RECLAMATION
Managing Water in the West

Technical Report No. SRH-2010-23

2010 Survey Report for Lake Mills and Lake Aldwell on the Elwha River, Washington

Lake Mills photograph courtesy of Tom Rooda at Northwest Territories Inc.

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

April 2011 – Amended June 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

2010 Survey Report and Area-Capacity Tables for Lake Mills and Lake Aldwell on the Elwha River, Washington

Report Prepared by:

Jennifer Bountry, P.E., M.S., Hydraulic Engineer
Sedimentation and River Hydraulics Group, Technical Service Center

Ron Ferrari, Hydraulic Engineer
Sedimentation and River Hydraulics Group, Technical Service Center

Kurt Wille, Physical Scientist
Sedimentation and River Hydraulics Group, Technical Service Center

Tim J. Randle, P.E., M.S., D.WRE., Hydraulic Engineer and Manager
Sedimentation and River Hydraulics Group, Technical Service Center

Peer Review Certification: This document has been peer reviewed per guidelines established by the Technical Service Center and is believed to be in accordance with the service agreement and standards of the profession.

REPORT PREPARED BY:

_________________________ DATE: 7-5-11

Jennifer Bountry, P.E., M.S.
Physical Scientist
Sedimentation and River Hydraulics Group (86-68240)

_________________________ DATE: 7-15-11

Ron Ferrari
Hydraulic Engineer
Sedimentation and River Hydraulics Group (86-68240)

_________________________ DATE: 7-17-11

Kurt Wille
Physical Scientist
Sedimentation and River Hydraulics Group (86-68240)

_________________________ DATE: 7-26-2011

Tim J. Randle, P.E., M.S., D.WRE.
Hydraulic Engineer and Manager
Sedimentation and River Hydraulics Group (86-68240)

PEER REVIEWED BY:

_________________________ DATE: 7-13-11

Elaina Gordon, P.E., M.S.
Hydraulic Engineer
Sedimentation and River Hydraulics Group (86-68240)

Table of Contents

List of Tables

List of Figures

Acknowledgements

The authors would like to thank Reclamation Glines Canyon and Elwha Dam operator staff members and Thomas Parker from the Elwha Tribe for assistance with the 2010 survey. The authors also would like to thank Richard Link of the Reclamation Pacific Northwest Regional Office for contributing to the review of sedimentation uncertainty computations, and Paul Kennard from the National Park Service for review of the report.

June 2011 Amendment Summary

An error in the OPUS solution for the Lake Aldwell survey control for the July 2010 survey was corrected which results in a vertical shift of the Lake Aldwell elevation data of 2.14 ft, and a horizontal shift of -5.5 ft in the easting and 9.2 ft in the northing values. As a result, the Lake Aldwell ACAP tables and datum shifts have been updated in this June 2011 report to reflect the correction. Data documented in this June 2011 report is the most accurate information based on current knowledge. This version of the report shall take precedence over the previous April 2011 version.

1.0 Introduction

The Elwha River is a gravel-bed stream that originates within a federally protected wilderness area and also within Olympic National Park (Figure 1). The river flows through a series of bedrock canyon and alluvial valleys before reaching the sea at the Strait of Juan de Fuca.

The U.S. Department of the Interior is removing Elwha and Glines Canyon Dams on the Elwha River near Port Angeles, Washington to restore anadromous fish and the natural ecosystem. These dams will be removed in controlled increments over a two to three-year period, beginning in 2011. Private companies constructed the two dams on the Elwha River during the early 1900s for the purpose of generating electrical power. Elwha Dam, constructed during the period 1910-13, is a 105-foot high concrete gravity dam located 4.9 miles upstream from the river's mouth. Glines Canyon Dam, built in 1927, is a 210-ft high concrete arch dam located 13.6 miles upstream from the river's mouth. Elwha Dam forms Lake Aldwell and Glines Canyon Dam forms Lake Mills. Both dams are presently operated to pass incoming flow such that no flood storage occurs and the reservoir pool elevation is not allowed to exceed 1 ft of change. River flow is currently measured between Glines Canyon Dam and Lake Aldwell at river mile (RM) 8.7 at the USGS gage at McDonald Bridge (long-term record), and at a USGS gage at the upstream end of Lake Mills that has been installed for monitoring in support of dam removal operations.

This report provides documentation on a July 2010 survey and updated reservoir area-capacity tables for Lake Aldwell and Lake Mills. The area-capacity tables will be used to assist with reservoir draw down during dam removal. The topographic surfaces generated from this effort serve as the baseline pre-dam removal reservoir topography. These data will be utilized for comparison and analysis of reservoir sediment erosion during dam removal as part of the adaptive management sediment monitoring program. The report also provides an updated sedimentation inflow rate and deposition volume for Lake Mills based on the changes that have occurred between 1994, the last estimates, and 2010.

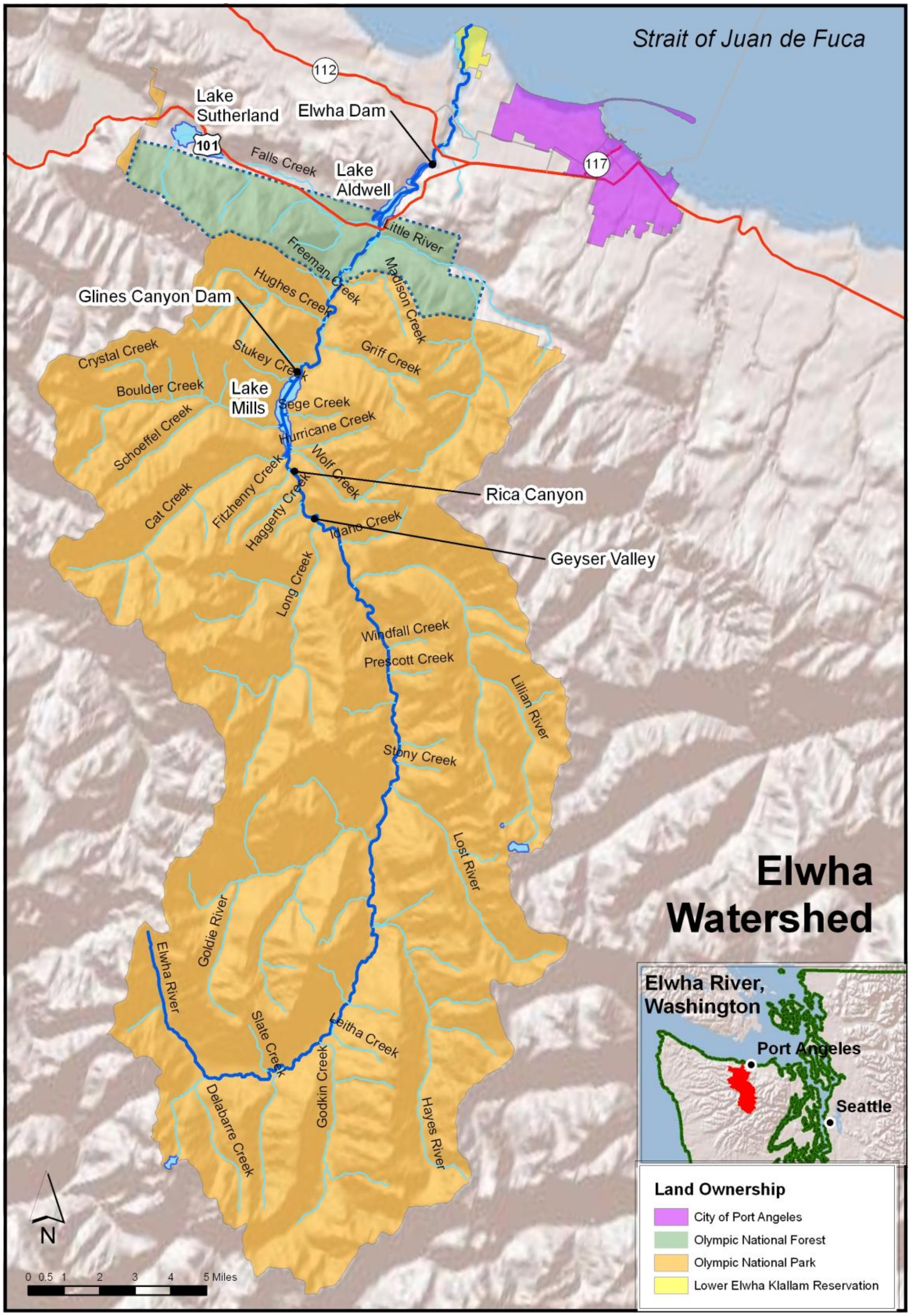


Figure 1. Project location map.

2.0 Topographic Data

This section provides a comprehensive documentation of available reservoir survey data for Lake Mills and Lake Aldwell. This documentation is intended to be used as a reference for the sediment monitoring program during dam removal and for other researchers interested in working on the project. Historical survey data are also documented because the data are used to evaluate reservoir sedimentation rates over time.

The 2010 survey was done in the most modern vertical datum available to facilitate comparison to future monitoring data that will be done in the same 1988 North American Vertical Datum (NAVD) with Geoid09. However, reservoir stage elevations are currently documented in a local project vertical datum on Reclamation's Hydromet server. Project drawings and historical data used to facilitate the dam removal are in the 1929 National Geodetic Vertical Datum (NGVD). Therefore, the first portion of this report chapter documents recommended conversions between vertical datums to make the information compatible.

2.1 Datum Shifts

Where there is accurate vertical data throughout the reservoir, a conversion program should be used that accounts for the horizontal position, which results in a slight variation of the vertical shift between NAVD 88 and NGVD 29 within each reservoir. An example program that could be utilized is VERTCON (Mulcare, 2003).

However, when a reservoir survey is done, there is error in vertical elevation solutions when points are collected in a rapid RTK GPS mode. It is standard practice for reservoir surveys to select a single elevation to represent the reservoir pool. Historical contour sets within the reservoirs are compared in this report to new data to evaluate changes in topography. The historical contours require a single vertical conversion to translate into the NAVD 88 datum. As a result, it is useful to document a single vertical conversion for the entire reservoir between datum sets. Project datum conversions were determined by comparing historically available benchmark elevations to new data collected in July 2010 where benchmarks could be reoccupied.

- NAVD 88 to NGVD 29: Reservoir elevations can be converted from NAVD 1988 to NGVD 1929 by applying a constant shift of negative 3.5 ft for Lake Aldwell and negative 3.7 ft for Lake Mills.
- Project datum to NAVD 88 at Lake Mills: The vertical shift from the project datum to NAVD 88 ft at Lake Mills is noted to be negative 15.8 ft based on the surveyed reservoir water surface elevation on July 26, 2010 of 593.8 ft (NAVD 88) and a corresponding Hydromet reservoir stage recorded as 609.6 ft (project datum). A similar conversion of 15.8 ft was computed based on information provided from a contract surveyor that resurveyed benchmarks at Glines Canyon Dam (see Figure 22 in Appendix A).
- Project datum to NAVD 88 at Lake Aldwell: The vertical shift from the project datum to NAVD 88 ft at Lake Aldwell is noted to be positive 13.0 ft based on the surveyed reservoir water surface elevation on July 27, 2010 of 200.6 ft (NAVD 88) and a corresponding Hydromet reservoir stage recorded as 187.6 ft (project datum).

- Project datum to NGVD 29 at Lake Mills: Based on the above conversions, reservoir elevations can be converted from the project datum to NGVD 29 by subtracting 19.5 ft. The vertical shift from the project datum to "mean sea level at Lake Mills" is noted to be negative 19.67 ft in a prior Bureau of Reclamation report (Reclamation, 1996). It is assumed that the reported mean sea level from 1996 is equivalent to the NGVD 1929 datum, which would provide a similar conversion within 0.2 ft.
- Project datum to NGVD 29 at Lake Aldwell: Based on the above conversions, Lake Aldwell elevations can be converted from the project datum to NGVD 29 by adding 9.5 ft.

2.2 Lake Mills

2.2.1 Historical Data Sets

Glines Canyon Dam was built in 1927, and a pre-dam survey of Lake Mills is available (Reclamation, 1995). A contour map, dated 1921, indicates that the pre-dam survey data are from 1921. Historical surveys of the reservoir area are also available from 1989 (Hosey, 1990b) and 1994 (Reclamation, 1995). The 1994 survey was conducted in support of analyses for an environmental impact statement (EIS). Lake Mills was additionally surveyed in 2005 by the NPS; the delta area at the upstream end of the reservoir was not surveyed.

The 1921 survey contains 10-ft contours between elevations 440 ft and 600 ft in a mean sea level datum, which is estimated to be a 1929 NGVD vertical datum. The Pacific Northwest Regional Office of Reclamation digitized the 1921 contour map and created a modified map with 1994 survey data to help estimate a bend in the reservoir that was not represented in the 1921data set (Reclamation, 1995). The composite contour map was horizontally adjusted to the 1983 North American Datum (NAD 83) based on a shift provided by a local contractor hired in 1994. When the contour map was recently plotted on a 2009 aerial photograph in ARCGIS, the shift to NAD 83 was determined to be misaligned. For comparison to new 2010 survey data, the contour map was further adjusted to match up immobile points along the reservoir shoreline and hillslopes, such as bedrock features that have not changed over time. Despite the efforts to correct the data and adjust the map, error is still present in the rectified 1921 map, including:

- The data was developed from a hard copy map that did not contain any documentation on survey methods
- There is uncertainty in the horizontal position of the contours;
- The vertical datum was noted as mean sea level and is only assumed to be NGVD 1929; and
- The contours are 10-ft contours indicating +/- 5 ft of potential error.

To allow comparison of the 1921 data with the July 2010 survey data, the 1921 contours were transformed to a 10-ft raster grid in ARCGIS (see Section 4.2, 4.3, and Appendix B for comparison results). Detailed metadata on the surface development is provided in the GIS file. Pre-dam channel bed elevations had to be estimated in the approximately 1-mile Rica Canyon segment with sedimentation that was not covered by the 1921 contour map. The 1921 map was used to represent the predam valley bottom prior to completion of the dam and sedimentation impacts. The 2010 underwater survey data was used to represent predam elevations for all reservoir areas near the reservoir shoreline (within reservoir pool) that are steep hillslopes and beyond the sediment delta.

A second contour map, generated from the 1989 and 1994 data, was used in combination with a geologic investigation for determining the amount of reservoir sediment present in Lake Aldwell (Reclamation, 1995). When the 1989/1994 contours were compared to the older 1921 contours along the reservoir shoreline, the 1995 report notes that significant mismatch occurred above about elevation 500 ft in the reservoir area and above about elevation 590 ft in the delta area and in the vicinity of Glines Canyon Dam.

The final historical dataset for Lake Mills consists of a 2005 survey accomplished by the NPS. This survey included 36,650 points in the main reservoir and log boom area. Data were collected on September 18, 2005, October 25, 2005, November 8, 2005, November 18, 2005, and December 14, 2005. The delta channels were not surveyed. The data were converted to reservoir bottom elevations using reservoir stage recorded with the Reclamation hydromet program, and then converted from the project datum to NAVD 88 using a vertical shift of 15.84 ft. A Triangular Irregular Network (TIN) was made from the 2005 data for comparison purposes (see Appendix B).

2.2.2 July 2010 Survey

Reclamation performed a survey of Lake Mills on July 26 and July 28, 2010 (see Appendix A for details). River flows were 1,390 cubic feet per second (cfs) and 1,280 cfs at the USGS gage above Lake Mills on July 26 and 28, and the hydromet reservoir elevations recorded by Reclamation were 609.64 and 609.58 ft (local project datum), respectively. The majority of survey points were collected by boats equipped with a depth sounder and survey grade GPS. In the upstream delta, the main channel was surveyed by boat. The delta channels were surveyed on foot with RTK GPS because conditions were too shallow to collect bathymetric data. The remaining delta areas were densely vegetated and due to budget and time constraints, the decision was made to represent these areas with 2009 LiDAR data. A comparison of the LiDAR data and ground survey methods is presented in Section 2.4.2.

Vertical accuracies of the survey points are estimated to be within 0.1 ft for topographic elevations collected on foot, and within 0.5 ft for bathymetric elevations collected by boat. The topo measurements were collected using a RTK GPS collection system which reports 2 centimeter accuracy in topo collection mode. Since the majority of these shots were taken on soft bottom conditions consisting of sand, mud and vegetation, it was estimated the error could be up to 0.1 feet. The larger error for the bathymetric elevations occurs due to the turbulence in the water, soft bottom conditions, and error in GPS position when collected in an instantaneous mode (single point rather than averaging) while continuously moving in a boat. The RTK GPS rover unit used during the bathymetric collection had a reported error in rapid mode of 0.8 feet vertically. This reported error was minimized during processing by removing spikes of the plotted vertical elevations within the collected data set. The method of removing the vertical spikes could be completed with confidence since the majority of the bathymetric collection was conducted in reservoir conditions with a very stable water surface as measured by the reservoir gage and topo shots of the water edge by foot. Although the error was minimized, data are still estimated to have up to +/- 0.8 ft of error due to other contributing factors.

2.2.3 Topography Changes since July 2010 Survey

In September 2010, the NPS hired a contractor to remove the dense alder forest on the Lake Mills delta that existed during the July 2010 survey, and construct a 1000-ft long pilot channel (Figure 2 and Figure 3). The Lake Mills delta, created by the river's sediments as they flow downstream, had become overgrown in recent years by a large number of alder trees. As the trees and root systems developed, the delta became more stable and less easily eroded by the river. The removal of vegetation and channel construction helped to maximize the potential for erosion through the delta before, during and after dam removal. In addition to removing trees and creating a pilot channel through the middle of the delta, workers positioned logs to help direct the river towards the entrance of the new pilot channel. A photograph of the Mills delta area post-construction work is shown in Figure 3 after a low-flow period and in Figure 4 after a flood peak of 22,000 cfs. Modifications to the delta topography are not included in the area-capacity or topographic surfaces provided in this report, since the reservoir surveys occurred prior to the construction work.

Figure 2. Lake Mills delta prior to construction of pilot channel and removal of vegetation. Photograph taken July 29, 2010 courtesy of Tom Rooda at Northwest Territories Inc.

Figure 3. Lake Mills delta with newly constructed center pilot channel and vegetation removal completed. Photograph taken September 28, 2010 courtesy of Tom Rooda at Northwest Territories Inc. The river was diverted into the pilot channel the following day (September 29, 2010) by relocating the log jam at the head of the pilot channel.

Figure 4. Lake Mills delta on December 15, 2010 following a flood that peaked at 22,000 cfs on December 12, 2010.

2.3 Lake Aldwell

2.3.1 Historical Data Sets

A pre-dam survey of Lake Aldwell is not available. The earliest known topographic survey of the reservoir area is from 1989 (Hosey, 1990a). Reclamation performed a survey in 1994 to support analyses for an EIS. Data were collected by boats equipped with a depth sounder and GPS in 1994 in the log boom area and in the main reservoir. A few of the delta channels were surveyed with a total station in 1994, and elevations were tied to the same datum as the bathymetric survey.

A contour map was produced from the 1989 and 1994 data (Reclamation, 1995). The contour surface was based on 1994 data except where insufficient detail existed from 1994 to produce contours. In these areas, 1989 data were used instead. The contour map did not cover areas of the Lake Aldwell delta that were above water. However, the perimeters of island areas were digitized using 1994 photography.

A terrain surface was generated in ARCGIS using the 1989/1994 contour map and 2009 Light Detection and Ranging (LiDAR) data in the delta area (Reclamation, 2010). This surface did not capture any of the delta channels below water. A new terrain surface has been produced using July 2010 data combined with the 2009 LiDAR that supersedes the previous surface (see section 2.3.2).

2.3.2 July 2010 Survey

Reclamation performed a bathymetric survey of Lake Aldwell on July 27 and July 29, 2010 (see Appendix A for details). Hydromet reservoir elevations (project datum) recorded by Reclamation were 187.59 ft and 187.64 ft respectively. The closest river flow measurement is at the USGS gage at McDonald Bridge (12045500), located at RM 8.7 between Lake Aldwell and Glines Canyon Dam. Mean daily river flows were 1,630 and 1,420 cfs on July 27 and 29, 2010. The survey was collected utilizing a boat equipped with a depth sounder and survey grade RTK GPS. Minimal points were collected in the upstream delta area on foot with RTK GPS. The remaining delta areas were densely vegetated, and due to budget and time constraints, the decision was made to represent these areas with 2009 LiDAR data.

Vertical accuracies of the survey points are estimated to be within 0.1 ft for topographic elevation collected on foot, and within +/- 0.8 ft for bathymetric elevations collected by boat as described in Section 2.2.2.

2.4 LiDAR Data

2.4.1 Available Data Sets

LiDAR data were collected across Clallam County in 2001 (Terrapoint, 2001). A bare-earth and first-return 6-ft grid is available from this survey set. LiDAR data were also collected along the

Elwha River corridor on April 4th to April 6th, 2009 (Terrapoint, 2009). Mean daily river flows during the 2009 LiDAR acquisition ranged between 585 cfs and 603 cfs at the USGS gage above Lake Mills (12044900) and 599 to 630 cfs at the USGS gage at McDonald Bridge (12045500). The data product was a 1-ft bare-earth grid. The 1-ft grid was post-processed by Randall McCoy at the Elwha Tribe into a 6-ft raster grid.

2.4.2 2009 LiDAR Data Comparison to 2010 Topographic Data

LiDAR data collected in 2009 were compared to July 2010 points collected in the Lake Mills delta area to provide an indication of how well the LiDAR represented the densely vegetated delta. The LiDAR grid provided by the contractor includes a continuous representation of Lake Mills, regardless of whether the area is wetted or above ground. In the main reservoir, topographic data are available from the bathymetric survey that can be used to completely replace the LiDAR data. However, in the Lake Mills delta, some areas had limited topographic data collected and LiDAR data best represented the terrain. LiDAR has increased uncertainty in areas that are wetted and areas that contain dense vegetation. The raw LiDAR data were not evaluated, but it is assumed that the wetted areas were removed, and that the grid elevations were developed from the closest above ground elevation value available. The delta has several wetted channels and dense vegetation through which LiDAR technology has difficulty penetrating and providing accurate ground elevations. Elevations that were collected on the Mills delta in July 2010 were used for comparison (Figure 5). ARCGIS was used to overlay the 1-ft grid 2009 LiDAR data on the July 2010 points to compare elevation values.

Changes in the lower portion of the delta are known to have occurred between the July 2010 surveys and the 2009 LIDAR acquisition. The largest peak flow recorded in this time period was 18,600 cfs on November 17, 2009 (USGS 12045500). Portions of the 2009 delta channels at the downstream end have filled in while other channels have eroded and become the new dominant river channel. However, the middle and upstream-most portions of the delta area have had less change. National Park Service (NPS) did cut down some alders through a path in spring of 2010 using hand saws, but the stumps were left and ground elevations within the delta were not altered.

The first comparison between LiDAR and ground survey points represents the maximum possible changes between data sets. When all July 2010 topographic points on the Mills delta (1,611 points) were compared with the 2009 LiDAR, including elevations in wetted areas and a small area known to have had some sediment deposition, elevation differences ranged between plus and minus (+/-) 5.1 ft with a mean difference of - 0.1 ft (LiDAR was slightly higher) and a standard deviation of about 1 ft (Figure 6). The slightly higher LiDAR mean is assumed to be due to areas where the LIDAR grid point was not accurately representing the ground elevation either due to the presence of water or dense vegetation.

A second comparison was completed for only the points in the middle, non-wetted portion of the delta with vegetation, where the least amount of change is expected to have occurred between 2009 and 2010 (92 points) (Figure 7). In this subset, the elevation difference ranged between -1 and + 3 ft. A negative value indicates that the 2010 surveyed data were lower than the 2009 LiDAR. A mean difference of + 0.6 ft was computed with a standard deviation of 0.5 ft.

Although the LiDAR was initially anticipated to have a higher return elevation due to inability of LiDAR to penetrate heavy vegetation in many areas, the comparison suggested that the 2010 surveyed points tended to be higher than the 2009 LiDAR. If of interest to further evaluate how the data sets compare, it is recommended that a similar comparison be completed with the original ASCII file of LiDAR data rather than the 1-ft processed grid, which would provide a more robust comparison and include only raw LiDAR points rather than interpolated values.

Figure 5. July 2010 RTK topo points on the Lake Mills delta shown on a 2009 aerial photograph. Points highlighted in turquoise were in the middle of the delta in non-wetted areas where little change is expected to have occurred since 2009.

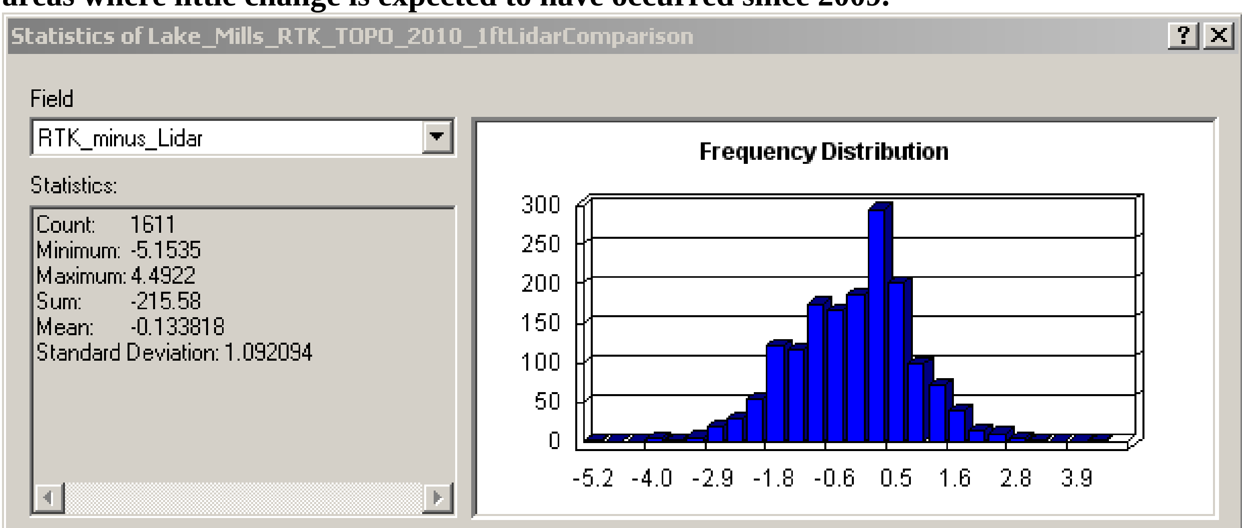


Figure 6. Statistics of the difference between all RTK topo shots from July 2010 survey data (above and below water) and the 2009 1-ft LiDAR surface on the Lake Mills delta. Negative values indicate that the 2009 LiDAR data were lower than the 2010 survey data.

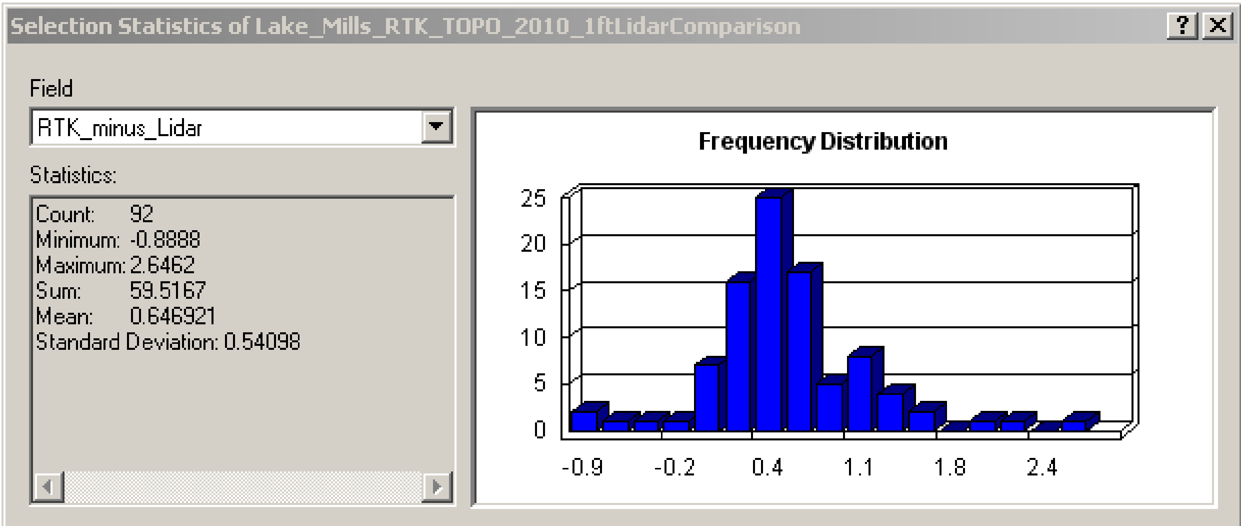


Figure 7. Statistics of the difference between RTK topo shots from July 2010 survey data in the middle of the delta in above water areas and the 2009 1-ft LiDAR surface on the Lake Mills delta. Negative values indicate that the 2009 LiDAR data were lower than 2010 data.

2.5 Aerial Photography

The most recent aerial photography available at the time of this report was acquired in 2009 (USDA, Aerial Photography Field Office, http//www.apfo.usda.gov). The collection dates were between August 27 and September 16, 2009 when mean daily river flows ranged between 303 cfs and 936 cfs at the USGS gage above Lake Mills (12044900). This photography was used to delineate a Lake Mills and a Lake Aldwell water surface elevation boundary for use in distinguishing a breakline between new reservoir survey data and available LiDAR data to assist in developing a new topographic surface that includes the surrounding reservoir hillslope areas.

3.0 Methodology

This section describes the development of topographic surfaces used to generate input data for area-capacity computations for Lake Aldwell and Lake Mills. The objective of the study was to represent the current terrain using the most complete and accurate data available. A composite of data from different sources and time periods were utilized in order to develop a continuous topographic surface as documented for each reservoir below.

3.1 Lake Mills Terrain

A terrain surface was previously generated in ArcGIS using the 1989/1994 contour map and 2009 LiDAR data in the delta area (Reclamation, 2010). The 1989/1994/2009 surface did not capture any of the below water delta channels in the upstream-most portion of Lake Mills and did not include any area within Rica Canyon. The 1989/1994/2009 surface was used to produce area-capacity tables for NPS (Reclamation, 2010).

A new terrain surface has been produced using July 2010 data combined with the 2009 LiDAR that supersedes the previous surface (Figure 8). The new Lake Mills terrain was generated using the following data sources:

- Log Boom Area and Main Reservoir: July 2010 data was used to represent the reservoir bottom elevations of Lake Mills. These data participated in the Terrain as mass points.
- Delta: The sediment delta was represented with 2010 ground survey data where available. Where 2010 data was not available, the 1-ft raster grid of 2009 LiDAR data was utilized to represent the delta topography. The LiDAR may be higher than the natural ground in some locations because of dense vegetation where the LiDAR could not penetrate to the ground surface (elevation returns from top of vegetation rather than ground), or where there was wetted areas the LiDAR could not penetrate through. No adjustment was made to the LiDAR data to accommodate these possible errors. In the case of wetted areas, the LiDAR grid elevation utilized was derived from adjacent above ground elevation returns. Both sets of data participated in the Terrain as mass points.
- Rica Canyon: Rica Canyon was represented by 2009 LiDAR data which approximates the water surface elevation for this segment at the time of the 2009 survey (no underwater data available).
- Reservoir Shoreline: A water surface boundary was mapped using 2009 NAIP aerial photography and assigned an elevation of 593.8 ft (NAVD 88) based on the normal operating pool captured in the July 2010 survey. The water surface boundary participated in the Terrain as a hard breakline.
- Reservoir Hillslopes: The topography outside of the delineated reservoir shoreline representing a reservoir stage of 593.8 ft (NAVD 88) was represented by a 6-ft grid of the 2009 LiDAR. The 6-ft rather than 1-ft grid was utilized because of computational limitations in ArcGIS when using the 1-ft files due to the large number of points. These data participated in the Terrain as mass points.

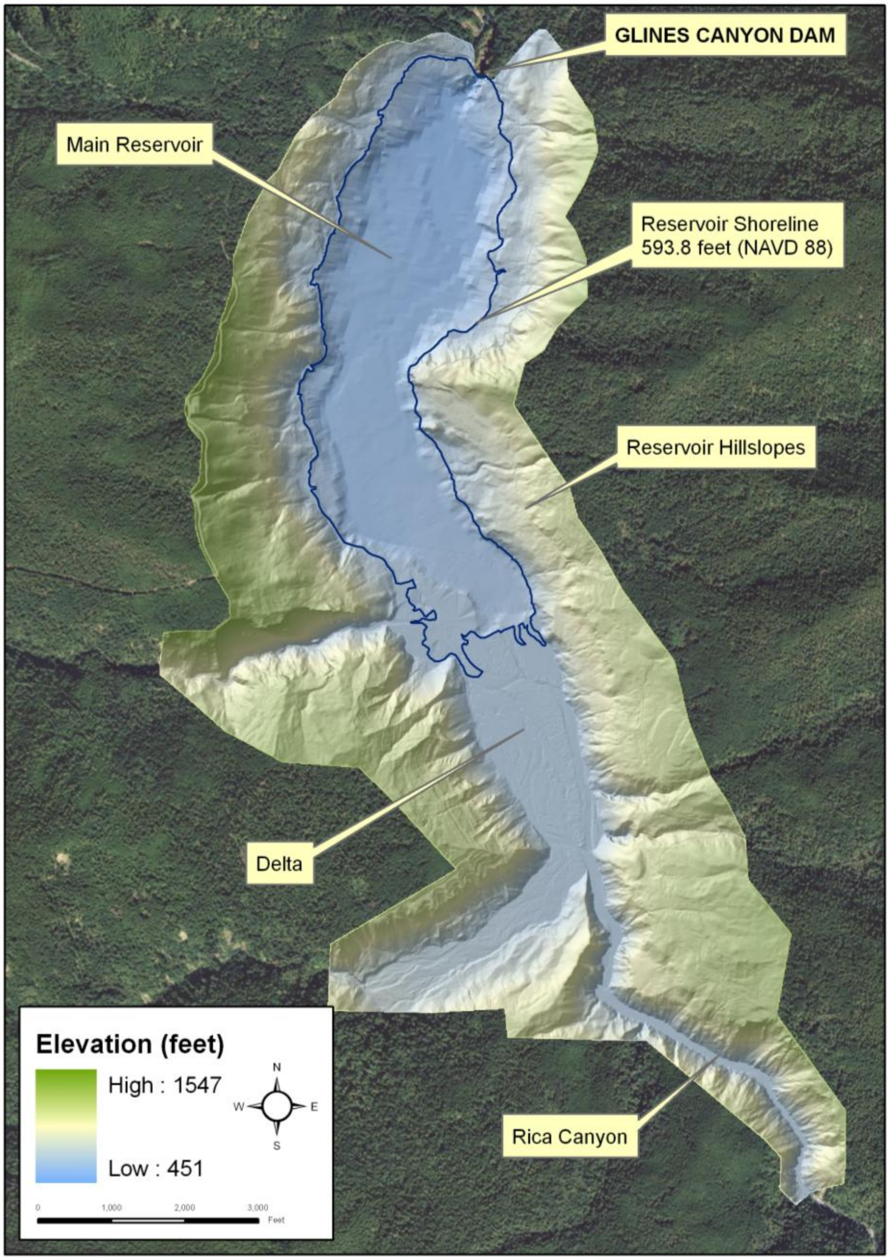


Figure 8. Lake Mills terrain based on July 2010 survey and 2009 LiDAR.

3.2 Lake Aldwell Terrain

A terrain surface was previously generated in ArcGIS using the 1989/1994 contour map and 2009 LiDAR data in the delta area (Reclamation, 2010). This surface was used to produce area-capacity tables for the NPS (Reclamation, 2010). A new terrain surface has been produced using July 2010 data combined with the 2009 LiDAR that supersedes the previous surface. The new ESRI ArcGIS 9.3.1 Terrain continuous ground surface representing Lake Aldwell was generated using the following data sources:

- Log Boom Area: The most recent data available for the Lake Aldwell log boom was from 1994. The log boom area is not anticipated to have greatly changed since 1994, as most of the incoming watershed sediment is captured in Lake Mills or the upstream delta and reservoir area of Lake Aldwell. These data participated in the Terrain as mass points.
- Main Reservoir: In the main reservoir, 2010 data was used to represent the reservoir bottom elevations of Lake Aldwell. These data participated in the Terrain as mass points.
- Delta: The above water areas of Lake Aldwell were represented with 1-ft grid of 2009 LiDAR. Delta channels were represented with 2010 data where available or 2009 LiDAR where underwater data did not exist. Both sets of data participated in the Terrain as mass points.
- Reservoir Shoreline: A water surface boundary was mapped using 2009 NAIP aerial photography and assigned an elevation of 200.6 ft (NAVD 88) based on the normal operating pool captured in the July 2010 survey. The water surface boundary participated in the Terrain as a hard breakline.
- Reservoir Hillslopes: The topography outside of the delineated reservoir shoreline representing a reservoir stage of 200.6 ft (NAVD 88) was represented by a 6-ft grid of the 2009 LiDAR. These data participated in the Terrain as mass points.

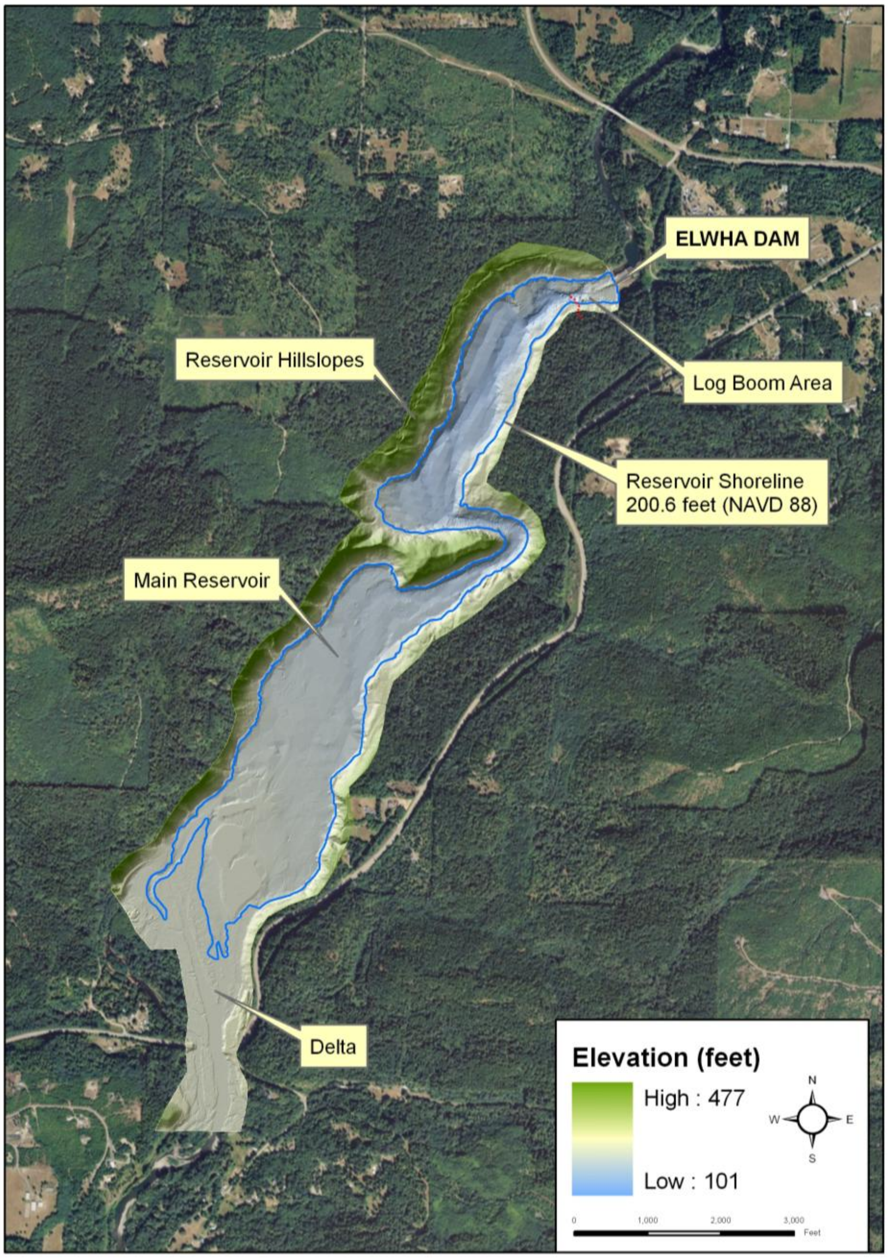


Figure 9. Lake Aldwell terrain.

3.3 Reservoir Area and Capacity Computations

Reservoir surface areas and capacities were computed in ArcGIS. A GIS approach to establish initial reservoir and sediment volumes sets the precedence for a repeatable method that may be used for future dam removal monitoring. For both lakes, surface areas and volumes were calculated at 1-ft intervals by running the ArcGIS 9.3.1 Surface Volume tool on the representative terrain surface. The Surface Volume tool calculates the area and volume of a terrain dataset surface above or below a given reference plane. Results of surface area and volume were computed using elevations in NAVD 1988 but are presented in the NGVD 1929 to be consistent with project drawings given to the dam removal contractor. Surface area and volume computations were computed at elevations 99 ft through 207 ft (NGVD 29) for Lake Aldwell, and at elevations 446 ft through 601 ft (NGVD 29) for Lake Mills.

Traditionally, Reclamation has utilized an area-capacity software program, ACAP, to generate area and capacity tables, rather than GIS (Reclamation, 1985). For comparison with the GIS method, the ACAP program was used to compute storage volumes in Lake Mills using the 1-ft surface area outputs from GIS. To run the ACAP program, the user must generate an input file that provides a corresponding reservoir water surface area for each increment of reservoir bottom elevation ranging from the minimum reservoir bottom elevation to the maximum operating pool elevation. ACAP has to rely on interpolations between given surface areas, whereas GIS can use the terrain to determine the areas and volumes between 1-ft increments and account for any irregularities in the surface topography. ACAP also rounds the capacity results in acre-ft, whereas GIS does not round any computations.

The difference between Lake Mills capacity computations from GIS versus the ACAP program at each 1-ft reservoir water surface increment was compared for Lake Mills (Table 1). Comparisons were made for the set of capacity computations within the normal operating pool, and for all reservoir pool elevations including those that extended above the normal operating pool. The storage computation at the normal operating pool was within 1 acre-ft for both reservoirs. The volume computations including the area above the normal operating pool had differences up to 5 acre-ft.

Table 1. Difference in capacity computations between a GIS-based method versus the ACAP software program.

GIS – ACAP Software Parameter	Lake Mills	
	Normal Operating Pool 446 to 590 (NGVD 29 ft)	Reservoir Pool 446 to 601 (NGVD 29 ft)
Average Difference Between 1-ft Surface Area Increments	0.03 acre-ft	0.1 acre-ft
Cumulative Difference at Maximum Reservoir Stage	0.1 acre-ft	1.9 acre-ft

4.0 Lake Mills Results

This chapter provides results for the Lake Mills area-capacity computations and sedimentation volumes.

4.1 Lake Mills Area-Capacity

Results of the Lake Mills area-capacity computations from the 2010 survey data are listed in Table 2 and are shown in Figure 10. For comparison purposes, historical values are included from the 1921 pre-dam contours based on an area-capacity chart developed in 1926 (Reclamation, 1996), and from a 1989/1994 contour map combined with 2009 LiDAR in the delta (Reclamation, 2010).

Table 2. Capacity table in 1-ft increments for Lake Mills.

Target Elevation (NGVD 1929 ft)	**Storage (Acre-Ft)**									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
450			1	2	6	12	20	32	46	64
460	83	105	130	156	186	218	254	294	336	382
470	431	483	539	599	661	726	794	865	940	1,018
480	1,100	1,187	1,280	1,379	1,481	1,586	1,693	1,802	1,913	2,026
490	2,141	2,257	2,376	2,496	2,619	2,745	2,874	3,005	3,141	3,281
500	3,424	3,571	3,722	3,877	4,036	4,199	4,367	4,538	4,713	4,891
510	5,072	5,255	5,441	5,629	5,818	6,011	6,205	6,401	6,599	6,799
520	7,000	7,204	7,409	7,616	7,824	8,035	8,247	8,461	8,677	8,895
530	9,115	9,336	9,559	9,784	10,011	10,240	10,471	10,703	10,937	11,173
540	11,411	11,651	11,893	12,138	12,384	12,633	12,885	13,138	13,394	13,652
550	13,913	14,175	14,439	14,705	14,972	15,241	15,512	15,785	16,059	16,335
560	16,613	16,892	17,173	17,456	17,740	18,025	18,312	18,601	18,891	19,182
570	19,475	19,770	20,065	20,362	20,660	20,960	21,260	21,562	21,866	22,170
580	22,477	22,785	23,094	23,405	23,718	24,034	24,352	24,675	25,001	25,334
590	25,671	26,031	26,417	26,816	27,227	27,651	28,085	28,527	28,975	29,429
600	29,888	30,351								

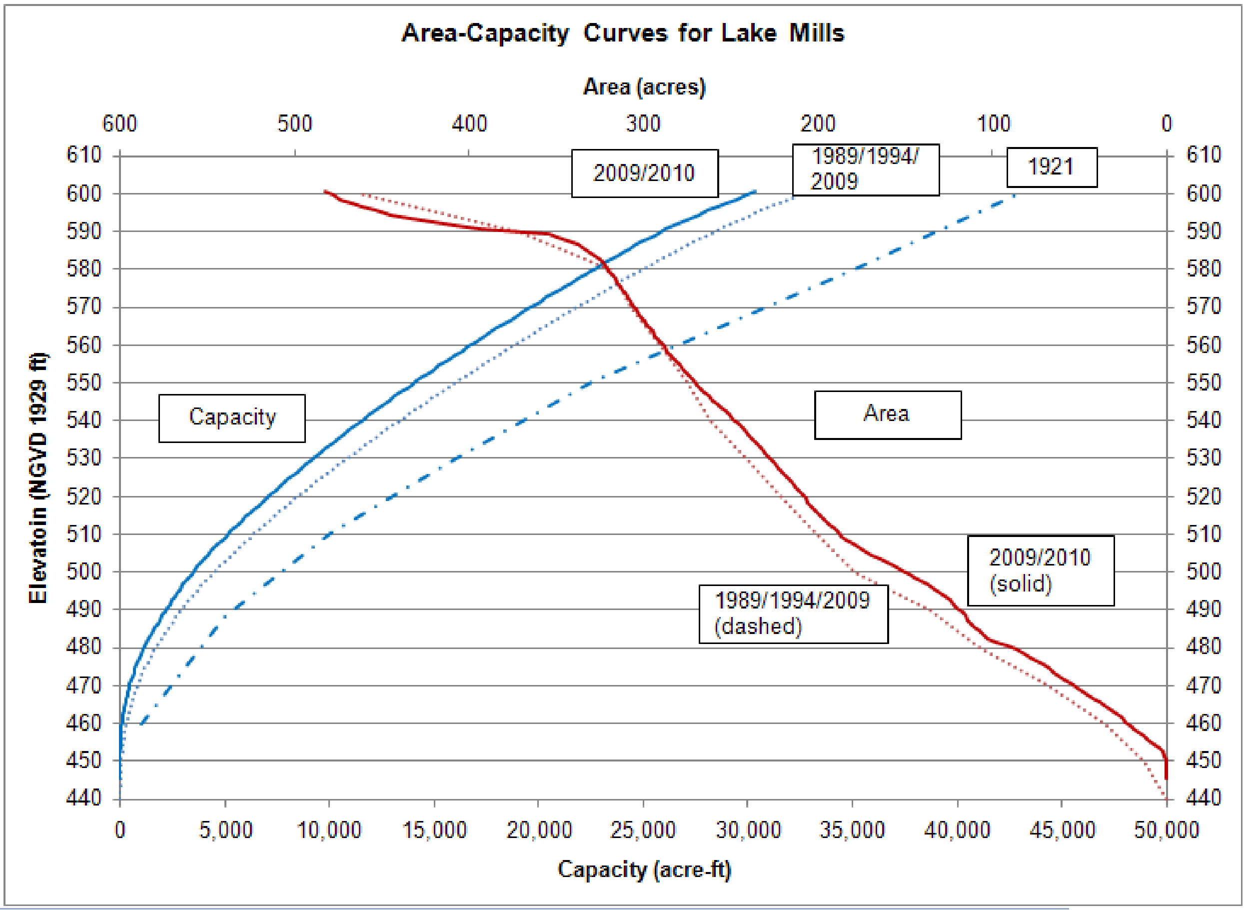


Figure 10. Diagram of area-capacity curves for Lake Mills from 2010 survey, 1989/1994 survey, and 1921 pre-dam contours.

4.2 Lake Mills Sedimentation Volume

The sedimentation in Lake Mills between 1927 and 2010 is computed as 20.4 million yd^3 (12,600 acre-ft) with an uncertainty of +/- 2.7 million yds^3 (1,700 acre-ft). Approximately 54% of the total sedimentation volume is located in the Lake Mills delta, 6% is located in Rica Canyon, and the remaining 40% is located in the main reservoir body. It is assumed that a portion of this volume is composed of wood. Log jams and buried pieces of wood have been observed within the delta. The last estimate based on 1989/1994 topography and drilling data was 13.9 million yd^3 for the 67 years since construction (Reclamation, 1995). For the much shorter time period of 16 years between 1994 and 2010, there was a 47% increase in the sedimentation volume.

The 1994 estimate was based on computing volumes from delineated areas associated with sediment thickness data. The sediment thickness was based on drilling data, 1989 and 1994 survey data, and the predam 1921 map.

The 2010 sedimentation estimate was based on the difference between the 2010 and 1921 10-ft rasters. The predam bed in Rica Canyon was estimated by extrapolating the 1921 slope within the reservoir upstream to a point where it intersects the slope of Rica Canyon above the sedimentation area based on 2009 LiDAR (Figure 11). The location at which these two slopes converge independently correlates with the downstream-most location where boulders and whitewater can be seen on the 2009 aerial photograph, indicating a transition between riverine and reservoir conditions (Figure 12).

The uncertainty estimate of 1,700 acre-ft was based upon the uncertainty associated with the 1921 and the 2010 volume computations. An uncertainty in sedimentation thickness of 1 ft and 5 ft was chosen for 2010 and 1921, respectively, based on estimated vertical accuracy of the measured topographic data. The errors were then squared and the square root taken to get a composite vertical error in sediment thickness of 5.1 ft. The composite vertical error was multiplied by an area of 14,300,000 ft^2, which represents the area where sedimentation has occurred between 1921 and 2010 (includes main reservoir and delta and portions of Rica Canyon, Cat Creek, and Boulder Creek). This computation results in an uncertainty of 13%.

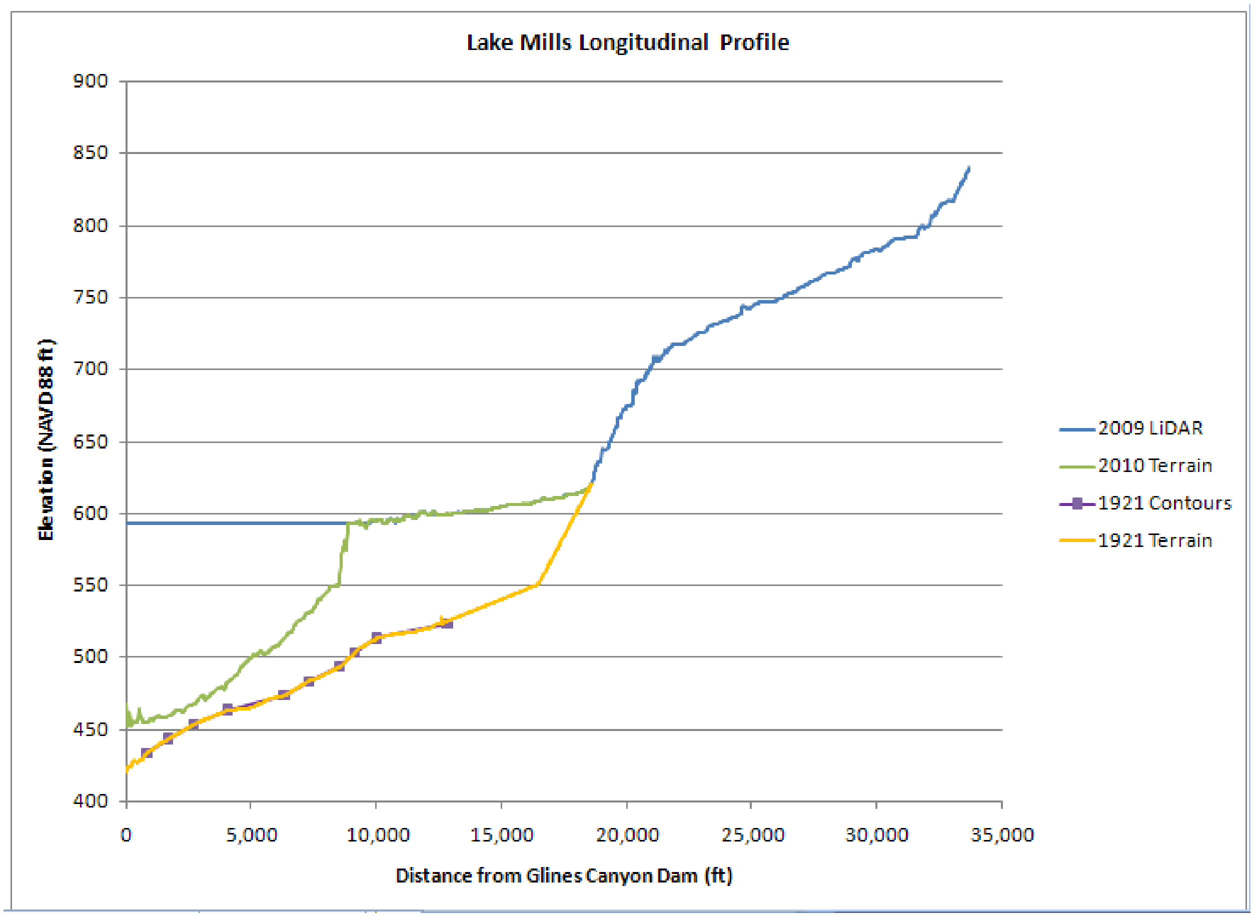


Figure 11. Longitudinal profile of Lake Mills pre-dam and 2009-2010 conditions.

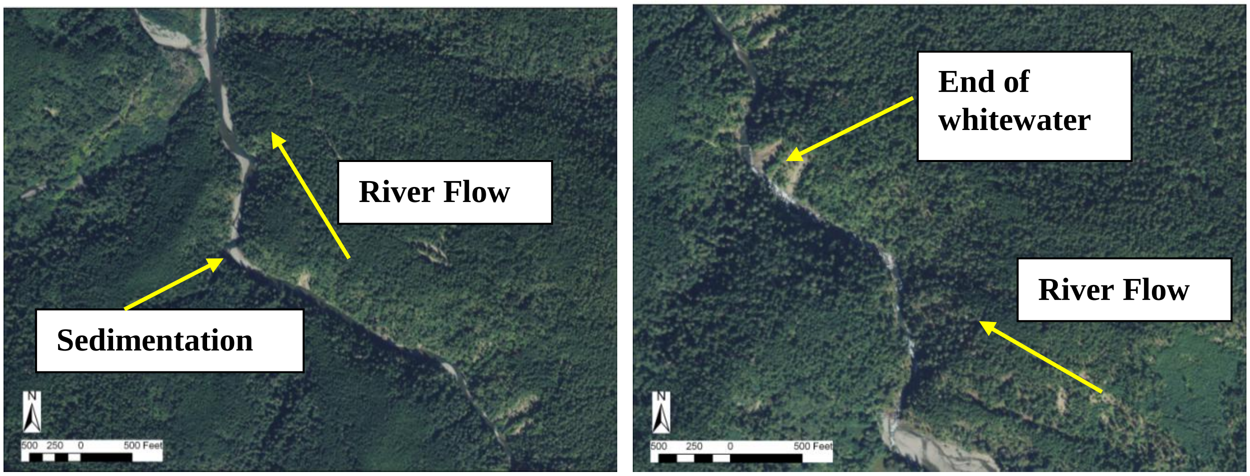


Figure 12. 2009 aerial photographs of Rica Canyon with downstream half on the left showing reservoir sedimentation, and upstream half on the right showing transition between reservoir sedimentation and slope break shown in Figure 11.

4.3 Lake Mills Sediment Thickness

A comparison of 1921 and 2010 10-ft raster grids was conducted to examine the approximate thickness of reservoir sedimentation since 1921 throughout the lake (Figure 13). Because of horizontal errors in the 1921 map, the steep sections of the reservoir that do not contain sedimentation were assumed to have no sedimentation. Note that only 2009 LiDAR data were available in Rica Canyon and Cat Creek to compare to 1921 elevations. Since LiDAR does not penetrate through water, estimated thicknesses at these locations represent maximum potential thicknesses. The predam surface in Rica Canyon was estimated, which introduces additional error in thickness computations. The total sediment volume in Lake Mills takes these potential errors into consideration (see Section 4.2).

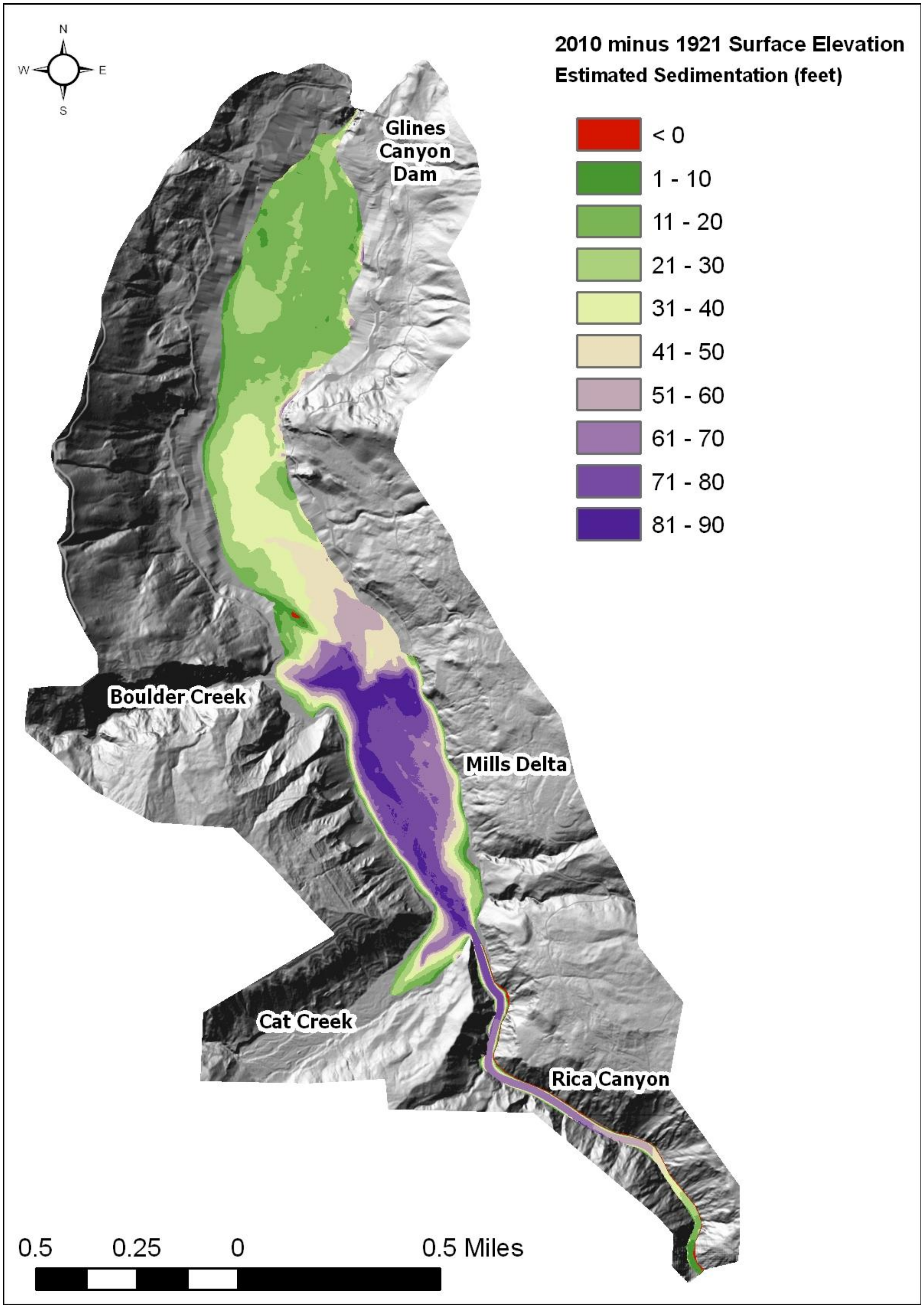


Figure 13. Image showing differences between 2010 and 1921 topography plotted on hillshade from 2009 LiDAR.

4.3.1 Depth of Sediment at Glines Canyon Dam

Sediment has deposited immediately upstream of Glines Canyon Dam. It is of interest to document the present sediment elevation at the dam for consideration during the removal of the dam. Several estimates of the riverbed elevation at Glines Canyon Dam were examined for determining the present depth of sediment and debris.

- The predam streambed is noted to be elevation 400 ft (mean sea level) in EIS reports (Reclamation, 1996).

- A 1921 pre-dam contour of 440 ft (NGVD 29) was located about 1,600 ft upstream of the dam (along the length of the predam river channel). The preceding lower contour on the 1921 map was 400 ft (NGVD 29) located about 1,200 ft downstream of the approximate Glines Canyon Dam location (along the length of the 1921 river channel). No contours between 400 ft and 440 ft were shown on the 1921 map. An approximate slope of 1.4% was computed from this data, which estimates the pre-dam riverbed elevation at Glines Canyon Dam at 417 ft (NGVD 29).

- The lowest elevation recorded in the 2009 LiDAR just downstream of Glines Canyon Dam was about 414 ft (NGVD29), which falls between the two streambed estimates. The LiDAR does not penetrate below the water, so the 414 ft value would be expected to be higher than the predam streambed. During LiDAR data collection the mean daily river flow above Lake Mills was between 585 and 603 cfs.

Glines Canyon Dam has a crest elevation of 590.33 ft (mean sea level) and a spillway elevation of 570.33 ft (mean sea level). The present reservoir bottom elevation upstream of the dam ranges between 446 and 451 ft (NGVD 29). This range in elevations is similar to the centerline elevation of the low-level sluiceway outlet on Glines Canyon Dam (no longer used) which is at 450 ft (mean sea level). Depths between130 and 140 ft can be seen throughout the historical Elwha Channel upstream of the dam in the log boom area, but do not extend laterally more than a width of about 100 to 130 ft (Figure 14). The deepest point measured near the dam in the log boom area in July 2010 was 143 ft. Depending on the predam riverbed elevation utilized (400 or 417 ft), sediment and debris thickness upstream of Glines Canyon Dam range from 30 to 50 ft.

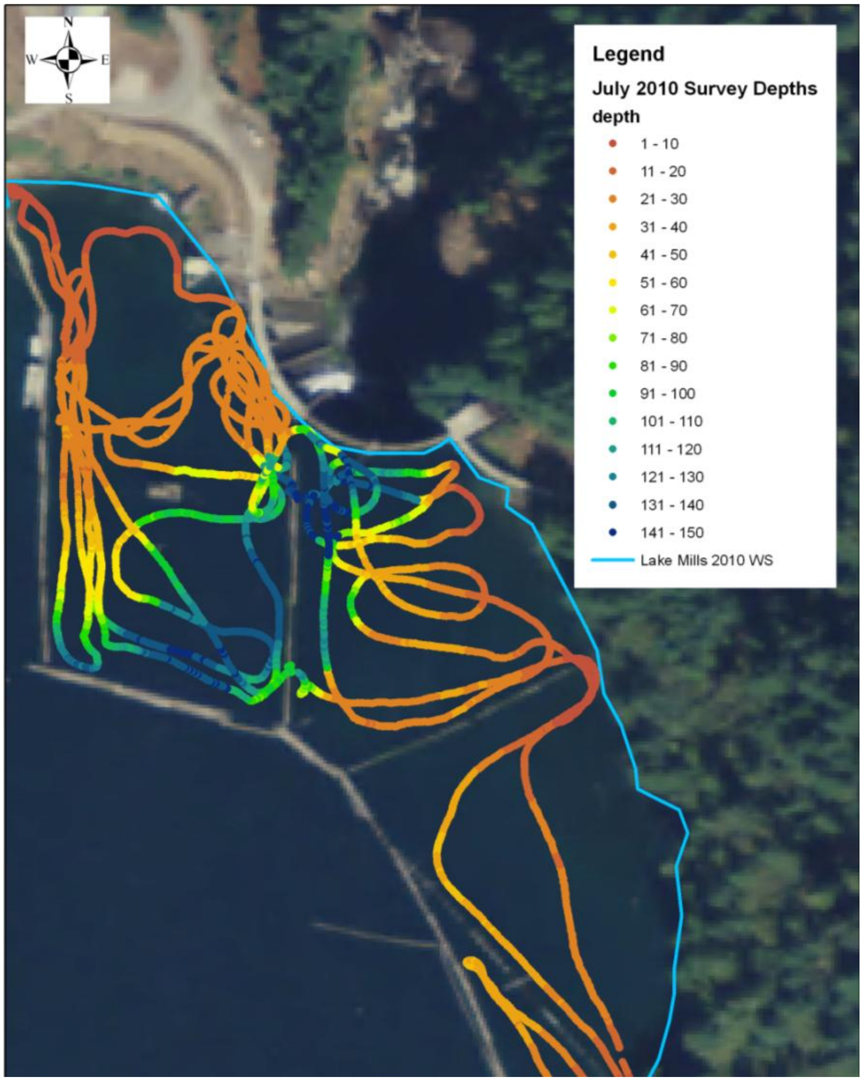


Figure 14. Survey depths (ft) from July 2010 survey in Lake Mills log boom area plotted on 2009 aerial photograph.

4.3.2 Lake Mills Historical Survey Comparisons

Historical survey data can be compared in Lake Mills between 1921 (predam), 1994, 2005, and the most recent survey done in July 2010. To evaluate spatial changes in sediment deposition within the reservoir, cross-sections were generated at locations of 1994 cross-sections and a few other areas of interest throughout Lake Mills (Figure 15). Stations and elevations were generated along each cross-section from 1921, 1994, 2005, and 2010 topographic data in ARCGIS. An example cross-section is provided in Figure 16 that is located where the downstream end of the Mills delta has prograded since 1994 (extended in length farther downstream within the reservoir). The remaining cross-section comparison plots are contained in Appendix B. The cross-sections indicate that in most areas, the reservoir bottom has continued to fill with sediment over the last 16 years.

The following observations are made from comparisons of the different data sets:

- Cross-sections 4 and 5, located at the downstream end of the Mills delta, experienced dramatic deposition between 1994 and 2010. In this location, the delta growth can also be observed by comparing available aerial photographs between 1994 and 2009.
- At cross-sections 1 through 3, located roughly in the middle of Lake Mills, about 10 ft of sediment deposited along the reservoir bottom between 1994 and 2010.
- Between cross-sections 103 and 106, about 5 feet of deposition is visible between 1994 and 2010.
- Within cross-sections 103 and 104 in the downstream portion of Lake Mills, abrupt rises of 10 to 25 ft are noted along the reservoir bottom in the 1994 data, but only in one place in the 2010 data. These abrupt changes in elevations are potentially standing (submerged) trees detected by the depth sounder. The trees may not have been detected in 2010 because bathymetry was collected longitudinally (north to south) with a spacing of approximately 100 ft. In 1994, bathymetry was collected in lines across the reservoir (east to west).

In addition to the cross-section comparisons, a comparison was done in GIS to evaluate the amount of deposition that has occurred between the 2005 and 2010 surveys. To accomplish the comparison, all 2005 survey points located within the reservoir throughout the main body of Lake Mills were compared to 2010 points within a 10 ft radius. The mean of the difference value between all 2005 and 2010 points was then computed. The result indicates the reservoir bottom has increased by about 2.5 ft over the last 5 years. The 2005 data was not collected in the delta located in the upstream portion of Lake Mills, so this comparison only represents the change in the lake bottom between the downstream end of the delta area and Glines Canyon Dam.

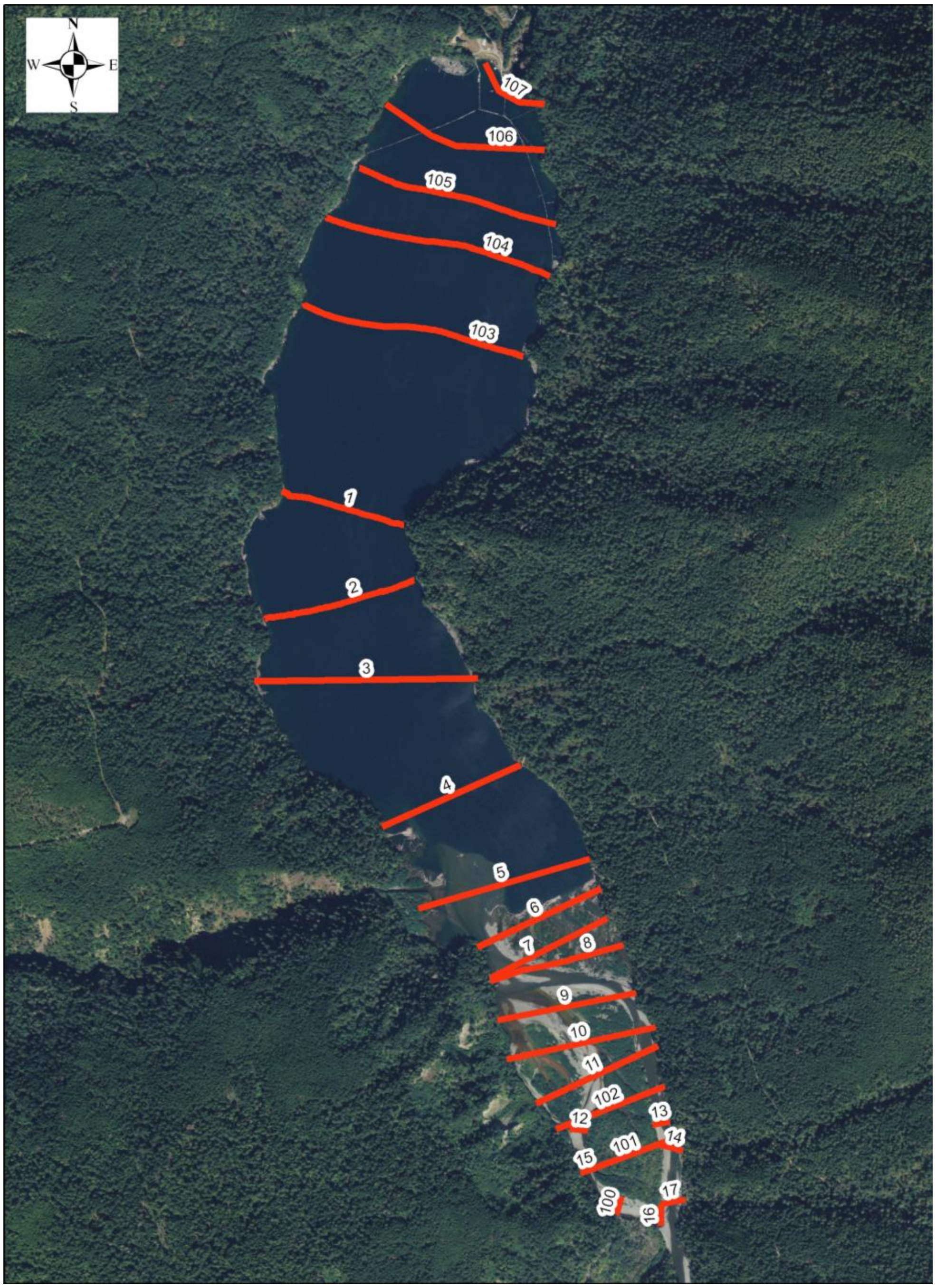


Figure 15. Lake Mills cross-section locations for historical survey data comparison on 2009 aerial photograph.

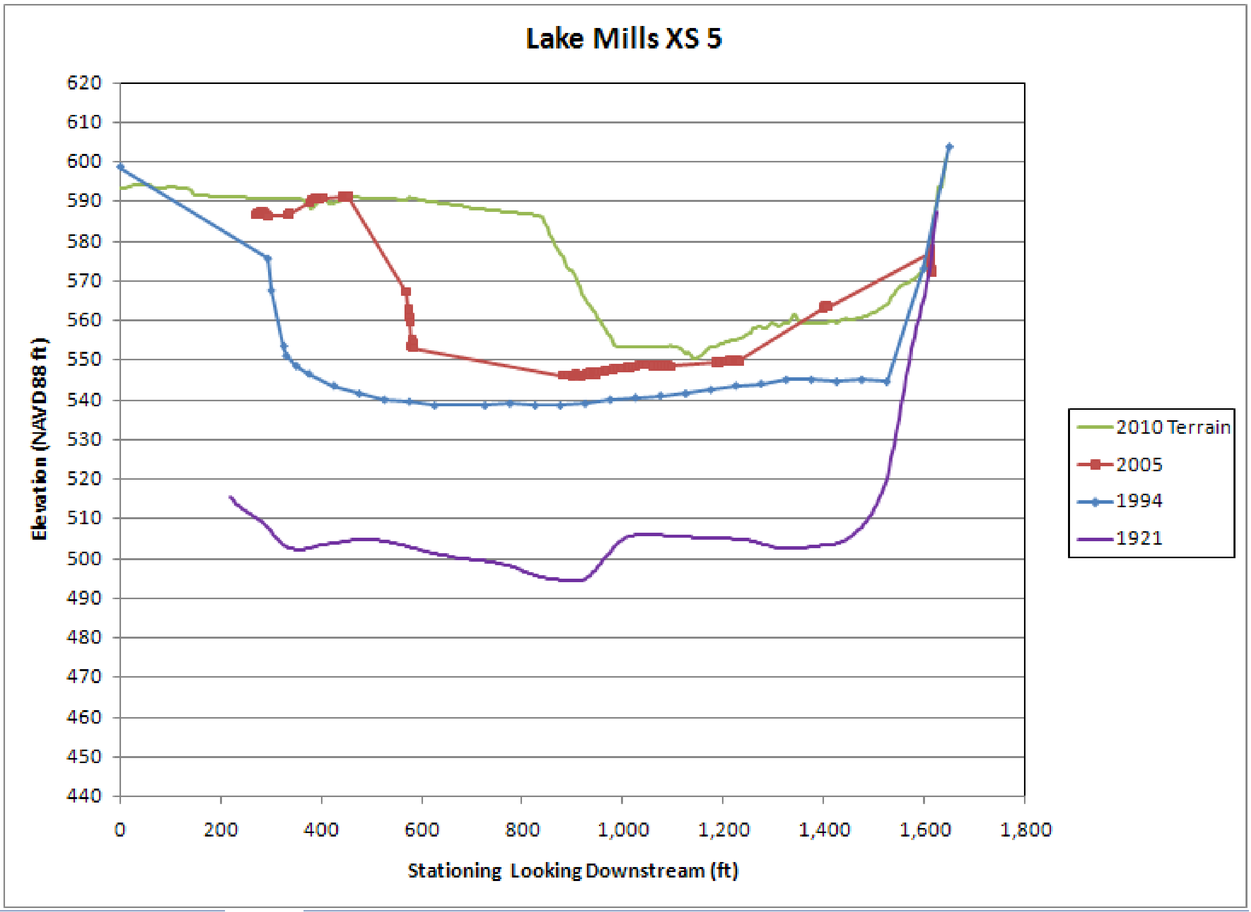


Figure 16. Cross-section at downstream end of Lake Mills delta near Boulder Creek showing sediment deposition since 1921 and recent growth of delta since 1994.

4.4 Average Incoming Sediment Load

The average annual incoming sediment load was compared for 1927 (construction date) to 1994 with the 1994 to 2010 time period to evaluate how the 67-year annual average compares with the more recent 16-year annual average incoming sediment loads. The watershed above Lake Mills is pristine and except for a small homestead has had virtually no detectable human impacts. Therefore, any changes to incoming sediment load are naturally occurring. Natural disturbances such as landslides and floodplain reworking have been observed to occur in the upper watershed on aerial photography. Wood is also routinely transported in from the upper watershed and contributes to the total volume of material deposited in Lake Mills.

Based on the 1994 sediment volume of 8,600 acre-ft (13.9 million yd^3), the average annual incoming sediment supply for the 67 years between 1927 and 1994 is 128 acre-ft (207,000 yd^3). The average annual incoming supply for 1994 to 2010 (16 years) is estimated to be 251 acre-ft (405,000 yd^3). This indicates the average annual sediment load in the last 16 years is roughly double the average annual load value for the 67-year period from 1927 to 1994. The new long-term average from 1927 to 2010 is 152 acre-ft (245,000 yd^3).

To evaluate if larger floods have occurred from 1994 to 2010 than 1927 to 1994, the long-term annual peak flows at the USGS gage at McDonald Bridge, located between Glines Canyon Dam and Lake Aldwell, are shown in Figure 17. In addition, a comparison is made of the occurrence of the number of floods exceeding given flood frequency values (Table 3). Interestingly, floods greater than the 50-year flood have only occurred once (in 1897) during the period of the stream discharge gaging record. There is also not an obvious trend in the occurrence of floods greater than the 10-year flood. However, the number of floods exceeding the 2- , and 5-year flood values has fluctuated on a decadal scale and has been higher in the last 3 decades relative to prior time periods.

In combination with floods, the occurrence of landslides or debris flows in the upper watershed could also affect sediment and wood loads transported into Lake Mills. Historical documentation on landslide occurrence in the upper watershed is limited. A large landslide is known to have occurred in 1967 in the Geyser Valley reach not far upstream of Lake Mills (see Figure 1) that caused notable changes to the course of the Elwha River (Acker et al, 2008). Anecdotal accounts from this event note that prior to 1967 boaters could motor upstream on Lake Mills into Rica Canyon, but afterwards this could no longer be done due to sedimentation in the reservoir. In recent years, local NPS and USGS staff have observed additional landslides in Geyser Valley and a log jam breach at the entrance to Rica Canyon during the timeframe of the November 2006 flood of 21,000 cfs and the December 2007 flood that peaked near 36,000 cfs. The 2007 flood is the largest on record since the construction of Glines Canyon Dam in 1927. The frequent flooding and observed mass wasting events likely contributed to the increased sediment loads over the past 16 years relative to the former 67 year period.

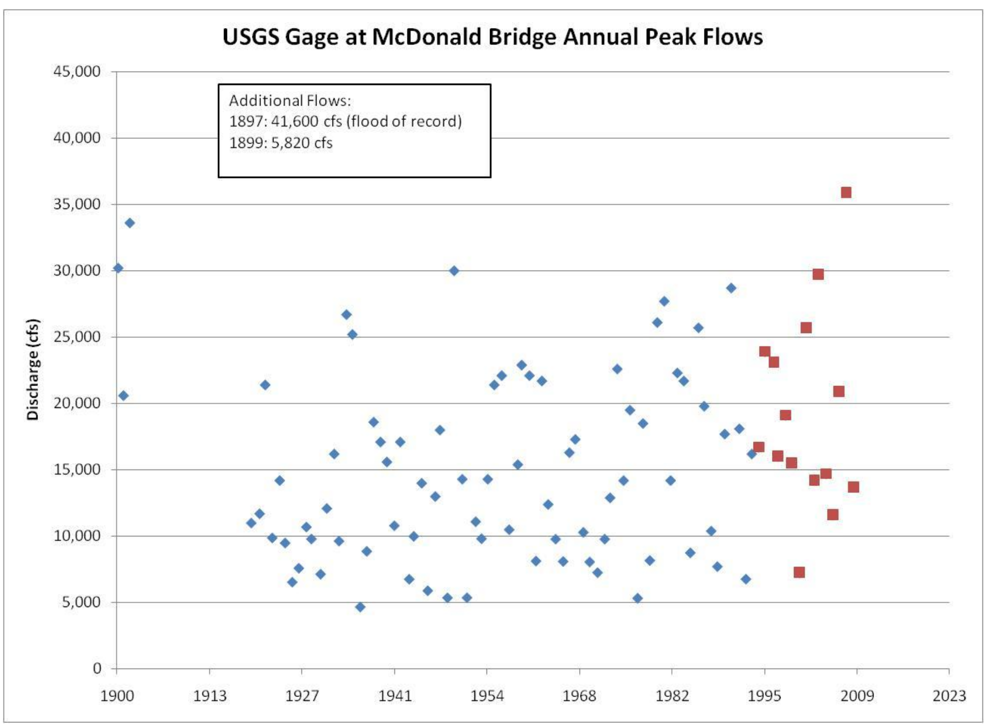


Figure 17. Long-term annual peak flows for Elwha River for 1900 to 1993 (blue) and since 1994 (red). Glines Canyon Dam was constructed in 1927.

Table 3. Comparison of floods over decadal periods from the USGS gage at McDonald Bridge.

Water Year	Number of annual peak flows greater than specified flood frequency value[1]				
	>2-year flood (14,000 cfs)	>5-year flood (21,100 cfs)	>10-year flood (26,200 cfs)	> 50-year flood (38,000 cfs)	# records
1898-1901	4	3	3	1	5
1920-1929	2	1	0	0	10
1930-1939	5	2	1	0	10
1940-1949	3	0	0	0	10
1950-1959	6	3	1	0	10
1960-1969	5	3	0	0	10
1970-1979	4	1	0	0	10
1980-1989	7	5	1	0	10
1990-1999	9	3	1	0	10
2000-2009	7	3	2	0	10

[1] Flood frequency values based on Seattle District USACE flood frequency curve database, July 2008. Note Glines Canyon Dam was constructed in 1927.

5.0 Lake Aldwell Results

This section provides results for Lake Aldwell including area-capacity tables, a sedimentation volume from a prior study, and a snapshot of topography near Elwha Dam based on the new topography where landslides have been previously identified. The landslide locations are of interest to evaluate whether they currently block the predam Elwha River channel or are in close proximity to it.

5.1 Lake Aldwell Area-Capacity

Results of the Lake Aldwell area-capacity computations are listed in Table 4 and shown in Figure 18. A pre-dam map of Lake Aldwell does not exist. Because no major tributaries are located in the 8.7 mile reach between Lake Mills and Lake Aldwell, the majority of reservoir sediment is assumed to have been contributed to Lake Aldwell between 1913 and 1927, prior to the completion of Lake Mills. Lake Mills now traps the majority of coarse and fine sediments transported in from the upper watershed. Some sediment is still contributed to Lake Aldwell from small, local sources between Glines Canyon Dam and Lake Aldwell. Using the new 2010 survey data, the most recent Lake Aldwell storage estimate at elevation 197 ft (NGVD29) is 8,100 acre-ft. A prior estimate of Lake Aldwell storage at elevation 197 ft from 1989/1994 survey data is 8,000 acre-ft (Reclamation, 2010).

Table 4. Capacity table in 1-ft increments for Lake Aldwell.

Elevation (NGVD 1929 ft)	Storage (Acre-Ft)									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
100	0	0	0	0	0	1	1	2	3	4
110	6	8	11	14	18	23	29	35	42	51
120	60	70	82	95	109	124	141	161	183	208
130	235	266	299	335	374	414	456	499	543	589
140	637	686	737	791	845	901	959	1,017	1,076	1,137
150	1,199	1,263	1,328	1,395	1,465	1,537	1,612	1,691	1,775	1,863
160	1,953	2,047	2,143	2,242	2,344	2,449	2,559	2,672	2,791	2,913
170	3,041	3,174	3,312	3,453	3,598	3,747	3,899	4,057	4,219	4,386
180	4,559	4,737	4,919	5,104	5,292	5,483	5,677	5,872	6,071	6,273
190	6,479	6,689	6,906	7,127	7,355	7,589	7,827	8,073	8,345	8,650
200	8,970	9,301	9,640	9,988	10,343	10,706				

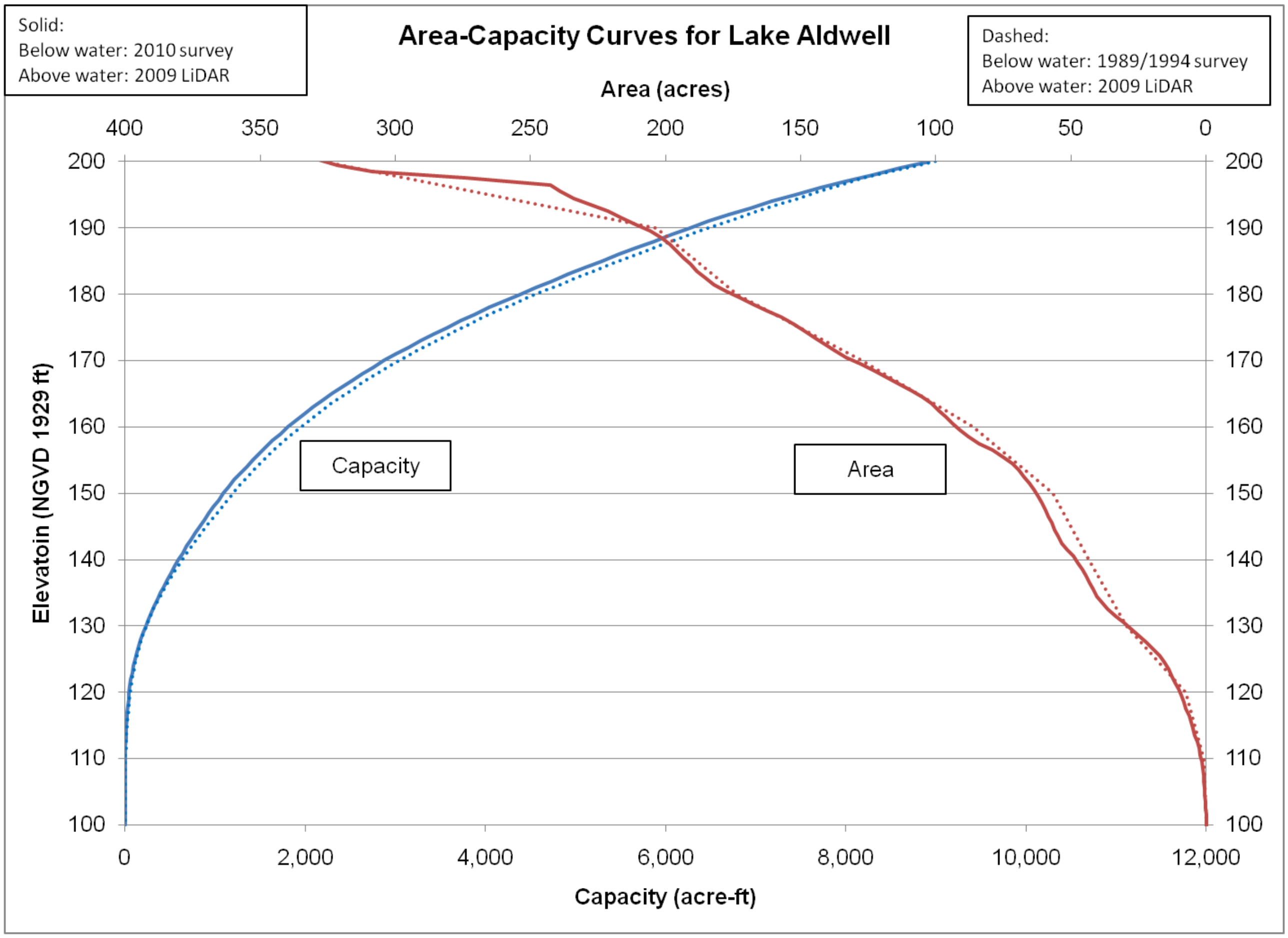


Figure 18. Diagram of area-capacity curves for Lake Aldwell from 2010 survey and historical 1989/1994 survey, both using 2009 LiDAR in delta.

5.2 Lake Aldwell Sedimentation Volume

A predam (before 1913) map for Lake Aldwell does not exist to compare to the present topography and estimate a total sedimentation volume. Based on 1989/1994 topography and drill hole data, an estimated 3.9 million yd^3 of sedimentation has occurred within Lake Aldwell (Reclamation, 1995). Reclamation (1995) noted that the largest sedimentation was in the delta at the upstream end of the reservoir and was 18 to 24 ft thick. The original number was generated by multiplying sediment thickness estimates by areas associated with each thickness. The sedimentation estimate was not updated for this report, but a sediment volume uncertainty was computed of +/- 1 million yd^3. The uncertainty was computed by applying a 25% error margin to the drill hole thickness estimates used in the 1995 report to generate sedimentation volumes. The areas used to generate the volumes were assumed to be accurate.

5.3 Landslides near Elwha Dam

Based on 1994 survey data, two landslides were identified in Lake Aldwell just upstream of Elwha Dam that could potentially block the Elwha River channel during reservoir drawdown

(Link, 2003; Young, 2009). Blocking the river channel would impact the transport of sediment during dam removal and could result in an undesirable fish passage barrier. In 2010, more detailed and updated survey data were collected in this area and a new 5-ft contour map generated (Figure 19). The historical Elwha River channel can be seen to the south (bottom end) of both identified landslides where depths were measured in 2010 as greater than 90 ft. This indicates that the landslides do not presently block the Elwha River channel, but should still be monitored during drawdown in case of additional sliding that would result in more material to the southeast. The log boom area is still represented by 1994 data because new data were not collected in 2010. The log boom area has relatively flat topography noted to occur from fill placed following a dam failure upon initial filling (Reclamation, 1995). The fill is planned to be removed during dam removal.

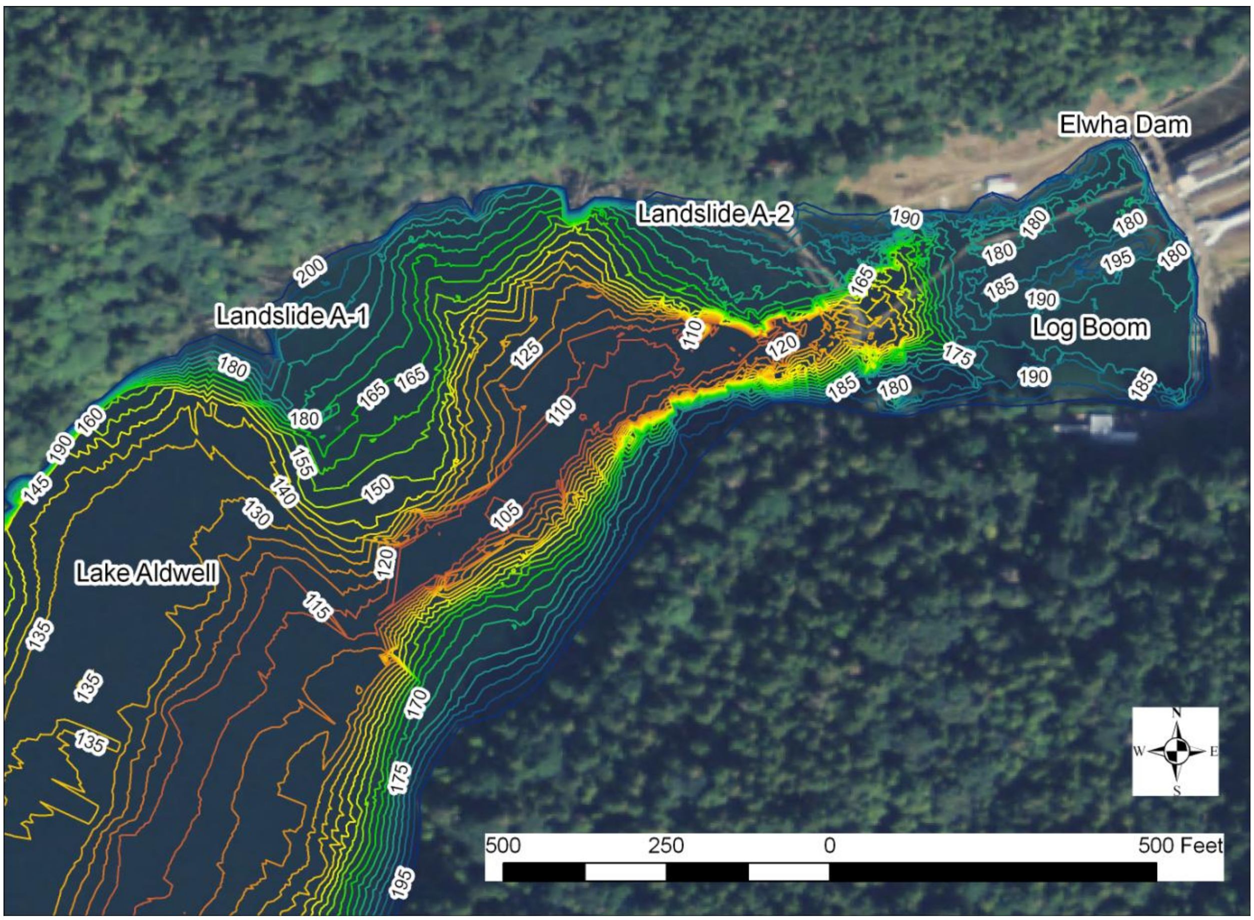


Figure 19. Topography of Lake Aldwell near log boom area where two landslides (A-1 and A-2) have been identified in previous reports (Link, 2003; Young, 2009).

6.0 Conclusions

A survey was performed of Lake Mills and Lake Aldwell in July 2010 that provides updated baseline topography and area-capacity curves 1 year prior to the commencement of dam removal. It is recommended that all future surveys be accomplished in the Washington State Plane North NAD 1983 horizontal ft and NAVD 1988 vertical datum ft to be consistent with the 2010 data. Comparison was made in Lake Mills to historical data to document the spatial and volumetric change in sedimentation since dam construction in 1927 and since the last sedimentation estimate in 1994.

The largest amount of change from the prior 1994 reservoir surveys occurred in Lake Mills because it traps the majority of river sediment being transported from the upper watershed, and there are no major tributaries in the 8.7 mile reach between Lake Mills and Lake Aldwell. The Lake Aldwell sedimentation estimate of 3.9 million yd^3 was, therefore, not updated for this report but a sediment volume uncertainty was computed of +/- 1 million yd^3. More detailed topography was collected upstream of Elwha Dam and the log boom area where two landslides have been identified. Current topography indicates the landslides do not presently block the predam Elwha River channel. It is not known if the landslides occurred during the dam failure following the initial filling of Lake Aldwell in 1913 or were in existence prior to 1913.

A new sedimentation volume for Lake Mills between 1927 and 2010 was computed as 20.4 million yd^3 (12,600 acre-ft) with an uncertainty of +/- 2.7 million yds^3 (1,700 acre-ft). The Lake Mills sedimentation estimate includes sediment that has deposited in the downstream-most 1 mile of Rica Canyon. In total, reservoir sediment that will be adaptively managed during dam removal is 24.3 million yd^3.

The last estimate of sedimentation of Lake Mills, based on 1989/1994 topography and drilling data, was 13.9 million yd^3 for the 67 years since construction. For the much shorter time period of 16 years between 1994 and 2010, there was a 47% increase in the sedimentation volume (Reclamation, 1995). The majority of sedimentation has occurred in the delta in the upstream portion of the reservoir. Additional sediment has been deposited on the lake bottom between the delta and Glines Canyon Dam. Sediment at Glines Canyon Dam is estimated to be 30 to 50 ft thick. The Lake Mills average annual incoming sediment supply for the 67 years between 1927 and 1994 is 128 acre-ft (207,000 yd^3). Based on the new sedimentation estimate, the average annual incoming supply for 1994 to 2010 (16 years) is 251 acre-ft (405,000 yd^3). This indicates the average annual sediment load contributed in the last 16 years is roughly double the 1927 to 1994 average. The new long-term average annual sediment load for 1927 to 2010 (83 years) is 152 acre-ft (245,300 yd^3). The sedimentation volume includes a portion of the wood load that was trapped in the reservoir.

7.0 References

Hosey, 1990a, “Lake Aldwell Bathymetric Map”, Engineering Hydraulics, Inc. (for James River II, Inc.), Glines Canyon Project (FERC No. 2683), Job No. 3535-003, dated February 7, 1990, scale 1” = 400’, Figure 4.1 (Hosey, 1990)

Hosey, 1990b, “Lake Mills Bathymetric Map”, Engineering Hydraulics, Inc. (for James River II, Inc.), Glines Canyon Project (FERC No. 588), Job NO. 3535-003, dated February 7, 1990, scale 1” = 400’, Figure 3.1 (Hosey, 1990).

Mulcare, Donald M., 2003, NGS Toolkit, Part 9: The National Geodetic Survey VERTCON Tool, Geodetic Services Division of the National Geodetic Survey, Maryland.

Reclamation, 2010, Area-Capacity Tables for Lake Mills and Lake Aldwell on the Elwha River, Washington, Technical Report No. SRH-2010-15, Sedimentation and River Hydraulics Group, Technical Service Center, Denver, CO.

Reclamation, 2003, Geologic Report on Lake Aldwell and Lake Mills Landslide Mapping and Elwha Dam Left Spillway Coffer Dam Foundation Explorations, Elwha Project, Washington, Pacific Northwest Region, Boise, ID, 32 pages.

Reclamation, 1996, Removal of Elwha and Glines Canyon Dam, (Technical Series PN-95-7), Pacific Northwest Region, Boise, ID.

Reclamation, 1995, Alluvium Distribution in Lake Mills, Glines Canyon Project and Lake Aldwell, Elwha Project, Washington (Elwha Technical Series PN-95-4), Pacific Northwest Region, Boise, ID, 60 pages.

Reclamation, 1985, Area-capacity Computation Program User Manual, Engineering and Research Center, Denver, CO.

TerraPoint, 2001, 6 ft-by-6ft grid bare-earth Lidar data, Clallam County, Washington.

TerraPoint, 2009, bare-earth Lidar data, Elwha S’Klallam Tribe, Washington.

Young, S., 2009, Lake Aldwell Landslide Evaluation for Reservoir Drawdown, Elwha Dam, Technical Memorandum No. ELW-8311-FD-2009-1, U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center.

Appendix A: July 2010 Survey Documentation

A survey of Lake Mills and Lake Aldwell was conducted by the Sedimentation Group at the Denver Technical Service Center of Reclamation and began on July 24 and ended on July 29 of 2010. The majority of survey work occurred in wetted areas and was performed on boats equipped with RTK GPS (in rapid mode) and single beam depth sounders. A portion of the Lake Mills sediment delta at the upstream end of the reservoir was measured by RTK GPS in topo mode. The reservoirs were near full conditions and varied little in reservoir pool elevation during the surveys.

The horizontal control for this study was in State Plane Washington North coordinates, in the North American Datum of 1983 (NAD83 ft). The vertical control was in the North American Vertical Datum 1988 (NAVD88 ft) with GEOID09. The vertical differences between these established coordinates and the project's or construction vertical datum and National Geodetic Vertical Datum 1929 (NGVD29) was also determined during this survey. Vertical accuracy of the survey points are estimated to be within 0.1 ft for RTK topo shots collected on foot, and within 0.8 ft for bathymetric shots collected by boat in RTK rapid mode. The larger error for the bathymetric shots occurs due to the turbulence in the water, depth sounding error, and error in GPS position when collected in an instantaneous mode (single point rather than averaging) on a boat.

A.1 Survey Control

A control survey was conducted using the on-line positioning user service (OPUS) and RTK GPS to establish a horizontal and vertical control network near the reservoirs for the hydrographic survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files for processing with known point data to determine positions relative to the national control network. OPUS solutions were run for the base coordinates each day of data collection. The averages of the daily OPUS coordinate solutions were used for the final survey coordinates.

For Lake Aldwell a temporary cap was placed in an unvegetated area of the reservoir slightly to the west of Elwha Dam. A radio repeater was used for the upstream portion of the reservoir. The repeater was placed at the Highway 101 overlook on the east side of the reservoir.

For Lake Mills the GPS base was set over a Federal Highway Administration cap stamped "Federal Highway Administration, Elwha 1" (Figure 20 and Figure 21). The survey control was set for the Olympic Hot Springs Road Repair. The base was set over ELWHA #1 during all days of the bathymetric and above water survey collection on July 25, July 26 and July 28, 2010. Coordinates for the benchmark could not be located at the time of the survey, so the base was initially set up on July 24, 2010 using the GPS "here" function and later corrected using OPUS. Collected data measurements were shifted to match NAD83/NAVD88 (Table 5).

Table 5. Coordinates of OPUS solutions for base stations used in July 2010 survey.

Point	Easting	Northing	Elevation	Description
1000	962997.503	378031.734	624.546	Elwha1 (Lake Mills)
1000	974,566.899	411,136.957	214.329	elw1000 (Lake Aldwell)

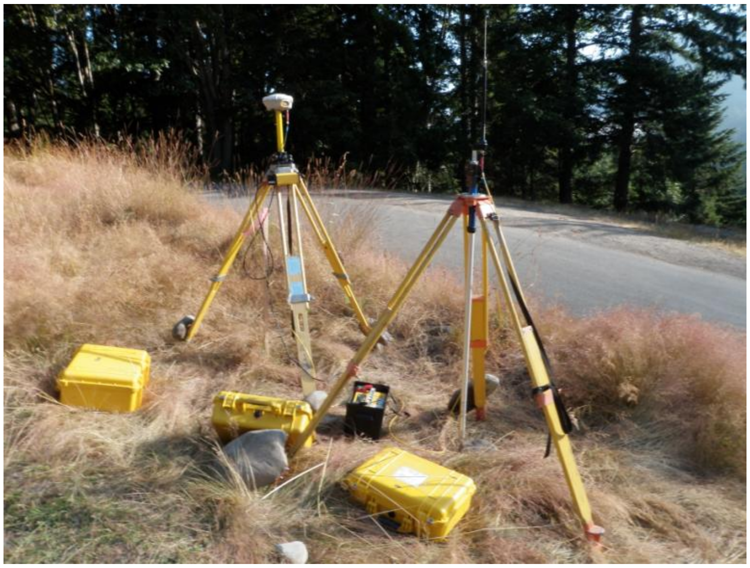


Figure 20. Base station setup for Lake Mills survey.

Figure 21. Benchmark where GPS base station was set up for Lake Mills survey work.

<u>Control Point Comparison to Previous Surveys at Glines Canyon Dam</u>

On July 28, 2010 control points located on the Glines Canyon Dam spillway walkway were surveyed that will remain in place after dam removal (Table 6). These points can be used to compare to historical surveys and where not disturbed, to compare to future surveys. Potential differences between the July 2010 and historical survey results could be due to differences in the number and extent of satellite occupation and equipment used for the surveys.

Table 6. Coordinates of benchmarks near Glines Canyon Dam from July 2010 OPUS solution.

Point	Easting	Northing	Elevation	Description
1000	962997.503	378031.734	624.546	Elwha1
5011	963171.679	377936.496	616.025	Elwha2
60608	963221.643	377778.484	604.032	CrownzA1
60609	963233.086	377731.201	604.058	CrownzB1
60610	963262.886	377693.673	604.024	CrownzA2
2000	963229.471	377826.953	608.900	COE Brass Cap S96-6D
5007	963201.512	377856.778	616.448	Near WSDOT BM 6513

The Federal Highway Administration (FHA) established two control points at Glines Canyon Dam in February 2010 near the dam that can be compared to the July 2010 survey (Elwha1 and Elwha2). FHA noted in written communication that "The values for points Elwha1 and Elwha2 were established using dual frequency survey grade GPS units. The Online Positioning User Service (OPUS) on the NGS website was used to establish the coordinates of Elwha2. Elwha1 was computed from there by computing a static baseline. The remaining points were calculated from these based on a closed loop traverse. Geoid separations and Orthometric Elevations were based on the Geoid09 model and OPUS results for Elwha2. Remaining elevations were determined using trigonometric methods." Elwha1 had an easting of 9962997.538, a northing of 378031.79, and an elevation of 624.396. Elwha2 had an easting of 963171.718, a northing of 377936.519, and an elevation of 615.888. When compared to values in Table 6, a difference in horizontal position was less than 0.07 ft for both points and the difference in vertical elevation was less than 0.15 ft.

The Reclamation Elwha project office provided information from a May 2010 survey at Lake Mills (Figure 22). Documentation on the methodology for the May 2010 survey was not available. The difference between the project datum and the reported NAVD88 elevations from the May 7, 2010 survey was around 15.8 feet, similar to the difference determined by Reclamation in July 2010 when comparing Hydromet reservoir stage to measured water surface elevation values. A CORPSCON calculation done after the July 2010 survey showed a 3.6 ft shift between NGVD 1929 and NAVD 1988 vertical datums at Lake Mills, which is different than the 4.1 ft shift indicated in Figure 22. Two points that can be directly compared in NAVD 88 between the May and July 2010 surveys were CE S96-6D and CrownzA2. CE S96-6D had a May 2010 elevation of 609.1 (NAVD 88), compared to 608.9 as surveyed on July 24, 2010. CrownzA2 had a May 2010 elevation of 604.3 compared to 604.0 as surveyed on July 24, 2010. This comparison shows a vertical difference of 0.2 to 0.3 ft between May and July 2010 surveys.

Station	NGVD-29	Datum PROJECT	NAVD88
L-36 1929	605.26	625.20	609.36
CE S96-6D	605.02	624.96	609.1
Sill	591.37	611.31	595.47
Dam (crest)	590.39	610.33	594.49
Water	589.68	609.62	593.78
CZ - D-3	605.21	625.15	609.31
CZ - C-1	600.19	620.13	604.29
CZ - D-2	600.15	620.09	604.25
CZ - D-2	600.15	620.09	604.25
CZ - A2	600.16	620.10	604.26

Notes

Determined elevations on CE S96-6D & CE A2 using RTK GPS (NAVD88)

Delta NGVD29 -> NAVD88 = 4.1 held 605.26 on L36 and shot all points with level for comparison

Measured at 12:27 local on 5/7/10 note: Gage on Gate House read 609.59

Figure 22. May 7, 2010 survey coordinates for Lake Mills and Glines Canyon Dam.

The 2009 LiDAR survey used a WSDOT benchmark for control that is located on Glines Canyon Dam (Figure 23). The LiDAR reported the coordinates of this point as 963,201.162 easting (ft), 377,856.296 northing (ft), and 616.515 ft elevation (NAVD 88). The LiDAR value at this location for elevation was 616.380 ft, with a reported difference of -.14 ft. However, when this monument was looked up on the WSDOT website (www.wsdot.wa.gov/monument), the latest reported coordinates were slightly different at 963,203.4 easting (ft), 377,857.2 northing (ft), and elevation was 616.345 ft (NAVD 88). The differences may be due to rounding error applied when converting the WSDOT monument sheet values from meters to feet (the values reported in this appendix used a conversion function in excel). The July 2010 survey got an elevation near this monument of 616.448 ft which compares within 0.1 ft.

Figure 23. WSDOT benchmark "Gobbling", monument ID: 6513. The mark is a punchmark in the bottom of the hand rail post.

Control Point Comparison to Previous Surveys at Elwha Dam

On July 27, 2010 control points located on Elwha Dam were surveyed that will be removed after dam removal (Table 7). The Reclamation Elwha project office provided vertical elevations of two control points on Elwha Dam from a May 2010 survey and a 1967 survey (presumably in a local datum) (Table 8). These two control points (A1 and A6) were within 0.14 and 0.02 ft of the July 2010 survey elevations.

The Ephrata Reclamation survey office also collected information on three control points on Elwha Dam in 2001 using a GPS control network (Table 9). The easting of the three control points (A6, B4, and B5) compared within 0.02 to 0.26 ft, the northing compared within 0.47 to 0.58 ft, and the elevation compared within 0.02 to 0.08 ft.

Table 7. Coordinates of benchmarks near and on Elwha Dam from July 2010 OPUS solution.

Point	Easting (NAD83ft)	Northing (NAD83ft)	Elevation (NAVD88 ft)	Description
1000	974,566.899	411,136.957	214.329	elw1000 (Base Station for July 2010 Survey)
1100	974,962.261	411,040.765	203.063	crownz1967B5 (on Elwha Dam)
1101	974,974.875	411,017.336	204.128	crownz1967A6 (on Elwha Dam)
1102	974,934.523	411,089.373	203.190	crownz1967B4 (on Elwha Dam)
1104	974,979.329	410,814.405	210.456	crownz1967A1 (on Elwha Dam)

Table 8. Elevations of benchmarks on Elwha Dam from May 2010 project survey, noting original benchmark elevations in local datum.

Point	1967 Survey (ft)	NGVD29 (ft)	NAVD88 (ft)	Description
1101	190.9	200.38	204.27	crownz1967A6 (on Elwha Dam)
1104	197.0	206.46	210.44	crownz1967A1 (on Elwha Dam)

Table 9. Coordinates of benchmarks on Elwha Dam from May 2010 project survey, noting original benchmark elevations in local datum.

Easting (NAD83ft)	Northing (NAD83ft)	NAVD88 (ft)	Description
974974.780	411016.838	204.145	crownz1967A6 (on Elwha Dam)
974934.502	411088.795	203.228	crownz1967B4 (on Elwha Dam)
974961.997	411040.300	203.146	crownz1967B5 (on Elwha Dam)

A.2 Lake Mills Survey

A bathymetric survey of Lake Mills was performed July 25, July 26, and July 28, 2010. River flows were 1,430, 1,390 and 1,280 cfs at the USGS gage above Lake Mills, and the hydromet reservoir elevations recorded by Reclamation were 609.61, 609.64 and 609.58 ft (project datum), respectively (www.usbr.gov/pn/hydromet). The average reservoir water surface elevation in NAVD 88 was 598.3 ft. A summary of data point collection is as follows:

- 27,188 points were collected in the main reservoir using a Hypack software system that processed the single beam depth sounder and GPS elevations.
- 9,202 points were collected in the delta area by boat using a Hydrolite single beam depth sounder tied to RTK GPS at one second intervals.
- 1,689 points were collected on the Mills delta using RTK topo mode.
- 5,967 points were collected by boat with a Hydrolite single beam depth sounder tied to RTK GPS in the log boom area.

On July 25, 2010 the bathymetric survey began on Lake Mills using a larger boat for mounting the collection instrumentation that included RTK GPS, single beam depth sounder, and a computer for storing the collected data. This method was used to map the major areas of Lake Mills and was completed on July 26, 2010. The data were collected by Ron Ferrari of the Sedimentation Group.

On July 26, 2010 three rovers were used to measure topography in the upper delta of the reservoir. Two rovers were used for collection of RTK GPS topo shots on the above water portion of the upper delta and additional topo shots were collected by the crew wading in the wetted zones where it was safe. The farthest delta channel to the east (right looking downstream) conveyed the majority of river flow during the survey. Vegetated areas of the delta were generally not surveyed, except in some locations in the middle and upstream portion to use as a QA/QC check on the 2009 LiDAR data. This collection was conducted by Tim Randle and Rob Hilldale of the Sedimentation Group and Josh Chenoweth of NPS. The third rover was mounted on a motorized small raft and hooked up to a Hydrolite depth sounder. Depths and RTK GPS shots in rapid mode were collected on a one second interval. The collection was conducted by Jennifer Bountry of the Sedimentation Group along with Thomas Parker from the Elwha Tribe.

The thalweg could not be surveyed in the east-most (right looking downstream) delta channel due to the swift current at the time of survey. Estimates of the water depth were about 3 to 4 ft in the upper end of the right channel where a pool was present, and 1.5 to 2 ft where a riffle was present. Surveyors were able to wade out into the channel until the water depth was about 2 ft. Estimates were made of the thalweg for generation of the terrain surface using a maximum depth in the right channel of 4 ft below the reported LiDAR elevation (e.g .approximate water surface) and decreasing in 0.5 ft increments towards the last known survey point at cross-sections that were surveyed.

On July 28, 2010 three RTK GPS rovers were used. One unit was used to measure depths in the log boom area near Glines Canyon Dam. In the log boom area, it was not possible to get the survey boat over the logs and it would have been difficult to safely navigate near the dam and outlet release gates. Therefore, a Hydrolite depth sounder and RTK GPS antennae was mounted to a small pontoon and pulled with a kayak. Two RTK rovers were used to collect additional topo data points in the upper delta of the reservoir.

The Lake Mills points were post-processed by subtracting the depth from the RTK GPS elevation point to generate a reservoir bottom elevation. A water surface elevation was generated by adding the transducer draft (typically 0.5 to 0.8 ft) to the RTK GPS recorded elevation. A total depth was generated by adding the transducer draft to the recorded depth. Depth soundings were recorded in areas greater than 1.5 ft deep.

Figure 24. Survey setup for Lake Mills log boom area utilized on July 28, 2010.

A.3 Lake Aldwell Survey

A bathymetric survey of Lake Aldwell was performed July 27 and 29, 2010. River flows were 1,380 and 1,170 cfs at the USGS gage above Lake Mills (12044900) on July 27 and 29, and the hydromet reservoir elevations (project datum) recorded by Reclamation were 187.59 and 187.64 ft respectively (www.usbr.gov/pn/hydromet). The average reservoir water surface elevation recorded during the July 2010 survey in NAVD 88 was 200.6 ft. This results in a conversion from the project datum to NAVD 88 of +13.0 ft. Mean daily river flows at the USGS gage at McDonald Bridge (12045500) were 1,630 and 1,420 cfs on July 27 and 29, 2010. Vertical accuracies of the survey points are estimated to be within 0.1 ft for topo shots collected on foot, and within 0.8 ft for bathymetric shots collected by boat.

A total of 14,174 points were collected using a Hypac software system that processed the single beam depth sounder and GPS elevations. The Hypac data were collected by Ron Ferrari of the Sedimentation Group. An additional 22,543 points were collected using a single-beam Hydrolite system on a raft by Jennifer Bountry of the Sedimentation Group and Thomas Parker from the Elwha Tribe.

The Lake Aldwell reservoir points were post-processed by subtracting the depth from a single RTK topo shot value of the reservoir water surface elevation of 200.6 ft to generate reservoir bottom elevations. A water surface elevation was generated by adding the transducer draft (typically 0.5 to 0.8 ft) to the RTK GPS recorded elevation. A total depth was generated by adding the transducer draft to the recorded depth.

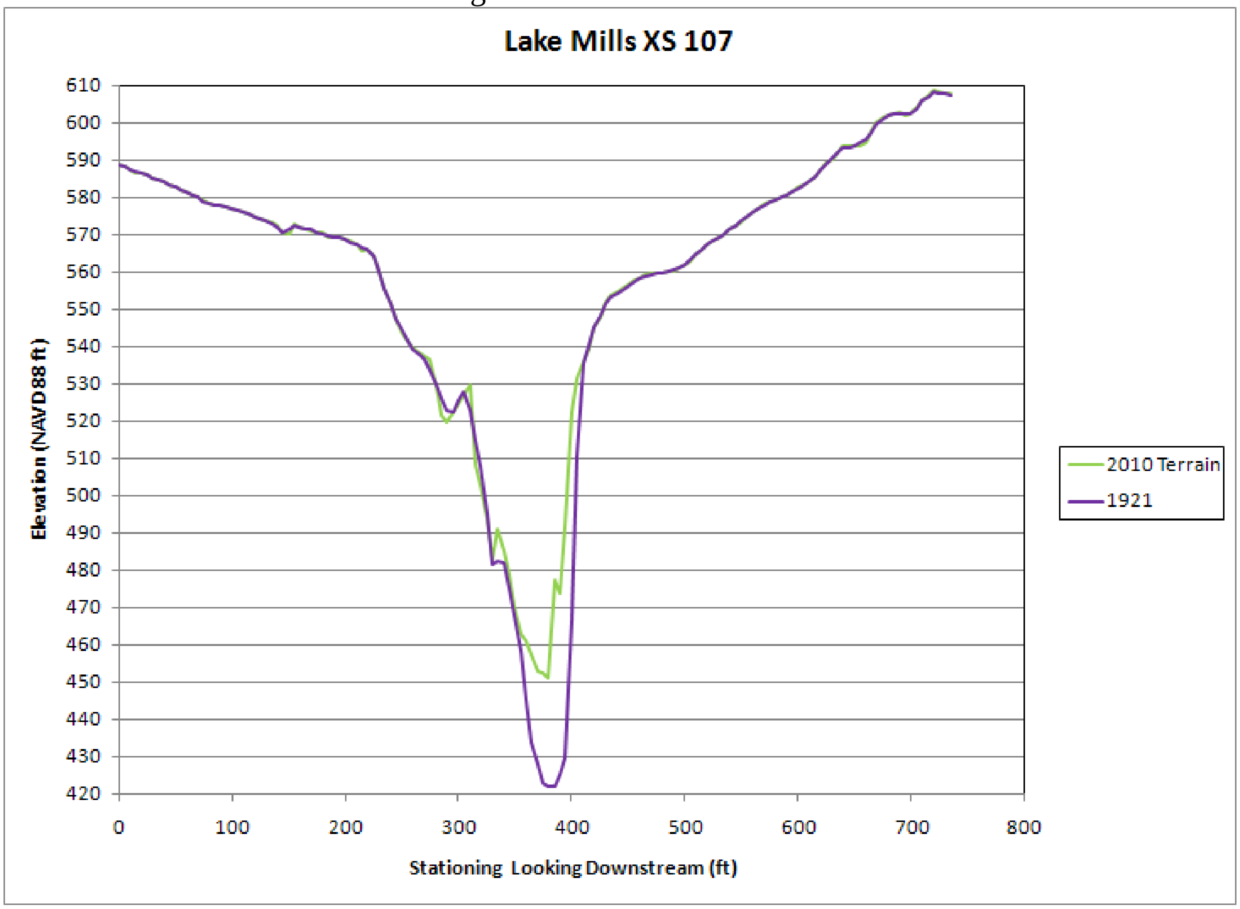
In the log boom area, a new survey was not done in 2010 under the assumption that little has changed in this area since the last 1994 survey. The 1994 survey included 11,198 points in the log boom. In the Lake Aldwell delta, channel areas were surveyed by boat where depths were greater than 1.5 ft and it was possible to navigate. Many areas had substantial accumulations of wood or clay at or near the reservoir water surface that prevented data collection by boat. GPS signals on the days of data collection were also poor in the upstream section of the Lake Aldwell delta.

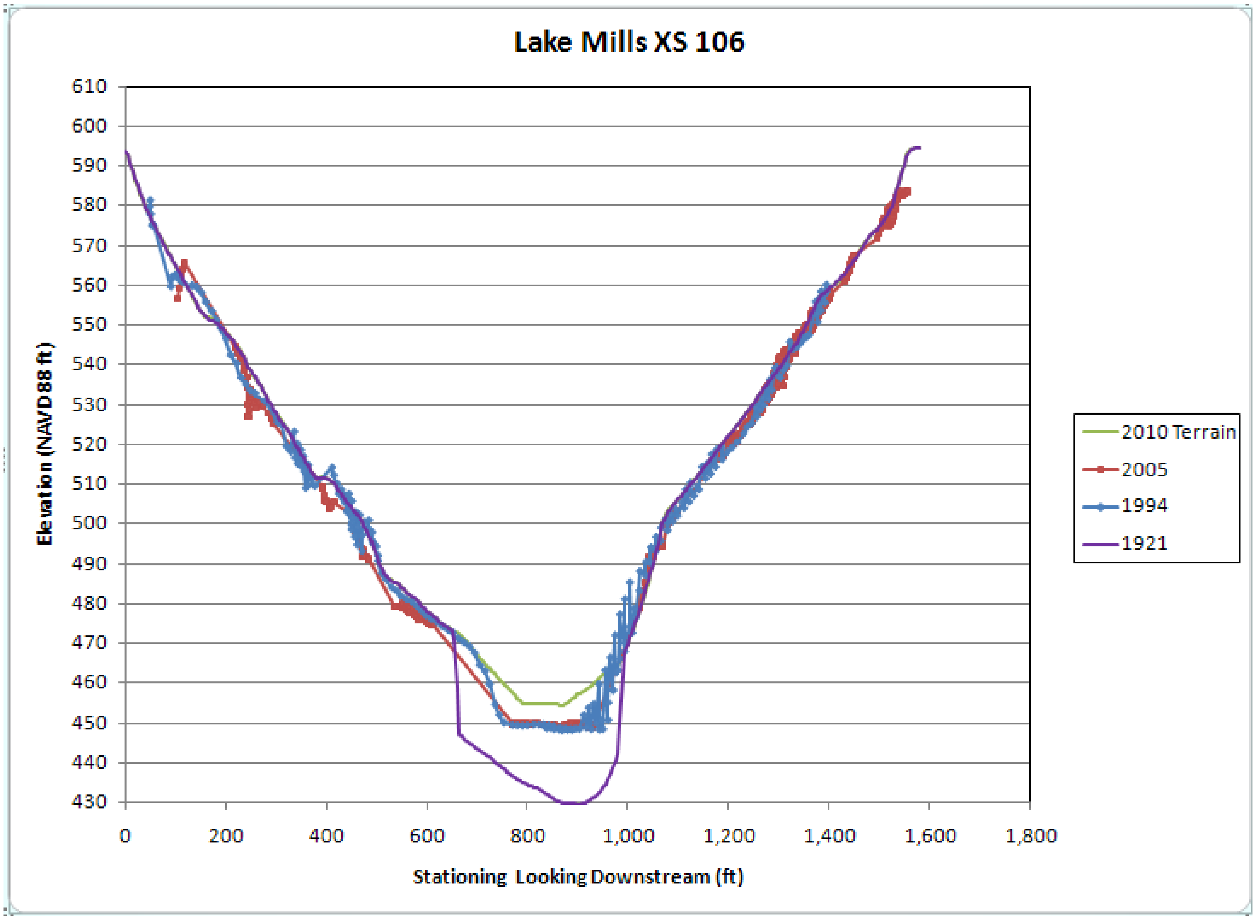
Appendix B: Cross-section Survey Comparison Plots

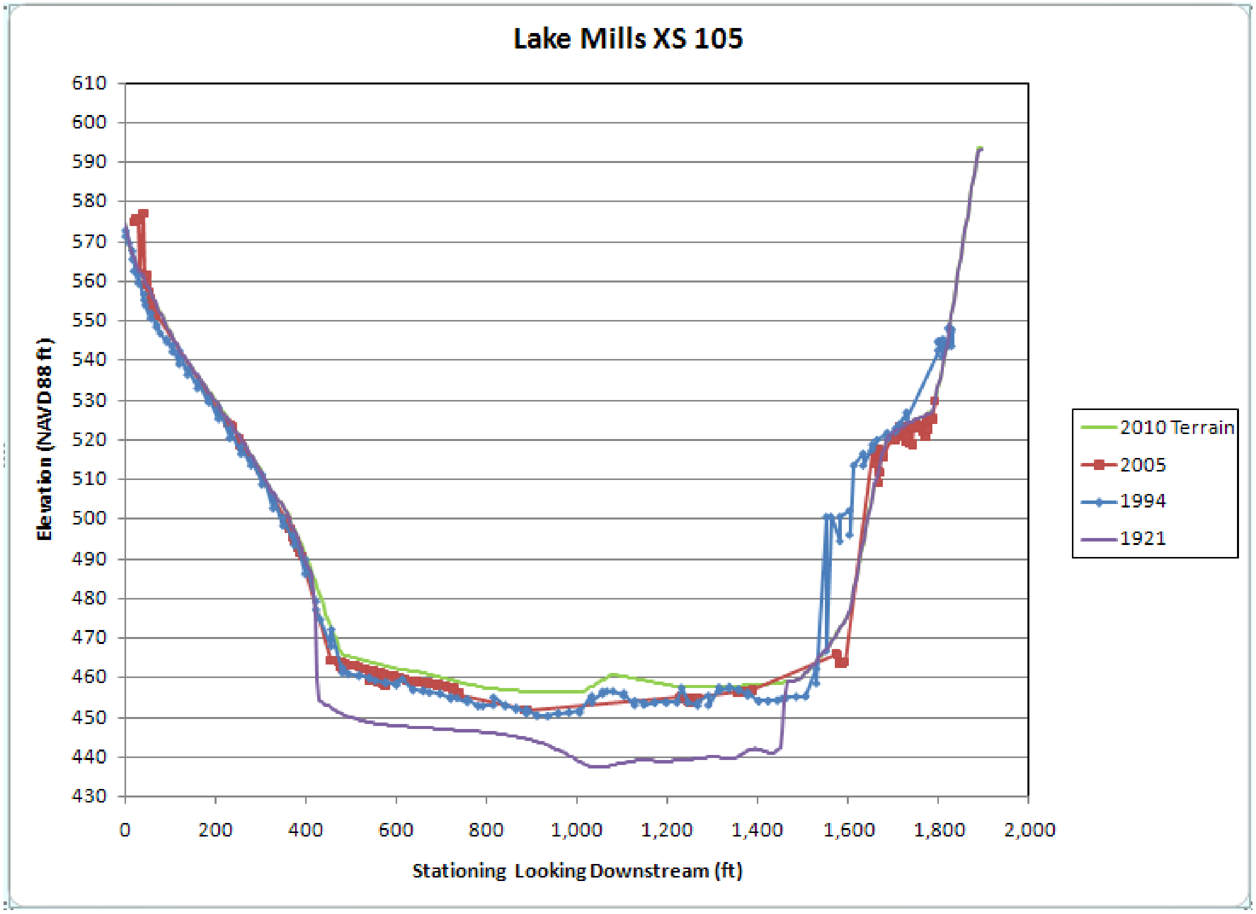
Data Sources:

- 1921: 5-ft raster grid generated from 10-ft pre-dam contour map;
- 1994: Reclamation survey data collected during 18-ft drawdown field experiment; data points used that fell within 30 ft of delineated cross-section lines
- 2005: NPS survey; data points used that fell within 20 ft of delineated cross-section lines
- 2010: Terrain generated as described in Section 3 of this report from Reclamation survey data collected to provided baseline conditions prior to the start of dam removal

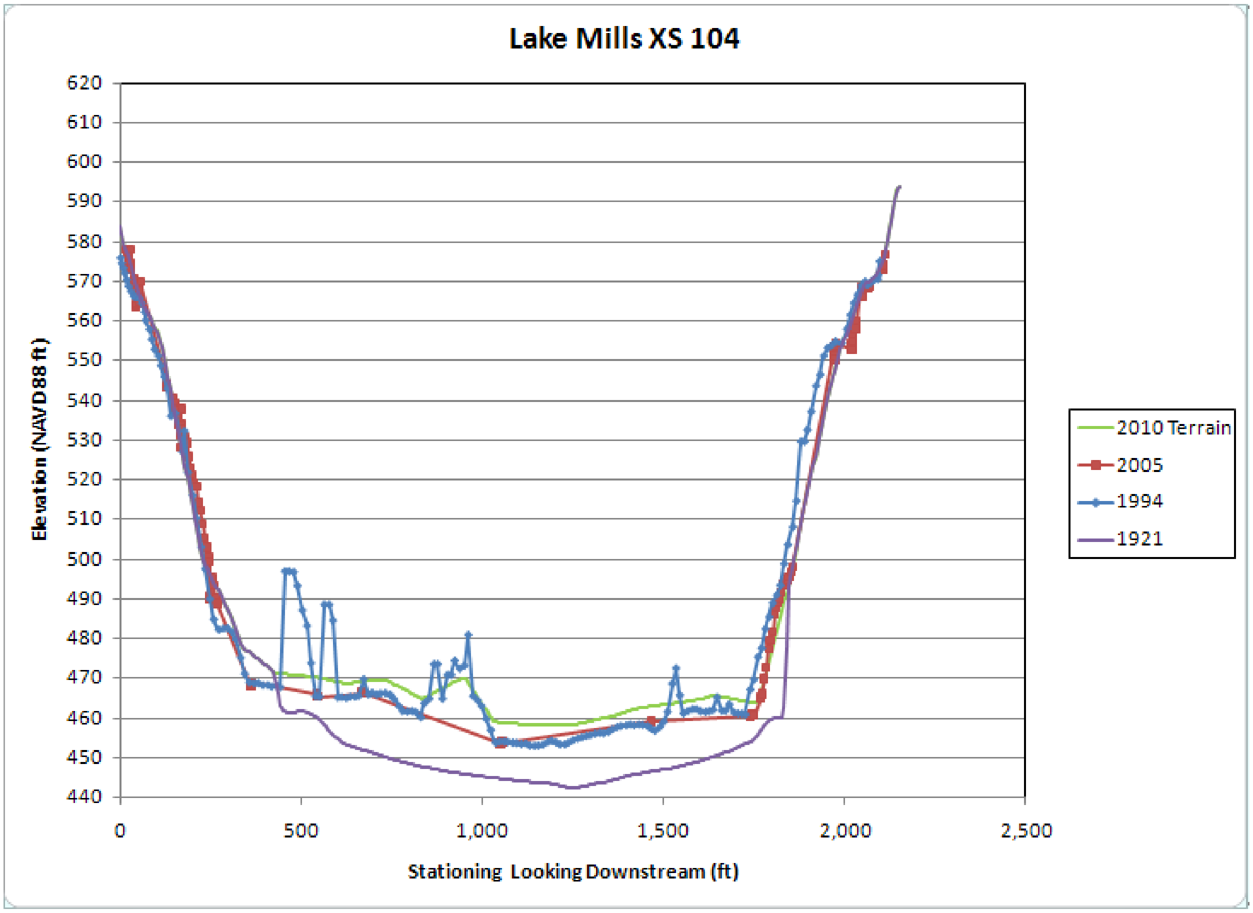
*Refer to Figure 15 in main report for cross-section locations. Cross-sections 1 to 17 are intended to replicate the numbering system used in the 1994 18-ft drawdown experiment. New cross-sections were numbered starting at 100.

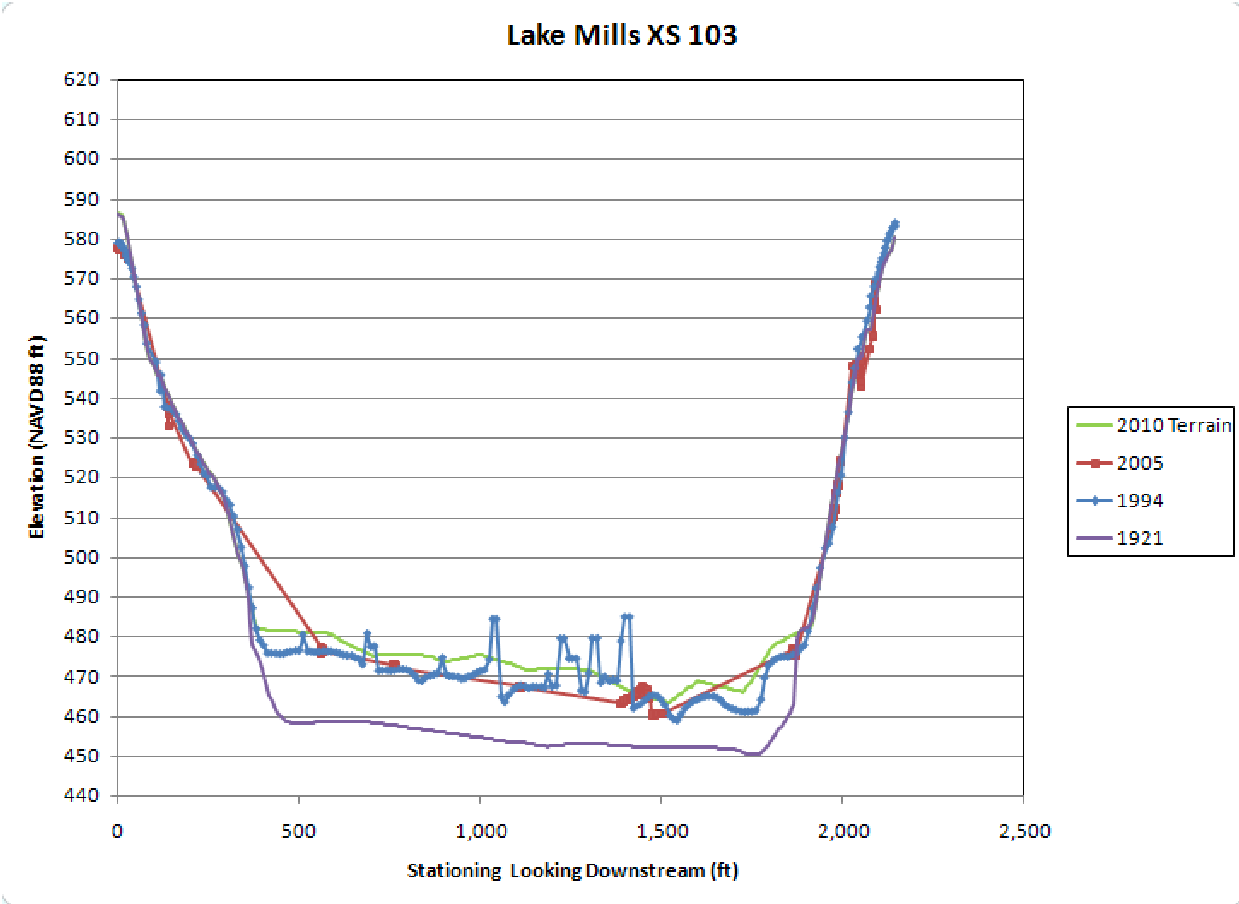


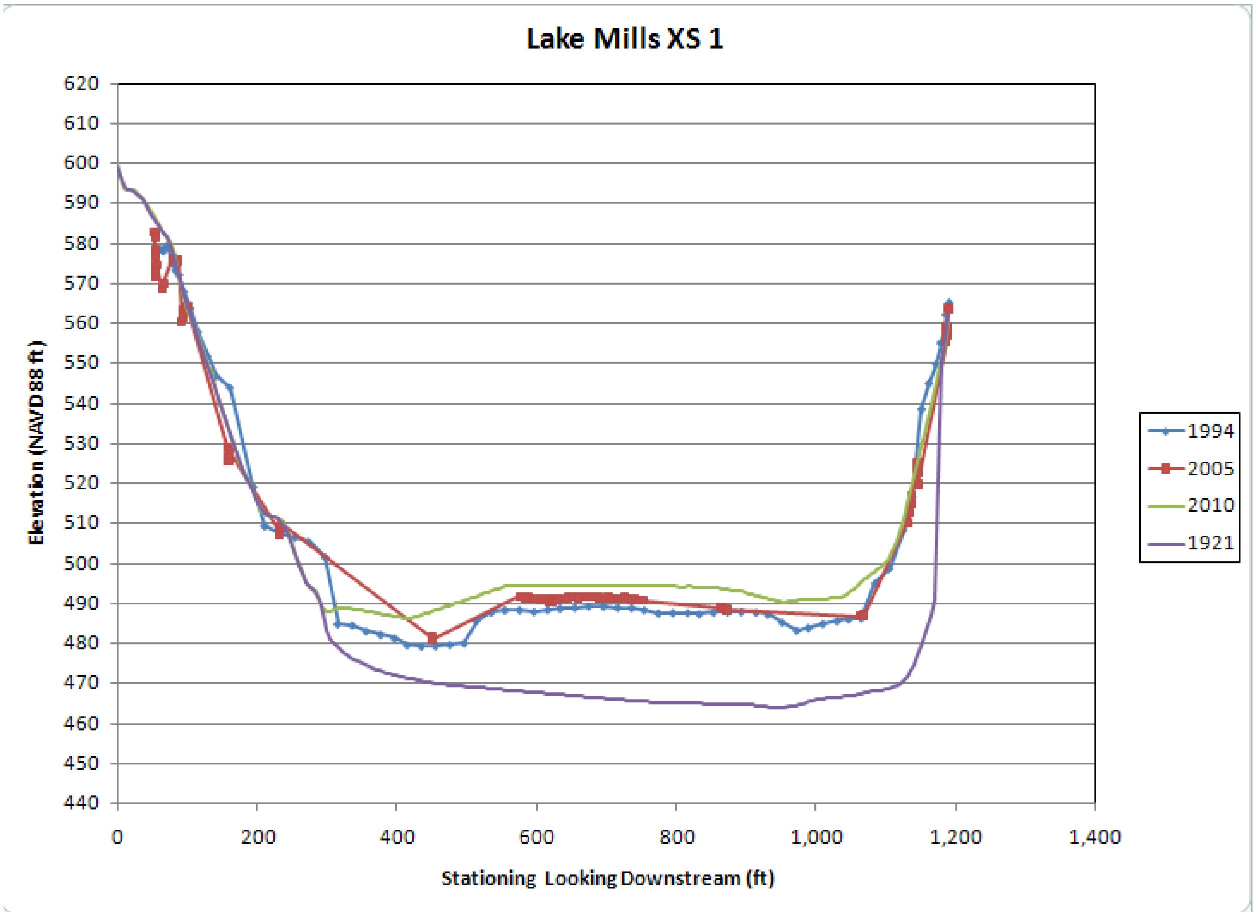

Lake Mills XS 106
Elevation (NAVD88 ft)
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
430
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921



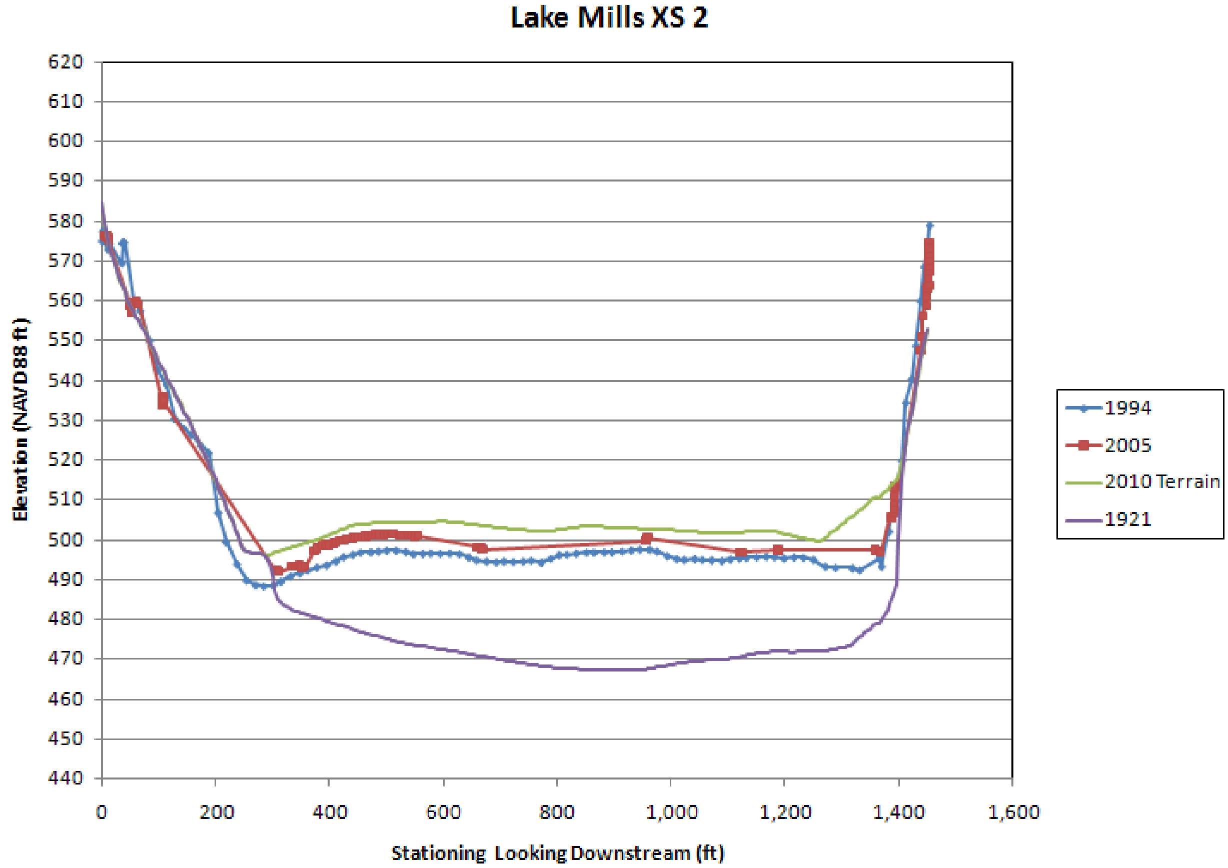
Lake Mills XS 105
Elevation (NAVD88 ft)
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
430
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921

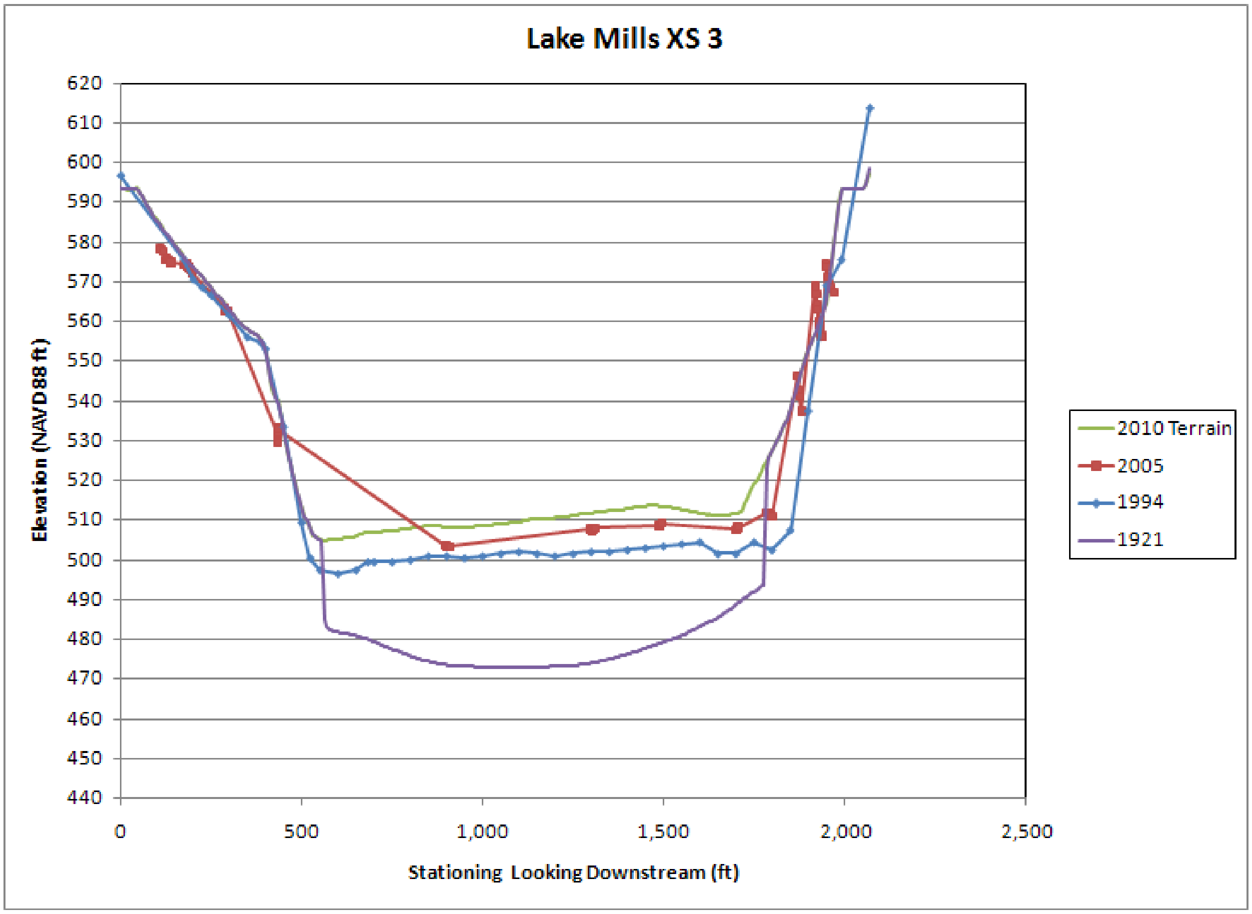

Lake Mills XS 104
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
500
1,000
1,500
2,000
2,500
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921

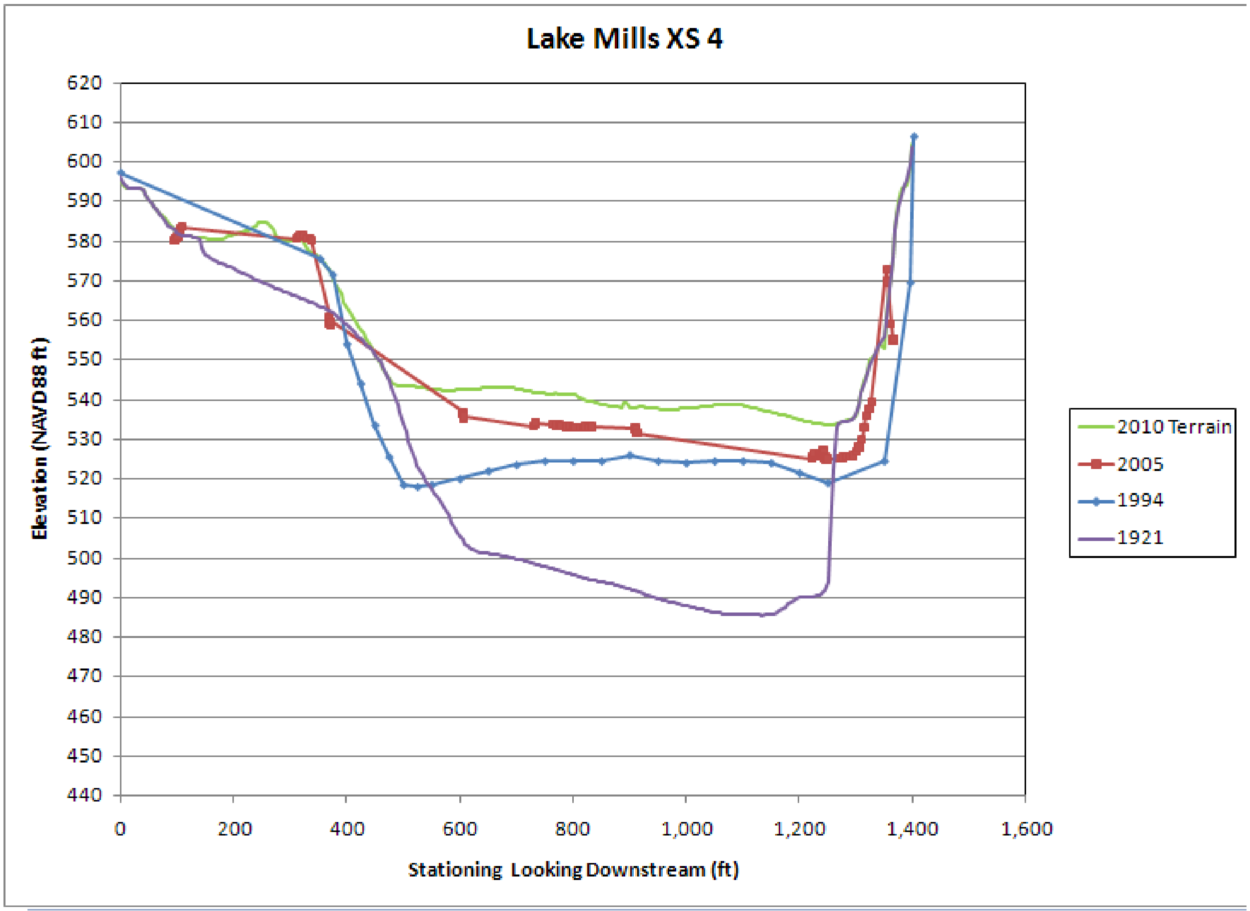

Lake Mills XS 103
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
500
1,000
1,500
2,000
2,500
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921

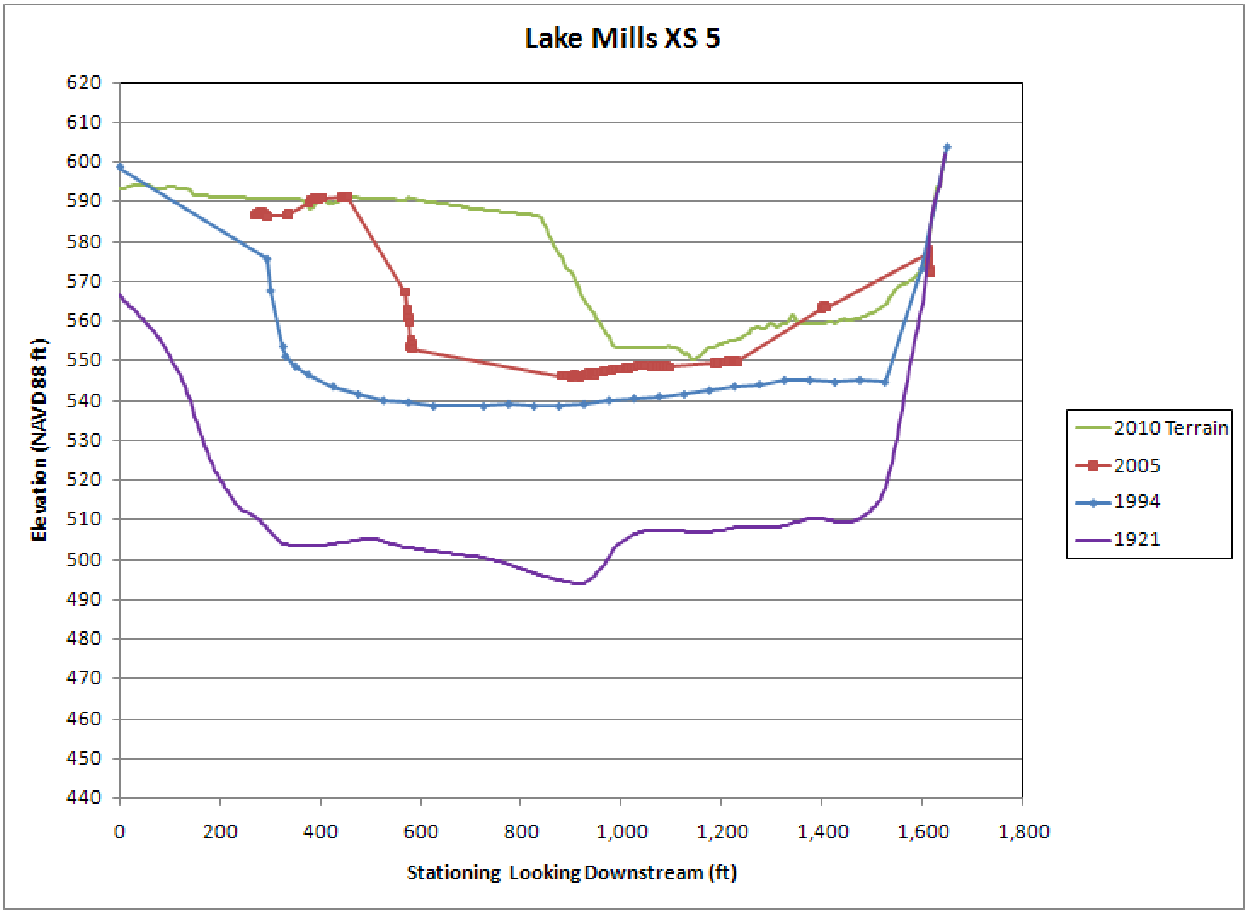


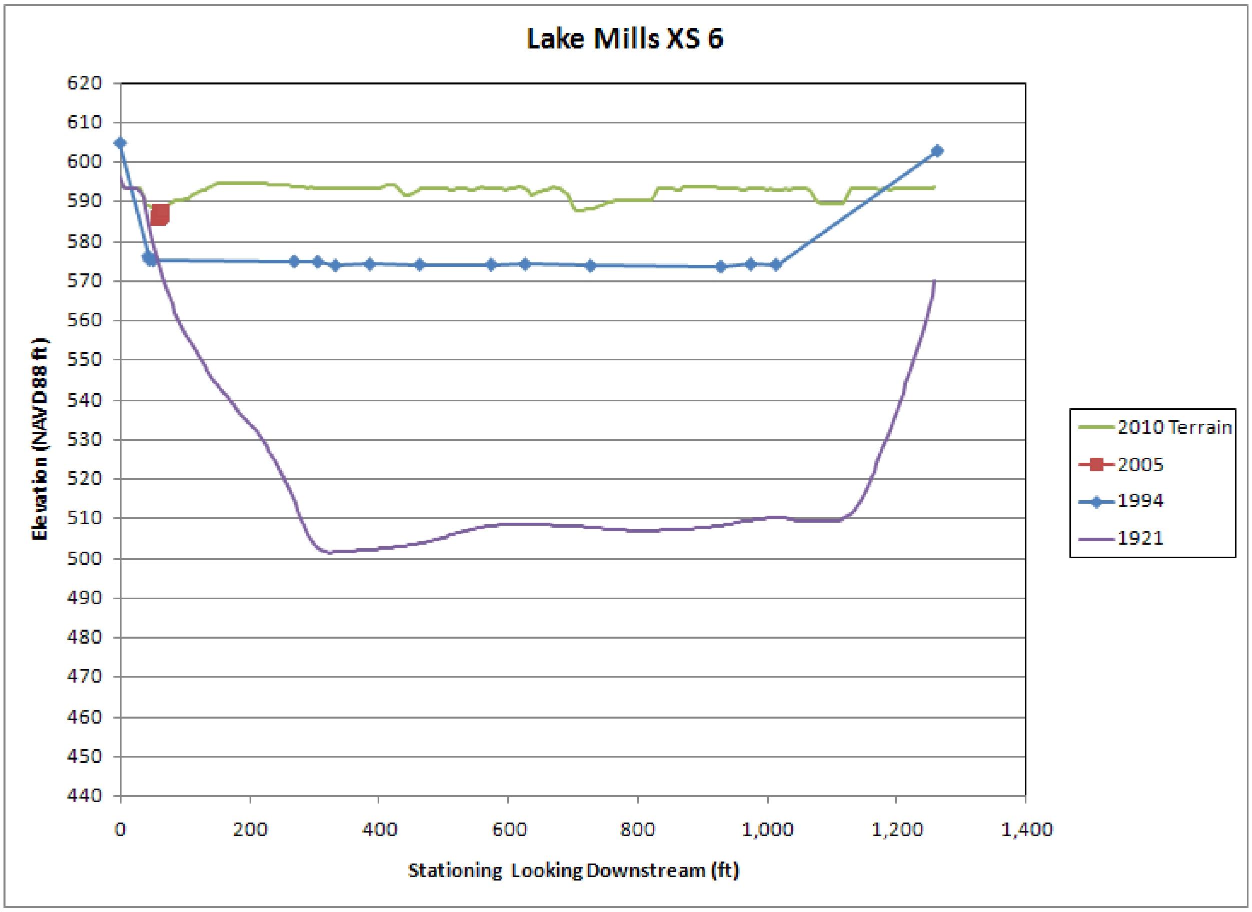
Lake Mills XS 1
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
Stationing Looking Downstream (ft)
1994
2005
2010
1921

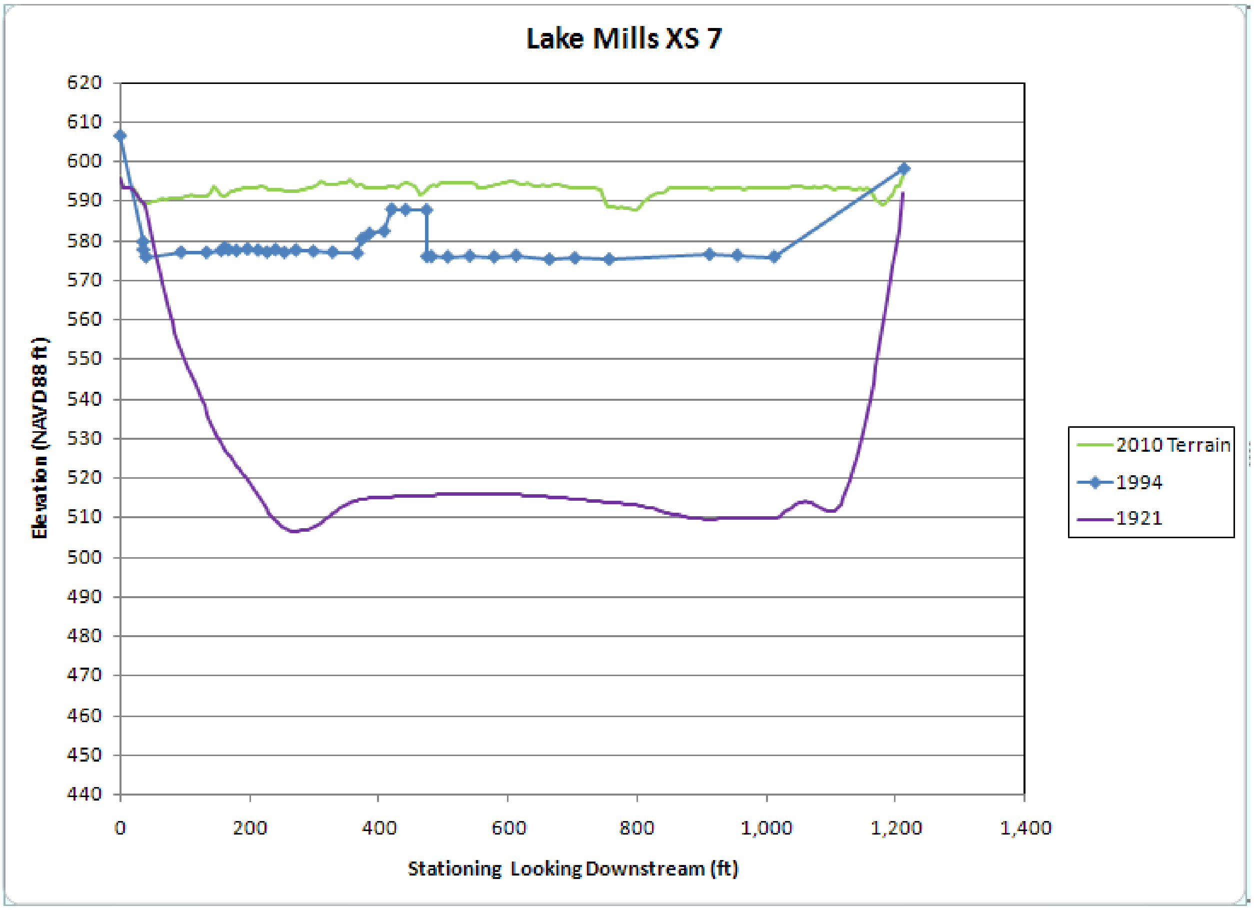

Lake Mills XS 2
Elevation (NAVD88 ft)
Stationing Looking Downstream (ft)
1994
2005
2010 Terrain
1921
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
1,600

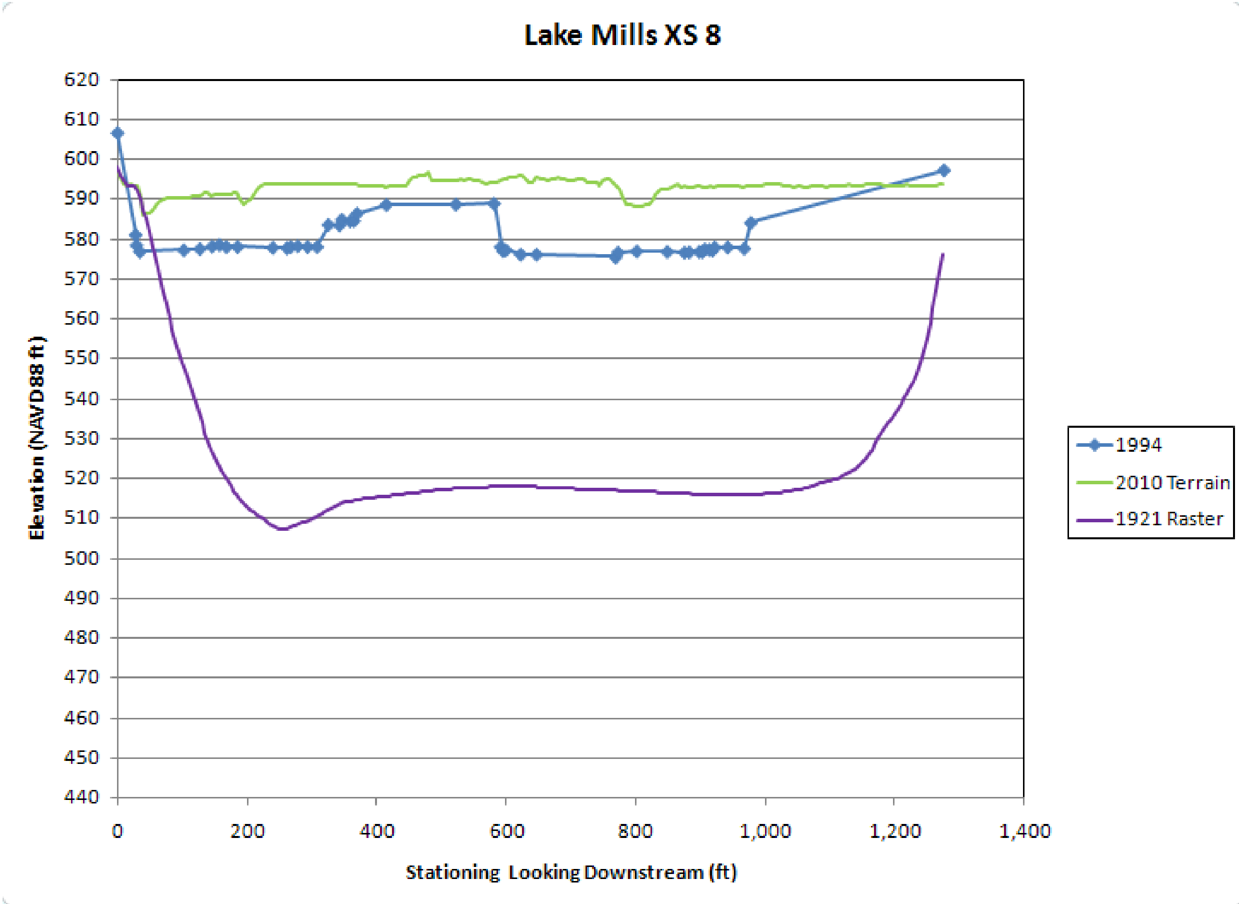

Lake Mills XS 3
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
Elevation (NAVD88 ft)
0
500
1,000
1,500
2,000
2,500
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921


Lake Mills XS 4
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
1,600
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921

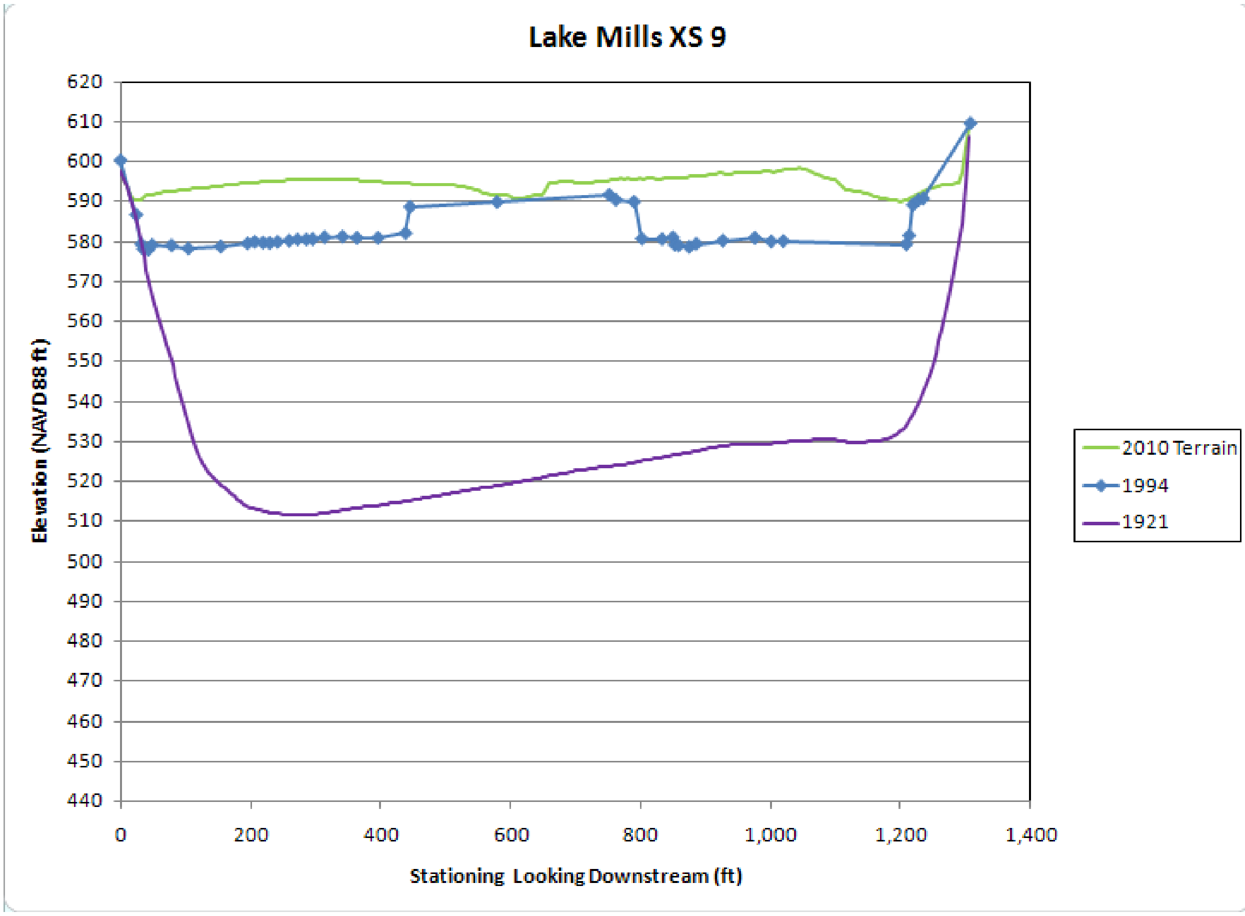

Lake Mills XS 5
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
Elevation (NAVD88 ft)
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921

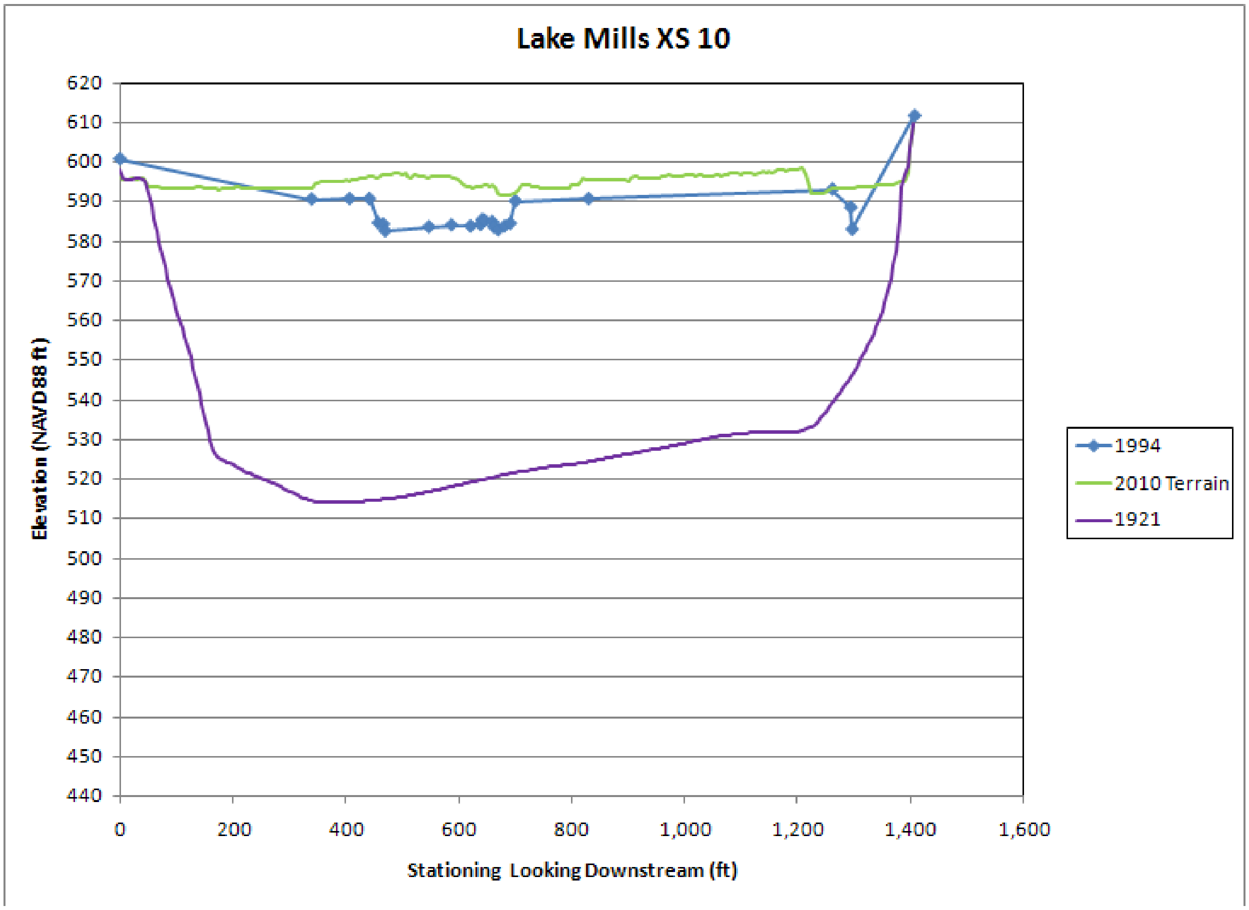

Lake Mills XS 6
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
Elevation (NAVD88 ft)
Stationing Looking Downstream (ft)
2010 Terrain
2005
1994
1921


Lake Mills XS 7
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

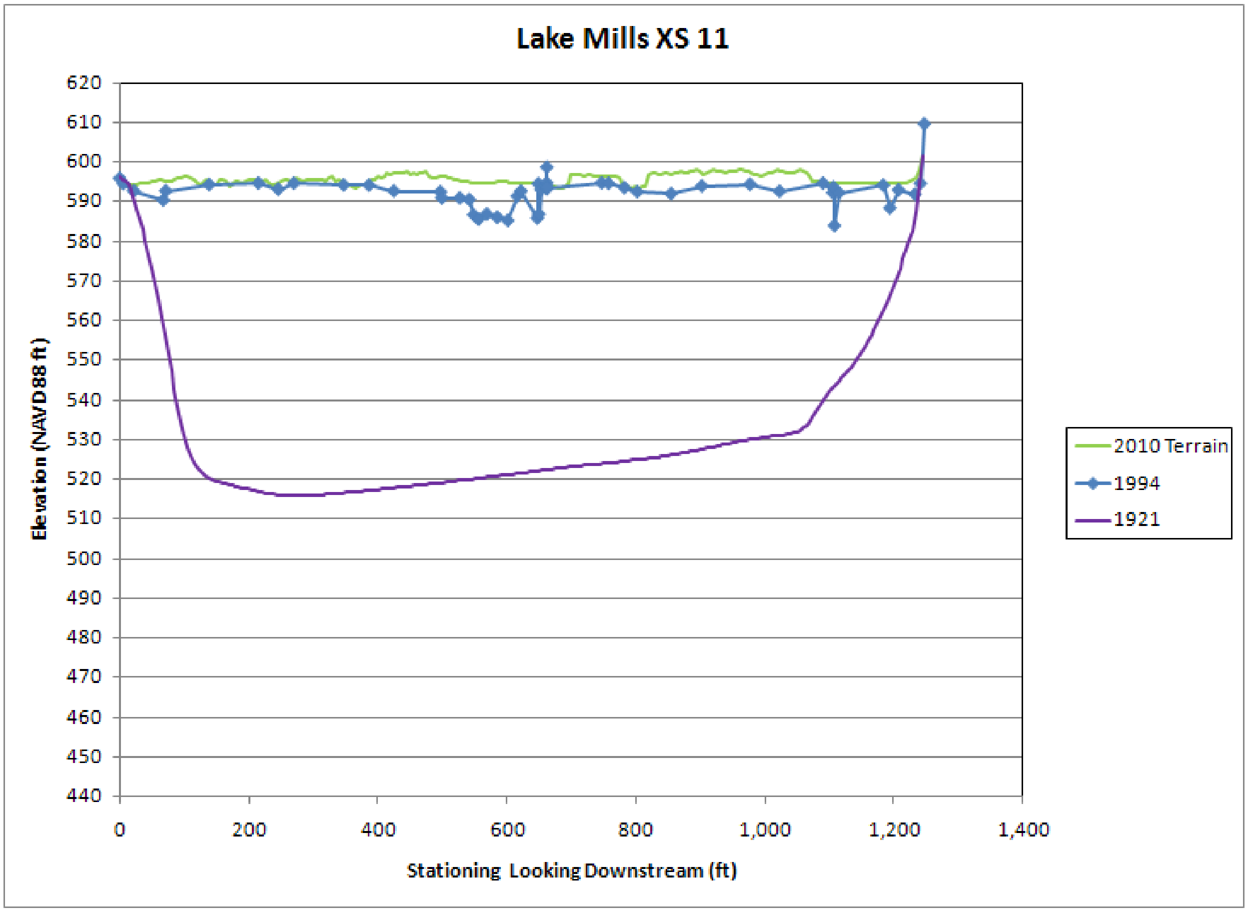


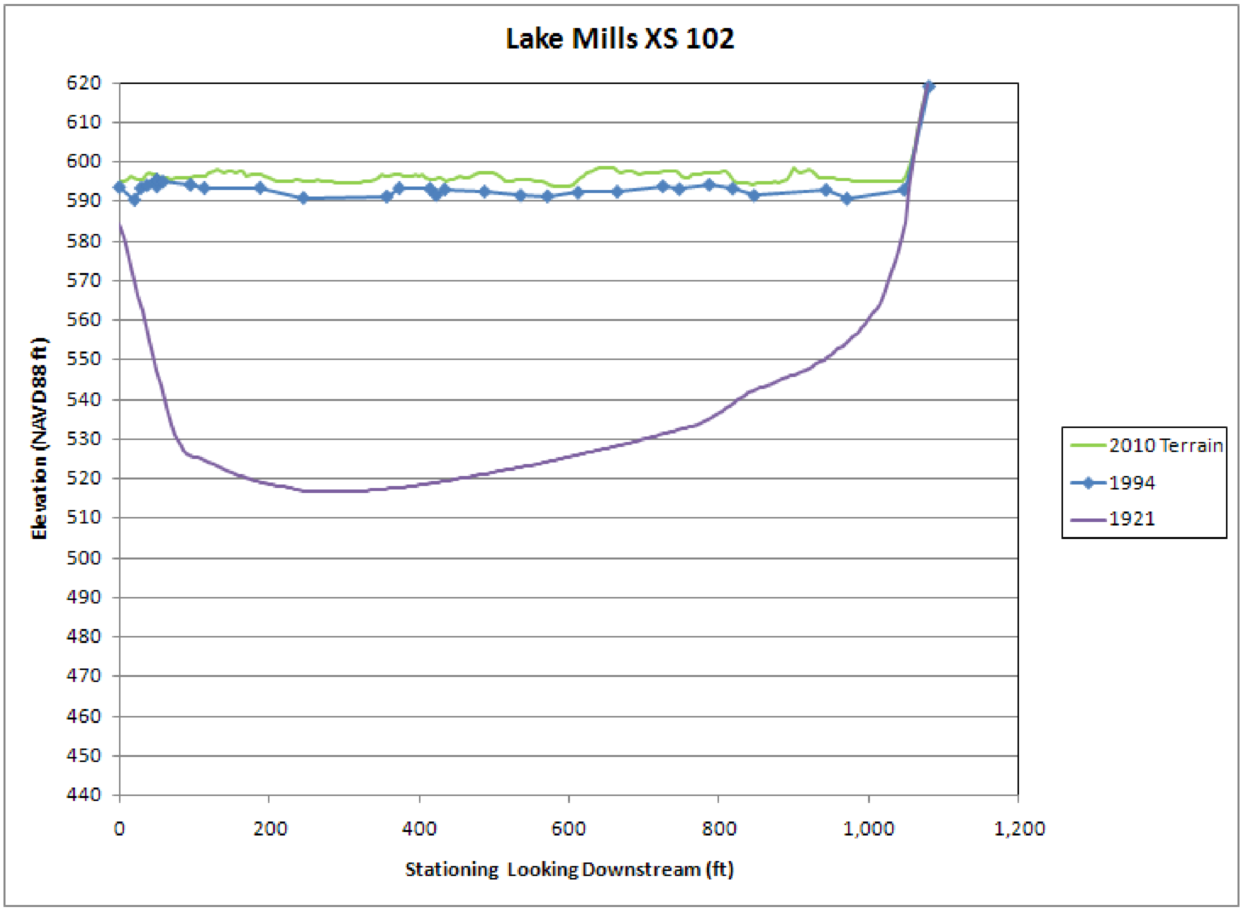
Lake Mills XS 8
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
Stationing Looking Downstream (ft)
1994
2010 Terrain
1921 Raster


Lake Mills XS 9
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
Elevation (NAVD88 ft)
0
200
400
600
800
1,000
1,200
1,400
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

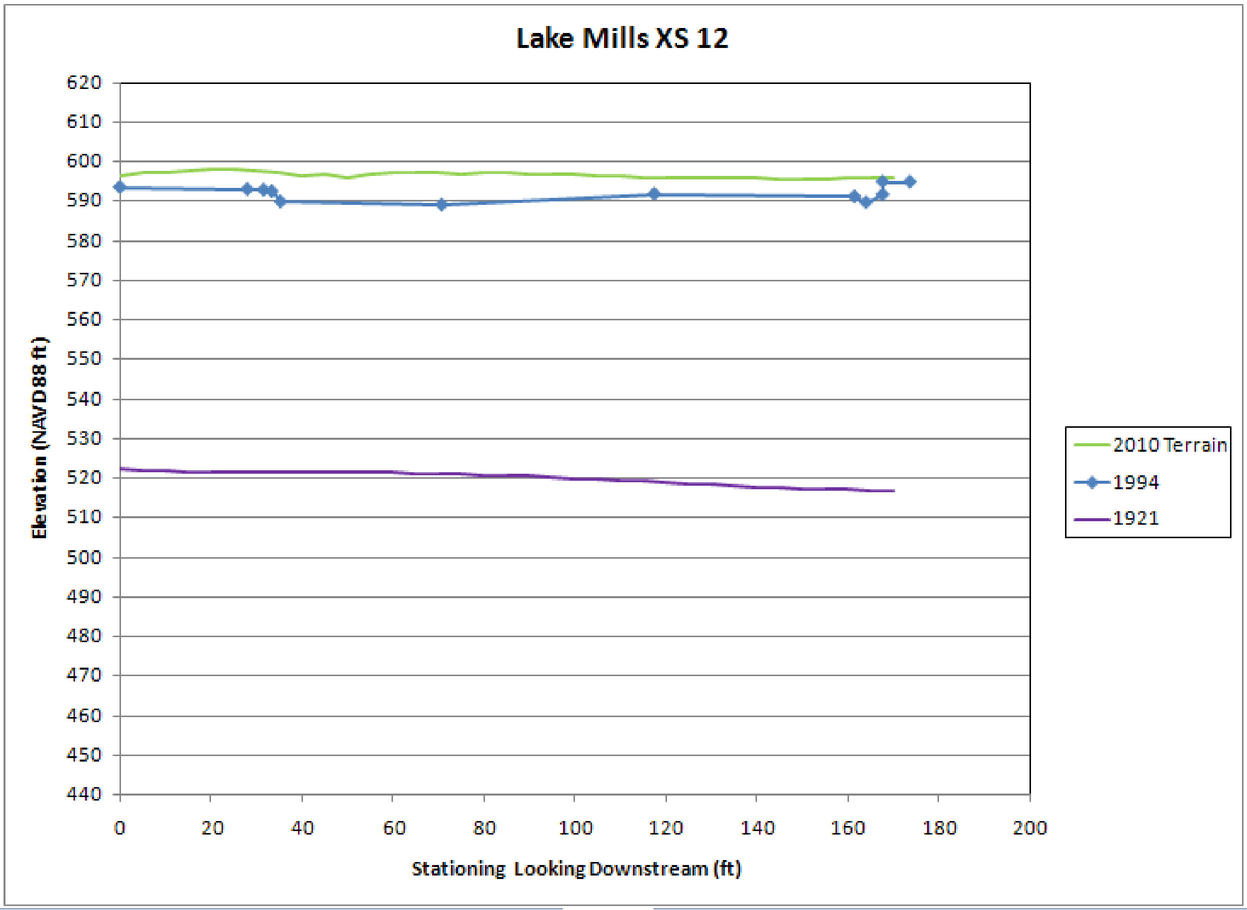


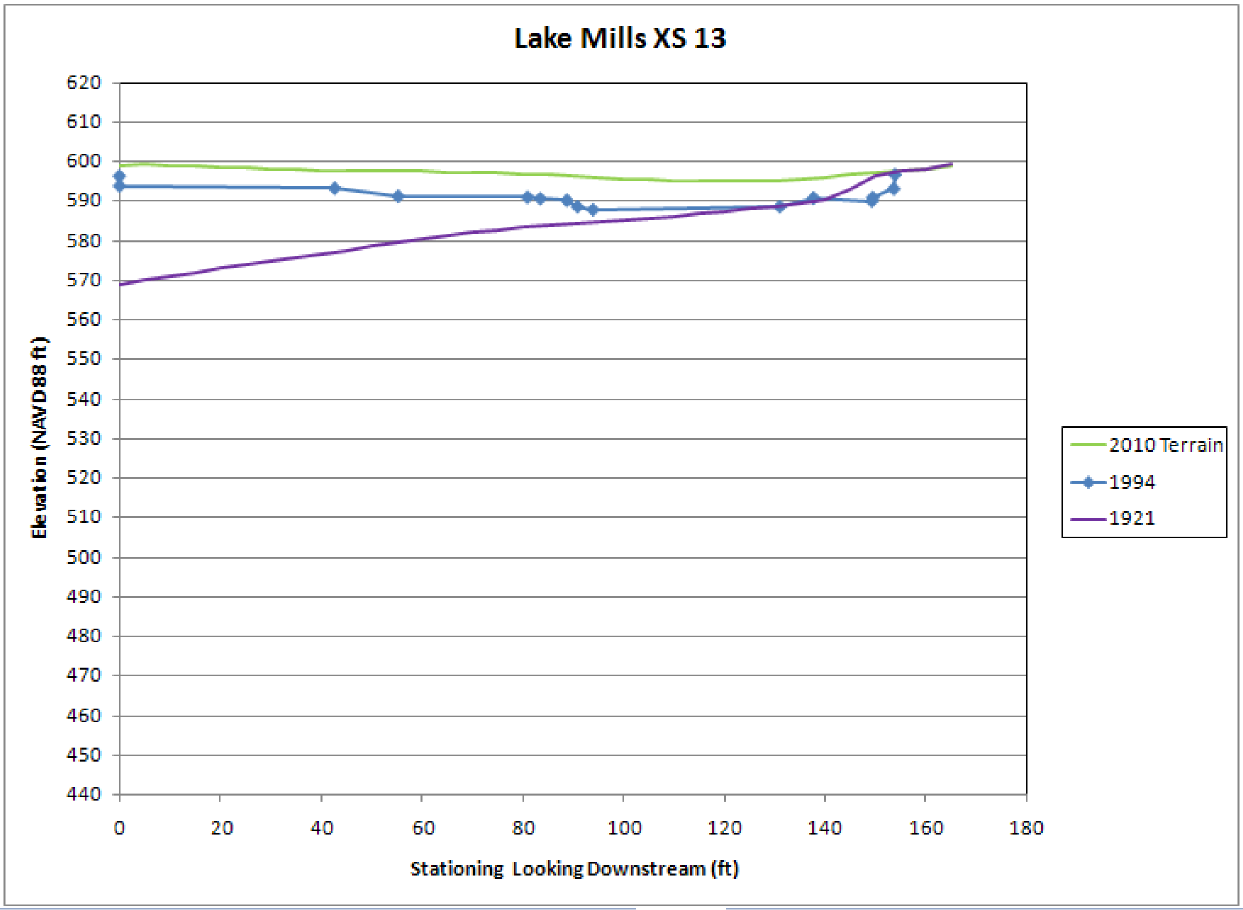
Lake Mills XS 10
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
1,600
Stationing Looking Downstream (ft)
1994
2010 Terrain
1921

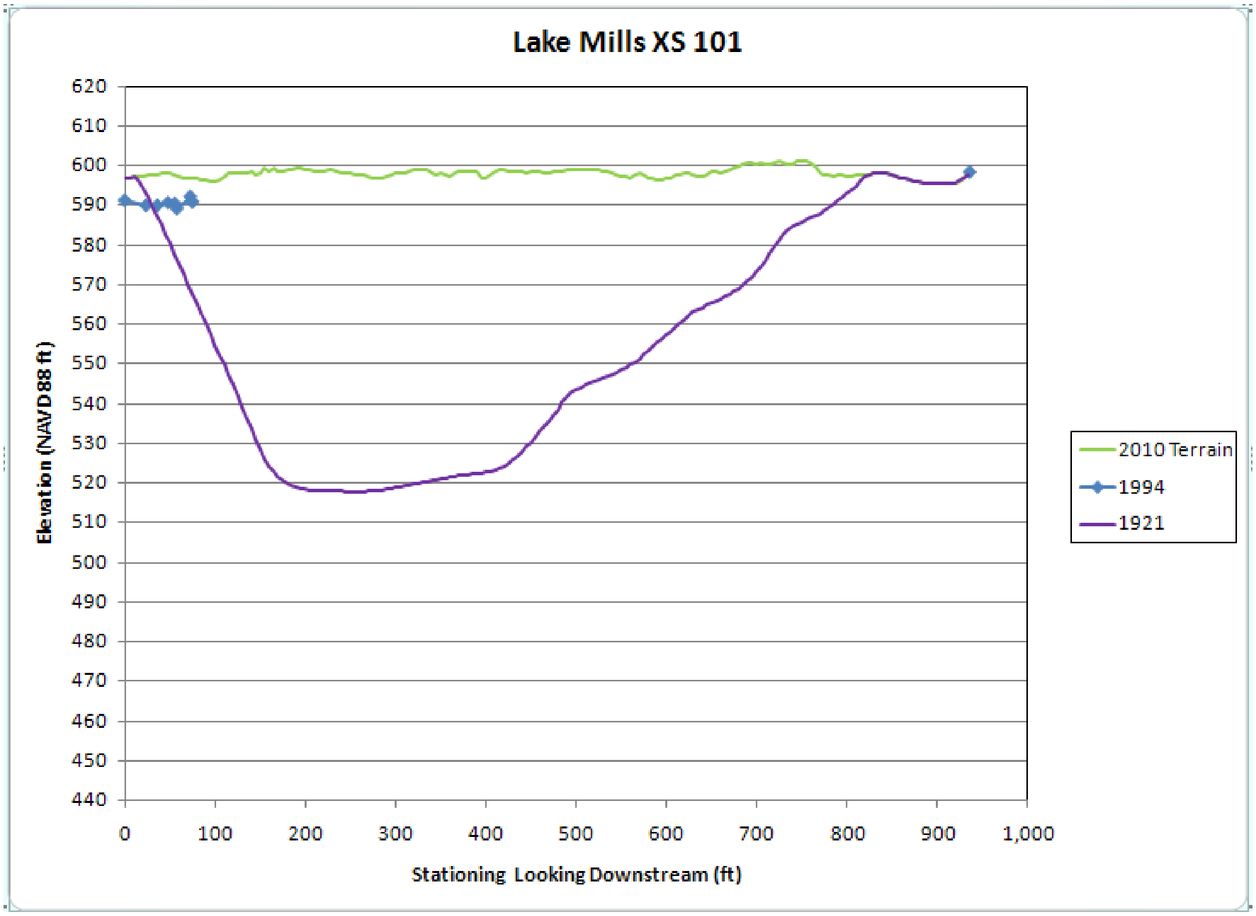

Lake Mills XS 11
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
200
400
600
800
1,000
1,200
1,400
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

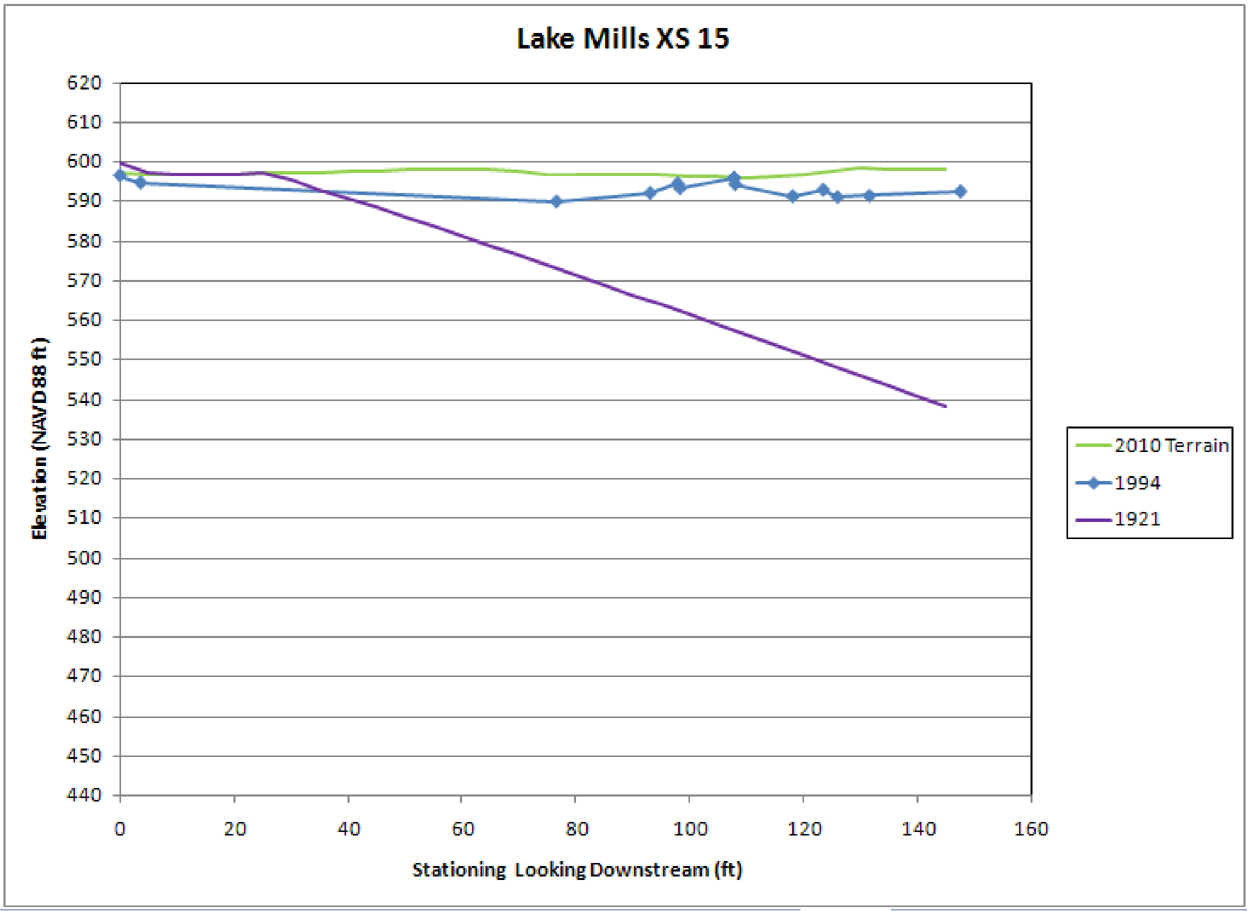


Lake Mills XS 102
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
Elevation (NAVD88 ft)
0
200
400
600
800
1,000
1,200
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

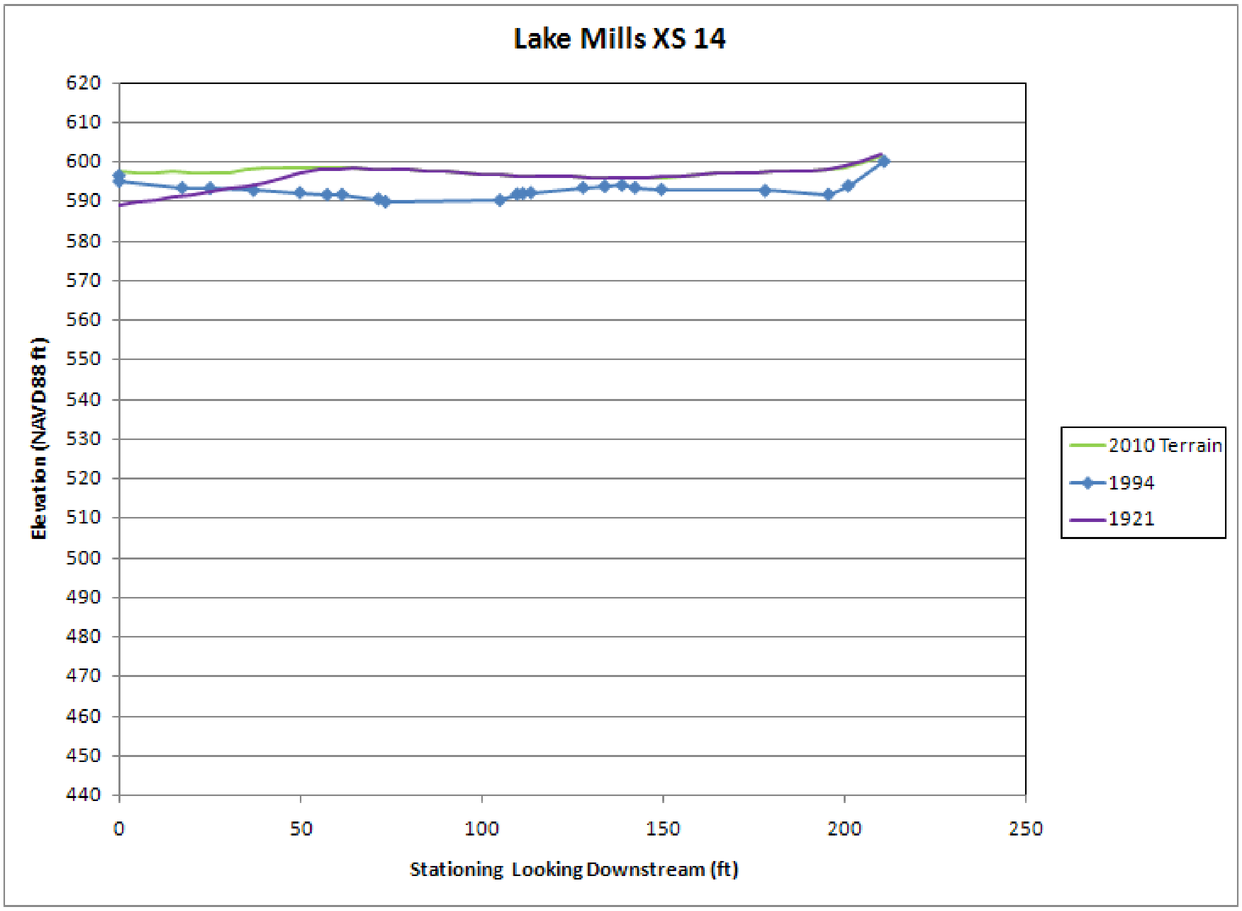

Lake Mills XS 12
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
Elevation (NAVD88 ft)
0
20
40
60
80
100
120
140
160
180
200
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

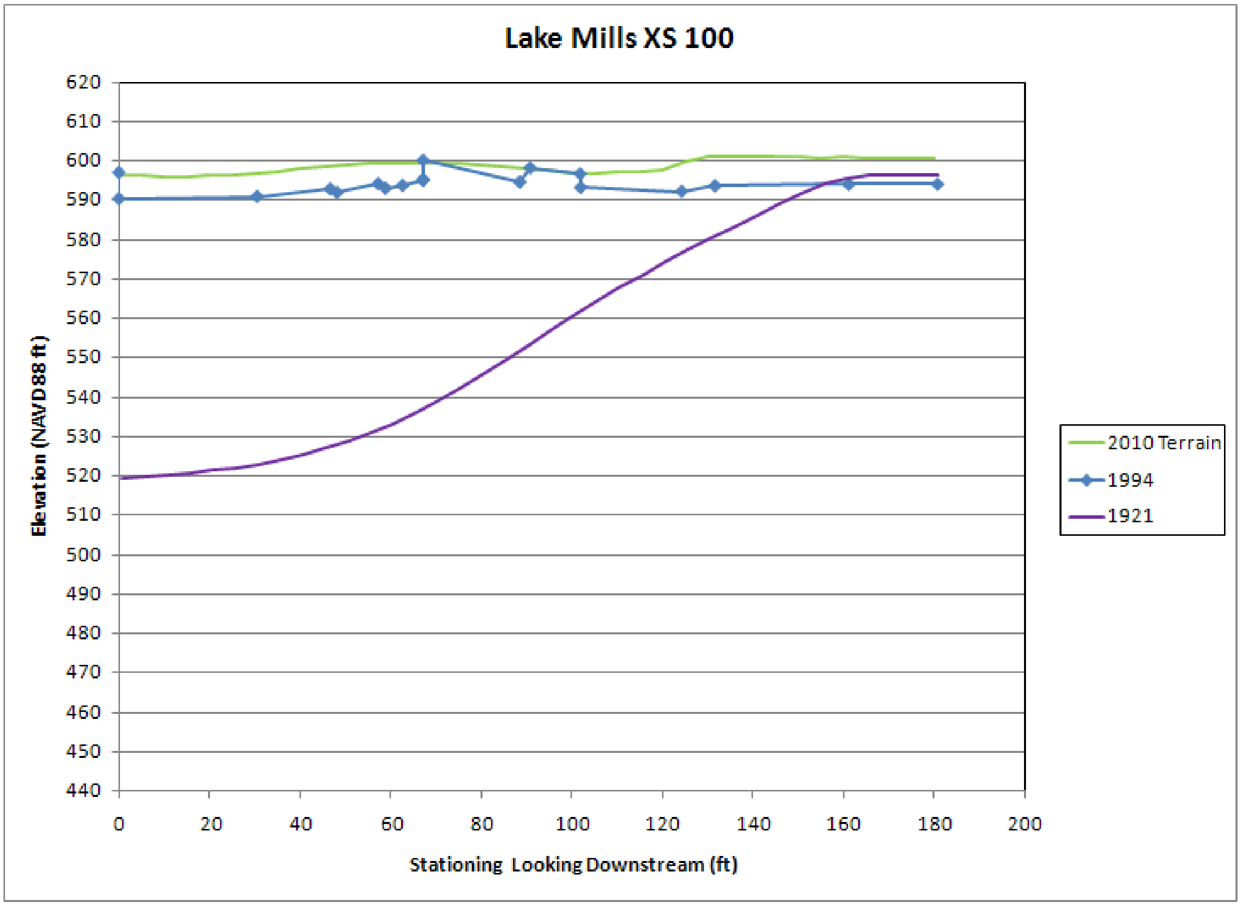

Lake Mills XS 13
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
20
40
60
80
100
120
140
160
180
Elevation (NAVD88 ft)
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921


Lake Mills XS 101
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
100
200
300
400
500
600
700
800
900
1,000
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

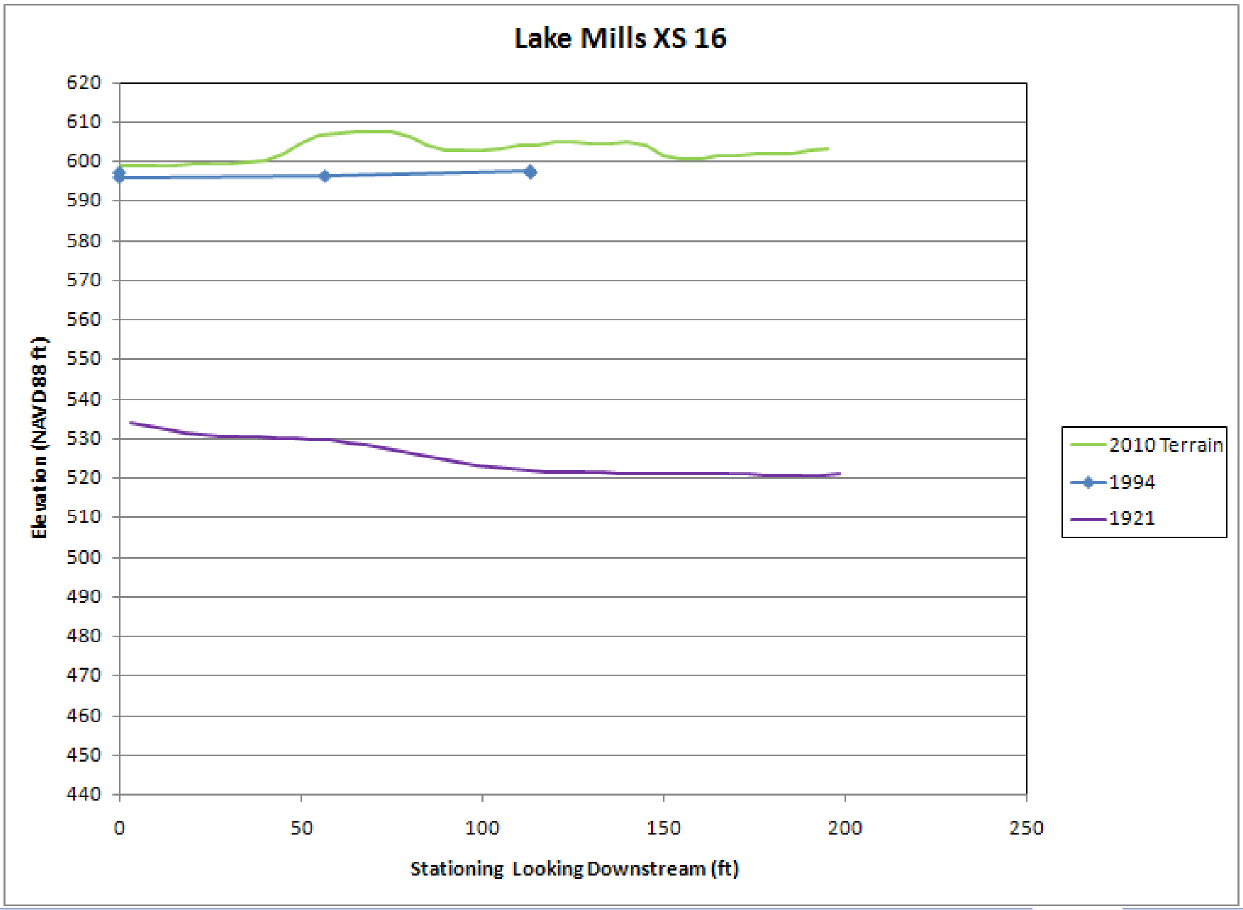


Lake Mills XS 15
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
Elevation (NAVD88 ft)
0
20
40
60
80
100
120
140
160
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921

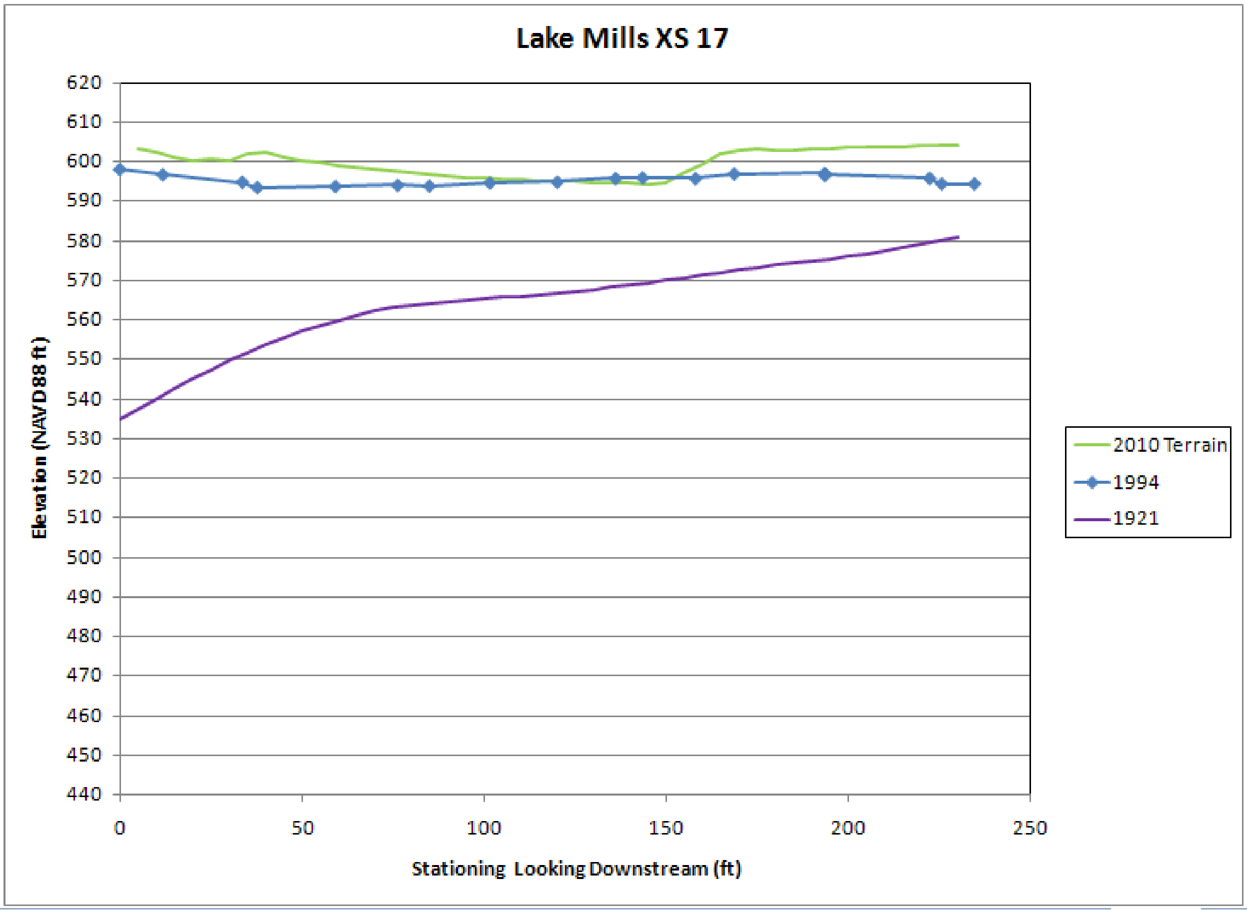

Lake Mills XS 14
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
50
100
150
200
250
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921



Lake Mills XS 100
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
20
40
60
80
100
120
140
160
180
200
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921



Lake Mills XS 16
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
50
100
150
200
250
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921


Lake Mills XS 17
Elevation (NAVD88 ft)
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
0
50
100
150
200
250
Stationing Looking Downstream (ft)
2010 Terrain
1994
1921