Appendix D

Water Quality Technical Report

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D.0 Water Quality Technical Report

This report is a summary of the *Final Las Vegas Wash Modeling Report* dated August 2003 (Black & Veatch 2003a), the *Lake Mead Water Quality Modeling Report* (Black &Veatch 2005b), and the *Lake Mohave Modeling Report* (J.E. Edinger 2003). These reports describe the modeling efforts conducted for the Systems Conveyance and Operations Program (SCOP) to determine the effects of the SCOP to the watershed. The modeling effort encompassed the Las Vegas Wash, Lake Mead, and downstream through Lake Mohave.

The Las Vegas Wash was modeled to determine what effects to water quality the projected amounts of effluent and removal of effluent would have on the Las Vegas Wash. The water quality in Lake Mead and downstream of Hoover Dam was modeled to determine the effects of the SCOP alternatives on the water quality in the Las Vegas Bay, Boulder Basin, and at the Southern Nevada Water Authority (SNWA) intakes, the Hoover Dam intakes, and downstream of Hoover Dam. The Las Vegas Wash Model output defines some of the input parameters for the Boulder Basin (Lake Mead) model.

Table D.0-1 presents the concentration and mass loading for parameters in the effluent (discharge) that were considered in the modeling effort. The parameters presented are consistent with the parameters addressed throughout the modeling process, and values presented are based on projected flow increases. Also presented in the table are the mass loading for parameters that are removed from Lake Mead via the SNWA intakes. The concentrations are used for comparison purposes only and not intended to represent proposed final concentrations. The final concentrations of all parameters discharged into Lake Mead will be determined through the permitting process administered by the Nevada Division of Environmental Protection (NDEP).

It is important to note that the effluent parameters would be mixed with Lake Mead waters and dilution of the concentrations would occur. Therefore, the concentrations presented in Table D.0-1 are not necessarily the concentrations that would be observed at the inner Las Vegas Bay, Boulder Beach, SNWA intakes, or Hoover Dam Discharge.

D.1 Las Vegas Wash Model

The Las Vegas Wash Model was created to determine the effects of various effluent quantities to Las Vegas Wash water quality and to determine the amount of effluent that should remain in the Las Vegas Wash. The Las Vegas Wash is generally known as the reach from Vegas Valley Drive downstream to Lake Las Vegas and is the drain for the entire Las Vegas Valley. It collects urban runoff, treatment plant effluents, and groundwater seeps.

The SCOP Water Quality Modeling Subcommittee decided to model the Las Vegas Wash using a mass balance approach. The mass balance approach assumes whatever enters the cell is equal to what exits the cell plus any losses through the cell. Two constituents, temperature and phosphorus, were modeled using methods other than flow-weighted mass balancing.

Temperature is modeled using three methods in the Las Vegas Wash Model. To calculate the total wetland influent, a flow-weighted mass balance is used on all of the wetland cell's influent sources to determine the composite influent into the wetland cell. Temperature change within the wetland cell is calculated using temperature equations that calculate the effect of air temperature on the water

Table D.0-1 Mass Loading of Discharge and Intake Parameters.

			Las Vegas Wash	Current Flows			Projected 2030 Flows			Projected 2050 Flows		
			30 MGD flow	383 MGD Influent	153 MGD Effluent		750 MGD Influent	300 MGD Effluent		1000 MGD Influent	400 MGD Effluent	
Parameter	**Intake Concentration (mg/L)**	**Effluent Discharge Concentration (mg/L)**	**Mass Loading (lbs/day)**	**Mass Loading (lbs/day)**	**Mass Loading (lbs/day)**	**Net Loading (lbs/day)**	**Mass Loading (lbs/day)**	**Mass Loading (lbs/day)**	**Net Loading (lbs/day)**	**Mass Loading (lbs/day)**	**Mass Loading (lbs/day)**	**Net Loading (lbs/day)**
Total Dissolved Solids	570.00	1,144.00	286,229	1,820,705	1,459,767	(360,939) [1]	3,565,350	2,862,288	(703,062) [1]	4,753,800	3,816,384	(937,416) [1]
Total Phosphorus	0.0045	0.14 (2030) 0.10 (2050)	50	14	255	241	28	334	306	38	334	296
Soluble Phosphorus	0.0044	0.11 (2030) 0.075 (2050)	38	14	191	177	28	375	348	37	500	464
Total Nitrogen	0.48	16.70	4,178	1,533	21,310	19,776	3,002	41,783	38,781	4,003	55,711	51,708
Ammonia	0.015	0.26	65	48	332	284	94	651	557	125	867	742
Bromide	0.081	0.20	50	259	255	(4) [1]	507	500	(6) [1]	676	667	(8) [1]
Sulfate	240	330	82,566	766,613	421,087	(345,526)	1,501,200	825,660	(675,540) [1]	2,001,600	1,100,880	(900,720) [1]
Chloride	82	250	62,550	261,926	319,005	57,079	512,910	625,500	112,590	683,880	834,000	150,120

Note:

[1] A greater mass loading of these substances is removed from Lake Mead through the SNWA drinking water intakes than is added through the effluent discharge.

temperature. Finally, a modification to the effluent temperature may be made by applying a temperature change due to evaporation. Within the Las Vegas Wash Model, it is expected that phosphorus is removed from the system through sedimentation. A sedimentation rate constant of 2.74 centimeters per day was used to determine how much phosphorus is removed in each wetland cell.

The Las Vegas Wash Model was created in a Microsoft Excel workbook format.

D.1.1 Las Vegas Wash Model Methodology and Assumptions

The SCOP Water Quality Modeling Subcommittee identified five parameters for modeling. Members of the subcommittee included representatives from the Clean Water Coalition, City of Henderson (COH), City of Las Vegas (CLV), Clark County Water Reclamation District (CCWRD), National Park Service, U.S. Bureau of Reclamation (Reclamation), and SNWA. The parameters selected for evaluation include:

- Flow,
- Temperature,
- Total inorganic nitrogen (TIN),
- Total phosphorus (TP),
- Total dissolved solids (TDS), and
- Selenium.

The Las Vegas Wash model accounts for wetlands formed or expected to form behind the 22 erosion control structures (ECSs) and the potential for the creation of wetland areas outside the main channel. It was assumed that these off-channel wetlands would most likely be created in the Duck Creek Channel and along the northern side of the Las Vegas Wash between the outlets of the Monson Channel and Duck Creek.

The inflows to the Las Vegas Wash, accounted for in the Las Vegas Wash Model, include flows from the Las Vegas Creek, Sloan Channel, Flamingo Wash, three wastewater treatment facilities, Monson Channel, Duck Creek, groundwater seep, and C-1 Channel. A base flow, not including effluent, of 20 million gallons per day (mgd) in the Las Vegas Wash was assumed based upon the Las Vegas Wash Comprehensive Adaptive Management Plan (Las Vegas Wash Coordination Committee 2000).

Once the model was created in the spreadsheets, it was necessary to compare the results calculated within the model to those measured at the lower end of the Las Vegas Wash. Data is regularly collected at Northshore Road, which is just downstream of Lake Las Vegas, and thus downstream of the area covered by the Las Vegas Wash Model. Since only five ECSs were in place when the data were collected, those were the only ECSs included in the calibration/verification model runs.

D.1.2 Las Vegas Wash Model Input Data

Effluent data were collected directly from the three treatment plants for the years from 1997 to 2001 and were input to the model for calibration purposes. Year 2002 data was used as baseline conditions (Table D.1-1). Water-quality data from the Las Vegas Wash and its tributaries were collected from the COH. Weather data were collected from the United States Geological Survey (USGS) website. Groundwater quality information was gathered from the groundwater seeps by SNWA.

Table D.1-1 Baseline Water Quality Conditions in the Las Vegas Wash.

Parameter	LW0.55
Temperature (°C) [°F]	22.6 [72.7]
Perchlorate (µg/L)	NA[1]
Conductivity (µS/cm)	2344
Total Dissolved Solids (mg/L)	1,675
Dissolved Oxygen (mg/L)	8.9
Chlorophyll (µg/L)	NA
Total Phosphorus (mg/L)	0.2
Soluble Phosphorus (mg/L)	0.1
Total Inorganic Nitrogen (mg/L)	16
Nitrate (mg/L)	15.8
Total Ammonia Nitrogen (mg/L)	0.1
Un-ionized Ammonia (mg/L)	NA
Bromide (mg/L)	NA
Sulfate (mg/L)	633
Chloride (mg/L)	309
Fecal Coliform (MPN/100mL) [2]	231
pH	8.3
Selenium (µg/L)	2.5

Notes:
[1] NA = Not available.
[2] Most probable number per 100 ml (1 deciliter).
Source: COH 2002d.

The CLV, CCWRD, and COH each provided compiled wastewater effluent data for inclusion in the model. The data set included water quantity and quality. The CLV also provided Las Vegas Wash and Lake Mead water quality data, which were used in the preliminary model runs and for verification of the model results. Weather data, including rainfall, evapotranspiration, wind, and solar radiation data were obtained via the internet.

D.2 Lake Mead Model

The Lake Mead Model was created to determine the effects of various effluent quantities and discharge locations to the water quality of Lake Mead. Boulder Basin, located immediately upstream of Hoover Dam, is the main study area of this project. The principal inflows to Boulder Basin are from the Colorado River via the Narrows, from the Virgin and Muddy rivers, and from the Las Vegas Wash, which discharges into Boulder Basin through the Las Vegas Bay. There are also two principal outflows from

Boulder Basin, through four outlet towers at Hoover Dam and through the SNWA intakes located at Saddle Island.

The goals of the data collection and analysis efforts for the Lake Mead Water Quality Model are to:

- Develop an understanding of the reservoir mixing and biochemistry,
- Prepare input data files for the Boulder Basin model, and
- Calibrate and validate the model.

D.2.1 Lake Mead Model Methodology, Calibration, and Confidence Level

Water-quality impacts to Lake Mead from each of the alternate discharge locations were analyzed using two steps: a hydrodynamic simulation and a biochemical simulation. Two separate models were used to perform the analysis: the Estuary and Lake Computer Model (ELCOM) and the Computational Aquatic Ecosystem Dynamic Model (CAEDYM).

The ELCOM is a stand-alone three-dimensional hydrodynamic code, whereas CAEDYM is a water-quality module that uses ELCOM as its hydrodynamic "driver". The outcome of the hydrodynamic simulation, ELCOM, is a detailed characterization of water movement and mixing in the Lake, coupled with a description of the thermal stratification.

The bio-chemical simulation, CAEDYM, computes interactions between biological organisms and the chemistry of their nutrient cycle. The ELCOM/CAEDYM model is a fully three-dimensional model that accounts for variation in water chemistry and biology as a function of depth, as well as horizontal position. The coupled models proved to be an effective tool to study the spatial and temporal relationships between physical, biological, and chemical variables in Lake Mead. These models are described in detail in *the Lake Mead Water Quality Modeling Report* (Black & Veatch 2005b).

The ELCOM/CAEDYM model has been validated and applied in numerous instances, many of which have been published in peer reviewed journals. ELCOM/CAEDYM has been verified for the specific application to Boulder Basin The widely used EPA PLUMES algorithm was incorporated into the model to account for the near-field dilution and insertion elevation of the diffuser plume. The EPA PLUMES algorithms have been in development for over 30 years, and are approved by the U.S. Environmental Protection Agency (EPA) for prediction of plume evolution and dilution in arbitrarily stratified water bodies. The modeling has been closely coordinated with the SNWA and their plans for new intakes and how they would manage Lake withdrawals in the future. All of the modeling was conducted jointly with SNWA.

The SCOP Water Quality Modeling Subcommittee identified the parameters and conditions that would be included in the modeling effort. Two Lake elevations and three effluent flow quantities were modeled. The two Lake elevations selected for modeling include:

- 1,178 ft (359 m) – The Lake elevation on January 1, 2002; and
- 1,000 ft (305 m) – The elevation selected by the Subcommittee to represent the probable lowest elevation of Lake Mead considering the historic 15-year below-normal precipitation cycle.

Variations of effluent flows were addressed by modeling three scenarios.

- 150 mgd - The effluent flow quantities in 2002 (baseline),
- 300 mgd - The projected effluent flows for year 2030, and

- 400 mgd – The projected effluent flows for year 2050.

The parameters modeled for the previously mentioned scenarios include:

- Chlorophyll *a,*
- Secchi Depth,
- Nitrates (NO_3)and TIN,
- Ammonia
- Un-ionized Ammonia (NH_3),
- Dissolved Oxygen (DO),
- Tracer for Effluent,
- Fecal Coliform (FC),
- Conductivity,
- Bromide,
- TP,
- Perchlorate,
- Chloride,
- Sulfate,
- Temperature,
- pH,
- Biological Oxygen Demand (BOD), and
- Total Nitrogen (TN).

The selection of modeled parameters was determined by the following factors:

- Ability of the code to model the parameter,
- Availability of sufficient data to calibrate the simulation, and
- Importance of the parameter to the Lake Mead study.

For example, total organic carbon (TOC) was not simulated in Lake Mead because the model does not include a variable specifically for TOC and, thus, it cannot be modeled directly. Insufficient measured data for zooplankton and total suspended solids in the inflows and the Lake made their simulation impractical. Furthermore, parameters such as iron, manganese, and aluminum were not modeled because of their relatively minor impacts on the water quality of Lake Mead.

The analysis of water quality includes the highest and lowest Lake levels, 1,178 and 1,000 feet respectively, with effluent flows of 300 mgd and 400 mgd projected for years 2030 and 2050. This provides a modeled prediction of the optimal (2030) and the most restrictive conditions (2050). A maximum phosphorus loading of 334 pounds per day (lbs/day) was analyzed for the pipeline alternatives based on the total maximum daily load waste load allocation for the Las Vegas.

Model sample locations were also determined by the Subcommittee. The complete list of model sample locations is presented in the *Lake Mead Water Quality Modeling Report* (Black & Veatch 2005b). The model locations most relevant to the alternatives analyzed in the SCOP Environmental Impact Statement (EIS) are the Inner Bay (LVB1.85 M), Inner Bay (LVB2.7), Boulder Basin (CR346.4), Boulder Beach, Hoover Dam Discharge, and SNWA Intake (Figure D.2-1). It is important to note that LVB1.85M is mobile and located at a depth of 16 to 18 meters (m) (52 to 59 feet [ft]) near the confluence of the Las Vegas Wash and Lake Mead. All other locations are stationary. The Hoover Dam discharge data

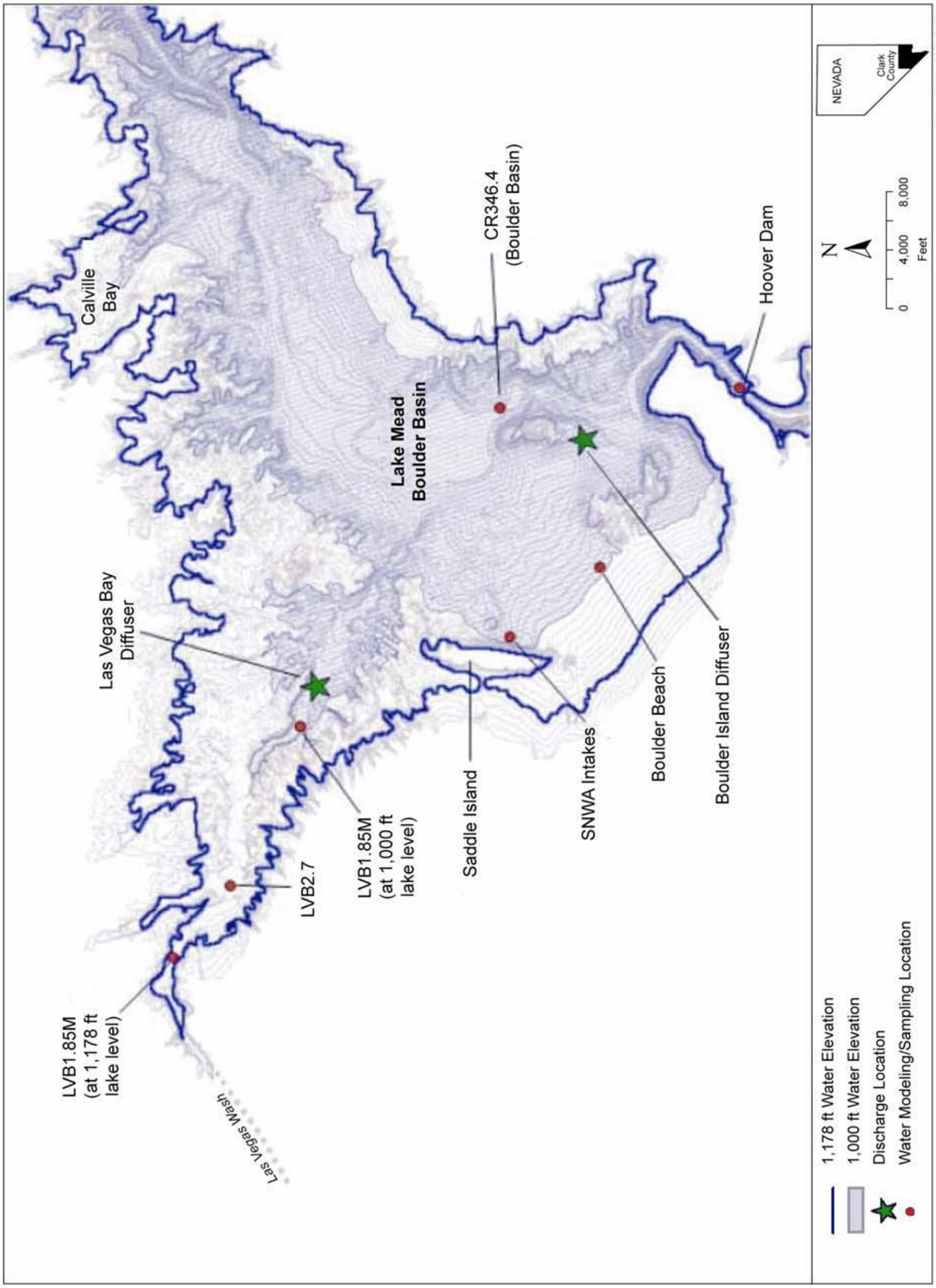

Figure D.2-1 Water Quality Modeling/Sampling and Discharge Locations in Lake Mead.

considered the upper and lower intakes combined, and the SNWA intake data considered the lower intake only.

Extensive data collection and model calibration was conducted. Model calibration and validation were required prior to applying the model to the analysis of the alternatives. Model calibration was conducted in two phases: an ELCOM calibration followed by a CAEDYM calibration. The ELCOM calibration focused on physical parameters such as temperature, conductivity, perchlorate, and FC. The CAEDYM calibration considered chemical and biological parameters such as chlorophyll, nutrients, DO, and pH. The model calibration was complete when the agreement between the model results and the field data was considered adequate. Model Calibration is discussed in detail in the *Lake Mead Water Quality Modeling Report* (Black & Veatch 2005b).

A medium grid (600-m grid size) was used for the modeling effort (Figure D.2-2). The ELCOM water quality variables that were included in the simulations are temperature, conductivity, perchlorate, FC, chloride, sulfate, bromide, and salinity. The ELCOM tracers that were included in the simulation were tracers for the effluent, Las Vegas Wash baseflow, stormwater, and Colorado River inflow. The CAEDYM variables that were included in selected simulations are BOD, DO, TP, soluble phosphorus, NO_3, NH_3, TN, pH, and chlorophyll.

For initial screening purposes, the original alternate discharge locations evaluated for the ELCOM/CAEDYM runs were Las Vegas Bay, Callville Bay, Promontory Point, Hemenway Wall, and Boulder Islands. The results of the modeling indicated that the discharge locations that best meet the purpose and need for the SCOP and maintain water quality standards are the Boulder Islands and Las Vegas Bay discharge locations.

The Boulder Islands and Las Vegas Bay scenarios consist of discharging 270 mgd of the effluent through a diffuser located at one of these locations, with the remaining 30 mgd of effluent being discharged into the Las Vegas Wash. The discharges are assumed to always be located below the thermocline unless specified otherwise. A surface discharge through the Las Vegas Wash (No Action Alternative) was also simulated, consisting of discharging the future 300 mgd of effluent flow into the Las Vegas Wash. In addition, several Las Vegas Wash/Las Vegas Bay Combined and Las Vegas Wash/Boulder Islands Combined cases were simulated to evaluate the effects of a range of scenarios with varying proportions of effluent being discharged through the Las Vegas Wash and a diffuser located at either Las Vegas Bay or Boulder Islands. These Combined case simulations are discussed further in the *Lake Mead Water Quality Modeling Report* (Black & Veatch 2005b).

All of these alternative simulations used meteorological data, Colorado River inflow volumes, water quality, tracer concentrations, and Hoover Dam release volumes from 2002. The limnology of Lake Mead was also considered and additional information regarding Lake Mead limnology is presented in the *Lake Mead Water Quality Modeling Report* (Black & Veatch 2005b).

Simulations using the ELCOM/CAEDYM model were performed for the years 1999 through 2003 (Black & Veatch 2005b). Of those years, complete destratification of Lake Mead occurred in 1999, 2001, and 2002. Complete destratification did not occur in 2000 and 2003 (LaBounty & Burns 2005). The modeling indicates that there is no accumulation of effluent when it is discharged into the hypolimnion through a diffuser, whether complete destratification of the Lake occurs or not. This is mainly a result of the effluent being significantly warmer and thus less dense than the ambient reservoir water. Additional information regarding destratification is presented in Attachment 1 of this Appendix.

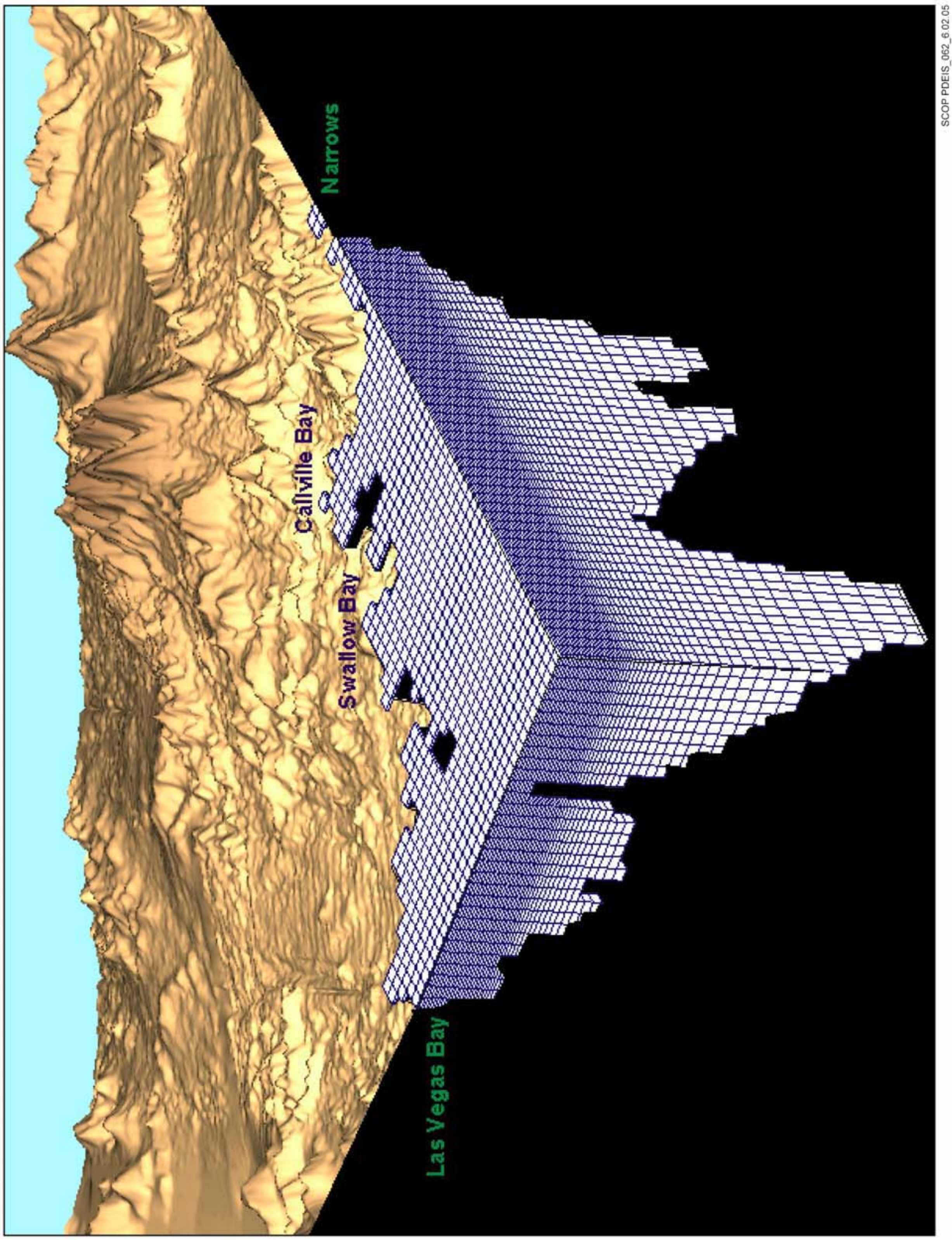

Figure D.2-2 600-meter Grid.

The confidence levels for ELCOM/CAEDYM predictions of yearly averages for various modeled substances (except chlorophyll *a*) were estimated based upon comparisons of perchlorate field data and calibration model results for a 3-year period (2000 through 2003). Initially, confidence levels for perchlorate yearly averages were computed based on a method of analysis that closely follows that used in determining model confidence level estimates for chlorophyll *a*. The computed confidence levels for perchlorate were then used to determine confidence levels for other substances that are considered in the ELCOM/CAEDYM model. Perchlorate was chosen since it is a conservative substance that enters Boulder Basin predominantly through the Las Vegas Wash. Perchlorate is not a parameter in the effluent but enters the Las Vegas Wash through a series of groundwater seeps. In addition, there are 40 to 60 perchlorate measurements available per year in the Las Vegas Wash, which enables meaningful statistical analysis. On the other hand, most other conservative substances computed in the model have significant contributions from both the Narrows and the effluent, making a direct estimate of confidence level difficult.

The errors of the model output are identified by determining the differences between the field and model averages. These errors are then combined over the four calendar years using the conservative “Root Mean Square” (RMS) method (Lorden 2004). Specifically, the RMS error is obtained by averaging the squares of the errors and taking the square root of the result. The percent RMS errors generally range from 10.4 percent to 13.5 percent. Based upon these results, a reasonable value to use to estimate model confidence limits for the annual average perchlorate value is 13 percent.

Confidence levels for the model estimates of conservative substances other than perchlorate (eg. effluent tracer, chloride, bromide) are also assumed to be 13 percent. A similar analysis for chlorophyll *a* indicated confidence levels of 35 percent (Lorden 2004). This difference in confidence levels is attributed to the fact that the predictions for conservative substances are more accurate than those for chlorophyll. This is a result of the uncertainty in model input parameters such as algae growth rates and their dependence on other factors such as water temperature, phosphorus concentrations, and solar radiation.

Other non-conservative parameters in Lake Mead such as phosphorus and nitrogen are expected to have confidence levels somewhere between 13 percent and 35 percent. This is a result of the belief that confidence levels for such substances are expected to be lower than those for chlorophyll, but higher than those for conservative substances. Due to lack of reliable field data, especially for phosphorus, the confidence levels for such parameters are simply estimated at 25 percent.

The estimated model confidence limits for all modeled parameters are shown in Table D.2-1. It should be noted that the percentage model confidence limits for each parameter are relative to the change in concentration above the background level.

D.2.2 Lake Mead Model Input Data

Water quality data was obtained from the CLV, CCWRD, COH, SNWA, Reclamation, USGS, Basic Management Inc. (BMI), and NDEP for the Lake Mead Model. Data collected included flow rates and water quality data for the effluent, Las Vegas Wash inflow, SNWA intakes, BMI intake, Hoover Dam discharges, and Boulder Basin data. Meteorological and water quality data for Boulder Basin and upstream areas of Lake Mead were also collected. Unless otherwise specified for the wastewater effluent data, all temperature, pH, DO, and FC data were measured using instantaneous (field) or grab samples.

Table D.2-1 Estimated Model Confidence Levels for Parameters.

Parameter	Estimated *Percentage*[1] Model Confidence Levels (percent)
Temperature (°C [°F])	13
Perchlorate (µg/L)	13
Effluent Tracer (%)	13
Conductivity (µS/cm)	13
Total Dissolved Solids (mg/L)	13
Dissolved Oxygen (mg/L)	25
Chlorophyll (µg/L)	35
Total Phosphorus (mg/L)	25
Total Nitrogen (mg/L)	25
Total Ammonia Nitrogen (mg/L)	25
Un-ionized Ammonia (mg/L)	25
Bromide (mg/L)	13
Sulfate (mg/L)	13
Chloride (mg/L)	13

Note:
[1] Relative to the difference between model estimate and background level.

The ELCOM/CAEDYM alternative runs were modeled using "base" conditions from 2002 (Table D.2-2). Year 2002 was selected as the baseline year for the following reasons:

- Prior to year 2000, a limited amount of water quality data is available for Lake Mead;
- A significant amount of data is available for years 2000, 2001, and 2002;
- Year 2001 was an atypical year concerning algal growth in Lake Mead, so it was eliminated from consideration;
- Year 2002 data is representative of typical conditions in Lake Mead including algal growth years; and
- Year 2002 Lake elevation was lower, which is expected to be typical in the future.

The modeling report provides data analysis and modeling of the Lake from 1999 to 2004, not just the baseline year (2002). However, extending the baseline conditions back to 1999 would result in higher baseline values for phosphorus loads through Hoover Dam. This is a direct result of the large algae bloom in 2001 and the fact that before 2002, the dischargers had not yet initiated year-round phosphorus removal (see Table 1 of Attachment 2). For constituents other than phosphorus, using several years for baseline data rather than the single year of 2002 did not produce any significant differences in the conclusions (Black & Veatch 2005b).

Meteorological data, Colorado River inflow volumes, water quality, tracer concentrations, Hoover Dam release volumes, and initial water surface elevations were used to define the meteorological and hydrologic conditions. Actual flow rates for the baseflow and stormwater components of the Las Vegas Wash were also used for each simulation year. The Narrows inflow rates for the alternative runs were adjusted slightly to maintain the same water levels as obtained in 2002. This was needed due to the

Table D.2-2 Baseline Modeled Water Quality Conditions in Boulder Basin
(1,178 ft [359 m] Lake level for Year 2002 effluent flows of 150 mgd [231 cfs] and TP = 292 lbs/day).[1]

Parameter	Inner Bay (LVB1.85M) [2]	Inner Bay (LVB2.7)	Boulder Basin (CR346.4)	Boulder Beach	Hoover Dam Discharge [3]	SNWA Intake [4]
Temperature (°C[°F])	20.3 [68.5]	20.3 [68.5]	19.6 [67.3]	19.3 [66.7]	13.2 [55.8]	13.0 [55.4]
Perchlorate (µg/L)	45.2	46.7	12.9	13.9	6.6	5.8
Conductivity (µS/cm)	1,085	1,094	947	952	901	896
Total Dissolved Solids (mg/L) [5]	687	693	599	603	570	567
Dissolved Oxygen (mg/L)	8.7	8.7	8.3	8.3	7.7	7.5
Chlorophyll Growing Season Average (µg/L) [6]	12.4	12.4	2.0	2.1	≤ 0.01	≤ 0.01
Chlorophyll Annual 95th Percentile (µg/L) [6]	23.0	23.0	3.8	4.1	0.2	0.1
Secchi Depth (m)	3.2	3.2	8.5	8.8	ND [7]	ND [7]
Total Phosphorus (mg/L)	0.018	0.018	0.005	0.005	0.005	0.004
Soluble Phosphorus (mg/L)	0.009	0.009	0.003	0.003	0.004	0.004
Total Nitrogen (mg/L)	1.61	1.68	0.42	0.44	0.34	0.36
Total Inorganic Nitrogen (mg/L) [8]	1.57	1.64	0.40	0.43	0.32	0.33
Total Ammonia Nitrogen (mg/L)	0.012	0.013	0.010	0.011	0.014	0.019
Un-ionized Ammonia (mg/L) [9]	0.0008	0.0008	0.0002	0.0004	0.0002	0.0003
Bromide (mg/L)	0.106	0.107	0.086	0.087	0.080	0.080
Sulfate (mg/L)	295	297	257	259	243	242
Chloride (mg/L)	107	108	85	85	79	78
Fecal Coliform (MPN/dL) [10]	1.0	1.1	0.0	0.0	0.0	0.0
pH	8.1	8.1	8.0	8.0	7.7	7.7

Notes: See following page.

Table D.2-2 Notes:

[1] Unless otherwise specified, sampling depth is surface to 1 m (3.3 ft) except at SNWA and Hoover Dam, which were sampled at the intake depths. All data is the annual average, except for chlorophyll, which includes the growing season average (April 1 to September 30) and the annual 95th percentile, and Secchi depth, which includes the growing season average.

[2] M = Mobile. LVB1.85M is mobile and located at a depth of 16 to 18 m (52 to 59 ft) near the confluence of Las Vegas Wash and Lake Mead. All other locations are stationary (See Figure 4.1-1). The position of LVB1.85M for the initial lake level of 1178 ft is the same as LVB2.7 for the entire growing season, but moves away from the Las Vegas Wash later in the year as the lake level drops. Therefore the chlorophyll concentrations (which are averaged over the growing season) are the same at LVB1.85M and LVB2.7, while other parameters (averaged over the entire year) are slightly different.

[3] Hoover Dam discharge data is from upper and lower intakes combined.

[4] SNWA data is for intake located at 1,000 ft.

[5] Total Dissolved Solids (TDS) are not simulated. It is computed from the correlation, TDS (mg/L) = 0.633 Conductivity (μS/cm).

[6] Sampling depth for chlorophyll was averaged over the top 5 m (16 ft), except at SNWA and Hoover Dam, which were sampled at the intake depths.

[7] ND = No Data. No Secchi depth data exists for Hoover Dam Discharge and SNWA Intake because Secchi depth is a property of lake surface.

[8] Total Inorganic Nitrogen is not simulated. It is computed as Nitrate + Total Ammonia Nitrogen. Nitrite is not simulated.

[9] Un-ionized ammonia is averaged over the entire depth.

[10] Most Probable Number per 100mL (1 deciliter).

Source: Black & Veatch 2004d.

projected increase in both the effluent discharge and SNWA withdrawals. Lake Mead limnological information was obtained from the University of Nevada, Las Vegas (UNLV) (1980 and 2002) and from Dr. Jim LaBounty (LaBounty and Horn 1997). Wastewater treatment process and effluent phosphorus information was obtained from the *SCOP Process Assessment* (Black & Veatch 2004b).

The input data for the alternatives characterized the Las Vegas Wash flows and water quality at the point of discharge to Boulder Basin (i.e., the composite flow), where the flow includes baseflow, possibly stormwater, and effluent. The water quality and tracer concentrations for the Las Vegas Wash in the alternative runs were computed based on a flow-weighted average of the baseflow, stormwater, and effluent components that are expected to comprise the Las Vegas Wash in 2030 and 2050. It was assumed that future baseflow and stormwater flow quality could be accurately defined using 2002 data.

D.3 Lake Mohave Model

The primary goal of the Lake Mohave modeling effort was to test the sensitivity of changing nutrient input to Lake Mohave on 1) the in-lake (Lake Mohave) water quality and 2) the nutrient discharged downstream of Davis Dam. CE-QUAL-W2, a time varying, longitudinal-vertical hydrodynamic and water quality model maintained by the Waterways Experiment Station of the U.S. Army Corps of Engineers (USACE), was chosen for application to Lake Mohave. The information presented in this section is based on *Lake Mohave Water Quality Model Project Report: Validation* prepared by J.E. Edinger Associates, Inc (2003). Figure D.3-1 provides a general view of Lake Mohave.

It is important to note that the nutrient loading through Hoover Dam is dependent on several factors. These factors include, but are not limited to the quality of the effluent being discharged into Boulder Basin, and water quality from sources upstream of Boulder Basin such as water from the Overton Arm, water released from Lake Powell, and water from the tributaries of the Colorado River. In addition, the nutrient loading that goes through Hoover Dam is dependent upon how Reclamation operates Hoover Dam. For modeling purposes, it was assumed that Reclamation would not modify the operation of

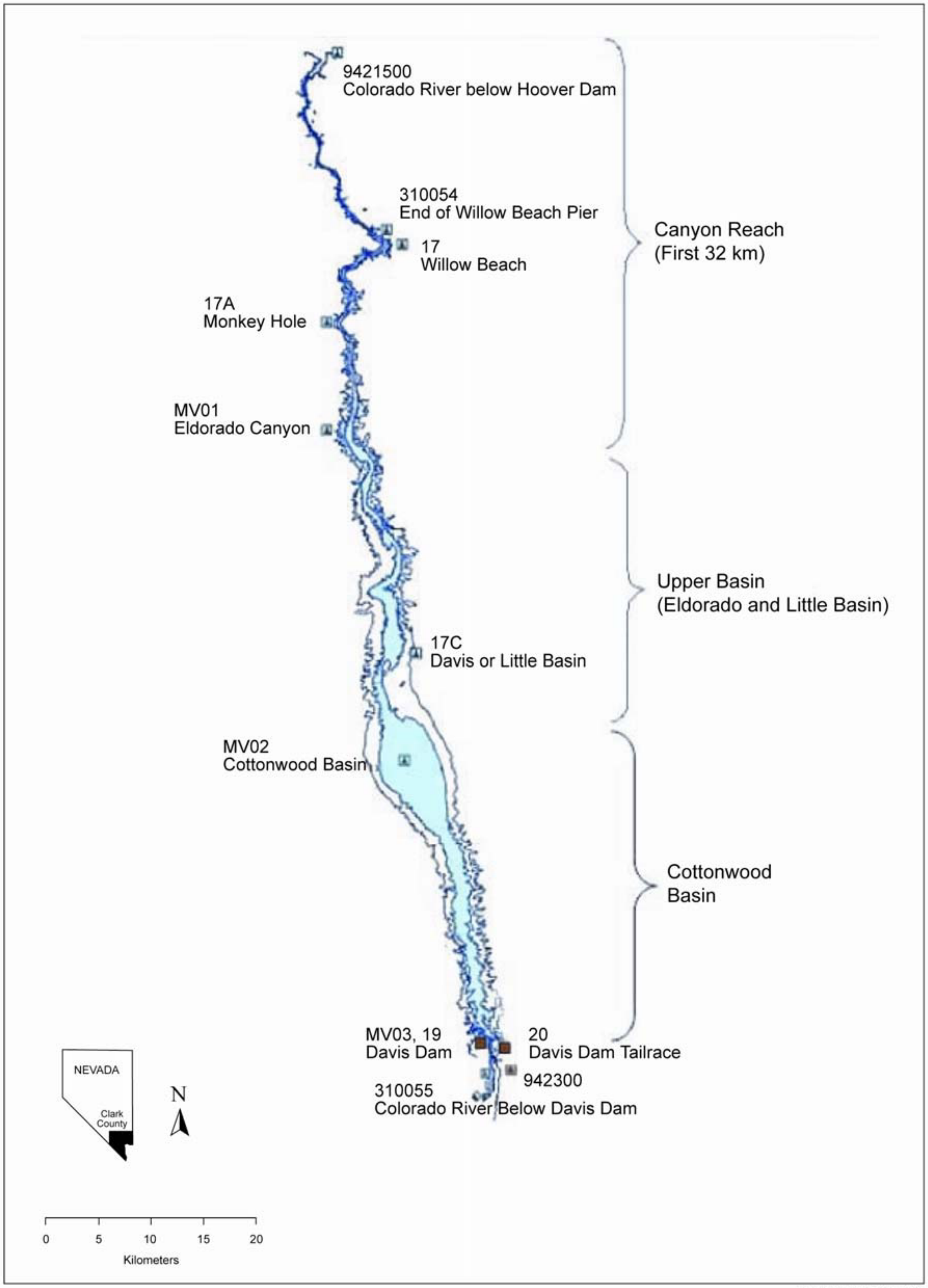

Figure D.3-1 General View of Lake Mohave.

Hoover Dam. A description of the Hoover Dam operations that were taken into consideration during the water quality modeling efforts is provided in the Lake Mead Water Quality Modeling Report (Black & Veatch 2005b), which is available upon request. However, Reclamation's operation of Hoover Dam is beyond the control and scope of this EIS.

D.3.1 Model Selection, Set-up, and Calibration

D.3.1.1 Model Selection

The Lake Mohave Model used CE-QUAL-W2, which is a longitudinal-vertical hydrodynamic and transport model built for long-term, time varying water quality simulations of lakes, reservoirs, and estuaries. CE-QUAL-W2 can accurately reproduce vertical and longitudinal water quality gradients when complete boundary condition data are available. CE-QUAL-W2 has been under development for the USACE since 1974 and has had extensive review and testing.

Lake Mohave's dominant gradients are in the longitudinal and vertical directions, which is readily obvious by noting Lake Mohave's long and narrow outline (Figure D.3-1) or by considering Lake Mohave's basic dimensions: length of 67 miles (mi) (108 kilometers [km]) , width of 4 mi (6 km), and maximum depth of 131 ft (40 m). Furthermore, the problem of phosphorus addition to Lake Mohave is one of simulating annual cycles. Both the longitudinal-vertical spatial domain and the long-term modeling needs fit well with CE-QUAL-W2's capabilities.

D.3.1.2 Model Set-up

Input data for the Lake Mohave Model had two main sources: Data included in reports prepared by UNLV and data downloaded from the USGS and STORET web sites. Researchers at UNLV designed, implemented, and interpreted the results of comprehensive field programs that measured physical, chemical, and biological variables for the periods 1977-1978 and 1981-1982. In addition, nutrient budget analyses were based on data downloaded from USGS and STORET web sites.

The Lake Mohave System characteristics most applicable to the Lake Mohave modeling effort are:

- The seasonally uniform, cold inflow from Lake Mead near-bottom releases (approximately 12ºC [54ºF] year round) transits the Canyon Reach (Figure D.3-1) with very little warming and enters the Upper Basins (Figure D.3-1) as an underflow through the spring, summer, and fall seasons. The location at which this inflow plunges varies with the density difference, flow rate, and water surface elevation. There is evidence that the inflow enters the Upper Basins as a surface flow in the winter due to insignificant density differences.
- Surface warming is important in the Upper Basins and especially in the Cottonwood Basin.
- Strong stratification develops in the Cottonwood Basin during the summer. Extension of the epilimnion all the way to Davis Dam is somewhat limited by upwelling in the vicinity of Davis Dam caused by the coldwater underflow. This underflow is larger than the inflow from Lake Mead due to entrainment of epilimnetic water at the plunge point. The upwelling can be strong enough to cause reverse currents on the surface.
- In contrast to the temperature differences between the Lake Mead outflow and the waters of Lake Mohave, there are no measurable differences in conductivity and TDS.

No seasonal pattern was apparent in the water quality characteristics of the inflow below Hoover Dam in the years for which seasonal data were available. Nitrate and dissolved phosphorus concentration averaged about 0.4 milligrams per liter (mg/L) and 0.015 mg/L, respectively, while the ammonia concentration was usually less than 0.020 mg/L.

Water quality characteristics within Lake Mohave are strongly influenced by Lake Mohave's uniformly colder year-round inflow that becomes an underflow through most of the lake during the stratified period. This limits the availability of nutrients during the summer in the Cottonwood Basin, except for upwelling of entrained surface water near Davis Dam.

The concentration of nitrate varies seasonally in relation to thermal stratification, declining at the surface in the summer due to phytoplankton uptake, and rising due to mixing with river water upstream and upwelling of inflow at the downstream end. A horizontal nitrate gradient, ranging from 0.3 or 0.4 mg/L at Monkey Hole to less than 0.2 mg/L at Davis Dam, was sustained because of a net conversion of nitrate to organic nitrogen.

Dissolved phosphorus undergoes a similar seasonal change. Strong vertical or horizontal gradients were not discerned for phosphorus. Depletion of dissolved phosphorus by phytoplankton in the epilimnion was not as prominent as nitrate depletion. This feature is likely due to a lower stoichiometric requirement and faster turnover rate of phosphorus compared to nitrogen.

Dissolved oxygen concentration was reduced in the hypolimnion of Lake Mohave during thermal stratification (June-October). Typically, the DO would go as low as 4 mg/L during summer. The pH in the hypolimnion decreased consistent with biological respiration and mineralization of organic material. However, oxygen concentrations remained relatively high. There was a general decrease in oxygen concentration in the hypolimnion at the downstream stations. A metalimnetic oxygen minimum usually did not develop in Lake Mohave.

A key assumption in the Lake Mohave Model is that there are no sources of nutrients other than the inflow from Hoover Dam. There appear to be no point sources on Lake Mohave other than a fish hatchery at Willow Beach. Precipitation in the region is small.

Though the comparison should be conducted for input and output loads (the product of flow and concentration), the input and output concentrations are used for simplicity, because over the long-term, flows will balance out in the inflow and outflow records. Another reason for comparing concentrations is that computation of the loads as a product of flow and concentration requires interpolating the sporadic concentration measurements to the frequency of flow measurements, which is daily. There is no unique way to interpolate. Thus, computing the loads introduces additional assumptions in the analyses. Therefore, it is instructive to examine the time series of the concentration data prior to computing loads from these data.

Assuming there are no other sources of nutrients to Lake Mohave, the implications are that historically Lake Mohave has not served as a significant sink of total phosphorus delivered to it through Hoover Dam. Unless changes in lake "metabolism" due to additional phosphorus load alter this input-output relationship, the additional load from the wastewater effluent is likely to be passed relatively unchanged to the downstream reservoir.

In the analyses, nutrient loads were computed as a product of daily concentration estimates and daily flows.

The years 1977-1978 and 1981-1982 were selected for model calibration because large amounts of in-lake water quality data are available from the intensive studies by UNLV. All supporting inflow, outflow, and water surface elevation data were also available from various agency websites.

The two simulation periods were used for calibration of the model as follows. The temperature calibration was first carried out for the 1981-1982 period. The calibration was confirmed further by using the same coefficients in 1977-1978 simulations and comparing the model results to the detailed temperature profile data available for these two years. Water quality calibrations were similarly started with 1981-1982. The additional confirmation step for the water quality calibration, where the same kinetic coefficients would be applied to another set of years and then the calibration checked, was not done for this report.

Meteorological data sets for the two study periods were developed from hourly National Weather Service observations of air temperature, dew point temperature, wind speed and direction, and cloud cover at Las Vegas, NV.

Flow data were available as daily releases from Lake Mead for 1977-1978 and 1981-1982. Temperatures of the inflow to Lake Mohave from Lake Mead were developed from observations.

Inflow water quality constituent files were developed only for 1981-1982. Long-term data were examined for any seasonality to help determine the best interpolation approach for refining the model upstream boundary. No consistent seasonal pattern could be discerned in the TP data, except for a slight suggestion that December through January values may be slightly higher than those during the rest of the year.

Development of concentration input files for CE-QUAL-W2 also requires assumptions about how the measurements are related to the model representations of the water quality constituents. The following two guidelines, sometimes in conflict with one another, were used to develop the boundary concentration files.

- Total Phosphorus and TN estimates should be accurate as these reflect the nutrient budgets that are crucial to mass balance accuracy.
- The partitioning of nutrients and organic carbon should reflect the lability of these components at short and long time scales. Constant stoichiometry of organic matter and algae in the model is a constraint to achieving the best representation.

D.3.1.3 Model Calibration

Calibration was conducted in three phases: water balance, temperature calibration, and water quality calibration. Each phase depended on the successful completion of the prior phase.

Water balance is the process of using observation of lake elevations to account for missing flows or inaccuracies. It is a necessary first step because it affects all other calibration efforts. Temperature calibration was conducted using time-series observations rather than synoptic measurements (i.e., vertical profiles at a particular time). This approach is consistent with the goal of modeling the seasonal behavior of the Lake Mohave system and also allows gross properties (e.g., seasonal temperature changes) to be examined prior to examining vertical profiles from the temperature and water quality observations.

Water quality calibration is a more involved exercise than temperature calibration because of fewer and less precise field data, a preponderance of non-linear and interaction terms in the underlying equations, and there are more constituents and parameters to consider. The water quality calibration isolated the key calibration features indicated by the field data in the aggregate, and then the model was calibrated to capture these key features. Key calibration target features were isolated from a review of the field data and prior reports. In no particular order of importance, these were:

- Approximately similar TP in Lake Mohave inflow and outflow,
- Approximate TN loss of 10 percent during passage through Lake Mohave,
- Significant increase in Total Kjeldahl Nitrogen in the outflow at Davis Dam,
- Significant (30 percent) decrease in NO_3 in the outflow at Davis Dam,
- Surface depletion of NO_3 to near detection limits,
- Nitrogen limitation may sometimes occur during the summer,
- High vertical gradient at the surface for primary production,
- DO vertical gradient not so high at the surface,
- No anoxia anywhere in any season,
- Slow longitudinal decline of DO towards the Davis Dam, down to about 4 mg/L,
- Primary production in the range of 500 to 3000 $mgC/m^2/day$,
- Secchi disk depth is highly variable, but in the range of 1 to 12 m (3 to 39 ft), and
- Chlorophyll *a* concentration ranges seasonally from 1 to 6 micrograms per liter (μg/L).

Given the relevance of nutrient retention for the problem being studied, model-based nutrient budget calculations formed a significant part of the calibration effort. Analyses of nutrient retention from long-term monitoring data, subject to the assumption of no phosphorus load besides Hoover Dam outflow, suggest a certain amount of "average" retention that may vary from year to year and is dependent on assumptions regarding outliers and below-detection values in the field data. For the calibration, the nutrient load corresponding to the distributed inflow was computed by estimating a reasonable runoff flow rate and reasonable runoff concentration separately.

D.3.2 Results

The Lake Mead Model simulated nutrient loads through the Hoover Dam for various scenarios of effluent discharge locations in Lake Mead. These nutrient loads were used as input to the Lake Mohave model.

Two scenarios were run in which the nutrient load estimated at Hoover Dam was increased by 25 percent and 100 percent. The same proportional increase was applied to all the nutrient species. These hypothetical and illustrative scenarios do not relate to any specific effluent or loading scenarios. Since all nutrient species were changed proportionally, it can be tempting to think of the two scenarios as indicative of loads under different hydrologic years, but it may be noted that higher flows will likely change the system retention. Increase in loading due to a higher flow is a very different perturbation to a system compared to an increase in loading due to a higher inflow concentration.

The year 2000 was selected for running scenarios as a result of discussions within the SCOP Water Quality Modeling Subcommittee. Table D.3-1 shows the fate of the nutrient under loads estimated from field data for year 2000.

Tables D.3-2 and D.3-3 show the fate of the total and the additional nutrient loading through Hoover Dam under the two scenarios (25 percent increase in nutrient loading and 100 percent increase in nutrient loading).

The effects of scenarios on the in-lake water quality are summarized in Table D.3-4. A 25 percent increase in loads led to an in-lake water quality change that appeared minor compared to measurement and modeling uncertainty for these metrics. A 100 percent load increase led to more significant effects. Two-year average clarity was reduced by 25 percent. Primary productivity and average algal population density were both increased 40 percent with a doubling of nitrogen and phosphorus loads.

Table D.3-1 Daily Average Nutrient Budgets for the Calibrated Model for 2000.

	Hoover Dam Release	Non-Hoover Load Assumed	Davis Dam Release	Percent Retention in Lake Mohave
TP (lbs/day)	471	115	524	10.4 %
TN (lbs/day)	50,824	7	42,916	15.6 %

Table D.3-2 Fate of a 25 percent Increased Load at Hoover Dam for 2000.

	Additional In	Additional Out	Percent Retention of Additional Load	Percent Retention of Total Load
TP (lbs/day)	119	88	26.2%	13.0 %
TN (lbs/day)	13,518	9,663	28.5%	18.3 %

Table D.3-3 Fate of a 100 percent Increased Load at Hoover Dam for 2000.

	Additional In	Additional Out	Percent Retention of Additional Load	Percent Retention of Total Load
TP (lbs/day)	471	352	25.5%	17.1 %
TN (lbs/day)	52,095	36,967	29.0%	22.4 %

Table D.3-4 Model Predictions of In-lake Water Quality Metrics.

Metric	2000 Load Estimated from Field Data	Scenario 1 125 percent 2000 Load	Scenario 2 200 percent 2000 Load
Minimum Secchi Depth (ft)	16.0	16.0	14.7
Average Secchi Depth (ft)	25.1	23.0	19.1
Areal Primary Production (mgC/m^2/day)	296.0	343.0	449.0
Maximum Chlorophyll *a* (µg/L)	4.4	5.3	7.5
Average Chlorophyll *a* (µg/L)	2.7	3.1	3.9

The model results showed a net reduction of the additional phosphorus and nitrogen during passage through Lake Mohave. In the two scenarios examined that scaled up the phosphorus and nitrogen load through Hoover Dam, this reduction was about 25 percent for TP and 30 percent for TN. The additional phosphorus and nitrogen assumed in the scenarios was retained by a larger percentage than baseline load. If there are phosphorus sources other than Hoover Dam outflow, the overall nutrient retention will be higher.

Effects of the hypothetical load increases on the water quality of Lake Mohave were quantified into five metrics (Table D.3-4). The results showed significant effects in all chosen metrics with a 100 percent increase in nutrient loads, but the effects were much less with a 25 percent increase.