an agency problem, and it is,

unless professionals begin to grapple with it, it will eventually become more immense than any professionals or managers would care to see. Public awareness is an issue which will become more critical as energy problems escalate, both in submerged and terrestrial contexts.

(6) Unfortunately, the use of police patrols is currently one of the most commonly invoked means of site protection from vandals. Although there should theoretically be no need for this practice, realistically the need is great, indeed greater than the available funding. This fact in itself is an indictment of this option's cost effectiveness. More funds than are now available are needed in order to place all our hopes in the basket of law enforcement.

(7) Increased liaison between agencies and concessionaires who are operating in reservoir areas. This is needed to implement almost any of the foregoing strategies, involving the dissemination of public information, water control and downriver committments, and interpretive information stemming from research.

It is only by developing such a group of alternate strategies that we are practicing sound cultural resource management. Researchers, academicians, and agencies all have a stake in doing so, as does the public, many of whom are looking for a broad based policy to which we must all contribute.

Figure 1. This aerial photograph dipicts the entrenchment of Glen Canyon and its tributaries into the Navajo Sandstone.

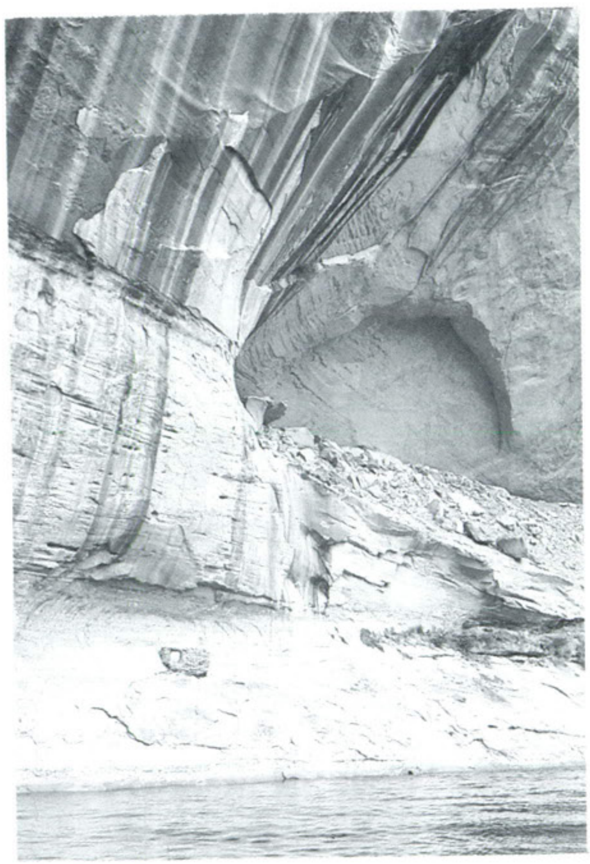

Figure 2. A closer view of the canyon wall reveals alcoves which were once the homes of the Anasazi, between A.D. 1000 and 1300. Note also the presence of the "bathtub ring."

Figure 3. The Steury Ledge Site provides one example of structure morphology present in the canyon. This site was the scene of preservation experiments.

Figure 4. These small storage rooms are typical of the degree of preservation possible in dry alcoves. The room in the foreground retains an intact roof.

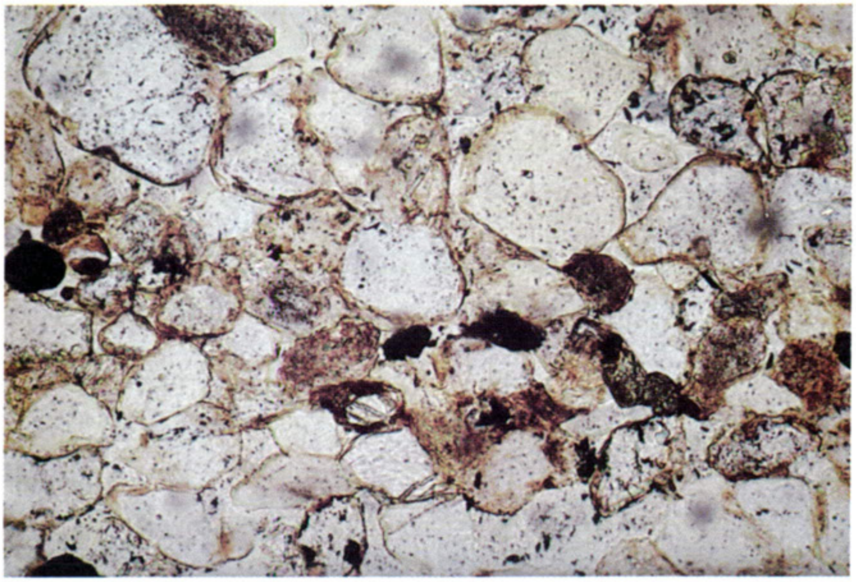

Figure 5. This microscopic thin-section of non-inundated Navajo sandstone is characterized by dark blotches and well defined perimeters of the sand grains. These features represent the iron oxide cement present in the stone.

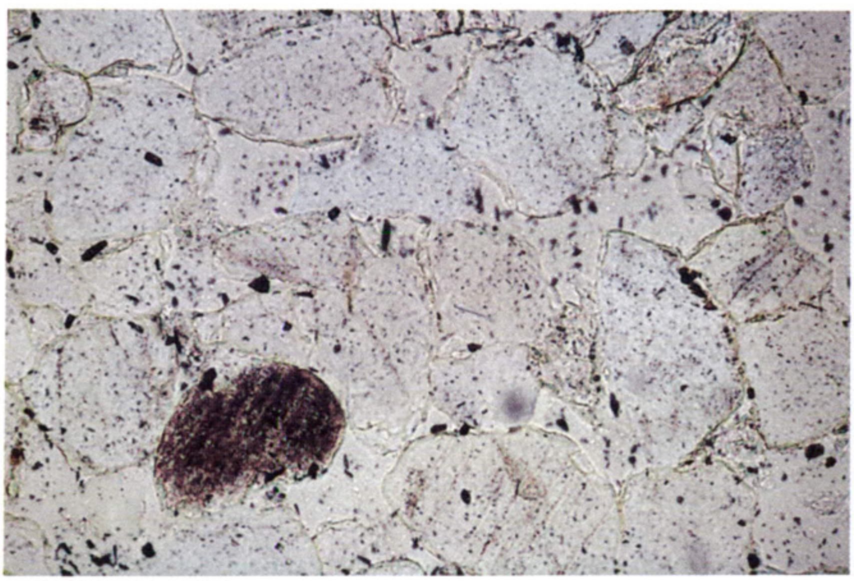

Figure 6. By contrast, the iron oxide cement is absent from a specimen which has undergone inundation.

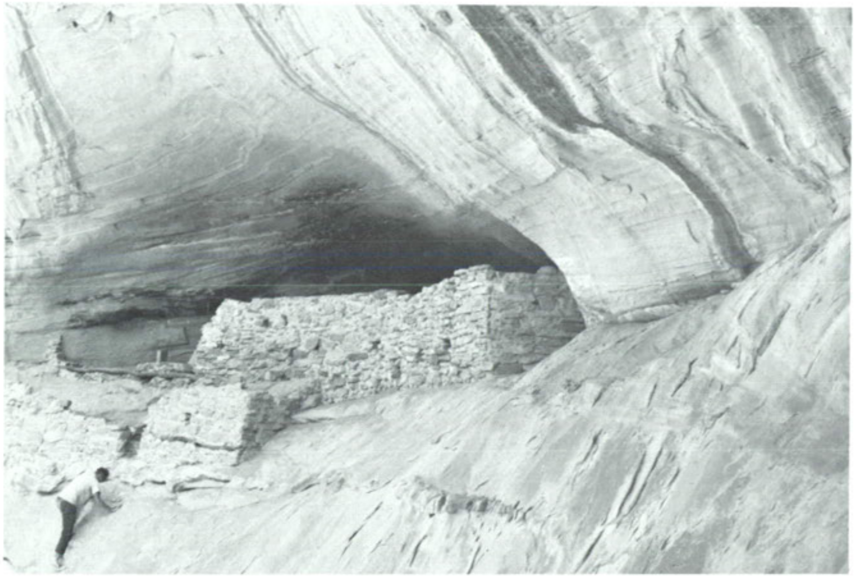

Figure 7. Gourd House, as it appeared during the archeological survey which preceded impoundment.

Figure 8. The remains of Gourd House, as they appeared in June of 1978, following inundation.

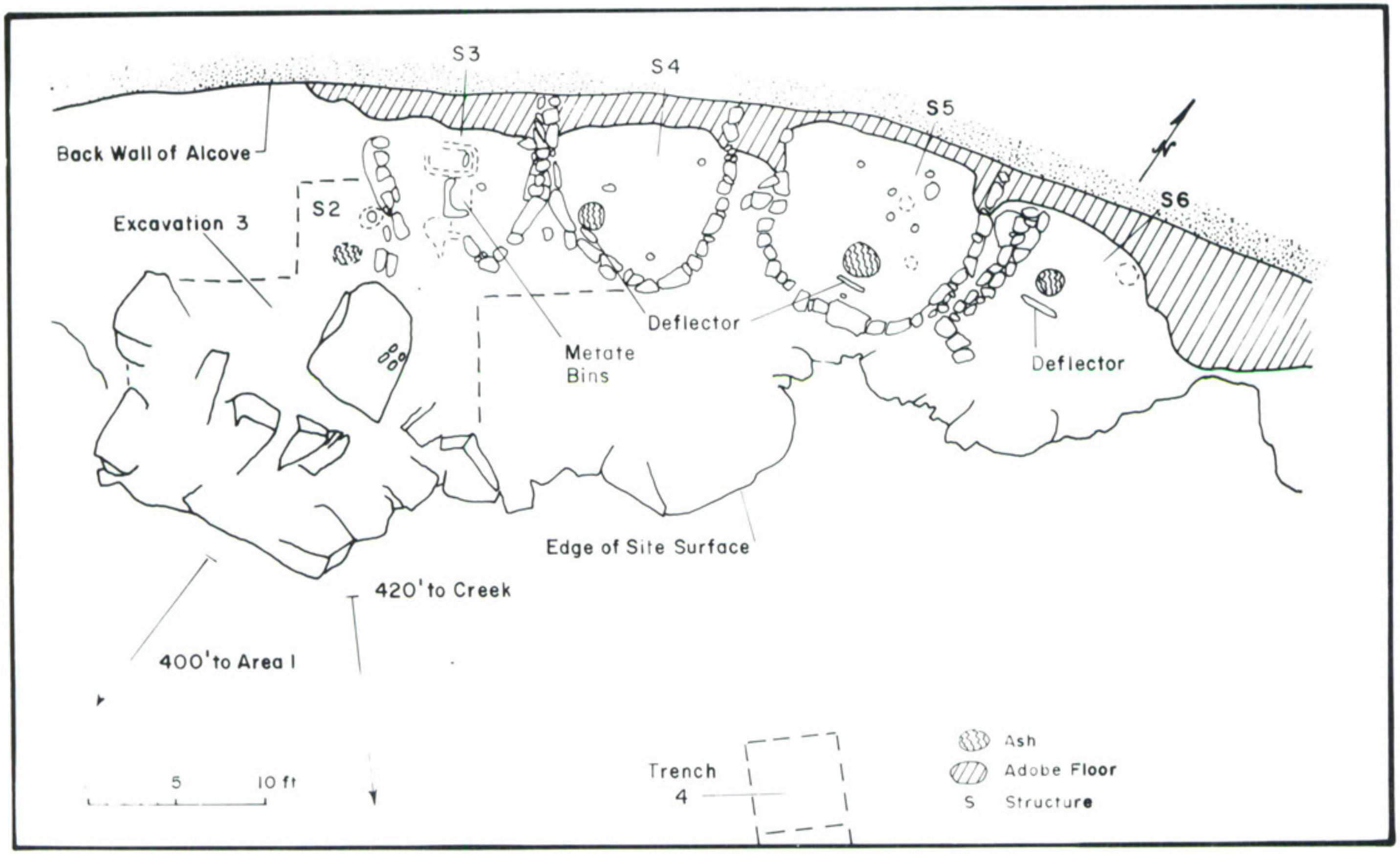

Figure 9. This map has been redrawn after Lipe et al. (1960:51), and illustrates the condition of Doll Ruin during the archeological survey performed prior to inundation. Especially note Structures 3 and 4.

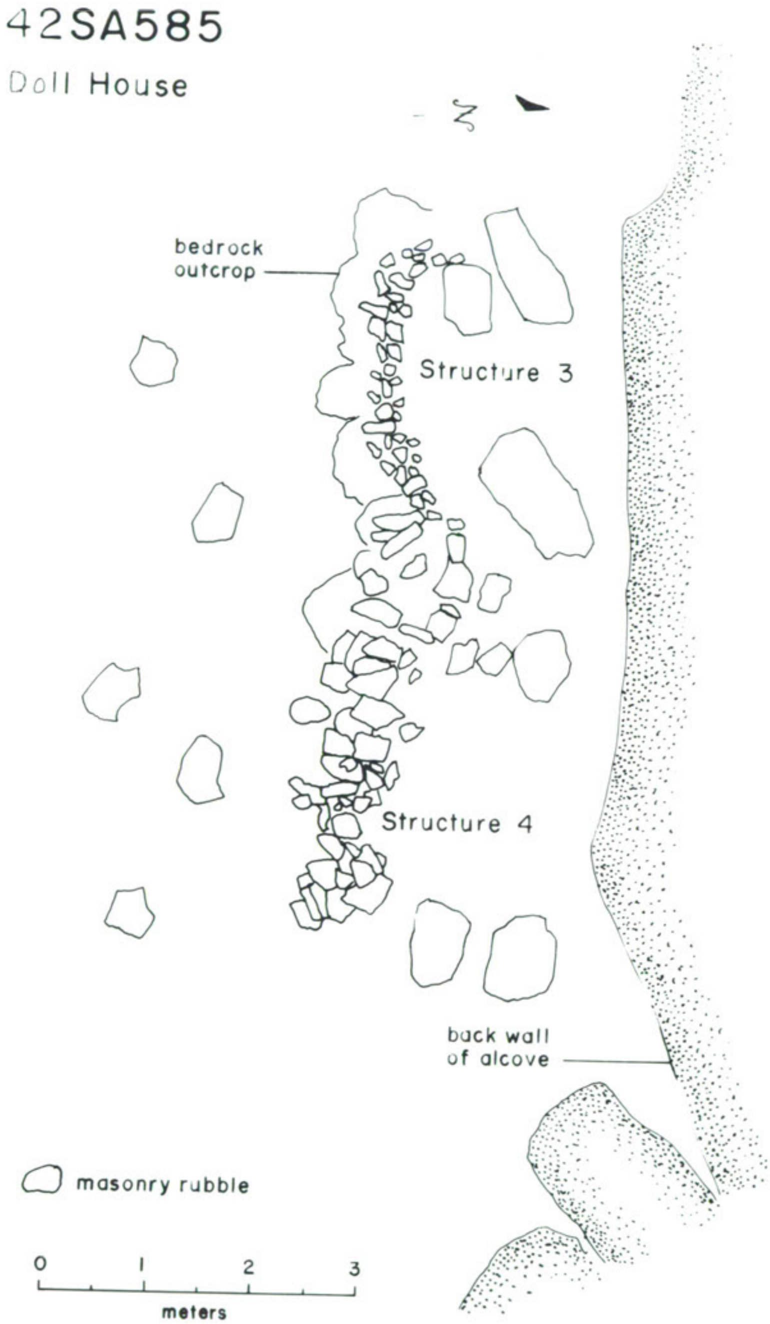

Figure 10. This map shows structures 3 and 4 as they appeared in 1978. Mounds of rubble denote the former wall outlines, and nothing remains of previous floor features. At the time that this map was prepared, the site was at a depth of 17 meters.

Figure 11. Overview of the Steury Ledge site before inundation, facing east. Structure 1 is the well-preserved room closer to the observer; Structure 2 is in the background.

Figure 12. The west wall of Structure 2 after inundation, but before stabilization.

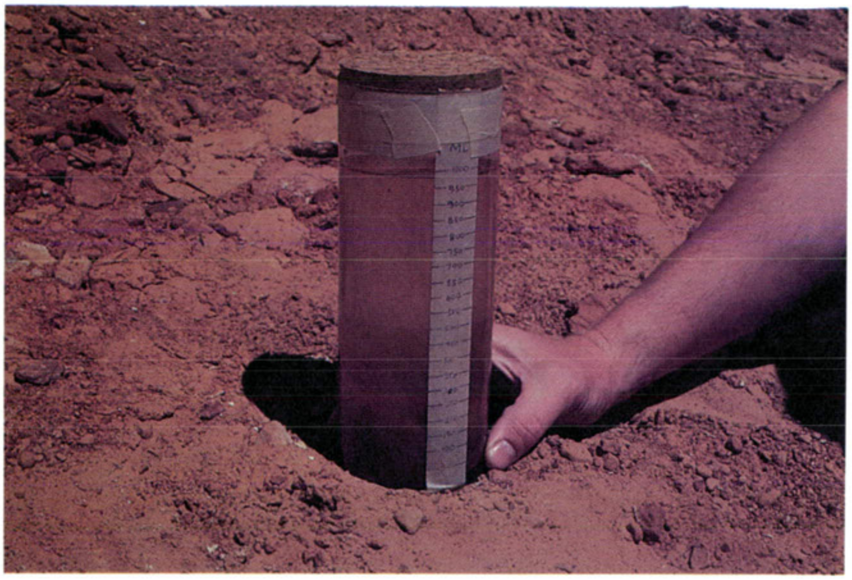

Figure 13. Conducting a field sedimentation test. Coarser particles will settle out from the crushed and agitated mortar first, permitting a visual approximation of particulate composition.

Figure 14. Recording Munsell color of aboriginal mortar from Steury Ledge.

Figure 15. The south wall of Structure 1 before stabilization.

Figure 16. The south wall of Structure 1 after stabilization using an unamended mud mortar.

Figure 17. The east wall of Structure 2 before stabilization.

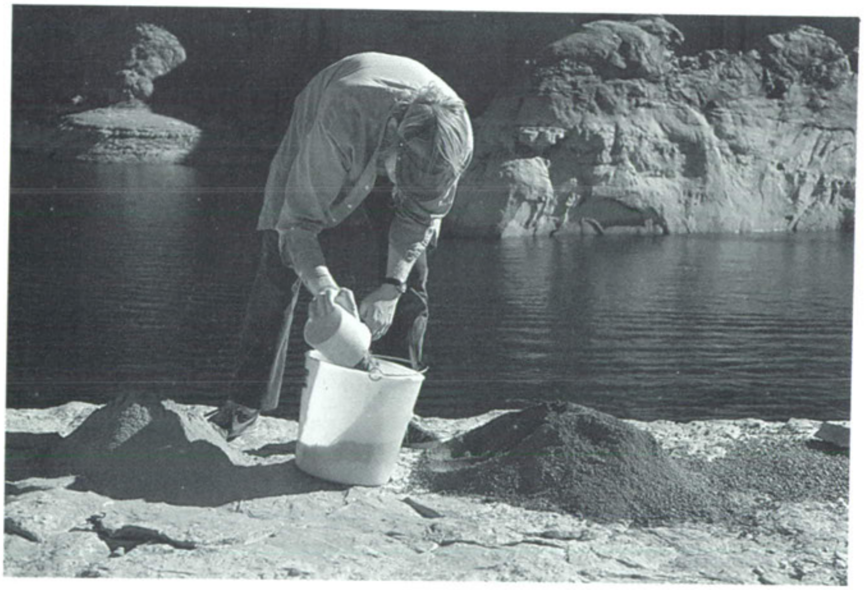

Figure 18. Mixing the screened sandy fill soil from the site with the clay imported from the Halls Crossing Marina in manufacturing an unamended mud mortar.

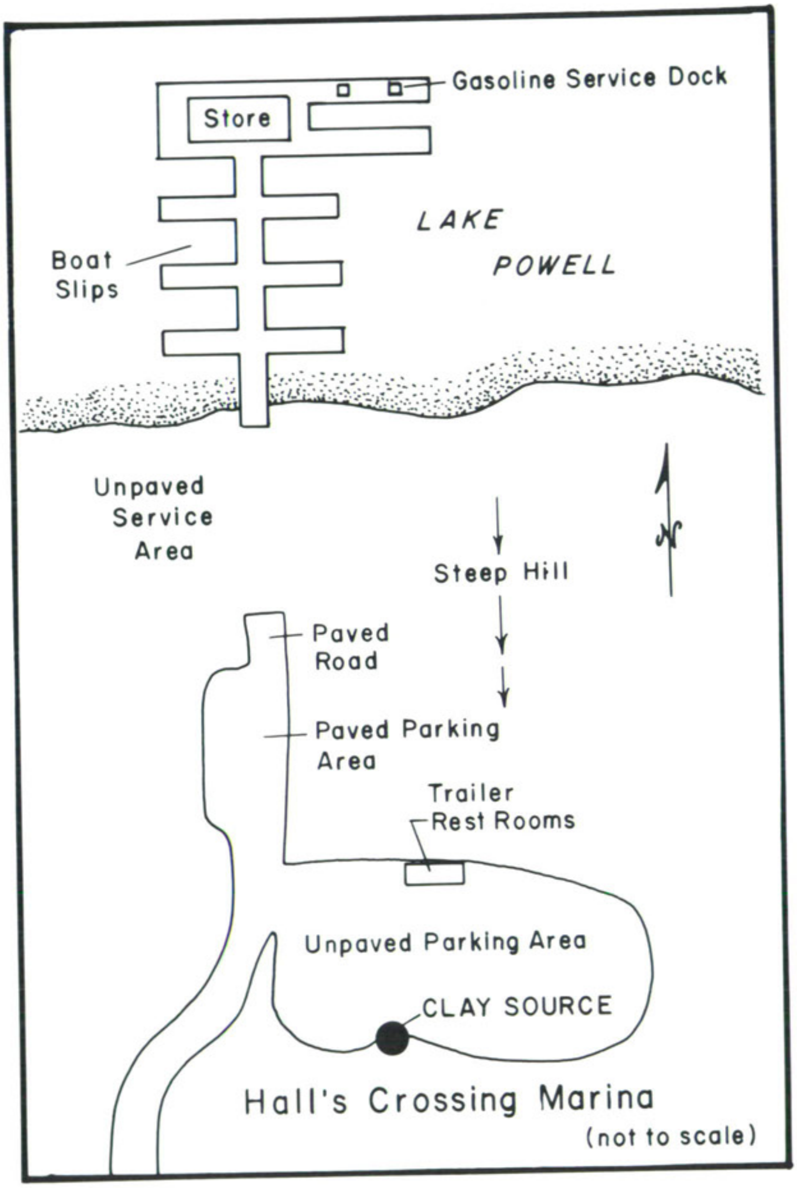

Figure 19. The location of imported clay selected for the field tests is shown in this sketch plan.

Figure 20. The west wall of Structure 1 before stabilization.

Figure 21. The west wall of Structure 1 after stabilization with a soil-calcium aluminate cement mortar.

Figure 22. The west wall of Structure 2 before inundation. White line indicates the extant wall height following ununda-tion. Photo courtesy of the University of Utah.

Figure 23. The west wall of Structure 2 after inundation, but before stabilization with a soil-calcium aluminate cement mortar. Compare the wall height with that in Figure 48.

Figure 24. The east wall of Structure 1 before stabilization with a soil epoxy mortar.

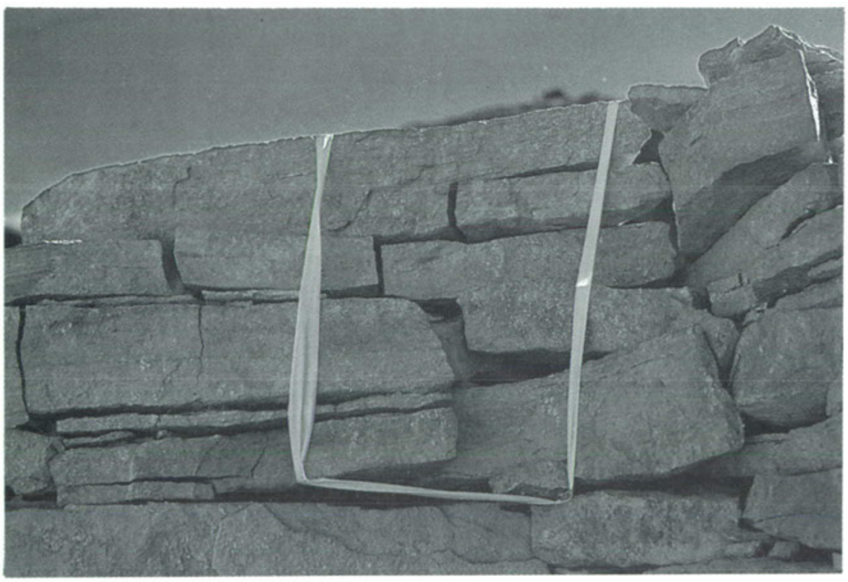

Figure 25. The south wall of Structure 2 before stabilization with a soil epoxy mortar.

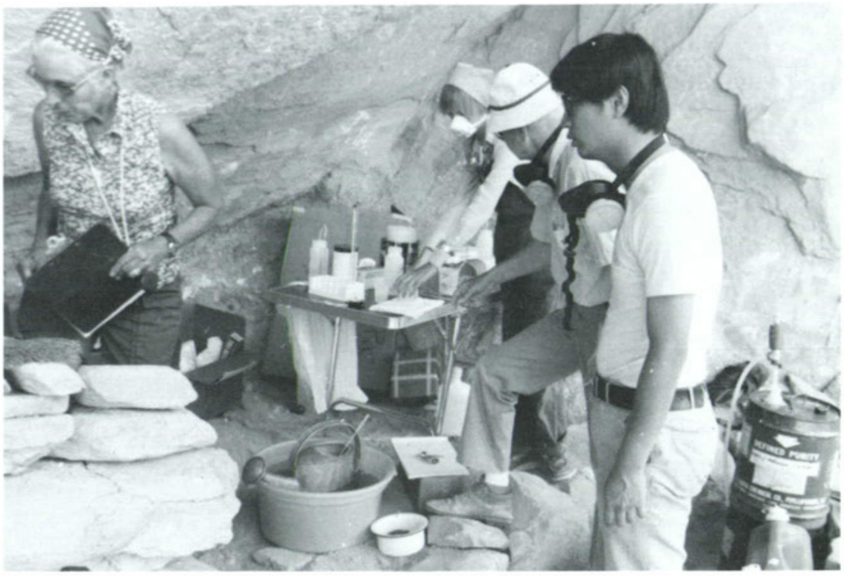

Figure 26. Dr. Burke and his crew brought a portable laboratory into the field and mixed their methyl methacrylate on-site.

Figure 27. After mixing, the chemical concoction was poured over the wall with a simple watering can, and wall stones and mortar were impregnated.

Figure 28. Mixing the components of the epoxy resin together.

Figure 29. The section of masonry wall in Structure 4 after stabilization with soil epoxy mortars.

Figure 30. This photograph shows the condition of the In-and-Out House (42Sa231) prior to treatment and inundation. The arrow designates a narrow crack which can be used to compare Figures 30 and 31.

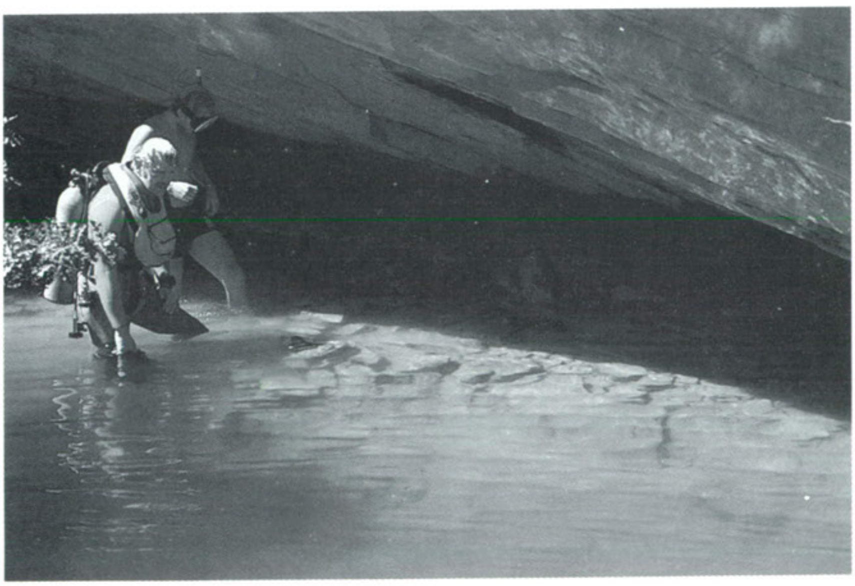

Figure 31. This photograph shows the same area as the above, following unsuccessful treatment and immersion. Note the unconsolidated sandy footing. The arrow designates the same crack in the alcove wall as in the prior photograph.

Figure 32. The remains of some of the masonry material which fell are shown here, at a depth of 1.5-2.0 meters. This portion fell as a monolith, with some of the soil epoxy mortar (shown at the arrow) still bonding the stones together.

Figure 33. The nature of the other In-and-Out House (42Ka595), is shown here, with T-shaped doorway and crack in wall at the left. The crack was stabilized with soil-epoxy mortar, but subsidence of the boulders upon which the structure reposes has caused further cracking since the photo was taken.

Figure 34. The interior wall of the In-and-Out House (42Ka595) reveals a much less stable configuration than the exterior, since the interior retains less mortar. This mortar was replaced with both soil epoxy and calcium-aluminate soil cement.

Figure 35. At a depth of ca. 17 meters, a hand-held grout gun was used to replace mortar which had been eroded when the site went under-water.

Figure 36. The resultant remortared area of the wall is best shown at the area designated by the arrow. This photograph was taken three months after the application.

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APPENDIX A: MATERIALS AND ECOLOGICAL TESTING LABORATORY

Western Archeological Center and Cooperative
Studies Unit, University of Arizona
Tucson, Arizona

Report of Analysis

TO: Larry Nordby
Southwest Cultural Resources Center
P.O. Box 728
Santa Fe, New Mexico 87501

We have completed the compressive strength analysis on the three rock samples you submitted to the laboratory. We characterize these samples as:

Your Number	Our Number	Description
1	133	Soft friable quartzose sandstone with bedding planes parallel to the sample surface. This sample was not inundated.
2	134	Soft friable quartzose sandstone with bedding planes dipping 75° from the surface. This sample was not inundated.
3	135	Soft friable quartzone sandstone with bedding planes parallel to the sample surface. This sample was inundated.

Method of Analysis

The compressive strength of these rocks was analysis in an accordance with ASTM specification C-170-50, a widely accepted standard method (1). The data obtained from these tests was analysed for statistical significance by the F-probability test and the associated contrast of means procedure (2).

Results	Our Number	Replicate Number	Compressive Strength ($lbs./in.^2$)
	133	1	3239
		2	4159
		3	4392
		Mean =	3930 ± 610 $lbs./in.^2$

134	1	1833
	2	2296
	3	2487
	Mean = 2206 ± 337 lbs./in.^{2}	
135	1	1783
	2	1981
	3	1788
	Mean = 1851 ± 113 lbs./in.^{2}	

Analysis of Variance

Source	DF	SS	MS	F
Total	8	8.4189×10^6		
Treats	2	7.4239×10^6	3.7119×10^6	22.3825 = 0.167%
Error	6	995047.3334	165841.2222	

This statistical analysis indicates that there is less than one chance in a thousand that the strength difference found in these samples is due to chance alone. In other words the samples differ in strength.

The sources of the difference between the samples is determined by the comparison of their mean strengths. The probabilities that the differences between pairs of samples is due to chance alone are:

Samples compared	F-ratio	Probability (%)
133 - 134	26.90	0.101
133 - 135	38.11	0.035
134 - 135	1.14	32.20
133 & 134 with 135	17.86	0.297
133 & 135 with 134	5.66	4.159

Conclusion and Discussion

The combined data from the two noninundated samples (133, 134) when compared with the inundated sample (135) shows that there are only three chances in a thousand that inundation has not significantly weakened the stone. Notice that the uninundated sample with non-parallel bedding (134) is much weaker than the parallel bedded sample (135). This comparison is, therefore, the worst case. The best case is comparison of the two parallel bedded samples (133, 135) where the probability that the strength is the same rises to 3.5 chances in 10,000. We believe that these data clearly indicate that inundation of this sandstone causes significant weakening.

When the data for the inundated sample (135) is compared to the nonparallel bedding (134), however, the difference in strength is not significant. There are thirty-two chances in a hundred that the difference in strength is due to chance alone. That is to say that the strength of the uninundated rock when the load is applied parallel to the bedding planes is the same as the strength of inundated rock loaded at right angles to the bedding. We must emphasize that these conclusions are based on three samples of rocks, previously detached, and whose past history and representativeness of all rocks in the area are unknown. Therefore, these data can only be applied to the real world with caution. Greater certainty can only be achieved by running more samples.

To put these data into perspective, we ran a test on NW grade commercial red brick. This brick was much weaker than even the inundated rock and had a bearing strength of 1273 $lbs./in.^2$

Peter S. Bennett
Laboratory Director

AN EXPERIMENT TO DETERMINE THE EFFECTS OF WET/DRY CYCLING ON CERTAIN COMMON CULTURAL MATERIALS

by
Larry Murphy
with contributions by Brian G. Barnett,
Richard G. Holloway, Charles M. Sheldon

ACKNOWLEDGMENTS

The original conception of the experiment was Dan Lenihan's, who also provided much encouragement during its implementation. Barbara Hamm and Toni Carrell provided assistance in the operation of the cycling phase in the absence of the author. Special thanks are due Stewart Peckham of the Laboratory of Anthropology, Santa Fe, who provided test specimens and guidance during the course of the experiment, and Larry Nordby, who assisted with the ceramic analysis. Henry Baker and George Percy of the Bureau of Historic Sites and Properties, Tallahassee, Florida, provided test specimens, as did Tom Windes of the National Park Service's Chaco Center in Albuquerque, New Mexico. Without the support of these people the experiment could not have been carried out.

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INTRODUCTION

This laboratory experiment was designed to test the impacts of wet/dry cycles on certain common cultural materials: ceramics, shells, human osteological material, and pollen. The conceptual division of a reservoir environment into specific zones of impact, discussed elsewhere in Volume I, raised the question of differential preservation of archeological materials within the maximum flood pool zone (zone 3). This zone is that portion of the impoundment area subject to occasional periodic inundation which consequently subjects archeological material to cycles of saturation and drying. Although rainfall causes a certain degree of wet/dry cycling to cultural materials, this is a qualitatively different process than complete saturation. Since little attention has been directed to this particular problem in the general literature of preservation, and the laboratory study of differential preservation in freshwater environments (Technical Report III, this volume) did not specifically address wet/dry cycle impacts, a separate laboratory study was instituted.

THE EXPERIMENT

The Problem

A general hypothesis was formulated to guide the research: Archeological remains subjected to wet/dry cycles will deteriorate at a faster rate than remains of similar composition which remain in a dry state. The test implication for the material classes was: If archeological materials suffer damage or loss of data when periodically exposed to drying cycles during drawdowns and alternately subjected to saturation during pool level rise, then measurable attrition will also take place during laboratory controlled wet/dry cycles, and the nature and extent of damage can be measured.

Experimental Design

Test material was selected so as to be generally representative of constituent elements of archeological sites in almost any region of the country. There was no attempt to be comprehensive. Wood was not included as there is abundant literature concerning wet/dry impacts.

In the attempt to make the results as immediately applicable as possible, the decision to use prehistoric materials for the test was made. Pollen was the single exception, as the collection of the range and amounts of pollen taxa necessary from prehistoric archeological sites for the experiment would have been quite difficult to obtain. Acetylated pollen, which represents pollen as found in a preserved state, was substituted (Holloway section, this report).

Material Classes Represented

Ceramics: Fifteen archeological ceramic types and four manufactured experimental ceramic types were used in the wet/dry cycle laboratory tests. The four experimental types were the same as those produced for the laboratory studies of differential preservation in freshwater environments (Technical Report III, this volume).

The use of prehistoric ceramics poses some problems, as recognized by Ware and Rayl (Technical Report III, this volume: 3-4). To minimize the variability within a specific ceramic type, a large test and control population would normally have been necessary. The problems of procurement of a large sample of numerous types from archeological repositories would be serious since the destruction of the test population was a possibility and few collections or sites could provide the necessary numbers of sherds to statistically minimize variability by the use of a large sample.

Rather than rely on a large sample of each type to minimize variability inherent in the test and control population, the decision was made to use a sample size of thirty for each ceramic type with each sherd sawn in half: one half to be the test specimen and the other half to serve as the control. This approach provided minimum variation between test and control populations and offered the added advantage of analysis by direct comparisons of the two halves of each sherd. The direct comparison of the test portion of the sherd to the control half would make analysis more dependable, as the only difference between the two should be the result of the test variable: the impact of wet/dry cycling. This procedure would also nullify the variations of sherd populations resulting from differences in processing and storage practices of the museums supplying the sample.

The time constraints for procurement, experiment formulation, cycle phasing, and analysis were tight because the experiment was carried out in the final year of the Inundation Study. The constraints imposed a limitation on the number of ceramic types available and the number of complete wet/dry cycles possible. The source of the ceramic type samples were three archeological laboratory collections: The Museum of Anthropology, Santa Fe; Chaco Center, National Park Service, Albuquerque; and Bureau of Historic Sites and Properties, Division of Archives, History and Records Management, Tallahassee, Florida. Requests were made to each of these institutions for a thirty-unit sample of a range of ceramic types that had been analyzed and typed and could be sacrificed for the experiment. Limitations on the range and number of different types was a function of availability within these institutions, although a varied cross section was sought. It was assumed that the type range, though limited, would produce sufficient data for determination of cycle effects and, consequently, serve as a basic guideline for management decisions regarding differential preservation of ceramic attributes within the maximum flood pool zone. It is hoped similar studies with a wider range of regional specific types will be carried out by future researchers to further the understanding of the effects of wet/dry cycles.

Table I: Ceramic Types Used for Wet/Dry Cycle Experiment

A. Reserve Smudged
paste - brown to dark brown

temper - light-colored sand grains
surface - general dull polished effect

B. Reserve Indented Corrugated
paste - brown to dark brown
temper - light-colored sand grains
surface - corrugated finger indented, interior smooth, sometimes rough

C. Piedra Gray
temper - crushed rock
surface - untextured, unslipped, unpolished, fired in reduced atmosphere

D. Rio Grande Pueblo IV Utility
paste - gray/black core, mica flakes
temper - crushed igneous rock, sand, micaceous
surface - coiled, scraped, smeared, striated, fired in oxidizing atmosphere

E. Rio Grande Glaze on Yellow
paste - red/brown to gray
temper - usually crushed igneous rock
surface - coiled, scraped, slipped (white), fired in oxidizing atmosphere

F. Jemez Black on White
paste - some large inclusions, though can be homogenous in texture
temper - sherd
surface - slipped, smoothed, fired in oxidizing atmosphere

G. Rio Grande Glaze on Polychrome
paste - red/brown to gray
temper - usually crushed igneous rock
surface - slipped or unslipped, coiled and scraped, fired in oxidizing atmosphere

H. Lino Gray
paste - gray, hard, durable
temper - coarse sand temper protruding through vessel surfaces
surface - not polished, not painted, not decorated

I. Rio Grande Glaze on Red
paste - red/brown to gray
temper - usually crushed igneous rock
surface - slipped (red-orange), unslipped, coiled, and scraped

J. Gallup Black on White
paste - fine, hard, medium gray to white, occasionally dark center
temper - about 2/3 quartz sand and 1/3 crushed potsherds
surface - scraped, never polished, underlying solid temper may protrude, uneven white slip, dull, heavy, black paint of iron

K. Red Mesa
temper - some fine round sand, occasional sherd, quartz sand
surface - painted, polished, slipped; iron paint

L. Wingate Black on Red
paste - grey to orange
temper - sherd
surface - bowls slipped inside and out with heavy maroon red slip, sometimes dull in finish, decorated on interior in heavy black carbon and iron paint; polished over designs

M. Null Set for Control

N. Sand Tempered
from southern Florida; no specific identifiable archeological type

O. San Marcos Complicated Stamped
grit tempered, surface stamped

P. Fiber Tempered
early southeastern pottery, fiber tempered, very porous, thick, and of variable color

Q. Manufactured Test Sherd IA
mineral paint, organic temper, fired at 750°C

R. Manufactured Test Sherd IB
organic paint, rock temper, fired at 900°C

S. Manufactured Test Sherd IIA
organic paint, rock temper, fired at 600°C

T. Manufactured Test Sherd IIB
mineral paint, rock temper, fired at 1050°C

Bone: Human osteological material from a single site was used for the study. There was no control population employed in this test. The results of the wet/dry cycles should affect anthropometric analysis or the impact can be considered inconsequential. Standard anthropometric measurements for each bone were taken prior to cycling for comparison to those taken of the same bone by the same physical anthropologist after the experiment.

Shell: Samples of clam (*Rangina cuneata*) and oyster (*Crossostrea virginica*) obtained from prehistoric shell midden sites in the Matagorda Bay region of the central Texas Gulf Coast were used for the study.

Preparation of Materials

Each ceramic sherd was sawn in half with a carbide blade ceramic saw and both pieces were labeled with indelible ink. Each type was given a letter designation, each sherd of the type was sequentially numbered, and the halves of the individual sherd were lettered A or B, e.g., A1A, A1B,...A4A, A4B...B1A, BIB, etc. Each sherd section was rinsed in deionized water, allowed to air dry for 48 hours, and weighed on an electronic balance scale to the nearest .01 gram. Individual sherds and arrays were photographed for later analysis.

Five shells were selected at random from both the oyster and clam sample and sawn in half. All were rinsed in deionized water, allowed to air dry, and weighed. All shells were not sawn in half as it was believed that the sawing would add an uncontrollable variability by exposing surfaces normally not exposed in nature to wetting/drying cycles. Close-up black and white photography of samples was taken for comparison and analysis.

The osteological material was measured using standard anthropometric procedures. Each bone was labeled and photographed. All were rinsed prior to the first cycle to remove any foreign matter.

Nalgene plastic trays were used for the actual container during the cycling. Two trays were used together; the smaller fitting inside the larger. Sections of the bottom of the smaller tray were cut out and nylon screen of less than 1-mm opening was laid across. Each ceramic test type, and the oysters, clams, and bones were in an individual, separate tray (Plate 1).

Procedure

The lengths of the wet/dry cycles were established during the first cycle. Deionized water was used to cover the test material. Certain large sherds of representative types were periodically weighed to estab-

PLATE 1: Nalgene plastic trays and light bar arrangement for wet/dry experiment.

lish a rough saturation curve. Very little increase in weight was observed after 24 hours; therefore, the wet cycle was set at 24 hours.

Drying curves were established much the same way. To speed up drying and shorten the time necessary for each wet/dry cycle, a light bar was constructed consisting of fifteen, 150-watt flood lamp type light bulbs. This bar was raised and lowered until the height sufficient to maintain a temperature no higher than 95° F was found. After the 24-hour saturation cycle, the inner pan containing the test specimens was removed and placed under the lights. It was found that complete drying of the ceramic material took about 12-18 hours. Some osteological material took longer, so a 24-hour drying time was used.

It is possible that the drying lights could affect the test material. The heat was within naturally occurring conditions and never rose above 95° F. A procedure was followed throughout the experiment to factor out the impact of the light. The sherds were turned over every five cycles. If, upon comparison of the test and control sherds, a discernible fading of paint or slip was discovered, the test sherds would have been subjected to the same amount of light to factor out the impact. This was not necessary, however, as fading of paint and color was not discernible in the test group relative to the control. The shells were turned when the sherds were, but the bones were turned over each cycle to insure complete drying.

The water was changed at least every three cycles to minimize biological growth. The water trays were periodically rinsed and dried during the dry cycle. Each tray contained the same amount of water, which was sufficient to inundate the material.

Periodically, the water was sampled at the end of a single wet cycle. A clean pipette was used and standard laboratory procedures to minimize contamination were followed. One tray, serving as a control, was treated exactly as the others but contained no test material. The samples were put into labeled laboratory grade plastic vials and stored until the completion of the experiment. These were analyzed for concentrations of sodium, potassium, magnesium, and calcium so some idea of the amount and nature of the leaching process could be developed.

The experiment was carried through forty complete wet/dry cycles. The cycles were interrupted after the thirty-fifth and continued six weeks later due to field commitments.

Analysis

Osteological material was measured with standard anthropometric techniques before and after the experiment for comparison. The measurements were made by the same researcher, and general observations were made at the time of both measurements. Black and white and color photography of each bone were done. An area was chosen and outlined on each bone for close-up photographic comparison, and photography of the area was accomplished before and after the experiment. Strength tests of bone material were not made.

Sherds were photographed in type arrays before the initiation of the experiment, and certain sherds were photographed close-up for later comparison of qualitative changes. For comparison purposes, both halves of each sherd were weighed prior to and after the cycling. Porosity tests were done at the completion of the experiment on both the test and control sherds. Comparison of the wet and dry weights of both control and test sherds and shells was made and used for deriving a porosity index as a percent of water absorbed relative to sherd weight. The change in porosity index should represent chemical leaching and as such should be related to the strength of the material.

Quantitative strength tests were attempted, without success, on the sherds (see Barnett section, this report). Pollen was analyzed with the use of transmitted light and electron microscopy (see Holloway section, this report). Osteological material was analyzed by noting changes in anthropometric measurements before and after the cycling and comparing before and after photographs.

Results

Osteological materials: All bones were affected by the 35 wet/dry cycles and exhibited some degree of degradation. Cortical lifting was present in all bone categories. The short bones were the least affected and the long bone fragments the most degraded. Thin sections of bone such as found in the scapula were subject to cracking. The innominates were notably distorted. The anthropometric measurements revealed an overall shrinkage of around 1%. Teeth were seriously affected and tended to disintegrate through spalling of the enamel.

Analysis of water at cycles 1, 3, 9, and 30 indicated that calcium, sodium, potassium and magnesium leach out in decreasing amounts. Over time, the principal leachate was calcium. Leaching diminished rapidly after the first few cycles but was detectable through the 30 cycles.

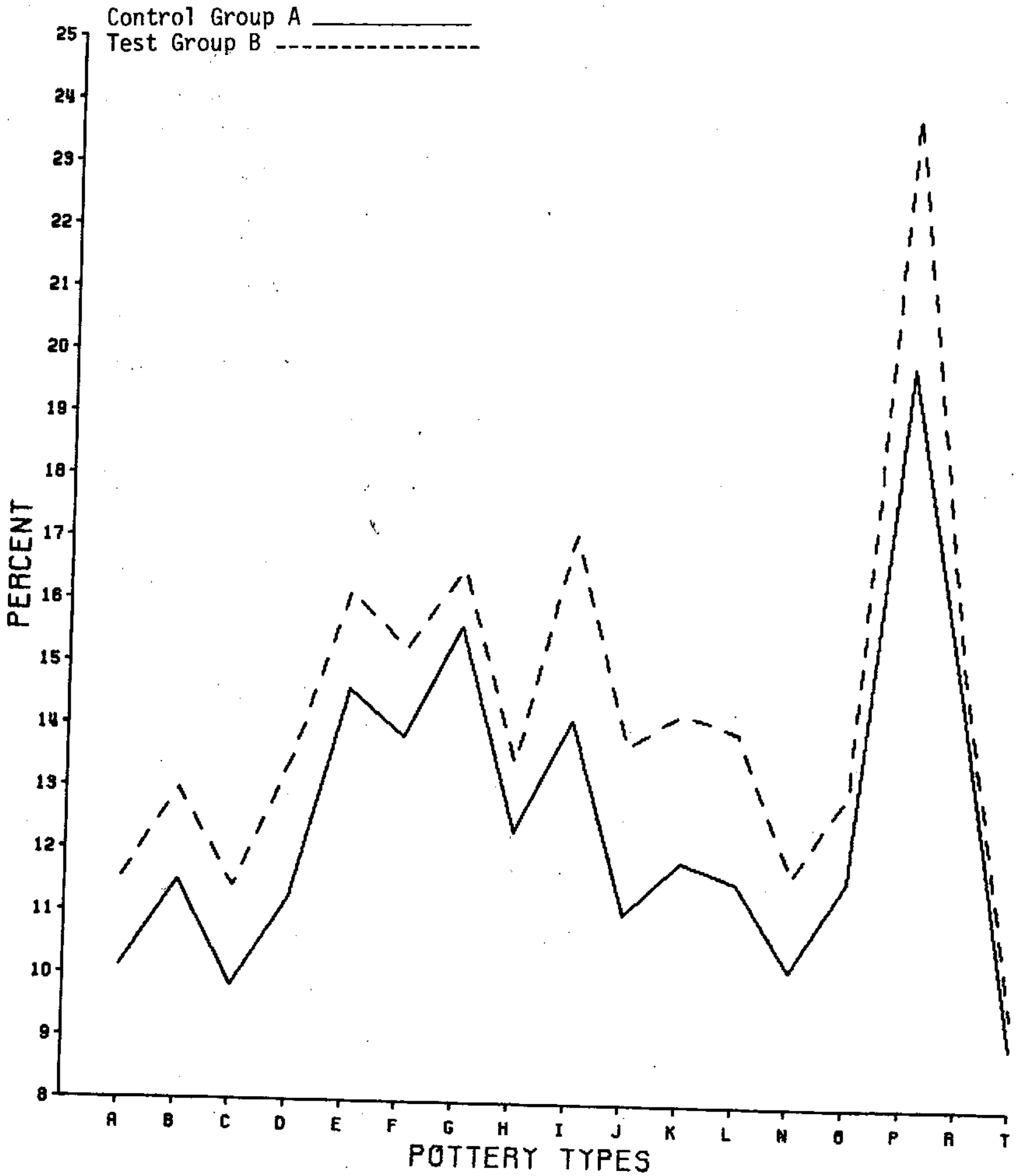
Pollen: The experiment revealed notable destruction of the pollen exine in all categories, resulting from the wet/dry cycles. The damage was basically mechanical and consisted of crumpling, folding or breaking, though corrosion was also evident.

Ceramics: The results of the ceramic portion of the experiment indicated that wet/dry cycling tends to weaken the sherd. The porosity index (derived by dividing the total water absorbed in the sherd by the dry weight of the sherd multiplied by 100) of the test sherds was significantly higher than that of the control sherds (Figure 1). A paired-t test was applied to the porosity indexes of the control and test sherds and revealed that the test sherds were significantly higher (more porous), to a confidence level of .001.

It is assumed that the increase of porosity of the test sherds represents a decrease in strength due to loss of fabric. To determine the nature of the leaching process, water analysis was done of each ceramic type at cycles 1, 3, 5, 10, 30, and 40. The samples taken at cycle 10 had to be disregarded due to faulty procedure, as a double cycle (9 and 10) was taken. Analysis of water determined the concentration of

FIGURE 1:

AVERAGE PERCENT OF WATER ABSORBED BY
CERAMIC SHERDS SUBJECTED TO WET/DRY CYCLING



calcium, magnesium, potassium, and sodium present. Generally, calcium was the principal leachate. Potassium, sodium, and magnesium followed in order of concentrations. The concentration in milligrams per liter rapidly diminished over time. The first few cycles represented the majority of loss of these elements though measurable loss continued in most cases throughout the cycling phase.

Shell: Both oysters (*Crosostrea virginica*) and clams (*Rangina cuneata*) showed a significant increase in porosity as a result of the wet/dry cycling. Little qualitative differences in the shells were noted as a result of the experiment. The principal change was a dulling of the surface of the test specimens which resulted in a somewhat chalky appearance after the test. No morphological changes were observed. Calcium and sodium were the principal leachates of the clams, while calcium and magnesium were the principal leachates of the oyster test sample.

CONCLUSIONS

Wet/dry cycling which results from pool level fluctuations in the maximum flood pool zone (Zone 3) can produce negative effects on the preservation of bone, shell, pollen, and ceramics.

Osteological material can potentially lose important data regarding population size estimates through shrinkage and disintegration of bones. Data pertinent to determination of health status and diseases present within a given population can be skewed by loss of data due to cortical lifting resulting from wet/dry cycles in a relatively short period of time (35 cycles). The contribution of data generated by dental analysis can be lost due to fracturing and spalling of the enamel of teeth which results from wet/dry cycles. Osteological materials in general can be seriously affected.

Oyster and clam shells, though they become more porous, do not seem to be seriously impacted by wet/dry cycling. However, the long-term deterioration of shell in the wet/dry cycle zone may make future analysis difficult.

Ceramics are affected by wet/dry cycling by a measurable increase of porosity over a relatively short period of time (40 cycles). Within the test sample, the sherds with the lowest known firing temperature (600°C in the manufactured test sherds II-A, Sample S) disintegrated after 10 cycles, which may indicate sherds of this range of firing temperature will have a very short life expectancy in the drawdown zone. Differential leaching of the soluble ions in the ceramic sherds during wet/dry cycling may make clay source identification and other studies based on element ratio analysis impractical. The loss of calcium as the principal leachate of most of the ceramic types may indicate a loss of tensile strength and eventual loss of the sherd itself.

Wet/dry cycling seriously impacts pollen exine preservation and can partially result in the loss of entire taxa and alteration of the reconstruction of the paleoenvrionment.

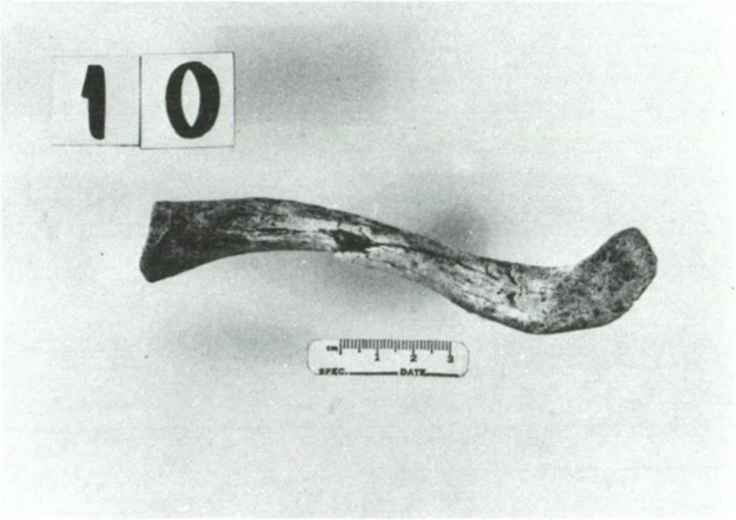
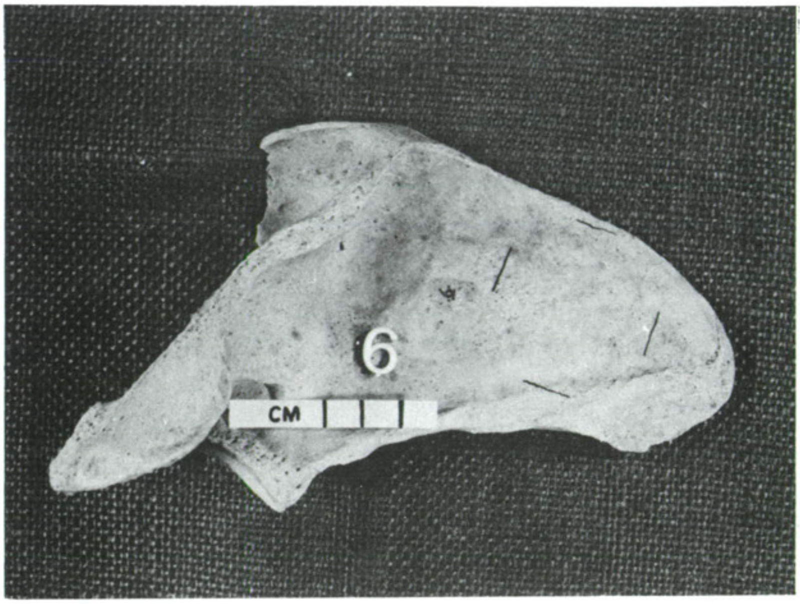


PLATE 2: Upper: Left clavicle prior to wet/dry cycling,
Lower: Results of 35 wet/dry cycles.

PLATE 3: Right proximal femur. Upper: prior to wet/dry cycling, Lower: After 35 wet/dry cycles.



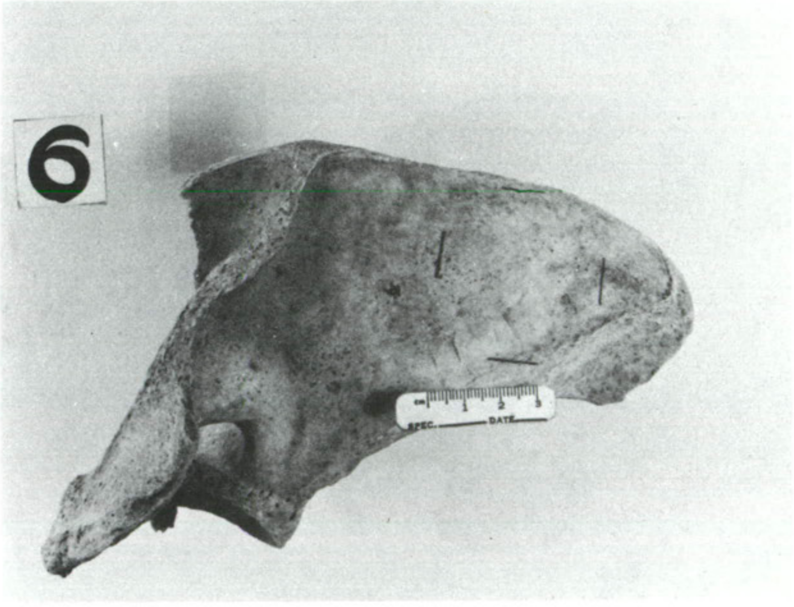


PLATE 4: Left scapula. Upper: Prior to wet/dry cycling, Lower: After 35 wet/dry cycles.

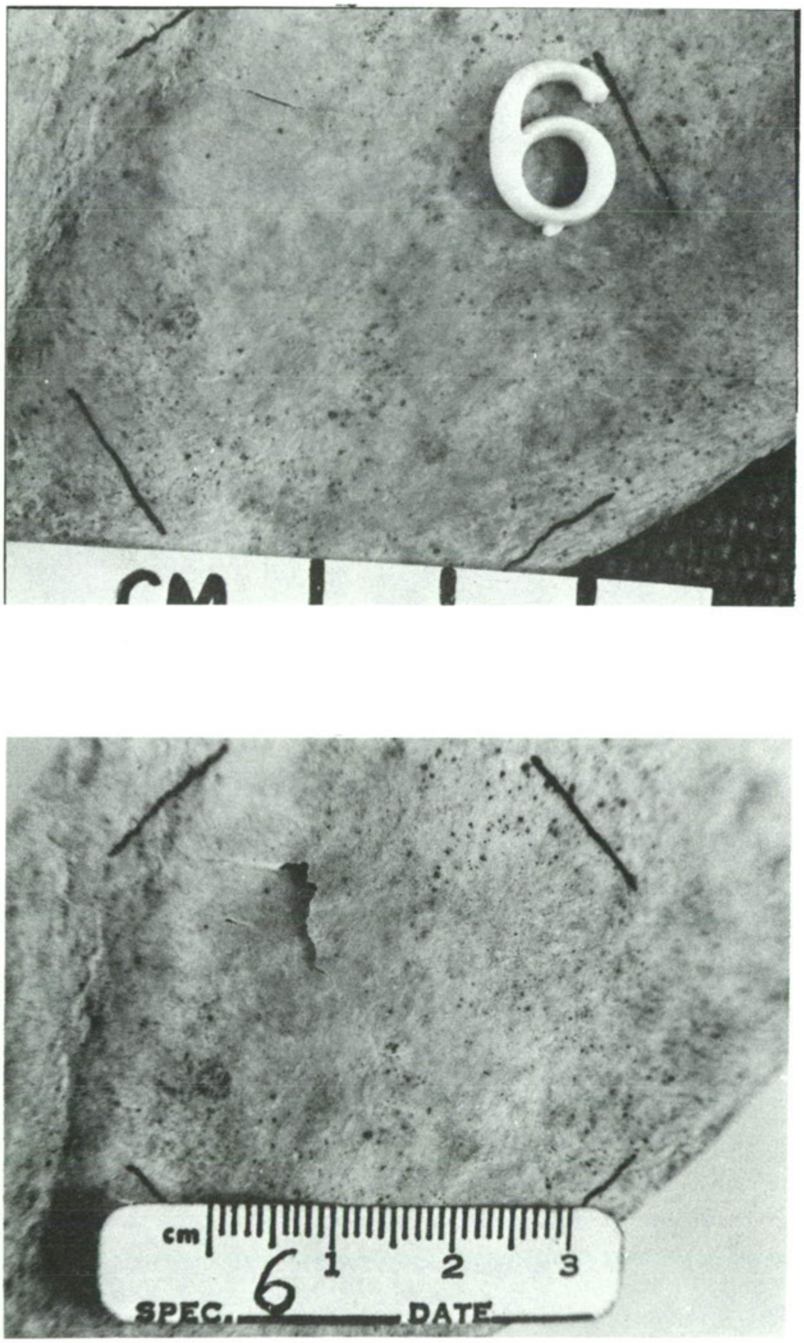


PLATE 5: Closeup of delineated area of left scapula.
Upper: Prior to wet/dry cycling,
Lower: After 35 wet/dry cycles.

OBSERVATIONS AND ANTHROPOMETRY OF HUMAN OSTEOLOGICAL MATERIAL SUBJECTED TO CONTROLLED WET/DRY CYCLES

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The absence of certain bones from prehistoric burial sites is in great part due to differential preservation. Because of their more delicate architecture, bones such as the scapulae, ribs, sacrum, and thin portions of the innominates tend to degrade faster than the heavier long bones and cranial bones. Many factors contribute to skeletal deterioration. Surface exposure to sunlight and precipitation, as well as below surface water flow and ground pressure, all contribute to bone degradation. In certain areas, acidic soil conditions, microorganisms, and rodent activity can greatly accelerate the deterioration and scattering of skeletal remains.

This water inundation experiment, which included 35 wet/dry cycles, provides a good example of water effects on bone, as well as illustrating the role of periodic moisture on differential preservation.

All of the bones in this wet/dry cycle experiment display some degree of deterioration, which could be placed in one of three categories: cracking, lifting of the cortical tissue, and bone distortion. Except for cortical lifting, almost all of the deterioration follows the natural architecture of the bones; that is, the patterns in the bones made up by cortical and cancellous tissue.

The bones which appear to be least affected by this process are the short bones of the hands and feet: the metacarpals and metatarsals. These bones show only a small amount of cracking at the head and base. The long bones (femora, tibiae, radius, and humerus) all display longitudinal cracking, with the tibiae also having areas of cortical lifting on the flat midshaft areas. Small areas of bone have cracked and broken away from the articular areas of the long bones, no doubt in part due to the thin cortex. The fragments of long bones have degraded more than the complete long bones, possibly due to more rapid wetting and drying. Under natural conditions the scapula is one of the first bones to deteriorate, and the experiment shows at least one of the reasons. The wetting/drying has caused cracking completely through the thin blade region, which would allow for easy breakup, especially with any movement or pressure. The condition of the clavicles range from almost unaffected to extensively deteriorated. Once again, degradation follows bone architecture with cracking running longitudinally. Both innominates display extensive changes, with large cracks in the ilium, ischium, pubis, and acetabulum regions. The complex architecture of this bone has probably contributed to the cracking and visual distortion which resulted from the wet/dry cycling. The mandible displays extensive cracking on the inferior border, with smaller cracking following the architecture of ascending ramii. One of the molar teeth is missing part of the crown due to cracking and spalling common in the upper portion of teeth because of the crystal-like nature of the enamel.

Deterioration of bones is produced by many factors: location of the remains, soil conditions, water flow patterns, and even the ante mortem health status of the individual. This experiment has shown what periodic saturation could contribute to the bone deterioration process. Besides the visual changes noted in these test bones, a significant and consistent dimensional change has occurred. Anthropometry done before and after the wet/dry cycling shows an overall shrinkage of approximately one percent in the test bones. Further tests of this type could produce data revealing the limits of such dimensional change and contribute to more realistic information for all types of osteological measurement.

TABLE II: Inventory of Human Osteological Remains Used in Wet/Dry Cycle Experiment

Bone

1. Right Innominate
2. Right Proximal Femur Associated with #1
3. Left Innominate
4. Left Proximal Femur
5. Left Distal Femur Probably Associated with #4
6. Left Scapula
7. Left Proximal Humerus
8. Left Clavicle, Part of Distal End Missing
9. Left Clavicle
10. Left Clavicle
11. Right Clavicle
12. Right First Metatarsal
13. Right Third Metatasal
14. Left Fourth Metatarsal
15. Left Fourth Metacarpal
16. Immature Left Tibia (80 mm in length = 0.5 years)
17. Complete Right Femur
18. Complete Right Tibia
19. Complete Left Tibia
20. Complete Left Humerus
21. Complete Left Radius
22. Complete Mandible with 3 Molars

TABLE III: Anthropometry -- Of Human Osteological Remains Subjected to 35 Wet/Dry Cycles

	Original Measurement	Final Measurement	Percent of Shrinkage
1. Right Innominate			
Maximum length	228.5 mm	225.0	1.02
Maximum breadth	162.5 mm	156.0	1.04
Acetabulum length A-P	55.0 mm	52.9	1.04
Height	51.5 mm	48.3	1.07
2. Right Proximal Femur			
Maximum fragment length from G.T.	88.0 mm	87.0	1.01
Maximum head diameter	47.5 mm	47.1	1.01
3. Left Innominate			
Maximum length	207.0 mm	201.0	1.03
Maximum breadth	141.0 mm	132.0	1.07
Acetabulum length A-P	47.5 mm	46.5	1.02
Height	45.6 mm	44.3	1.03
4. Left Proximal Femur			
Maximum fragment length from G. G.	63.5 mm	64.0	0.99
Maximum head diameter	48.0 mm	47.0	1.02
5. Left Distal Femur			
Bicondylar width	73.5 mm	71.8	1.02
Maximum width	83.5 mm	81.6	1.02
Maximum length midshaft	58.5 mm	57.6	1.02
6. Left Scapula			
Maximum length	152.0 mm	150.0	1.01
Maximum breadth	106.5 mm	106.0	1.00
Glenoid Cavity A-P	39.5 mm	36.0	1.10
Glenoid Cavity height	28.0 mm	27.2	1.03
7. Left Proximal Humerus			
Maximum diameter of head	40.5 mm	39.8	1.02
Maximum length of fragment	54.5 mm	53.5	1.02
8. Left Clavicle			
Maximum length	133.0 mm	132.0	1.01
9. Left Clavicle			
Maximum length	125.5 mm	125.5	0.00
10. Left Clavicle			
Maximum length	142.5 mm	141.0	1.01

	Original Measurement	Final Measurement	Percent of Shrinkage
11. Right Clavicle			
Maximum length	147.0 mm	147.0	0.00
12. Right First Metatarsal			
Maximum length - midline	59.0 mm	58.0	1.02
13. Right Third Metatarsal			
Maximum length - midline	59.5 mm	59.0	1.01
14. Left Fourth Metatarsal			
Maximum length - midline	67.0 mm	65.5	1.02
15. Left Fourth Metacarpal			
Maximum length - midline	51.0 mm	50.0	1.02
16. Immature Left Tibia			
Maximum length	80.0 mm	78.0	1.03
17. Complete Right Femur			
Maximum length	433.5 mm	427.0	1.02
Physiological length	430.0 mm	425.0	1.01
Maximum diameter of head	43.8 mm	42.5	1.03
Maximum diameter midshaft	27.5 mm	27.5	0.00
18. Complete Right Tibia			
Maximum length	390.5 mm	386.0	1.01
Maximum diameter at nutrient foramen	36.0 mm	36.0	0.00
19. Complete Left Tibia			
Maximum length	341.0 mm	337.0	1.01
Maximum diameter at nutrient foramen	31.6 mm	31.8	0.99
20. Complete Left Humerus			
Maximum length	296.5 mm	291.0	1.02
Maximum diameter head	41.0 mm	40.5	1.01
Maximum diameter midshaft	20.6 mm	21.0	0.98
21. Complete Left Radius			
Maximum Length	199.0 mm	197.0	1.01
Maximum diamter at nutrient foramen	13.5 mm	13.3	1.02
22. Complete Mandible with Three Molars			
Maximum length	95.5 mm	95.0	1.01
Gonion-gonion	105.0 mm	105.0	0.00
Maximum ramus breadth	35.0 mm	35.0	0.00
Coroniod height	65.0 mm	64.0	1.02
Symphysial height	31.5 mm	30.8	1.02

INVESTIGATION OF MOISTURE EFFECTS OF WET/DRY CYCLES ON THE PRESERVATION OF THE POLLEN EXINE

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Continued investigations on the preservation of palynomorphs were undertaken in conjunction with the National Reservoir Inundation Study. This investigation was designed to study the specific effects of moisture on the pollen exine, with the ultimate goal of understanding the role of this environmental factor in the eventual preservation of the pollen exine.

Very little previous research has been centered on the mechanical form of degradation (Holloway, this volume). The majority of previous research investigated the preservation of pollen enzymes or the retention of pollen viability after exposure to freezing temperatures (Farrant and Morris, 1973; Nath and Anderson, 1973, 1975; Farmer and Barnett, 1974; Anderson and Nath, 1975; Anderson, Nath, and Harner, 1978).

Experimental laboratory degradation of the pollen exine by exposing them to high temperatures and pressures has recently been studied by Sengupta (1974, 1977), Sengupta and Rowley (1974), and Sengupta and Muir (1977). Gray and Boucot (1975) and Manum et al. (1976) have both reported on the apparent color changes which accompany high temperatures and pressure during lithification in pre-Quaternary sediments.

METHODS AND MATERIALS

A mixture was prepared utilizing the same thirteen pollen taxa as used in previous investigations for the National Reservoir Inundation Study (Technical Report No. 4, this volume) Table IV. This mixture was prepared by adding small amounts of fresh pollen of these taxa (Table I) to a centrifuge tube. The resulting mixture was spot checked by placing a drop of the mixture on a microscope slide and examining the pollen using 200X magnification. Additional pollen of weakly represented taxa were added to this mixture until all taxa were represented by approximately 2% frequency.

One half of this mixture was acetylated following Erdtman's (1960) method. The solution was prepared by combining 9 parts acetic anhydride to 1 part concentrated sulfuric acid (H_2SO_4). This solution containing the pollen mixture was heated at 99°C. for a period of 30 minutes. Acetolysis removes the cellulose intine as well as the external lipids and proteins and effectively simulates a "fossilized" condition.

The acetylated and unacetylated pollen mixtures were suspended in distilled water and autoclaved to sterilize the samples and to prevent biological growth. The centrifuge tubes were covered with a Nytex screen (15 micron mesh) and placed in a drying oven held at a constant temperature of 80°C. for a period of 24 hours. This allowed the water to be completely evaporated. Five (5) mls of autoclaved distilled water were added to each centrifuge tube and these were allowed to stand at room temperature (19° C.) for 24 hours in order to completely hydrate. This sequence was repeated 25 times.

At the completion of the alternation of moisture conditions, the pollen mixtures were dehydrated using 95 and 100% ETOH and transferred to the mounting media (1000 cs silicon oil) by Tertiary Butyl Alcohol (TBA) for analysis by Transmitted Light Microscopy (TLM).

Specimens for examination by Scanning Electron Microscopy (SEM) were stored in 100% ETOH and dried using the critical point drying method of Lewis and Nemanic (1973). After the specimens were dried, they were mounted on aluminum stubs, coated to a thickness of 200 A with gold palladium, and examined using a Joel-JSM U35 Scanning Electron Microscope.

During the analyses of these specimens, the degradation categories of Cushing (1967) were used. These categories were: 1) nonaffected or normal; 2) broken; 3) corroded; and 4) degraded. Each grain was first identified to taxon and then placed into one of the four degradation categories. Normal grains were defined as those having no observable evidence of deterioration. These grains were easily recognized since they were in pristine condition and structurally intact. Category 2, broken grains, included those in which the exine had been ruptured. Included also within this category were those grains with small tears as well as those with almost continuous splits along the surface. The phenomenon of "pitting" appears as small punctures on the surface of the exine; it was included within category 2 since, structurally, the pitting is a rupture of the exine. However, Cushing (1967) included this phenomenon within category 3, corroded.

TABLE IV: POLLEN TAXA USED IN WETTING/DRYING EXPERIMENT

Zea mays	Corn
Pseudotsuga sp.	Douglas Fir
Populus alba	White Poplar
Picea pungens	Colorado Blue Spruce
Pinus edulis	Pinyon Pine
Quercus virginiana	Virginia Live Oak
Artemisia sp.	Common Sagebrush
Juniperus monosperma	One-Seeded Juniper
Salix nigra	Black Willow
Iva sp.	August Marshelder
Carya illinoiensis	Pecan
Amaranthus sp.	Careless Weed
Typha latifolia	Cattail

Corroded and degraded grains (categories 3 and 4) are very similar in the type of degradation exhibited. Corroded grains can be distinguished since they have a noticeable thinning of the exine surface so that the aperture, although less distinct, is still intact. Degraded grains, on the other hand, show an advanced stage of deterioration in which the grains are severely thinned and in many cases remain only as ghost images with apertures no longer distinct.

RESULTS

The thirteen pollen taxa used in this experiment were subjected to 50 alternating changes in moisture content in order to determine the effects of this environmental parameter on the pollen exine. Originally, I had intended to sample this mixture at various time intervals throughout the study. However, several problems with the mixtures prevented this approach.

A major difference between the reactions of acetylated and unacetylated samples was immediately noticed. After the samples had dried and rehydrated with autoclaved water for the first time, it was noted that the unacetylated pollen samples had hydrated completely and no clumping of the pollen grains had occurred, while the acetylated samples had clumped into a very compact pellet after the initial drying at 80°C. After rehydrating for 24 hours at room temperature, the acetylated pollen was still clumped. No attempt was made to artificially break up this aggregate, however, because of the unknown effects of using chemicals or ultrasonic vibration on the pollen exine. Since I was investigating the effects of moisture, I did not choose to introduce an additional variable into my research design by artificially breaking up this clump of pollen. Rather, instead of adding sterile water on day 50, a 5% solution of sodium phosphate (Na_3PO_4) was added to each centrifuge tube containing the pollen mixtures. This chemical acts as a deflocculent and should have disaggregated the clumped pollen. The single use of this weak solution was not thought to alter the integrity of the experimental design. This solution did succeed in breaking up the clumped pollen to a certain extent, but not completely. Again, I decided against the use of stronger chemicals for the above reasons. The samples were prepared for examination by TLM and SEM as explained earlier.

The severity of this clumping occurred only with the samples which had been acetylated. Quite possibly this was a result of the chemical reaction of residues from the acetolysis, but it is only speculative.

The effects of wetting and drying changes of these pollen mixtures had a much more demonstative effect on the pollen exines than did a similar study investigating changes in temperature. Only 11.7% of the acetylated pollen and 18.3% of the unacetylated pollen were degraded in control samples examined at the start of the study. After 50 changes of moisture, 69.8% of the unacetylated and 83.2% of the acetylated pollen were degraded. This drastic increase in percentages of degraded pollen suggests that the environmental factor of moisture plays an extremely important role in the eventual preservation of the pollen exine.

Pinus (Plate 6 A & B) was usually preserved fairly well (Plate 6 A) but occassionally showed evidence of severely collapsed bladders and a crumpled configuration of the cappa. *Picea* sp., belonging to the Vesiculate (having bladders) morphological class of pollen, like *Pinus* sp., also evidenced this same pattern of deterioration. In many cases, however, the bladders were intact yet the cuppula was ruptured along the region of the germinal furrow (Plate 6 C). In other cases, the entire grain was folded and collapsed. *Pseudotsuga* sp. (Plate 6 D), a thin-walled member of the Coniferophyta (Pinaceae), was generally broken, as were pollen grains of *Juniperus monosperma* (Cupressaceae) (Plate 7 A).

Amaranthus sp. appeared quite often in a broken condition (Plate 7 B) and also very commonly was crumpled. *Populus alba*, another thin-walled grain, likewise revealed evidence of degradation. The most severely altered grains of *Populus alba* (Plate 7 C) revealed evidence of both rupturing and crumpling.

Carya illinoiensis, which in most examples was found to preserve rather well, was severely distorted (Plate 7 D). Zea mays also was very crumpled (Plate 3 A), but no evidence of actual rupturing of the exine was observed.

The two genera of the Compositae family (Iva and Artemisia) both preserved very well. However, there was some observed distortion of the exine of both taxa (Plate 8 B&C).

Salix nigra showed some evidence of a slightly different type of degradation. The exines apparently weakened along the plane parallel to the aperture, resulting in the exine collapsing in on itself, giving the appearance of an elongated pollen grain (Plate 8 D; Plate 9 A).

Quercus virginiana was virtually unaffected (Plate 9 B), whereas Typha latifolia exhibited a great deal of crumpling and corrosion (Plate 9 D). Often in these grains, the entire tetrad was collapsed and there appeared to be a general weakening of the cohesion of the tetrad members (Plate 9 D), resulting in the grains starting to pull apart. This may in part be a result of the heating of the sample to 80° C during the evaporation, which causes a chemical reaction between the cohesive agent of the tetrad and the head acting as a catalyst. This reaction quite possibly was the result of changes in the temperature and not the temperature itself.

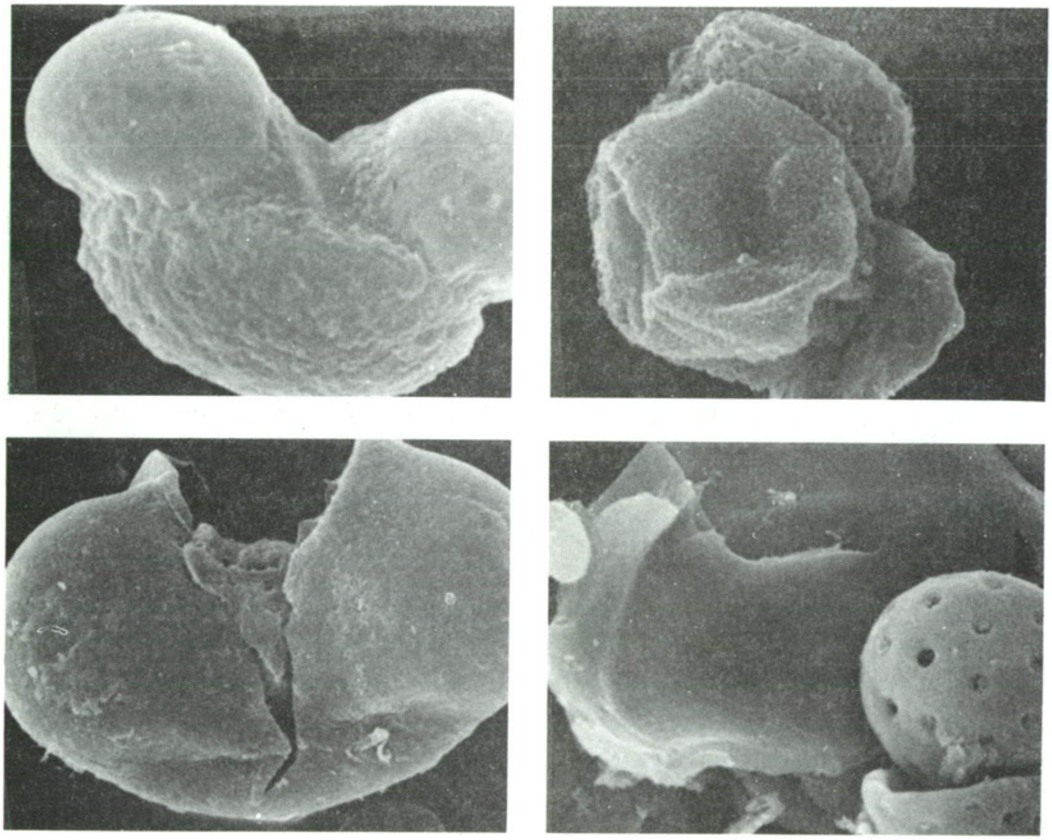

PLATE 6

A	Pinus edulis	unacetylated	2000X
B	Pinus edulis	unacetylated	2400X
C	Picea pungens	unacetylated	860X
D	Pseudotsuga sp.	acetylated	2000X

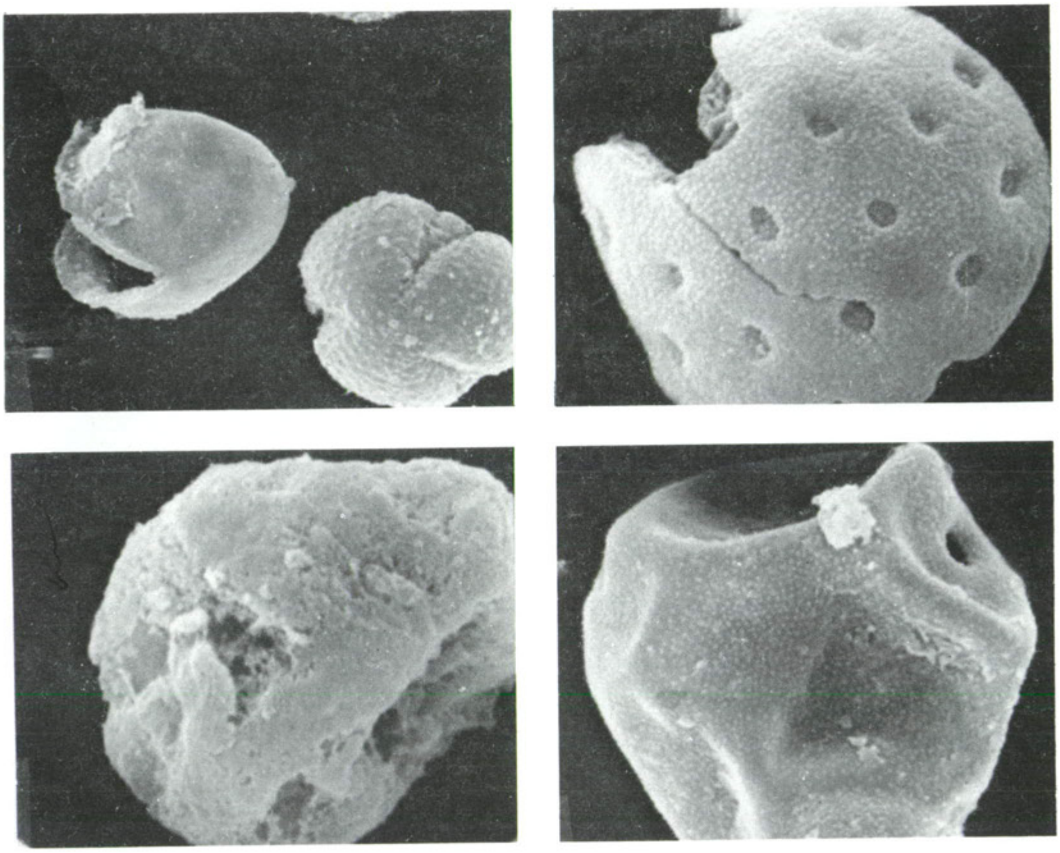

PLATE 7

A	Artemisia sp. and Juniperus monosperma	unacetylated	2400X
B	Amaronthus sp.	acetylated	1800X
C	Populus alba	unacetylated	4000X
D	Carya illinoensis	unacetylated	1800X

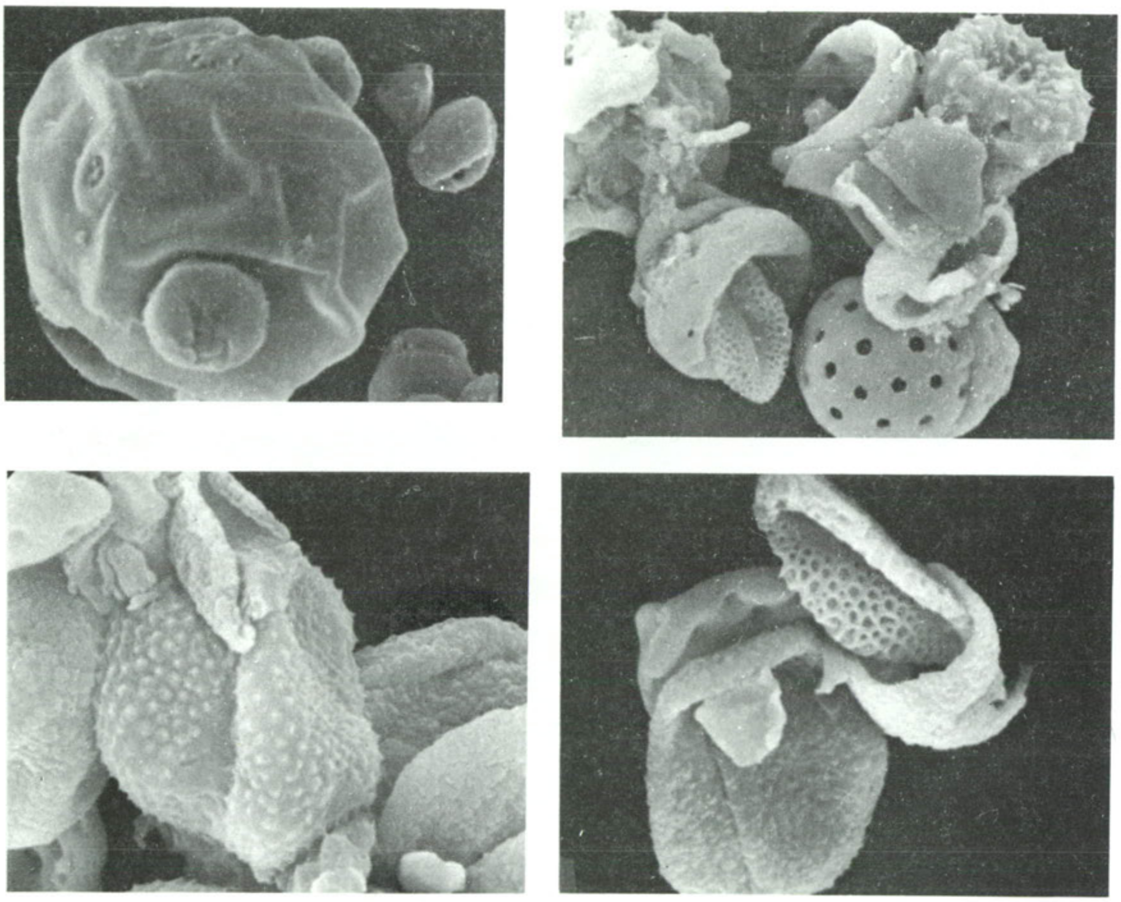

PLATE 8

A	*Zea mays*	unacetylated	940X
B	Group	acetylated	1600X
C	*Artemisia* sp.	acetylated	3000X
D	*Salix nigra*	acetylated	2400X
	Juniperus monisperma		
	Populus alba		

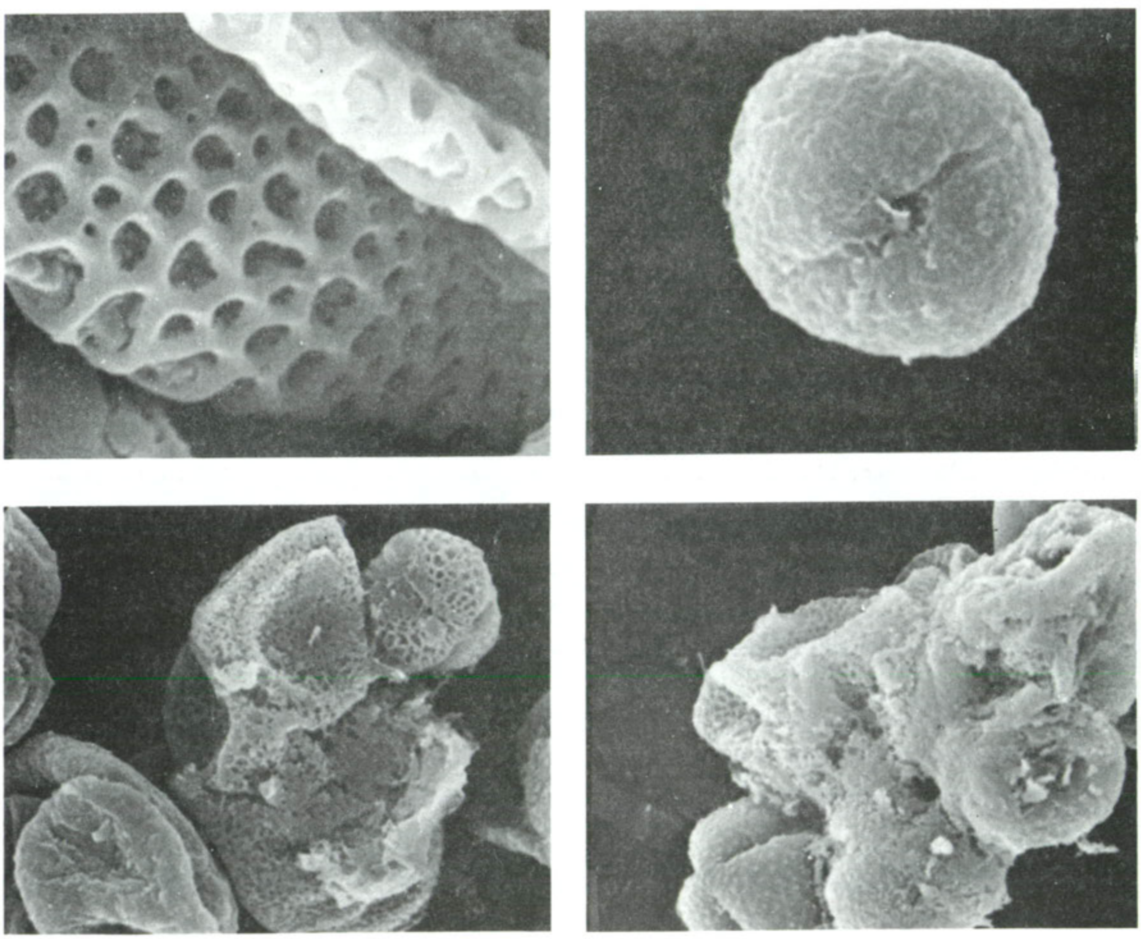

PLATE 9

A	*Salix nigra*	acetylated	9400X
B	*Quercus virginiana*	unacetylated	3200X
C	*Typha latifolia*	unacetylated	1800X
D	*Typha latifolia*	unacetylated	1600X

DISCUSSION

The results of this experiment have shown a great deal of destruction of the pollen exine as a result of the alternation of moisture/dry cycles. A similar study by the author indicated that variations in temperature (i.e., freezing and thawing) have little or no effect on the preservation of the pollen exine.

At least a partial explanation for the amount of damage to the pollen exine encountered in the present study may lie with the high pressure which accompanies the evaporative process in changing from a liquid to a gaseous state. As Burstyn and Bartlett (1975) have explained, a cylinder only 10 cm in diameter (such as microvilli), if allowed to air dry after saturation, would have over 28 atmospheres of pressure applied to the surface during the evaporation. While the pressure would probably not be quite this high on the pollen surface due to its morphology, the evaporative pressure could very easily act to severely distort the surface shape of the pollen grain.

The results of this experiment have demonstrated several applications for archeological research. In the American Southwest the climate is characterized by alternating periods of precipitation and aridity. According to Martin, "Summer rains (May-October) account for 60 to 70 percent of the annual precipitation in southeastern Arizona and over 70 percent in eastern New Mexico" (Martin 1970:3). Palynological preservation is known to be rather poor in most of the American Southwest (Bryant 1969; Martin 1970; Hall n.d.).

As Bryant (1969), Hall (n.d.), and my own studies (Holloway, this volume) have shown, pollen preservation is a function of a combination of factors. The southwestern United States is also characterized by soils containing a high pH. Dimbleby (1957) observed that pH is an extremely important factor in pollen preservation. However, the southwestern United States contains both these factors (high pH and moisture content), which potentially act on the pollen exine against its preservation.

In addition, the present study has provided data on the preservation of palynomorphs from archeological sites which have been inundated. The effects of weathering and biological activity on the pollen exines in completely submerged environments, as evidenced from the data recovered from Brady Reservoir (Holloway, this volume), are very minor in comparison to the effects observed in this present study. This does not imply that the degradation of samples in Brady Reservoir was minimal only that the samples in the wet/dry cycle experiment were more highly degraded.

While the preservation of palynomorphs is usually not good in inundated archeological sites, this study has indicated that the location of the site in relation to the reservoir is also important. For example, if a site is located in an area of the inundated region which is constantly submerged, the pollen, while being damaged, will be less so than in sites which are alternately wet and dry. These latter sites, usually located on the periphery of reservoirs, are exposed to wet/dry cycles as the water level of the reservoir changes. These sites will most likely exhibit a marked decrease in the amount of pollen preservation in a very short period of time. It is within these sites that the preservation of palynological and perhaps other botanical and/or organic data will be most seriously affected.

CONCLUSIONS

The effects of abrupt changes in the moisture content appear to have a pronounced effect on the preservation of the pollen exine. This damage is primarily of a mechanical nature and consists of crumpling, folding, or breaking, although a large frequency of corrosion was evident during examination of the samples by TLM. A possible explanation of this type of degradation is correlated with the amount of pressure generated by the evaporation of water from the pollen surface. On the basis of these data, it is suggested that inundated archeological sites subjected to occasional or seasonal drying will exhibit large amounts of palynomorph degradation or even loss of entire taxa within a relatively short period of time.

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THE MECHANICAL TESTING OF POTTERY SHERDS

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Materials and their various properties are of great concern to nearly all branches of the engineering and scientific community. In general, the testing of materials may be performed with one of three objectives in mind: 1) to supply routine information of the quality of a product (commercial or control testing); 2) to develop new or better information on known materials or to develop new materials (materials research and developmental work); or 3) to obtain accurate measures of fundamental properties of physical constants (scientific measurement). It is important at the outset to determine into what category the specific test falls. Selecting the proper test category often defines the type of testing and measuring equipment to be used, the desired precision of the work, the character of the personnel to be employed, and the costs involved.

The evaluation of pottery sherds presents an interesting and challenging type of material test. This test is classified as materials research, the primary purpose being to obtain a better understanding of a known material. It is the purpose of this paper to present a brief introduction to the general features of mechanical behavior and the standard tests used to evaluate these features. An examination will also be made of the special problems encountered in testing a material with as many relevant variables as pottery.

Mechanical properties may be specifically defined as those having to do with the behavior of a material under applied forces. The fundamental mechanical properties are strength, stiffness, elasticity, plasticity, and energy capacity. Before each is discussed, it should be pointed out that these properties are expressed in terms of quantities that are functions of stress or strain, or both. Stress is defined as the intensity of the internal forces that resist a change in the form of a body. Strain, on the other hand, is defined as the change per unit length in a linear dimension of a body. This length change accompanies a change in stress. In mechanical testing the primary measurements of load and change in length are translated into terms of stress and strain through consideration of dimensions of the test specimen.

The strength of a material is measured by the stress at which some specific limiting condition is developed. The principal limiting conditions, or criteria of failure, are the termination of elastic action or rupture. Elasticity refers to the material property in which deformations caused by stress disappear upon the removal of the applied forces. Rupture refers to the stress at which the material completely pulls apart and fails. Hardness, usually indicated by resistance to indention or abrasion, may be considered a particular type of measure of strength. Stiffness deals with the magnitude of deformation which occurs while a material is under load. Within the range of elastic behavior, stiffness is measured by the modulus of elasticity, meaning the ratio of stress to corresponding strain. Plasticity is the term used to indicate the ability of a material to deform in the inelastic range without rupture. The ability of a material to absorb energy depends upon both strength and stiffness. Energy capacity in the range of elastic behavior is termed resilience, and toughness refers to the energy required to rupture a material.

There are three classifications of test conditions: 1) the condition of the material or specimen itself at the time of the test; 2) the conditions of the surroundings during the progress of the test; and 3) the manner in which load is applied. In mechanical testing, the method of loading is the most common basis for classification. Three factors define the manner in which load is applied: the kind of stress induced, the rate at which the load is applied, and the number of times the load is applied.

When discussing the stress condition to be induced on a specimen, there are five primary types of loading: tension, compression, direct shear, torsion, and flexture. In tests of tension (a pulling apart of the specimen) and compression (a "squeezing" together of the specimen), an axial load is applied to the test specimen so as to obtain a uniform distribution of stress over the critical cross section. In shear tests, an attempt is made to obtain uniform distribution of stress. A shearing stress is one that acts parallel to a plane, as distinguished from tensile and compressive stresses that act normal to a plane. A torsion test twists, or rotates, a specimen which is usually circular in cross section. In flexture tests, both tension and compression are involved. A beam in bending is an example of this type of test.

Tests involving the rate at which load is applied are classified into three groups. A static test is one in which the load rate is slow enough that the speed of testing can be considered to have a negligible effect on results. A large majority of tests fall into this category.

Dynamic tests are carried out with the load being applied very rapidly. Impact tests call for the load to be applied suddenly in the manner of striking a blow.

Two basic classifications are made when dealing with the number of times load is applied. Most tests involve the load being applied once to the material. Fatigue tests, however, call for the load to be repeated many times. The purpose of this test is to determine the fatigue limit of the material or of an actual part.

In addition to loading conditions, consideration must be given to the state of the specimen at the time of loading. Normally, tests are conducted at normal atmospheric or room temperatures. However, because of the conditions under which the material will be stressed while in actual use, some tests are run at varying ranges of temperature.

Before actual testing begins, a great deal of attention must be given to the manner in which the specimen is held, gripped, or supported in the different types of test apparatus. For common materials such as steel, wood, and concrete, the American Society for Testing and Marials (ASTM) has set forth standards for material specifications and methods of testing. These standards not only make the job of testing easier, but results can be compared to similar tests run throughout the world.

The preceding paragraphs serve as an introduction to material characteristics and their testing. As stated earlier, the testing of pottery sherds presents a unique and challenging undertaking, primarily due to the variable nature of the sherds. Size and material composition are the two main variables which make testing difficult.

Many times the size of a specimen will determine what types of tests can be performed on it, and directly related to the test is the piece of apparatus used to conduct it. The specimens for this particular investigation range in size from several inches square to only a few millimeters in length. It is obvious that due to the specimen's size and the relatively low strength of the pottery itself, large apparatus cannot be used to determine its properties. These facts, therefore, rule out the two most common tests, tension and compression. Standard apparatus used to perform these types of tests have the capacity of applying thousands of pounds load. In other words, equipment at the University of New Mexico Engineering Laboratory is "over-sized" for testing the low tensile and compressive strength of the pottery.

If smaller load capacity apparatus were available, another consideration must be given to the time and cost involved in preparing the test specimen. Both tension and compression tests require a constant critical cross section of the specimen. In compression testing it is also of considerable importance that the specimen have flat, smooth ends. As a result of the great variability in size, texture, and shape of each sherd, considerable expense and preparation time would be necessary. Again, because of each specimen's size and shape, the load capacities of apparatus, and the time required to prepare specimens, tests such as torsion, shear, and flexture are not feasible.

As stated earlier, one measure of the strength of a material is its hardness. The topic encompasses many diverging areas of testing and analysis of results. There are basically five types of hardness: indentation hardness (resistance to permanent indentation under static or dynamic loads), rebound hardness (energy absorption under impact loads), scratch hardness (resistance to scratching), wear hardness (resistance to abrasion), and machinability (resistance to cutting or drilling). The most common type of hardness test involved indentation of the material.

One important point to consider when discussing hardness is that no single measure of hardness universally applicable to all materials has yet been devised. Also, no method of measuring hardness uniquely indicates any other single mechanical property. For example, some hardness tests seem to be more closely associated than others with tensile strength. Some, however, are closely related to resistance or ductility. Therefore, a given hardness test is of practical use only for comparing the relative hardness of similar materials. Because of the size of the sherds and their unique composition, it was initially felt that a hardness test would be the only practical means of examining the material characteristics of the various specimens. This was primarily due to the fact that the load and measurement capacity of the hardness tester is small and accurate enough to detect and record the relatively low strengths of the sherds. Before testing began, it was hoped that the hardness test could be used to "grade" each sherd type, and then a comparison could be made utilizing the different values.

The type of instrument used to conduct the test incorporates the fundamental concept that hardness is measured by the resistance to indentation. The indentor is a small ball made of hard steel or diamond. The load that produces a given depth of indentation is accurately measured. The load is, in turn, converted to a hardness scale which is distinct for each type of apparatus. A Rockwell Hardness Tester was used to conduct the research on the sherds.

Several problems arose when using the hardness tester. First it was discovered that the tester's minimum load capacity was too heavy for some of the sherds. Several types shattered when the load was applied. When this occurs no hardness reading can be obtained. Secondly, it is recommended that test specimens be flat and smooth. Due to the variability of the fragments, smooth, flat test specimens were sometimes impossible to achieve. When a flat specimen cannot be used, complex stresses occur in the piece being tested. These stresses are difficult to analyze, and the hardness value obtained is variable and subject to question.

A great deal of variability in hardness values was found for similar pieces. These differences can be traced to the fact that even among similar sherds, the composition is not consistent. For example, a high hardness value would be obtained if the reading was taken in the vicinity of a pebble or rock. This value, in turn, could not be characterized as being representative of the entire piece. It is obvious that lengthy testing would be required to obtain representative hardness values for the various sherds, and averages would not reflect changes which occurred in the wet/dry test sherd relative to the control half.

Another point to consider is that several of the sherd types have very strong glazed finishes. On careful examination of each test, it was determined that the steel ball was not penetrating the glazed exterior. In effect, the hardness value obtained was a measure of the exterior surface and not of the pottery clay itself. This fact can make comparisons difficult between pieces with glazed exteriors and those without.

In general, it can be concluded that the mechanical testing of pottery sherds is difficult and time consuming, and the results are inconclusive and unreproducible. The above discussion points to the fact that tests conducted on a variable material such as pottery must be of a nondestructive nature.

NOTE: The book, The Testing and Inspection of Engineering Materials, by Davis, Troxell, and Wiskocil, served as the reference for the above text.

THE APPLICATIONS AND LIMITS OF UNDERWATER ARCHEOLOGY FOR MITIGATING IMPACTS TO CULTURAL RESOURCES IN RESERVOIRS

by
Larry Murphy

This report was written in order to familiarize resource managers and archeologists with current technical capabilities in underwater archeology.

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INTRODUCTION

As indicated in the Volume I (Chapter 5) of this report, underwater archeology should not be seen as an acceptable alternative to pre-impoundment data retrieval efforts, although it does have real potential as a mitigation tool in other ways.

There are many impoundments in the United States that were constructed and filled before federal antiquities and environmental legislation ensured reasonable mitigation of impacts to cultural resources. Consequently, significant archeological remains which may represent a complete aspect of certain prehistoric activity patterns may be intact in a reservoir.

In some cases, all significant vestiges of a particular cultural horizon may be tied to the lower contours of a drainage, now submerged. Such a situation makes it incumbent on archeologists and contracting agency representatives to understand the application, range, and limits of existing underwater technology. This becomes particularly germaine if some construction activity or change in dam operating guidelines results in a raising or lowering of the existing pool. The building of another large dam downstream that would result in significantly raising the pool level, perhaps by topping the old dam, for example, would make sites in the old pool deeper and less accessible to standard underwater archeological recovery techniques. If there were knowledge or suspicion of significant resources being further isolated, it might be advisable to conduct some testing or limited excavation on the submerged areas before increased depth or turbidity made this a less practical option for underwater specialists.

Significant lowering of an existing pool may also call for underwater investigation of a site. Sometimes large sites were flooded by a dam in such a way that minimal impact could have been expected; the area was one not subject to heavy wave action; the pool rise was quick; and the existing vegetation acted as a reasonable buffer to mechanical disturbance while the high energy level band passed quickly over it. A new action, such as lowering the pool, may be much more traumatic to the intact remains. If the pool were lowered slowly, and the high energy beach zone over the saturated soil matrix left unprotected by a vegetative mantle, much greater deflation of the area would be expected with subsequent impact to archeological remains. In such cases, the use of diving technology should be considered to gather baseline data before the site integrity was further compromised.

Underwater archeology is simply archeology done underwater; the theory, methodology of data collection, and interpretation of underwater sites vary little from terrestrial archeology. There are some techniques of site location, testing and excavation peculiar to underwater archeology, resulting from the conditions imposed by this environment, but this is not sufficient justification to consider underwater archeology a separate or unique discipline.

This technical report is designed to present a brief outline of the uses and limits of state-of-the-art underwater archeology and potential applications in a reservoir environment in order to familiarize resource managers and archeologists with some current technical capabilities. It is not intended as a "how to" report, but addresses more the question of "what can be done?" In all cases, principal investigators should look to underwater archeological specialists to carry out the actual work.

A concept considered basic to all underwater archeological endeavors is, that simply because a site is underwater is not reason enough to employ an approach which would be considered substandard if instituted on a dry archeological site. The present state of the art in underwater archeological techniques is such that in virtually any conditions likely to be encountered on an underwater site, at least the same level of data can reasonably be collected comparable to a similar site excavated on land. However, underwater archeology is more expensive and slower, as a result of the environmental constraints, than a comparable land project.

In certain states the principal investigator may get assistance from the office of the state archeologist on underwater problems. In any case, advice may be obtained from the Advisory Council on Underwater Archeology or the Submerged Cultural Resources Unit of the National Park Service.

There are three main areas of consideration in the application of underwater technology to cultural resources research in reservoirs. The first is location and survey of sites while maintaining an accurate geographic location. This survey and "positioning" function is more complex when dealing with submerged sites, particularly because the margin of acceptable error is much smaller. This report first addresses the survey and positioning functions, emphasizing remote sensing and electronic postioning as tools. The other two overlapping functions, rendered discrete for purposes of this presentation, are mapping and photographic/videographic documentation, and mechanical retrieval of data through removal of overburden (coring, excavating, survey and positioning).

SURVEY AND POSITIONING

Inundation Study researchers have been made painfully aware of a fundamental problem in archeological mapping techniques during the course of the five-year study. Many sites have not been relocated after inundation due to inaccurate plotting of sites on original base maps and the lack of fixed stations beyond the existing flood pool.

Accurate positioning is important in reservoir areas for survey and relocation of sites. Postioning systems are either optical or electronic and often costly, but are necessary if relocation of sites and monitoring programs are to be successful. Some considerations for determining the most appropriate positioning system required are:

1. Personnel required for operation.
2. Number of plotted points produced per transect -- some survey requirements necessitate continuous plot, others do not.

3. Accuracy of system should be commensurate with survey objectives.

4. Cost.

Electronic Systems

The needs of the offshore oil survey industry have generated a number of electronic positioning systems. Generally, they were developed to overcome the limitations of optical systems, which are: 1) only line of sight operation 2) effective only in time of good visibility 3) slow individual fixes and high potential for human error.

Electronic positioning is normally done from two stations which transmit radio waves. These radio stations transmit wave patterns which, when received on board a vessel passing within the lattice produced, give a continuous position of the vessel relative to the shore station datums. When the position of the shore stations is known, the data generated on board can be converted into geographic coordinates (range-range to x-y) with a high degree of accuracy -- usually at least ± 1 meter. As the data is generated it can be fed directly into an on board computer to provide a direct readout on an x-y track plotter. This capability can give real time position data, allowing the helmsman to follow closely a prescribed course on the plotter or permit accurate relative lane spacing to prevent gaps in the survey record.

Site Relocation

Sonar pingers, usually within the 8-50KHz frequency, can have a range of one-half to five miles and an installed battery operation life expectancy of up to five years. A surface vessel approaching the area uses a highly directional antenna mounted underwater for relocation. The directional antenna is swept in arcs until the loudest tone is received, giving the direction for the vessel to proceed to the pinger location. A variation of this device is produced in a diver-held unit which uses lights or sound to indicate the direction to the pinger itself, allowing the diver to return exactly to the pinger location with minimal effort.

A variation on the continually pulsing pinger is the "call pinger." This device is silent until activated from the surface by means of a vessel mounted transducer. An advantage of the call pinger is that it can be coded to answer only a specific interrogatory frequency, applicable when security considerations prevail. By responding only on signal, battery life can be extended, and the coding feature can allow one specific pinger to be activated when a number of pingers are used to relocate specific features within a site, even under conditions of reduced visibility.

Optical Systems

The use of sextants to turn horizontal angles from shore-based targets has proven effective in Florida and the Mediterranean (Green 1973). Inexpensive plastic sextants can be read consistently to an accuracy of ± 5 minutes of angle. The angles can be plotted on base maps which include the surveyed positions of the land datum targets. At least three datum targets are needed to produce the two intersecting angles required. Relocation of a particular point on the water with sextants poses some difficulty for an inexperienced operator since arcs must be followed by the boat pilot. The use of two sextants, one to hold the boat on the arc of one fix and the other to determine the location of the second fix on the piloted arc, may expedite relocation.

A relatively inexpensive optical system set up by Clausen and Arnold (1976), and used by Garrison et al. (1978), similar to a system devised in Florida in 1969, was used to survey two sites for a total of 135,000 m^2. The system used two sets of range markers for course alignment and position. The survey vessel course was run with a transit operator assisting by radio communication with the boat pilot in maintaining a straight course into shore. As each of the double range poles comes into alignment, the event marker on the instrument chart readout is marked, giving relatively accurate midtransect positions which allow accurate plotting of survey data.

Two transits can also be used for positioning. The survey vessel is guided on a prescribed course, by radio, toward a transit set up on shore. The second transit tracks the movement of the vessel and periodically records the angle from the baseline between the two stations of the vessel position to the boat. There are limits to the accuracy of this system and the number of possible plots per transect. Analog readouts of survey equipment can be coordinated with the transect plots through radio contact with the tracking instruments. The data can be post-plotted quite accurately. In some applications the advantages of ease of operation and fast set-up time, in addition to the necessity for only minimally trained survey personnel for the operation of this system, make it a practical choice within its limits.

Repositioning with the dual transit system is fairly easy. The guide transit is set up on the proper transect lane and the desired angle is turned from the baseline on the second instrument. The vessel starts toward shore guided by radio contact with the transit operator from beyond the estimated position on the lane. When the vessel enters the field of view of the second transit the boat is alerted so that a buoy may be dropped on the desired position when the vessel is aligned with the crosshair.

Two transits can be used to track a vessel during a random search. Radio control between the transits and boat allow a position to be obtained at a signal from the lead transit operator or at the wish of the vessel crew. Both transits record their angle from the baseline at the same time. An event mark is made on the data readout at the same time a transit position is made.

UNDERWATER REMOTE SENSING

Magnetic Survey

The principal and largest anomalies on any site are usually due to the presence of ferrous material, although magnetic disturbances have many origins in an archeological site. Detectable anomalies are not limited to iron. Subtle magnetic disturbances can be caused by archeological features which produce a contrast between occupation zones and the soil rock or water matrix surrounding them. Archeological features can be detected by both a decrease as well as an increase in total field output, e.g., basalt rocks can be detected in a sand matrix by the increase in magnetism noted, while a sandstone wall covered with humus-rich soil or magnetite-rich silt can be detected by a decrease in intensity at the wall location (Briener 1965, LeBorgne 1955).

The most significant magnetic property of archeological features (except the presence of ferrous material) is thermoremanent magnetism. Thermoremanent magnetism occurs when a material containing some magnetic mineral is cooled after being heated to a high temperature (usually above the Curie point) (Briener 1965). This heating allows orientation of some of the magnetic crystals parallel to the earth's ambient field, creating a net magnetic effect. Potsherds, brick, kilns, fire pits, and roofing tiles exhibit detectable thermoremanent magnetism.

The suggestion that thermoremanent magnetism in the clay of a pottery kiln could probably be detected by a magnetometer was made by J.C. Belshe in 1957; an effort to test that suggestion with a proton magnetometer was carried out successfully in 1958 (Aitken et al. 1958). A Romano-British kiln was located which exhibited no surface indications, and it was noted that other features such as filled in pits could also be detected.

There are three basic techniques for the location of thermoremanent archeological features. The first is to have the sensor head transported over a transect slowly enough to detect magnetic anomalies. The second technique is to use the magnetometer in a single sensor mode. The area to be surveyed is gridded appropriately depending on the size and depth of features expected, and the sensor is then placed on the desired coordinates. It should be pointed out that the closer the sensor is to the ground, the more probable will be noise caused by small ferrous debris (such as nails or wire) on the ground surface.

The third possibility for sensor deployment is in a differential or gradiometric mode. The basic criterion for isolating archeological features from geological ones is a relatively sharp change of magnetic intensity in a short distance (usually a foot or so). In this mode the magnetic gradient is more important than the anomaly intensity. Two sensors are used for gradiometric detection. The dual sensors may be affixed to a pole at different heights or one sensor may remain stationary at the height of the mobile detection head. The reading is of the difference in the magnetic intensity or the average gradient over the distance between the heads.

The overall accuracy of a survey of this nature can be influenced by a number of conditions. Remanent magnetism is also a property of natural rocks which have been heated and cooled, such as volcanic or igneous rocks. Rocks in high concentration or as underlying strata may make magnetic survey in some areas impossible. In the absence of naturally occurring rocks of this nature, however, intrusive cultural features made from rocks with magnetic properties can be located. Examples are basalt metates or even statuary (Briener and Coe 1972:514).

Diurnal variations can complicate magnetic survey. These solar induced short duration variations can complicate the separation of spatial anomalies from the data during periods of solar activity. There are a number of ways to compensate for this phenomenon. A constant value can be added or subtracted to each point on a given line to make the average value of that line equal to the average of the entire grid (Briener and Coe 1972:573). Another method would be to set up a second stationary magnetometer similar to the mobile survey instrument and record both readings at each point. The variations of the stationary instrument would be due to diurnal variation and readily added to, or subtracted from, the survey instrument readings as required. The important point is that personnel familiar with magnetic survey for archeological features should be consulted when determining the applicability of the technique to the specific site conditions.

These techniques have not yet been tried underwater to locate prehistoric features, although an unsuccessful attempt was made on a Roman shipwreck near Campo Marina on the Ionian Coast of Italy to locate potsherds and amphora in the silt near a shipwreck with a rubidium magnetometer (Breiner 1965). There are no other reported attempts to locate thermoremanent archeological features underwater in the generally available literature, however, this could be a viable remote sensing technique for location of features of this type. Highly sensitive magnetometers used in the gradiometric mode would be capable of locating hearths and firepits, walls and ditches, kilns, filled in pits, or concentrations of ceramics or baked rocks.

Limitations of this procedure underwater are similar to those expected on land. For a pit or ditch to show up magnetically, the material filling the cavity must be different than the surrounding matrix. Features dug into the subsoil and filled with topsoil or silt could be detected, whereas those artifically filled might not be. Features as small as 15 inches deep and 3 feet across have been located, and a feature 18 inches across and 14 inches deep filled with magnetically contrasting soil gave a strong anomaly (Aitken 1959).

The technique of using the magnetometer as a gradiometer is an effective one. Briener (1965) used a multilevel survey with the magnetometer set at different heights to produce a vertical gradient which enabled researchers to resolve broad anomalies into their separate sources.

A comparison of the resistivity survey to proton magnetometer survey was carried out in Tar Quinia, Italy (Lerici 1961) during a search for Etruscan tombs of the sixth to third centuries B.C. These tombs were in sedimentary deposits of shell limestone at a depth of 3 to 6 meters. It was found that the magnetometer accurately detected all but 1 of the 11 tombs in the survey area, while the resistivity survey detected seven.

Metal Detectors

Underwater metal detectors are useful on inundated historic sites to locate small metallic artifacts beneath the sediment. One of the first applications of these devices in underwater archeology was by George Bass during the Cape Gelidonya wreck excavations in 1960 (Bass 1966). A metal detector survey carried out on the Spanish Armada expedition in 1969 demonstrated the ability of the detector to locate ferrous and non-ferrous metal objects up to a depth of two feet below the surface (Green and Martin 1970). Recent models have increased detection and discrimination circuitry.

Metal detectors are a useful adjunct to magnetometry surveys because they allow divers to pinpoint buried magnetic sources for evaluation. The detector is able to pick up small metallic objects invisible to the magnetometer during the survey, and aid in determination of extent of site scatter.

Side Scan Sonar

Side scan sonar employs sonar transducers mounted to scan the bottom laterally with a vertical pan of high frequency sound. The operation generates micro-second pulses at fraction-of-a-second intervals: with a receiving phase following the interval of sound generation. The device measures variations in acoustic backscatter reflecting from the bottom surface and protruding objects, and records these variations on a chart readout as intensity of line darkness vs. time of return of the reflected sound from the object. Areas of high reflectivity are recorded as dark lines and shadow areas. Those areas not returning a signal are white. Range of frequency for operation are from 100HKz to more recently developed high resolution units employing 500HKz.

Potential Uses of Side Scan: 1) the detection and monitoring of submerged structures such as cliff dwellings, historic structures and mounds, 2) the determination of extent of debris over a site area which must be removed before testing and excavation begins, and 3) monitoring of bank slumping and erosion impact to site areas near the reservoir bank.

Side scan sonar, though producing an accurate topographic-like rendition of the bottom features, has certain limitations to be considered when specifying its use in a survey. The side scan should be towed at less than four knots; the faster the towhead is moving the narrower the readout recorded from an object and the more difficult the interpretation. A two-knot speed is preferable but survey time per area is, of course, greatly increased.

A second consideration is the width of area covered with each pass. Survey lanes should be set up for 50% overlap. The temptation would be to select the range of greatest coverage to partially compensate for the slow forward speed of the survey vessel, however, the shorter the widths of coverage, the higher the resolution. Resolution becomes quite important when trees, fences, and modern trash are to be differentiated from cultural features of archeological interest in the reservoir.

Sub-bottom Profiling

The sub-bottom profiler (or seismic profiler) is an instrument somewhat similar to the side scan in that it is an acoustical emission device. A low frequency sound is generated to penetrate the bottom sediment as well as the water. A variety of sound sources are used -- explosives, electric sparks, steam bubbles, compressed air, mechanical vibrators, propane-oxygen, etc. The low frequency sound penetrates the water column and the underlying strata and is reflected back to hydrophones and recorded on a strip chart recorder. The usual record from a sub-bottom profile shows travel time of the sonic wave with the record appearing much like that of an echo sounder or fathometer.

The sub-bottom profiler samples only a small area at a single pass. The area to be covered must be surveyed at very close lane spacing to provide full coverage. Palmer (1965) gives the best review of limitations of subbottom profilers.

The acoustical qualities of the bottom sediments and accumulated silt can interfere with the sonar record. A problem encountered by surveyors in Lake Chunyazche, Mexico (Farris and Miller 1977) is one that may beset reservoir surveys. It was found in this survey that although the bottom sediment was soft, it produced only multiple surface reflections due to the high gas content of the silt created by organic decomposition. U.S. Army Corps of Engineers survey crews from the Waterways Experiment station have reported similar problems in their riverine work to Inundation Study researchers. Currently there is no technology available to filter the noise problem. Penetration of certain clays and gravels can also be difficult and prevent the use of the sub-bottom profiler.

High resolution sub-bottom profilers can detect silted-in historic and prehistoric features. An accurate trace of the original ground surface can be generated due to the different densities of the overlying silt. The depth of silt and stratigraphic compaction can be monitored in known sites. Areas can be surveyed by the instrument to locate sites and features unrecorded before the reservoir construction.

Side Scan Interfaced with Sub-bottom Profiling: The coupling of side scan sonar to sub-bottom profiles can be used to produce what is essentially a three-dimensional map of an area prior to excavation or for monitoring purposes. The first production of a three-dimensional topographical map of this type preceded the excavation of King Henry VIII's vessel Mary Rose in 1966 (McKee 1973). The minimum depth of the sediment over the wreck varied between 5 and 15 feet. The sediment was mud and allowed clean penetration of the sonic waves. Had there been gravel and rock deposits the production of the map would not have been possible with current technology. Sites such as masonry structures that become covered with silt during the life of the reservoir can be monitored by this procedure and the production of three-dimensional maps would greatly facilitate excavation, should that course of action be desired.

Aerial Remote Sensing

Aerial remote sensing in reservoirs is a promising technique which may prove to be an effective addition to mitigation and monitoring plans. Archeologists have long been aware of aerial photographic techiques. As early as 1921 aerial photography was used at the Cahokia Mound Site in Illinois (Solecki 1960). Discussions of more recent developments in the use of aerial remote sensing in archeological applications are to be found in Lyons (1976), Lyons and Hitchcock (1977), Lyons and Mathien (1980).

The use of aerial photointerpretive techniques in underwater archeological applications occurred prior to World War II in the Mediterranean for examination of inundated ports (Throckmorton 1972). More recently these techniques were used during an archeological survey of Fort Jefferson National Monument by the National Park Service to locate shipwrecks on a shallow reef. Fischer (1974) and Lenihan (1974) reported the use of aerial photography as part of the survey designs for shipwrecks in other areas. The techniques of aerial photography have yet to be applied to reservoirs, but their use should prove beneficial to mitigation programs.

Small scale aerials are useful for synoptic overviews, and the largest scale photographs would benefit local monitoring and site survey applications. The scale of a vertical aerial photograph is a function of the height of the camera above the ground and the focal length of the camera lens. Proper scale for the specific use should be determined in consultation with those experienced in remote sensing specification.

Shallow inundated sites may be recorded with the use of the proper film/filter combination in many instances. Experimentation and experience are needed to produce the ideal combination for the specific reservoir conditions. (An assessment of the efficiency of water penetration and accurate bottom portrayal capabilities of various combinations may have to be done prior to the actual photography). There have been some limited experimentation and water penetration tests done for marine applications. Some of these are applicable to aerial reservoir photography.

Results of recent studies of the light transmittance of water basically agree that maximum transmittance in distilled water and clear ocean water occurs in the spectral range between 440 and 540 nanometers (nm) (Hulbert 1945; Clark and James 1939; Boller and McBride 1974). Duntley (1963) states: "Water possesses only a single important window . . . . near 480 nm unless it is shifted toward green by discolored yellow substances. . ." The shift toward green was reported earlier by Hulbert (1945) who noted a shift of peak transmission in coastal and bay waters towards the green wavelengths. This shift is due to the presence of yellow organic material which causes the shift in the peak spectral transmittance wavelengths and a decrease in the total transmittance. The peak transmittance for turbid waters occurs at a wavelength of about 550 nm.

One of the most comprehensive evaluations of the water penetration ability of film/filter combinations was by Lockwood et al. (1974). This group tested nine different combinations and reported that the best overall image was produced by Ektachrome EF Aerograph Film on a 4-mil base (SO-397) with a Wratten-3 filter for haze elimination. They generally found color imagery superior to black and white when a wide spectral range is present since the color is an aid to discrimination. Kodak Plus-X Aerographic film (2402) with a Wratten-21 and 57 filter combination was the most effective black and white film, roughly equal to the SO-397/Wratten-3 combination. Recent experimentation (Richards 1980) has demonstrated the utility of black and white high contrast copy film for water penetration. A new film, Kodak TP (technical pan) with an ASA of 100, may prove particularly useful. Additional consideration should be given to the use of high contrast film and processing with edge enhancement during analysis. Multi-lens cameras are useful for producing comparative images.

UNDERWATER MAPPING AND PHOTOGRAPHIC/VIDEOGRAPHIC DOCUMENTATION

MAPPING

Relatively accurate mapping of underwater archeological sites dates back at least to 1948 when the Underwater Study and Research Organization at Toulon, under the direction of Cousteau and Taillez, produced a plan of the Mahdia wreck (Taylor 1966).

The first recording of a stationary grid being used to control excavation was by Lambogila in 1958 on the Roman wreck off the island of Spargi near Sardina (Taylor 1966). The original 2x2 meter grid was constructed of yellow canvas tape. A rigid frame grid was found to be superior in the second season of excavation in 1959. The use of the rigid frame grid allowed accurate drawings and controlled excavation.

The use of a grid composed of equlateral triangles has been developed and applied to the excavation of prehistoric lakes in Europe by Laurent (Bocquet 1979). These lakes normally have only a few centimeters of visibility. Interlocking equilateral triangles five meters on a side were used to establish a reference grid. Each of these triangles was further subdivided into 25 small triangles 1 meter on a side. The triangles can easily be extended in any direction as excavation warrants. In one lake excavation a hexagon 30 meters in circumference was constructed with six large triangles and had a cumulative closure error of only seven centimeters. Instead of manipulating two perpendicular lengths to the side of a square grid, three tapes may be affixed to the apexes of the triangle grid to rapidly and accurately position a point.

Three tape trilateration is a slow procedure underwater, but it has a demonstrated accuracy of ± 0.5% (Green 1973). Three tapes are fixed to surveyed datum points and the desired point is measured using the three tapes. The process can be speeded up by the use of hardline communication to the surface with the data for each point recorded on the surface. A sketch map of the surveyed area with each numbered point located should be produced concurrently by another diver.

PHOTOGRAPHIC DOCUMENTATION

Photogrammetry

Due to time limits on site and the potentially huge number of measurements that must be taken for mapping and documenting, the use of photogrammetric techniques becomes practical and should be considered for underwater sites. Photogrammetric methods range from simple graphic obliques to precision mosaic photogrammetry utilizing specialized techniques. Graphic obliques, applicable to any underwater camera where visibility allows, will produce photographs from which many accurate measurements of an area may be obtained (Williams 1969).

Underwater mapping with the use of stereo pairs, suggested in the 1950's by Dimitri Rebikoff, was first applied to archeological data retrieval by George Bass (1964) during the excavation of the shipwreck near Yassi Ada at a depth of 120 feet. A horizontal bar was anchored and buoyed six meters above the site. A camera was suspended from the bar on gimbals, and photographs were taken at predetermined intervals to produce stereo-pairs of high resolution. In another application, the small submarine Asherah was fitted with synchronized 70mm aerial type cameras and used to produce stereo pairs of a late Roman wreck (Bass 1966).

Periodic photogrammetric views can accurately monitor site change and destruction over time to allow assessment of deterioration. Management decisions can be made about the need for the excavation of sites based on photogrammetric analysis.

Photomosaics have been used to record fairly large sites (3,000 sq. meters) with an accuracy of about ± 5% over distances of 20 m (Green 1973). A small site plan would allow an accuracy increase to about 1%.

Photogrammetry should be considered prior to the initiation of excavation of sites with visible features. The generation of photomosaics as the excavation continues can greatly enhance data collection during underwater excavation. Photogrammetry is particularly useful considering the time limits and stresses of diving in situations where structural features are common and proper recording could conceivably require hundreds of measurements. Photogrammetry can be a cost-effective approach to data recording on many submerged sites in reservoirs. Underwater photogrammetry is least effective in situations which involve high relief from the bottom of material and cultural features, and low visibility which precludes a high flight line.

Standard Still Photography

Since the first successful underwater photography by Louis Boutan in 1893 (Mertens 1970; Rebikoff 1972) photography has been a part of data collection and recording for underwater sciences.

The reservoir environment poses particular problems for underwater photography. Visibility is rarely good, often measured in inches due to suspended silt and organic matter. Although the optical characteristics of clean water and ocean water have been studied extensively, turbid conditions such as those expected in reservoirs have been practically ignored.

Attenuation of light occurs as it is transmitted through the water and does affect the quality of the photographic image. Attenuation is caused primarily by two processes: absorption and scattering. Absorption is the process by which the light photons are lost to the light beam. The actual amount of absorption depends on the distance of the light source - the farther the distance, the more absorption takes place. Scattering is the dispersal of light rays by suspended sediment.

The use of auxiliary light sources and wide angle lenses with highly sensitive film emulsions is necessary for successful (effective) photography in most reservoir situations. Various techniques and equipment combinations have been developed to overcome the degraded photographic image due to loss of contrast in turbid conditions. Some of these techniques are briefly discussed and some more recent technological developments in imagery systems, applicable to the problems of photography in reservoirs, are presented.

Lenses: Two basic camera systems are available - the land camera in a water tight housing and the self-contained camera which needs no housing. When a housed camera is used, the optics of the glass port are important. A flat port has a distorting and magnifying effect and introduces many serious aberrations unacceptable for accurate archeological recording. Wide angle lenses are necessary for photography in anything other than very clear water but the aberrations introduced by the use of a plane port degrade the image produced.

To overcome the difficulty posed by a flat port, a camera lens designed to correct the effects of the port may be used, or the camera housing can incorporate a water-corrected dome port of a diameter sufficiently large to minimize field curvature. Rosencrantz (1971) discusses photographic systems applicable to underwater documentation.

Clear Water Housings

The problems posed by turbid water in reservoirs and the basic necessity for quality photographic and videographic documentation of archeological excavation can be partially alleviated by the use of clear water boxes or housings. First used at the turn of the century by Etienne Petan to obtain pictures in low visibility water with a remote camera (Mertens 1970), clear water devices have been more recently suggested and experimented with on archeological sites (Johnston et al. 1978; Bass 1966).

The device basically consists of a housing unit into which clear water is introduced. A flexible bag or plexiglass housing is attached to a camera so when an object is to be photographed (or examined) the device is pressed against the object and photographed through the clear water. Photographic grid towers can be shrouded and purged with clean, filtered water supplied from the surface to create conditions conducive to photographic recording in virtually any condition (Bass 1966). The bottom of such a device may be closed with clear plastic sheeting which will conform to the objects being photographed or left open. The excess water from continual slow pumping is simply allowed to purge out the bottom of the structure.

Larger constructions have been built on the same principle to allow divers to work in a clear water environment in otherwise low visibility conditions (Johnston et al. 1978). Large sites could be cofferdammed and the same process used to maintain clear water conditions within the cofferdam.

Technology is available to clear relatively large bodies of water by chemical treatment and filtration. The sacred well of Chichen Itza, a 13 meter deep, 63 meter diameter Mexican cenote was clarified to produce at least 5 meter visibility in water described as "worse than a New York sewer" (Romero 1972).

The problems of limited visibility is not sufficient reason for substandard data recording on inundated sites in reservoirs. Combinations of photographic and videographic techniques, coupled with specialized imagery and clear water devices, can allow documentation no less exacting than those carried out on land excavations, admittedly at the cost of greater time commitment and expense.

TELEVISION

Closed circuit television systems and video recording have been successfully applied to many underwater archeological efforts. (Bass 1966; Cockrell 1975a, b; Cederlund 1977; Garrison et al. 1978; Murphy 1978). Television and video recording have the advantage of real time viewing, immediate playback, nondestructive electronic editing, and low light level capabilities that solve many problems of data recording in the reservoir environment. Consequently they are often preferable to other visual recording systems. High resolution video camera systems have capabilities comparable to 35mm motion picture cameras and are inexpensive by comparison.

Recent advances in television technology may prove to be of great advantage in reservoirs areas. In order to obtain a video record of a Swedish shipwreck under extremely poor conditions, a wide angle (110°) silicone lense was used (Cederland 1977). This camera could work in light down to 1/10 lux. The recording was made with a single 50 watt spotlight at a distance of 0.5 meters to 1.5 meters from the wreck. The systematic video recording was used to produce an accurate outline of the ship structure in very low visibility conditions.

Current underwater television camera systems are products of a rapidly developing microcircuitry technology, and have been reduced in size in recent models as a result of increased demand for underwater television systems for offshore oil field inspection and observation applications. Cameras and support equipment had been developed specifically for the rugged demands of this industry and incorporate features not normally found in surface systems. These features include:

1. Ease of operation with a minimum of training and experience through use of automatic regulation and sensitivity control circuits.
2. Wide viewing angles in water.
3. Extended viewing penetration and resolution typically exceeding that of the human eye in water.
4. Safe, low voltage current and power requirements with open and short circuit protection.
5. High reliability.

All of these features should be considered when evaluating an underwater video system for archeological applications. Another useful feature is the stop function on the video recorder. A single frame may be positioned on the screen and a photograph taken from the monitor. Computer and edge enhancement may then be employed to produce quality photographic prints from the video tape.

Remote Operated Systems

Various configurations of remote controlled television systems may be used for monitoring deep sites in the reservoir as well as minimizing dive time during various phases of the survey and excavation. These systems are of two basic types: systems lowered from the surface and cable-tethered mobile systems. The former may have a protective cage containing a remote operated camera with pan and tilt functions. The cable-tethered mobile vehicle is capable of free movement by self-contained propellers or jets to move the system into desired position (Bascom 1976).

Underwater remote controlled vehicles, normally cable-tethered, are controlled by a surface operator. Equipped with high intensity lights, video, still cameras and stereo-photographic cameras and strobes, these vehicles can be useful for data retrievals on deep archeological sites. Multi-function mechanical manipulators have been added which could be adapted for sample collection. The vehicle can be accurately positioned and maneuvered.

Although the lease price on remote controlled vehicles is high at present, the expense may be offset by efficiency of operation when surveying for deep reservoir sites. In some cases inspection and monitoring activities could be carried on without a diver in the water. The vehicle can replace a video diver during excavations. In virtually all instances, commercial operators report much greater accuracy in data returns from remote controlled vehicle search and inspection techniques than from divers who are influenced by the stress of depth.

Developments in these vehicles will open new areas of application to underwater archeology. Color video capabilities, cameras designed to photograph the area of the video screen and color stereo-photography are anticipated.

Closed circuit television was first used on an underwater archeological site by Captain Jacques Cousteau during the excavation of the

2200-year-old Greek ship near Grand Congloue in 1953 (Cousteau 1954). The instrument employed was a steel housed Thomson-Houston camera suspended from the surface, using 6000-watt light bulbs for illumination. The camera was focused by a diver who received instructions from the surface via a speaker enclosed in the camera housing. The importance of communication with the surface in order to enable archeologists and specialists to direct excavation was immediately recognized.

In 1967, a Sony TV camera was enclosed in a plexiglass housing and coupled with a surface monitor for use in the search for fur trade sites in Minnesota rivers by the Minnesota Historical Society (Wheeler et al. 1975). However, it was not until 1975 that underwater television coupled with video tape recording was integrated into the overall excavation design of an underwater archeological site in Warm Mineral Springs, Florida, by W. A. Cockrell (1975a, b; Murphy 1978). Video recordings were done both during terrestrial and underwater excavation.

Various applications in the use of video equipment were developed during the excavation of the inland inundated early man site at Warm Mineral Springs, Florida. The participation of visiting scientists contributing to the multi-disciplinary excavation was greatly aided by viewing previously recorded video tapes. Nondiving scientists could get synoptic overview of excavation feature areas and were able to direct collection of required samples. Selected discussions between scientists and dive planning sessions were recorded which contributed to solving specific problems, such as the successful video taping of the interior of the main spring outlet at a depth of 70 meters. The tapes produced comprise a unique data bank and can be kept indefinitely. The tapes from Warm Mineral Springs are archived in a permanent collection (Cockrell Collection, Florida State Library, Tallahassee).

Underwater videotape recording should be considered basic to archeological excavation in reservoirs. Integration of video into long-term monitoring programs can be of great benefit.

Acoustical Imaging

The expansion of human activities underwater has provided the impetus for development of systems designed to overcome the frequently restricted range of optical viewing. One response to the limitations inherent in optical systems in turbid conditions has been the research and development of acoustic imaging.

Acoustic images of objects can be formed in an analogous manner to optical imaging. These acoustic images, which consist of spatial amplitude and phase variations of the ultrasonic field in an imaging plane, can be detected with appropriate acoustic sensors and displayed on a television monitor. Underwater sound wave propagation at low frequencies (the frequency range for high resolution in water of high turbidity) is not affected appreciably by the presence of typical suspended sediments.

Experimental work carried out by the Lockheed Palo Alto Research Laboratory has confirmed that high resolution viewing is practical, at least over short ranges, in turbid conditions as high as several parts per million of suspended sediment (Lockheed 1970). Although working prototypes were constructed by the Laboratory, the device has not been commercially produced.

SITE SAMPLING AND TESTING

Sampling underwater sites is methodologically no different from terrestrial sites; the sampling design developed must be sufficient for the coverage required for the archeological target. Rather than the shovel and backhoe, characteristic of land survey, the archeologist relies on mechanical devices especially suited to overburden removal and penetration underwater.

Coring has been demonstrated as an effective sampling tool on land. It can be equally effective underwater (MacKereth 1978; Murphy 1978). Mechanical or hand coring has been used in underwater site testing and a hand corer, capable of extracting 7.5cm x 3 meter cores, encased in plastic pipe was built and used by the Inundation Study Team.

A tool which can be useful for sampling is the jet probe. The device is basically a long pipe through which water from the surface is pumped. The probe is inserted into the sediment to search for the presence of objects below the bottom sediments. Structural features can be delineated with this technique. The jet probe requires a water pump and the probe can be fabricated from parts available at most hardware stores. If the probe is marked from the distal end, the depth of the feature below the surface can be easily determined.

Excavation in reservoirs may require the removal of overburden. The principal tools for removal of sediment underwater are the airlift, dredge, and jet. The airlift is a simple device which requires a high volume, low pressure air compressor. Air is pumped down from the surface and allowed to rise within a pipe. The air-water mix within the pipe, less dense than the surrounding water, rises rapidly and creates a suction capable of moving large amounts of sediment and rocks. One problem presented by the airlift is the difficulty of control. The device can be very powerful, able to lift heavy objects and, if not carefully controlled, quickly decimate archeological features. There have been various schemes to minimize loss of this nature by having the overburden pumped out on the surface to be sifted or into a catchment screen below the surface. These have proven inadequate and the airlift should be considered for the removal of sterile overburden only. A very small airlift (perhaps two or three inches in diameter) may be useful for more controlled excavation in areas close to archeological features.

The water jet is also an overburden removal tool. A stream of water is used to wash the overburden away. Normally, the nozzle should be self-balancing or of the vulcan type so the diver can control it. The powerful stream of water, similar to that produced by a fire hose, is difficult to use precisely underwater. The chief disadvantage of the water jet is that unless there is some way of determining when the overburden is removed, archeological features can be quickly destroyed.

The water dredge can be produced in many sizes. The dredge head is designed so that water that is pumped down from the surface is forced through a tapered nozzle creating a vortex which, in turn, develops a suction useful for sediment removal. The sediment is transferred horizontally, rather than vertically as with the airlift. A small version of the device with a flexible hose intake nozzle has proven useful for precise stratigraphic excavation when used in conjunction with a trowel and brush (Murphy 1978).

In the event that archeological excavation underwater becomes the only viable alternative to site destruction, consideration must be given to the nature and extent of possible data recoverable. In one of the first major discussions of archeological sites underwater, Goggin (1960) stated that stratigraphy would not be important in underwater sites. This view has been proven false in light of more recent excavations. Dumas (1965) recognized through excavation carried out on silted Mediterranean harbor constructions by Poidebard that "In some places, therefore, the depth of burial of a sherd or a lost anchor has the same kind of significance as on land: they are stratified." More recent excavations in the New World (Fischer 1975; Cockrell 1973, 1975a, b; and Murphy 1978) have shown that stratigraphic excavation is not only possible underwater, but can be done at the same level of data retrieval that would be expected from a terrestrial site.

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GUIDELINES FOR DATA COLLECTION AND SITE PREPARATION FOR INUNDATION

by
Toni Carrell

These guidelines were developed to aid research archeologists and reservoir managers in planning for cultural resources management in reservoir areas

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INTRODUCTION

What are the impacts of freshwater flooding on archeological sites? What mitigative measures are best suited to cope with these impacts? These were the two overriding questions posed by The National Reservoir Inundation Study. In an effort to gather baseline data needed to answer the above questions, a set of data collection guidelines were developed by the study. These first appeared as Chapter III in the Preliminary Report of The National Reservoir Inundation Study (Lenihan et al. 1977).

Many of the specific data collection elements requested in that chapter were based upon the hypotheses and test implications presented in the preliminary report. The data that accrued as a result of guideline implementation in reservoir areas across the U.S. aided inundation study archeologists in the empirical testing of those hypotheses. The data collection and site preparation information presented in this technical report has been revised and updated as a result of discussion with archeologists and researchers who have worked with the National Reservoir Inundation Study Team.

An important point to be understood is that the guidelines were not and are not directed toward studying human behavior at the archeological sites under investigation. Rather, they should be used to determine the relative effects of immersion on the archeological data-potential and physical integrity of a site over time.

Standardization is stressed in the guidelines to eliminate the variable of data collection methods on the results, to facilitate computerization, and also to permit inter- and intra-site comparison of results. No effort has been made to address the relative value of the procedures presented; rather, the continuing focus of inquiry is on the ability to obtain comparable returns from these procedures after inundation.

The specific methods for data collection presented here may be contradictory to the previous training or experience of some researchers. This may in part be due to the specific nature of the information needed to isolate the causal relationship between environment and inundation impacts. The methods outlined do not, therefore, necessarily reflect all of the ways in which a sample could be taken or analyzed. For example, testing for soil pH should optimally be done on both dry and damp samples. The guidelines procedure requests the results from a dry sample only. Analysis of damp soil samples, whether resulting from rain, snowfall or other phenomena, could alter test results because the chemical nature of these "introduced" waters will probably not be the same as that which will eventually flood the site. The National Reservoir Inundation Study was concerned with the interaction between the reservoir water and the soil, and the results of pH analysis of samples in their natural state were best suited to meet the research needs of the project. In order to ensure continued comparability of data returns, all data collection and site preparation procedures set forth in this technical report should be implemented according to the specifications outlined below.

The research approach used by the principal investigator of a particular project may require a different method of sample collection than that outlined in these guidelines. When such a situation occurs, both methods of sample collection should be employed whenever possible. The guidelines are not intended to interfere with the research design planned for use at the site under investigation; rather, they are intended to ensure that the data that accrues from a particular archeological effort will also meet the long term goal of continued inundation study research.

The guidelines are divided into two sections: the first with data collection; and the second with site preparation.

The data collection section deals with overall site data-acquisition and organization. The first part of this section addresses the organization of standard data normally required to document all sites excavated under contract reservoir archeological programs, and presents a standardized format for this data that will readily lend itself to assimilation into the continuing study of inundation impacts. Maps, datum placement and stabilization, excavation unit information, photography, remote-imagery, provenience control for pre- and post inundation comparative samples, and artifact distributional analysis are all considered. The second part of this section deals with the various types of dating and analysis techniques that are used by archeologists to glean interpretive data from archeological sites. Specifications for sample collection have been developed in consultation with researchers in each of the various specialty areas. Not all of the dating procedures presented will be applicable to each site under investigation; however, the inclusion of as many of the procedures as possible into the excavations being conducted is urged. The results of the standardized approach to data collection presented in the first section will provide for inter- and intra- regional information comparisons.

The site preparation section presents selected methods for monitoring direct mechanical impacts of inundation such as slumping, erosion, and sedimentation, as well as subtle effects on soil color, stratigraphic compaction, loss of provenience for artifacts, and differential destruction of features or other remains. Information on the placement of site relocation devices, such as sonic pingers, markers, and buoys, for use after immersion, are outlined. Also considered are specific preparations for standing structures, machinery, excavated units, pictographs and petroglyphs, and post inundation temperature determination.

DATA COLLECTION

This section deals with overall site data acquisition and organization and provides a format for the integration and comparability of data on inundation impacts across the country. It is hoped that the information provided will serve to encourage the addition of interpretive techniques or data recording procedures not previously considered or widely used. Many of the particulars of site selection and preparation, and the implementation of these guidelines, will depend on the imagination and judgment of the individual conducting the archeological investigation. It is not within the scope of these guidelines to discuss the viability of excavation or data organization procedures currently employed in New World archeology; they are often dependent upon local conditions and research designs. Each researcher approaches excavation of a site with certain goals and questions, and these guidelines should in no way hinder the development of any particular research orientation.

Minimum Site Data Requirements

To facilitate the use and computerization of all site data, a baseline approach has been developed wherein informational elements common to most archeological research programs are standardized. These informational elements are comprised of the minimum data required to adequately document sites excavated through contract-archeology programs in reservoirs and of data that are considered critical to the development of a nationwide comparative base for cultural resources that will be impacted through inundation.

Maps

Mapping and mapmaking are important parts of careful documentation of any archeological site. The use of the standard mapping techniques used to obtain information for planimetric and topographic maps is extremely time-consuming, and errors can be made. These problems are amplified in the mapping of large or complex sites.

Photogrammetric procedures have been successfully used at large, complex Pueblo sites in the Southwest (Lyons, Hitchcock and Ebert 1976) and greatly facilitated the analysis of site characteristics and relationships. Photogrammetric procedures can also provide more accurate and detailed maps than can be obtained by traditional methods (Pouls, Lyons and Ebert 1976) with savings of both time and money. An ancillary advantage to photogrammetry is its adaptability to digitization of mapping information. The computerization of data relevant to terrain and site can provide the archeologist with not only accurate, clear topographic and planimetric maps, but also with drawings of the site from any perspective desired (Pouls, Lyons and Ebert 1976).

Photogrammetry is potentially applicable to many different types of archeological sites, but it is most practicable as a mapping tool when applied to very large sites of two acres or more (Lyons, personal communication 1977) which are not situated in densely forested areas. It is also applicable to areas that contain numerous small sites which often occur in reservoir impoundment areas. The use of photogrammetry should be seriously considered in such areas.

A topographic map, a planimetric map, and a soil profile, should be prepared for inundation site information controls. The scale used on the maps should be adequate to clearly depict such aspects as surface collection or excavation units, features, soil stratigraphy, structures, and datum points. All measurements should be referenced to the primary datum. The use of the metric system is preferred.

The two maps and the profile should all be prepared to the same scale, when feasible, and a plastic or mylar overlay system devised. These measures will facilitate the use of the materials by the followup research teams and aid in computerization for an information recall system. This system can then be made available to contracting archeologists, managers, and planners to aid in total cultural resources management in the reservoir. Use of the "three map system" (two maps plus soil profile) for site documentation will allow archeologists and scientists to readily select informational elements for specific research needs, pinpoint areas where impacts have occurred, and duplicate samples for comparative purposes.

A grid system should be developed for the site within which excavation or surface collection units can be clearly defined and the primary datum point located. This system should be used to designate the locations of the photographic stations discussed in this section and to facilitate the gathering of information on the soil profile. Whether a numerical, letter, or alphanumeric grid system is used should be clearly defined.

Topographic Map

A contour map should be prepared, which depicts all significant vegetational and physiographic aspects of the site. Such aspects as site limits, features, structures, trash or dump areas, and primary datum and secondary datums above maximum flood pool should be clearly indicated. The distance between contour intervals will depend upon the terrain, but should be small enough to reflect changes in elevation of not more than 2 meters (6'). Such minimal interval information will aid considerably in planning postinundation monitoring of the site. The site's geomorphic setting (for example levee deposit, stream terrace, alluvial fan) should also be noted in some manner on this topographic map.

Planimetric Map

The planimetric map will be more detailed in nature, and should show all excavation units, surface collection units, datums, photographic stations, structures, features, and so forth, and clearly indicate those units that have been prepared for inundation (as specified in the site preparation section of these guidelines). The nature of the site preparation may be coded in some manner in the map legend.

The grid system devised for the site should also be included on this map or on an appropriate clear plastic overlay; each unit should be easily identifiable, whether surface collection or excavation was carried out and unit designations should be clearly indicated.

Soil Profile

Several vertical measurements should be made to record the depths of the cultural deposits and the changes in soil stratigraphy. These measurements can be made with a power- or hand-operated soil auger having a 1" or 1-1/2" bit or bore; the auger hole locations should be tied into the overall site grid-system previously discussed, and holes should be distributed evenly throughout the site. In addition, some off-site areas away from the obvious cultural activity zone should be augered for comparative purposes.

Soil deposition processes (such as water or wind) should be noted on the cross-section. Standard soil terminology should be used to differentiate between soil types (pedalfers, pedocals, and laterite) and soil horizons (A, B, and C). Artifact density, e.g., artifacts per cubic meter, as it relates to the soil stratigraphy within the site, should also be shown.

Datum Points

A permanent datum point set in concrete should be established for the site under investigation and should be accurately tied in to physical features which lie above maximum flood pool. Whenever possible, this primary datum should be referenced to a USGS bench mark or similar permanent point. This datum should not be a wooden stake, but rather a length of galvanized steel pipe or white PVC (plastic) pipe, 1-1/2" to 2" minimum diameter. It should be set a minimum of 50 centimeters below the ground surface with 1 meter protruding above the surface of the site. A post-hole digger or soil auger with a large bore should facilitate this procedure. If galvanized pipe is used for the datum, all identifying information should be clearly marked near the top of the pipe; steel letter stamps are recommended for this purpose. If PVC pipe is used, the requisite information should be engraved into the pipe near the top and marked over with permanent black marker. Threaded caps for either the PVC or steel pipe may be used to record the most pertinent data, e.g., "Datum No. 1," but this information, as well as site number, grid designation, etc., should be repeated on the pipe. One or two small holes should be drilled in the cap to allow air to escape when the pipes become inundated.

Two secondary datums, also set in concrete, should be established above maximum flood pool and accurately located relative to the primary datum. These secondary datums should be located so they can be used for triangulation of the primary datum after the site has been flooded. These datums should be set in concrete as specified above, but should protrude no more than 30 centimeters above the ground surface. If possible, a concrete base 15 centimeters above the ground surface surrounding the lower portion of the pipe should be constructed to help prevent accidental disturbance of the datums. In addition to being marked with the datum-designation information each datum should be clearly marked or labelled: "Federal Property Do Not Remove."

Excavation Data

The particulars of unit selection for excavation, surface collection or trenching and the specific procedures employed for each, will be dependent upon the research strategy of the principal investigator for the site in question. However, all units undergoing examination should be referenced to an overall grid system which accurately locates the unit vis a vis the permanent primary datum and indicates its relationship to other units. Whether a numerical, letter, or alphanumerical grid system of unit designation is used, the system and unit designations should be clearly defined.

One permanent corner stake should be left for each excavated unit that is used for inundation study research purposes. Each excavation-unit should have a subdatum which will facilitate taking measurements within the unit, and all units should have the same subdatum, i.e., northwest corner, etc. This subdatum should be used as the permanent corner-stake for the unit. The stakes should be of the same material as specified above for the datums--galvanized steel or PVC pipe--and they should be set in concrete in the same manner as previously outlined. If the excavation units are juxtaposed with no intervening bulks, sufficient numbers of outside stakes should be left to adequately define the shape of the unit. The stakes should then be permanently set. In the event that this type of excavation unit or any other areas within the site is allocated a subdatum, it too should be permanently set in concrete. Each corner-stake should clearly identify the unit under investigation. Steel letter stamps on galvanized steel pipe and engravings and permanent, water-proof black marker on plastic pipe are recommended to identify the unit stakes. (For more detailed information on minimum stake size and the setting up and location of identifying information on the stakes, see the "datum points" heading earlier in this section.)

Information to be gathered during excavation, and if feasible to be included in or as an appendix to the site report, should include but not be limited to:

1. Unit excavation level planimetric maps (show sample collection areas, features, etc.).

2. Unit profile maps for finished unit (clearly designate sample collection areas).

3. Unit datum point (reference all measurements for samples collected, features, artifacts, etc., within the unit to this subdatum; all units should have the same subdatum, i.e., northwest, southwest corner, etc.).

4. Unit excavation procedures and other general information should include but not be limited to: An explanation of excavation procedures used (for example, arbitrary 10 centimeter, 20 centimeter, levels;

stratigraphic excavation levels; horizontal excavation levels from unit surface; etc.);

Unit surface preparations (cleared of brush, surface collection of artifacts, etc.);

Rationale for unit selection (sampling, hearth noted on surface, etc.). Screening process used and size of screens, etc.;

Complete record of all excavation activities within the unit, samples collected, features, photos, artifacts, condition of unit as left for inundation, description of preparation methods employed, etc.

Photographic Record

A complete photographic record should be maintained and should include general photographs of the site prior to excavation and general photographs of the site and excavation units as they are left for inundation. These photographs will be especially helpful in the assessment of direct mechanical impacts and in the accurate determination of specific locations in the site after immersion. Photographs should be taken from established stations which have been set up within the overall site grid system. Photographic documentation of the excavation as it progresses and of significant features should also be made from these stations. For complete photographic documentation, both black-and-white and color print or slide film should be used.

In situations in which artifacts, osteological material, features, and so forth, are left *in situ* for the purpose of comparative analysis after inundation, photographs that show the general condition of the material or features should be taken. Careful attention should be paid to photographing soil discolorations that reflect past human activity; these stains *may* be the only visual clue available to the archeologist. Preliminary research indicates that they may be lost when inundated.

The use of black-and-white infrared film to photograph soil-profiles or soil discolorations should be considered. Stratigraphy that is often not clearly discernible on panchromatic photographs becomes visible when infrared film is used. The high-contrast properties of infrared film and its sensitivity to moisture content make it useful for documentation of stratigraphy, especially if the profile is complex or difficult to interpret.

If any protective measures are taken for the excavation-unit under investigation, such as lining with plastic or backfilling with anomalous material, photographs should clearly show what methods were employed.

The following minimal information should be recorded on photographic record forms:

Name of reservoir
Date
Site number
Type of film used
Film speed

Camera and lens type (if using more than one lens, indicate other lenses used, and code with asterisks or some other indicator; e.g., 35mm SLR Pentax w/55mm Lens [*], 2/38mm [**], or w/21mm [***]).

Photographic station (if more than one station is on a sheet, skip one line and indicate new station).

Camera direction (from photo station).

Subject description (including unit designations or feature number, etc., and lens code, e.g., "*BRM-2 at rt. ctr., Feat. 33 in ctr. Jones Creek enters at rt. foreground (thick bushes)."

Frame number.

Photograph catalogue number.

Note: If continuation sheets are used, indicate page numbers as 1 of 3, 2 of 3, etc.

Provenience Control for Samples

The location of all samples collected should be referenced to the excavation unit subdatum and measurements recorded in unit notes and on sample collection cards. In the case of samples collected for inundation research and in cases in which the wall or sample collection area will not be further excavated during the course of work at the site, the exact location of the sample should be marked by a galvanized steel spike. The spike should measure 12" by 3/8", and the sample number should be recorded on a strip of brightly colored contact paper, pressed just below the head, forming a flap. Plastic surveyors' tape is also suitable and may be sewed and tied in place, leaving a loose flap end. The number should be recorded on the flap with a permanent black marker. The spike should be left in place, whether the excavation unit is backfilled or left open, to pinpoint sample collection areas and to also aid in the collection of duplicate samples after immersion.

Remote Sensing

Remote sensing is the most promising method of fast, efficient site location and general site data collection and mapping available to the archeologist and it is being more and more widely accepted and used in the field.

Remote sensing can provide the regional scope needed in archeology because it presents information in a manner that is readily adaptable to the integration of sites into an overall prehistoric system, as that system functioned within the environment and as it was expressed through intersite dynamics. The extent of the role that remote sensing can play in archeological discovery, data collection, and constructive inference has, unfortunately, been only surficially considered by archeologists (Ebert and Lyons 1976). Although remote sensing is not yet fully exploited as a tool in archeology, the loss of the potential data which can accrue by this process is considered to be an important factor in the continued inundation research. Through a comparison of remote sensing returns prior to, during, and after inundation, the question of what remote sensing data is lost as a result of flooding can be addressed.

Aerial photographs of the reservoir area are most often taken early in the project planning stage by the involved Federal agency for management and construction purposes. However, remote sensing programs designed for optimum archeological data retrieval are not usually included in these flyovers. This may be attributed in part to the still nascent nature of the archeological applications of remote sensing. Consultation between reservoir construction planners, remote sensing specialists, and contracting archeologists regarding the inclusion of archeologically oriented remote sensing at the earliest stages of the reservoir planning process would enable dual use of remote sensing flyovers for the benefit of both management and archeology.

In those instances where the consulting archeologist was unable to coordinate early with the reservoir planners and the project status has moved beyond the stage of initial flyovers, copies of existing imagery should be obtained and known sites or general site areas pinpointed. The scale, film type, and resolution of the imagery should be noted in the site report and on the back of each photograph. If additional aerial photography is planned, archeology oriented programs should be included.

There are also on-the-ground remote sensing programs that can be implemented after initial flyovers of the reservoir have been completed.

Electrical resistivity, subsurface radar, and magnetometry are three such programs that are applicable to many different types of cultural manifestations and should be considered in planning the remote sensing programs to be used in the reservoir.

There is an extremely wide range of programs and uses to which remote sensing can be applied in archeology. The National Park Service has published an excellent report on remote sensing, entitled Remote-Sensing Experiments in Cultural Resource Studies, Non-destructive Methods of Archeological Exploration, Survey, and Analysis (Lyons 1976) which can provide the concerned archeologist with an overview of remote sensing applications.

Artifact Distribution

As a result of human activity, clusters of artifacts and other materials are nonrandomly distributed within archeological sites. Analysis of artifact distribution can be used to discover different activity areas within a site or to infer use of an artifact through its association with tools of known use. For this reason, distributional analysis is a valuable interpretive tool in archeology.

The impacts on the distribution of surface artifacts caused by initial flooding or of currents occurring during inundation, and the loss of associational information that could otherwise be obtained, is of concern in the continuing study of inundation impacts. Careful pre-inundation mapping of surface artifactual material will help to address the problems of what artifact associations are lost as a result of inundation.

The surface artifact collection criteria used will, of course, be dependent upon the research goals and sampling strategy chosen by the principal investigator at the site under investigation. However, it is strongly urged that a 100% collection of surface materials not be made. Only by leaving a representative sample of the various types of surface artifacts found at the site can a determination be made regarding the differential migration of artifacts as a result of inundation.

The information on artifact distribution gathered from the surface collection/mapping units and artifact provenience information from the excavation units can be plotted in either chart or map form. One simple mapping method is presented below. Whatever mapping system is used to gather provenience information on surface materials, it should relate to the overall grid system for the site in such a manner that surface collection units and artifactual locations are clearly designated.

The suggested surface artifact mapping procedure can take advantage of the overall grid system set up for the site. Through the use of north-south/east-west baselines, surface collection/mapping units can be laid out. A portable 1-meter-by-1-meter wooden-frame grid, cross strung to create 10-centimeter increments, can be laid along these baselines to form 1-meter-by-1-meter surface collection units. The location of surface material found under the grid can be listed on a sheet of paper (several units fit easily on each sheet). By this means provenience information relating to collected artifacts is immediately available and all other materials are permanently referenced for comparison of location after inundation. An example of one entry using this method could be: "Surface unit - North 1, East 2 - grid square 50N, 30E - utilized chert flake." The locational process is very similar to that in which a point is located on a map by section, township, and range.

DATING AND ANALYSIS PROCEDURES

The number of dating and analysis procedures employed by archeologists to interpret and further understand the material record left by ancient peoples has grown tremendously during the last 30 years.

The testing procedures presented in this section are not all-inclusive; rather, a cross section of techniques has been selected, some of which are widely used and others which have traditionally been area specific. The fundamental consideration in the selection of the various techniques has been the development of the broadest possible data base upon which to make determinations of the impact of inundation upon cultural resources.

To facilitate the use of the guidelines, specifications for each of the dating and analysis techniques requested are provided under each subheading. Samples should be taken from areas within the site that an underwater or terrestrial team of archeologists could return to with reasonable ease. Whenever possible, several samples of the same type should be selected from various locations within the site. All samples should be carefully packaged and sealed so as to prevent the loss or destruction of the material. Double-bagging is advisable. Labels should be taped securely to the outside of the samples. For those samples placed in clear plastic bags for preservation, the label may be taped to the main bag; the second bag may be used to protect the label and to ensure against the loss of a portion of the sample material, and this second bag should also be taped. Sample identification labels should be prepared and marked neatly and legibly with permanent waterproof marker or pen (preferably black). Field sample data cards should be typed; if this is not possible, they should be printed neatly in black ink. A clear Xerox or typed copy of the card should accompany each sample sent out for analysis; the original card is retained with other site excavation information.

Soil Analysis

The study of relationships in soils--such as stratigraphic layering, content and color--has become an integral part of efforts to reconstruct prior human activity patterns from archeological investigations. The soil analysis and testing methods to be described include many of the standard procedures currently employed by archeologists, and also a few not previously considered, which are aimed directly at monitoring the mechanical impacts of inundation. These testing methods should be conducted on all sites where such testing is feasible, and samples should be taken in a manner that will enable them to be subjected to a variety of chemical, mechanical, and visual analyses.

Soil Type and Color

Soil type identifications should be taken from the most recent county soil surveys available which will provide a standard reference for all soil types. Soil color identification should be made with the

Munsell color charts designed for this purpose and it should be clearly stated whether the color determinations are being made from wet or dry samples. The standardization of soil terminology and soil color will provide control from area to area and site to site so thatthe most accurate cross referencing of data will be possible.

Soil Composition

The analysis of soil composition is useful in interpreting paleoenvironmental conditions. The textural data recovered from such analysis provides information about the nature of soil-particle transport from its source to deposition and also about the weathering processes to which it has been exposed.

This soil analysis will be useful in comparisons of the weathering and depositional processes to which inundated archeological sites have been subjected.

Sample Collection Instructions

1. Sample(s) should be taken from soil profiles representative of the site as well as representative of locations outside apparent cultural activity zones.

2. 2 liters minimum quantity per sample.

3. Sample should be placed in 7 x 12½" plastic or cloth bag. Plastic is preferred.

4. A field sample data card should accompany each sample; information should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Location relative to permanent datum-points
Provenience
Matrix description

5. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Note: If samples will not be analyzed within 2 weeks of collection, it is highly recommended that they be oven-dried to prevent growth of mold fungus.

Soil Chemistry

Soil chemicals are subject to varying degrees of leaching or percolation due to seasonal variations in temperature and humidity. Inundation, whether permanent or periodic, alters the extant environment and may concurrently affect the chemical nature of the soil.

The phosphate, nitrate, potassium, and organic contents of anthropic soils are currently being used as indicators of differential human activities (Sjoberg 1976; Eddy and Dregne 1964) and the loss or alteration of this data through inundation affects the potential returns for site interpretation. To determine the degree of alteration of these chemicals in the soil and changes in gross organic content, soil samples to be used specifically for this type of analysis should be taken prior to and after inundation.

Sample Collection Instructions

1. Areas selected for samples should be representative of the site, as well as representative of locations outside apparent cultural activity zones.
2. Minimum quantity:

Phosphate analysis-------	50 ml
Nitrate analysis---------	50 ml
Potassium analysis-------	50 ml
Organic content----------	50 ml

3. Clean sample area from top to bottom.
4. Collect samples from bottom to top.

5. Use clean tools and containers (free of clinging sediment). Use distilled water to clean tools, if possible.

6. Samples should be placed in clean plastic bags and sealed.

7. A field sample data card should accompany each sample and information should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Location of sample relative to permanent datum-points
Provenience

8. A sample identification label should be taped securely to the <u>outside</u> of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

<u>Note</u>: If samples will not be analyzed within 2 weeks of collection, it is highly recommended that the sample be oven-dried to prevent growth of mold fungus.

<u>pH Analysis of Soil</u>

The analysis of the hydrogenion content of soils (pH) to delineate food preparation or refuse areas has been a standard procedure in archeological investigations for a number of years. Leaching has a direct bearing on the pH content of soils. Inundation dramatically alters this process, and in so doing may affect the potential usefulness of this technique. In order to deal directly with this concern, pH analysis of representative areas of the site under investigation should be conducted prior to and after inundation. In an effort to obtain the most accurate data possible, testing for pH should be done <u>in situ</u>.

Sample Collection Instructions

1. Areas selected for analysis should be representative of the site as well as of locations outside apparent cultural activity zones.

2. Analysis should be done _in situ_ with a portable metering device. Any of the chemical meters currently on the market (e.g., Beckman, Chemtrix) are acceptable.

3. A field sample data card should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Method used to take sample (include type of meter)
Initial condition of sample (damp, dry, etc.)
Results of test
Location of sample relative to permanent datum-point
Provenience

Flotation Samples

Flotation samples should be taken wherever feasible. If possible and archeologically acceptable, a control column or block should be left intact adjacent to the sample and marked for later relocation (see section on site preparation). Careful documentation of the location of visible materials in the sample prior to immersion, as well as a listing of materials floated out, will provide a check on the impacts that reservoir inundation may have on this data recovery technique.

Sample Collection Instructions

1. Sample(s) should be taken from profiles representative of the site and of locations immediately outside apparent cultural activity zones.

2. A field sample data card should include, but not be limited to, the following information:

Name of reservoir
Date
Site number
Type of sample
Sample number
Location of sample relative to datum-points
Provenience

Type of materials floated out, e.g., seeds, nuts, leaves; include taxonomic identification, if possible
Initial weight and volume of sample

Erosion and Consolidation Testing

The destruction of archeological sites through slumping, wave-action and currents within a reservoir is another consideration. In order to develop predictive models for mitigative purposes, standardized erosion tests should be made on samples from sites that will be subjected to inundation, either permanent or periodic.

Archeological sites that are inundated are subjected to increased ambient pressure, due to the presence of the water column that is introduced when a reservoir is flooded. This increased pressure, along with the saturation of the site, may cause the soil-matrix of the site to be weakened and may also cause differential consolidation of the strata within the site. To account for this phenomenon and develop predictive models for mitigative purposes, consolidation tests should be made on samples from sites that will undergo permanent or periodic inundation.

Sample Collection Instructions

1. Sample(s) should be taken from area(s) representative of the site.

2. Sample(s) should be a solid undisturbed block (detailed instructions for taking undisturbed block samples are included as Appendix A to this technical report).

3. Block samples should be 20cm x 20cm x depth of cultural deposit to be tested. The sample should contain strata that are representative of the site. However, it is not necessary to include a sample of the entire cultural deposit if there is little or no change in soil matrix; in this case a 20cm cube is sufficient.

4. A field sample data card should accompany each sample, and information should include, but not be limited to:

Name of reservoir
Date
Type of sample
Sample number
Location relative to permanent datum points
Provenience

5. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number
Please also mark package with "PROTECT FROM FREEZING OR OVERHEATING"

Stratigraphic Column (Monolith) Testing

The most satisfactory monolith samples for recording and interpreting the stratigraphy of archeological sites are those that share certain characteristics:

1. The completed sample must be stable in a vertical position.

2. It must be thick enough to preserve sedimentary and pedologic structures.

3. It must show clearly the character of depositional and developmental horizon boundaries.

4. It must be long enough to preserve the entire meaningful profile if a soil is involved or to permit satisfactory overlap if stratigraphic units are sampled in sections.

5. Its matrix must be sufficiently strong to support the weight of large or heavy rock and bone fragments necessary for adequate representation of the material to be sampled (Fryxell and Daugherty 1964).

However, monoliths should be taken even if there is no obvious layering within the site. This will provide a comparison that will lead to understanding of the effects of immersion on the stratigraphic components of archeological sites. (Specifics on sample preparation, collection and required materials are included as Appendix B to this technical report).

Sample Collection Instructions

1. Samples should be taken in areas representative of the site.

2. A control area should be left adjacent to sample area and suitably marked for relocation.

3. A field sample data card should accompany each monolith and information should include, but not be limited to:

Name of reservoir
Date
Sample number
Matrix description
Location relative to premanent datum-points
Provenience

4. A sample identification label should be taped securely to the <u>outside</u> of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

<u>Amino-Acid Racimization Dating</u>

This dating technique is based upon the measurable depletion of amino acids found in buried bone. Given a stable environment, the rate of depletion is a constant which can yield an absolute date of burial for the specimen. Environmental fluctuations in temperature, precipitation, and pH of soil and water will all influence the rate of amino-acid depletion within the specimen, and such fluctuations can alter the delicate balance of the chemical reaction upon which the dating technique is based (Ortner et al. 1972; Bada et al. 1973; Hare 1974a and 1974b).

Minute fluctuations in temperature can produce significant variations in dates resulting from this analysis. Data relating to the mean air temperature of the area--either from weather records or from a station in a nearby and similar temperature regime--should accompany all samples. Records of weekly or bi-monthly ground temperatures are even more valuable and can often be obtained from an agricultural experiment station or Soil Conservation Service office.

A more technical approach is needed to determine mean temperature in an inundated situation, and the Pallmann method is suggested. (Information on preparation for this procedure may be found in the site preparation section of these guidelines. Exact specifications are provided as Appendix C to this technical report.)

The amino acid racemization dating process has not yet been perfected and its application to various types of freshwater-inundated samples is questionable. However, amino acid racemization dating should be attempted whenever possible; a comparison of results from samples prior to and after flooding would aid in the determination of the viability of this dating technique for inundated samples given the current state of the art.

The following sample collection procedures have been developed in coordination with specialists in this field and should be strictly adhered to:

Sample Collection Instructions

1. 1 gm minimum sample size for shell or bone.

2. An accompanying soil sample should be taken from within a 30cm radius of shell or bone to be dated; 10-20gms minimum quantity.

3. Package soil and shell or bone samples separately in sterile plastic Ziploc bags and tape securely. Use corresponding field sample numbers.

4. Take one soil sample per shell or bone specimen. If taking numerous specimens from the same location, the ratio should be 5 specimens to 1 soil sample.

5. Use clean tools (free of clinging sediment); clean tools with distilled water if possible.

6. Clean tools between samples.

7. A field sample data card should accompany each pair (specimen and soil) of samples and information should include, but not be limited to:

Name of reservoir
Date

Site number
Type of sample
Sample number
Location of sample relative to permanent datum-points
Provenience
Content of sample (burial, hearth, etc.)
Environmental context (riverbed, erosion-gully, etc.)
Annual precipitation
Annual temperature range
Mean annual temperature
If site previously inundated, indicate and give approximate length of time
Soil pH, if known
Associated carbon-14 date, if available
If time period of associated materials is known, indicate

8. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Archeomagnetic Dating

Samples for archeomagnetic dating should be taken whenever possible. A wide variety of materials are suitable for archeomagnetic dating, and full advantage of this diversity should be taken when selecting samples (Tarling 1975). If feasible and acceptable to the principal investigator, a portion of the sample area large enough to duplicate the pre-inundation samples should be left undisturbed and suitably marked for relocation with nonmagnetic materials such as an aluminum or brass rod.

The direct mechanical impacts of slumping, wave-action, or differential consolidation of soils adjacent to the feature, may disturb a feature that would otherwise be suitable for this type of dating. Periodic inundation or freezing and thawing, causing a change in the volume as well as a weakening of the internal structure of a sample, may also disrupt the magnetic orientation and make a precise determination of the past orientation impossible.

The control of sample orientation and collection is critical to the successful application of this dating procedure and all samples should be taken in a manner consistent with pre-established guidelines. (For a reference on a specific technique employed for taking archeomagnetic samples see Appendix D to this technical report.)

Sample Collection Instructions

1. Magnetic orientation and provenience data should be scratched into plaster covered samples and repeated on sample forms.

2. A field sample data card should accompany each sample and information should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Precise orientation of sample
Location of samples relative to each other
Sample number, e.g., 1 of 5
Location of sample relative to permanent datum-points
Provenience
Type of feature

3. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Carbon-14 Dating

Based upon a review of the literature dealing with the theory and techniques of carbon-14 dating and preliminary results from field studies, it is strongly indicated that freshwater immersion will not alter the data results obtainable from the analysis of viable samples. However, those naturally occurring agents that affect the amount of datable carbonized material still recoverable in a dry site may be magnified through inundation and in those areas where individual samples are marginal in size or availability prior to inundation, the necessary volume or weight needed may not be obtainable after immersion.

To control for this factor in those areas where datable samples are marginal, bulk samples containing at minimum 10 grams of datable carbon material should be taken in addition to individual samples. If the amount of carbon material in the soil is unknown, the field method out- in the following paragraph may be used to estimate the amount of carbon.

Heat the soil sample to boiling (100°C) to evaporate most of the water then weigh the sample. Reheat the sample over a wood fire (600°C) and weigh the sample again. The weight difference will provide a rough approximation of the carbon (Ericson, personal communication 1976).

Sample Collection Instructions

1. Minimum quantity for individual samples:

   Charcoal--10 grams (yields most reliable ages)
   Wood--15 grams (yields 2nd most reliable ages)
   Bone--200 grams (charred bone preferred)
   Peat--25 grams
   Shell--30 grams

2. Minimum quantity of datable material in bulk charcoal samples--10 grams. For all other samples the same quantities as stated above.

3. Modern rootlets and roothairs should be picked out of the sample with tweezers.

4. Sample should be placed in plastic bag, sealed, then wrapped with aluminum foil and securely taped.

5. Standard precautions for contamination should be followed, e.g., clean instruments, no smoking, etc.

6. A field sample data card should accompany each sample, and information should include, but not be limited to:

   Name of reservoir
   Date
   Site number
   Type of sample
   Sample number

Sample composition (charcoal, wood, shell, etc.)
Location relative to permanent datum-points
Provenience
Matrix description
Possible contamination (if any)
Bulk sample: gross weight and size

7. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Dendrochronology

Tree ring dating (dendrochronology) is at present best developed in the Southwestern United States. Only certain species of trees are acceptable for tree ring analysis because of the need for a clear pattern of variable, annual growth rings. Suitability of species will vary with the environmental sections of the country and contact should be made with a tree ring analysis laboratory to determine which species are acceptable for the area being investigated.

Although dating may not yet be possible in all sections of the country samples should still be taken; they would prove valuable in the future if a master chronology is developed and they may aid current research efforts directed toward developing a master chronology.

If feasible and archeologically acceptable to the principal investigator, some of the material should be left in place and be suitably marked for relocation. This will provide future researchers with a control and a comparative sample.

Sample Collection Instructions

1. Datable species are required. Either collect samples from each species represented or contact the laboratory scheduled to do analysis for type of species desired.

2. Solid logs, or sections are preferable so that a complete ring pattern is present.

3. Charcoal is often datable, if a complete ring-pattern is present, and should not be overlooked when collecting samples for tree-ring analysis.

4. If sawing of a cross-section is not acceptable or feasible, a bore may be taken.

bore should be 1/4" to 1" in diameter

the sample must run to or through the core

a hooked wire may be used to break the sample at the core for easy removal.

5. Fragile or water saturated samples are collected in the same manner, but great care must be taken to avoid damage.

The sample may not be strong enough to support itself (particularly true of water-saturated samples) and support must be provided and maintained until delivery to the laboratory.

Water-saturated samples must be kept wet; drying out will damage the sample. Sample should be kept immersed until delivery to the laboratory.

6. A field sample data card should accompany each sample and information should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Location relative to permanent datum-points
Provenience

7. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Fission-Track and Alpha-Recoil Dating

Although the fission-track and alpha-recoil dating techniques were originally developed to enable determinations of the initial formation of certain minerals and the process dealt with time periods beyond the needs of New World archeology, recent developments have permitted the adaptation of these techniques to the archeological dating of more recent materials.

Ceramics that contain micaceous material are most commonly used for the alpha-recoil dating process. The presence of mica in sufficient quantities, at least 10 sq mm, in the sherd is the criterion for assessing the suitability of a sample for alpha-recoil dating. As a general rule of thumb for sample collection it is advisable to choose the largest specimens that contain the most mica discernible to the naked eye.

In Europe, manmade glasses from the 17th and 18th centuries may be suitable for fission-track dating because of the quantity of uranium found in these specimens. Most New World glasses do not contain uranium in sufficient quantities for this dating process. However, imported glassware manufactured during the last 200 or 300 years may be suitable and should not be discounted.

Both fission-track and alpha-recoil dating are based upon the depletion of the uranium and thorium content by natural radioactive decay in a sample over a period of time. The successful application of these nascent techniques to freshwater-inundated samples is unknown; however, it is expected that because of the soluble nature of uranium, during inundation the hydration of minerals may result in a reduction of the local radioactive structure, causing anomalous dates.

In an effort to assess the impacts that inundation may have on these dating methods, samples suitable for dating should be collected whenever possible.

Sample Collection Instructions

1. Minimum sample size: the largest sherd available that contains clear evidence of micaceous material, and glass samples known to have been manufactured in Europe during the 17th and 18th centuries.

2. Package samples in Ziploc plastic bags and tape securely.

3. A field sample data card should accompany each sample and information should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Location of sample relative to permanent datum-points
Provenience
If site was previously inundated, indicate and give approximate length of time
Associated carbon-14 date (if available)

4. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of Reservoir
Date
Site number
Type of sample
Sample number

Flourine Dating

This dating technique is based upon the effects of ground-water percolation through soil. Trace elements of fluorine in ground-water accumulate in porous bone material at a specific rate (Oakley 1970). The amount of fixed fluorine in a specimen can be used to infer a relative age of time of burial of the specimen.

Given stable environmental conditions, the rate of fluorine accumulation in bone would provide an absolute date. However, fluctuations in groundwater percolation, temperature, and soil and water hydrogen ion content (pH) can all act upon the amount of fluorine available for accretion in the specimen.

Data concerning the mean air temperature in the area, from either weather records or a station in a nearby and similar temperature regime, should accompany all samples. Weekly or bi-monthly ground temperatures are even more valuable and can often be obtained from an agricultural experiment station or Soil Conservation Service office. A technical approach is needed to determine mean temperature in an inundated situation and the Pallmann method is recommended. (Information concerning this procedure may be found in the site preparation section of the guidelines and exact specifications are appended to this technical report.)

The flourine dating process has not been perfected and its application to freshwater-inundated samples is unknown. However, fluorine dating should be attempted whenever possible. This will permit an accurate assessment of the viability of this dating technique for use with inundated samples, given the current state of the art.

Fluorine dating of stone is also possible (Taylor 1975) and samples of this nature should not be overlooked during sample selection.

The following sample collection procedures have been developed in coordination with specialists in this field and should be strictly adhered to.

Sample Collection Instructions

1. 1 gm minimum sample size.
2. An accompanying soil sample should be taken from within a 30cm radius of bone to be dated--10-20 gms minimum quantity.
3. Package soil and bone samples separately in sterile plastic Ziploc bags and tape securely. Use corresponding field sample numbers.
4. Take one soil sample per bone specimen, except if taking numerous specimens from the same location, then the ratio should be 5 specimens to 1 soil sample.
5. A field sample data card should accompany each pair (specimen and soil) of samples and information should include, but not be limited to:

Name of reservoir
Date

Site number
Type of sample
Sample number
Location of sample relative to permanent datum-points
Provenience
Context of sample (burial, hearth, etc.)
Environmental context (riverbed, erosion gully, etc.)
Mean annual temperature
Soil pH (if known)
Associated carbon-14 date (if available)
If site previously inundated, indicated and give approximate length of time

6. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Obsidian Hydration Dating

The dating of obsidian fragments should be attempted wherever feasible, even if such dating has no real relevance or is not high priority in terms of the overall research design. If possible and acceptable to the principal investigator, some of the material should be left *in situ* and suitably marked for relocational purposes (see site preparation section).

Temperature is a critical factor in the hydration rate of obsidian (Friedman and Smith 1960; Friedman and Long 1976). Based upon preliminary results from the laborary experiment conducted at UNM (discussed elsewhere in Volume 2), it is expected that short term inundation will not affect the thermal environment appreciably and therefore the hydration rate. It is not known what the effects of prolonged inundation would be on hydration rates.

To assess the impact of long term inundation on hydration rates, a technical approach to obtain the effective hydration temperature is required and the Pallmann method is suggested (further information on preparation for this procedure may be found in the site preparation section of the guidelines and exact specifications for the process are included as an appendix to this technical report.)

Sample Collection Instructions

1. Minimum quantity: single component site 10-24 samples
   multi-component site 10-24 samples per component

2. Preferred sample size larger than 5 sq mm.

3. Sample should be placed in plastic or cloth bags.

4. A field sample data card should accompany samples and information should include, but not be limited to:

   Name of reservoir
   Date
   Site number
   Type of sample
   Sample number
   Location relative to permanent datum-points
   Provenience
   Mean annual temperature
   Annual temperature range
   Weekly soil temperature at various depths (if available)
   Associated carbon-14 data, if available
   Source determination of artifacts, if known

5. A sample identification label should be taped securely to the <u>outside</u> of the sample and the following information recorded:

   Name of reservoir
   Date
   Site number
   Type of sample
   Sample number

Pollen Analysis

The success or failure of pollen analysis in adding meaningful data to the overall research at any archeological site depends upon the samples themselves as well as upon the reason behind taking the samples. Often special situations in which pollen is likely to be deposited and preserved within sites and in nearby lakes and bogs, are not considered. Pollen is also well preserved when the soil matrix is in direct association with some metals such as copper (King, Klippel and Duffield 1975).

Careful consideration of the presence of sedimentary disconformities, erosional surfaces, and traces of fire or peat cuttings is also important. Generally, sandy or alkaline soils are considered unfavorable for pollen preservation but may yield adequate pollen counts if the sample is large enough.

Because of the need to interpret palynological data and integrate it into the research results as more than a pollen record of an archeological site, and because data results can often lead to a redefinition of questions for future or ongoing research at the archeological site, the palynologist should be provided with detailed information concerning the context from which the sample was taken. For example, if the sample was removed from a burial it should be noted whether it came from the head or thoracic region. If removed from a room or storage pit, the prevailing wind direction may provide the additional information required to prepare more meaningful data returns.

Pollen grains may be adversely impacted and preservation hindered when the matrix in which they are deposited becomes inundated. A shift in the chemical balance of the soil, redeposition or loss of context as a result of erosion or slumping, and vertical displacement through the swelling or shrinking of soil particles will all affect the pollen.

The following sample collection procedures have been developed in coordination with palynologists and should be carefully followed.

Sample Collection Instructions

1. Sample(s) should be taken from strata representative of site.
2. Alluvium--400 gms minimum
   Peat--3 cubic centimeters minimum
   Sandy soils--30 cubic centimeters minimum
3. Clean sample area from top to bottom.
4. Collect samples from bottom to top.

5. Remove 3-5cms from the profile samples area immediately prior to collection of sample; this will reduce the potential of airborne contamination.

6. Use clean tools and containers (free of clinging sediment); clean tools with distilled water, if possible.

7. Clean tools between samples.

8. Samples should be stored in fresh, unused plastic bags. Samples should be kept moist because desiccation wrinkles grains and seeds and alters surface morphology.

9. Wrap bags with aluminum foil and tape (seal bags from airborne contamination).

10. DO NOT put labels inside bags; tape securely to outside.

11. A field sample data card should accompany each sample and information should include but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Condition of sample when taken (damp, dry, etc.)
Location relative to permanent datum-points
Provenience
Matrix description
Context of sample (burial, storage pit, room, etc.)
Environmental context (riverbed, erosion gully, bog, etc.)
Environmental conditions under which sample was taken (windy, hot, snowing, morning, etc.)

12. A sample identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Thermoluminescence Dating

Although thermoluminescence is a controversial and complicated dating process, it should be attempted whenever possible, even if it is not high priority in terms of the research design. Ceramics are the primary materials dated by this method, but hearths, heat-treated lithics, and fire-cracked rock may also be used (Goksy, et al. 1974; Huxtable et al. 1976). If feasible, some of the material should be left in situ and suitably marked for relocation.

A major change in the results in this dating technique is expected due to the shielding effects of groundwater. The state of the art in thermoluminescence dating is such that long term immersion in the past or periodic immersion may skew the dating sample beyond the correction capabilities of the process. It is important that data on annual precipitation and periods of past inundation accompany all samples.

Sample Collection Instructions

1. Ceramic Samples

   a. 1 square cm minimum size per sample.

   b. An accompanying soil sample should be taken from within a 30 cm radius of ceramic to be dated (2-3 cubic centimeters minimum quantity). Package separately. Be sure to use corresponding field sample numbers.

   c. Amount: take 1 soil sample per sherd sample, except if taking numerous sherd samples from the same location, then the ratio should be 5 sherds to 1 soil sample.

2. Hearth Samples

   a. A 2-3 cubic centimeter sample is the minimum quantity of burned soil. The upper 1 cm layer should be removed and the sample taken in a core, can or similar container to prevent prolonged exposure to a light source.

   b. An accompanying 2-3 cubic centimeter soil sample from the hearth-fill, taking the same precautions as listed in ceramics discussion above.

3. Heat-treated lithics and fire-cracked rocks

   a. If possible send BOTH heated and unheated samples of same type of material.

   b. An accompanying 2-3 cubic centimeter soil sample should be taken, observing the same precautions as listed in ceramics discussion.

4. Field sample data cards should accompany each sample and information should include, but not be limited to:

Name of reservoir
Date
Site number
Type of sample
Sample number
Location of sample relative to permanent datum-point(s)
Provenience
Annual precipitation
If site was previously inundated, please indicate approximate length of time
Presumed cause of last heating; i.e., burned structure, roasting pit, hearth, etc., if known.

5. An identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

Weathered Glass Dating

The dating of glass objects should be attempted even if it is not a priority in terms of the research design. Although there is some controversy concerning the viability of this dating technique (Newton 1971) weathered glass samples should be taken when available for the purposes of this study. If feasible and archeologically acceptable to the principal investigator, some of the material should be left in place and suitably marked for relocation (see site preparation section of guidelines). These samples will provide both a control and comparative sample for analysis.

Sample Collection Instructions

1. Sample(s) should be taken from area(s) representative of the site.

2. Use extreme care to keep weathering crust intact. DO NOT CLEAN OBJECT.

3. If sample is obtained from moist environment, keep moist. DO NOT let it dry out; this could cause flaking and loss of datable weathering crust.

4. Sample should be stored in Ziploc plastic bags and taped shut.

5. A field sample data card should accompany each sample and information should include, but not be limited to:

Name of reservoir
Date
Site number
Sample number
Location of sample relative to permanent datum-point(s)
Provenience
If time period of associated materials in site is known, please indicate.

6. An identification label should be taped securely to the outside of the sample and the following information recorded:

Name of reservoir
Date
Site number
Type of sample
Sample number

SITE PREPARATION

The preparation of archeological sites for inundation in such a manner as to make them amenable to an external monitoring process and to provide for easy relocation after immersion is a major concern to the continued study of inundation impacts. Without adequate site preparation the capability of the research team to replicate samples, assess impacts, and plan mitigation would be seriously impaired. Procedures presented in this section address the preparation of historic structures and features (such as standing structures and machinery), excavated units, pictographs and petrogplyphs, and placement of postinundation temperature-determination ampules, and relocational devices after immersion.

Preparation of Standing Structures and Associated Features

Archeological sites may contain standing structures, machinery (such as flumes), and associated cultural features (such as railroad beds), or culturally associated botanical remains (such as orchards or vineyards), which pose a different set of problems from sites not containing these features in terms of both preservation and mitigation. Structures are often razed and machinery removed because they may present navigational or other safety hazards.

Sites containing the cultural manifestations mentioned above are important to the understanding of the total picture of human occupation of an area. Measures for the protection and preparation of these sites for inundation should be developed in cooperation with reservoir managers and planners and integrated into the resource management plan for the reservoir. Potentially the most important protection activity for these sites is the prevention of vandalism and destruction until they are completely submerged. In all cases these sites should be carefully recorded on site forms and maps and be photogaphically documented prior to flooding.

The condition of the materials from which a structure or machine is built should be noted. Samples of the structural material--such as adobe or other brick composition, wooden siding, masonry, or metal--should be collected and referenced with standard provenience data if these remains will not be completely removed or destroyed during reservoir construction.

Excavation units associated with these sites should be treated in the same manner as outlined under the subsection on minimum site data and where applicable should include preparation as presented under the following subsection on inundation preparation for excavated units.

Preparation of Excavated Units

Adequate preparation of excavated units will aid in assessing mechanical impacts and begin to address questions ranging from the most basic--whether or not to backfill units slated for inundation tion--to the technical--whether or not to employ sophisticated protective coverings or treatment for selected features or structures.

A representative sample of the excavated units should be selected for testing--some to be left open, unbackfilled, and unprotected--and others to be partially or competely backfilled. Outlined below are procedures that will provide information on inundation effects while preparing the site for postinundation monitoring. Individual unit selection is up to the discretion of the principal investigator; however, excavation units containing sample collection areas for dating or other analysis should be included.

Completely Backfilled Unit: The selected unit(s) should be completely lined with plastic sheeting--either PVC or polyethylene--and be backfilled. If possible, the unit should be filled with material anomalous to the site. If not possible or feasible, plastic sheeting should be of a contrasting color to the soil matrix. This will provide a visual clue to archeologists if re-excavation is conducted after immersion or subsequent draw down.

Half-Filled Unit: A vertical portion of the selected unit(s) should be lined with brightly colored plastic sheeting and be backfilled with the adjacent portion of the unit(s) left completely open.

Profile Unit: Plexiglas sheet(s) should be securely placed directly against a profile or wall that exhibits any of the following:

stratigraphic layering (soil)
features, either cultural or environmental
artifacts
data remains (such as osteological material)

This information should be engraved directly on the Plexiglas showing the location of these items and marked over with permanent waterproof black marker. University of Tennessee archeologist Gerald F. Schroedl found that a router with 1/8-inch veining bit set to engrave 1/8-inch deep was an effective tool for engraving the plexiglas (Schroedl 1977). This sheet should be covered with plastic and buried.

Information concerning the location and protective treatment of these units should be clearly delineated in overall site maps. Unit maps and written records should also reflect procedures employed.

Preparation of Pictographs and Petrogylphs

Specially manufactured pictographs on a sandstone matrix were subjected to simulated lake environment conditions in a laboratory test of various chemical preservative coatings (Turner and Burke 1976). Poly methyl methacrylate was successful in protecting the treated portion of the rock art sample, but the untreated portion showed severe deterioration at the conclusion of the 8-month test. This chemical has been tested on a series of representative Southwest sandstones and shows promise for protecting rock art from the potentially harmful effects of inundation. Poly methyl methacrylate is also suitable for use on rock types other than sandstones, including basalt, granite, tuff, and diorite.

Material sources, chemical preparation and application method instructions are available upon request to interested individuals from William J. Burke, Department of Chemistry, Arizona State University.

It should be noted that the chemical application process is still in the experimental stage and chemical penetration of the rock matrix will be variable. More detailed information on the experimental procedures upon which the chemical preservation method is based can be found in Preservation of Pictographs and Petroglyphs, by Christy G. Turner II, and William J. Burke (1976). Questions on this document should be addressed to Burke.

Whenever possible, chemical protection of inundation-threatened rock art should be attempted. If possible, a small portion of the rock art panel should be left untreated to facilitate a determination of the efficacy of each method.

Site Preparation for Postinundation Temperature Determination

Accurate temperature information is critical for dating by obsidian hydration, amino acid racemization, fluorine dating, and thermoluminescence. Data on the mean temperature, either from weather records or from a station in a nearby and similar temperature regime should accompany samples for use in these dating methods. Weekly or bi-monthly ground temperatures are even more valuable and can often be obtained from an agricultural experiment station or the Soil Conservation Service.

In order to assess the impacts of inundation on the above dating techniques, a technical approach to temperature determination is required. The Pallman method for mass sampling of soil, water, or air temperatures is suggested. It is based upon the breakdown of cane sugar into simple sugars and is accomplished through implanting vials containing a specially prepared solution of cane sugar in the soil. Specific information on this temperature method is included as Appendix C to this technical report.

Consultation with and/or the employment of trained personnel in solution preparation, sample placement and interpretation of the data is strongly recommended. The local USGS may be able to provide this expertise or to provide information on individuals who can provide this service.

The locations of cane sugar vials should be noted on site maps.

Site Relocation Devices for Postinundation Use

Determining the precise location of an archeological site after it has been flooded was one of the most difficult problems faced by the National Reservoir Inundation Study personnel. Turbid water, a lack of easily recognizable landmarks, vegetational changes, and so forth, all contributed to this problem. Although triangulation from secondary datums set above flood pool (discussed in the first section of these guidelines) aided in general relocation of a site, in order to locate the exact position of the site's primary datum (a critical need in order to work at the site) additional methods must be employed.

The first method presented in these guidelines involves the placement of an acoustic pinger and is preferred because of the high degree of accuracy available. The pinger instrument is quite small and does not present navigational or other safety hazards.

The second method employs 55-gallon drums, weighted with concrete, and used in conjunction with a fathometer for site relocation. The use of the second method will be contingent upon prior approval and clearance by the Federal agency charged with navigational jurisdiction and safety in the reservoir because the drums could create a boating hazard in some situations. Permission may also be required from the construction agency even if that body does not hold navigational and safety authority.

Acoustic Pingers: A wide range of acoustic pingers are available through commercial diving suppliers and manufacturers, and any brand may be used. However, the selected pinger should conform to the following specifications:

1/4 watt
3-year battery life (minimum)
27 kHz
1-mile range
200' operating depth (minimum)

The pinger should be attached securely to the upper third of the primary datum pipe by means of radiator clamps in such a manner as to prevent loss due to initial flooding or strong currents after flooding. To prevent loss of the pinger due to vandalism, the instrument should not be attached to the datum until just before the site is flooded.

Fifty-Five Gallon Drums: Three 55-gallon steel drums, stacked one on top of the other and spot welded together should be placed in a location near the primary datum. Numerous large holes should be punched in all of the drums and the bottom drum weighted with concrete. Any easy-mix, quick-setting concrete is suitable and two 90-pound bags should produce enough concrete to sufficiently weight the drums to prevent their loss.

A point on the drums, level with the top of the primary datum pipe, should be selected and information on the distance and compass-bearing to the primary datum permanently marked on the drum. Steel letter stamps are suggested for this purpose. The drum point may be also indicated in this manner; however, a ring or loop welded at the selected point is preferred. The distance and compass bearing of the primary datum from the drums, as well as the location of the drums relative to the secondary datum triangulation-points, should be recorded on site maps.

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APPENDIX A: SUPPLEMENTS TO GUIDELINES FOR DATA-COLLECTION AND SITE-PREPARATION

Undisturbed block or cube samples.[1] The surface of the soil to be sampled is trimmed smooth and roughly level. For large cube samples, a square column of soil 1 in. *[3 cm] smaller on each side than the inside dimensions of the box. [The cube may be wrapped with cheese-cloth prior to placing the box over sample]. The box is centered over the sample and is seated on the soil surrounding the bottom of the sample. Loose soil may be lightly tamped around the outside bottom of the box to effect a good seal. A 50/50 mixture of paraffin (crystalline wax) and microcrystalline wax that has been allowed to cool almost to the congealing point is poured around the sample to the top of the box. After the wax mixture has cooled, the box cover is attached. The sample is then cut loose with a spade and turned over. The bottom of the sample is trimmed out to 1/2 in. [2 cm] below the bottom of the box, and this space is filled with the wax mixture. Care must be taken to ensure a good bond between this wax and the wax previously poured so that the sample is completely encased in the wax. As the soil at the bottom of the sample is trimmed out, the exposed surface of the wax mixture should be scraped clean of all foreign material, and a small amount of very hot wax mixture first applied in order to partially melt the exposed wax to ensure a good bond between the two pours. After the wax mixture has cooled, the bottom of the box is attached.

[1] U.S. Army Corps of Engineers Manual, Engineering and Design, Soil Sampling, June 30, 1969, p. 70.

*The material in brackets has been added during a review process by Inundation Study personnel.

APPENDIX B: SOIL MONOLITH PREPARATION[1]

1. Locate a representative site. Avoid roadcuts or other disturbed areas.

2. Prepare a nearly vertical plane surface on one wall of the pit.

3. Mark out the section to be sampled. Lateral variation of horizons determines a suitable width. Most of our monoliths are 6 inches wide.

4. Apply as much vinylite resin solution as will soak into the soil. A plastic bag or an ice cream carton is a suitable container. Punch a small hole near the bottom of the container when you are ready to apply the solution. If the soil is not structurally stable wait 24 hours. Otherwise proceed as soon as the resin surface is dry (15 to 30 minutes).

5. Apply one uniform coating of cellulose acetate solution by pouring it from a carton or can. Some guiding or brushing may be necessary.

6. Wait until the surface is dry (15 to 30 minutes). Excavate the soil on either side of the treated section. Be <u>cautious</u> as you cut close to the edge of the treated section, using a <u>sharp</u> knife.

7. Place a <u>smooth</u> board against the treated section. Cut behind the soil column, starting at the top. Secure cloth ties around the soil column and board. If the soil is not structurally stable, put the ties very close together. If necessary, slide a sheet of cloth or plastic behind the soil column as you cut behind it, and then secure the ties. Cut <u>clear to the bottom</u> of the section. You will need pruning shears and a pruning saw to cut roots.

8. Cut through any remaining soil; make sure that the bottom of the column is severed, and then pull the board and its soil column to a horizontal position.

9. Remove the cloth ties. Put a <u>clean</u> mounting board beside the soil column. It should be wider and longer than the column. Leave about 1 inch of board at the top and about 6 inches of board at the bottom.

10. Apply a strip of cellulose acetate solution to the mounting board.

11. Lift the removal board and the soil column over the mounting board, and slide the removal board out from under the soil column. Avoid scraping the cellulose acetate glue off the mounting board. Have some assistants help in this step the first time you attempt it.

12. Position the soil column carefully, and push any loose soil pieces back into place. Scrape off any excess cellulose acetate.

13. Wrap the soil monolith securely before transporting it.

14. Unwrap the soil monolith. When it dries to a moisture content in the upper field capacity range the structure will be most apparent. Work out a natural looking surface. Avoid leaving knife marks. If the soil is too dry when collected, or becomes dry before you are ready to remove excess soil, rewet the profile and let it dry to a suitable water content. Do not try to work out a completely dry profile except in the case of very sandy or gravelly soils. Do not try to work out massive horizons when they are dry. Use a knife with care. Use air from a hose or suction from an industrial-type vacuum cleaner as you remove excess material.

15. Let the soil dry completely. Keep it in a safe place, where it will not be moved or jarred, since it is not stable.

16. Apply enough vinylite resin solution to soak the soil completely to the board. A can or cardboard carton with a hole punched near the base works well. Soak a small section of the profile (about 6" x 6") at one time. Avoid going back over a wetted section, to prevent forming a shiny resin skin on the surface.

17. Let the profile dry 24 hours. Test structural pieces with the fingers to see if any are loose. If many are loose repeat step 16. This is rarely necessary but may be required if a soil has a high content of swelling clay and strong blocky or prismatic structure.

18. Let the profile dry 24 hours if it has been retreated.

19. Check again for loose pieces. Use cellulose acetate dispensed from a simple oil can (enlarge the tip) to glue any loose pieces. Use care.

20. Apply a bead of cellulose acetate around the edge of the profile. This will have to be done with the board and monolith tipped, and may have to be repeated. Wait until the bead on one edge is completely dry before you tip the board at a different angle. If there are large voids between the board and monolith surface, fill with tissue and moisten with cellulose acetate. Compress the tissue to a smooth surface. Apply extra coats of cellulose acetate to the tissue surface until it is entirely smooth along the bead.

21. Wait 24 hours. Paint the exposed board and attach a mounting wire.

22. Attach pictures or other information - items below the monolith.

23. Handle with care. At five- to ten-year intervals reglue any loose pieces. If an entire section becomes loose, use vinylite resin again. The board will then need to be sanded and repainted.

24. Materials

(a) Mount on plywood 1/2 inch thick.

(b) Acetone -- any chemical supply house and some paint stores. Store away from any flame. Avoid breathing fumes. Source example:

Van Waters and Rogers
N. 809 Washington Street
Spokane, Washington

About $1.00 per gallon.

(c) Methyl isobutyl ketone -- many chemical supply houses. See precautions under acetone. Source example:

Great Western Chemical Company
West 1133 College Avenue
Spokane, Washington

About $1.20 per gallon.

(d) Cellulose acetate -- very <u>few</u> chemical supply houses. Source example:

Cellulose acetate E-398-3, from
Eastman Chemical Products
Kingsport, Tennessee

$30.00 per 50-pound bag (minimum).

(e) Vinylite resin -- very few sources. Source example:

VYHH grade, from
Union Carbide Corporation
Plastics Division
22 Battery Street
San Francisco, California

$50.00 per 100-pound bag (minimum).

(f) Cellulose acetate solution:
2,250 grams cellulose acetate in 5 gallons of acetone. Store in an all-metal container. Make up at least one week before it is needed. Shake or stir frequently to speed solution. Put some acetone in the bottom of the container before you add the cellulose acetate to ensure solution. Keeps indefinitely. Shake before using. Avoid getting glue on the threads of the plug.

(g) VYHH vinylite resin solution:
1,200 grams VYHH resin in 5 gallons of a mixture of acetone

(about 2/3) and methyl isobutyl ketone (about 1/3). See item (f) for precautions. Keeps indefinitely.

25. This procedure is based on the original work of Voight, in Germany, and of Berger and Muckenhirn, in Wisconsin, U.S.A. Modifications have been proposed by many persons. For selected references see Smith and Moodie (Soil Sci. 64:61-69, 1947) and Smith, McCreery, and Moodie (Soil Sci. 73:243-248, 1952).

[1] Henry W. Smith
Professor of Soils
Washington State University
Pullman, Washington 99163

May, 1973

APPENDIX C: PALLMANN METHOD FOR MASS SAMPLING OF SOIL, WATER, OR AIR TEMPERATURES[1]

Abstract

Mass sampling of temperature is required in many types of earth science problems. An accurate, precise, and economical technique for mean temperature determination in soil, water or air is afforded by the Pallmann solution method, which relies on the irreversible breakdown of sucrose sugar into the simpler forms, d glucose and d(-) fructose. These sugars are optically active, thus changes in their concentration results in measurable changes in the optical properties of the solution. Since optical rotation ratios are proportional to chemical concentration ratios, one may determine the reaction velocity coefficient, which in turn depends on temperature according to the van't Hoff-Arrhenius Law...

Theory

...This irreversible breakdown of cane sugar into simpler sugars is accompanied by changes in the optical properties of the solution, which can be measured by means of an optical polarimeter...

Accuracy and Precision

*[The temperature determined by this method is not the arithmetic mean temperature. Since sucrose hydrolysis responds exponentially to temperature changes, the "Pallmann Temperature" will be an integrated exponential temperature. However, the change of rate of hydration of obsidian with temperature is also an exponential function, and the Pallmann temperature is a closer approximation to the effective hydration temperature than is the arithmetic mean annual temperature. The precision of the Pallmann method depends upon proper calibration of the Pallmann solutions]...The absolute accuracy of the Pallmann method is "...influenced by a series of minor laboratory and field measurement problems...but overshadowing all other sources of inaccuracy is that sucrose hydrolysis responds exponentially to temperature changes..." (Lee 1969, p. 425). The cumulative error from field and laboratory sources is considered small.

Solution Preparation

The Pallmann solution is an acidified, buffered sucrose solution composed of two solutions mixed in volume 1:1. In one there are 1,500 gm

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[1]Philip J. O'Brien, <u>Geological Society of America Bulletin</u>, October, 1971, 82:2927-2932.

*The material in brackets has been added during a review process by the Inundation Study personnel, and Dr. Irving Friedman, geochemist with U.S. Geological Survey in Denver, Colorado.

of sucrose in 1,000 ml of water, and in the other 404 ml of 0.2 m sodium citrate (buffer) plus 596 ml of 0.2 n hydrochloric acid. In order to inhibit the growth of microorganisms, a small amount of formaldehyde is added. Each sensor costs about $0.15 to prepare.

The Pallmann solution freezes at -4.7°C. This results in cessation of the sucrose hydrolysis reaction; moreover, the reaction will not continue until complete thawing of the solution has occurred. Addition of 150 gm liter $^{-1}$ of reagent grade sodium chloride depresses the freezing point from -4.7°C to about - 20°C. If salt is added to the solution, the constants a and b of equation (7) becomes 5656.3 and 19.5797 respectively, as determined by Lee (1969, p. 429). [EQ. 7]:

$$T_{(°K)} = \frac{-a}{pH - b - \log + \log[\log(\underline{Rinit} - \underline{Rinfi}) - \log(\underline{Rtime} - \underline{Rinfi})]}.$$

Since the sucrose hydrolysis reaction is catalyzed by hydrochloric acid, setting of solution pH must be carefully controlled to at least two decimal places.

Selection of the appropriate pH may be guided by reference to graphs published by Schmitz and Volkert (1959, p. 6). To use these charts three quantities must be estimated. First, an estimate of the mean temperature to which the solution will be exposed must be made; further, the approximate number of exposure days must be determined and finally, the amount of rotation which the experimenter wishes the solution to undergo is selected. The usual range of Rtime is 10° Rtime 30° using a mercury light source. With these three values, the pH needed to achieve the desired optical rotation is ascertained.

Two sample batches are taken from the mixed chemicals. The first is composed of two subsamples whose rotation angles are immediately read to establish the initial roatation angle (Rinit) of the solution prior to any hydrolysis. The other batch of ten 20 ml samples is placed in an oven at low heat. Every 15 min. one sample is removed and its rotation angle read. This procedure is continued through the end point of the reaction in order to establish the final rotation value of the solution (Rinfi). The remainder of the sample batch is poured into 20 ml glass ampoules and sealed quickly with a high intensity flame. The ampoules are then immediately frozen since sucrose inversion stops when the sensors are frozen. Ampoules must be kept frozen prior to exposure at the field site and refrozen upon retrieval. This is easily accomplished with dry ice.

Laboratory Analysis and Computation

Rotation angle readings are made on a precision polarimeter such as the Rudolph Model 70 used by the writer. The device consists of a mercury vapor light source, a polarizer unit, a tube trough, a sample tube and an analyzer head. --

Ampoules are removed from the laboratory freezer at 5 minute intervals and placed in a water bath at room temperature. After 15 min each ampoule is removed, dried, and shaken vigorously for a few seconds to disperse liquid crystals which form after thawing. The crystals have a threaded texture and polarimetric determinations are impossible in their presence.

At this point, the ampoule is broken open at the neck and about 4 ml of the solution is poured into the sample tube, washed about and poured out. The sample tube is then filled, making sure that trapped air bubbles are released. The tube is placed in the tube trough and readings are made through the reading port on the analyzer head after adjusting the image through the microscope. Immediately after reading the rotation angle, a mercury bulb thermometer is inserted in the sample tube and a measurement made so that correction to standard temperature conditions can be made if necessary. At this point, all values needed for calculation of the exponential mean temperature according to equation (7) are available. [A commented FORTRAN IV computer program for calculation of (°F) from equation (7), with a standard temperature correction subroutine is available from the author].

Field Use Example

The writer studied the soil temperature regime in an area of the Mohawk River Valley flood plain west of Schenectady, New York, during 1968-1969. A series of 58, 6 ft. deep, ½ in. diameter auger holes were constructed for this purpose. Temperatures were measured at each station of this network on eight different occasions during the two-year experiment period using an electronic thermistor probe system. During the winter period (1968-1969), when the ground was frozen and snow-covered, mean soil temperatures 6 ft. below ground surface were determined by the sucrose hydrolysis method.

Field installation of the ampoules was accomplished as follows. About four frozen ampoules at a time were transferred from a picnic cooler containing dry ice to a small, hand-carried cold case also provided with dry ice. At each auger hole site the 1-ft long, wooden marking stake [for Inundation Study purposes - minimum marker stake length should be 1.5m, set for 60cm below the surface to aid stability] was removed and a 6-ft. strand of no. 20 copper wire was fastened to the tip of the stake. An ampoule was then removed from the cold case and the free end of the copper wire attached to it. The ampoule was lowered to the bottom of the auger hole, thus coming to rest in the temperature environment of the surrounding soil. The marking stake was then replaced and the soil was firmly tamped about it...the 6-ft soil temperature range, in the subject area, was 5.6°C about a mean of 7.5°C. Thus, departure of the exponential mean from the arithmetic mean was slight, as is commonly the case in soils.

A comparison of the mapped temperature data for each of the eight different observations series revealed significant spatio-temporal consistency of the 6-ft soil temperatures. The elongate, north-south temperature axis persisted as a maximum and several subsidiary temperature convolutions maintained themselves.

The quasi-steady state soil temperature regimen, suggested above, allowed a simple test of sucrose method reliability. One would expect the chemically determined soil temperature pattern to be closely similar to the pattern occurring before and after the period of ampoule exposure.

Conclusions

The sucrose hydrolysis method is an accurate, precise, and economical method for mass sampling of mean temperature. The technique should therefore find increasing application in ecological and environmental studies. This paper, in addition to the cited references, provides an adequate basis for effective utilization of Pallmann solution methodology.

REFERENCES CITED

Lee, R.
1969 "Chemical Temperature Integration" Journal of Applied Meteorology 8(423-430).

Schmitz, W.; Volkert, E.
1959 The Measurement on a Reaction Velocity Basis With the Polarimeter and its Use in Climatology and Ecology, Especially in Hydrology and Forestry. U.S. Department of Commerce-Foreign Area Section-Translation WB/T-110, 1966, 30 p. [trans. from German by Brumbach, J.J., and Lee, R.].

APPENDIX D: FIELD COLLECTING PROCEDURES AND MEASUREMENT PREPARATION[1]

The primary consideration in selecting suitable burnt features for magnetic dating is whether any movement has occurred in the sample since baking. Disturbed features will introduce unknown amounts of error in the results. Second, is a practical question whether the samples can be extracted without breaking. Third, they should be well baked and free from impregnation of organic matter. Finally, since local magnetic fields can introduce error, it is desirable to obtain at least 5 samples from any single locality, and preferably as many as 20.

The Archaeological Research Laboratory in England, one of the principal institutions conducting research and development in this technique, has published a rating of the quality of various kinds of features with respect to archaeomagnetic dating:

> Category I (good): Structures containing a substantial floor of well-baked clay.
> Category II (average): Kilns and ovens having an intact circumference of solid wall, not less than a foot in height; well-built clay hearths.
> Category III (poor): Unsubstantial hearths, kilns with incomplete walls, patches of burning, iron-smelting sites.
> Category IV (very poor): Stone structures, poorly fired tile, and brick ovens.

Once the best sampling area of the feature to be dated has been select ed, the next step is to isolate a series of close-spaced, tiny pillars of burnt clay which can fit into the 2-by-2-inch brass frame of the extraction jig. This is a time-consuming process, since such pillars have to be excavated out from the surrounding material. The task must proceed cautiously so as not to dislodge or break off the stumplike projections that are being isolated. Dental picks, awls, knives, chisels, and other small hand tools are employed for this purpose. The burnt clay matrix is often very hard and makes the job especially difficult.

The extraction jig is then mounted, in turn, over each isolated sample. The brass frame is slipped carefully over the pillar, and with the aid of modeling clay it is carefully leveled (by reference to built-in bubbles for leveling), and oriented to present-day magnetic north. The orientation is carried out with a Brunton compass that fits over the top of the jig. Dental plaster then is poured into the frame, surrounding and covering the pillar of clay. The plaster is smoothed

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[1] Joseph W. Michels, Dating Methods in Archaeology, Seminar Press, New York, 1973, pp. 134-136.

flush with the top of the brass frame while still wet. After the plaster has dried (a matter of a few minutes), a cutting instrument is carefully inserted beneath the frame, and the base of the tiny pillar is cut off flush with the frame. The sample now can be moved. It is turned upside down and additional plaster is poured over the bottom and smoothed flush with the frame. Once dry, the frame is removed and a perfect 2- by -2 inch cube of white plaster is revealed. Notations are inscribed on the surfaces of the cube indicating orientation and provenience. When the cubes are received at the dating laboratory, they are routinely washed clean of any viscous remnant, chemical or isothermal magnetization by means of thermal demagnetization from a temperature of 60°C to standard room temperature.

THE FINAL REPORT OF THE NATIONAL RESERVOIR INUNDATION STUDY: AN ANNOTATED BIBLIOGRAPHY

Toni Carrell
editor and chief compiler

This bibliography resulted from research undertaken by National Reservoir Inundation Study personnel over a 4½-year period.

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INTRODUCTION

The publication of the final two volumes of the National Reservoir Inundation Study makes obsolete and supercedes both of the previous publications of the study, The Effects of Freshwater Inundation of Archeological Sites Through Reservoir Construction: A Literature Search (Carrell et al. 1976) and The Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977).

Both of those publications contained numerous references used by the research team to gain an understanding of the nature of reservoir impacts and to apply that knowledge in the development of hypotheses and test implications addressing the problem of impacts to cultural values resulting from freshwater flooding.

The present bibliography includes references from the above documents and, additionally, has been expanded upon with the continued of the inundation study research. This technical report is designed to serve several purposes: 1) it is a compilation of reference materials used by the National Reservoir Inundation Study personnel over the 4½-year study. This information is provided so that the reader may find those documents which lead to our research conclusions; 2) it highlights areas of special concern to the Inundation Study research, i.e., mechanical and biochemical impact processes, dating and analysis techniques, mitigation efforts, etc.; 3) it provides an annotated list of reports or other documents generated as a result of the Inundation Study research; and 4) it is a comprehensive bibliographic list for both volumes of the final report.

Invaluable assistance was provided by the research library of the Bureau of Reclamation Engineering and Research Center, Denver, Colorado, for references on reservoir processes. The Department of the Interior Field Services Library was also very cooperative; however, they were only able to offer four additional references on freshwater flooding impacts.

It should be understood that this bibliography was not intended to be exhaustive of any of the categories of special interest investigated. Rather, it is an overview of information on the particular subject and lists references cited in the two volumes of the final report. Not all of the references in each section were annotated. An effort was made, however, to annotate those citations of particular relevance to the subject in question, others were annotated simply because of their ready availability for review.

The bibliography is broken into sections. Section headings and a brief discussion of each follows:

Section 1: Effects of Freshwater Inundation -- Research Reports

This section includes reports or other documents generated as a result of the inundation study research. In some cases, the reports or analysis were contracted for by the study, in others principal investigators coordinated with the study archeologists of their own accord to ensure that some of their work would be applicable to the inundation research. This section was annotated to aid individuals with specific areal or impact interests.

Section 2: Biochemical Impact Processes

The biochemical environment of a freshwater reservoir may have substantial long term impact on the preservation of cultural remains. Hydrologic processes which influence the reservoir environment are addressed in the subsection General Limnology. A brief subsection on Soils is included because of its particular relevance to the overall quality and chemical content of impounded waters. The subsections on Soil Microbiology and Biodeterioration were included because of their obvious implications for long term preservation of buried remains in reservoirs.

Section 3: Mechanical Impact Processes

Mechanical impacts to archeological resources includes all those dynamics associated with water movement such as wave action, currents, and winds. Many of the sources of information on this subject come from the Bureau of Reclamation Engineering and Research Center Library.

Section 4: Reservoir and Nonreservoir Freshwater Impacts

This section includes references dealing with inundation impacts upon archeological resources in reservoirs. The General subsection lists references dealing with the subject of inundation per se. Official correspondence is included in this subsection in order to provide an historical perspective to the Inundation Study research. The Reservoir Specific subsection includes references dealing directly with inundation impacts, noted by archeologists and others, in specific reservoir areas. Riverine, Karst, and Natural Lake environments share many of the same variables as reservoirs and so are included as subsections.

Section 5: Differential Preservation of Cultural Materials

This section provides references documenting artifact preservation or deterioration in both the freshwater and marine environments. Texts contributing to an overall understanding of environmental processes on preservation of cultural remains are also included.

Section 6: Dating and Analysis Techniques

Publications dealing with the technical research aspects of the study are included in this section. Much of the generating data for the hypotheses presented in The Preliminary Report of the National Reservoir Inundation Study (Lenihan et al. 1977) was based upon these documents. Some of the references are general in nature or provide introductions to these disciplines. This section is not intended to be an exhaustive listing, but rather represents a subjective choice of technical items used by the Inundation Study researchers.

Section 7: Mitigation

This section includes references on experimental work undertaken for protection or stabilization of sites undergoing attack through various reservoir processes. Also included are references on general techniques for stabilization of soils, slope protection, and plastic covers or linings. References on the conservation of cultural materials after removal from an aqueous environment are also in this section.

Section 8: Cultural Resources Management

References dealing with the general issue of cultural resource management and those potentially having a direct bearing on submerged remains are included in this section. Some articles dealing with the overall question of salvage/conservation in American archeology are also included.

Section 9: Underwater Archeology and Remote Sensing

This section lists references dealing with three broad areas of underwater archeology. The General subsection provides an overview of publications in the field. These range from popularized magazine articles to books directed at the professional archeologist. The Method and Techniques subsection includes papers and texts which stress methodological concerns along with a representative listing of techniques used in underwater archeology. Selected publications have been annotated, some because of their particular relevance to the inundation study, others because they stress useful approaches to underwater data retrieval.

The returns that can be gleaned from archeological remote sensing techniques, as they apply to pre- and postinundated sites, was one area of special concern to the Inundation Study. This subsection, Remote

Sensing, includes articles dealing with both conventional aerial remote sensing and specialized underwater archeological remote sensing techniques.

Section 10: Legal Aspects, Vandalism, and Antiquities Violations

The references in this section address the legal considerations of underwater archeology. An overview of pertinent legislation, articles, newspaper clippings, and other materials are listed. References on vandalism and antiquities violations are included because this type of depreciative behavior tends to increase following reservoir pool filling and increased site accessibility.

Section 11: Miscellaneous References

This section includes references of relevance to the inundation study problem not covered by the prior section headings.

SECTION 1: EFFECTS OF FRESHWATER INUNDATION--RESEARCH REPORTS

Adovasio, J. M.; J. Donahue; W. C. Johnson; J. P. Marwitt; R. C. Carlisle; J. D. Applegarth; P. T. Fitzgibbons; and J. D. Yedlowski
1980 "An Inundation Study of Three Sites in the Bluestone Reservoir, Summers County, West Virginia." Unpublished report. University of Pittsburg, Pittsburg, Pennsylvania. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

> Adovasio et al. discuss the differential impacts of flooding on cultural remains at three sites. The sites, continuously, aperiodically and never inundated are temporally similar and, therefore, provide an excellent base for comparative studies. Analyses include grain size and soil chemistry; water absorption, tensile strength and calcium concentration in bone; differential preservation of bone, shell, ceramics, pollen and stone; human and faunal impacts; and carbon 14 and thermoluminescence dating.

Arnold, J. Barto III and A. Wayne Prokopetz
1977 "Prehistoric and Historic Archeological Site Magnetometer Surveys in the Palmetto Bend Reservoir Area." Unpublished report. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

> Arnold and Prokopetz conducted a baseline magnetometer survey of two sites in Palmetto Bend Reservoir. This study was designed to test the NRIS hypothesis that the results obtained from a magnetometer after flooding would not be substantially altered. This report provides the baseline data prior to flooding for later comparison.

Carrell, Toni L.; J. Alan May; and Ervan G. Garrison
1980 <u>National Reservoir Inundation Study Research at Round Spring and Alley Spring, Ozark National Scenic Riverways, Missouri</u>. U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

> Carrell, May and Garrison provide an overview of the research undertaken at the two springs during the establishment of a field experiment to test the impacts of freshwater immersion on archeological materials. During the investigations an archeological site was discovered

under 10 feet of water in Round Spring Grotto. The report includes analysis of the artifacts recovered and discussion of inundation impact hypotheses addressed by follow-up analysis of the artifacts.

Chance, David H.; Jennifer V. Chance; and John L. Fagan
1977 "Kettle Falls: 1972 Salvage Excavations in Lake Roosevelt." University of Idaho Anthropological Research Manuscript Series No. 31. University of Idaho, Laboratory of Anthropology, Moscow, Idaho.

Chance, Chance and Fagan provide a thorough research report and provide indirect information on inundation impacts to soil strata; preservation of perishables such as wood, seeds, nuts, and other fiberous materials; and iron and other related historic remains.

Cox, Jerry L.; Victoria D. Kaplan; Scott M. Patterson; and Steven E. Stoddard
1977 "The Effects of Freshwater Immersion on Cultural Resources of the Coyote Dam-Lake Mendocino Project Area, Ukiah, California." Unpublished report. Sonoma State College, Foundation for Educational Development, Rohnert Park, California.

The U.S. Army Corps of Engineers, San Frnacisco District, contracted with Sonoma State College to undertake a survey and evaluation of several sites in Lake Mendocino which had been flooded for nearly 20 years. The drought in 1976 provided an excellent opportunity to evaluate these sites to determine the nature of the remaining cultural deposits and their potential for future research after a prolonged inundation. Cox et al. discuss the problems encountered in relocating previously recorded sites, their condition during the drought along with the effects of increased accessibility by visitors to the lake.

Fosberg, Stephen L.
1978a "A Laboratory Experimental Design for Investigating the Effects of Water Chemistry Variables on Various Classes of Submerged Archeological Data." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Fosberg's experimental design addresses the problem of water chemistry impact to cultural remains. Water chemical concentrations 10x greater than normally found in reservoirs were used to simulate extended periods of immersion. A variety of cultural materials were used in the laboratory; their deterioration was monitored by periodic removal and testing. The results of this experiment are reported on elsewhere in Volumes 1 and 2 of this report.

1978b "An Experiment at Lake Powell." In Glen Canyon Revisited: The Effects of Reservoir Inundation on Submerged Cultural Resources, Rayl et al.:59-66. Unpublished report. U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Fosberg discusses a field experiment to gather additional data on the effects of short term immersion on cultural remains.

1979 "A Field and Laboratory Program for Determining the Differential Effects of Reservoir Biological Activity and Water Chemistry on the Preservation of Archeological Materials." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Fosberg outlines an approach to collect data on macro- and microbiological impacts to cultural remains through a 3-pronged field and laboratory research project. A variety of cultural materials, similar to those used in a laboratory experiment, were used. The results of this experiment are reported on elsewhere in Volumes 1 and 2 of this report.

Foster, John W.; Jeffrey C. Bingham; Christina Carter; Karen Cooley-Reynolds; and John L. Kelly
1977 "The Effects of Inundation on the Pedersen Site, CA:ELD:201, Folsom Lake, California." Unpublished report. California State Parks and Recreation Department, Sacramento, California. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Foster et al. discuss the impacts of wave action and erosion on the Pedersen Site. Housepit remnants have been pedestalled and clams have burrowed into the remaining midden areas. Advanced deterioration of stone artifacts was also documented.

Foster, John W. and Jeffery C. Bingham
1978 "Archeology in Solution: Testing Inundation's Effects at Folsom Reservoir California." Unpublished report. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Foster and Bingham discuss the effects of hydrodynamic sorting of artifacts at the Pedersen Site which resulted from wind and wave action coupled with soil redeposition. They documented a direct correlation between downslope location and artifact weight. Carbon 14 dating results from a previously inundated hearth were not skewed as a result of inundation, nor were artifacts "settling" within remaining intact midden areas. Bone fragments buried in the site appeared to be in a good state of preservation with butchering scars still visible after 20 years of inundation. Stone artifacts high in soluble chemicals showed a high degree of deterioration.

Fredrickson, David A. and Thomas M. Driger
1977 "The Archaeology of the Lake Mendocino Project Area, Mendocino County, California." Unpublished report. Sonoma State College, Foundation for Educational Development, Inc., Rohnert Park, Californa.

Garrison, E. G.; J. A. May; W. H. Marquart; and A. Sjoberg
1979 A Final Report on the Effects of Inundation on Cultural Resources: Table Rock Lake, Missouri. University of Missouri-Columbia, American Archaeology Division, Department of Anthropology, Missouri.

Garrison et al. discuss the results of over two years research into inundation impacts at four sites in Table Rock reservoir. Areas addressed in this report included: differential preservation of stone, microscopic analysis of stone artifacts, phosphorus concentration in soils, loss of qualitative data relating to strata and features, mechanical impacts to soil strata and faunal impacts.

Gradwohl, David M. and Nancy M. Osborn
1977 "Eyeing the Gathering Waters Whilst Building the Ark: Preparation of Archaeological Site 13PK183, Saylorville Reservoir, Iowa, for Post-Inundation Study." Unpublished report. Iowa State University, Archaeological Laboratory, Ames, Iowa.

Gradwohl and Osborn outline the specific procedures undertaken at 13PK183, a prehistoric site within the conservation pool of Saylorville Reservoir, to prepare it for initial flooding and to facilitate follow-up study. Profiles were prepared, a plexiglas stratigraphic sheet installed and samples collected for later post-inundation comparative analysis.

Holloway, Richard G.
1980 "Pollen Exine Deterioration and Preservation in Brady Reservoir." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Laing, David
1978 "Trace Elements and Inundation: No Effect." Unpublished report. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Laing was contracted to determine whether trace element analysis would be affected as a result of inundation of obsidian. His conclusion of "no effect" may be invalid, however, due to errors in selection of elements as well as the nature of those elements selected. Schaafsma (1978:53-56) discusses the potential problems in Laing's approach and concludes that a no effect finding is not supportable based solely on Laing's analysis.

Lenihan, Daniel J.; Toni L. Carrell; Thomas S. Hopkins; A. Wayne Prokopetz; Sandra L. Rayl; and Cathryn S. Tarasovic.
1977 _The Preliminary Report of the National Reservoir Inundation Study_. U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico and Cultural Resources Management Division (Archeology), Washington D.C.

Lenihan et al. outline specific hypotheses to be tested over the four-year duration of the National Reservoir Inundation Study. The results of this testing program are reported on in Volumes 1 and 2 of this final report.

Padgett, Thomas J.
1978 "Blue Mountain Lake: An Archeological Survey and an Experimental Study of Inundation Impacts." _Arkansas Archeological Survey, Research Report No. 13_. Fayetteville, Arkansas.

Padgett discusses the setting up of a completely artificial site along with numerous experiments to test the impacts of freshwater flooding on archeological remains. A complete record of the tests and procedures is included. Following the next reservoir drawdown the site is to be re-excavated and comparitive analyses performed.

Rayl, Sandra L.; Stephen L. Fosberg; Daniel J. Lenihan; Larry V. Nordby; and John A. Ware
1978 "Glen Canyon Revisited: The Effects of Reservoir Inundation on Submerged Cultural Resources." Unpublished report. U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Rayl documents the impacts resulting from relatively short-term immersion of several Anasazi sites in Lake and Moqui Canyons in Glen Canyon National Recreation Area. Also included are special sections by Nordby on an attempt at structural stabilization underwater, and Fosberg on a field experiment to gather data on inundation impacts to selected cultural materials.

Rowlett, Ralph M. and Carol Bates
1979a "Inundation Effects on Thermoluminescence Response of Archaeological Lithics from Chesbro Reservoir." Unpublished report. University of Missouri, Department of Anthropology, Columbia, Missouri. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe New Mexico.

Rowlett and Bates suggest that continuous inundation may indeed adversely affect thermoluminescence dating. Periodic inundation does not appear to skew TL results.

1979b "Effects of Inundation on Archaeological Materials from the Navajo Reservoir." Unpublished report. University of Missouri, Department of Anthropology, Columbia, Missouri. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Rowlett and Bates conclude that continuous inundation has a deleterious effect on TL response making it "less consistent and... diminishing the amount of response" (Rowlett and Bates 1979b:9).

1980 "Inundation Effects on Thermoluminescence Response of Archaeological Remains from Bluestone Lake Reservoir, Somers County, West Virginia." Unpublished report. University of Missouri, Department of Anthropology, Columbia, Missouri. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Rowlett and Bates analysed a total of 26 samples for TL response. Shell tempered samples from a rarely inundated site provided the most accurate results; samples that had been periodically and annually inundated were adversely affected, TL response having been reduced.

Schaafsma, Curtis
1977 "Evaluation of Abiquiu Reservoir Archaeological Materials for Inclusion in the National Park Service Inundation Study." Unpublished report. School of American Research, Santa Fe, New Mexico.

Schaafsma evaluates the potential research value of the Abiquiu sites to the ongoing inundation research.

1978 The Mechanical and Chemical Effects of Inundation at Abiquiu Reservoir. School of American Research, Santa Fe, New Mexico.

Schaafsma documents a variety of impacts including siltation, soil erosion, collapse of cliffs and collisions between floating driftwood and standing structures. Results of computer testing of lithic redistribution revealed that those materials on gentle slopes were not disturbed, however, lithic distributions on steeper slopes or impacted by moderate to heavy wave action were severely disturbed. Surface contact or shallowly buried features have suffered varying degrees of destruction. Loosely compacted soil, direct mechanical activity, and degree of slope appear to be the major factors involved in preservation or deterioration of these features.

Schroedl, Gerald F.
1977 Experiments for Monitoring the Effects of Inundation on the Toqua Site (40Mr6), Tellico Reservoir, Monroe County, Tennessee. University of Tennessee, Department of Anthropology, Knoxville, Tennessee.

Four trenches were excavated and set up at Toqua to test impacts of inundation. Soil profiles were drawn and samples collected for analysis. Trenches 1, 2 and 4 were backfilled while trench 3 was left open. Prior to backfilling trench 4, a plexiglas profile sheet was placed against the east wall. Two hearths were also capped with a thin mantle of concrete. Prior to initial flooding, extensive vandalism completely destroyed the inundation study experiments.

Sjoberg, Alf
1978 "A Final Report on Chemical Effects of Inundation on Archaeological Sites in the Abiquiu Reservoir, New Mexico." Unpublished report. American Archaeology Division, Department of Anthropology, University of Missouri, Columbia, Missouri. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Sjoberg analysed 160 soil samples from 3 sites for pH, phosphorus, potassium, sodium, calcium and magnesium. The two applications of the soil analysis at Abiquiu addressed: a) intra-site patterns of surface chemical variability; and b) patterns of chemical variability of features. A detailed review of Sjoberg's analysis is provided by Schaafsma (1978).

Stafford, Jean and Robert Edwards
1979 "A Baseline Data Study of Three Archaeological Sites at Chesbro Reservoir." Unpublished report. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Stafford discusses in detail the approach used in gathering baseline data at three sites in Chesbro Reservoir. These sites, one continuously inundated, one partially inundated on a seasonal basis, and one never inundated, provided an excellent opportunity for inter- and intra-site comparisons of inundation impacts. Preliminary results of pH analysis, phosphorus and soil texture analysis are included. Two longevity studies were set up; one to test differential rates of faunal osteological remains deterioration, the other to quantify artifact redistribution and midden soil erosion/deposition. A thorough, very complete report.

Stafford, Jean and Robert Edwards
1980 "Results of Testing Inundation Impacts on Site CA-SCL-52 at Chesbro Reservoir." Unpublished Report. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Stafford and Edwards address the short term results of four experiments on: 1) the effects of seasonal inundation on the provenience of surface artifacts; 2) the effects of seasonal inundation on the preservation of artifacts; 3) the effects of seasonal inundation on soil stratigraphy; and 4) the effects of inundation on the subsurface faunal component of archeological sites. A well written, informative document.

Stoddard, Steven E. and David A. Fredrickson
1978 "Supplementary Investigations into the Effects of Freshwater Immersion on Cultural Resources of the Lake Mendocino Reservoir Basin, Mendocino County, California." Unpublished report. Sonoma State College, Foundation for Educational Development, Rhonert Park, California.

Stoddard and Fredrickson report on the condition of prehistoric and historic sites, not investigated in 1976, which had been inundated for nearly 20 years. These sites were exposed as the result of a prolonged drought in the Western states. Erosion, slumping and terracing, along with differential preservation of historic and prehistoric cultural materials are documented.

Struever, Mollie
1980 "Seed Deterioration Under Inundation Conditions: An Experimental Study." In The Final Report of the National Reservoir Inundation Study, Volume II, Lenihan et al., U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Ware, John A.
1978 "National Reservoir Inundation Study Interim Report." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Ware presents a brief progress report on selected preliminary results of two years of inundation study research. This manuscript contains a good discussion of reservoir related mechanical impact processes.

Ware, John A.; Sandra L. Rayl; and Stephen Fosberg
1979 "The Assessment of Freshwater Inundation Impacts on Cultural Resources: An Experiment in Differential Preservation." Unpublished manuscript. Presented at the Second Conference on Scientific Research in the National Parks, November 26-28, 1979, San Francisco, California. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Ware, Rayl and Fosberg discuss the experimental design of a laboratory experiment addressing differential preservation of a wide variety of common cultural remains. This project was conducted at the University of New Mexico under the auspice of the National Reservoir Inundation Study. The results are reported on elsewhere in the Volumes 1 and 2 of this final report.

Winter, Joseph C.
1977 "The Archeological Resources of Chesbro Reservoir." Society for California Archaeology Occasional Papers in Cultural Resources Management No. 1.

Winter presents a preliminary discussion of inundation impacts to three sites in Chesbro Reservoir. A detailed follow-up baseline study and experimental program of research has been reported by Stafford and Edwards (1979).

Wolfman, Daniel
1977 "An Inundated Archeomagnetic Sample." Unpublished manuscript. Arkansas Archeological Survey, Russelville, Arkansas. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Wolfman analysed a series of nine individually oriented samples from a periodically inundated hearth in Abiquiu Reservoir, New Mexico. Seven of the nine samples produced statistically reliable results and produced a data compatible with the estimated age of the site.

Wolfman, Daniel and Thomas M. Rolniak
1977 "Effects of Inundation on Alpha-Recoil Track Samples from the Abiquiu Reservoir Region." Unpublished manuscript. Arkansas Archeological Survey, Fayetteville and Russellville, Arkansas. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Wolfman and Rolniak tentatively conclude that samples will be subject to uranium contamination in those situations where long inundation and shallow burial in uranium rich soils occurs, rendering analysis results unusable. More deeply buried samples with short term inundation, even in enriched soils, do not appear to be affected.

SECTION 2: BIOCHEMICAL IMPACT PROCESSES

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SECTION 3: MECHANICAL IMPACT PROCESSES

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1975 "Computer Simulation of Beach Erosion and Profile Modification Due to Waves." In Symposium in Modeling Techniques, Vol. II. pp. 1369-1384. American Society of Civil Engineers, New York.

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SECTION 4: RESERVOIR AND NON-RESERVIOR FRESHWATER IMPACTS

GENERAL

Albright, Alan B.
1973 Correspondence with Cal Cummings on the subject of Submerged Archeological Sites. University of South Carolina, Columbia, South Carolina.

Banks, Larry
1973 "Effects of Water Resource Development on Cultural Resources." Need Statement. U.S. Army Corpos of Engineers, Tulsa District, Oklahoma.

> Banks emphasizes the need for research into the effects of inundation upon cultural remains. To salvage and preserve sites threatened by inundation, viable alternatives are needed.

Bingham, Jeffery and Peter D. Shultz
1977 "The Effects of Prolonged Freshwater Inundation on Cultural Resources - Preliminary Report and Recommendations." Unpublished research proposal. California Department of Parks and Recreation, Cultural Heritage Section, Sacramento, California.

> Bingham and Schultz examined archeological sites in four reservoirs in central California which had experienced severe pool level drawdowns during a recent drought episode in the West. The results of their field observations, suggested reasons for the impacts noted and recommendations for future work are provided.

Carrell, Toni
1974 Effects of Inundation (A Research Proposal for Underwater Archeology). University of California, Santa Cruz, California. Unpublished manuscript. On file National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

> Carrell delineates specific areas of data collection, to determine effects of inundation upon cultural remains.

1976 "The Inundation Study: An Introduction." Unpublished manuscript. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Cultural Resources, Santa Fe, New Mexico. Xeroxed.

> Carrell's manuscript documents the historic de- Study and the role of the National Park Service, both in underwater archeology and as the

coordinating agency in this research project. The paper sets forth project goals and orientation within the cultural resource management framework, and outlines the current status and organization of the study.

Carrell, Toni L.
1979 "The Inundation Study: A Unique Approach to Cultural Resources Management." In *Proceedings of the First Annual Conference on Scientific Research in the National Parks ,1976 Vol. II*, New Orleans Nov. 9-12, 1976 Robert M. Linn, editor. U.S. Government Printing Office, Washington, D.C.

Carrell's paper outlines the research approach to be implemented over the 4½-year inundation study. Examples of the hypotheses and specific test implications to be implemented are given.

Cummings, Calvin R.
1975 "Summary of National Park Service Underwater Archeological Activities." Paper presented at the annual meeting of the Society for American Archeology, 7-10 May, 1975, Dallas, Texas.

Cummings' 1975 paper discussed the role of the National Park Service in both marine and inland submerged cultural resource management. The author stressed the importance and implications of the National Reservoir Inundation Study which was in the planning stage at that time.

1976 "A Proposed Study of the Effects of Inundation on Cultural Resources." Paper presented at the Seventh International Conference on Underwater Archaeology, 1976, Philadelphia, Pennsylvania.

In this paper, Cummings analyzed the scope and intent of the National Reservoir Inundation Study, outlining its approach and describing the reservoir variables being selected for study. The presentation emphasized the possible implications that these studies hold for the salvage concept in American archeology.

Fischer, George R. and Marion J. Riggs
1969 *Prospectus for Underwater Archaeology*. U.S. Department of the Interior, National Park Service, Office of Archeology and Historic Preservation, Washington, D.C.

Fischer and Riggs discuss on page 13 the need for underwater archeological investigations of sites immersed following the construction of Roosevelt Dam. Their prospectus was one of the pioneer efforts in the development of an underwater archeological capacity in the National Park Service.

Garrison, E. G.
1975 "A Qualitative Model for Inundation Studies for Archeological Research and Resource Conservation." Plains Anthropologist 20(7) part I:279-296.

Garrison analyzes reservoir dynamics and construction, and summarizes literature dealing with problems of inundation. The paper falls short of a true model for inundation studies, but does sketch a research strategy for various aspects of the problem.

Gates, Gerald R.
1973 "Does Long Term Flooding Harm Sites?" Society for California Archaeology Newsletter 7(1):6-7. California State University, Fullerton, California.

Gates notes that the effects of long term inundation on one particular site in the Van Norman Reservoir seem minimal, but the site's location within the reservoir may explain this result.

Gordon, Garland J.
1976 Draft Inundation Effects Study Proposal." U.S. Department of the Interior, National Park Service, Office of Archeology and Historic Preservation, Interagency Archeology Services, San Francisco, California. Xeroxed.

Gordon expands upon many of the categories which appeared in the draft propectus for the National Reservoir Inundation Study (Lenihan et al. 1975). The author discusses, in depth, factors that can contribute to the preservation or loss of data, and provides a list of data categories that may be affected by immersion. His proposal also considers the question of loss of accessibility and assessment of significance of sites.

Husted, Wil
1973 Correspondence with Cal Cummings on the subject of Effects of Inundation on Archeological Sites. U.S. Department of the Interior, National Park Service, Philadelphia, Pennsylvania.

Jewell, Donald P.
1961 "Freshwater Archaeology." American Antiquity 16(3):414-416. Society for American Archaeology, Washington, D.C.

Jewell's classic early article urges the underwater archeological investigation of reservoir-inundation sites. The author explains the unique preservative properties of freshwater inundation, but also warns that, without underwater research, data will be lost from the destructive processes of reservoir immersion.

1964 "Limnoarcheology in California." In Diving into the Past: Theories, Techniques and Applications of Underwater Archeology, J. Drenning Holmquist and A. Hillman Wheeler, editors, pp. 27-31. Minnesota Historical Society, St. Paul, Minnesota.

Jewell uses the term "Limnoarcheology" to refer exclusively to reservoir inundation studies in the context of this article. Here, Jewell reiterates the concern he expressed in his 1961 article about the loss of data in inundated sites. He suggests possible mitigative measures, such as protective asphalt caps.

Johnson, Jerald J.
1971 "Archeological Sites as Non-Renewable Resources." Proceedings of the Symposium on Environmental Resources Development, 14-15 June, 1971. Institute of Technology and Society, Sacramento State College, Sacramento, California.

Johnson discussing various aspects of site destruction, stresses impacts resulting from reservoir construction. Inundated sites, the author declares, are not preserved; midden areas become soft and gelatinous and lose all associative contextual properties. Therefore, they lose their value as sources for scientific investigation.

Kenney, Lyle A.
1973 Letter to the Editor re: Long-Term Flooding of Sites. Society for California Archaeology Newsletter 7(2):2. Californa State University, Fullerton, California.

Kenney's letter tells of the effect of wave action in erosion of sites, and the subsequent "availability" of artifacts during drawdown periods. The letter suggests the establishment of permanent survey stations, and also proposes reassessment of California dams.

King, Thomas F.
1972 Correspondence with Douglas Scovill. University of California, Riverside, California.

Referring to Jerald Johnson's publication cited above, King's letter emphasizes the need for an intensive study of the effects of inundation of archeological sites.

Lenihan, Daniel J., ed.
1974 "Inundation Studies." In Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources, pp. 28-30. U.S. Dapartment of the Interior, National Park Service, Southwest Regional Office, Santa Fe, New Mexico.

In discussing reservoir inundation of archeological sites, Lenihan officially announces the intent of the Southwest Regional Office's Division of Archeology to initjate studies which, he hopes, will result in better understanding and mitigation of the problem. The author suggests procedures for investigating and testing before, during and after flooding.

Lenihan, Daniel J.
1975 "Directions and Developments in Limnoarcheology in the National Park Service." Paper presented before the Sixth International Conference on Underwater Archaeology, 1975, Charleston, South Carolina. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Archeology, Santa Fe, New Mexico.

Lenihan here redefines "limnoarcheology" (a term coined by Jewell in 1964) to include all aspects of freshwater archeology in a resource-management framework. Reservoir inundation studies, the author believes, are an important aspect of the National Park Service's underwater archeological programs which have been developed in response to its legal mandate to help protect and conserve cultural resources within the United States.

Lenihan, Daniel J. and consultants
1975 A Draft Prospectus for a Multi-Agency Cooperative Research Project to Determine the Effects of Inundation on Cultural Resources in The United States. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Archeology, Santa Fe, New Mexico.

Lenihan's prospectus shows the scope of work and the general research areas upon which the National Reservoir Inundation Study will focus. It is not intended as a detailed research design, because specific data needs that will emerge during a course of preliminary investigations of submerged sites cannot be predicted _a priori_. The research design, according to the prospectus will be written and finalized at the end of phase I.

Leverty, Richard
1974 Orientation Meeting for the Study of the Effects of Inundation. Transcripts of meeting between Bruce Anderson, National Park Service, and Ward Weakly, Bureau of Reclamation, with letter to Ward Weakly from Dave Breternitz. Held in the Bureau of Reclamation's Denver Service Center, with a followup meeting, May 8, 1975, in Dallas, Texas. Xeroxed.

Participants at these meetins defined premises regarding inundation, and delineated areas to be examined in an attempt to understand inundation effects.

1976 _Effects of Inundation on Archaeological Resources_. Environmental Action Program, U.S. Army Corps of Engineers, Office of the Chief.

Leverty tells of the U.S. Army Corps of Engineers' participation in the National Reservoir Inundation Study which is coordinated by the National Park Service.

Ruppe, R. J. and Dee F. Green
1975 _Feasibility Study: Effects of Inundation on Cultural Resources: A Research Proposal for Roosevelt Lake, Arizona_. Arizona State Univeristy, Tempe, Arizona, and U.S. Forest Service, Albuquerque, New Mexico.

Ruppe and Green propose a preliminary examination of selected archeological sites in Roosevelt Lake, to determine the feasibility of conducting further research on inundation effects within the lake.

Schneider, Fred; Carl Falk; Stan Ahler; and Gary Leaf
1975 Program presented to the U.S. Army Corps of Engineers, Omaha District, Nebraska.

The program prepared by Schneider, Falk, Ahler, and Leaf focused on the need for resource management in reservoir areas, and suggested ways of dealing with vandalism, emergency salvage, and long term management.

Schnell, Frank T.
1969 "Archaeological Resurvey: A Relatively Unexplored Potential." Proceedings of the Twenty-Sixth _Southeastern Archaeological Conference, Bulletin No. 11_, pp. 55-57. Paper presented at the 1969 Southeastern Archaeological Conference, Morgantown, West Virginia.

Schnell delves into the problem of erosion of sites caused by fluctuation in pool level, and the high incidence of artifact collecting--" Indian-head-hunting" by the general populace. The author advocates resurvey of reservoirs during drawdown periods.

Schnell, Frank T. and Jack Tyler
1976 "Hydrology and Archeological Site Conservation." Unpublished manuscript. Columbus Museum of Arts and Crafts, Columbus, Georgia. Xeroxed

In this short paper, Schnell and Tyler focus attention on river erosion, relating it to the primary flooding of archeological sites. The impact of initial inundation of sites is one of a number of variables to be researched in the multi-agency sponsored National Reservoir Inundation Study.

Weakly, Ward F.
1974 Correspondence to F. P. Sharpe on the subject of Proposed Archeological Studies--Painted Rock Reservoir.

Weakly's memo proposes Painted Rocks as a possible location for general inundation studies to determine impacts of immersion on cultural resources.

1975 "Archaeology and Reclamation." Bureau of Reclamation Research News 5(4):2-3. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

In this article, Weakly emphasizes the need for research into the effects of inundation on archeological sites and outlines the Bureau's participation in the multi-agency funded by National Reservoir Inundation Study.

RESERVOIR SPECIFIC

Ahler, Stanley A.; David K. Davies; Carl R. Falk; and David B. Madsen
1974 "Holocene Stratigraphy and Archeology in the Middle Missouri River Trench, South Dakota." Science 184:905-908. American Association for the Advancement of Science, Washington, D.C.
Ahler, Davies, Falk, and Madsen note the discovery of numerous pre-ceramic cultural features on eroded shorelines along reservoirs in North and South Dakota. However, massive

slumping, a result of bank erosion, is destroying these sites at an alarming rate. One example is the Walth Bay Site, which contains both Pleistocene and Holocene stratigraphic components.

Anderson, Bruce A.
1974 An Archeological Assessment of Amistand Recreation Area. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Archeology, Santa Fe, New Mexico.

Anderson states that "the effects of water inundation on archeological sites have not been adequately studied, and that more data on inundated archeological sites and cultural materials recovered from those sites are needed." Judging by another Texas reservoir where sites have been detrimentally affected by inundation, the author states that it is reasonable to assume inundated sites in Amistad may also be destroyed.

Brauner, David R.; Hallett H. Hammatt; and Glen D. Hartmann
1975 "Lower Granite Dam Pool Raising: Impact on Archaeological Sites." Washington Archaeological Research Center Project Report No. 22, Pullman, Washington.

Brauner, Hammatt, and Hartmann examine and provide phot-documentation of the mechanical effects of initial pool raising on selected archeological sites along the Snake River. Their report considers the location within the dam and the geomorphology of each site; then, making their projection upon basic geological processes of erosion and deposition, they postulate long term effects of mechanical action of waves and saturation of these sites.

Bureau of Reclamation
1975 Draft Environmental Impact Statement, Columbia Basin Project. U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

This statement cites the report, Archeological Investigations in the Coulee Dam National Recreation Area, Spring 1969, by Lester A. Ross, regarding the effect of submersion on the interpretation of soil sediments, soil profiles and other porous materials: "...[They] absorb chemical precipitates and so may be chemically altered to such a degree that incorrect interpretations could be made...Bone, shell, and charcoal require some special care when first exposed..." Ross adds that annual fluctuation in the lake level has damaged or destroyed a number of sites within the reservoir area.

Caldwell, Warren W. and G. Hubert Smith
1963 Oahe Reservoir: Archaeology, Geology, History. U.S. Army Corps of Engineers, Omaha District, Nebraska.

Caldwell and Smith's basically interpretive booklet on the ethnohistory and archeology of the Oahe Reservoir area lists a number of historic and prehistoric sites, now submerged. Jewell's 1964 article referred to three sites within this reservoir that have been either destroyed or severely damaged by inundation.

Canouts, Veletta; John Beezley; Gordon L. Fritz; Mark Grady; Timothy M. Kearns; Michael R. Polk; and Lyn S. Teague
1975 An Archeological Survey of the Orme Reservoir. Arizona State Museum, University of Arizona, Phoenix, Arizona.

Canouts et al., predict that the construction of Orme Reservoir and its subsequent flooding will directly impact over 50 known historic or prehistoric sites, representing most of the recorded archeology done in this area of Arizona. They propose a number of mitigative measures to protect, preserve, or obtain the maximum data from these sites.

Collins, Michael B.
1969 "Test Excavations at Amistad International Reservoir, Fall 1967." Papers of the Texas Archeological Salvage Project, No. 16, Austin, Texas.

Collins presents a standard salvage report, but also suggests the closing of a number of rock shelters, which will be situated above the maximum pool level, to protect them from further looting when the reservoir becomes a recreation area.

De Jarnette, E. I.; E. B. Kurjack; and B. C. Kell
1973 "Archaeological Investigations of the Weiss Reservoir of the Coosa River in Alabama." Journal of Alabama Archaeology 19(1-2):1-201. The Alabama Archaeological Society, University, Alabama.

Dragoo, Don W. and Stanley W. Lantz
1973 Archaeological Salvage of Selected Sites in the Allegheny Reservoir in New York, 1971-1972. Allegheny Reservoir Project. Carnegie Museum, Section of Man, Pittsburgh, Pennsylvania.

Dragoo and Lantz offer a purely descriptive salvage report dealing with two sites that have been inundated several times since completion of the Allegheny Reservoir. The authors do not discuss the effects of inundation on the cultural remains, but they do mention that several nearby sites have undergone extensive bank erosion. "Pottery sherds and lithic materials were found on the eroding river bank for a distance of 250 feet indicating a loss of at least 10,000 square feet" at one site; major portions of another site had been eroded into the river.

Falk, Carl R. and F. A. Calabrese
1973 "Helb: A Preliminary Statement." Plains Anthropologist 18(62) parts 1,2:336-343.

Falk and Calabrese show that the destruction of this site is a good example of the effects of bank erosion in the Oahe Reservoir. Loss of data from several components of the site and rapid physical loss of site area has aggravated the situation. Since the site was first recorded in 1966, 5 acres, or half of the total site area, have been lost through erosion.

Garrison, Ervan
1975 "A Research Design for Quantification of Inundation Effects: Ozark Bluff Shelters Located Along Beaver Reservoir." Arkansas Archeological Survey, Fayetteville, Arkansas. Xeroxed

Garrison attempts to develop a badly needed needed statistical test for the effects of inundation on archeological sites--specifically, rock shelters. Unfortunately, his design has some flaws: in terms of cell size for a chi-square test, and in the development of his null hypothesis. The author presents an interesting statistical problem in archeological sampling strategy.

Gates, Gerald R.
1975 Report on the Salvage Excavation of CA-LAn-493 and CA-LAn-645 Located in the Van Norman Reservoir Complex, City of Los Angeles. California State University Northridge, Northridge Archaeological Research Center, Department of Anthropology, Northridge, California.

Gates' descriptive report contains data on sites inundated since the early 1900's. An earthquake in 1971 damaged the lower Van Norman Reservoir, and the Reservoir was drained as a result. An archeological survey conducted in the reservoir complex yielded 11 sites; of these, 2 were excavated.

Gradwohl, D. M. and N. M. Osborn
1973 "Stalking the Skunk: A Preliminary Survey and Appraisal of Archaeological Resources in the Ames Reservoir, Iowa." Ames Reservoir Environmental Study, Volume 2. Iowa State University, Department of Sociology and Anthropology, Ames, Iowa.

Gradwohl and Osborn charge that the proposed reservoir poses a serious threat to nearly all of the existing archeological sites in the region. Twenty-three will be immediately and totally destroyed by construction activites, permanent inundation, and pool wave action. Thirteen other sites will suffer partial destruction because of intermittent inundation and wave action.

Haberman, Thomas W. and Fred Schneider
1975 1974 Archeological Survey of Portions of the Garrison Reservoir Shoreline, North Dakota. University of North Dakota, Grand Forks, North Dakota.

Haberman and Schneider call attention to the problem of bank slump around the reservoir, and the resulting site destruction. Through resurvey of shorelines, new sites have been discovered. Unfortunately, because of a combination of wave action and slumping, they are being destroyed at a rapid rate.

Howell, Charles D. and Donald C. Dearborn
1953 "The Excavation of an Indian Village of the Yadkin River Near Trading Ford." Southern Indian Studies 5:3-20. The Archaeological Society of North Carolina and Research Laboratories of Anthropology, University of North Carolina, Chapel Hill, North Carolina.

Howell and Dearborn describe work carried out in 1946 and 1948 on a precontact Uwharrie-type site during low-water periods after construction of High Rock Dam. Of interest is the fact that 61 pits and 46 post molds were located, indicating fair preservation of such features in this particular reservoir. Stone implements, bone tools, pottery, and one burial were also found reasonably intact.

Leatherman, Thomas L.
1979 "Nimrod Lake: An Archeological Survey of a Reservoir Drawdown." Unpublished report. On file Arkansas Archeological Survey, Feyetteville, Arkansas and the U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Leatherman discusses the variety of mechanical impacts to sites along the pool margins and the severe problems of unauthorized removal of artifacts by collectors in the area. Collectors gained access to the exposed sites by truck, boat, and motorcycle. Newspaper articles and warning signs about the unlawful nature of this collecting did not appear to deter the numerous individuals engaged in this activity.

McGuff, Paul R. and Mary Margaret Ford
1974 "Galveston Bay Area, Texas: A Study of Archaeological and Historical Resources in Areas Under Investigation for Navigation Improvement." Texas Archaeological Survey, Research Report No. 36, University of Texas, Austin, Texas.

McGuff and Ford located a number of historic and prehistoric sites along the rivers and bayous feeding into Galveston Bay. Those sites lying adjacent to the shoreline were badly eroded by wave action, which was aggravated by increased boat traffic, and were subject to vandalism because of their accessibility. Reservoirs, expecially those slated for recreation use, can be expected to show similar destruction.

Mohs, Gordon
1977 Arrow Lakes Reservoir Region Post-Inundation Studies of the Archaeological Resource. Province of British Columbia, Ministry of Provincial Secretary and Government Services, Heritage Conservation Branch, Resource Management Division, Victoria, British Columbia.

Mohs discusses the impact on 152 archeological sites of which 132 have all but been destroyed as a result of water level fluctuations in excess of 70 feet and the activities of relic collectors. In 1967 only a few individuals were active in the Arrow Lakes region; as of 1977 there were over 100 active artifact collectors, some amassing collections in excess of 2000 pieces.

Padgett, Thomas J.
1976 "Dierks Lake: A Problem Study in Cultural Resource Management." Arkansas Archeological Survey Report No. 9. Arkansas Archeological Survey, Fayetteville, Arkansas.

Padgett presents several hypotheses, based upon literature research, on the effects inundation may have on the preservation of cultural resources. Due to limited funding and lead time, pre-impoundment archeological research at Dierks Lake was hampered, precluding the actual field testing of these hypotheses. Padgett does attempt to predict certain impacts, and urges the Corps of Engineers to regularly survey the shoreline to document impacts upon known sites in the reservoir and to record new sites.

1977 "Norfork Lake: A Cultural Resources Management Study with Implications for Prehistoric Settlement-Subsistence Patterns in the Ozarks." Unpublished report. Arkansas Archeological Survey, Fayetteville, Arkansas.

Padgett documents the mechanical impacts to cultural resources at Norfork Lake, including "rapid removal of soil matrix, bank cutting and sheet erosion." Differential weathering of the limestone bluffs, as a result of wave action, was observed.

Prewitt, Elton
1972 "An Assessment of the Archeological and Paleontological Resources of Lake Texoma, Texas-Oklahoma." Texas Archeological Salvage Project, Research Report No. 10, Austin, Texas.

Prewitt's summary of the effects of inundation on archeological sites at Lake Texoma is concise, and provides pertinent data on the mechanical erosion of sites. The author also approaches the problem of data interpretation and preservation: "...those artifacts mentioned had been subjected to prolonged saturation and, as a result, their condition was such that they literally began to disintegrate upon exposure...It has already been pointed out that inundation will probably affect detrimentally less durable artifacts and [cause] soil changes."

1974 "Upper Navasota Reservoir: An Archaeological Assessment." Texas Archaeological Survey, Research Report No. 47. Austin, Texas.

On the basis of previous experience with inundated sties, Prewitt predicts that archeological sites within the Navasota Reservoir will undergo erosion and deflation in the wash zone; that shallow sites will be intermittently deflated; and that sediments deposited will obscure the vertical separation of artifacts.

Prewitt, Elton R. and Kerry A. Grombacher
1974 "An Archeological and Historical Assessment of the Areas to be Affected by the Proposed Twin Oak and Oak Knoll Projects, East-Central Texas." Texas Archeological Survey, Research Report No. 43. Austin, Texas.

Having previously observed sites located within a thin, sandy matrix, Prewitt and Grombacher believe that sites within this project area will prove highly susceptible to erosion and subsequent deflation "when they are either inundated or exposed to a shoreline situation (either stable or fluctuating)."

Prewitt, Elton R. and David Dibble
1974 "The San Felipe Creek Watershed Project, Val Verde County, Texas: An Archeological Survey." Texas Archaeological Survey, Research Report No. 40. Austin, Texas.

Prewitt and Dibble stress the potentially adverse impacts of inundation of sites within the reservoir in terms of soil matrix and the nature of the inundation-- that is, periodic or permanent. Other problems are increased access by the general public, and the very real possibility of vandalism of sites.

Ross, Lester A.
1969 Archaeological Investigation in the Coulee Dam National Recreation Area, Spring 1969. A Report submitted to the U.S. Department of the Interior, National Park Service, by the Laboratory of Anthropology, Washington State University, Pullman, Washington.

Ross deals, in one section of this report, with the effects of inundation of a periodic nature of archeological remains in Roosevelt Lake. The author devotes attention to three specific types of impact: 1) the effects of lake water upon the preservation or destruction of remains within a site; 2) the physical effects of annual lake fluctuations; and 3) the physical effects of cultural activities upon sites within the lake.

Schaafsma, Curtis
1976 Archaeological Survey of Maximum Pool and Navajo Excavations at Abiquiu Reservoir, Rio Arriba County, New Mexico. School of American Research, Santa Fe, New Mexico.

Schneider, Fred
1975 The Results of Archeological Investigations at the Moe Site 32MN101, North Dakota. University of North Dakota, Grand Forks, North Dakota.

Schneider investigates a site located in Garrison Reservoir which contains some of the oldest cultural materials known in North America. Excavations and aerial photographs reveal that most of the site has eroded into the reservoir; loss is estimated at 6 meters per year since construction.

Schnell, Frank T.
1974 "An Archaeological Survey of Lake Blackshear." In Proceedings of the 31st Southeastern Archaeological Conference, 1975, Atlanta, Georgia, edited by D. A. Peterson, Jr. pp. 117-122. Memphis, Tennessee.

Schnell points out that after the Lake Blackshear water level was lowered 11 feet in 1973, a resurvey of the exposed area was conducted. Erosion of sites was extensive, with 20 to 40 cm having been washed away and an additional 10 to 15 cm having been "thoroughly worked." Ceramic material had deteriorated considerably in hardness and in obliteration of surface decoration. Schnell summarized the investigation as "our most pessimistic hypotheses confirmed [and our] most optimistic hypotheses denied." An extremely informative report.

Schroeder, Albert H.
1964 "Review of Historical Sites in the Glen Canyon, Mouth of Hanson Creek to Mouth of San Juan River." University of Utah Anthropological Papers, No. 61 and in American Antiquity 29(1):4. Society for American Archeology, Washington, D.C.

Trubowitz, Neal L.
1976 "Status of Archaeological Investigations on the New York State Portion of the Allegheny River Basin and Mitigation Recommendations for Sites Found Therein." Department of Anthropology, State University of New York at Buffalo, New York. Xeroxed.

Tunnell, Curtis
1963 "Salvage Archaeology in Amistad Reservoir." The Mustang, Newletter of the Texas Memorial Museum, Mimeographed Papers No. 9 (5:8). Austin, Texas.

Tunnell, in his basically descriptive account of the diversity and richness of sites located within the proposed impoundment project, states his fear that Amistad will "flood and destroy hundreds of sites," and that those sites not immediately affected by inundation will be "destroyed by looters, vandals and people bent on indiscriminate digging."

Tunnell, Curtis and W. W. Newcomb
1962 "When the waters Recede--A Mystery." The Mustang, Newsletter of the Texas Memorial Museum, Mimeographed Papers No. 9 (4:6). Austin, Texas.

A burial and several stone hearths were exposed during a drawdown period for the Buchanan Dam in 1962. Tunnel and Newcomb reported that the burial was badly damaged by wave action; there were no good artifactual associations for the same reason. From six inches to a foot of topsoil had been removed from this site, and from several previously unrecorded sites nearby. All were exposed on low sandy beaches, and "virtually all of the occupation debris uncovered."

Tyler, Jack E.
1976 "Erosion of the Roods Creek Site 9Swl." Paper presented at the Georgia Academy of Science Annual Meeting, April 1976. Columbus Museum of Arts and Crafts, Columbus, Georgia.

Tyler evaluates limnological maturation, flood flow, and recreation use as causes of erosion, then estimates the effect of each upon the Roods Creek Site. The author compares present erosion rates with those occurring prior to impoundment, and surmises probable erosion rates if direct conservation measures had been taken.

U.S. Army Corps of Engineers
1970 Draft Environmental Impact Statement for Laneport, North Fork and South Fork Lakes, San Gabriel River, Texas. Fort Worth District, Texas.

This Draft Environmental Impact Statement notes that the construction of three proposed dams

and lakes for the San Gabriel River watershed will mean that over 100 archeological sites will be directly impacted, either through building activities or inundation. Salvage operations are the only mitigative action proposed in this report.

1975a Review of Draft Environmental Impact Statement of Operation, Maintenance and Implementation of Master Plan, Jemez Canyon Dam, Sandoval County, Rio Grande, New Mexico. Albuquerque District, New Mexico.

This review makes the following specific reference, on page 26, paragraph 5.05: "It is also accepted by some authorities that under appropriate circumstances inundation ...can be effective ...for the protection of archeological sites."

1975b Aquilla Lake, Aquilla Creek, Hill County, Texas, Environmental Impact Statement. Fort Worth District, Texas.

In the Adverse Effects section this statement, under Table V-1, page 13, is the following sentence: "Unless salvaged, some of these archeological sites which would have been exposed to wave wash by the conservation pool will now be protected by permanent inundation."

Unfortunately, insufficient research has been conducted to support the assertion by the Corps that long term inundation has a positive effect on the preservation of archeological sites. This controversial matter needs study to determine either positive or negative effects.

1975c Shidler Lake, Salt Creek, Oklahoma, Final Environmental Impact Statement. Tulsa District, Oklahoma.

Comments and responses were elicited prior to the Final Environmental Impact Statement and are reviewed here. Paragraph 9.7 suggests that depends upon their location within the reservoir. The authors of the Environmental Impact Statement agree. Paragraph 9.8 states that retrieval of sites at a later date assumes that inundated sites are preserved, but that there is insufficient data for such an assumption. The authors disagreed. The Final Environmental Impact Statement was unchanged as a result of the comment.

1976a Cultural Resource Study and Management at the Warm Springs Dam and Lake Sonoma Project, Sonoma County, California, Draft Copy. San Francisco District, California.

Prior to 1974, an archeological survey was conducted concurrent with the proposed construction of the Warm Springs Dam-Sonoma Lake Project; however, after the Draft Environmental Impact Statement was issued, an additional survey in the project area seemed necessary, particularly relating to archeology and ethnohistory. As a result, a memorandum of agreement concerning the protection and further study of the area was signed by various agencies. This 1976 report deals with the significance, management and interpretation of those cultural resources affected directly and indirectly by the construction project.

1976b. Draft Environmental Impact Statement for Operations and Maintenance Programs of Birdwell Lake, Benbrook Lake, Grapevine Lake, and Navarro Mills Lake, Trinity River Basin, Texas. Albuquerque District, New Mexico.

In this statement's section 4.09, Cultural Resources, the following sentence appears: "Impoundment and operation of the lakes has had the beneficial effects of providing Federal control and protection of remaining dry land archeological sites and covering other sites with water and silt deposits so they cannot be disturbed."

Unfortunately, extensive documentation of site destruction around impoundment projects contradicts the above statement. In addition there is insufficient data to support the statement of protection and/or preservation of inundated sites.

1976c Draft Supplement to the Final Environmental Impact Statement for Operation and Maintenance, Wister Lake, Poteau River, Le Flore County, Oklahoma, 76/342. Tulsa District, Oklahoma.

This supplement indicates that 50 archeological sites within Lake Wister are scheduled for various types of mitigative activities during a drawdown period. In an effort to reduce the impact of inundation, 9 of the sites are to be reseeded to provide a more resilient vegetative covering; 1 site is to be treated with a 2-inch layer of gunite to provide direct site protection.

Westec Services, Inc.
1978 Archaeological/Historical Survey of the Lake Hodges Fishing Program Project San·Diego, California. Westec Services, Inc., San Diego, California

Three newly discovered sites within Lake Hodges Reservoir are briefly discussed. These sites had all been inundated previously, however, no data are presented on the length or number of flooding episodes they were subjected to. The presence of midden soil, sherds, lithics, groundstone, shellfish remains and bone fragments at the sites is reported on. No mention is made of their condition or numbers.

Weston, Timothy, D. A. Golding and S. A. Ahler
1979 "Reconnaissance At The Travis 2 Site, 39WW15, Oake Reservoir, South Dakota." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Witty, Thomas A.
1972 Correspondence with Dr. Wilfred Logan on the subject of Effects of Inundation at Elk City Reservoir, Kansas. Kansas State Historical Society, Topeka, Kansas.

RIVERINE ENVIRONMENT

Bearss, Edwin C.
1964 "Underwater Archaeology and the Cairo." In Diving into the Past: Theories, Techniques and Applications of Underwater Archaeology, J. Drenning Holmquist and A. Hillman Wheeler, editors, pp. 12-18. Minnesota Historical Society, St. Paul.

Bearss describes the underwater investigation and recovery of some materials from the Civil War ironclad Cairo between 1956 and 1962.

Croes, Dale R.
1975. "An early 'Wet' Site at the Mouth of the Hoko River, the Hoko River Site." Washington State University, Department of Anthropology, Pullman, Washington.

Croes reports that the changing course of the Hoko River exposed a watersaturated archeological site with numerous layers of waterlogged vegetal materials and perishable artifacts wood, basketry and composite artifacts were found; a number of conservation methods were employed in an attempt to preserve the materials.

Fairbanks, Charles H.
1964 "Underwater Historic Sites on St. Mark's River." Florida Anthropologist 17(2):44-49. Florida Anthropological Society, Gainsville, Florida.

Fairbanks discusses the archeological implications of materials removed (most of them unscientifically, by amateurs) from St. Mark's River. The author also discusses the work done by students from Florida State University, under a National Park Service grant, on submerged lines of historic wooden posts. The comments on the preservation of various items from this riverine context are particularly important for the National Reservoir Inundation Study.

Ferguson, Homer L.
1939 "Salvaging Revolutionary Relics from the York River." William and Mary Quarterly, Series 2, 19(3).

Gluckman, Stephen J. and Christopher S. Peebles
1974 "Oven Hill (Di-15), a Refuge Site in the Suwanne River." Florida Anthropologist 27(1):21-30. Florida Anthropological Society, Gainesville, Florida.

Gluckman and Peebles recall the periodic archeological investigation of the underwater portion of the Oven Hill site by John Goggin and some of his students between 1958 and 1962. One statement, in particular has relevance to the National Reservoir Inundation Study "The river bottom shows evidence of disturbance and rearrangement due to the periodic flooding of the river but apparently this has had little effect on distribution of the archeological material." This observation runs contrary to what many archeologists would expect in a zone exposed to the effects of moving river water.

Hume, Ivor Noel
1956 Treasure in the Thames. London.

Lenihan, Daniel J.
1974 Report on a One-Day Underwater Archeological Reconnaissance at Buffalo National River, Arkansas. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Archeology, Santa Fe, New Mexico.

Lenihan's short report, including text, photos, and maps of a submerged cave and a small section of the Buffalo National River near Buffalo Point, proposes the use of rivers as archeological "indicators," much in the sense that different types of vegetation serve as indicators in remote sensing applications.

McGill, Doris K.
1963 "Underwater Finds in the French River." Canadian Geographical Journal 67(2):48-53.

Olsen, Sigurd F.
1963 "Relics from the Rapids." National Geographic Magazine 124 (9):412-435. National Geographic Society, Washington, D.C.

Wheeler, Robert C.: Walter A. Kenyon; Alan R. Woolworth; and Douglas A. Birk
1975 Voices from the Rapids, An Underwater Search for Fur Trade Artifacts 1960-73. Minnesota Historical Society, Series No. 3, St. Paul Minnesota.

Wheeler, Kenyon, Woolworth, and Birk's well-written book discusses the use of underwater archeological techniques to reconstruct patterns of early fur trade in the Midwest. These studies offer insight into what to expect in the way of preservation of tin, copper, brass, and iron artifacts in a freshwater environment similar to that of a reservoir.

KARST ENVIRONMENT

Andrews, E. W.
1959 "Dzibilchaltun: Lost City of the Maya." National Geographic 115(1):90-109. National Geographic Society, Washington, D.C.

1962 "Excavationes en Dzibilchaltun, Yucatan, 1956-1962." Estudios de Cultura Maya 2:149-183.

Brooks, Harold K.
1961 "Geology in Devil's Den." Paper presented before the 1961 Southeastern Archaeological Conference, Gainesville, Florida.

Clausen, Carl J.
1972a "Little Salt Springs Yields Clues to the Past." Florida Division of Archives and History Newsletter 3(2). State of Florida, Tallahassee, Florida.

Clausen notes that the excellent preservation of organic and human skeletal material recovered from the springs has yielded information on the environment and early inhabitants of the Southeast. Much of the data would not have been obtainable under normal - that is, dry site conditions. Caves and sinks are a valuable resource for studying long term inundation effects.

1972b. "Little Salt Springs." New Vistas 8(3):14-19.

Clausen states that cooperation between private development and the profession of archeology resulted in the successful recovery of ancient human skeletal remains and artifacts from Little Salt Springs, Florida. The achievement is a major one: the retrieval of multidisciplinary data through a cooperative effort.

Clausen, Carl J.; H. K. Brooks; and Al B. Wesolowsky
1975 "The Early Man Site at Warm Mineral Springs, Florida." Journal of Field Archaeology 2(3):191-213. Boston University Scholarly Publications, Boston, Massachusetts.

Clausen, Brooks, and Wesolwsky report comprehensively on the archeological and geological investigations of a stratified prehistoric site in Florida. The varying water levels that this sinkhole experienced during the Holocene provide insights into what adverse impacts may be expected on a macrotemporal level from pool raising and lowering in reservoirs.

Cockrell, W. A.
1973a "Florida's Underwater Heritage." The Florida Handbook. Peninsula Publishing Co., Tallahassee, Florida.

Cockrell offers evidence to show that a portion of Florida's heritage lies submerged beneath various rivers, lakes, springs, and coastal waters. These sites include campsites, shrines, refuse sites, and shipwreck sites, all of which can contribute important data to an understanding of the State's history and prehistory.

1973b "Remains of Early Man Recovered from Spring Cave." Archives and History News 4(2). State of Florida, Department of State, Tallahassee, Florida.

Cockrell announces the removal of a human skull from Warm Mineral Springs, Florida, by the Underwater Archaeology Research Section of the Bureau of Historic Sites and Properties. The article also documents the excellent preservation of organic material in the sink.

1974 "Current Status of Early Man Investigations at Warm Mineral Springs, Florida (8 SO 19)." Paper presented at the 1974 Conference for Historical Archaeology and the International Conference on Underwater Archaeology, Berkeley, California.

Cockrell's paper provided a data update on the previous season's fieldwork at Warm Mineral Springs, Florida.

1976 "Warm Mineral Springs: 1974-75. An Interdisciplinary Approach to a Drowned Terrestrial Site." Paper presented at the Seventh International Conference on Underwater Archaeology, 1976, Philadelphia, Pennsylvania.

Cockrell, W. A. and Larry Murphy
1978 "Pleistocene Man in Florida." Archaeology of Eastern North America, Louis A. Brennan, editor, 6:1-13. Braun-Brumfield, Ann Arbor, Michigan.

Deagan, Kathleen A.
1972 "Fig Springs: The Mid-Seventeenth Century in North-Central Florida." Historical Archaeology 6:23-46. Society for Historical Archaeology, Lansing, Michigan.

Deagan competently analyzes artifactual material removed by John Goggin and his students from Fig Springs in Florida. Although the material is from a freshwater context, the article's area-specific and analytical nature make it of limited relevance to the National Reservoir Inundation Study.

Ediger, Donald
1971 The Well of Sacrfice. Doubleday, Garden City, New York.

Fellows, Robert
1962 "Warm Mineral Springs." Bayplay Magazine, January, pp. 20-22 29, 30.

Fishcher, George R.
1974 "Underwater Archeological Survey of Montezuma Well." In Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources, Daniel J. Lenihan, editor, pp. 13-26. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Divison of Archeology, Santa Fe, New Mexico.

Fischer gives an account of the underwater excavation conducted at Montezuma Well, Arizona. Most of the material derives from talus slopes beneath large pueblo and cavate ruins.

Folan, William J.
1974 "The Cenote Sagrado (Sacred Well) of Chichen Itza, Yucatan, 1967-68, The Excavation, Plans and Preparation." International Journal of Nautical Archaeology and Underwater Exploration 3(2):283-293. Academic Press, New York.

Friedman, Robert
1972 "Little Salt Spring Expedition." Proceedings of the Fifth Annual Seminar on Cave Diving, Jack Banbury, editor. National Association for Cave Diving, Gainesville, Florida.

Friedman's brief article concentrates on the project's techniques, discoveries, and unique use of sport divers as safety personnel.

Griffin, John W.
1974 "Investigations in Russell Cave." Publications in Archeology, No. 13. U.S. Department of the Interior, National Park Service, Washington, D.C.

Halliday, William R.
1955 "The Miner's Bathtub." In Celebrated American Caves Mohr and Sloane, editors. Rutgers University Press, New Brunswick, New Jersey.

Halliday appraises the unique submerged cave known as Devil's Hole. This site may be well worth checking in terms of accumulated aboriginal and prehistoric remains. Devil's Hole must have received much attention from surrounding cultures over the years, because it is located in an area with a marginal water supply.

Lenihan, Daniel J.
1975 "Resource Potential of Submerged Caves and Suggested Procedures for Safe Exploration and Study." Paper presented at the 1975 National Cave Management Symposium, Albuquerque, New Mexico.

Above reference also published in
1976 Proceedings of the National Cave Management Symposium, 1975. Speleobooks, Albuquerque, New Mexico.

Lenihan examines the resource management parameters of submerged cave studies. A large portion of this paper deals directly with the archeological potential of underwater caves, and discusses techniques for safely and efficiently working within them.

Lenihan, Daniel J. and Larry Murphy
1976 "The Archaeology of Submerged Sinkholes and Caves." Paper presented at the Seventh International Conference on Underwater Archaeology, 1976, Philadelphia, Pennsylvania. Manuscript on file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Lenihan and Murphy concentrate on several aspects of cave diving, applicable to archeology. Their paper includes a history of archeology in submerged caves and sinkholes, accepted survey procedures, and a summary of various specialized techniques and equipment useful to both diving and excavation. The authors also outline specific problem-oriented research goals.

Marden, Luis
1959 "Dzibilchaltun: Up from the Well of Time." <u>National Geographic Magazine</u> 115(1):110-129. National Geographic Society, Washington, D.C.

Marden's account primarily describes his diving experiences in the cenote. The author mentions that the recovered clay pots were soft and crumbly, and that bone was well-preserved. All of the materials were recovered from within a heavy silt layer--a condition that may be encountered in reservoirs.

Martin, Richard A.
1966 <u>Eternal Spring, Man's 10,000 Years of History at Florida's Silver Springs</u>. Great Outdoors Publishing Co., St. Petersburg, Florida.

Martin provides information about the regional history of Silver Springs, including a history of the springs' formation, their paleontology and archeology, and the role these springs have played in Florida's cultural heritage since 1600.

Miller, Arthur G.
1976 "The Subaquatic Excavation of the Sacred Cenote of Tancah, Quintana Roo, Mexico." Paper presented at the Seventh International Conference on Underwater Archeology, 1976, Philadelphia, Pennsylvania.

Miller's presentation emphasized the great archeological potential of this cenote, and also described the great technical problems encountered in conducting controlled scientific investigations in such an environment.

However, the problems encountered in photographic recording, and so forth, resulting from siltation might have been alleviated if a specially trained team of expert cave divers had been used.

Neill, Wilfred T.
1964 "The Association of Suwannee Points and Extinct Animals in Florida." Florida Anthropologist 17:17-32. Florida Anthropological Society, Gainsville, Florida.

Olsen, Stanley J.
1958 "The Wakulla Cave." Natural History 67(7):396-403. American Museum of Natural History, Bergenfield, New Jersey.

Olsen describes paleontological remains of mastodon, sloth, and deer that were discovered at a depth of 200 feet within the Wakulla Cavern. Among the finds were over 600 bone spearpoints. The possibility of contemporary association was dismissed because of the nature of the deposition. Olsen suggests a few techniques for recovering the specimens, including the use of special equipment.

Rayl, Sandra Lee
1974 "A Paleo-Indian Mammoth Kill Site near Silver Springs, Florida." Unpublished Master's thesis. Northern Arizona University, Department of Anthropology, Flagstaff, Arizona.

Rayl's thesis reports the excavation of apparently butchered mammoths from an underwater site in Florida. This is a significant site report in terms of its implications for Southeastern prehistory. The report is relevant to the National Reservoir Inundation Study since many reservoir variables are present in the spring context.

Romero, Pablo Bush
1972a "The Sacred Well of Chichen Itza and Other Freshwater Sites in Mexico." In Underwater Archaeology: A Nascent Discipline, pp. 147-151. UNESCO, Paris.

Romero summarizes the results of numerous expeditions into the sacred cenote at Chichen Itza, Mexico. The author describes various special techniques employed, including a pump for attempting to drain the well, chemicals to clarify and purify the water, and airlifts for artifact recovery. Explorations in various other lakes are also described.

1972b "The Sacred Well of Chichen Itza." UNESCO Courier 5:30-33.

Royal, William and Eugenie Clark
1960 "Natural Preservation of Human Brain, Warm Mineral Springs, Florida." American Antiquity 26(2):285-287. Society for American Archaeology, Washington, D.C.

Royal and Clark report on this startling example of preservation, in an underwater context, of what is apparently human brain material. The find has obvious relevance to the National Reservoir Inundation Study. A factor contributing to organic preservation in Warm Mineral Springs is the fact that the water is almost completely anaerobic below 12 feet.

Tozzer, Alfred M.
1957 "Chichen Itza and its Cenote of Sacrifice." Memoirs of the Peabody Museum, Vols. 11, 12. Cambridge, Massachusetts.

1967 "Chichen Itza" Well of Sacrifice." In History Was Buried, A Source Book of Archeology, Margaret Wheeler, editor, pp. 175-200. Galahad Books, New York.

Tozzer gives historical accounts of the cenote as a cacrificed well, and also tells of early attempts at recovery of artifacts.

NATURAL LAKE ENVIRONMENT

Bowen, Dana Thomas
1952 Shipwrecks of the Lakes. D. T. Bowen, Daytona Beach, Florida.

Glob, P. V.
1969 The Bog People. Faber and Faber, London.

Guthe, Alfred K.
1967 "A Cache of Blakes from Watts Bar Lake." Tennessee Archaeologist 22(1):40-42.

Hoffmann, Frank
1974 The Mystery Ship from 19 Fathoms. Avery Color Studios, Au Train, Michigan.

McNutt, Charles H. and J. Bennett Graham
1967 "Archeological Investigations at Kentucky Lake, Tennessee: 1965." Anthropological Research Center Occassional Paper No. 1. Memphis State University, Memphis, Tennessee.

Morrison, Ian A.
1973 "Geomorphological Investigation of Marine and Lacustrine Environments of Archaeological Sites, Using Diving Techniques." In Science Diving International, N. C. Flemming, editor, pp. 41-46. Standard Press, Adover, Massachusetts.

Morrison used a variety of sophisticated methods and techniques, including C-14, aerial photography, and hydrographic survey methods to recover data concerning the nature and causes of submergence. The author also applied these methods to underwater archeological sites, attempting to discern architectural features. The nature of submergences, sedimentation, and level changes in coastlines all influence the quality of site preservation.

Niewiecki, Wlodzimierz
1973 "The Discoveries of Inland Underwater Archeology in Poland." In Science Diving International, N. C. Flemming, editor, pp. 77-83. Standard Press, Andover, Massachusetts.

Niewiecki mentions a number of types of sites --a bridge, settlements, and a dugout--found in submerged lake environments in Poland. This article discusses the various excavation techniques employed. Conservation techniques applied to the dugout were a matter of trial and error and provide much information on the effects, both negative and positive, of the various preservatives.

Perryman, Margaret
1967 "A New Winter Sport: Exploring the Bottom of Lake Allatoona." Georgia Magazine 11(4):26-29.

Warren, Lyman O.
1968 "Caladesi Causeway: A Possible Inundated Paleo-Indian Workshop." Florida Anthropologist 17(4): 227-230. Florida Anthropological Society, Gainsville, Florida.

Warren writes about lithic tools and debris, along with two Suwannee point fragments, which were found eroding from a manmade beach composed of dredged fill. The area from which the fill was obtained may have been covered by only about 2 to 3 feet of water until recently.

Fluctuations in water table levels have importance because they may be indicators of potential sites which have been intermittently submerged. Perhaps more Paleo-Indian sites will

be located in submerged environments as more is learned about water table fluctuations over the past 10,000 years.

SECTION 5: DIFFERENTIAL PRESERVATION OF CULTURAL MATERIALS

Andersen, S. T.
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> Nath and Anderson found that rapid freezing of pollen produces the highest rate of viability. Germinability of freeze-dried pollen at temperatures below -50C was prolonged. (Annotation provided by R. Holloway).

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Peterson affirms that the differential preservation of artifacts recovered underwater is the result of a number of factors, including soil pH, temperature, rate of leaching, availability of oxygen in the soil, and the location of artifacts relative to other artifacts.

To inhibit further destruction, the author urges that proper treatment involving three processes--storage, evaluation, and conservation--be undertaken.

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1948 "Studies in the Logic of Explanation." Philosophy of Science 15:135-175.

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1966 "A Prehistoric Community in Eastern Arizona." Southwestern Journal of Anthropology 22:9-30. University of New Mexico Press, Albuquerue, New Mexico.

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1974 "Combined Thermal and X-Ray Diffraction Technique for Identification of Ceramic Ware Temper and Paste Minerals." American Antiquity 39(3):477-483. Society for American Archaeology, Washington, D.C.

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1965 "Laboratory-Scale Instrumental Neutron Activation for Archaeological Analysis." American Antiquity 30(3):345-347. Society for American Archaeology, Washington D.C.

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1972 Ceramics: Industrial Processing and Testing. Iowa State University Press, Ames, Iowa.

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1976 "X-ray Photo Electron Spectroscopy. A New Analytical Method for the Examination of Archaeological Artifacts." Archaeometry 18(2):169-180. Bulletin of the Research Laboratory for Archaeology and the History of Art Oxford Univerity, London.

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1973 "Critical Point Drying Techniques." ITTRI Symposium Proceedings, pp. 767-774. Electron Microscopy Society of America.

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McKee, Edwin H. and David H. Thomas
1973 "X-Ray Diffraction Analysis of Pictograph Pigments from Toquima Cave, Central Nevada." American Antiquity 38(1):112-114. Society for American Archaeology, Washington, D.C.

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1973 "Archaeology and Explanation." World Archaeology 4(3):260-276. Routledge and Kagen Paul Ltd., Henley-On-Thames, Oxon, London.

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1968 "Some Aspects of Fixation of Uranium from Natural Waters." Japan Atomic Energy Research Inst. Report, NSJ Translation No. 91. Mining Geology (Japan), 1965, 15:287-298.

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1971 "The Enigma of the Layered Crusts on Some Weathered Glasses, A Chronological Account of Investigations." Archaeometry 13:1-11. Bulletin of the Research Laboratory for Archaeology and the History of Art, Oxford University, London.

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1972 "The Effect of Temperature on Protein Decay in Bone: Its Significance in Neutron Dating of Archeological Specimens." American Antiquity 37:514-520. Society for American Archaeology, Washington, D.C.

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1971 "Pottery Analysis by Neutron Activation." In Science and Archaeology, R. Brill, editor, pp. 182-195. MIT Press, Cambridge, Massachusetts.

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1976 Pre-operational Environmental Study of Lake Anna, Virginia. Final Report for the Virginia Electric and Power Company. On file Virginia Polytechnic Institute, Blacksburg, Virginia.

Register, Joe
1980 "Shell Mineralogy: X-ray Diffraction." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

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1973 Paleoethnobotany: The Prehistoric Food Plants of the Near East. Columbia University Press, New York, New York.

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1977 "Hydrothermal Uranium Deposits." In Economic Geology 6. Economic Geology Publishing Co., University of Minnesota, Duluth, Minnesota.

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1979 SAS Users Guide. SAS Institute, Raleigh, North Carolina.

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1976 Behavioral Archeology. Academic Press, New York.

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1977 Wood as Raw Material in Prehistorical Times. Canadian Conservation Institute, Ottawa, Canada.

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1973 Prehistoric Technology. Adams and Dart, Bath, England.

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1974 "The Use of Light and Electron Microscopy in the Study of Experimentally Altered Spores and Pollen Grains." Journal of Microscopy 109:153-158.

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1974 "Re-exposure of Tapes at High Temperature and Pressure in the lycopodium clayatum Spore Exine." Grana Palynologica 14:143-151.

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1979 "Organic Residue Analysis in Determining Stone Tool Function." In Lithic Use-Wear Analysis, Brian Hayden, editor, pp. 385-399. Academic Press, New York.

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1941 "A Rapid Method for the Determination of Total Phosphorus in Soil and Plant Material." Iowa State College Journal of Science 15:408-413. Iowa State College, Iowa City, Iowa.

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1957 Ceramics for the Archaeologist. Publication 609, Carnegie Institution of Washington, Washington, D.C.

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1973 "Soil Monolith Preservation." Unpublished manuscript, Washington State University, Pullman, Washington. Xerox.

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1971 "An Evaluation of X-ray Fluorescence Analysis as a Method for Correlating Obsidian Artifacts with Source Location." Archaeometry 13(1):17-25. Bulletin of the Research Laboratory for Archaeology and the History of Art, Oxford University, London.

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1968 An Introduction to Tree-Ring Dating. University of Chicago Press, Chicago, Illinois.

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1698 "Flotation Techniques for the Recovery of Small-Scale Archaeological Remains." American Antiquity 33:353-362. Society for American Archaeology, Washington, D.C.

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1975 "Archeomagnetism: The Dating of Archeological Materials by their Magnetic Properties." World Archeology 7(2). Routledge and Kagen Paul Ltd., Henley-On-Thames, Oxon, London.

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1975 "Flourine Dating of Stone." World Archaeology 7(2):125-135. Routledge and Kagen Paul, Ltd., Henley-On-Thames, Oxon, London.

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1977a "An Improved System of Using Artificial Substrates with SCUBA to Sample the Macrobenthos of Reservoirs." Hydrobiologia 53(3):257-269. B.V. Publishers, The Hague, Netherlands.

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1973 "X-ray Diffraction Analysis of Prehistoric Pottery." American Antiquity 38(3):339-343. Society for American Archaeology, Washington, D.C.

Weymouth, John H. and M. Mandeville
1975 "An X-ray Diffraction Study of Heat Treated Chert and Its Archaeological Implications." Archaeometry 17(1):61-67. Bulletin of the Research Laboratory for Archaeology and the History of Art, Oxford University, London.

Williams, Aubrey W., Jr.
1956 "Conception of Time in Eastern United States Archaeology: Part I." Southern Indian Studies 8:3-26. Archaeology Society of North Carolina and Research Laboratories of Anthropology, University of North Carolina, Chapel Hill, North Carolina.

Williams discusses the applications and limitations of various relative and absolute dating techniques, including age-area analysis, typological method, fluorine-content method, stratigraphy, dendrochronology, varve analysis, pollen analysis, and radiocarbon dating.

Wilmsen, Edwin N.
1968 "Lithic Analysis in Paleoanthropology." Science 161(3845): 982-987. American Association for the Advancement of Science, Washington, D.C.

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Woods, William I.
1977 "The Quantitative Analysis of Soil Phosphate." American Antiquity 42(2):248-252. Society for American Archaeology, Washington, D.C.

SECTION 7: MITIGATION

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1966 "The Preservation of Small Water-logged Wood Specimens with Polyethylene Glycol." Curator 9(3):228-234. American Museum of Natural History, New York.

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Acheson, Steve
1979 "The Little Qualicum River Wet Site (DiSc 1): Implementation of the Heritage Conservation Ethic." Datum: Newsletter of the Heritage Conservation Branch 4(1):6-7. Ministry of Provincial Secretary & Government Services, Victoria, British Columbia, Canada.

Acheson discusses an attempt to stabilize the Little Qualicum River Wet Site using a modified rip rap technique. Pre-mix concrete bags and heavy chain link fencing were employed. Upon examination 9 months later it was found that both the site and the rip rap were holding up well.

Barkman, Lars and Anders Franzen
1972 "The Wasa: Preservation and Conservation." In Underwater Archaeology: A Nascent Discipline, pp. 231-242. UNESCO, Paris.

Barkman, Lars G.; Sven Bengtsson; Birgitta Hafors; and Bo Lundvall
1976 "Processing of Waterlogged Wood." In Pacific Northwest Wet Site Wood Conservation Conference, Vol. I, Gerald Grosso, editor, pp. 17-26. Neah Bay, Washington.

Bengtsson, S.
1975 "The Sails of the Wasa: Unfolding, Identification and Preservation." International Journal of Nautical Archaeology and Underwater Exploration 4:27-41. Academic Press, London, England.

Blackshaw, Susan M.
1976 "Comments on the Examination and Treatment of Waterlogged Wood Based on Work Carried Out During the Period 1972-1976." In Pacific Northwest Wet Site Wood Conservation Conference, Vol. I, Gerald Grosso, editor, pp. 27-34. Neah Bay, Washington.

Brooke, Stephen and Kenneth Morris
1978 "Conservation of Underwater Archeological Artifacts from the Defence: A Regional Conservation Center Approach." In Beneath the Waters of Time: Proceedings of the Ninth Conference on Underwater Archaeology, J. Barto Arnold, editor, pp. 93-97. Texas Antiquities Committee Publication No. 6, Austin, Texas.

Brown, Margaret Kimball
1974 "A Preservative Compound for Archaeological Materials." American Antiquity 39(3):469-473. Society for American Archaeology, Washington, D.C.

Byers, Douglas S.
1962 "The Restoration and Preservation of Some Objects from Etowah." American Antiquity 28(2):206-216. Society for American Archeology, Washington, D.C.

Caley, Earle R.
1955 "Coatings and Incrustation on Lead Objects from the Agora and the Method Used for Their Removal." Studies in Conservation 2(2):49-54.

Christensen, B. Brosson
1970 Conservation of Waterlogged Wood in the National Museum of Denmark. National Museum of Denmark, Copenhagen.

1971 "Conservation of Wooden Objects in Denmark During the Years 1962-1969." In Conservation of Wooden Objects, 2nd ed., Vol. 2. The International Institute for Conservation of Historic and Artistic Works, London.

Ciba Co., Inc.
1961 A Method of Wood Preservation Using Arigal W.P. (Provisional Circular) Ciba Co., Inc., Ardsley, New York.

Croes, Dale R., ed.
1976 "The Excavation of Water-Saturated Archaeological Sites (Wet Sites) on the Northwest Coast of North America." Washington State University, Pullman, Washington.

Croes' compilation of articles centeres on saturated-sites excavation and conservation methods.

Davis, F. J.; L. R. Burton; A. B. Crosby; L. D. Klein; and E. R. Lewandowski,
1973 Riprap Slope Protection for Earth Dams: A Review of Practices and Procedures. REC-ERC-73-4. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

DeGroot, G.
1971 Soil-Cement Slope Protection on Bureau of Reclamation Features. REC-ERC-71-20. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Dowman, Elizabeth A.
1970 Conservation in Field Archaeology. Methuen, London.

Foley, Vincent P.
1965 "Another Method for the Treatment of Ferrous Artifacts." Florida Anthropologist 18(3):65-68. Florida Anthropological Society, Gainsville, Florida.

Grosso, Gerald H., editor
1976a Pacific Northwest Wet Site Wood Conservation Conference September 19-22, 1976, Neah Bay, Washington, Vol. 1. National Museum Act Program and Makah Indian Tribe, Neah Bay, Washington.

Numerous articles discussing both field methods for treating waterlogged materials and laboratory conservation techniques are included in this volume. A good overview of disparate techniques, their sucess and problems.

1976b Pacific Northwest Wet Site Wood Conservation Conference September 19-22, 1976, Neah Bay, Washington, Vol. 2. National Museum Act Program, National Endownment for the Arts Museum Program, Robert Lewis & Assoc., and the Makah Indian Tribe, Neah Bay, Washington.

Proceedings of the question and answer period following each report presentation is proviced; discussion sessions are also included. A partial list of references, which address the ranges of processes and techniques for wood stabilization and drying problems, is presented.

Guldbeck, Per E.
1969 "Leather: Its Understanding and Care." In American Association for State and Local History, Technical Leaflet No. 1, History News 24(4).

Hamilton, Donny Leon
1973 "Electrolytic Cleaning of Metal Articles Recovered from the Sea." In Science Diving International, N. C. Flemming, editor, pp. 96-104. Proceedings of the Third Symposium of the Scientific Committee of the Confederation Mondiale des Activities Subaquatiques, 8-9 October, 1973, London.

Hamilton gives details of a step-by-step approach to cleaning and preserving metal (particularly iron) artifacts recovered from marine contexts. The author takes into account various factors, including the condition of the matal and a number of variables directly related to the electrolytic process.

1976 "Conservation of Metal Objects from Underwater Sites: A Study in Methods." Miscellaneous Papers No. 4, Texas Memorial Museum, Austin, Texas; and In Texas Antiquities Committee Publication No. 1, Austin, Texas.

Hickey, M. E.

1969 "Investigations of Plastic Films for Canal Linings." Bureau of Reclamation Research Report No. 19, A Water Resources Technical Publication. U. S. Government Printing Office, Washington, D.C.

Hickey evaluates various plastic lingins, including polyvinylchloride and polyethylene materials, which were tested under laboratory and field conditions to determine their feasibility for use as canal linings. The tests were designed to extract data on strength and weatherability. Some of these materials may prove useful in enhancing the preservation of some endangered features in submerged archeological sites.

1971a Asphaltic Concrete Canal Lining and Dam Facing. U.S. Department of Reclamation, Engineering and Research Center, Division of General Research, Applied Sciences Branch, Denver, Colorado.

Hickey studied performance characteristics of various materials used for canal lingings and dam facings. Materials were subjected to both field and laboratory testing before final evaluation.

1971b Synthetic Rubber Canal Lining, Laboratory and Field Investigations of Synthetic Rubber Sheeting for Canal Lining-Open and Closed Conduit Systems Program. REC-ERC-71-22. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Ice, Ronald J.

1976 "A Shoreline Artifact Study at Padre Island National Seashore, Texas." Paper presented at the Seventh International Conference on Underwater Archaeology, 1976, Philadelphia, Pennsylvania.

Ice announces the intention of the Southwest Regional Office's Division of Cultural Resources to implement an ongoing shoreline-monitoring program. The program will be geared toward documenting, over a period of time, the movement of artificially-placed artifact equivalents in a littoral zone at Padre Island Natural Seashore.

Inverarity, Robert Bruce

1964 "The Conservation of Wood from Fresh Water." In Diving into the Past: Theories, Techniques and Applications for Underwater Archaeology, J. Drenning Holmquist and A. Hillman Wheeler, editors, pp. 68-70. Minnesota Historical Society, St. Paul, Minnesota.

Inverarity describes his technique for preserving water logged wooden boats. Essentially, the process involves construction of a watertight tank into which the boats are placed; the preservative used is a mixture of polyethylene glycol and water.

Keel, Bennie Carlton

1963 "The Conservation and Preservation of Archaeological and Ethnological Specimens." Southern Indian Studies 15:5-65. Archaeological Society of North Carolina and Research Laboratories of Anthropology, University of North Carolina, Chapel Hill, North Carolina.

Kell explains techniques for conserving a variety of materials, including ceramics, bone, shell, antler, stone, various metals, wood, textiles, and skins. The author also analyzes approaches to registration, storage, and insect-control.

Leigh, David

1972 First Aid for Finds: A Practical Guide for Archaeologists. University of Southampton, Department of Archaeology, Southampton, England.

1973 "Reasons for Preservation and Methods of Conservation." Colston Papers No. 23: Marine Archaeology, D. J. Blackman, editor, pp. 203-218. Shoe String Press, Hamden, Connecticut.

Leigh records the processes of marine decay, and appraises conceptual approaches to the problem of marine preservation and conservation, particularly emphasizing the conservation of wood and metals.

Lynott, Mark J.
1978. <u>An Archeological Assessment of the Bear Creek Shelter, Lake Whitney, Texas</u>. Southern Medthodist University, Department of Anthropology, Archeology Research Program, Dallas, Texas.

Lynott recommends preservation of the site "as the most desirable alternative available to mitigate against the threat of wave action and vandalism..." (1978:103). Since the time of this recommendation, the U.S. Army Corps of Engineers has covered portions of the site with gunnite.

1980 "The Dynamics of Significance: An Example from Central Texas." <u>American Antiquity</u> 45(1):117-120. Society for American Archaeology, Washington, D.C.

Madsen, H. Brinch
1967 "A Preliminary Note on the Use of Benzotriazole for Stabilizing Bronze Objects." <u>Studies in Conservation</u> 12(4):163-167.

Marx, Robert F.
1969 <u>Glass Bottles Recovered from the Sunken City of Port Royal, Jamaica</u>, pp. 6-7. Caribbean Research Institute, St. Thomas, Virgin Islands.

Marx lists various methods used to preserve recovered silver and pewter artifacts. Differential preservation required differential conservation techniques.

McKerrell, H. and E. Roger
1971 "Some Problems and Experimental Evaluation of Conserved Waterlogged Oak." Duplicated notes. International Institute of Conservation, UK Group, London.

McKerrell, H. and W. A. Oddy
1972 "The Conservation of Waterlogged Wood Using De-watering Fluids: An Evaluation." <u>Museums Journal</u> 71(4):165-167.

McKerrell, H.; E. Roger; and A. Varsanyi
1972 "The Actone/Rosin Method for Conservation of Waterlogged Wood." <u>Studies in Conservation</u> 17(3):111-125.

Morrison, William R.
1971 <u>Chemical Stabilization of Soils: Laboratory and Field Evaluation of Several Petrochemical Liquids for Soil Statibilization</u>. U.S. Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

Morrison analyzed and evaluated various water and solvent base stabilizers under a variety of laboratory and field testing situations to judge their performance potential as soil stabilizers. The two most successful, a liquid vinylpolymer and an acrylic-copolymer, may be tested as preservatives on certain types of submerged archeological sites.

Morrison, W. R.; R. A. Dodge; and J. Merriman
1971 Pond Linings for Desalting Plant Effluents (Supplement). Research and Development Progress Report No. 734. U.S. Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

Morrison, Dodge, and Merriman conducted field and laboratory tests on a number of types of linings, including membrane linings, hard-surface linings, earth linings, and soil sealants. Materials were tested for permeability, seepage, and physical properties.

Morrison, W. R. and L. R. Simmons
1977 Chemical and Vegetative Stabilization of Soils. REC-ERC-76-13. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Muhlethaler, B.
1973 Conservation of Waterlogged Wood and Wet Leather. Editions Eyrolles, Paris.

Nordby, Larry V.
1978 "Experiments in the Structural Preservation of Submerged Cultural Resources." In Glen Canyon Revisited: The Effects of Reservoir Inundation on Submerged Cultural Resources, Rayl et al.:67-98. Unpublished report. United States Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Nordby discusses the application of stabilization materials to Anasazi structures while inundated, and prior to re-flooding in an effort to prevent further wall deterioration. An excellent presentation of methods employed.

1980 "Preliminary Experiments in the Structural Preservation of Submerged Anasazi Masonry Units." Unpublished report. United States Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Nordby considers the impacts of freshwater inundation on submerged prehistoric masonry structures in the southwest and discusses the National Park Service's attempts at preservation prior to and during inundation. The success and failure of these experiments are discussed as well as their potential as viable cultural resources management alternatives.

Oddy, W. A. and M. J. Hughes
1970 "The Stabilization of 'Active' Bronze and Iron Antiquities By The Use of Sodium Sesquicarbonate." Studies in Conservation 15(3):183-189.

Organ, R. M.
1959 "Carbonwax and Other Materials in the Treatment of Waterlogged Paleolithic Wood." Studies in Conservation 4(3).

1963 "The Consolidation of Fragile Metallic Objects. In Recent Advances in Conservation, G. Thompson, editor, Butterworth, London.

Organ, R. M. and A. E. Werner
1961 "Consolidation of Fragile Objects." Studies in Conservation 6(4):133-135.

O'Shea, C.
1971 "The Use of De-watering Fluids in the Conservation of Waterlogged Wood and Leather." Museums Journal 71(2):71-72.

Plenderleith, H. J. and A. E. A. Werner
1971 The Conservation of Antiquities and Works of Art, 2nd ed. Oxford University Press, London.

Sanford, Elizabeth
1975 "Conservation of Artifacts: A Question of Survival." Historical Archaeology 9:55-64. Society for Historical Archaeology, Athens, Georgia.

Sanford's informative and relevant article links a review of basic conservation philosophy with an outline of approaches for stabilizing the deterioration of specific items from an underwater context--ferrous objects, lead, wood, leather, and textiles.

Seborg, Ray M. and Robert B. Inverarity
1962a "Conservation of 200-year Old Water-logged Boats with Polyethylne Glycol." Studies in Conservation 7(4)111-120.

1962b "Preservation of Old Waterlogged Wood by Treatment with Polyethylene Glycol." Science 136(3516):649-650. American Association for the Advancement of Science, Washington, D.C.

Seborg, Ray M.
1964 "Treating Wood with Polyethylene Glycol." In Diving into the Past: Theories, Techniques and Application of Underwater Archaeology, J. Drenning Holmquist and A. Hillman Wheeler, editors, pp. 70-71. Minnesota Historical Society, St. Paul, Minnesota.

Seborg is an employee of the Forest Products Laboratory, a Federal institution that concentrates its research efforts on wood. Although its primary research is conducted with green wood, the laboratory agreed to experiment with decayed wood. The results on the decayed, waterlogged material proved satisfactory.

Smith, James B., Jr. and John P. Ellis
1963 "The Preservation of Underwater Archaeological Specimens in Plastic." Curator 6(1):32-36. American Museum of Natural History, New York.

Sytron, C. R., III
1979 Evaluation of Rigid and Flexible Materials for Bank Protection. 32 Program Streambank Erosion Control Evaluation and Demonstration-Work Unit 4-Research on Soil Stability and Identification of Causes of Streambank Erosion. Investigative Report 2. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Taylor, Robert A. and Karen Cooley-Reynolds
1980 "Inundation Studies at the New Melones Reservoir Project, Sonora, California." Paper presented at the 11th Annual Conference on Underwater Archeology, Albuquerque, New Mexico, January 11-15, 1980.

Taylor and Reynolds discuss the preliminary results of an experiment designed to protect prehistoric sites during inundation. Five sites were chosen to receive protective caps of either gunnite, concrete, or rip rap. After one inundation episode all sites were re-examined. The gunnite caps were plagued with rodent activity and cracking in areas where excavation units settled. The rip rap remained stationary, but debris was beginning to collect behind the walled areas. No rodent activity or cracks were noted in the cement cap, this covering showing the least effects of one inundation.

Timblin, L. O., Jr.
1977 US/USSR Studies on Polymers for Canal Construction. Reprint No. 2880. America Society of Civil Engineers, Spring Convention and Exhibit, Dallas, Texas.

Townsend, Samuel P.
1964 "The Conservation of Artifacts from Salt Water." In Diving into the Past: Theories, Techniques and Applications of Underwater Archeology, J. Drenning Holmquist and A. Hillman Wheeler, editors, pp. 68-68. Minnesota Historical Society, St. Paul, Minnesota.

Townsend examines various methods of preserving artifacts recovered from saltwater contexts. Materials included are brass, tin, lead, steel, iron, leather, wood, and horn.

1972 "Standard Conservation Procedures." Underwater Archaeology: A Nascent Discipline, pp. 251-256. UNESCO, Paris

Townsend delineates the various steps involved in preserving artifacts recovered from marine contexts. The author mentions treatments applicable to iron, steel, brass, copper, lead, pewter, tin, gold, silver, stone, ceramics, glass, and small waterlogged organic objects made of wood, horn, bone, and leather.

Turner, Christy G. and William J. Burke
1976 Preservation of Pictographs and Petroglyphs. Arizona State University, Tempe, Arizona.

In this report, Turner and Burke's major objective is to present a viable method for treating prehistoric rock art to provide for preservation--preservation with little or no loss of esthetic character. This excellent report is directly applicable to any broad-based cultural-resource--management program.

Uhlig, H. H.
1963 Corrosion and Corrosion Control. Wiley, New York.

U.S. Department of the Interior, Bureau of Reclamation
1963 Linings for Irrigation Canals. U.S. Government Printing Office, Washington, D.C.

This compilation of data pertains to various materials used for canal linings. For convenient reference, subdivided sections outline cost, planning, seepage, and various design considerations of each lining material.

USDA Forest Service
1979 User Guide to Vegetation. USDA Forest Service General Technical Report INT-64. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Winterkorn, H. F.
1968 State-of-the-Art Survey Soil Stabilization, Vol. 1. Naval Air Engineering Center, Philadelphia, Pennsylvania.

SECTION 8: CULTURAL RESOURCES MANAGEMENT

Anonymous
1972 Guidelines for State Historic Preservation Legislation. Historic Preservation Workshop. National Symposium of State Environmental Legislation.

> Part III of the guidelines--"Protection and Recovery of Underwater Historic Properties and Sites"--deals directly with inundated cultural resources. The guidelines recommend joint regulation of underwater archeological sites with land archeological management.

Arnold, J. Barto III
1978 "Some Thoughts on Salvage Law and Historic Preservation." International Journal of Nautical Archaeology and Underwater Exploration 7(3):173-176. Academic Press, New York, New York.

Bennett, R. J. and R. J. Chorley
1978 Environmental Systems: Philosophy, Analysis and Control. Metheun, London.

Binford, L.
1964 "A Consideration of Archaeological Research Design." American Antiquity 29:425-441. Society for American Archeology, Washington D.C.

Davis, Hester
1972 "The Crisis in American Archaeology." Science 175:267-272. American Association for the Advancement of Science, Washington, D.C.

> Davis presents the problem of the increasing number of sites facing destruction, and the decreasing funds with which to salvage data. The problem stems from the lack of a cooperative program in several states and within some Federal agencies. However, the problem does not lie wholly with Federal and State agencies, but also with private business and individuals. Davis feels that it is the responsibility of the archeologist to arouse and involve the public; to re-analyze and re-evaluate research designs to best cope with the problem at hand; and that it is the responsibility of the various agencies and states to realize the importance of preserving these important nonrenewable cultural resources.

Cockrell, Wilburn A.
1980 "The Trouble with Treasure - A Preservationist View of the Controversy." American Antiquity 45(2):333-339. Society for American Archaeology, Washington, D.C.

Cockrell's excellent article outlines the serious problems facing underwater archeology and the preservation threat to submerged cultural resources. Must reading for the concerned resource manager.

1981 "Some Moral, Ethical and Legal Considerations in Underwater Archaeology." In the Realms of Gold: The Proceedings of the Tenth Conference on Underwater Archaeology, W. A. Cockrell, editor, pp. 215-220. Fathom Eight, San Marino, Carlifornia.

Cummings, Calvin R.
1975 "Professional Criteria for Underwater Archeology." Paper presented at the Sixth International Conference on Underwater Archeology, 1975, Charleston, South Carolina. Published in Historical Archeology 9:83-85. Society for Historical Archaeology, University of South Carolina, Columbia, South Carolina.

Cummings points out that to keep pace with the increasing legislation and activity connected with the management of cultural resources--particularly underwater archeology--we must establish qualification standards for underwater archeologists. A concomitant need is for specialized training in advance diving techniques, and in the use and interpretation of remote sensing equipment.

Fischer, George R., ed.
1972 New World Underwater Archeology, 1971. U.S. Department of the Interior, National Park Service, Office of Archeology and Historic Preservation, Divison of Archeology and Anthropology, Washington, D.C.

Fischer's compilation consists of information on the status of underwater archeology in both the United States and Canada during the 1971 field season.

1973a New World Underwater Archeology, 1972. U.S. Department of the Interior, National Park Service, Office of Archeology and Historic Preservation, Division of Archeology and Anthropology, Washington, D.C.

Fischer compiled general information on the status of underwater archeology in the United States and Canada during the 1972 field season.

1973b "Underwater Archeology in the National Park Service: Problems in Resource Management." Cedam International Bulletin, Winter, 1973. Paper presented at the Fourth International Conference on Underwater Archeology, St. Paul, Minnesota.

Fischer calls for a more active program in the management of submerged sites, and states that underwater archeology can and should be used as a management tool. The author further recommends that underwater archeology include a large number of techniques on many levels. Such techniques will make possible the acquisition of a broad base of information that will promote management of submerged resources in a manner that will yield the greatest amount of "scientific data and insure their preservation in the wisest manner."

1974 "The History and Nature of Underwater Archeology in the National Park Service." In Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources, Daniel J. Lenihan, editor, pp. 3-7. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Santa Fe, New Mexico.

Fischer shows the development of underwater archeological efforts in the National Park Service, and suggests directions to be taken in the future.

Glassow, Michael A.
1977 "Issues in Evaluating the Significance of Archaeological Resources." American Antiquity 42:413-420. Society for American Archaeology, Washington, D.C.

Grady, Mark A.
1977 "Mitigation Recommendations for the Orme Reservoir Project." In Conservation Archaeology: A Guide for Cultural Resource Management Studies, Michael B. Schiffer and George J. Gumerman, editors, pp. 331-343. Academic Press, New York, New York.

Hickman, Patricia Parker
1977 "Problems of Significance: Two Case Studies of Historical Sites." In Conservation Archaeology A Guide for Cultural Resource Management Studies, Michael B. Schiffer and George J. Gumerman, editors, pp. 269-275. Academic Press, New York, New York.

Judge, James W.
1979 "Minimal Impact Archeology." American Society for Conservation Archeology Proceedings.

King, Thomas F.; Patricia Parker Hickman; and Gary Berg
1977 Anthropology in Historic Preservation Caring for Culture's Clutter. Academic Press, New York, New York.

Lenihan, Daniel J., ed.
1974 Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources. U.S.

Department of the Interior, National Park Service, Southwest Regional Office, Santa Fe, New Mexico

Lenihan's compilation of short papers deals with different aspects of the field of underwater archeology, applied to a resource management framework. The collection includes sections on such subjects as inundation studies, history of underwater archeology in the National Park Service, remote sensing, and artifact preservation.

1976 "Underwater Archeological Aspects of Historic Preservation." Paper presented at the Second Denver Service Center Workshop, Preserving Our Architectural Heritage, January 19-23, 1976, Denver, Colorado.

Lenihan explores the legal mandates that explicitly make underwater archeology an integral part of official United States historic preservation efforts. The author then points out how various aspects of submerged sites archeology should be integrated into cultural resource management plans, and provides some implications for submerged architectural features. Lenihan explains in detail the National Reservoir Inundation Study being conducted by the National Park Service with multi-agency funding.

Lipe, William D.
1974 "A Conservation Model for American Archeology." The Kiva 39(3-4):213-25. Arizona Archeological and Historical Society, Tucson, Arizona.

Lipe's article is relevant because it deals directly with the controversial question of "salvage" in American archeology. Conservation, rather than reactive excavation, as an approach to dealing with cultural resources threatened by reservoir construction, or other marine or riverine alteration projects, must be given the fullest consideration and critical review by the archeological and CRM community.

Lipe, William D. and Alexander J. Lindsay, Jr., eds.
1974 Proceedings of the 1974 Cultural Resource Management Conference. Museum of Northern Arizona Technical Series No. 14. Museum of Northern Arizona, Flagstaff, Arizona.

Lipe and Lindsay's edited proceedings of this conference are well worth reading because they discuss critical issues of conservation and contract archeology, particularly volatile issues at the time of this meeting. The viewpoints of Federal, State and institutional archeologists are well expressed.

Longacre, William A. and R. Gwinn Vivian
1972 "Salvage Archaeology -- a Reply to Gruhn on the Crisis in American Archaeology." Science 178:811-812. American Association for the Advancement of Science, Washington, D.C.

Lynott, Mark J.
1980. "The Dynamics of Significance: An Example from Central Texas." American Antiquity 45(1):117-120. Society for American Archaeology, Washington, D.C.

Lynott discusses the ever changing patters of significance criteria through the use of a brief case study. In the late 1940's the Bear Creek shelter site was not considered "significant" in terms of the then current research interests of the River Basin Survey. However, re-examination of the site in the mid-1970's resulted in a reassessment of the site's value based, partially, on the paucity of similarly well-preserved sites in that area. This site, located in the fluctuation zone of Lake Whitney, was being impacted through wave action and erosion. It was determined to be eligible for the National Register of Historic Places after it had been partially flooded.

The importance of this determination by the Advisory Council to archeologists and land managers concerned with the flooding of sites is clear -- inundation and moderate adverse impacts resulting from this activity, do not necessarily hinder the eligibility of a site for National Register status. The act of flooding does not prevent nomination, nor should it be construed to do so.

McGimsey, Charles R., III
n.d. Archeology and Archeological Resources: A Guide for Those Planning to Use, Affect, or Alter the Land's Surface. Society for American Archaeology, Washington, D.C.

McGimsey, Charles R. III
1972 Public Archaeology. Seminar Press, New York.

McGimsey is expressly concerned with the preservation and protection of archeological resources, and with educating the public about them. He provides a listing of State and local legislation dealing with archeological remains.

Legislation pertinent to the National Reservoir Inundation Study includes: Reservoir Salvage Act, 1960; Proposed Amendment to Reservoir Salvage Act, 1960 (Archeological Conservation Act); National Environmental Policy Act, 1969; Antiquities Act, 1906; Archaeological Resources Protection Act, 1979; and various State antiquities acts.

Moratto, Michael J.
1975 "On the Concept of Archaeological Significance." Paper presented at the Annual Northern California Meeting of the Society for California Archaeology, 1975, Fresno State University, Fresno, California.

Moratto, Michael J. and Roger E. Kelly
1978 "Optimizing Strategies for Evaluating Archaeological Resources." In Advances in Archaeological Method and Theory, Vol. 1, M. B. Schiffer, editor, pp. 193-202. Academic Press, New York, New York.

Portnoy,
1978 Scholars as Managers. U.S. Department of the Interior, Heritage Conservation and Recreation Services, Inter-Agency Archeology Services, Washington, D.C.

Raab, L. Mark and Timothy C. Klinger
1977 "A Critical Appraisal of 'Significance' in Contract Archaeology." American Antiquity 42:629-634. Society for American Archaeology, Washington, D.C.

Robertson, Ben P. and Linda B. Robertson
1974 "The North Carolina Coastal Plain Survey Project--A Predictive Model for Site Location." Unpublished manuscript. State of North Carolina, Department of Cultural Resources, Division of Archives and History, Archeology Section. Photoduplicated.

Schiffer, Michael B. and William L. Rathje
1973 "Efficient exploitation of the Archeological Record: Penetrating Problems." In Research and Theory in Current Archeology, Charles L. Redman, editor, pp. 168-179. John Wiley and Sons, New York, New York.

Schiffer, Michael B. and John H. House
1977 "An Approach to Assessing Scientific Significance." In Conservation Archaeology: A Guide for Cultural Resource Management Studies, M. B. Schiffer and G. J. Gumerman, editors, pp. 249-257. Academic Press, New York, New York.

Schiffer, Michael B. and George J. Gumerman, editors
1977a Conservation Archaeology A Guide for Cultural Resource Management Studies. Academic Press, New York, New York.

1977b "Mitigation." In Conservation Archaeology A Guide for Cultural Resource Management Studies, pp. 321-330. Academic Press, New York, New York.

1977c "Assessing Significance." In Conservation Archaeology: A Guide for Cultural Resource Management Studies, pp. 249-257. Academic Press, New York, New York.

Scovill, Douglas H; Garland J. Gordon; and Keith M. Anderson
1972 Guidelines for the Preparation of Statements of Environmental Impact on Archeological Resources. U.S. Department of the Interior, National Park Service, Western Archeological Center, Tucson, Arizona.

Sneed, Paul G.
1978 "Cultural Heritage Resources in British Columbia: Guidelines and Procedures for Impact Assessments and Mitigation." Unpublished manuscript. On file Provincial Archeologist's Office, Province of British Columbia, Victoria, British Columbia.

Streuver, Stuart
1968 "Problems, Methods and Organization: A Disparity in the Growth of Archaeology." In Anthropological Archaeology in the Americas, Betty J. Meggers, editor, pp. 131-151. The Anthropological Society of Washington, Washington, D.C.

Taylor, Walter W.
1964a "Tethered Nomadism and Water Territoriality: An Hypothesis." Sobretiro del XXXV Congreso Internacional de Americanistas, Mexico, 1962, pp. 197-203.

> Taylor's concepts are particularly applicable to areas where water is limited; they relate directly to site locations near impoundment projects in the Southwest. Very often, whole cultures and their remnant material manifestations are restricted to river valleys or canyons that have been slated for impoundment.

1964b A Study of Archaeology. Southern Illinois University Press, Carbondale, Illinois.

U. S. Army Corps of Engineers
1967 "Survey Investigation and Reports." Pamphlet No. 1120-2-0. Department of the Army, Office of the Chief of Engineers, Washington, D.C. Xerox.

1975 How the U.S. Army Corps of Engineers Projects are Conceived, Authorized, Funded and Implemented. U.S. Army Corps of Engineers, Washington, D.C.

1978 "Civil Works Projects Identification and Administration of Cultural Resources." Part 305, 43(64):13990-13998. Federal Register, Rules and Regulations. Office of the Federal Register, Archives and Records Service, General Services Administration, Washington, D.C.

Williams, Stephen and James B. Stoltman
1965 "An Outline of Southeastern United States Prehistory with Particular Emphasis on the Paleo-Indian Era." In The Quarternary of the United States, H. D. Wright and David Frey, editors, pp. 669-683. Princeton University Press, Princeton, New Jersey.

Williams and Stoltman emphasize the dependence Paleo and archaic man upon river drainage systems for trade and communication routes in the Southeast. The impacts of placing water impoundment structures at critical points on river drainage systems are clearly major ones for potential site destruction.

SECTION 9: UNDERWATER ARCHEOLOGY

General

Arnold, J. Barto III, editor
1978 Beneath the Waters of Time: The Proceedings of the Ninth Conference on Underwater Archeology. Texas Antiquities Committee, Austin, Texas.

Arnold, J. Barto III and Robert S. Weedle
1978 The Nautical Archeology of Padre Island, The Spanish Shipwrecks of 1554. Academic Press, New York, New York.

Basch, Lucien
1972 "Ancient Wrecks and the Archaeology of Ships." International Journal of Nautical Archaeology and Underwater Exploration. 1(1):1-58. Academic Press, London.

Bascom, Willard
1976 Deep Waters, Ancient Ships. Doubleday, New York, New York.

Bass, George F.
1963 "Underwater Archeology: Key to History's Warehouse." National Geographic 124(1):138:156. National Geographic Society, Washington, D.C.

1966 Archaeology Underwater. Fredrick A. Praeger, New York.

> Bass, in his discussion of underwater archeology, investigates a broad range of topics, including the physiological effects of diving, specialized equipment, and techniques for survey, mapping, and object recovery. Although most of his work has been concentrated in the Mediterranean area, Bass expands his horizons to include underwater fieldwork performed in other parts of the globe.

1967 "Cape Gelidonya: A Bronze Age Shipwreck." Transactions of the American Philosophical Society 57(8). American Philosophical Society, Philadelphia, Pennsylvania.

1971 "A Byzantine Trading Venture." Scientific American 224:22-23. Scientific American Inc., New York, New York.

1980 "Maritime Archaeology: A Misunderstood Science." In Ocean Yearbook 2: Marine Science and Technology, Borgese and Ginsburg, editors, pp. 137-151. University of Chicago Press, Chicago, Illinois.

Bass, George F., ed.
1975 Archaeology Beneath the Sea. Walker and Company, New York.

1972 A History of Seafaring Based on Underwater Archaeology. Walker and Company, New York, New York.

Blackman, D. J., editor
1973 Marine Archaeology. Colston Papers No. 23. Butterworth & Co., London, England.

Blair, Clay Jr.
1960 Diving for Pleasure and Treasure. World Publishing Company, Cleveland, Ohio.

Blawatsky, Vladimir D.
1972 "Submerged Sectors of Town on the Black Sea Coast." Underwater Archaeology: A Nascent Discipline, pp. 115-122. UNESCO, Paris.

Blawatsky reports on several submerged town sites along the Black Sea coast, one of which is a stratified site dating between the second and fifth centuries B.C. Various methods of excavation and some of the problems encountered in working such sites are discussed.

Borhegyi, Stephen F.
1958 "Aqualung Archaeology." Natural History 67:121-125. American Museum of Natural History, Bergenfield, New Jersey.

CEDAM Bulletin
1965 Proceedings: Fifth Annual Convention of the Underwater Society of America. CEDAM, Mexico City, Mexico.

Clausen, Carl J.
1965 "A 1715 Spanish Tresure Ship." Florida State Museum, Social Sciences Contributions No. 2. Florida State Museum, Tallahassee, Florida.

Cockrell, W. A.
1972 "Underwater Archaeological Research in Florida." Archives and History News 3(5). State of Florida, Department of State, Tallahassee, Florida.

1980 "Drowned Sites in North America." In Archaeology Underwater. Keith Muckelroy, editor, pp. 138-145. McGraw Hill, New York, New York.

Cockrell, W. A., ed.
1979 In the Realms of Gold: The Proceedings of the Tenth Conference on Underwater Archaeology. Fathom Eight, San Marino, California.

Cousteau, Jacques-Yves
1953 The Silent World. Harper and Row, Co., New York, New York.

1954 "Fish Men Discover a 2,200 Year Old Greek Ship." National Geographic 105(1):1-36. National Geographic Society, Washington, D.C.

1971 Diving for Sunken Treasure. Doubleday and Co., Garden City, New York.

Cousteau, Jacques-Yves and James Dugan
1959 Captain Cousteau's Underwater Treasury. Harper and Row, New York, New York.

Deuel, Leo
1969 Flights into Yesterday. St. Martin's Press, New York, New York.

Diole, Phillipe
1953 The Undersea Adventure. Julian Mesner, Inc., New York.

1954 4000 Years Under the Sea. Simon and Schuster, New York.

Dugan, James
1956 Man Under the Sea. New York.

Dumas, Frederic
1962 Deep-Water Archaeology. Routledge and Kegan Paul, London.

1972 "Ancient Wrecks." In Underwater Archaeology: A Nascent Discipline, pp. 27-34. UNESCO, Parks.

Dumas discusses problems posed by ancient wrecks, wreck formation, differences among wreck site-types and some geological and biological considerations of these sites.

du Plat Taylor, Joan, ed.
1966 Marine Archaeology, Developments During Sixty Years in the Mediterranean. Thomas Y. Crowell Company, New York.

Ellmers, D.
1973 "The Earliest Report on an Excavated Ship in Europe." International Journal of Nautical Archaeology and Underwater Exploration 2:177-179. Academic Press, London.

Fischer, George R.
1970 "Bibliography for Underwater Archeology." Unpublished manuscript. On file U.S. Department of the Interior, National Park Service, Southeast Archeological Center, Tallahassee, Florida. Xeroxed.

Fisher has compiled a list of source on historical archeology, including many references that deal primarily with underwater sites. Some sources listed in Fischer's work were not readily found by other means; the compilation is recommended for research into underwater archeological topics.

Flemming, N. C.
1959 "Underwater Adventure in Applonia." Geographical Magazine 31:497.

1971 Cities in the Sea. Doubleday, Garden City, New York.

Frost, Honor
1962 "Submarine Archaeology and Mediterranean Wreck Formations." Mariner's Mirror 48:82-89.

1963 Under the Mediterranean. Routledge and Kagan Paul, Londong.

1973 "The First Season on the Punic Wreck in Sicily." International Journal of Nautical Archaeology and Underwater Exploration 2:33-39. Academic Press, London, England.

Green, W. S.
1960 "The Wrecks of the Spanish Armada on the Coast of Ireland." Geographical Journal 27:429-451.

Greenhill, B.
1976 The Archaeology of the Boat. A. and C. Black, London.

Goggin, John M.
1960 "Underwater Archaeology, Its Nature and Limitations." American Antiquity 25(3):348-354. Society for American Archaeology, Washington, D.C.

Goggin defines underwater archeology, and describes four main types of underwater sites. In addition, the author mentions some factors that may or may not be actual limitations; one must remember that underwater techniques have improved greatly since the early 1960s.

1962 "Recent Developments in Underwater Archaeology." Newsletter of the Southeastern Archeological Conference 8, pp. 80, 83. Cambridge, Massachusetts

Guilmartin, J. F.
1974 Gunpowder and Galleys; Mediterranean Warfare in The Sixteenth Century. Cambridge University Press, London, England.

Hall, John E.
1969 "Ancient Underwater City." Oceans 1(4):48-51. Oceanic Society, San Francisco, California.

Hass, Hans
1972 Challenging the Deep. William Morrow and Co., New York.

Hasslof, O.; H. Henningsen; and A. E. Christensen, eds.
1972 Ships and Shipyards, Sailors and Fishermen: An Introduction to Maritime Ethnology. Trans. M. Knight and H. Young. Copenhagen University Press, Copenhagen, Denmark.

Hudson, Dee Travis
1976 Marine Archaeology Along the Southern California Coast. San Diego Museum Papers, Number 9. San Diego Museum of Man, Balboa Park, San Diego, California.

International Journal of Nautical Archaeology and Underwater Exploration, Vol. 1, 1972- Academic Press, New York, New York.

This journal, published by the Council for Nautical Archeology, focuses its attention on underwater (nautical) archeology. Its purpose is to inform the public about various research endeavors, as well as about the latest techniques of recovery, preservation, and legislation pertaining to protection of nautical sites.

Johnstone, P.
1974 The Archaeology of Ships. Bodley Head, London.

Jones, Virgil C. and Harrold L. Peterson
1971 USS Cairo, The Story of a Civil War Gun Boat. U.S. Government Printing Office, Superintendent of Documents, Washington, D.C.

Katzev, Michael
1970 "Resurrecting the Oldest Known Greek Ship." National Geographic 137(6):841-857. National Geographic Society, Washington, D.C.

Katzev, Susan W. and Michael L. Katzev
1974 "Last Harbor for the Oldest Ship." National Geographic 146(5): 618-625. National Geographic Society, Washington, D.C.

Linder, E. and A. Raban
1975 Marine Archaeology. Cassel, London.

Marintos, Spyridon N.
1960 "Helice, Submerged Town of Classical Greece." Archaeology 13(3):186-193. Archaeological Institute of America, New York, New York.

Marintos provides historical accounts of the ancient city of Helice, which was destroyed and submerged by earthquake and tidal wave activity in the year 373 B.C., and an account of a later earthquake in 1861. Marinatos believes that the city of Helice can be rediscovered and scientifically excavated to retrieve historical data and possible works of art.

Marsden, Peter
1974 The Wreck of the Amsterdam. Stein and Day, New York.

Martin, Colin
1975 Full Fathom Five, Wrecks of the Spanish Armada. Viking Press, New York.

Marx, Robert F.
1972 "The Drowned City of Port Royal." UNESCO Courier 5:28-29. UNESCO, Paris.

McKee, Alexander
1969 History Under the Sea. E. P. Dutton Co., New York, New York.

Muckelroy, Keith
1978 Maritime Archaeology. Cambridge University Press, Cambridge, England.

Muckelroy, Keith, editor
1980 Archeology Under Water: An Atlas of the World's Submerged Sites. McGraw-Hill, New York.

National Geographic Society
1974 Undersea Treasures. Special Publications Division National Geographic Society, Washington, D.C.

Olsen, Stanley J.
1962. "Underwater Treasure." Florida Wildlife 11:15.

Peterson, Mendel
1973 History Under the Sea, A Handbook for Underwater Exploration. Mendel Peterson, Alexandria, Virginia.

Petsche, Jerome
1974 The Steamboat Bertrand, History, Excavation, and Architecture. U.S. Government Printing Office, Superintendent of Documents, Washington, D.C.

Potter, John S., Jr.
1958 The Treasure Divers of Vigo Bay. Doubleday and Company, Inc., Garden City, New York.

Rackl, Hans-Wolf
1968 Diving into the Past: Archaeology Underwater. Charles Scribner's Sons, New York, New York.

Ruoff, Ulrich
1972 "Palafittes and Underwater Archaeology." Underwater Archaeology: A Nascent Discipline, pp. 123-137. UNESCO, Paris.

Ruoff's concern is not only with underwater archeology, but also with the effects of erosion, boat traffic, and interferences with the natural environment caused by construction projects. Such projects create new patterns of current flow and alter the rate of sedimentation.

Ruoff makes an important contribution in realizing the importance of multidisciplinary research in the extracting of data on soil and climatic conditions and on paleoecological relationships. The article also covers various underwater excavation techniques and problems of artifact conservation.

Ruppe, Carol
1975 "Underwater Archaeology: A Bibliographic Guide." Arizona State University, Department of Anthropology, Tempe, Arizona. Xeroxed.

Ruppe's list of sources is not as extensive as the bibliography by George Fischer (in this section), but is perhaps a little better organized.

Silverburg, R.
1963 Sunken History: The Story of Underwater Archaeology. Philadelphia, Pennsylvania.

Stenuit, Robert
1969 "Ireland's Rugged Coast Yields Priceless Relics of the Spanish Armada." National Geographic 135(6):745-777. National Geographic Society, Washington, D.C.

1973 Treasures of the Armada. David and Charles, Newton-Abbott, England.

1974 "Early Relics of the VOC Trade from Shetland." International Journal of Nautical Archaeology and Underwater Exploration 3:213. Academic Press, London, England.

1975 "The Treasure of Porto Santo." National Geographic 148(2): 261-275. National Geographic Society, Washington, D.C.

1976 "The Wreck of the Pink Eusfaffi, A Transport of the Imperial Russian Navy, Lost off Shetland in 1780." International Journal of Nautical Archaeology and Underwater Exploration 5(3):221-243. Academic Press, London, England.

Tailliez, Phillippe
1954 To Hidden Depths. London.

Throckmorton, Peter
1965 The Lost Ships. Cape.

1970 Shipwrecks and Archaeology: The Unharvested Sea. Atlantic. Little Brown, Boston

UNESCO
1972 Underwater Archaeology: A Nascent Discipline. Unesco, Paris.

Webb, H.
1972 "The Treasure in Rivers." Triton 17:299-301.

Weigel, Robert L.
1964 Oceanographical Engineering. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Wheeler, Robert C.
1962 "History Below the Rapids." Minnesota History 38:24-34.

Wilkes, Bill St. John
1971 Nautical Archaeology. Stein and Day, New York.

METHOD/TECHNIQUES

Arnold, H. A.
1967 "Manned Submersibles for Research." Science 158:85-95. American Association for the Advancement of Science, Washington, D.C.

> "Although there are many sophisticated instruments such as underwater TV or stereo-cameras, man's abilities of observation and response far surpass those of instruments" (Arnold).

Baker, P. E. and J. N. Green
1976 "Recording Techniques Used During the Excavation of the Batavia." International Journal of Nautical Archaeology and Underwater Exploration 5:143-158. Academic Press, London.

Barker, P.
1977 Techniques of Archaeological Excavation. Batsford, London, England.

Bascome, Willard
1972 "A Tool for Deep-Water Archaeology." International Journal for Nautical Archaeology and Underwater Exploration 1:180-184. Academic Press, London, England.

Bass, G. F.
1965 "The Asherah, A Submarine for Archaeology." Archaeology 18(1):7-15. Archaeological Institute of America, New York, New York.

Bass, George F. and Peter Throckmorton
1961 "Excavating a Bronze Age Shipwreck." Archaeology 21(3):164-173. Archaeological Institute of America, New York, New York.

Bass, George F. and Charles R. Nicklin, Jr.
1968 "New Tools for Undersea Archeology." National Geographic 134(3):403-422. National Geographic Society, Washington, D.C.

Blot, Jean-Yves
1981 "Saint-Geran, 1744, Mauritius Island. Potential of a Plundered Site." In In the Realms of Gold: Proceedings of the Tenth Conference on Underwater Archaeology, W. A. Cockrell, editor, pp. 24-32. Fathom Eight, San Marino, California.

Blot approaches the wreck of the Saint-Geran with a multi-facited research approach in order to maximize the data returns from a very small sample of remaining archeological materials.

Bocquet, Aime
1979 "Lake Bottom Archaeology." Scientific American 240(2):56-64. Scientific American, New York.

Bocquet discusses the application of equilaterial triangles to form an excavation grid and the employment of a water curtain to aid in removal of suspended silt during excavation.

Boll, R.
1973 "The Tools for Wreck Excavation." Triton 18(5):253.

Butland, W. E. and J. M. Stubbs
1976 "Survey and Excavation of the Sloop Lovely." Maritime Wales 1:51-62.

Carrell, Toni L.
1979 "An Inter-tidal and Underwater Archeological Survey of the Point Arquello Boathouse Area, Vanderberg Air Force Base, California." Unpublished report. U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Cederlund, C. O.
1976 "Conditions Present for Underwater Archaeological Documentation on the Swedish Coast of the Baltic: Techniques of Documentation on Shipwrecks in These Areas." Underwater 75, J. A. Adolfson, editor, pp. 89-100. Proceedings of the Fourth Wold Congress of Underwater Activities, September 12-18, Stockholm.

1977 "Preliminary Report on Recording Methods Used for the Investigation of Merchant Shipwrecks at Jutholmen and Alvsnabben in 1973-74." International Journal of Nautical Archaeology and Underwater Exploration 6(2):87-99. Academic Press, London, England.

Cederlund, C. O.; C. Ingleman; and R. Sendberg
1973 "The Excavation of the Jutholmen Wreck 1970-1971." International Journal of Nautical Archaeology and Underwater Exploration 2:301-328. Academic Press, London, England.

Cockrell, W. A., producer
n.d. Videotape data bank and catalog of excavations at 8So19, Warm Mineral Springs, Florida. On file Florida State Library, Special Collections, Tallahassee, Florida.

The catalog is an index of 117 video tapes (½" reel to reel) of three seasons, 1975-1977, of excavation at this early man site (10,000 BP). A repository of underwater archeological techniques and excavation procedures many of which are original and project specific.

Cockrell, W. A.
1974 "Rethinking Florida Archaeology: New Data and New Approaches from Underwater Research." Paper presented to Symposium on the Quaternary of the Southeast, West Georgia College, Department of Geology, Carrollton, Georgia.

1975 "Warm Mineral Springs 1975: A Multidesciplinary Approach to a 10,000 BP Archaeologica Site." Florida Scientist 38(1). Abstract.

Cockrell, W. A.; E. Murphy; L. Murphy; and W. Spencer
1974 "Underwater Archaeological Investigations at Fort Jefferson National Monument, Dry Tortugas, Florida: 1974." Unpublished manuscript. On file National Park Service, Southeast Archeological Center, Tallahassee, Florida.

Cockrell, W. A. and Larry Murphy
1978 "8S117: Methodological Considerations of a Dual Component Site Near Fort Pierce, Florida." In Beneath the Waters of Time: The Proceedings of the Ninth Conference on Underwater Archaeology, J. Barto Arnold, editor, pp. 175-182. Texas Antiquities Committee Publication, No. 6, Texas Antiquities Committee, Austin, Texas.

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1976 "The Application of Gas Chromatography to the Tracing of Oil in Ancient Amphorae." Archaeometry 18(2):195-201. Bulletin of the Research Laboratory for Archaeology and the History of Art, Oxford University, London.

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1972 "Problems of Wreck Excavation." In Underwater Archaeology: A Nascent Discipline, pp. 155-160. UNESCO, Paris.

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Exley and Friedman have prepared an excellent guide to underwater cave mapping. Because cave areas often provide an excellent context for researching the long term effects of fresh-water immersion, this guide will be useful in the National Reservoir Inundation Study.

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Frey, D. A.; F. D. Hentschel; and D. H. Keith
1978 "Deepwater Archaeology: The Capistello Wreck Excavation, Lipari, Aeolian Islands." International Journal of Nautical Archaeology and Underwater Exploration 7:279-300. Academic Press, London.

Frost, Honor
1973 "Anchors, the Potshers of Marine Archaeology." In Marine Archaeology, D. J. Blackman, editor, pp. 397-409. Butterworth, London.

Gianfrotta, P. A.
1977 "First Elements for the Dating of Stone Anchor Stocks." International Journal of Nautical Archaeology and Underwater Exploration 6:285-292. Academic Press, London.

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1967 "Underwater Archaeology: Theory and Methods." Unpublished Master's thesis. University of Florida, Department of Anthropology, Gainesville, Florida.

Gluckman's wide ranging topics pertains to the nature and methodology of underwater archeology. The section on underwater mapping procedures is valuable.

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Holmquist, June Drenning and A. Hillman Wheeler, eds.
1964 Diving into the Past, Theories, Techniques and Applications of Underwater Archaeology. Minnesota Historical Society, St. Paul, Minnesota.

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1978 "The Cornwallis Cave Shipwreck, Yorktown, Virginia." International Journal of Nautical Archaeology and Underwater Exploration 7(3):205-226. Academic Press, London.

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1978 "Excavation of a Third Century B.C. Shipwreck at La Secca Di Capistello, Italy: A Pioneer Application of Saturation Diving Techniques in Nautical Archeology." In Beneath the Waters of Time: Proceedings of the Ninth Conference on Underwater Archaeology, J. Barto Arnold, editor, pp. 3-14. Texas Antiquities Committee Publication No. 6, Austin, Texas.

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1973 "Locating Objects Underwater Using a Hydrolite." International Journal of Nautical Archaeology and Underwater Exploration 2:371-378. Academic Press, London, England.

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1964 "Principles of Underwater Archaeology." Pacific Discovery 17(5):18-25.

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1973 Port Royal Rediscovered. Doubleday, Garden City, New York.

Marx supplies historical data to lay the ground work for his discussion of the excavation of Port Royal, a submerged city off the Jamaican coast. His treatise describes excavation techniques used.

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1974 "New Concepts in Marine Archaeology: Shallow Water Historical Archaeology in the Lower Florida Keys." Unpublished manuscript. Paper presented at the Fifth Conference on Underwater Archaeology, Berkeley, California.

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1974 "The Defense: Search and Recovery 1972-3." International Journal of Nautical Archaeology and Underwater Exploration 3:312-313. Academic Press, London.

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Merifield and Rosencrantz present a mapping technique using a hyperbaric level which was employed to gather ground control data for stereo-photogrammetric mapping of a shipwreck site. This method is readily applicable to other mapping situations.

Milne, P. H.
1971 "Underwater Instrumentation and the Scuba Diver." Hydrospace 4(5):44.

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1975 "A Systematic Approach to the Investigation of Scattered Wreck Sites." International Journal of Nautical Archaeology and Underwater Exploration 4:173-190. Academic Press, London.

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1977 "Historic Wreck Sites and Their Environments." In Progress in Underwater Science, K. Hiscock and A. D. Baume, editors, pp. 111-120. Pentech Press, London.

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1978 "8So19: Physiological, Methodological, and Technical Aspects of the Excavation at Warm Mineral Springs, Florida." In Beneath the Waters of Time: The Proceedings of the Ninth

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1975 "How We Found the Monitor." National Geographic 147(1):48-61. National Geographic Society, Washington, D.C.

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1973 Man Beneath the Sea: A Review of Underwater Ocean Engineering. Wiley InterSceince, New York, New York.

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1955 Diving for Science. Whittlesey House, New York, New York.

Sanleaville, Paul
1972 "Vermetus Dating of Changes in Sea Level." In Underwater Archaeology: A Nascent Discipline, pp. 185-192. UNESCO, Paris.

Schwartz, G. T. and G. Junghaus
1967 "A New Method for Three Dimensional Recording of Archaeological Finds." Archaeometry 10:64-69. Bulletin of the Research Laboratory for Archaeology and the History of Art, Oxford University, London, England.

Shenton, Edward H.
1972 Diving for Science: The Story of the Deep Submersible. Norton, New York.

Spiess, F. N. and J. K. Orzech
1981 "Location of Ancient Amphorae in the Deep Waters of the Eastern Mediterrranean Sea by the Deep Tow Vehicle." In In the Realms of Gold: Proceedings of the Tenth Conference on Underwater Archaeology, W. A. Cockrell, editor, pp. 149-162. Fathom Eight, San Marino, California.

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1969 Surveying in Archaeology Underwater. Colt Archaeological Institute Monograph No. 5. Bernard Quaritch, London, England.

University of the State of New York
1969 Diving into History: A Manual of Underwater Archaeology for Divers in New York State. Office of State History, State Education Department, Albany, New York.

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REMOTE SENSING

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1962 "A Gradient Magnetometer Using Proton Free Processing." Journal of Scientific Instrumentation 39. Institute of Physics, Techno House of Redcliff Way, Bristol, England.

Aitken, J. J.; G. Webster; and H. Rees
1958 "Early Land Survey with Magnetometer." American Antiquity 32:270. Society for American Archaeology, Washington, D.C.

Anderson, Ralph Oliver
1947 "Photogrammetric Control Extension." Supplement to Applied Photogrammetry. Chattanooga.

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1974 "The Archaeological Applications of Computerized Contour and Perspective Plotting." Newsletter of Computer Archaeology 10:1-7.

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> Arnold reports on the use of proton-magnetometer instrumentation in archeological surveys. Although this instrumentation can be used in land surveys, the author deals primarily with its use in underwater contexts. The proton-magnetometer has been successfully employed in locating shipwrecks.

1975b "A Marine Archaeological Application of Automated Data Acquisition and Processing." Newsletter of Computer Archaeology 11(4):5-12.

Arnold provides information about a magnetometer survey designed to locate shipwrecks, which was conducted along a section of the Texas coast. The data acquired from the survey were subjected to three phases of processing and analysis: field plot of anomalies; transfer from cassette to tape; and contour plotting by computer. The author believes these techniques could also be applied to land archeology.

1976 An Underwater Archeological Magnetometer Survey and Site Test Excavation Project Off Padre Island, Texas. Texas Antiquities Committee, Austin, Texas.

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1981 "The U.S.S. Hatteras: A Preliminary Report on Remote Sensing Data and Litigation." In In The Realms of Gold: Proceedings of the Tenth Conference on Underwater Archaeology, W. A. Cockrell, editor, pp. 3-23. Fathom Eight, San Marino, California.

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1975b "A Magnetometer Survey with Electronic Positioning Control and Calculator-Plotter System." The International Journal of Nautical Archaeology and Underwater Exploration 4(2):353-366. Academic Press, New York, New York.

Arnold J. Barto III and George B. Kegley
1974 "A Magnetometer Survey of a Prehistoric Village in Western Texas." Paper presented to the annual meeting of the Society for American Archaeology, 1974, Washington, D.C.

Barto and Kegley describe remote sensing techniques (by proton-magnetometer device) that were used to detect subsurface features and structures not visible on the surface. The device is capable of detecting pottery and hearths, because it is sensitive to remanant magnetism. Two methods of exploration were employed: in-site survey, and search-mode survey.

Belderson, R. H., et al.
1972 Sonographs of the Sea Floor, Elsevier Scientific Publishing Co., Amsterdam, Netherlands.

Black, Glenn A. and Richard B. Johnston
1962 "A Test of Magnetometry as an Aid to Archaeology." American Antiquity 28(2):199-205. Society for American Archaeology. Washington, D.C.

Black and Johnston field tested the proton-magnetometer's ability to locate subsurface features in southern Indiana. An earlier model has successfully located Old World pits containing pottery, kilns, and ditches; therefore it was thought this instrumentation might be useful in New World archeology. The preliminary tests proved successful, but the method needs further refinement to obtain maximum data returns.

Block, F.
1946 "Nuclear Induction." Physics Review 70:461.

Boller, B. K. and C. E. McBride
1974 "Experimental Black and White Film for Underwater Photography." Photogrammetric Engineering and Remote Sensing 40:673-6811973. American Society of Photgrammetry, Falls Church, Virginia.

Bond, Clell L.
1979 Palo Alto Battlefield: A Magnetometer and Metal Detector Survey, Report No. 4. Texas A & M University, Cultural Resources Laboratory, College Station, Texas.

Borchers, Perry E.
1977 Photogrammetric Recording of Cultural Resources U.S. Department of the Interior, National Park Service, Washington, D.C.

Breiner, Sheldon
1965 "The Rubidium Magnetometer in Archeological Exploration." Science 155:185-193. American Association for the Advancement of Science, Washington, D.C.

Breiner discusses the application of differential rubidium magnetometry to archeological survey for thermoremnant magnetic features such as kilns, hearths, etc.

1973 Applications Manual for Portable Magnetometers. Geometrics, Palo Alto, California.

Breiner's manual is a guide for the use of the portable proton-magnetometer, and includes interpretation. A section of the manual is devoted to the proton-magnetometer's application in archeological exploration.

Bunik, J. A. and K. S. Turner
1971 "Remote Sensing Applications to the Quantitative Analysis of Drainage Networks." In Proceedings of the Fall Meeting of American Society of Photogrammetry 71:313. Falls Church, Virginia.

Clark, Anthony
1970 "Resistivity Surveying." In Science in Archaeology, Don Brothwell and Eric Higgs, editors, Praeger, New York.

Clark G. L. and H. R. James
1939 "Laboratory Analysis of the Selective Absorption of Light by Sea Water." Journal of the Optical Society of America 29:43-53. American Institute of Physics, New York, New York.

Clausen, Carl J.
1966 "The Proton Magnetometer: Its Use in Plotting the Distribution of the Ferrous Components of a Shipwreck Site as an Aid to Archaeological Interpretation." Florida Anthropologist 19(2)-(3):77-84. Gainsville, Florida.

Clausen conducted to proton-magnetometer survey off the Florida coast to establish the extent and orientation of a known shipwreck. The survey was successful. When the method is combined with aerial photography, much useful information can be gleaned about fruitful areas for field checks.

Clausen, Carl J. and J. Barto Arnold III
1976 "The Magnetometer and Underwater Archeology." Magnetic Delineation of Individual Shipwreck Sites, a New Control Technique." International Journal of Nautical Archeology and Underwater Exploration 5(2):159-169. Academic Press, New York, New York.

Chesterman, W. D.; P. R. Clywick; and A. H. Stride
1958 "An Acoustic Aid to Sea Bed Survey." Acoustica 8:285-290.

Chesterman, Clywick and Stride discuss the results of this first effort in side scan survey.

Coleman, J. M.
1969 "Brahmaputra River: Channel Process and Sedimentation." Sedimentary Geology 3:131-239. International Journal of Pure and Applied Sedimentology, Elseiver Sceintific Publishing Company, Amsterdam, Netherlands.

Coleman, J. M. and W. G. McIntire
1971 "Transisting Coastal River Channels." International Hydrographic Review 48:13-43.

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1974 Sonar and Underwater Sound. Lexington Books, Lexington, Massachusetts.

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1954 Elementary Photogrammetry. Edward Arnold, London, England.

Duntley, S. Q.
1963 "Light in the Sea." Journal of the Optical Society of America 53:214-233. American Institute of Physics, New York.

Ebert, James I. and Thomas R. Lyons
1976 "The Role of Remote Sensing in a Regional Archeological Research Design: A Case Study." In Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of Archeological Exploration, Survey, and Analysis. Reports of the Chaco Center, No. 1, assembled by Thomas R. Lyons, pp. 5-10. U.S. Department of the Interior, National Park Service, Chaco Center, New Mexico, and University of New Mexico, Albuquerque, New Mexico. Offset.

Edgerton, H.E.
1963 "Sub-Bottom Penetrations in Boston Harbor." Journal of Geophysical Research 68(9):2753-2760.

Edgerton, H. D. and J. Yves
1964 "Bottom Sonar Search Techniques." Undersea Technology 5(11).

Eichen, Leo; Lawrence D. Alexander; Frank O. Haseldon; Richard F. Pascuci; and D. M. Ross-Brown
1974 "Remote Sensing--Environmental and Geotechnical Applications." Dames & Moore Engineering Bulletin No. 45. Los Angeles, California.

> Eichen and his colleagues provide a good introduction to remote sensing technology. They discuss its application to the areas of geology, hydrology, land use planning, biovegetational analysis, aerial photogrammetry, and terrestrial photogrammetry.

Farris, N. M. and A. G. Miller
1977 "Maritime Culture Contacts of the Maya: Underwater Surveys and Test Excavations in Quintana Roo, Mexico." International Journal of Nautical Archaeology and Underwater Exploration 6(2):141-151. Academic Press, London, England.

Fischer, George R.
1974 "A Survey of the Offshore Lands of Gulf Islands National Seashore." Paper presented at the Fourth International Conference on Underwater Archaeology, Berkeley, California.

Fraser, H. A. D.
1901 "The Unifilar Magnetometer of the Magnetic Survey of India." Terrestrial Magnetics and Atmospheric Electronics 6:65-69.

This article documents the first use of a magnetometer for geomagnetic survey.

Frey, D.
1972 "Sub-bottom Profile of Porto Longo Harbour." International Journal of Nautical Archaeology and Underwater Exploration 1:170-175. Academic Press, London, England.

Frost, Honor
1969 "On the Plotting of Vast and Partly Submerged Installations from Aerial and Underwater Photographs." Surveying in Archaeology Underwater. Colt Archaeological Foundation, Quartich, London.

Garrison, Ervan; J. Alan May; and William H. Marquardt
1978 "Search for the USS Queen City: Instrument Survey 1977." In Beneath the Waters of Time: The Proceedings of the Ninth Conference on Underwater Archeology, J. Barto Arnold III, editor, pp. 45-49. Texas Antiquities Publication No. 6, Austin, Texas.

Green, Jeremy N.
1973 "An Underwater Archaeological Survey of Cape Andreas, Cyprus, 1969-70: A Preliminary Report." In Marine Archaeology, Colston Papers No. 23, D. J. Blackman, editor, pp. 141-179. Butterworth and Co., London, England.

Green, J. N. and Colin Martin
1970 "Metal Detector Survey of the Armada Ship Santa Maria de la Rosa." Propez Archaeology 5:95-100.

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1971 "Simple Underwater Photogrammetric Techniques." Archaeometry 13:221-232. Bulletin of the Research Laboratory for Archaeology and History of Art, Oxford University, London, England.

Griepentrog, Thomas
1972 The Chiefland Test Site Boring Program. Florida Department of Transportation, Remote Sensing Section, Tallahassee, Florida.

Hall, E. T.
1966 "Use of a Proton Magnetometer in Underwater Archaeology." Archaeometry 9. Bulletin of the Laboratory for Archaeology and the History Art, Oxford University, London, England.

Hansen, R. L.
1976 "Remote Sensing in Archeology--A Review of the Techniques." Principal Investigator, Jacquelyn Bouck. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado. Applied Sciences Branch Memorandum.

Hansen's memo offers an excellent review of the different applications of multilevel imagery in the detection of archeological remains. Remote sensing provides information on land formations that existed during past geologic eras. Using this data, archeologists can predict high probability areas for site locations.

Helgeson, G. A.
1970 "Water Depth and Distance Penetration." Photogrammetric Engineering and Remote Sensing 36(2):164-172. American Society of Photogrammetry, Falls Church, Virginia.

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1970 "Remote Sensor Imaging for Oceanography." Oceanology International 5(9):20-25.

Hine, Alfred
1968 Magnetic Compasses and Magnetometers. University of Toronto Press, Toronto, Canada.

Hulbert, E. O.
1945 "Optics of Distilled and Natural Water." Journal of the Optical Society of America 35(11):698-705. American Institute of Physics, New York.

Jorde, Lynn B.
1976 "Current and Future Applications of Aerospace Remote Sensing in Archeology: A Feasibility Study." In Remote Sensing Experiments in Cultural Resource Studies, Reports of The Chaco Center, No. 1, assembled by Thomas R. Lyons, pp. 11-68. U.S. Department of Interior, National Park Service, Chaco Center, New Mexico, and University of New Mexico, Albuquerque, New Mexico. Offset.

Jorde affirms that remote sensing techniques have broad applications: locating archeological sites; predicting the location of sites; contributing information about the nature of available natural resources. This study was designed to assess the justification for, and the implementation and feasibility of, utilizing remote sensing techniques for the protection and management of cultural resources. However, as the study progressed, additional applications were recognized, such as data-collection and photogrammetric measuring.

Karius, Rudolf; P. Merrifield; and D. Rosencrantz
1965 "Stereo-Mapping of Underwater Terrain from a Submarine." Ocean Science and Engineering. Transactions of the Joint Conference, Marine Technology Society and American Society of Limnology and Oceanography, June, Washington, D.C.

Klein, M.
1967 "Side Scan Sonar." Undersea Technology, April.

Kuper, William and David Schlobohm
1972 Geographic Investigation of the Chiefland Test Site. Florida Department of Transportation, Remote Sensing Section, Tallahassee, Florida.

Lankes, L. R.
1970 "Optics and the Physical Parameters of the Sea." Optical Spectra 4:42-49. Optical Publishing Co., Pittsfield, Massachusetts.

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1972 "An Underwater Sensing Device." International Journal of Nautical Archaeology and Underwater Exploration 1:165-169. Academic Press, London.

Lerici, C. M.
1961 "Archaeological Surveys with the Proton Magnetometer in Italy." Archaeometry 4. Bulletin of the Research Laboratory for Archaeology and the History of Art, Oxford University, London, England.

Lingrey, J. L.
1968 "A Study of Underwater Phot Optics." Instrumentation Applications Seminar Proceedings, San Diego, California.

Lockwood, H. E.; Lincoln Perry; Gerard E. Sauer; and Noel T. Litmar
1974 "Water Depth Penetration Film Test." Photogrammetric Engineering and Remote Sensing 40:1303-1314. American Society of Photgrammetry, Falls Church, Virginia.

Lundin, E.
1973 "Determining the Positions of Objects Located Beneath a Water Surface." International Journal of Nautical Archaeology and Underwater Exploration 2:371-378. Academic Press, London.

Lyons, Thomas R., assembler
1976 Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of Archeological Exploration, Survey, and Analysis. Reports of the Chaco Center, No. 1 U.S. Department of the Interior, National Park Service, Chaco Center, New Mexico, and University of New Mexico, Albuquerque, New Mexico. Offset.

Lyons, Thomas R. and Robert K. Hitchcock, eds.
1977 Aerial Remote Sensing Techniques in Archeology. U.S. Department of the Interior, National Park Service, Chaco Center, Albuquerque, New Mexico.

Lyons, T. R.; B. G. Pouls; and R. K. Hitchcock
1972 "The Kin Bineola Irragation Study: An Experiment in the use of Aerial Remote Sensing Techniques in Archaeology." Proceedings of the Third Annual Conference on Remote Sensing in Arid Lands, 1972, pp. 266-283. Arizona University Office of Arid Land Studies, Tucson, Arizona.

Lyons, Pouls and Hitchcock analyzed a prehistoric irrigation system at Kin Bineola, near Chaco Canyon, New Mexico, using conventional black-and-white aerial photographs and a Kelsh Plotter for microtopographic mapping. The purposes of this experiment were: 1) to determine the effectiveness of photogrammetric procedures in identifying cultural features in an arid area of extremely low relief; 2) to aid in the interpretation and analysis of any identifiable features; and 3) to determine the value of these techniques in planning research strategies. A number of cultural features were identified and mapped, including canals, diversion dams, and habitation sites. The authors explain in some detail the photogrammetric procedures employed, and they demonstrate aptly the application of these techniques to the archaeological problem in question.

Lyons, T. R.; M. Inglis; and R. K. Hitchcock
1972 "The Application of Space Imagery to Anthropology." Proceedings of the Third Annual Conference on Remote Sensing in Arid Lands, 1972, pp. 244-265. Arizona University Office of Arid Land Studies, Tucson, Arizona.

Lyons, Inglis, and Hitchcock assert that Gemini and Apollo imagery has, since the return of the first film to earth, served the earth sciences, pointing the way to more sophisticated data-gathering, data-handling, and data-analyzing systems. These systems also apply to the study of man and his environment, when used to analyze patterns of human modification of the environment or changes in land use and settlement. The authors also call attention to the influence of physiography upon man's activities--another viable application of remote-sensing to archeology. These remote-sensing techniques also can be useful in locating land forms from past geologic eras and in determining high-probability areas for archeological sites.

Lyons, Thomas R.; Robert K. Hitchcock; and James I. Ebert
1976 "Photogrammetric Mapping and Digitization of Prehistoric Architecture: Techniques and Applications in Chaco Canyon National Monument, New Mexico." In Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of

Archeological Exploration, Survey, and Analysis. Reports of the Chaco Center, No. 1, assembled by Thomas R. Lyons. U.S. Department of the Interior, National Park Service, Chaco Center, New Mexico, and University of New Mexico, Albuquerque, New Mexico. Offset.

MacConnel, William and William Niedzwiedz
1979 "Remote Sensing and the White River in Vermont." Photogrammetric Engineering and Remote Sensing 45:1393-1399. American Society of Photogrammetry, Falls Church, Virginia.

Marmelstein, Allan D.
1972 "A Feasibility Demonstration of Aerial Photographic Support for Marine Archeological Surveys." Manuscript on file at U.S. Department of the Interior, National Park Service, Southwest Regional Office, Division of Cultural Resources, Santa Fe, New Mexico, and at the Earth Resources Observation Systems Library, Garretson, South Dakota.

> Marmelstein field tested the feasibility of using aerial photographic techniques as an archeological survey tool at Fort Jefferson National Monument, in the Dry Tortugas. In water of high clarity, all filter/film combinations adequately portrayed bottom features, but for more turbid conditions, blue insensitive/blue filtered color films proved most successful.

1977 "Aerial Remote Sensing Techniques in Archeology." In Aerial Remote Sensing Techniques in Archeology, T. Lyons and Robert Hitchcock, editors, pp. 108-110. National Park Service, Chaco Center, Albuquerque, New Mexico.

> Marmelstein reports that the National Park Service enlisted the services of the Earth Satellite Corporation to assess the feasibility and practicality of using aircraft-borne remote sensing techniques and equipment to locate shipwrecks within Fort Jefferson National Monument in the Dry Tortugas. A multiband system of aerial infrared photography was selected. Experiments with several film/filter combinations yielded varying results, depending upon the depth and turbidity of the water. Two important sites were located and recorded with this technique. A proton-magnetometer reading and field check verified both finds.

McGehee, Maurice S.; Bruce P. Luyendyk; and Dwight E. Boegeman
1968 "Location of an Ancient Roman Shipwreck by Modern Acoustic Techniques." In A Critical look at Marine Technology,

Proceedings of the 4th Annual Conference of the Marine Technology Society. Washington, D.C.

McNeil, G. T.
1954 Photographic Measurements - Problems and Solutions. Pitman, New York, New York.

1972 Optical Fundamentals of Underwater Photography. 2nd edition. Mitchell Photogrammetry, Inc., Rockville, Maryland.

Mikee, Alexander
1973 "The Search for King Henry VIII's Mary Rose" In Marine Archaeology, Colston Papers No. 23, D. J. Blackman, editor, pp. 185-202. Butterworth and Co., London, England.

Moffitt, F. H.
1967 Photogrammetry. International Textbook Co., Pennsylvania.

Morrison, I.
1969 "An Inexpensive Photogrammetric Approach to the Reduction of Survey Diving Time." Underwater Association Report 22-28.

Murphy, Larry
1978 "Remote Sensing Applications to Shallow Water Historic Shipwreck Archeology." Unpublished manuscript. On file Florida State University, Geography Department and U.S. Department of the Interior, National Park Service, Southwest Cultural Resources Center, Santa Fe, New Mexico.

Neil, L.
1955 "Some Theoretical Aspects of Rock Magnetism." Advances in Physics 4:191-243.

Nelson, David A.
1973 "The Hamilton Scourage Project 1973: A Log-Book." Archaeological Newsletter of the Royal Ontario Museum No. 103. Ontario.

> Nelson's article is an account of the progress of an underwater remote-sensing search being conducted to locate two United States gunboats sunk during the War of 1812 in Lake Ontario. The author reports on the interface of the positioning system, magnetometer, and side-scanning sonar.

Packard, M. and R. Varian
1954 "Free Nuclear Induction of the Earth's Magnetic Field." Physics Review 93:941.

Palmer, Harold D.
1965 An Introduction to Marine Seismic Reflection Survey.

Pouls, Basil G.; Thomas R. Lyons; and James I. Ebert
1976 "Photogrammetric Mapping and Digitization of Prehistoric Architecture: Techniques and Applications in Chaco Canyon National Monument, New Mexico." In Remote Sensing Experiments in Cultural Resource Studies. Reports of the Chaco Center No. 1, assembled by Thomas R. Lyons. U.S. Department of the Interior, National Park Service, Chaco Center, Albuquerque, New Mexico and University of New Mexico, Albuquerque, New Mexico.

Rebikoff, Dimitri
1972 "Photogrammetry in Dirty Water by Mosaic and Strip Scanning." In Underwater Archeology: A Nascent Discipline, pp. 223-230. UNESCO, Paris.

Rosencrantz, Donald
1971 "Underwater Photography Systems." Photogrametric Engineering and Remote Sensing. 37(9):969-972. American Society of Photogrammetry, Falls Church, Virginia.

Rosencrantz, Donald M.; M. Klein; and Harold E. Edgerton
1972 "The Uses of Sonar." In Underwater Archaeology: A Nascent Discipline, pp. 257-270. UNESCO, Paris.

Ross, D. S.
1969 Experiments in Oceanographic Aerospace Photography I. Ben Franklin Spectral Filter Tests, Philco-Ford Corp. U.S. Naval Oceanographic Office, Contract No. N62306-69-C-0072, August, Washington, D.C.

Scollar, Irwin
1969 "Some Techniques for the Evaluation of Archeological Magnetometer Surveys." World Archaeology 1(1):77-89. Routledge and Kagen Paul Ltd., Henley on Thames, Oxon, London.

Scollar describes various methods of evaluating the data obtained from proton-magnetometer surveys, including means of isolating anomalies of desired sizes and means, and filtering out undesired ones.

Solecki, Ralph S.
1960 Manual of Photographic Interpretation. American Society of Photogrammetry, Menasha.

Sprecht, R. D.; D. Needler; N. L. Fritz
1973 "A New Color Film for Water Penetration Photography." Photogrammetric Engineering and Remote Sensing 39:359-369. American Society of Photogrammetry, Falls Church, Virginia.

Thompson, M. M., editor
1966 Manual of Photogrammetry. Third edition. American Society of Photogrammetry, Falls Church, Virginia.

Throckmorton, P. and J. Bullitt
1963 "Underwater Surveys in Greece." Expedition 5(2):16-23.

U.S. Army Corps of Engineers
1963 Photogrammetric Mapping. Engineer Manual EM-1110-2-1000. Washington, D.C.

Vacquier, V.; N.C. Steenand; R. G. Henderson; and I. Zeitz
1951 Interpretation of Aeromagnetic Maps. Geological Society of America Memoir No. 47. Geological Society of America, Boulder, Colorado.

Vickers, Roger; Lambert Dolphin; and David Johnson
1976 "Archeological Investigations at Chaco Canyon Using a Subsurface Radar." In Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of Archeological Exploration, Survey, and Analysis. Reports of the Chaco Center, No. 1, assembled by Thomas R. Lyons, pp. 81-102. U.S. Department of the Interior, National Park Service, Chaco Center, New Mexico, and University of New Mexico, Albuquerque, New Mexico. Offset.

Vigil, A. E.
1975 "A New Low Light Level Television Camera for Underwater Applications." Marine Technology Society Bulletin 581-600.

Vogt, Evon Z.
1974 Aerial Photography in Anthropological Field Research. Harvard University Press, Cambridge, Massachusetts.

Walls, Michael D.
1974 "Applications of Remote Sensing in Archaeological Site Identification." Paper presented to the 31st Southeastern Archaeological Conference, Atlanta, Georgia.

Waters, G. S. and P. D. Francis
1958 "A Nuclear Magnetometer." Journal of Scientific Instrumentation 35:88-93. Institute of Physics, Techno House of Redcliff Way, Bristol, England.

Watts, Gordon P.
1975 "The Location and Identification of the Ironcald U.S.S. Monitor." International Journal of Nautical Archaeology and Underwater Exploration 4:301-330. Academic Press, London, England.

Weymouth, John H.
1974 A Magnetic Survey of the Walth Bay Site (39WW203). U.S. Department of the Interior, National Park Service, Midwest Archeological Center, Lincoln, Nebraska.

Weymouth discusses theory and methodology for proton-magnetometer survey work in archeological contexts. A magnetometer survey was conducted in Walth Bay, on the shore of the Oahe Reservoir, to determine its value prior to excavation. The results were generally successful; however, Weymouth points out that local conditions affecting magnetism must be taken into account.

Williams, J. C. C.
1969 Simple Photogrammetry. Academic Press, London, England.

1972 "Underwater Surveying by Simple Graphic Photogrammetry with Obliques." In Underwater Archaeology: A Nascent Discipline, pp. 211-222. UNESCO, Paris.

Wood, Roland and Frank Stapor
1974 "Remote Sensing Investigation of Fort Poinsett." In Underwater Archeology in the National Park Service: A Model for the Management of Submerged Cultural Resources, Daniel J. Lenihan, editor, pp. 52-60. U.S. Department of the Interior, National Park Service, Southwest Regional Office, Santa Fe, New Mexico.

Wood and Stapor used aerial photographs and multiband infrared photographs and photogrammatic techniques, illustrated a change in the coastline in the suspected area of the fort. This corresponded to the results from the infrared photos. The authors suggest that a magnetometer survey be conducted to confirm or reject the suspected location of the fort.

Yules, J. and H. E. Edgerton
1964 "Bottom Sonar Techniques." Undersea Technology, November.

Section 10: LEGAL ASPECTS, VANDALISM, AND ANTIQUITIES VIOLATIONS

Anson, Richard H.
1976 "Recreation Deviance: Some Mainline Hypotheses." Journal of Leisure Research 8(3):177-180. National Recreation and Parks Association, Arlington, Virginia.

Anonymous
1976 "Wreckage of Ship Ruled Private." Denver Post 8 January.

This newspaper article reports a recent Federal ruling that awarded the wreckage of a Spanish galleon to private salvagers. The ruling raises questions regarding the application of the Antiquities Act to underwater sites.

Campbell, Frederick L; John C. Hendee; and Roger Clark
1968 "Law and Order in Public Parks." Parks and Recreation 3(12): 28-31, 51-55. National Recreation and Parks Association, Washington, D.C.

Christensen, Harriet H. and Roger N. Clark
1978 "Understanding and Controlling Vandalism and Other Rule Violations in Urban Recreation Areas." Paper presented at the National Urban Forestry Conference, November 13-16, Washington, D.C.

Clark, Roger N.
1976 "Control of Vandalism in Recreation Areas--Fact, Fiction or Folklore?" In Vandalism and Outdoor Recreation: Symposium Proceedings, Sam S. Alfano and Arthur W. Magill, editors, pp. 62-72. U.S. Department of Agriculture, Forest Service General Technical Report PSW-17. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Clark, Roger N.; John C. Hendee; and Frederick L. Campbell
1971a "Values, Behavior, and Conflict in Modern Camping Culture." Journal of Leisure Research. 3(3):143-159. National Recreation and Parks Association, Arlington, Virginia.

1971b "Depreciative Behavior in Forest Campgrounds: An Exploratory Study." Pacific Northwest Forest and Range Experiment Station PNW-161. U.S. Department of Agriculture, Forest Service, Portland, Oregon.

Cockrell, W. A.
1980 "The Trouble with Treasure-A Preservationist View of the Controversy." American Antiquity 45(2):333-339. Society for American Archaeology, Washington D.C.

Cockrell's excellent article outlines the serious problems facing underwater archeology and the preservation threat to submerged cultural resources. Must reading for the concerned resource manager.

Collins, Robert B. and Dee F. Green
1978 "A Proposal to Modernize the American Antiquities Act." Science 202(12):1055-1059. American Association for the Advancement of Science, Washington, D.C.

Collins and Green discuss several court cases that were tried under the Antiquities Act of 1906 in Arizona and New Mexico. They call for the enactment of a new law which would include stiff penalties for violations, including trafficking in stolen artifacts.

1978 Problems in Managing Forest Recreation Facilities: A Survey of Field Personnel. Survey of Recreation Management Equipment Needs, ED&T 7093. U.S. Department of Agriculture, Forest Service Equipment Development Center, Missoula, Montana.

Drissen, Jon
1978 Problems in Managing Forest Recreation Facilities: A Survey of Field Personnel. Survey of Recreation Management Equipment Needs, Ed&T 7093. U.S. Department of Agriculture, Forest Service, Equipment Development Center, Missoula, Montana.

Fischer, George R.
1976 "Legal Considerations in Underwater Archaeology." Paper presented, at the Seventh International Conference on Underwater Archaeology 1976, Philadelphia, Pennsylvania.

Fischer mentions various pertinent items of legislation, but the primary focus of this paper is upon the question of marine jurisdictions and jurisdictions of internal waters. The archeologist must know the ownership and controlling status of the waters and submerged lands in which they are working in order to comply with the various permits and antiquities legislation.

Fowler, John M.
1976 "Federal Historic Preservation Law: National Historic Preservation Act, Executive Order 11593, and Other Recent Developments in Federal Law." Wake Forest Law Review 12:31-78. Wake Forest University School of Law, North Carolina.

Frizzel, Kent
1975 Correspondence to Hon. Robert H. Brok on the subject of United States vs. Farish Jenkins case.

Frizzel's letter relates to Antiquities Act violations with regard to paleontological materials.

Green J. N. and G. Henderson
1977 "Maritime Archaeology and Legislation in Western Australia." International Journal of Nautical Archaeology and Underwater Exploration 6:245-248. Academic Press, London.

Hendee, John C. and Frederick L. Campbell
1969 "Social Aspects of Outdoor Recreation--The Developed Campground." Trends in Parks and Recreation. October.

Hoots, Thomas A.
1976 "Vandalism and Law Enforcement on National Forest Lands." In Vandalism and Outdoor Recreation: Symposium Proceedings, Sam S. Alfano and Arthur W. Magill, editors, pp. 20-23. U.S. Department of Agriculture, Forest Service General Report PSW-17. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Hothem, L.
1978 "Indian Artifacting." Fur, Fish and Game. August, pp. 26-40.

Jensen, C. W. and J. Jensen
1960 Modern Laws Relating to Salvage and Sunken Treasure. Natick, Massachusetts.

Krippene, Ken
1973 "Illicit Treasure--A Billion Dollar Bonanza." Treasure 4(11):11-16.

Meenan, James Kevin
1978 "Cultural Resources Preservation and Underwater Archeology: Some Notes on the Current Legal Framework and a Model Underwater Antiquities Statute." San Diego Law Review 15(3):623-662. University of San Diego School of Law, San Diego, California.

Meenan provides a good discussion of extant laws relating to underwater archeological jurisdiction including: common law of abandonment, rule of sovereign perogative, American rule, devolution, abandoned property act, antiquities act, jurisdiction over the seabed etc. Includes discussion of Atocha rulings.

Mertes, J. D.; A. N. Gluek; and W. Bell
1979 "A Solution to Recreation and Resource Management in Remote Areas." Parks and Recreation Magazine 8:27-32, 48. National Recreation and Parks Association, Washington, D.C.

Miller, Thomas
1976 "Vandalism in California State Parks." In Vandalism and Outdoor Recreation: Symposium Proceedings, Sam S. Alfano and Arthur W. Magill, editors, pp. 14-15. U.S. Department of Agriculture, Forest Service General Technical Report PSW-17. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Muth, Robert M. and Roger N. Clark
1978 Public Participation in Wilderness and Back Country Litter Control: A Review of Research and Management Experience. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

North Carolina Division of Archives and History
1971 Rules and Regulations Governing Exploration and Salvage of Abandoned Shipwrecks and Other Underwater Archaeological Artifacts. Raleigh, North Carolina.

Pearson, C.
1976 "Legislation for the Protection of Shipwrecks in Western Australia." International Journal of Nautical Archaeology and Underwater Exploration 5:171-173. Academic Press, London.

Rensberger, Boyce
n.d. "Bulldozers and the Threat to Prehistoric Sites." Newpaper clipping, New York Times Service.

> Rensberger cites numerous examples of site destruction and inundation that occurred prior to scientific archeological recovery. Much of the destruction resulted from land development, highway and reservoir construction, farming activities, and vandalism.

Rippeteau, Bruce E.
1979 "Antiquities Enforcement in Colorado." Journal of Field Archaeology 6(1):85-103. Boston University Press, Boston, Massachusetts.

> Rippeteau discusses the differing classes of "antiquities destroyer", the nature of antiquities markets, and how the law sometimes helps, sometimes hinders prosecution of violators. Presented are case studies of antiquites violation prosecutions in Colorado and adjacent states. Efforts of private, state and Federal agencies to reduce adverse impacts to the resource and increase public awarenesss of the fragile nature of cultural resources is included.

Rister, Carl C.
1931 "Harmful Practices of Indian Traders of the Southwest, 1865-1876." New Mexico Historical Review 6(July):231-248.

Scott, D.
1977 "Two Vandalized Pueblo III Burials: Some Key Factors Affecting Vandalism of Sites." Southwestern Lore 43(1977):10-14.

Stephenson, Robert L.
1974 The South Carolina Underwater Salvage Law. Revised uniform rules and regulations adopted by the Institute of Archaeology and Anthropology, University of South Carolina, Columbia, South Carolina.

Stephenson's booklet contains all the laws, rules, and regulations pertaining to the recovery of submerged archeological artifacts from state-controlled waters.

Trenerry, Walter N.
1964 "Some Legal Problems in the Field of Underwater Archaeology." In Diving into the Past: Theories, Techniques and Applications of Underwater Archeology, J. Drenning Holmquist and A. Hillman Wheeler, editors, pp. 37-43. Minnesota Historical Society, St. Paul, Minnesota.

Trenerry deals with the question of landownership (including submerged lands) and the legal responsibilities of archeologists and salvagers regarding land and water status. The author concentrates primarily on International Maritime Policy, but devotes some attention to state policy and employer obligations as they relate to insurance and liability.

Utano, Jack J.
1979 "The Criminal and the Spatial Choice Process: A Behavioral Approach." In Proceedings of the East Great Lakes Division Association of American Geographers, Edward Hanten and Jack Utano, editors, pp. 14-19. University of Akron, The Center for Urban Studies, Akron, Ohio.

Ward, Colin, editor
1973 Vandalism. Van Nostrand Reinhold Co., New York, New York.

Wehr, Arno
1976 "Indians Everywhere." Skin Diver Magazine 25(2):89.

Wehr's article in the most popular sport diving magazine in the United States actually publicizes the whereabouts of prehistoric sites in Table Rock Reservoir, and describes how to get underwater guides to help pothunt them! The article demonstrates the need for cultural resource management in submerged areas. The education of the public about the scientific importance of archeological sites, whether submerged or not, is of paramount importance if these sites are to be preserved.

Westover, Theresa and Michael Chubb
1979 "Crime and Conflict in Urban Recreation Areas: Research in Progress." Paper presented at the Second Conference on Scientific Research in the National Parks, San Francisco, California.

Whelen, Nicholas
1976 "Law Enforcement and Vandalism in Our National Parks." In Vandalism and Outdoor Recreation: Symposium Proceedings, Sam S. Alfano and Arthur W. Magill, editors, pp. 27-29. U.S. Department of Agriculture, Forest Service General Technical Report PSW-17. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

SECTION 11: MISCELLANEOUS PUBLICATIONS

Allan, William C. and David E. Stuart
1977 "Archeological Survey of the River-Water Pipeline." In Settlement and Subsistence Along the Lower Chaco River: The CGP Project, Charles A. Reher, editor, pp. 603-614. University of New Mexico Press, Albuquerque, New Mexico.

Davis, R. H.
1955 Deep Diving and Submarine Operations. 6th edition. Siebe Gorman, London, England.

Edit, Robert C. and William D. Woods
1974 Abandoned Settlement Analysis: Theory and Practice. Field Test Associates, Shorewood, Wisconsin.

Ferguson, Leland, ed.
1977 Historical Archaeology and the Importance of Material Things. Society for Historical Archaeology.

Fitzsimmons, Stephen J. and Ovadia A. Salama
1973 A Social Report--Man and Water. Prepared for the Bureau of Reclamation. Abt Associates, Cambridge, Massachusetts.

> Fitzsimmons and Saloma examine the socio-psychological relationship of man to water resources development, and present a model to man. The authors make recommendations for pilot testing of the model, synthesis of the data, and future structuring of environmental impact statements. The report is an important first step in moving away from considering man solely as "Homo Economicus," toward an awareness of the ways in which programs and policies affect the quality of life of vast numbers of people.

Fitzsimmons, Stephen J.; Peter C. Wolff; R. L. Goodrich; and R. J. Emerine
1974 Draft Social Assessment of the Proposed Narrows Unit, and Alternatives Thereto, Pick-Sloan Missouri River Basin, Colorado. Prepared for the Bureau of Reclamation. Abt Associates, Cambridge, Massachusetts.

> Fitzsimmons, Wolff, Goodrich, and Emerine, in this subsection of an environmental impact study, evaluate the proposed Narrows Unit Impoundment Project. The consider impacts upon the affected local communities in terms of both economics and quality of life. This is the first report resulting from the Bureau

of Reclamation with both positive and negative feedback concerning the proposed means by which this agency can make major contributions to the overall well-being of the directly affected families, as well as to more distant communities, which will also share in the benefits of the Narrows Dam.

Fitzsimmons, Stephen J.; Lorrie I. Stuart; and Peter C. Wolff
1975 Social Assessment Manual: A Guide to the Preparation of the Social Well-Being Account. Prepared for the Bureau of Reclamation. Abt Associates, Cambridge, Massachusetts.

This manual, prepared by Fitzsimmons, Stuart, research and analyzing data so that probable beneficial and adverse social impacts of implementation of water development plans can be predicted.

Flannery, Kent V.
1976 The Early Mesoamerican Village. Academic Press, New York, New York.

Hudson, Kenneth
1976 The Archaeology of Industry. Charles Scribner's Sons, New York, New York.

Piggott, Stuart
1965 Ancient Europe from the Beginnings of Agriculture to Classical Antiquity: A Survey. Aldine, Chicago, Illinois.

Reher, Charles A., ed.
1977 Settlement and Subsistence Along the Lower Chaco River: The CGP Suvey. University of New Mexico Press, Albuquerque, New Mexico.

Vita-Finzi, C. and E. S. Higgs
1970 "Prehistoric Economy in the Mount Carmel Area of Palestine: Site Catchment Analysis." In Proceedings of the Prehistoric Society 36:1-37.

Wheeler, Sir Mortimer
1954 Archaeology from the Earth. Oxford Press, Oxford, England.

Wiley, Gordon R.
1953 "Prehistoric Settlement Patterns in the Vira Valley Peru." Bureau of American Ethnology Bulletin, No. 155

1956 "Prehistoric Settlement Patterns in the New World." Viking Fund Publications in Anthropology, No. 23. Werner-Gren Foundation for Anthropological Research Inc., New York, New York.

1966 *An Introduction to American Archaeology, Vol. I, North and Middle America*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Yellen, John E.
1974 "The !Kung Settlement Pattern: An Archaeological Perspective." PhD dissertation, Harvard University, Boston, Massachusetts.