RECLAMATION

Managing Water in the West

Technical Report No. SRH-2012-06

Franklin D. Roosevelt Lake – Grand Coulee Dam 2010-11 Survey

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

June 2012

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Reclamation Report

This report was produced by the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Mail Code 86-68240), PO Box 25007, Denver, Colorado 80225-0007, www.usbr.gov/pmts/sediment/.

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prepared by

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14. ABSTRACT

Reclamation's survey of Franklin D. Roosevelt Reservoir (Lake Roosevelt) began in October 2010 and continued during portions of June, July, and August of 2011. The primary purpose was to develop detailed digital reservoir topography. The underwater survey was conducted between water surface elevation 1,260 and spilling elevation 1,290 (project datum in feet). This study measured the project vertical datum around 2.5 feet lower than the North American Vertical Datum of 1988 (NAVD88). The generated reservoir topography elevations were tied to NAVD88. The surface area and volume computations from the topography were shifted -2.5 feet to match the Grand Coulee project's vertical datum. The underwater survey used sonic depth recording equipment interfaced with real-time global positioning systems that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessels. The 2010-11 reservoir topography was generated by importing digital coverages from 1974 aerial photogrammetry, 2007 bathymetry of the upper reservoir, and 2009-10 Light Detection and Ranging (LiDAR) surveys combined with the 2010-11 bathymetric data. The 2010-11 bathymetric data was the first detailed bottom information of the deeper portions of Lake Roosevelt, below elevation 1,160.

As of August 2011, at reservoir water surface elevation 1,290.0, the surface area was 81,991 acres with a total capacity of 9,715,346 acre-feet and an active capacity, between elevation 1,208.0 and 1,290.0, of 5,349,560 acre-feet.

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Franklin D. Roosevelt Lake – Grand Coulee Dam 2010-11 Survey

Abstract

The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics (Sedimentation) Group of the Technical Service Center surveyed Franklin D. Roosevelt Reservoir (Lake Roosevelt) starting in October 2010 and continuing during portions of June, July, and August of 2011 with the primary purpose of developing detailed digital reservoir topography. The underwater survey was conducted between reservoir water surface elevation 1,260 and spilling elevation 1,290 (project datum in feet). The underwater survey used sonic depth recording equipment interfaced with real-time global positioning systems (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessels. The reservoir topography was generated by importing digital coverages from several sources including contours developed from 1974 aerial photogrammetry, 2007 bathymetry of the upper reservoir, and 2009-10 Light Detection and Ranging (LiDAR) surveys. These data coverages, combined with the 2010-11 bathymetric data, were used to generate digital topography of Lake Roosevelt. The 2010-11 bathymetric data was the first detailed bottom information in the deeper portions; below elevation 1,160; of Lake Roosevelt. The reservoir topography elevations were tied to the North American Vertical Datum of 1988 (NAVD88). This study measured the project vertical datum (1947 Supplemental Adjusted Datum) to be around 2.5 feet lower than NAVD88. For Grand Coulee Dam operation purposes the surface area and volume computations from this study's topography were shifted down 2.5 feet to match the project's vertical datum. The 2010-11 study, at reservoir elevation 1,290.0, measured a reservoir surface area of 81,991 acres with a total capacity of 9,715,346 acre-feet.

Introduction

Grand Coulee Dam and Lake Roosevelt on the Columbia River in Ferry, Grant, Lincoln, Okanogan, and Stevens Counties, is 90 miles northwest of Spokane, Washington (Figure 1). Grand Coulee Dam, once the world's largest concrete structure, is the key feature of Reclamation's Columbia Basin Project. Lake Roosevelt extends behind the dam 151 miles northeast to the Canadian border and 32 miles up the Spokane River to within 37 miles of Spokane. The lake has approximately 600 miles of shoreline. The project is a multi-purpose development that provides storage and operates for irrigation, flood control, hydropower, municipal, industrial, recreation, and fish management uses.

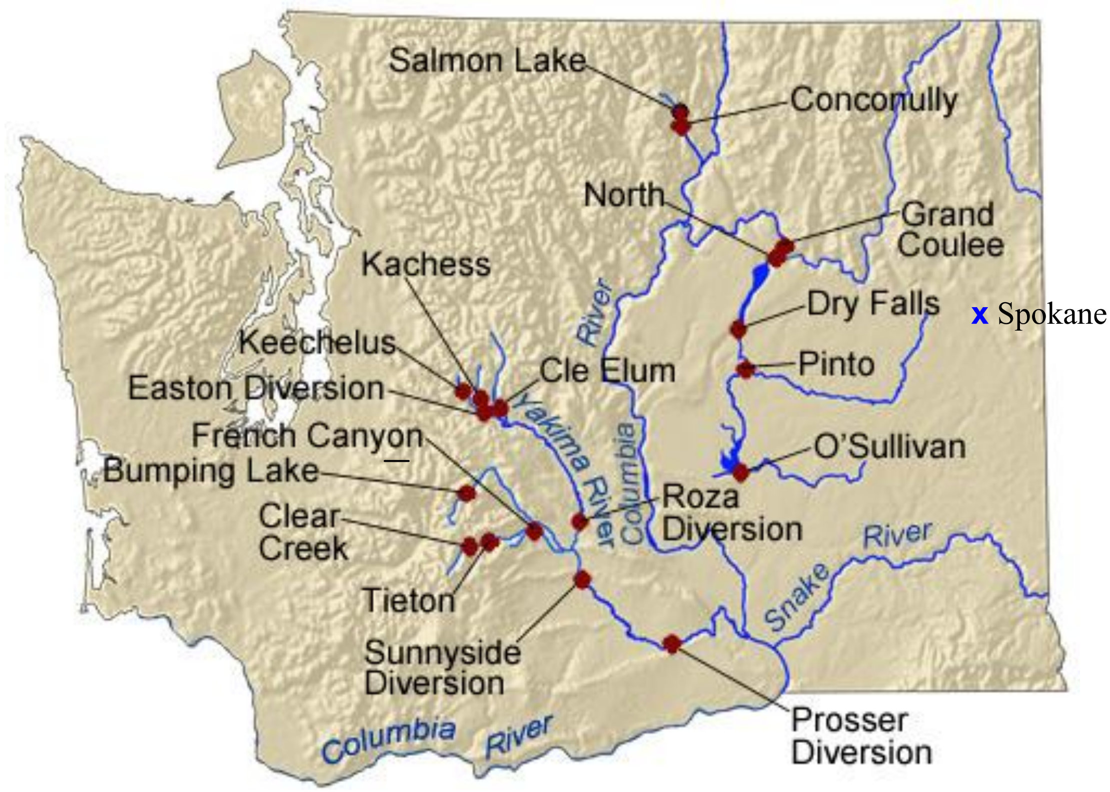

Figure 1 - Bureau of Reclamation reservoirs in Washington.

Grand Coulee Dam construction began in 1933 and was completed in 1941 with recorded water storage beginning May 1938. The original dam was modified (1967 through 1974) for the third power plant by constructing a 1,170-foot-long and 201-foot-high forebay dam along the right abutment, Figure 2. The dam is a concrete gravity structure with the following dimensions in feet[1]:

Hydraulic height[2]	380	Structural height	550
Top width	30	Crest length	5,223
Crest elevation	1,311.08	Top of parapet wall	1,314.58

Figure 2 - Downstream view of Grand Coulee Dam showing the third power plant on the left and 40 river outlets on the face of original dam below the spillway crest.

[1]Elevations in feet. Unless noted, all elevations are based on original project datum established by Reclamation that this study measured as 2.5 feet lower than NAVD88. The original project datum was listed as tied to the National Geodetic Vertical Datum of 1929 (NGVD29) that was adjusted in 1947. The reservoir topography developed during this study and presented in this report is tied to NAVD88.

[2] The definition of such terms as “hydraulic height,” “structural height,” etc. may be found in manuals such as Reclamation’s *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs*, or ASCE’s *Nomenclature for Hydraulics.*

The dam's spillway, located in the center of the original portion of the dam, is controlled by 11 drum gates each 135 feet long and 20 feet high. The spillway crest elevation is 1,260.0 with top elevation 1,288.0 with gates closed. Two-foot flashboards raised the reservoir normal operation to elevation 1,290.0. At crest elevation 1,290.0; the spillway provides a maximum discharge of 1,000,000 cubic feet per second (cfs).

Figure 3 - Grand Coulee Dam spilling, July 2011.

There are forty 102-inch-diameter outlet tubes located in the spillway section of the original dam that operate to regulate reservoir outflow during periods of normal operations, Figure 2. The invert elevation of the lower tier outlet tubes is 1,032.5 and the upper tier is 1,132.5. The total outlet capacity is 265,000 cfs.

Grand Coulee Dam is one of eleven hydropower generating facilities on the Columbia River. Grand Coulee Dam has three power plants, 32 turbines, and a maximum generating capacity of 6,809 megawatts. The facilities consist of a power plant on both the left and right sides of the original dam and a third power plant on the right abutment that began construction in 1967. The invert elevation of the main unit penstocks is 1,026.0 and the third powerhouse penstocks is 1,120.0. The lowest lake elevation for full power plant capacity is 1,208.0 and the penstock capacity of the generating outlets is 280,000 cfs.

The total drainage area above Grand Coulee Dam is 741,100 square miles (mi^2). Lake Roosevelt's basin sediment contributing area is controlled by several Canadian reservoirs on the Columbia River arm, along with Little Falls and Long Lakes located at the headwaters of the Spokane River. The average discharge at Grand Coulee is approximately 109,000 cfs. The maximum recorded discharge of 637,800 cfs passed through the turbines and spillway on June 12, 1948. The average annual inflow is 93.3 million acre-feet and has varied from 48.5 to 111.8 million acre-feet (Reclamation, 2012). The average annual inflow could fill the reservoir nearly ten times each year.

Topographic Data of the Reservoir

Prior to the October 2010 survey, the PN region researched the existing data coverages of Lake Roosevelt and several were used by this study. The previous digital data was from surveys between 1930 and 2007. The data sets had limited documentation on how they were collected and processed. General knowledge was obtained through discussions with people that had worked with the data. None of the previous data sets contained information in the deep channel portions of the reservoir from the dam upstream. The purpose of this study was to fill in that void.

A U.S. Army Corps of Engineers (USACE) LiDAR survey of the Columbia River was made available for this analysis in January 2012. During the 2010-11 bathymetric collection it was assumed the LiDAR was flown at near-full lake conditions. The Lake Roosevelt portion of the 2009-10 LiDAR was flown near reservoir elevation 1,280. The LiDAR covered the majority of the Columbia River arm, but only partially covered the Spokane River, Figure 4. The 1974 data set is the only one that enclosed the entire reservoir. The aerial data was collected when the reservoir was drawn down during construction of the third power plant and 10-foot contours were developed from elevation 1,160.0 through 1,290.0.

1930 Data Set

The 1930 data set was compiled by the Spokane Tribe through the scanning of 1930 USGS topographic maps and on-screen digitizing to create contours. The questionable accuracy of the 1930 data was one of the primary factors prompting this study. The 1930 data set was not part of this analysis, but recent USGS quad contours of the reservoir above elevation 1,290 were used to enclose the study area when other data sources were lacking.

1974 Reservoir Contours

Photogrammetric contour maps at 10-foot intervals of the entire reservoir area were developed from an aerial survey conducted in 1974 when the reservoir was drawn down over 130 feet during the construction of the Grand Coulee Dam third power plant. In 1998-99, digital shapefiles from 160 photogrammetric contour maps were developed by scanning and on-screen digitizing of the reservoir area. The spatial reference of the shapefiles was tied horizontally to UTM Zone 11, North American Datum (NAD83), in meters and the vertical datum was tied to NGVD29 (Supplemental Adjustment 1947) in feet. The coverage of the entire reservoir provided 10-foot contours for elevations 1,160.0 through 1,290.0. The digital coverage was shifted to Washington state plane coordinates, north zone, in feet and the elevations shifted upward 2.5 feet to NAVD88, in feet, for topographic development for this study. During the 2010-11 bathymetric field collection, the contours were used as a background to guide the survey vessel to areas lacking data.

2007 Bathymetric Data

In 2007 the Colville Tribe conducted a bathymetric survey of the upper arm of Lake Roosevelt from near Kettle Falls upstream to the Canadian Border. There was no metadata on the 5-foot contour coverage. The elevations were assumed tied to the project vertical datum and were shifted to NAVD88 by adding 2.5 feet for the 2010-11 topographic development. The Colville Tribe data was collected in the upper portion of the reservoir and backwater elevations may have been affected by inflows, meaning the vertical shift there may be greater. However, insufficient information exists to justify applying a greater shift. It is also possible that the 2007 study accounted for the backwater affect. The areas of the 2007 survey overlapped by the 2010-11 bathymetry were removed.

2007 Aerial Photogrammetry

Also in 2007, aerial photogrammetry was collected with the reservoir drawn down near elevation 1,252. No known contours were developed from the aerial survey, but a contour from the rectified photo image could be developed by digitizing the water surface and using it as a breakline. Sufficient time was not available for this study to complete that effort. For areas near elevation 1,252 and those not covered by the 2010-11 bathymetry, the 1974 contours were used.

2009-10 LiDAR Survey

The 2009-10 Columbia River LiDAR survey was a USACE collaborative effort to develop high density terrain data along the Columbia River. The LiDAR data covering Lake Roosevelt was collected between November 2009 and March 2010 near reservoir elevation 1,280 (USACE, August 2011). The survey covered the majority of the Columbia River reach of Lake Roosevelt, but only a small portion of the Spokane River arm, Figure 4. The data sets that covered Lake Roosevelt were provided as multiple raster and xyz point files. Due to the size of the point files, contours were generated from the raster files and used as hard breaklines for the 2010-11 topographic development. To obtain the detail of the reservoir area, below elevation 1,330, the contours were developed in 1-meter increments starting at the reservoir water surface at the time of the flight. Minor editing was required to remove stray contour lines near the reservoir water surface. The data covered the majority of the main body of the Columbia River except for a few small coves. For these areas, the 1974 contours and most recent USGS contours were used to enclose the reservoir. A second coverage from the LiDAR raster files was generated at 5-foot increments from elevation 1,285 to elevation 1,700 (NAVD88) and used during the reservoir topographic development.

For the portion of the reservoir covered by the LiDAR, the 1974 contours of elevation 1,280 and 1,290 were not used. For the reservoir areas not covered by the LiDAR, such as the Sanpoil River across from Keller Ferry and the upper Spokane River, these upper contours of the 1974 data were used.

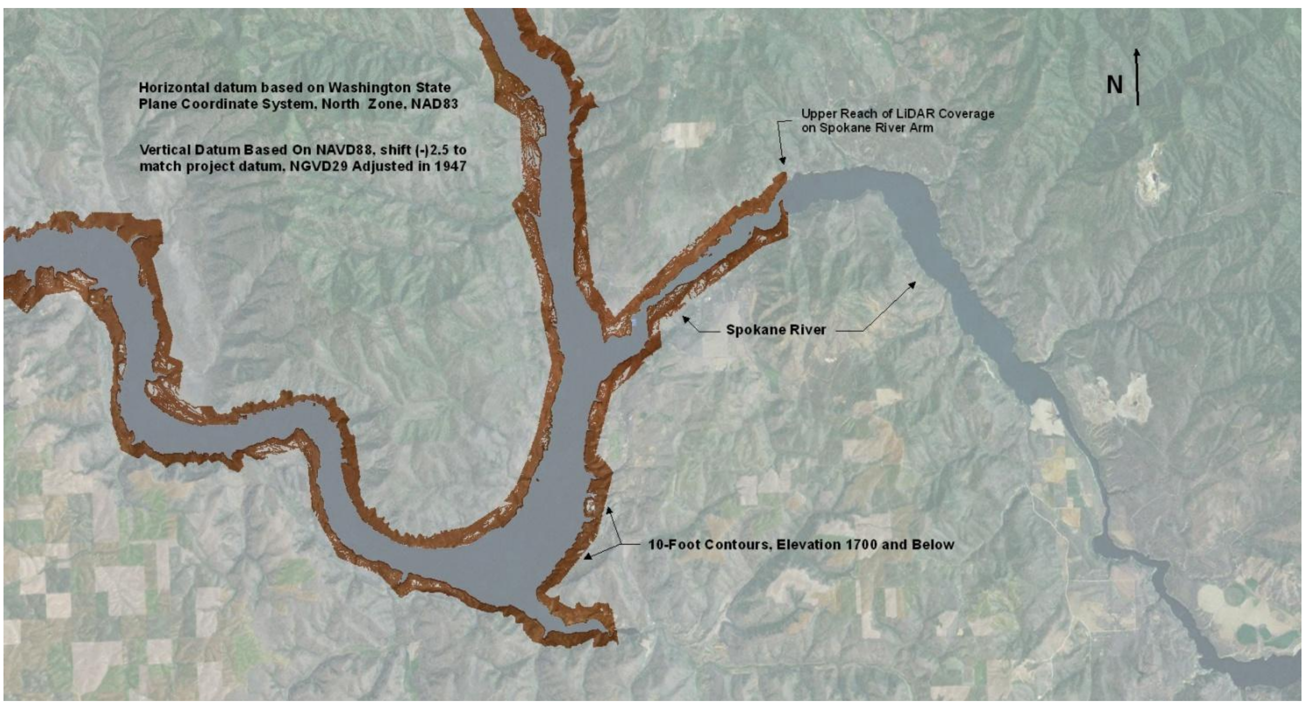

Figure 4 - 2009-10 LiDAR coverage area along the Columbia and Spokane shoreline of Lake Roosevelt. LiDAR coverage only extended up a small portion of the Spokane arm.

Control Survey Data Information

During the 2010-11 bathymetric collection, numerous control surveys were conducted using the on-line positioning user service (OPUS) and real-time kinematic (RTK) GPS to establish the horizontal and vertical control near the reservoir used for the hydrographic survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The GPS base was set over temporary survey markers throughout the reservoir starting at Crescent Bay boat ramp, near the dam, and progressing upstream along the lake about 134 reservoir miles to the Northport boat ramp. The OPUS generated coordinates were used to determine positions and the vertical difference between NAVD88 and the recorded water surface elevations at the dam.

The horizontal control was established in Washington state plane coordinates, north zone, on the North American Datum of 1983 (NAD83) in feet. The vertical control was tied to Grand Coulee project vertical datum and NAVD88. The Grand Coulee project vertical datum was referenced to NGVD29 that was adjusted in 1947. The shift between Grand Coulee project vertical datum and NAVD88 was determined from numerous RTK GPS water surface measurements periodically collected throughout the 2010-11 survey and compared to the recorded reservoir water surface measured at the dam. The majority of the measurements where collected in fall 2010 during very calm weather conditions. Average measurements found the project vertical datum was around 2.5 feet lower than NAVD88 for the area of the reservoir from the dam upstream to Kettle Falls. The measurements above Kettle Falls found the water surface started to slope upward from there as the shift increased to about 2.8 feet at Onion Creek and about 3.4 feet at Northport.

It should be noted that the measured vertical shifts above Kettle Falls were for the river inflow and reservoir conditions at the time the bathymetric data was collected (October 2010 in this area). The vertical shift or water surface slope in this portion of the reservoir would vary depending on several conditions including river inflow and reservoir elevation at the dam. In December 2010, with the reservoir level about 10 feet lower than in October 2010, a vertical shift of 5.0 feet was measured at Northport. During the October 2010 bathymetric collection the survey crews observed a change in the reservoir hydraulics at Kettle Falls just upstream of the highway 395 bridge and downstream of the Onion Creek confluence. These areas were surveyed near elevation 1,288 and at Kettle Falls the reservoir had minor turbulence as water flowed through the restriction and deep scour holes. Near Onion Creek, the channel width became restricted and surface turbulence was much greater, affecting the steering ability of the survey vessels as the channel water dissipated its energy through surface boiling. Deep scour holes were measured in the Onion Creek area. Upstream of Onion Creek to

Northport, the reservoir conditions were calm except for the noticeable surface currents.

In December 2010, an OPUS solution was computed on Banks Lake located west of Lake Roosevelt and Grand Coulee Dam. The Banks Lake water surface gage readings determined that the NAVD88 elevation vertical shift was around 2.5 feet, matching the project vertical datum of Lake Roosevelt. Measurements were also taken on a National Park Service monument located on a vertical wall overlooking the reservoir near the left abutment of Grand Coulee Dam (stamped 8-78; C-15; EL 1386.239, Figure 5). The RTK GPS measured coordinates on the monument in Washington State Plane, north coordinates, in feet were:

East	2,092,581.86	
North	352,234.24	
Elevation	1,390.16	(NAVD88)
Elevation	1,386.239	(stamped elevation, assumed NGVD29)
Difference	3.92	(NAVD88-NGVD29)

The NGS published data in the study area shows NAVD88 elevations are around 3.92 feet higher than NGVD29. The difference between the elevation stamped on the monument and the NAVD88 measured elevation matched the NGS reported shift, meaning the monument elevation is likely tied to NGVD29.

Figure 5 – Survey monument set by the National Park Service in August of 1978.

For the 2010-11 bathymetric study, the horizontal control in NAD83 was tied to the Washington north state plane coordinate system in feet. The vertical control, in feet, was tied to NAVD88 and the Grand Coulee construction or project vertical datum. Unless noted, all elevations in this report are referenced to the project vertical datum that is around 2.5 feet lower than NAVD88. The 2010-11 reservoir topography presented in this report is tied to NAVD88. The resulting surface areas and volumes for the 2010-11 topography were shifted -2.5 feet to match the project's vertical datum.

Reservoir Operations

Lake Roosevelt, part of the Columbia Basin Project, provides storage for irrigation, flood control, hydropower, municipalities, industry, recreation, and fish management. The August 2011 total capacity was computed as 9,715,346 acre-feet below top-of-flashboard elevation 1,290.0, also consider normal pool elevation. The capacity at top-of-parapet wall elevation 1,314.6 is 11,843,200 acre-feet. The maximum stated water surface elevation is 1,321.8 and total capacity is 12,516,080 acre-feet (Reclamation, 2012). It is assumed that at any elevation above 1,314.6 the entire dam becomes an active spillway.

Reclamation is responsible for the general management and operation of Grand Coulee Dam and Lake Roosevelt by coordinating with the USACE for flood control and the Bonneville Power Administration for power production. The top of dead pool elevation is 1,026.0, the invert elevation of the main penstocks. The minimum agreed upon elevation is 1,208.0 that is the lower limit for full power plant capacity, but the actual annual drawdown is set by USACE based on inflow forecast. Water from Lake Roosevelt is pumped to Banks Lake at Grand Coulee Dam where it is diverted for irrigation. Reclamation also coordinates with state and federal fish and wildlife agencies and several native tribes for release flows to the Columbia River for fish and water storage within the reservoir for resident fish. The reservoir is operated to minimize spilling to meet the numerous obligations and usually fills to near elevation 1,290 by July 4th.

672,880 acre-feet of surcharge pool storage between elevation 1,314.6 and 1,321.8.

2,127,854 acre-feet of flood pool storage between elevation 1,290.0 and 1,314.6.

5,349,560 acre-feet of joint use storage between elevation 1,208.0 and 1,290.0.

4,055,742 acre-feet of inactive use storage between elevation 1,026.0 and 1,208.0.

310,044 acre-feet of dead pool storage below elevation 1,026.0.

Lake Roosevelt reservoir stage records are listed by water year on Table 1 for the period of May 1938 through August of 2011. Computed annual inflow values were not available, but Reclamation publications list the average discharge at Grand Coulee Dam as 109,000 cfs with the maximum recorded discharge of 637,800 cfs that passed through the turbines and spillway on June 12, 1948. The average annual inflow is 93.3 million acre-feet and has varied from 48.5 to 111.8 million acre-feet per year. The table lists the measured maximum reservoir elevation as 1,290.3 occurring in 1943, 1945, and 1976. The table shows that during most years, the maximum recorded reservoir elevation is near elevation 1,290 and since first filling in 1942, the minimum reservoir elevation was 1,156.7 in 1973.

Hydrographic Survey Equipment and Method

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 6) and a second smaller aluminum vessel that also provided support to the larger boat by ferrying crew and fuel during daily survey operations. The hydrographic system included a GPS receiver with a built-in radio, single and multibeam depth sounders, helmsman display for navigation, laptop computers, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to the larger boat equipment while the smaller vessel's gear was powered by onboard batteries. The shore equipment for the GPS base setup included a GPS receiver with an external radio. The GPS receiver and antenna were mounted on a survey tripod over a temporary datum point and a 12-volt battery provided the power for the shore unit. The majority of the reservoir was mapped using leased GPS rovers that received real time corrected positions (10 to 30 centimeter accuracy) transmitted by satellite signals. This setup did not require a base station and greatly reduced the field collection time and cost while meeting the necessary accuracy for collection. The multibeam system was mounted in the 24-foot vessel that was the primary collection vessel. The single beam system was mounted on the smaller vessel and focused on collection in the shallow, shoreline, and cove areas when not providing support to the main vessel and crew.

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes. The basic output from a RTK receiver are precise 3-D coordinates in latitude, longitude, and height with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically. The output is on the GPS datum of WGS-84 that the hydrographic collection software converted into Washington's state plane coordinates, north zone in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously, just like with differential GPS. The RTK GPS system was used throughout the reservoir from the dam upstream to Northport and also up the Spokane River arm to measure water surfaces that were compared to readings recorded at the dam to determine the average vertical shift from NAVD88 to the project's vertical elevation. The RTK GPS units were also used for part of the bathymetric mapping from the face of the dam upstream to above Keller Ferry area, reservoir mile 24. For the majority of the bathymetric survey, real time differential GPS units were leased that provided 10 to 30 centimeter position accuracy for the survey vessels. The elevations were obtained by applying the measured water gage readings at the time of collection and the measured vertical shift to match NAVD88 for the specific areas of topographic development.

Figure 6 - Survey Vessel with mounted instrumentation mapping within buoy lines at Grand Coulee Dam - Lake Roosevelt, Washington.

The first survey phase of Lake Roosevelt began October 1, 2010 near water surface elevation 1,287. The survey vessels were launched near the dam and mapped upstream about 38 miles to Seven Bays Marina. Due to ongoing fish studies, a few sections of this reach were skipped and completed in June 2011. Also during this phase, the survey vessels were launched at Porcupine Bay boat ramp on the Spokane arm for one day, surveying downstream to the confluence using the multibeam system and upstream about 15 miles using the single beam system.

For the second phase, the crew returned in mid October 2010 near water surface elevation 1,288 collecting bathymetric data from around mile 90, near Rice, upstream to the Northport boat ramp near reservoir mile 134. Above Kettle Falls changes in surface currents were observed compared to calmer reservoir conditions downstream. Due to an adverse change in the weather conditions, the planned window of the second phase survey was reduced several days for crew and public safety.

Due to the extensive 2011 snow pack and projected inflows, the reservoir was drawn down below elevation 1,218. The third phase of collection couldn't start until the later part of June 2011 when the reservoir had risen near elevation 1,260 and more boat ramps extended into the reservoir. The third trip was the most extensive of all the survey phases. Beginning at Two Rivers Marina, the 3-person crew filled in the reservoir area from mile 30 up to the Spokane River confluence and extended the survey upstream through the remote areas of the reservoir upstream of the Spokane confluence to around reservoir mile 75 at the Gifford campground. Due to the drastic drawdown and large inflows, the survey vessels had to deal with extensive amounts of driftwood along with the fact that none of the marinas had fuel available. That meant fuel had to be hauled to the large survey vessel each day.

The fourth phase of collection started in early July 2011 with the reservoir spilling and near elevation 1,290. The 2-person crew returned to the Gifford area and began surveying just downstream of the Gifford Campground area and upstream just above Rice near reservoir mile 90 to fill in areas not previously mapped. To complete the mapping a fifth collection phase occurred in late August 2011 near reservoir elevation 1,282. A two-person crew spent a few days on the Spokane arm mapping from Porcupine Bay to fill in areas not mapped the previous fall. A few days were also spent near the Rice area to conclude the 2010-11 bathymetric mapping.

The bathymetric survey used sonic depth recording equipment interfaced with a GPS capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along the previously established gridlines that were spaced to cover the deeper portions of the reservoir using the multibeam depth sounder. For mapping purposes, most transects (grid lines) were run somewhat parallel to the upstream-downstream alignment of the reservoir. The spacing varied to allow maximum coverage of the multibeam system while allowing some overlap of the outside beams for quality assurance. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course alignment along these predetermined lines. The vessel with single beam system mounted ran primarily along the shoreline and in the coves using a digital background image of the 1974 contours as a guide. For larger areas where there were shallower water conditions (50 to 100 foot depths), grid lines were laid out to guide the single beam vessel for collection.

The main purpose of this study was to map the reservoir area below elevation 1,160. To assure adequate coverage the field crew used the elevation 1,200 contour as a guide for boat alignment during collection. The wide swath (120 degrees) of the multibeam system and the large, deep, and open channel geometry with many areas of steep vertical walls, allowed the outer beams to extend above elevation 1,200 over the majority of the reservoir areas covered by this survey. When mapping the deeper sections of the channel, the outside beams covered large portions of the 1974 developed contours. However, at times the deeper portions of the many small coves were not mapped. To map these areas, additional outer channel lines were surveyed while the vessel passed through the reservoir sections as it traveled to and from the launch sites. Tilting the multibeam head and collecting a continuous path along the shoreline to map even more of the shallow water portions of the reservoir was considered, but time constraints prevented this during the survey.

The collected data were digitally transmitted to the computer collection system through RS-232 ports. The single beam depth sounder also produced digital charts of the measured depths. These graphed charts were analyzed during post-processing, and when the charted depths indicated a difference from the computer recorded bottom depths, the computer data files were modified to match the chart. The water surface elevations at the dam, recorded by a Reclamation gage, were used to convert the sonic depth measurements to true lake-bottom elevations. For topographic development, the gage elevations were shifted to match NAVD88 in the areas of the reservoir surveyed.

In 2001, the Sedimentation Group began utilizing an integrated multibeam hydrographic survey system. The system consists of a single transducer mounted on the center bow or forward portion of the boat. From the single transducer a fan array of narrow beams generates a detailed cross section of bottom geometry as the survey vessel passes over the areas mapped. The system transmits 80 separate 1-1/2 degree slant beams resulting in a 120-degree swath from the transducer. The 200 kHz, high-resolution, multibeam echosounder system measures the relative water depth across the wide swath perpendicular to the vessel's track. Figure 7 illustrates the swath on the sea floor that is about 3.5 times as wide as the water depth below the transducer. For the deeper channel conditions near Grand Coulee Dam, a single swath on the flat areas in depths of 400 feet covered nearly 1,400 feet of the bottom.

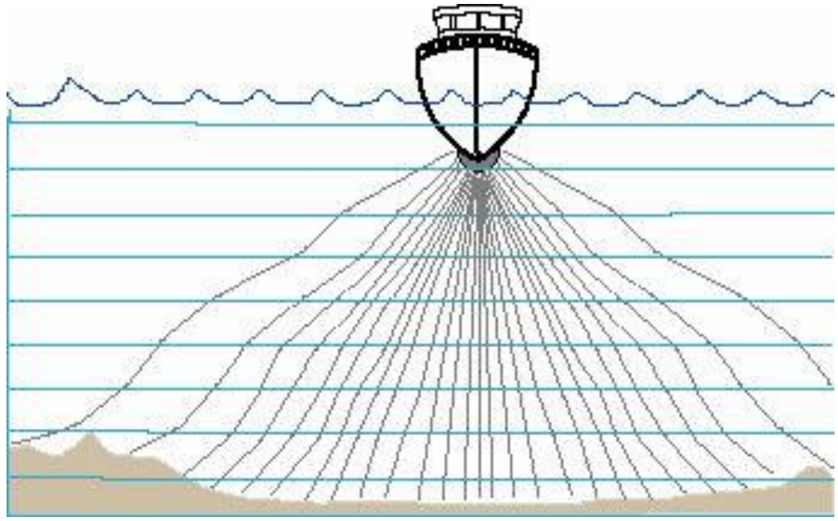

Figure 7 - Multibeam collection system.

The multibeam system is composed of several instruments all in constant communication with a central on-board laptop computer. The components included the GPS for positioning; a motion reference unit to measure the heave, pitch, and roll of the survey vessel; a gyro to measure the yaw or vessel attitude; and a velocity meter to measure the speed of sound through the vertical profile of the reservoir water. The multibeam sounder was calibrated by lowering an instrument that measured the sound velocity through the reservoir water column. The individual depth soundings were adjusted by the measured speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. With proper calibration, the data processing software utilizes all the incoming information to provide an accurate, detailed xyz data set of the lake bottom.

The sound velocity profiles were collected daily in the areas being surveyed. The information was used to adjust the single and multibeam soundings. The first sounding profile was collected upstream of the dam by lowering the probe below the survey vessel about 100 meters. Initial sound velocity measurements raised concerns since readings in the upper level of the reservoir did not vary much from the deeper portions of the reservoir as expected and observed on previous surveys in other reservoirs. To verify initial measurements, a second calibrated velocity profiler was obtained and produced the same results. These results were further confirmed by comparison with water quality data collected on the reservoir during the same time of the year. The measurements all showed the water was well mixed as temperatures at the surface of the reservoir only differed slightly from those in deeper portions of the reservoir. These well-mixed conditions were measured in October 2010. During June, July, and August 2011, the measured conditions during the high inflows were somewhat different, but still indicated a well-mixed water column.

The multibeam survey instrumentation was the primary system utilized to map the main channel of the reservoir from the dam upstream 134 miles to the Northport boat ramp. Multibeam data was also collected on several side tributaries: primarily 10 miles upstream from the Sanpoil River confluence at Keller Ferry and over 30 miles upstream from the Spokane River confluence. The single beam collection system was used to collect underwater data along the shoreline and in shallow water areas not covered by the multibeam system. The single beam system was not used throughout the reservoir since the main focus of the smaller vessel was to provide support for the multibeam vessel effort, and at times, additional crew members were not available.

The multibeam and single beam soundings were combined and filtered into multiple 10-foot grid files totaling 22.7 million xyz points representing the majority of the deep channel portions of the reservoir. The underwater collected data was processed using the same hydrographic system software used during the data collection. The analysis applied all measurements, such as water depth and vessel location along with corrections for the roll, pitch, and yaw. Other corrections included applying the sound velocity through the reservoir water column and converting all depth data points to elevations using the measured water surface elevation at the time of collection. The water surface elevations recorded at the dam at the time of the bathymetric collection were shifted to match NAVD88. The 2010-11 data was combined with previous data sets to generate the Lake Roosevelt topography presented in this report (Figure 8). Additional information on collection and analysis procedures is included in *Engineering and Design: Hydrographic Surveying* (Corps of Engineers, January 2002) and *Reservoir Survey and Data Analysis* (Ferrari and Collins, 2006).

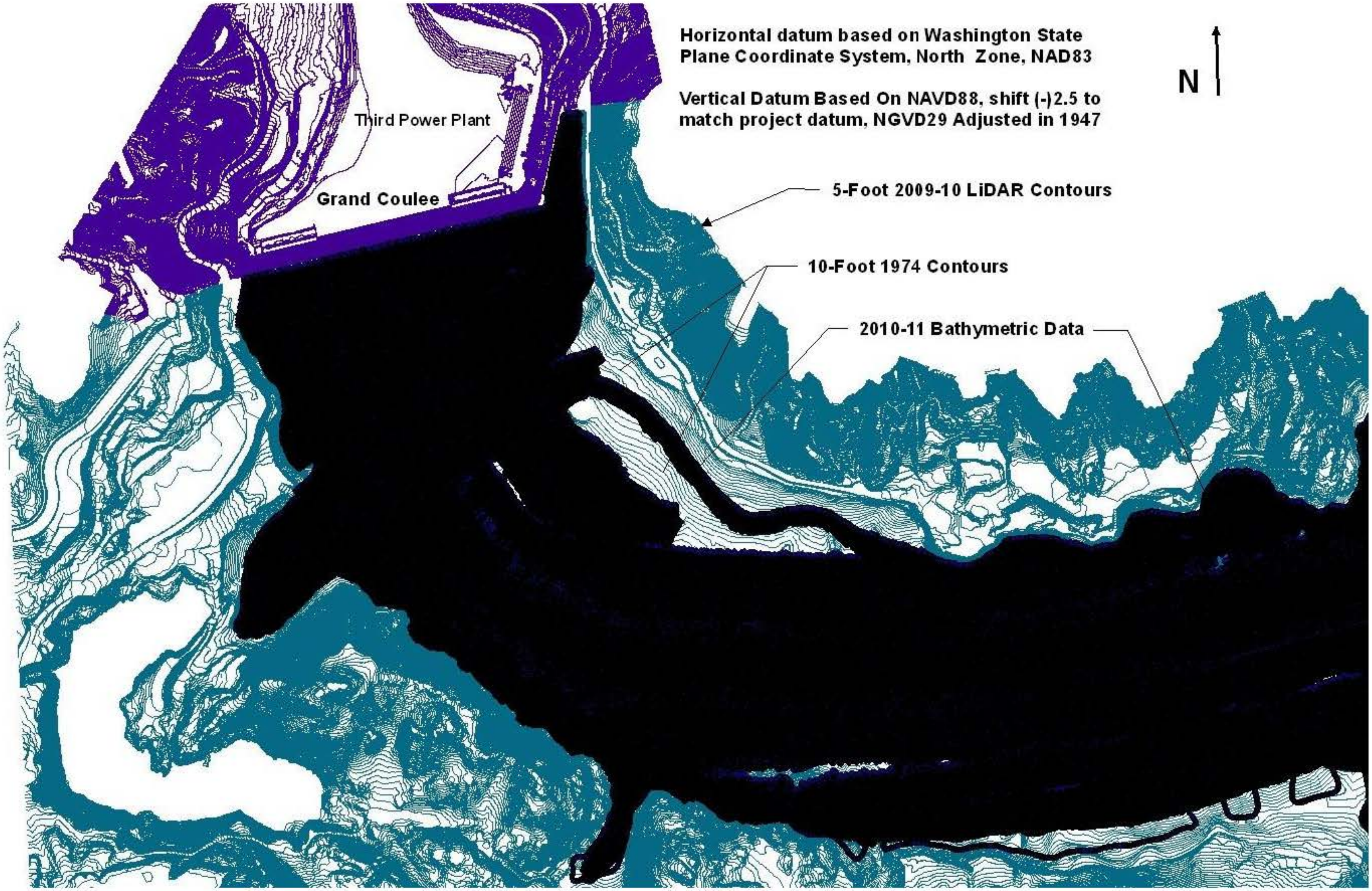

Figure 8 – 2010-11 bathymetric data merged with 1974 aerial and 2009-10 LiDAR contours.

Development of the 2010-11 Lake Roosevelt Surface Areas

Topography Development

This section discusses the methods for generating the topographic contours of Lake Roosevelt. The 2010-11 topography of Lake Roosevelt was developed from combined data sets that included the 2010-11 bathymetry xyz data points and the 2009-10 LiDAR contours as the primary coverages. The 2009-10 LiDAR was flown between reservoir elevations 1,280 and 1,285 (NAVD88) and the 2010-11 bathymetric data mainly concentrated on the deep channel portions of the reservoir below elevation 1,200. At times the bathymetric data extended above elevation 1,200 and in vertical bank areas approached the LiDAR coverage. However, the bathymetry and LiDAR did not cover the entire reservoir area and were supplemented with contours from the 1974 aerial survey of the entire reservoir, the 2007 bathymetric survey in the very upper portion of the reservoir, and digitized USGS quad contours to develop the 2010-11 reservoir topography presented by this study. The 2009-10 LiDAR coverages were provided as multiple raster and xyz data files that included a large portion of the Columbia River basin and Lake Roosevelt area. Due to the density and size of the xyz data files, contours were generated from the raster files and used as hard breaklines for the topographic development.

As previously discussed, the older data sets contained limited to no metadata, but were the best available digital information at the time of this study. The 1974 aerial data were collected when the reservoir was drawn down over 130 feet, resulting in 10-foot contours from elevation 1,160.0 to 1,290.0 that were shifted upward 2.5 feet to match NAVD88 for topographic development. During the 2010-11 bathymetric survey and analysis, it was found that in most cases the data sets lined up very well and any differences appeared to be in areas of noticeable shoreline erosion.

For reservoir topographic development all data coverage layers were combined as Washington state plane coordinates, north zone, in NAD83 and elevations tied to NAVD88. The portions of the 1974 and 2007 developed contours that were overlapped by the 2010-11 bathymetric and 2009-10 LiDAR data were removed using Arc tools (ESRI, 2011). Polygons were developed around the 2010-11 bathymetric data that overlaid the 1974 and 2007 developed contours and were determined to better represent current reservoir conditions. Using the *Clip* tool in ArcGIS, the contours within the polygons were removed. The 1974 contours of elevation 1,280 and 1,290 were removed for all areas of the reservoir shoreline covered by the LiDAR survey. A large portion of the shoreline on the Spokane arm was not covered by the LiDAR, so the 1974 contours at elevations 1,280 and 1,290 were used in those areas. The remaining contour lines from the different layers were used as hard breaklines for the 2010-11 Lake Roosevelt topographic development.

The reservoir topography was first generated and checked by dividing the reservoir into multiple sections where a triangulated irregular network (TIN) was developed. A TIN is a data structure used to model surfaces, such as elevations, as a connected network of triangles. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that all the data points are connected to their nearest neighbors. This method, referred to as Delaunay's criteria, preserves all the collected data points and breaklines. The TIN method is described in more detail in the ArcGIS user's documentation. From the developed TIN coverages some minor data issues were identified and resolved, Figures 9 and 10.

In Figure 9, the TIN at the Sanpoil River confluence in the Keller Ferry area shows how a lack of data within the deeper channel caused the topographic development to create a false blockage in the deeper portion of the channel. The general conclusion was this computer generated contour blockage was due to lack of data, not an actual physical blockage. This appears to be the only portion of the reservoir where the issue of lack of 2010-11 bathymetric data in the deeper channel area occurred and the only location where a hard breakline was interpolated to resolve an issue without the presence of actual data. The TIN in Figure 10 illustrates the details obtained from the multibeam data where bottom material and local scour holes were mapped in the main channel. This material may be from either shoreline erosion since reservoir filling, or from previous river material deposits that formed a restriction and caused sour holes there. During the TIN development process only minor issues were identified and primarily included removal of occasional stray contour breaklines.

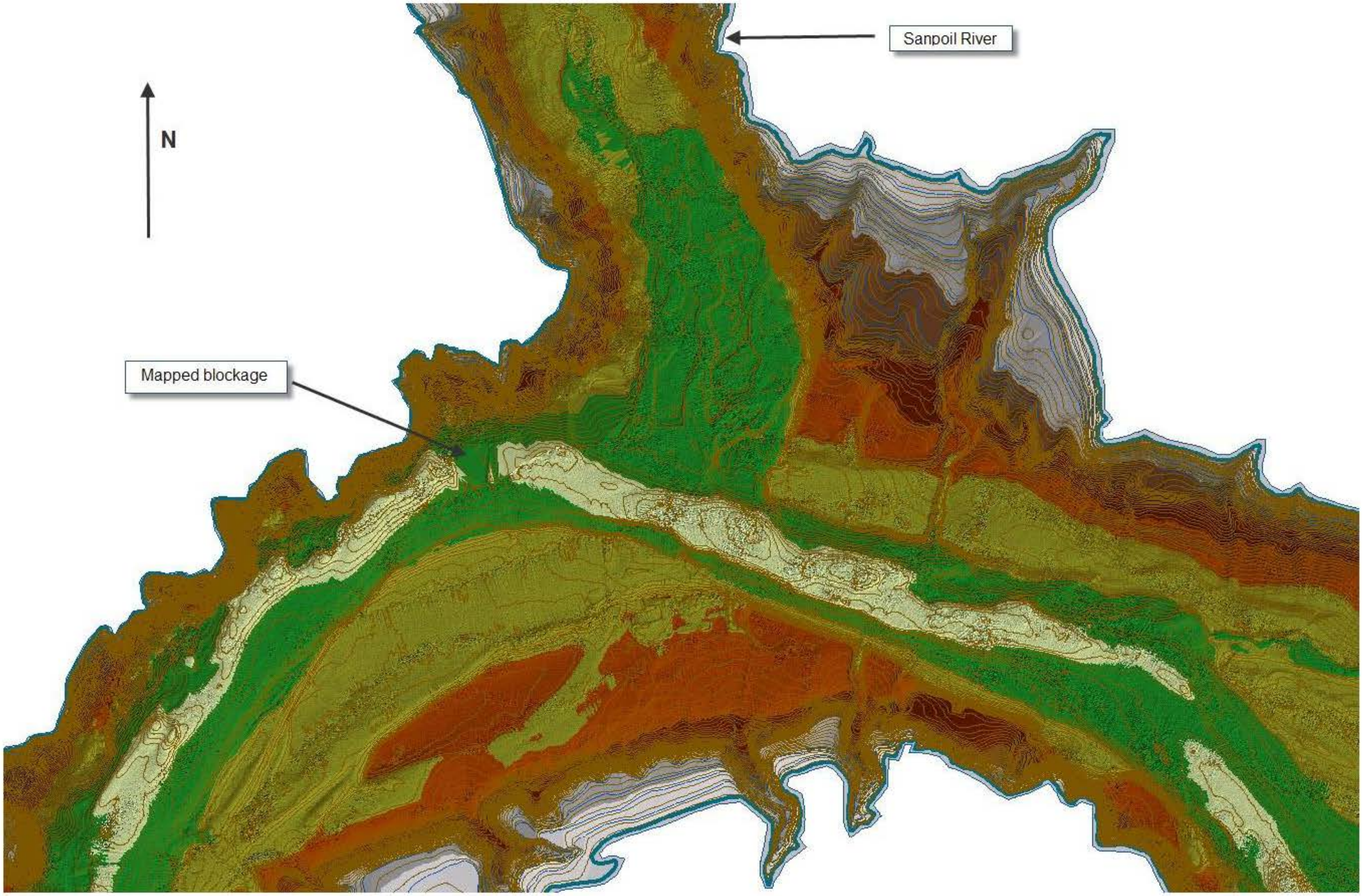

Figure 9 - Roosevelt TIN downstream of Sanpoil River confluence. Notice green color zone downstream of the confluence indicating a blockage.

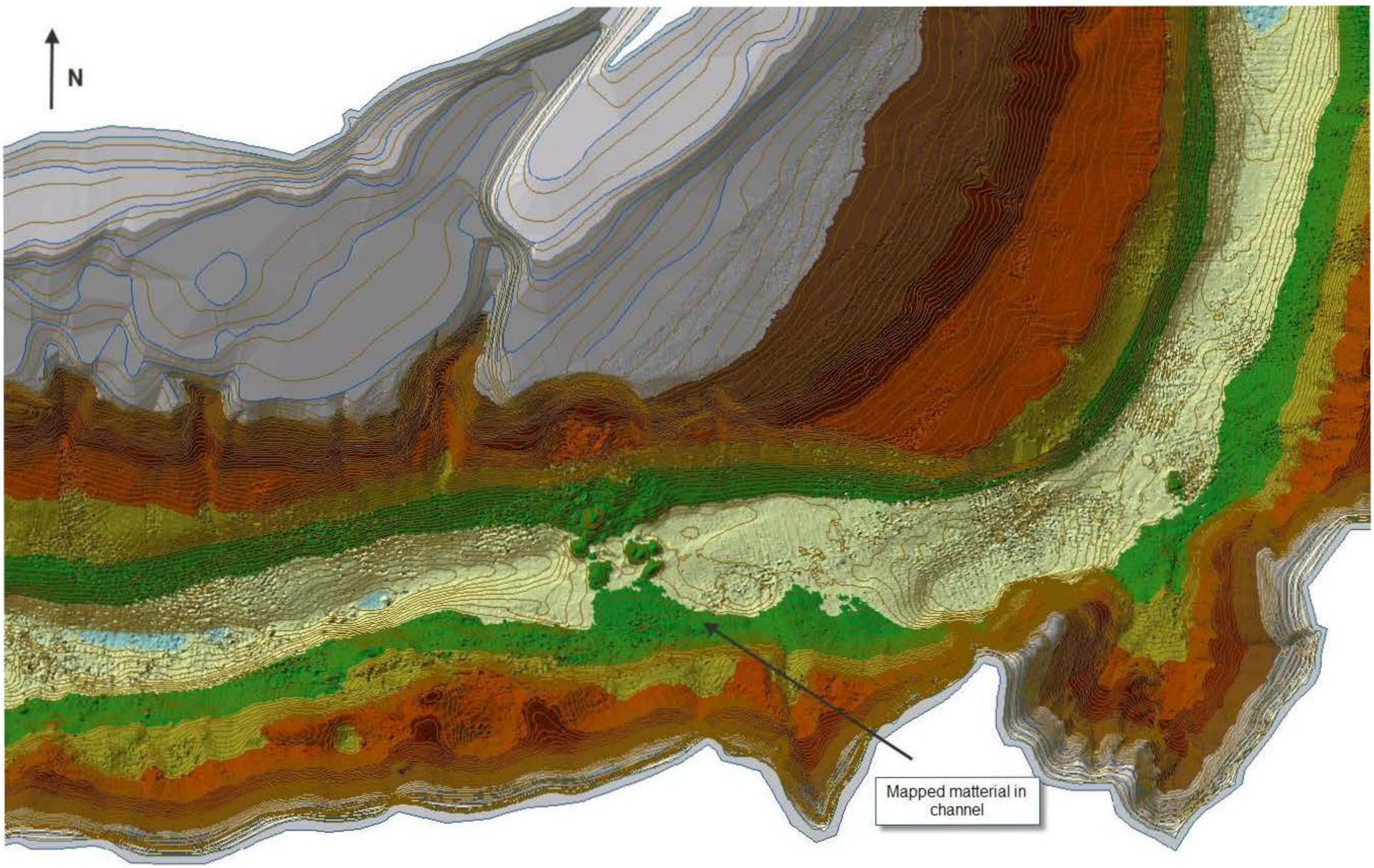

Figure 10 - Roosevelt TIN near mile 13, material within channel area possible land slide material.

Once the identified issues were resolved, the coverage layers were processed as a terrain using Arc tools. A terrain is based on the TIN method that uses geodatabase feature classes as the data sources. The terrain dataset is a series of TINs that can be quickly displayed as a coarser-grained map within a larger extent, but become finer as the coverage is zoomed to view detailed images. The boundary of the study area and all the file coverages were enclosed by a polygon clip that ran along the alignment of Grand Coulee Dam and assigned no elevation. The terrain took hours to process and resulted in multiple issues when developing contours and computing reservoir surface areas and volumes. The issues were attributed to the large size of the combined data sets, so the reservoir was divided into multiple terrains. Dividing the reservoir area into multiple, smaller terrains resolved the contouring issue in all but the upper 30 mile portion of the reservoir and the developed LiDAR contours above the maximum flood pool, elevation 1,321.8. This issue was eventually resolved by removing the LiDAR contours above elevation 1,330 for this section of the reservoir only. Removing these contours did not affect the terrain development of the reservoir surface areas and resulting volume computations. Contours for the reservoir were developed from the multiple terrains and merged together resulting in a coverage for the total reservoir area. The contours were developed in 5-foot intervals ranging from elevation 870.0 and above. Figures 11 through 14 are examples of the developed contours.

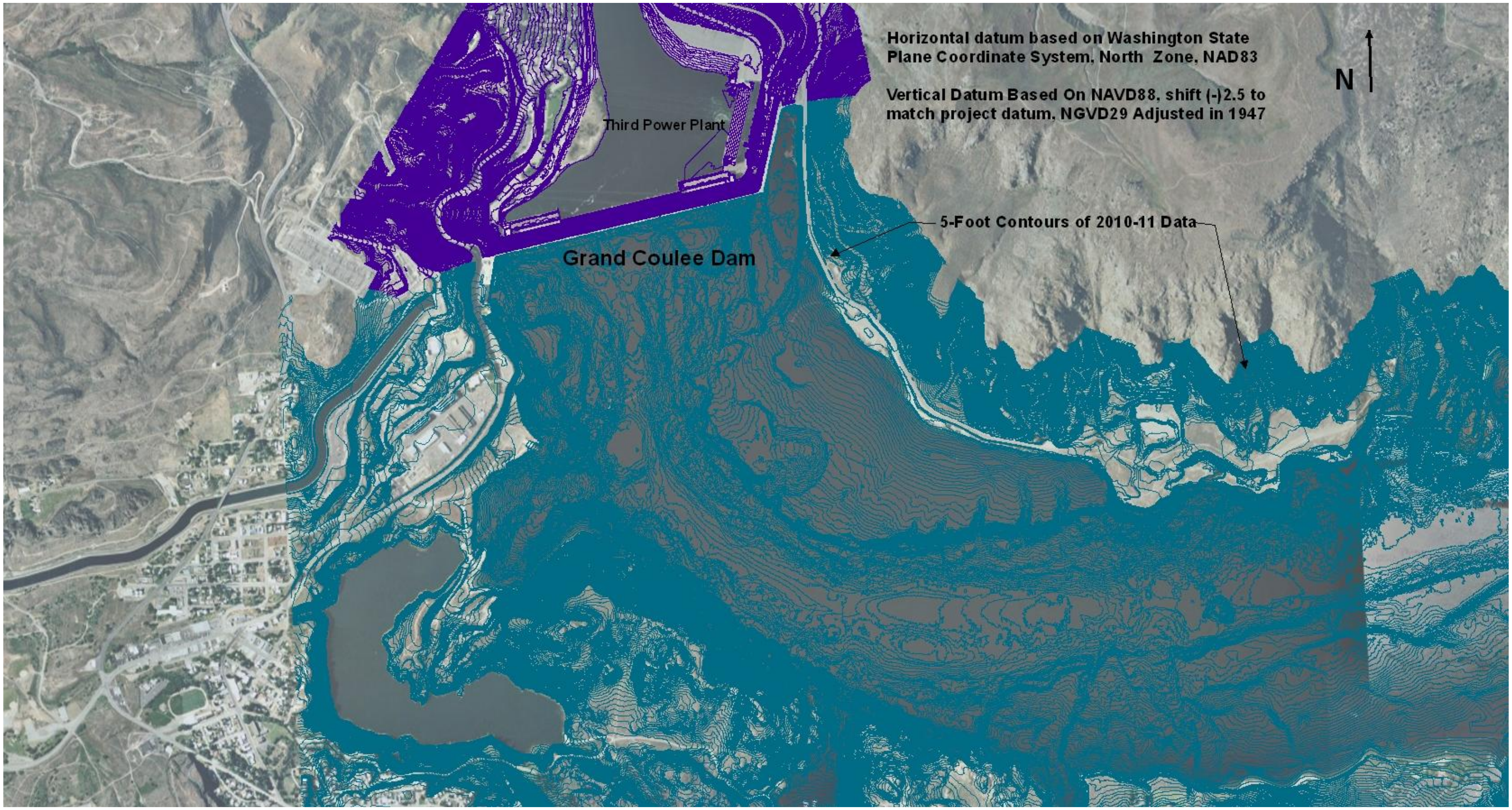

Figure 11 - 2010-11 Lake Roosevelt at Grand Coulee Dam. 5-foot contours from developed terrains.

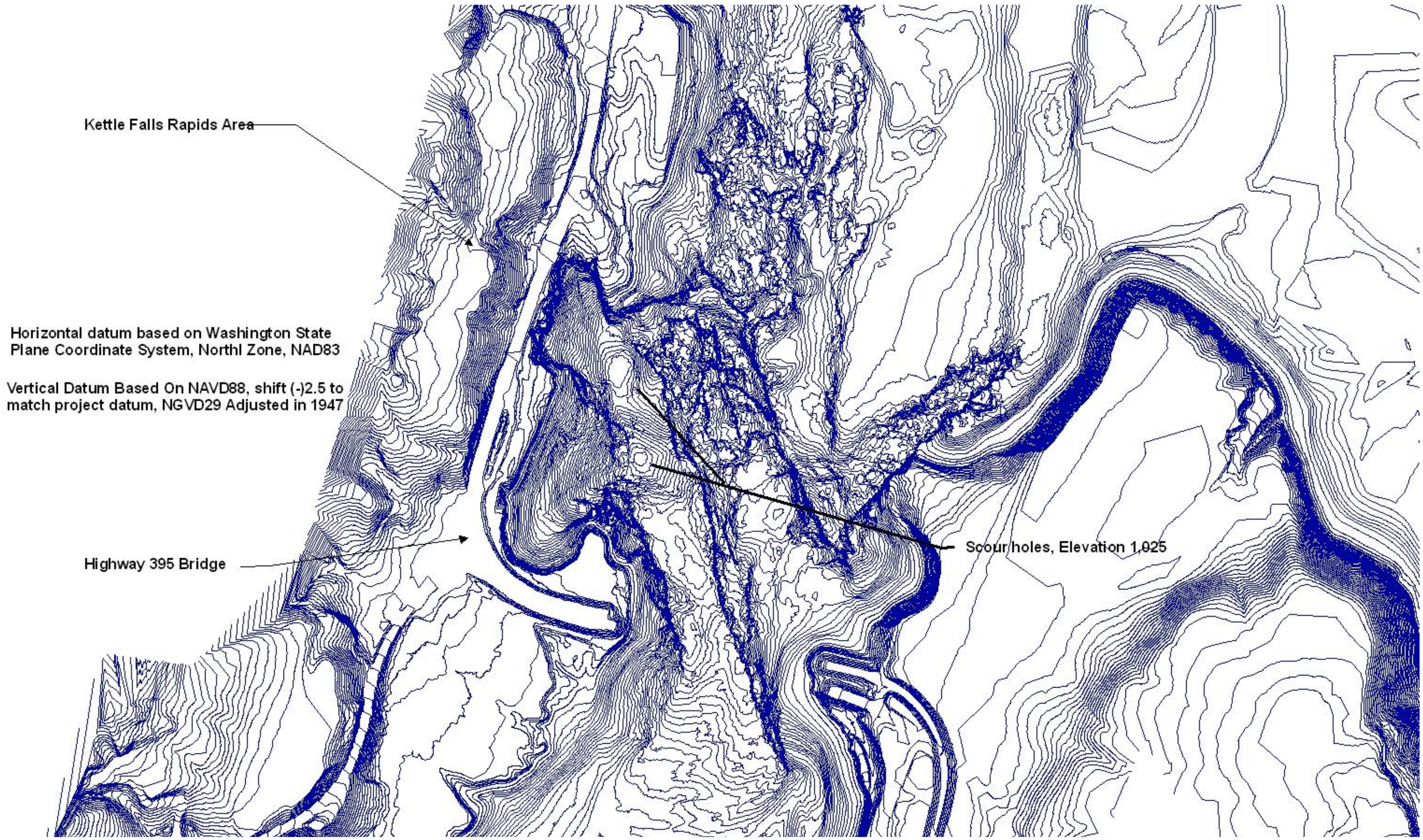

Figure 12 - 2010-11 Lake Roosevelt at Kettle Falls. 5-foot contours developed from developed terrains.

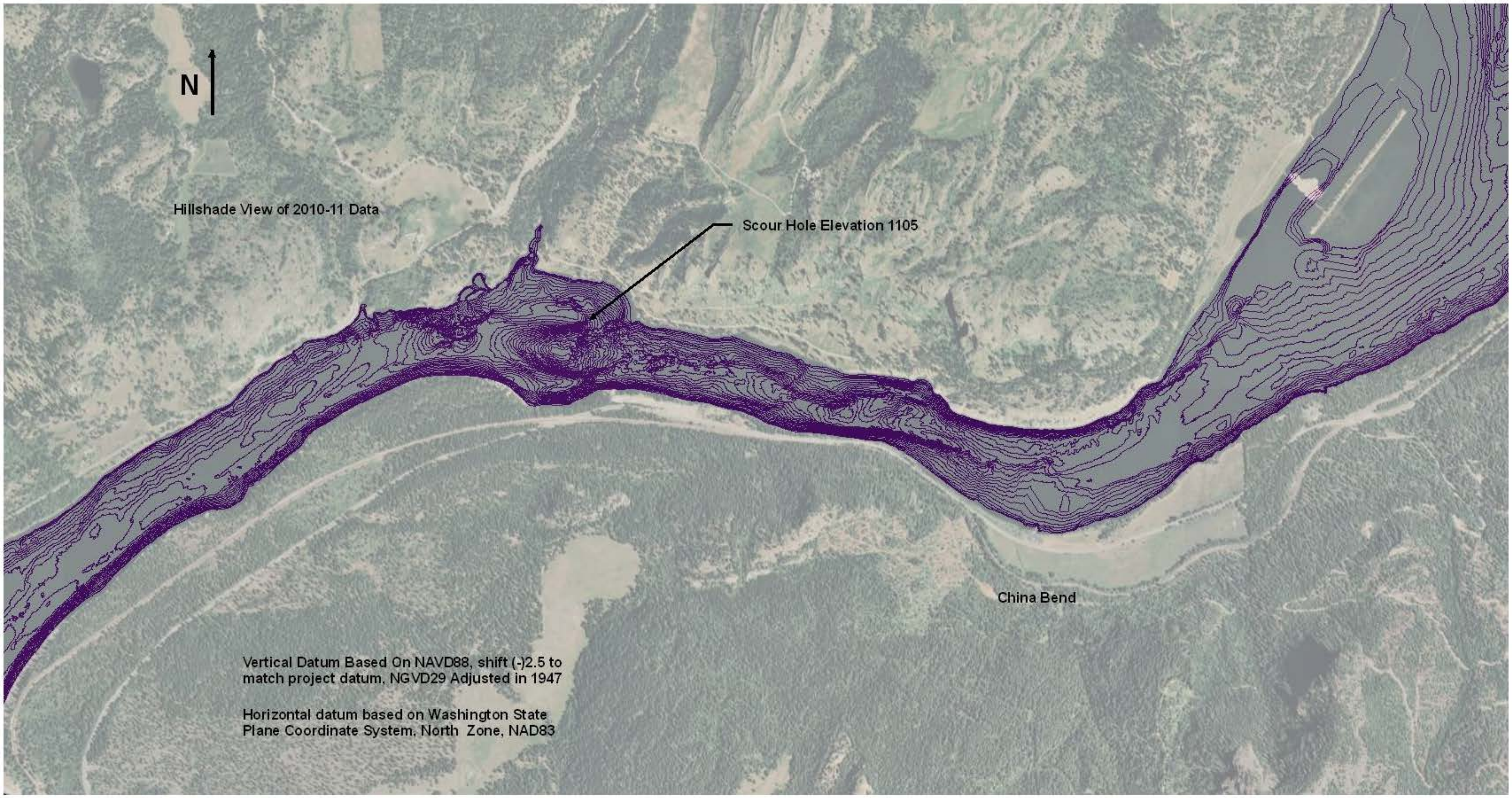

Figure 13 - 2010-11 Lake Roosevelt at China Bend. 5-foot contours from developed terrains.

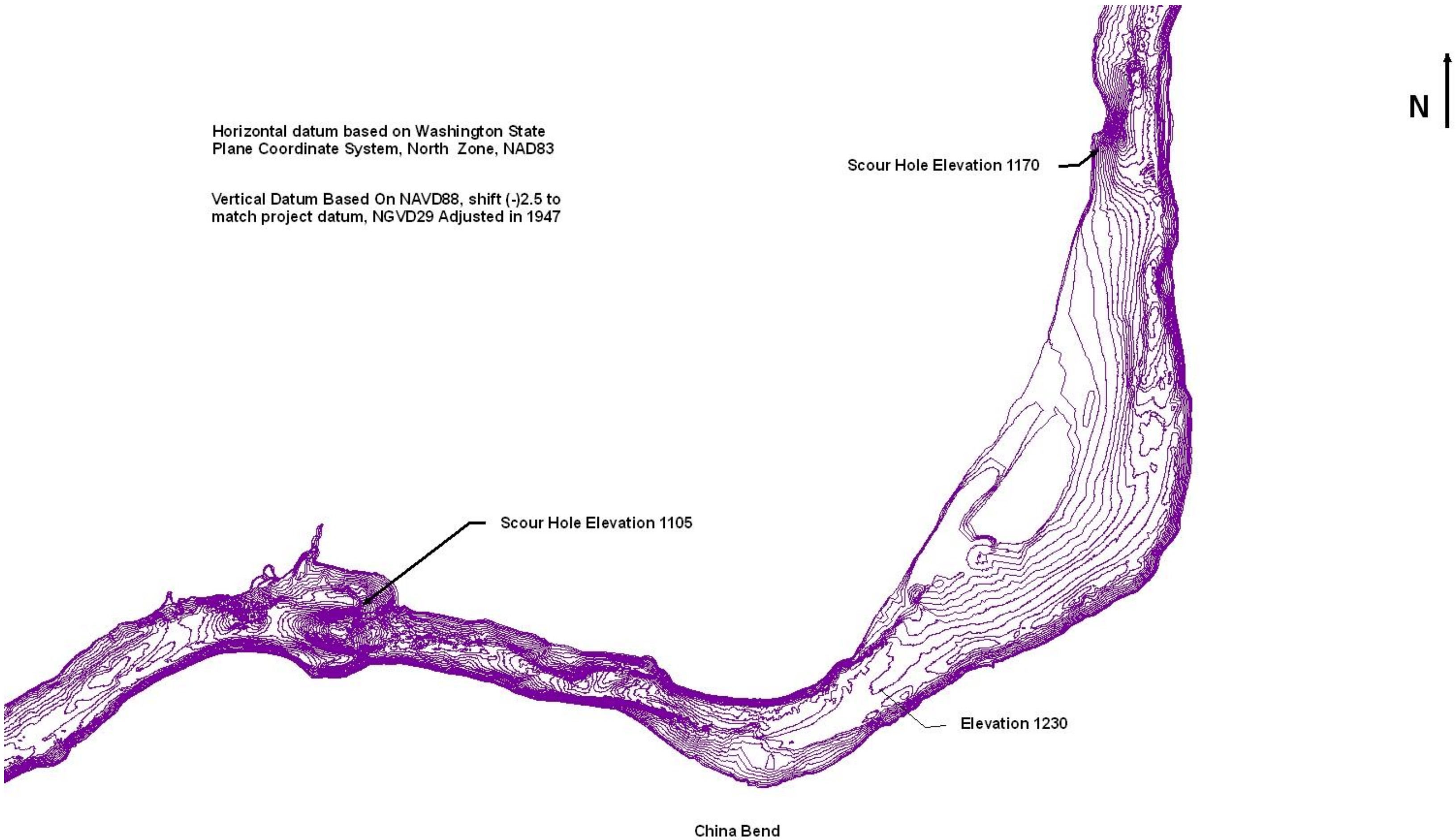

Figure 14 - 2010-11 Lake Roosevelt at China Bend. 5-foot contours developed from terrains.

From the developed terrains, attempts were made to compute surface areas and volumes. The computations ran overnight and all sections were successful except for the terrain near the dam. Some time was spent to resolve the issue, but with no success. The general conclusion was that the problem was likely due to the large file size and detailed reservoir topography in that area. Using Arc tools the developed terrain sections were converted to raster coverages with 10-foot grid details. A raster is a set of cells arranged in rows and columns to represent geographic information and it greatly streamlines the analysis process. The raster coverages were mosaic or merged into one reservoir coverage from which surface area and volumes were computed. Contours were developed from the mosaic of the rasters of the reservoir and compared to the contours from the developed terrains and TINs. Generally, everything matched up well. There were some cases however, such as the very small contours within the mapped scour holes, where the raster information appeared not to capture the deepest details. This had little to no effect on the overall volume computations and only occurred in a few cases.

For presentation and analysis purposes a hillshade image was developed from the mosaic file. The hillshade is a shade relief from the surface rasters that allows visualization of the bottom details in the reservoir areas mapped. Figures 15 through 18 are zoomed in views that show the scour hole details around Kettle Falls, Onion Creek, and China Bend. Figures, 19 through 31, are zoomed out sections of the hillshade images and provide views of the 2010-11 developed topography. The images are presented in a north-south alignment. Points of interests are labeled on the images for location purposes.

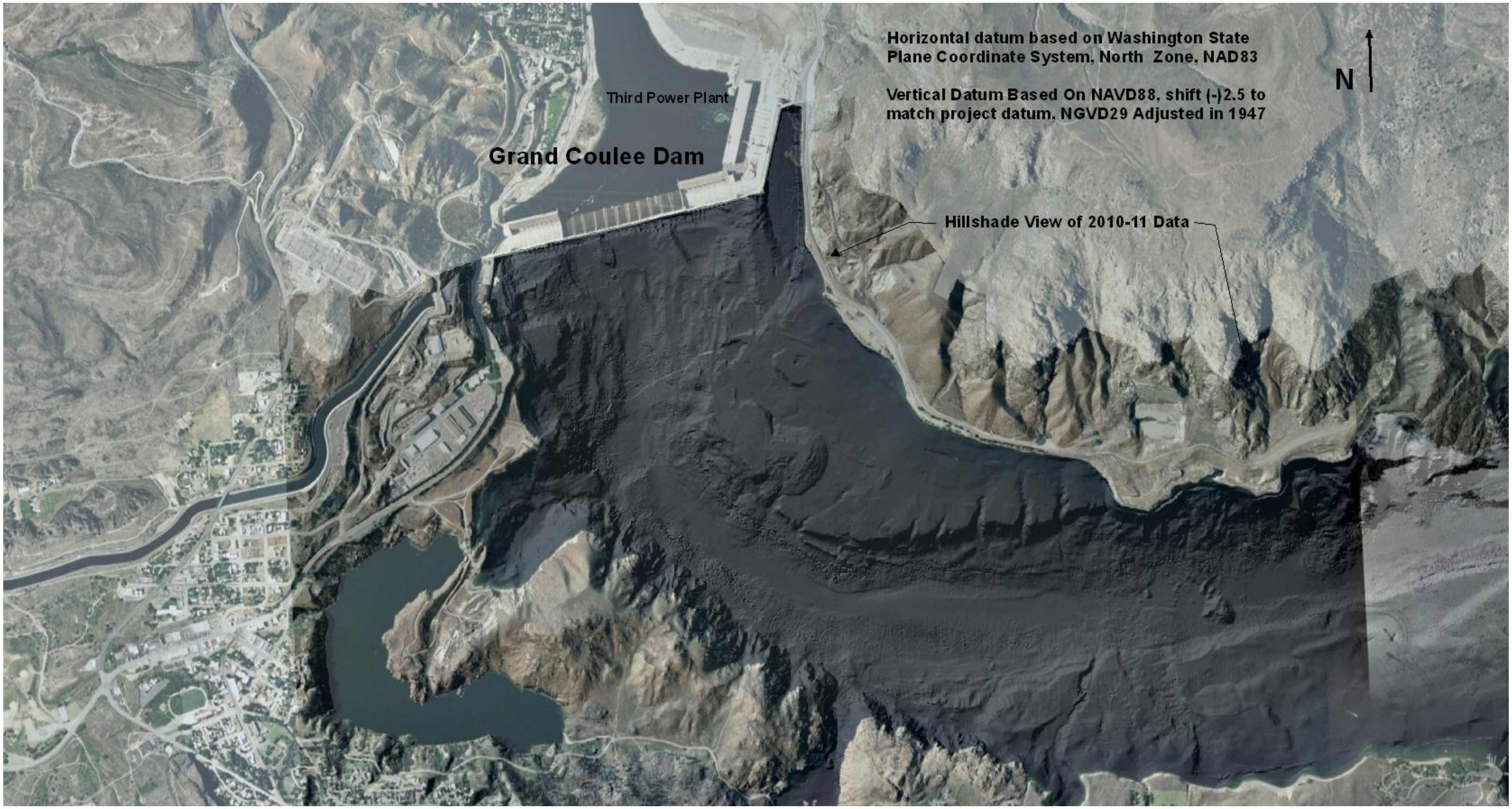

Figure 15 - Hillshade view of 2010-11 Lake Roosevelt data at Grand Coulee Dam.

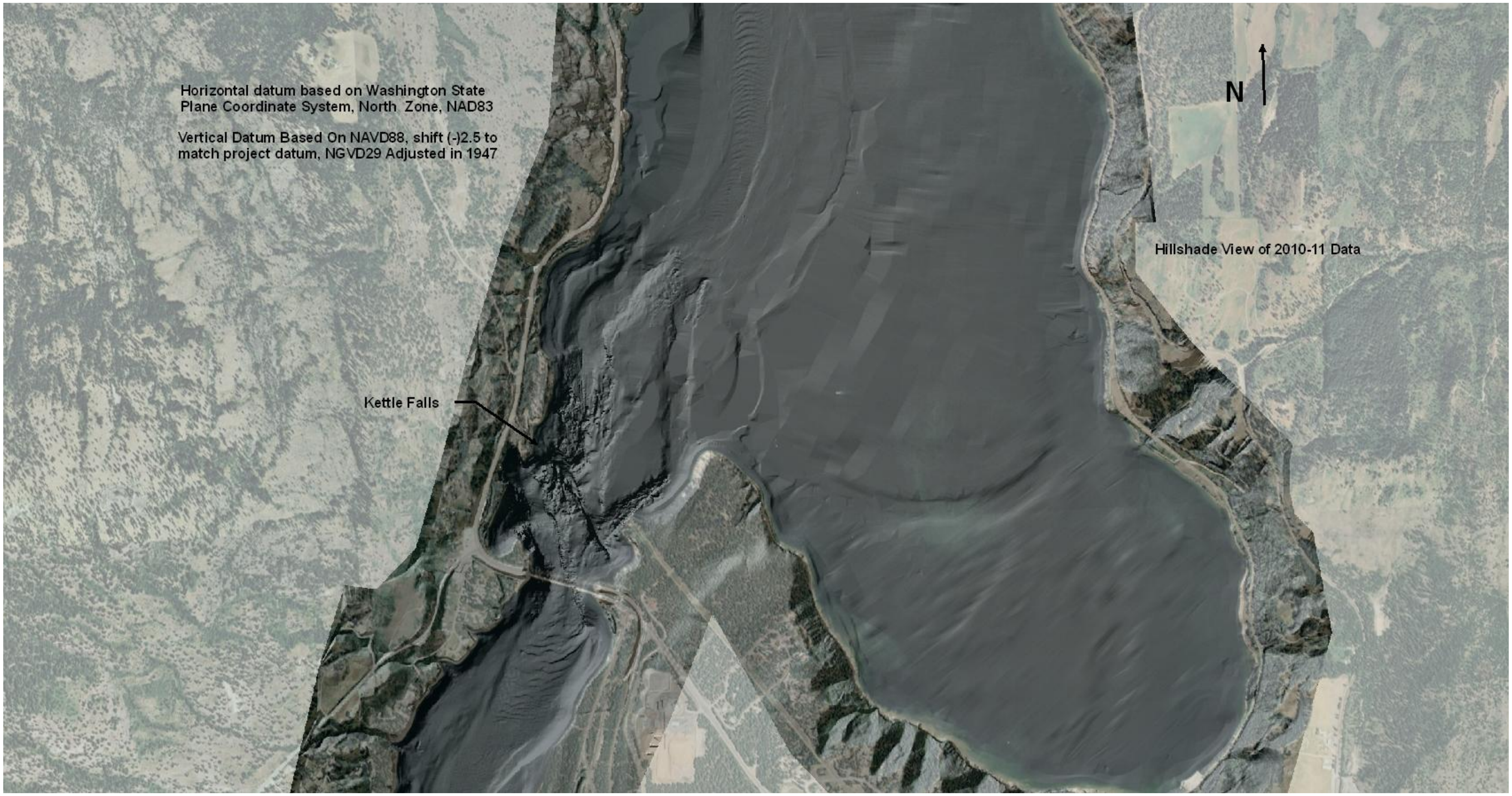

Figure 16 - Hillshade View of 2010-11 Lake Roosevelt data at Kettle Falls.

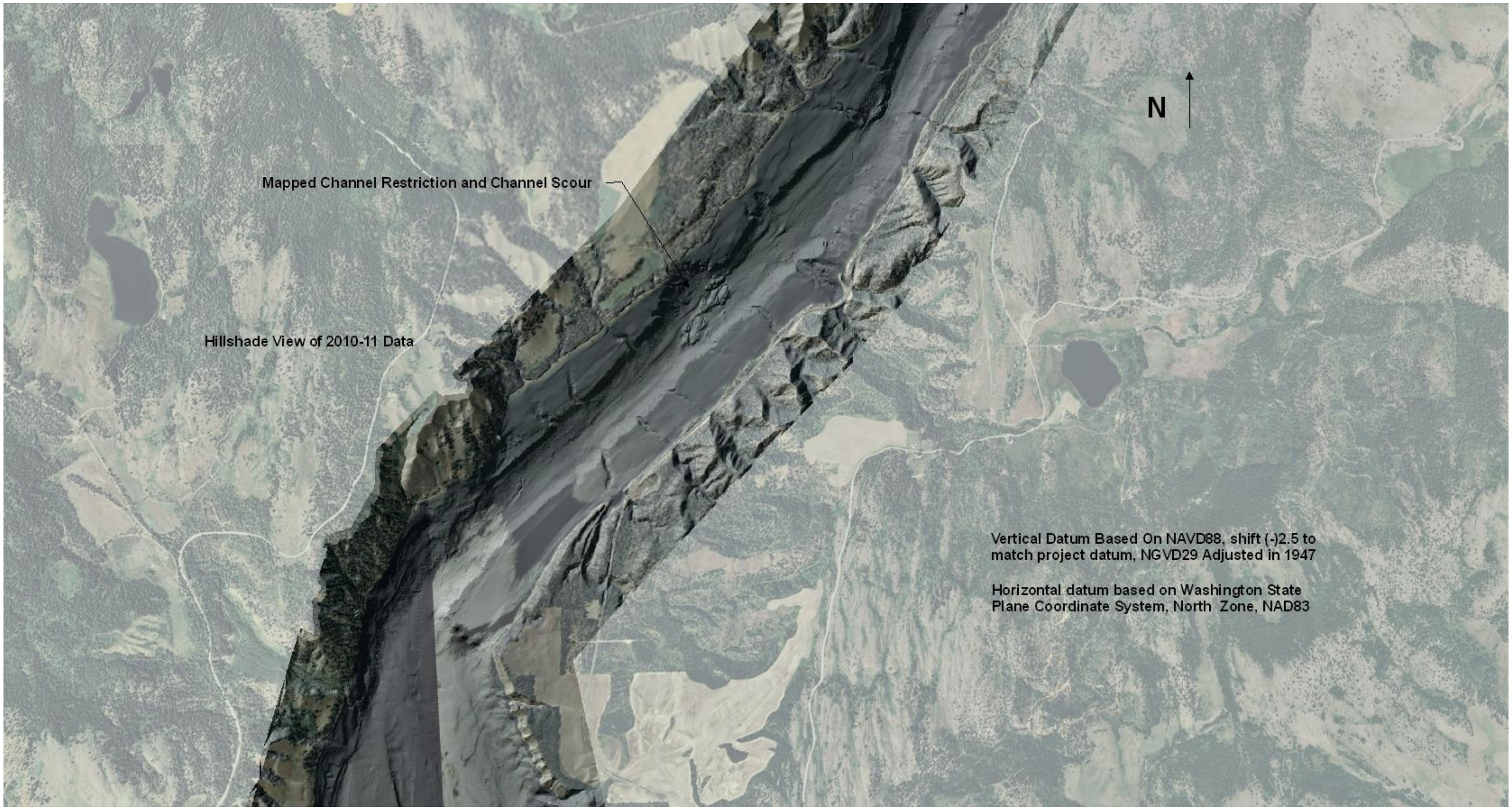

Figure 17 - Hillshade view of 2010-11 Lake Roosevelt data.

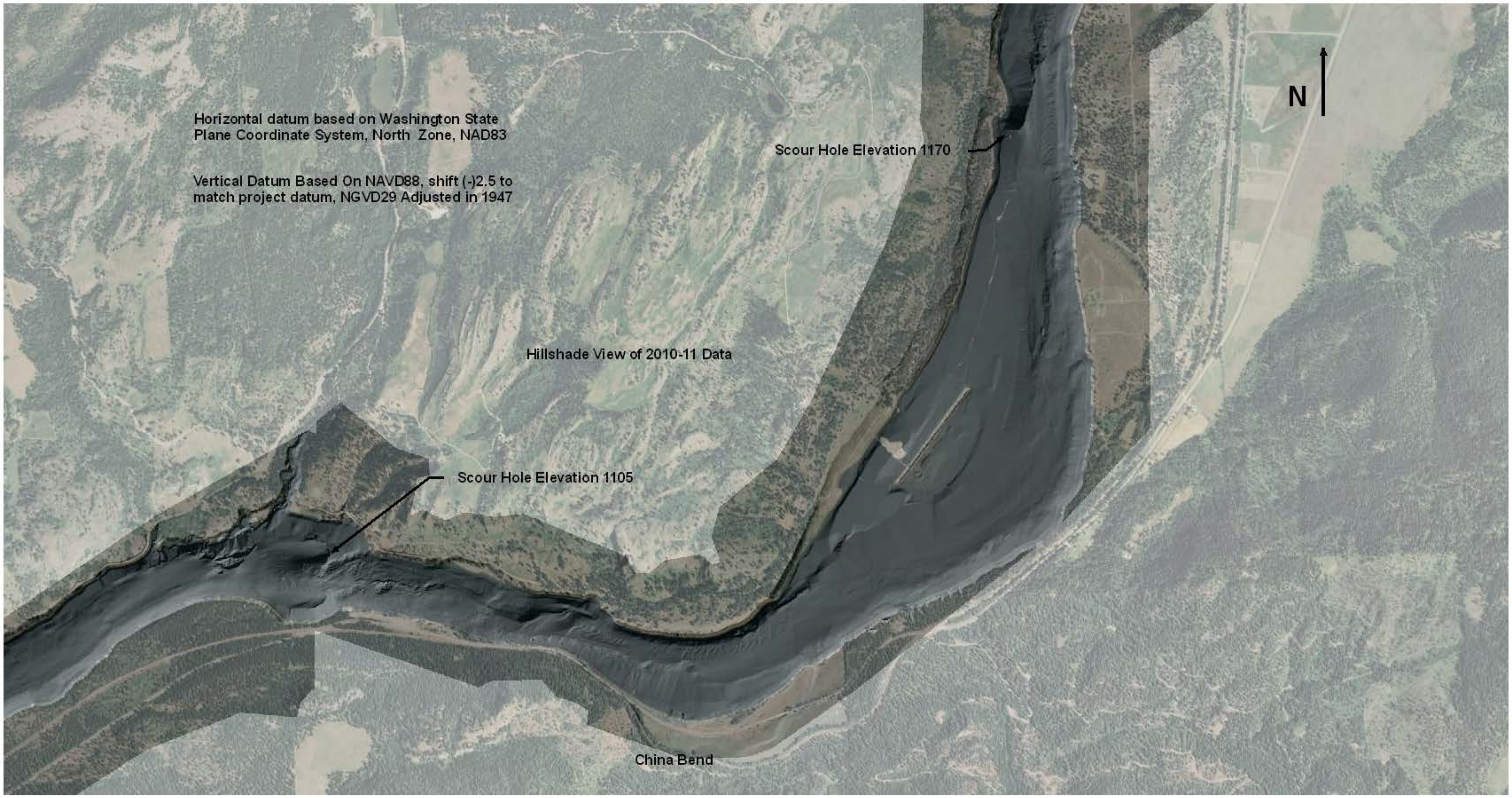

Figure 18 – Hillshade of 2010-11 Lake Roosevelt data at China Bend.

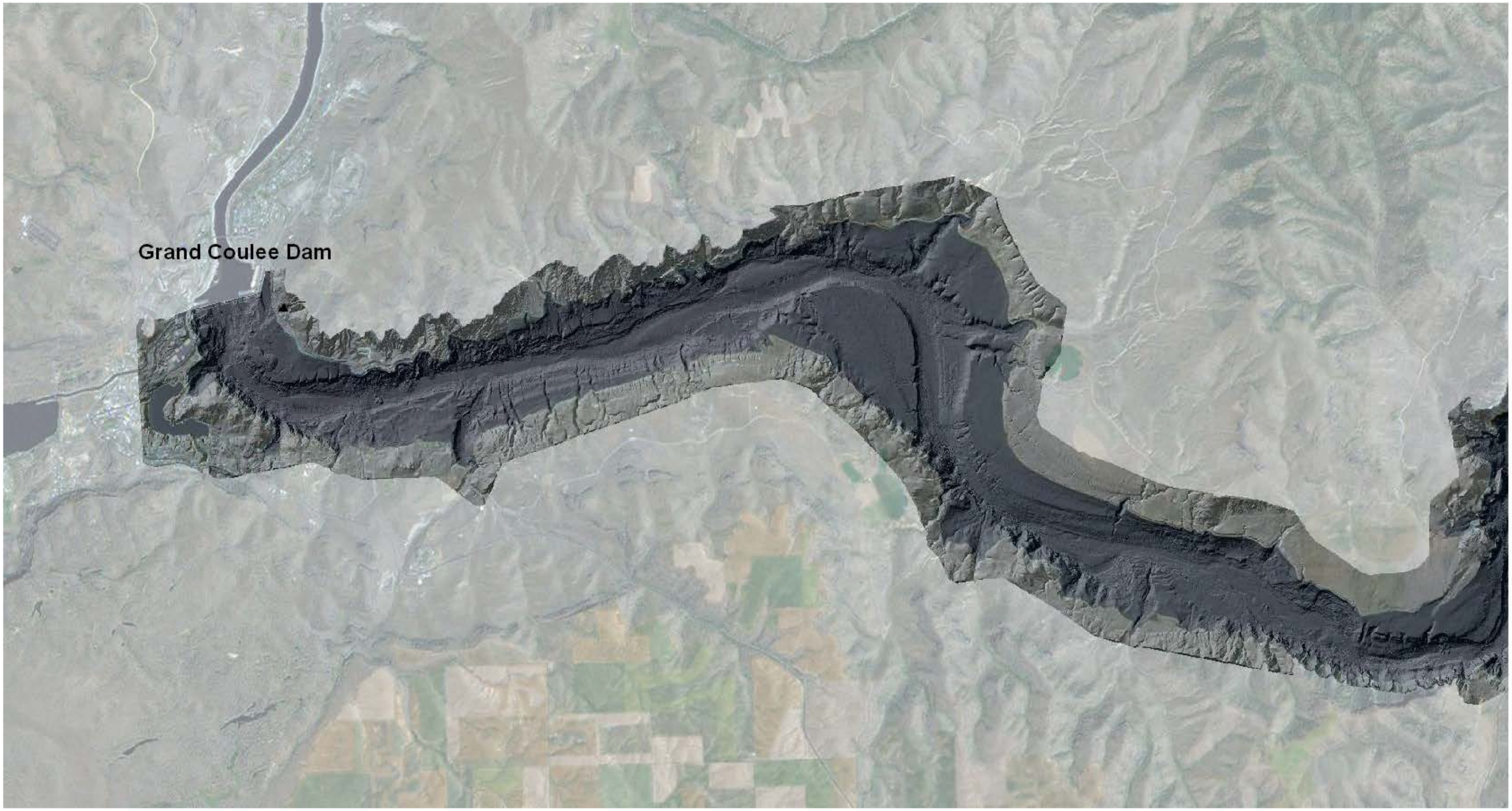

Figure 19 - Hillshade view of 2010-11 Lake Roosevelt data

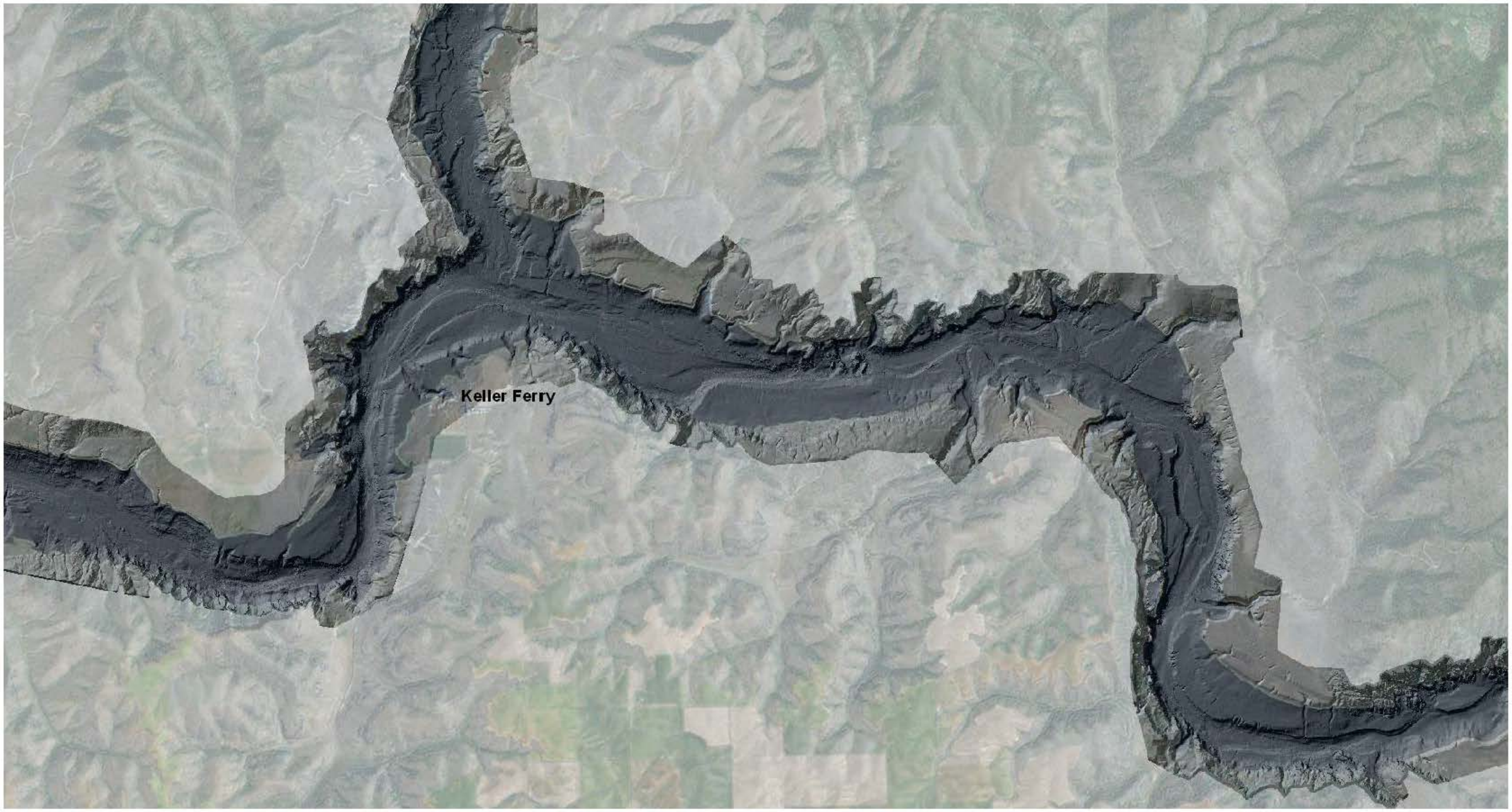

Figure 20 - Hillshade view of 2010-11 Lake Roosevelt data.

Figure 21 - Hillshade view of 2010-11 Lake Roosevelt data

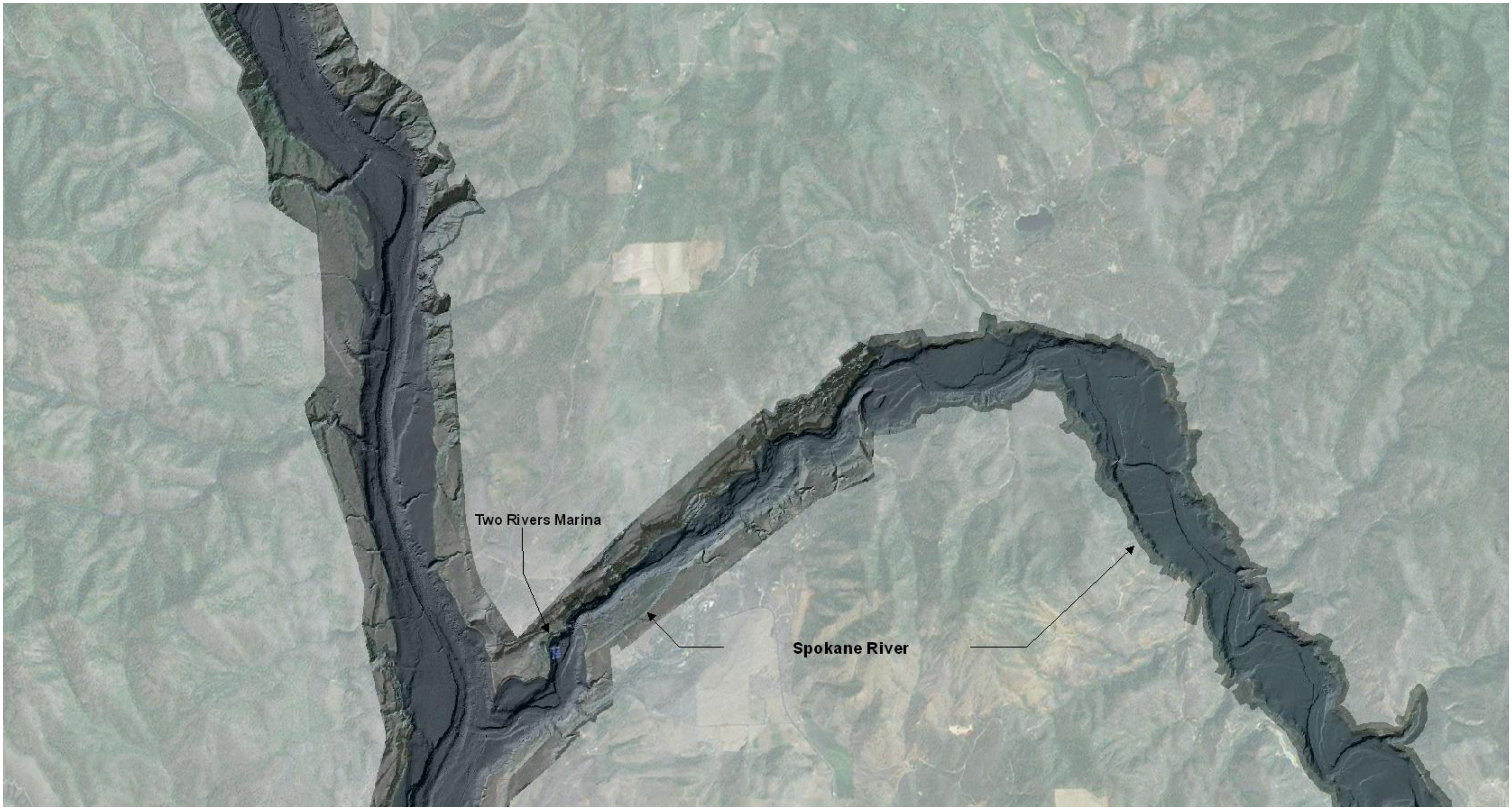

Figure 22 - Hillshade view of 2010-11 Lake Roosevelt data.

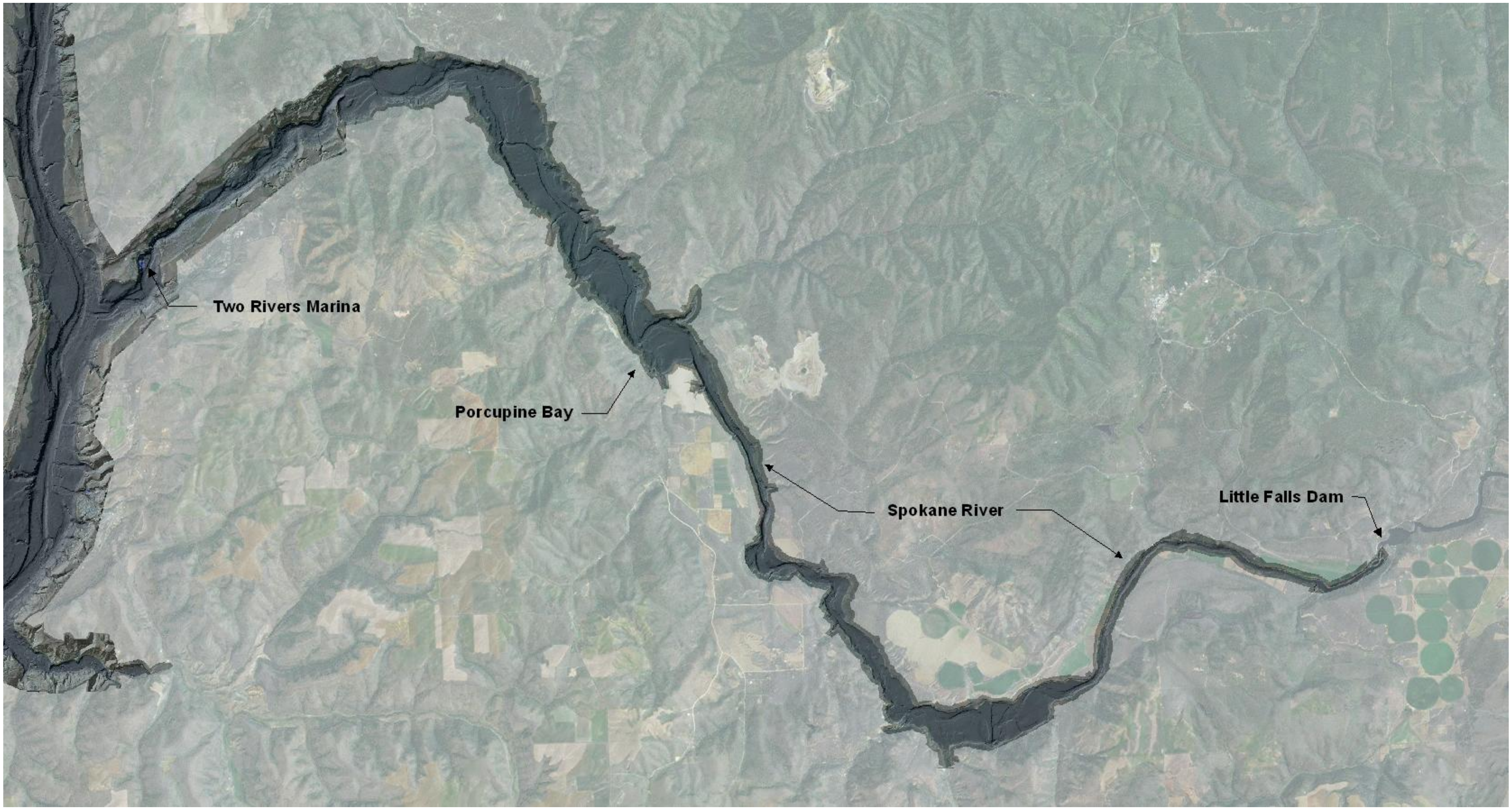

Figure 23 - Hillshade view of 2010-11 Lake Roosevelt data.

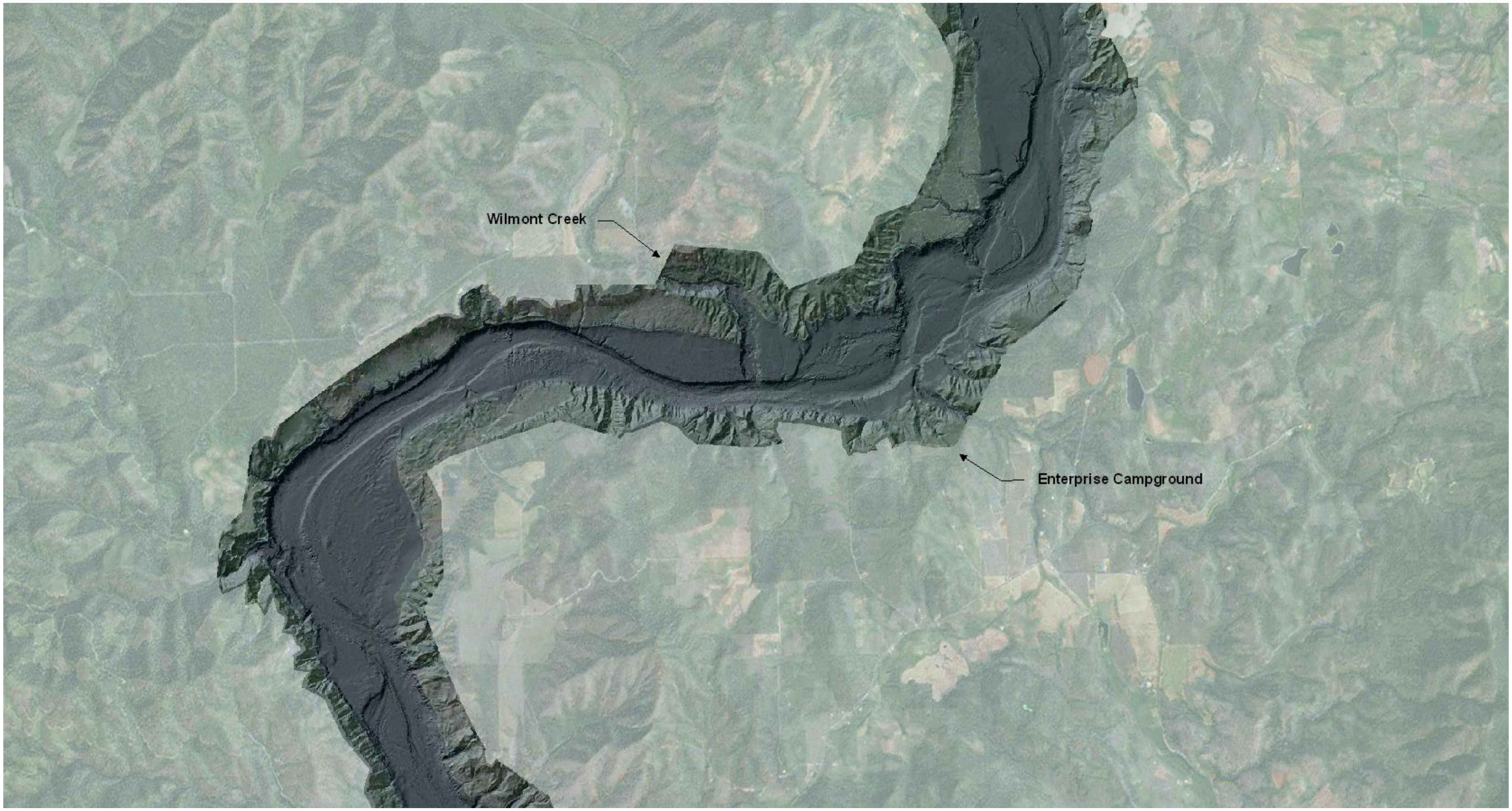

Figure 24 - Hillshade view of 2010-11 Lake Roosevelt data.

Figure 25 - Hillshade view of 2010-11 Lake Roosevelt data.

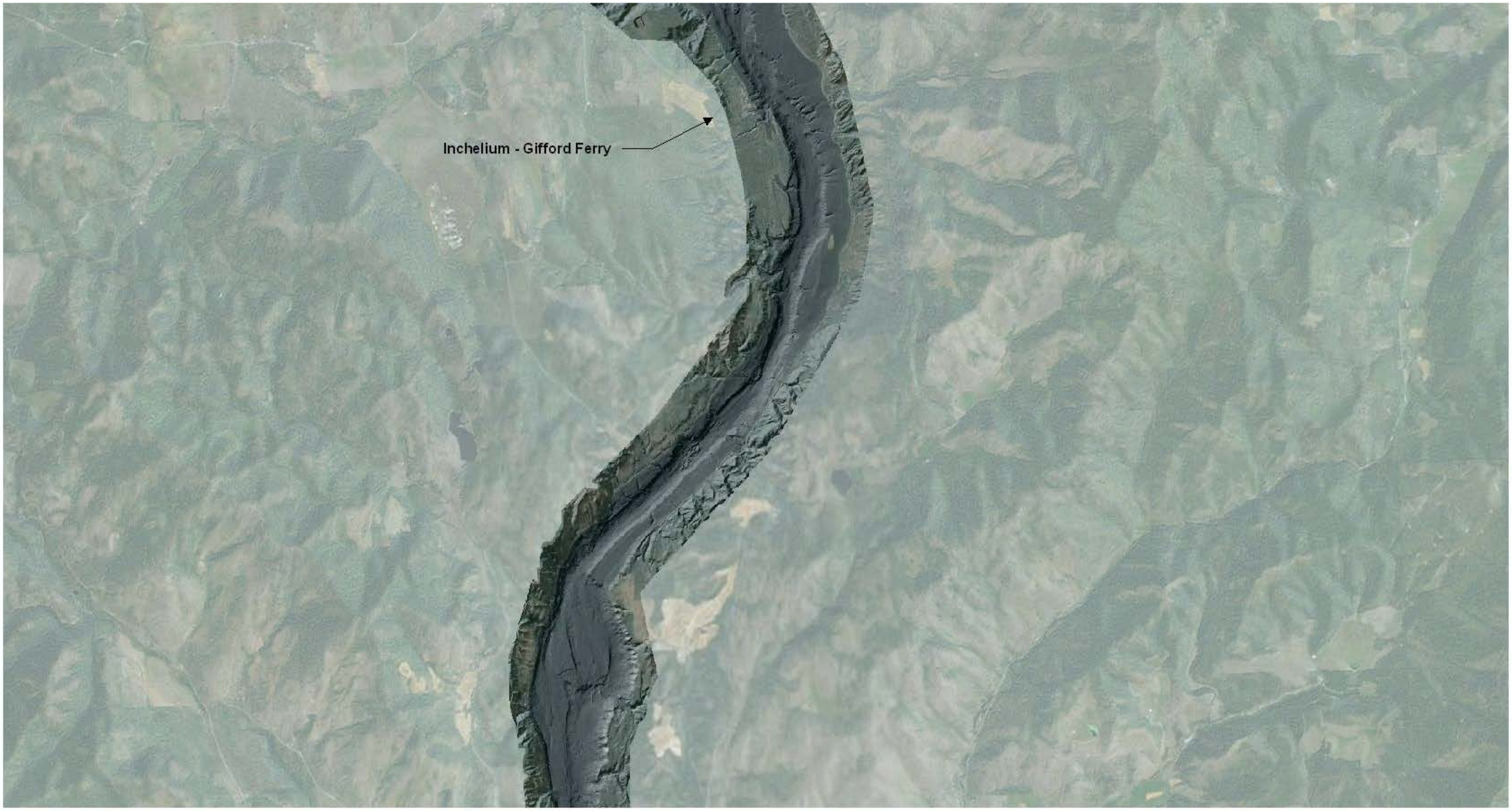

Figure 26 - Hillshade view of 2010-11 Lake Roosevelt data.

Figure 27 - Hillshade view of 2010-11 Lake Roosevelt data.

Figure 28 - Hillshade view of 2010-11 Lake Roosevelt data.

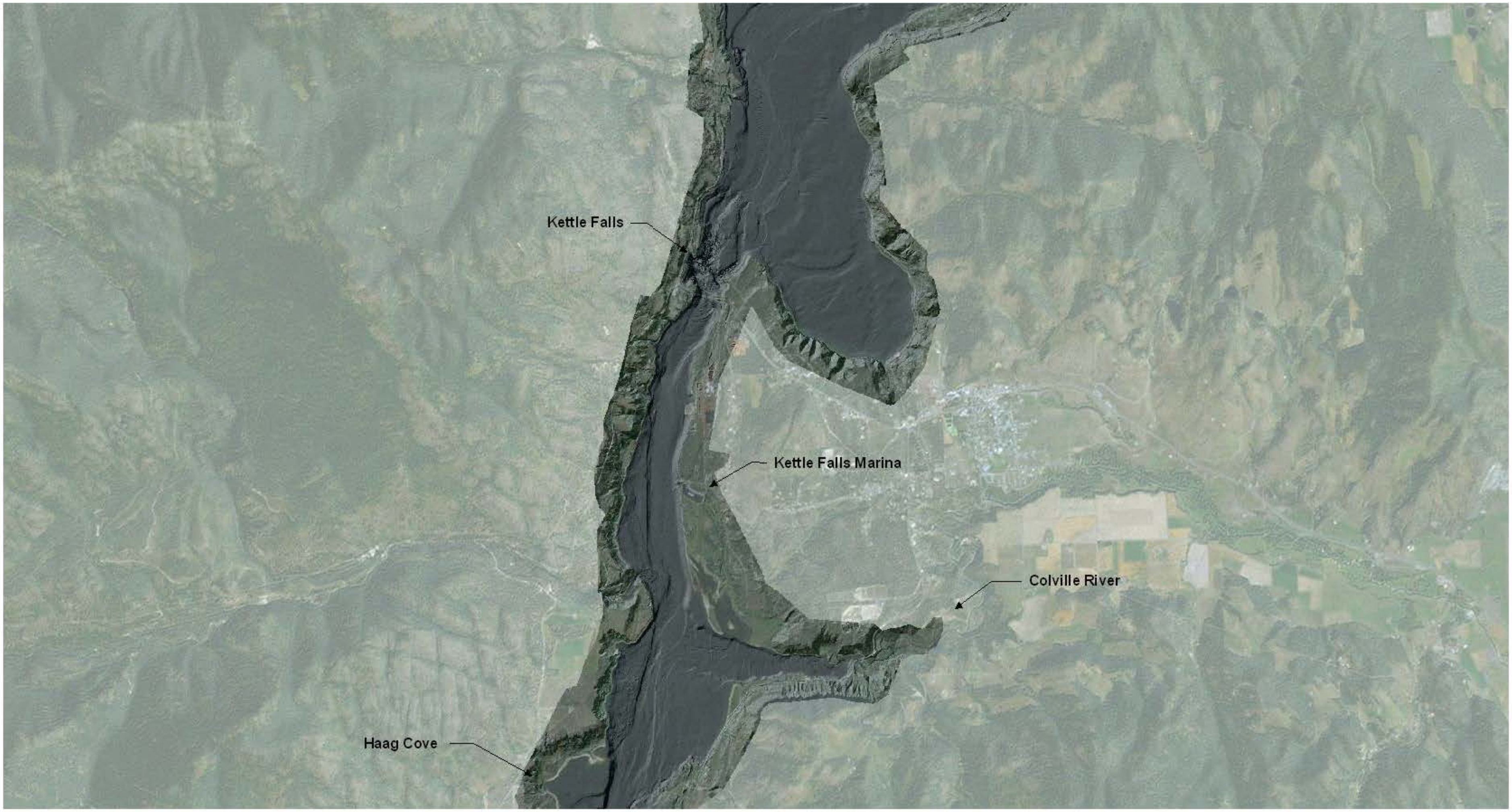

Figure 29 - Hillshade view of 2010-11 Lake Roosevelt data.

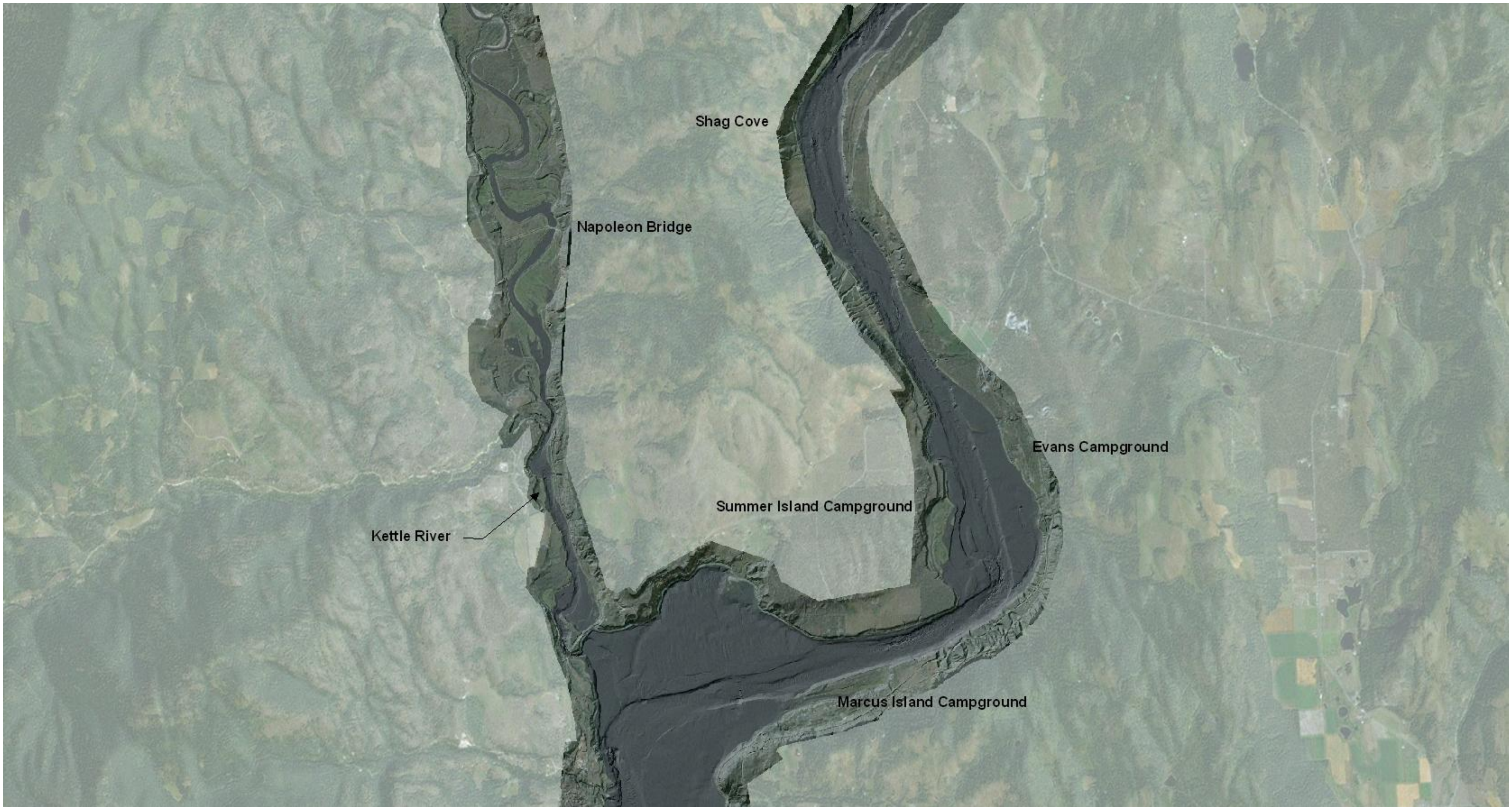

Figure 30 - Hillshade view of 2010-11 Lake Roosevelt data.

Figure 31 - Hillshade view of 2010-11 Lake Roosevelt data.

2010-11 Lake Roosevelt Surface Area Methods

The 2010-11 surface areas for Lake Roosevelt were computed at 2-foot increments directly from the developed reservoir raster from elevation 868 through 1,326.0 (NAVD88) and provided information for the area-capacity tables. The minimum elevation from the 2010-11 survey was around elevation 866. Surface area calculations were performed using ArcGIS commands that compute areas at user-specified elevations directly from the developed 2010-11 raster of Lake Roosevelt. The resulting surface areas were shifted down 2.5 feet to match the project vertical datum used for reservoir operations.

2010-11 Lake Roosevelt Storage Capacity Methods

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The ACAP program computes the area and capacity at elevation increments from 0.01 to 1.0 foot through linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Lake Roosevelt. The capacity equation is then used over the full range of intervals fitting within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from the basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Through differentiation of the capacity equations, which are of second order polynomial form, final area equations are derived:

$$y = a_1 + a_2x + a_3x^2$$

where:

y = capacity
x = elevation above a reference base
a_1 = intercept
a_2 and a_3 = coefficients

Results of the Lake Roosevelt area and capacity computations are listed in a separate set of 2010-11 area and capacity tables and have been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation, 2012). A description of the computations and coefficients output from the ACAP program is included with those tables. As of August 2011, at normal use elevation 1,290.0, the surface area was 81,991 acres with a total capacity of 9,715,346 acre-feet.

Longitudinal Distribution

To illustrate the bottom conditions a longitudinal profile was cut through the 2010-11 developed contours for the Columbia and Spokane arms of the reservoir (Figures 33 and 34). The distances from this effort do not match previously published mile markers since care was taken to align the thalweg through the deepest portion of the channel with the purpose of plotting the numerous scour holes within the reservoir. To adequately locate the scour features, the thalweg alignment became quite sinuous through certain areas, such as Kettle Falls, compared to following a straighter/smoother route. The results were longer thalweg distances for this study than in previous publications. The general locations on the plots are identified by naming features in the general area, such as campgrounds, marinas, and creeks.

The Spokane River longitudinal profile showed that the upper end has several scour holes of around 20 feet in depth, which should be expected considering the basin is controlled by dams starting just above the normal pool elevation of the reservoir, trapping much of the inflowing sediment. Also, with the reservoir dropping every spring, any material that may have accumulated would be flushed out annually. The deepest scour hole measured was more than 40 feet located near a large rock island downstream of Porcupine Bay. A major restriction was measured about two miles upstream of the Highway 25 bridge crossing. An aerial view shows a major land slide that deposited over 60 feet of eroded material above the original river channel area, Figure 32. There are many documented landslides within the reservoir, but from the two thalweg plots this location appears to be the only one that has caused such a massive constriction across the entire original channel width. Further examination would likely identify other locations where the deposited landslide material restricts the original channel, but the landslide contraction near Highway 25 was the only significant restriction identified on the longitudinal profiles for this study.

The Columbia River longitudinal profile identified numerous scour holes from the dam upstream more than 150 miles, Figure 34. For the first 40 miles upstream of the dam, there are numerous scour holes that range from 30 to 40 feet deep. The hillshade views provide an aerial view of their locations, Figures 15 and 19 through 21. The scour holes exist throughout the reservoir and those in the deep water closer to the dam indicate that sediment has not moved downstream far enough to fill in these voids. Upstream of that area, there are some deeper scour holes around 60 feet and others even deeper near Kettle Falls and Onion Creek where multiple scour holes over 120 feet in depth were measured, Figures 12, 16, and 31. Kettle Falls was a documented rapid location prior to the reservoir and it is assumed Onion Creek was a rapid as well. With the annual drawdown of the reservoir, large turbid inflows move accumulated material from these scour holes downstream. Several scour holes ranging from 30 to 80 feet deep were also measured in the China Bend area, Figures 13, 14, and 18.

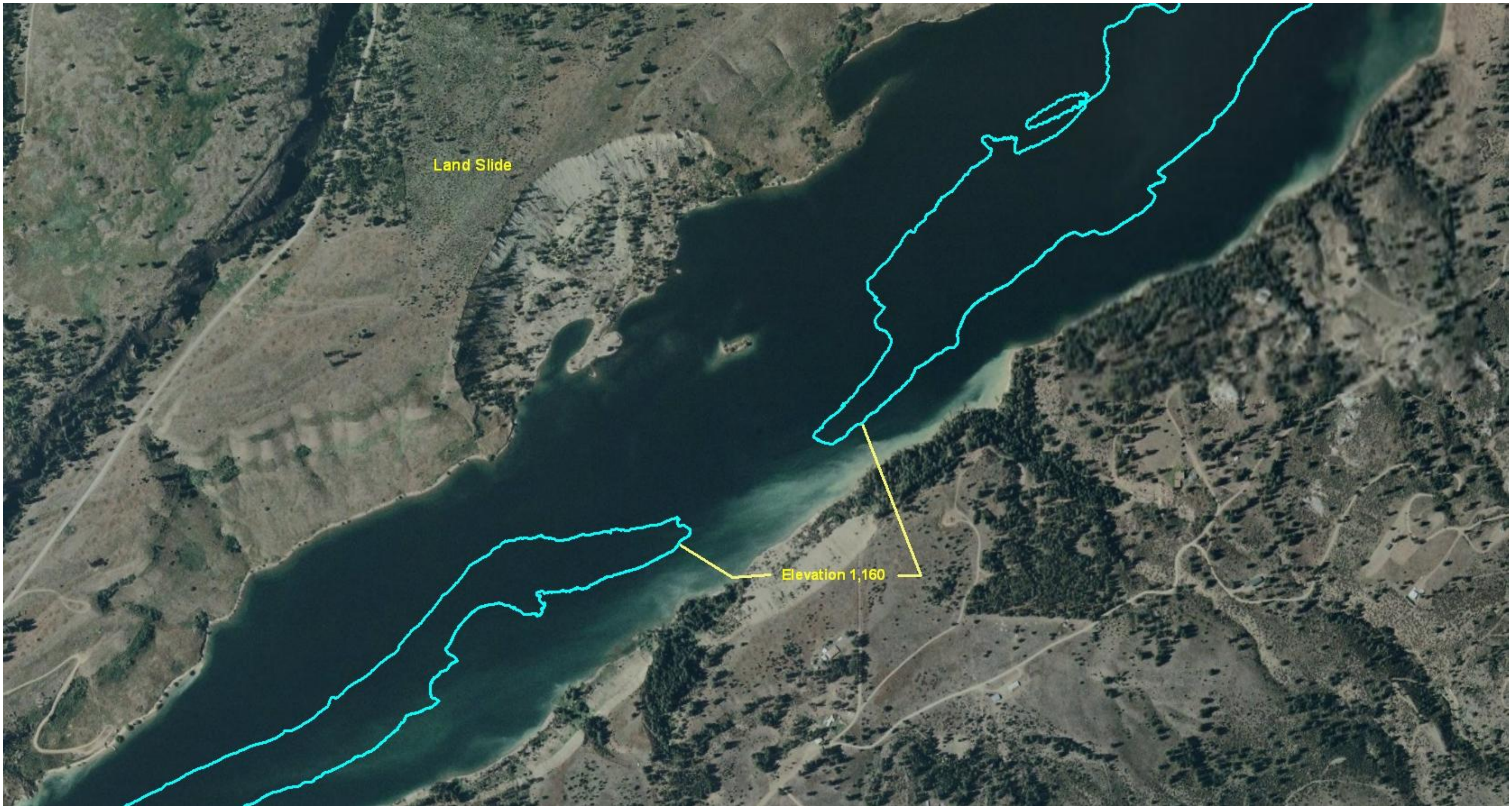

Figure 32 – Lake Roosevelt. View of major landslide on Spokane arm that has blocked the original river channel.

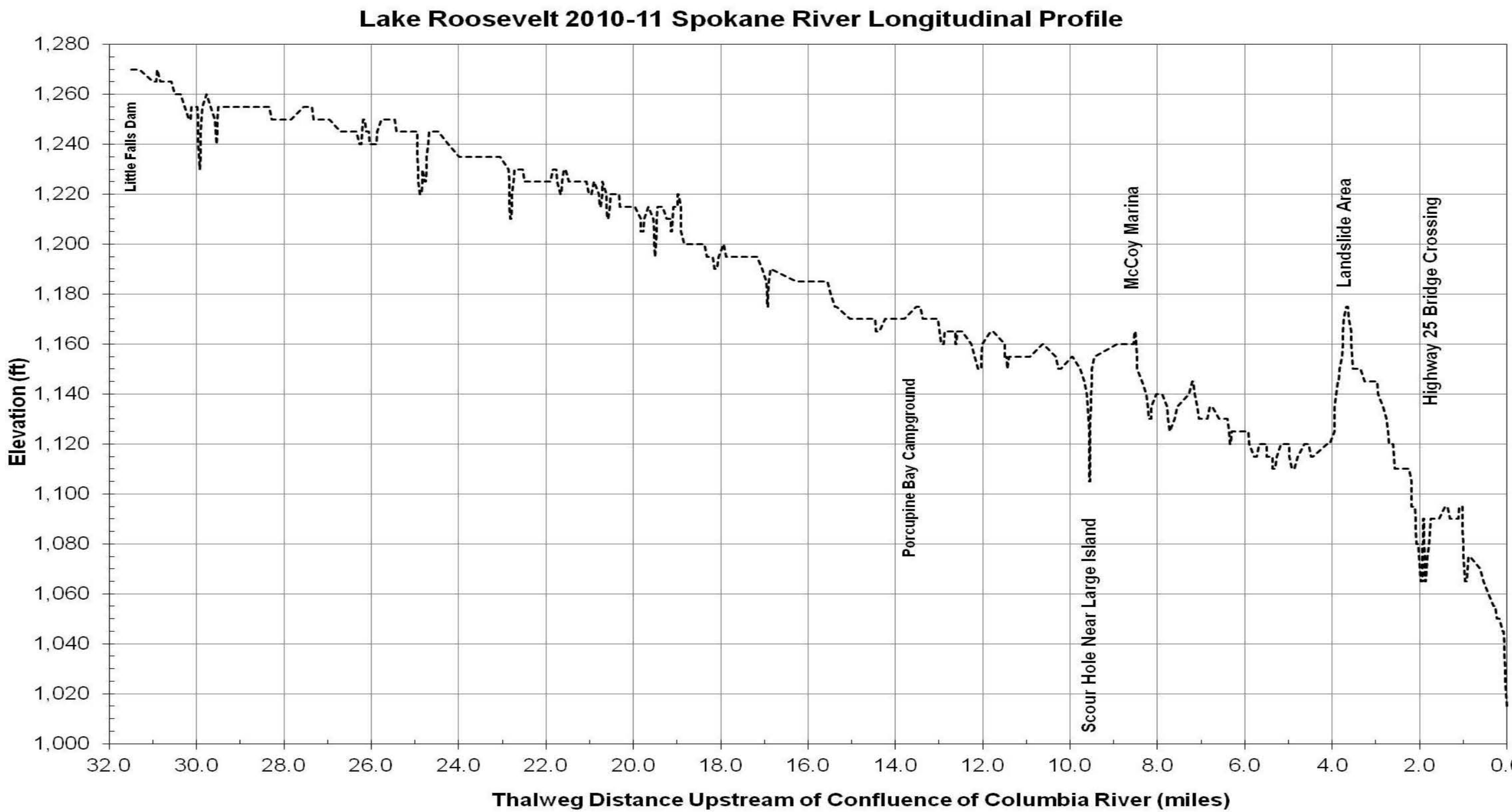

Figure 33 – Longitudinal profile of Spokane River arm of Lake Roosevelt.

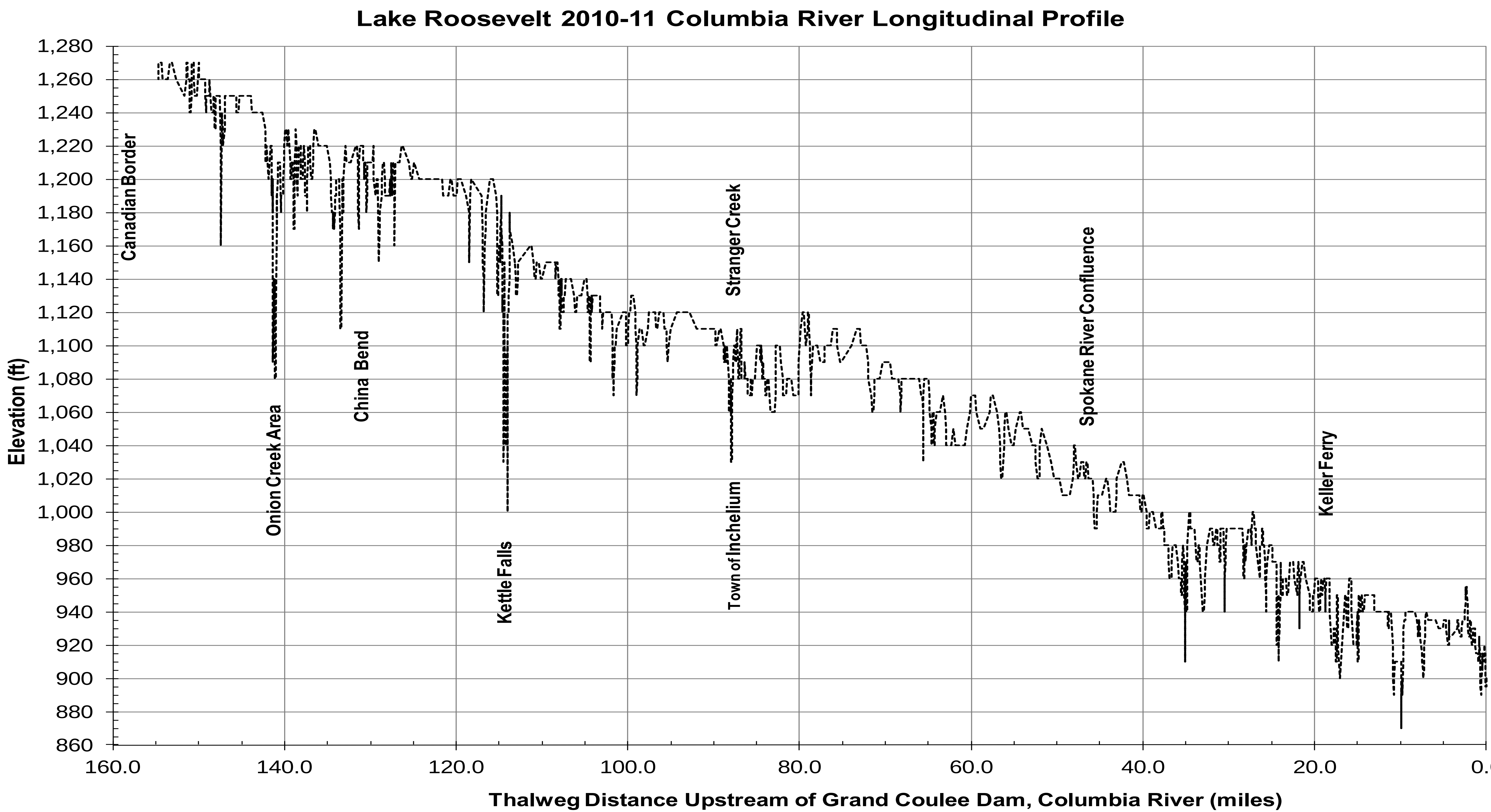

Figure 34 – Longitudinal profile of Columbia River arm of Lake Roosevelt.

RESERVOIR SEDIMENT
DATA SUMMARY

Lake Roosevelt
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: Columbia River	3. STATE: Washington
A	4. SEC 1 TWP. 28N RANGE 30 E	5. NEAREST P.O. Grand Coulee	6. COUNTY Ferry [1]
M	7. LAT 47 ° 57 ' 20 " LONG 118 ° 59 ' 02 "	8. TOP OF DAM ELEVATION: 1,311.1 [2]	9. SPILLWAY CREST EL. 1,260.0 [3]

	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. 2010-11 SURFACE AREA, ACRES	13. 2010-11 CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15. DATE STORAGE BEGAN
R	a. SURCHARGE	1,321.8 [4]	95,124	672,880	12,516,080	5/1938
E	b. FLOOD CONTROL	1,314.6	90,798	2,127,854	11,843,200	
S	c. POWER					
E	d. JOINT USE	1,290.0	81,991	5,349,560	9,715,346	16. DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION					10/1941
V	f. INACTIVE	1,208.0	47,758	4,044,742	4,365,786	
O	g. DEAD	1,026.0	6728	310,044	310,044	
I R	17. LENGTH OF RESERVOIR 187 [5] MILES		AVG. WIDTH OF RESERVOIR 0.7 MILES			

B	18. TOTAL DRAINAGE AREA 741,100 [6] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 6.8 [6] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA [6] SQUARE MILES	23. MEAN ANNUAL RUNOFF 21.3 [7] INCHES
S	20. LENGTH MILES AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 93,300,000 [7] ACRE-FEET
I N	21. MAX. ELEVATION 9900+ MIN. ELEVATION	25. ANNUAL TEMP, MEAN 51 °F RANGE -16 °F to 108 °F [7]

	26. DATE OF SURVEY	27. PER. YRS	28. PER. YRS	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVALS	31. SURFACE AREA, AC.	32. CAPACITY ACRE - FEET	33. C/I RATIO AF/AF
SURVEY	8/2011			Contour (D)	5-ft	81,991 [8]	9,715,346 [8]	0.10

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	36. WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
8/2011		93,300,000 [7]	111,800,000			

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
	[9]					

26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	b. TOTAL TO DATE	42. SEDIMENT INFLOW, PPM a. PER. b. TOT.
				[9]	[9]	

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	50-60	60-70	70-80	80-90	90-100	100-105	105-111	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

Table 1 – Reservoir Sediment Data Summary (1 of 2).

45. RANGE IN RESERVOIR OPERATION [10]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1938	979.4	956.1		1939	1,025.2	961.8	
1940	1,167.8	1,009.0		1941	1,256.8	1,127.5	
1942	1,290.0	1,236.6		1943	1,290.3	1,284.1	
1944	1,290.2	1,259.4		1945	1,290.3	1,275.8	
1946	1,289.8	1,286.6		1947	1,289.9	1,285.5	
1948	1,290.1	1,279.2		1949	1,290.0	1,277.0	
1950	1,290.0	1,270.5		1951	1,290.0	1,281.9	
1952	1,289.9	1,225.2		1953	1,290.1	1,225.8	
1954	1,290.0	1,255.6		1955	1,290.1	1,219.5	
1956	1,290.1	1,250.8		1957	1,290.0	1,240.2	
1958	1,290.1	1,244.5		1959	1,290.0	1,251.0	
1960	1,290.1	1,252.0		1961	1,290.0	1,252.5	
1962	1,290.0	1,251.8		1963	1,290.0	1,255.2	
1964	1,290.2	1,251.4		1965	1,290.0	1,255.1	
1966	1,290.0	1,224.6		1967	1,290.1	1,225.2	
1968	1,290.0	1,201.2		1969	1,290.2	1,159.5	
1970	1,290.1	1,211.8		1971	1,290.1	1,208.2	
1972	1,289.5	1,205.3		1973	1,289.8	1,156.7	
1974	1,289.9	1,212.2		1975	1,289.9	1,212.2	
1976	1,290.3	1,217.8		1977	1,289.1	1,237.2	
1978	1,290.1	1,223.2		1979	1,288.2	1,223.0	
1980	1,290.1	1,224.6		1981	1,290.1	1,257.6	
1982	1,289.9	1,211.1		1983	1,289.9	1,218.5	
1984	1,289.5	1,238.4		1985	1,288.1	1,215.6	
1986	1,289.6	1,241.9		1987	1,288.7	1,275.3	
1988	1,289.4	1,241.7		1989	1,288.7	1,220.7	
1990	1,289.9	1,255.4		1991	1,289.8	1,221.8	
1992	1,289.6	1,262.8		1993	1,289.2	1,254.6	
1994	1,286.4	1,263.9		1995	1,289.6	1,253.3	
1996	1,289.7	1,227.2		1997	1,289.9	1,208.6	
1998	1,289.7	1,252.3		1999	1,289.9	1,213.4	
2000	1,287.8	1,233.9		2001	1,287.3	1,216.7	
2002	1,289.4	1,240.0		2003	1,289.5	1,265.2	
2004	1,289.6	1,258.5		2005	1,289.6	1,252.8	
2006	1,289.6	1,230.9		2007	1,289.9	1,247.8	
2008	1,289.3	1,228.4		2009	1,289.4	1,257.7	
2010	1,289.7	1,259.2		2011	1,290.0	1,217.7	

46. ELEVATION - AREA - CAPACITY - DATA FOR **2010-11**

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2010-11	**SURVEY**	[9]	865.0	0	0	900.0	26	221
950.0	1,339	22,171	1,000.0	4,550	163,956	1,026.0	6,728	310,044
1,050.0	8,972	497,717	1,075.0	11,964	758,059	1,100.0	16,073	1,106,004
1,110.0	18,076	1,276,622	1,120.0	20,318	1,468,200	1,130.0	22,957	1,684,455
1,140.0	25,603	1,927,174	1,150.0	28,240	2,196,384	1,160.0	31,152	2,492,907
1,170.0	34,331	2,820,285	1,180.0	37,488	3,179,421	1,190.0	40,746	3,570,255
1,200.0	44,603	3,996,521	1,208.0	47,758	4,365,786	1,220.0	52,920	4,969,268
1,230.0	57,331	5,520,927	1,240.0	62,346	6,118,683	1,250.0	66,375	6,763,427
1,260.0	70,035	7,446,416	1,270.0	73,324	8,163,965	1,280.0	77,435	8,917,229
1,290.0	81,991	9,715,346	1,300.0	85,694	10,554,200	1,310.0	89,248	11,429,100
1,314.6	90,798	11,843,200	1,320.0	94,582	12,345,350	1,321.8	95,124	12,516,080

47. REMARKS AND REFERENCES

[1] Ferry, Grant, Lincoln, Okanogan and Stevens Counties.

[2] Elevation in feet. Vertical datum NGVD29 (Adjusted in 1947). Add 2.5 feet to shift to NAVD88. Top Parapet wall elevation 1,314.58.

[3] Spillway center of original dam. Top gate elevation, closed, 1,288.0, with 2-foot flash boards raised the normal operation to elevation 1290.0.

[4] Elevations from Reclamation online information. www.usbr.gov/projects

[5] Reservoir length and drainage area information from 2010-11 study. Columbia River 155 miles, Spokane River 32 miles.

[6] Total drainage area above reservoir. Net area affected by numerous reservoir in Canada and on Spokane arm.

[7] Bureau of Reclamation Project Data Book, 1981 and www.usbr.gov. BOR publications state average inflow 93,300,000 acre-feet.

[8] 2010-11 capacities computed by Reclamation's ACAP program.

[9] First detailed survey of reservoir. Not able to compute sediment values by comparing to original values.

[10] End of month maximum and minimum elevations. No inflow values available. BOR publications states average inflow 93,300,000 acre-feet.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE June 2012

Table 1 – Reservoir Sediment Summary (2 of 2).

1	2	3	4	5
	2010-11	2010-11	2010-11	
Elevations	Total	Total	Active	Percent of
	Area	Capacity	Capcity	Reservoir
(feet)	(acres)	(acre-feet)	(acre-feet)	Depth
1,321.8	95,124	12,516,080		
1,314.6	90,798	11,843,200	7,477,412	100.0
1,300.0	85,694	10,554,200	6,188,415	96.8
1,290.0	81,991	9,715,346	5,349,560	94.5
1,280.0	77,435	8,917,229	4,551,443	92.3
1,260.0	70,035	7,446,416	3,080,630	87.9
1,240.0	62,346	6,118,683	1,752,897	83.4
1,220.0	52,920	4,969,268	603,482	79.0
1,208.0	47,758	4,365,786	0	76.3
1,200.0	44,603	3,996,521		74.5
1,180.0	37,488	3,179,421		70.1
1,160.0	31,152	2,492,907		65.6
1,140.0	25,603	1,927,174		61.2
1,120.0	20,318	1,468,200		56.7
1,100.0	16,073	1,106,004		52.3
1,080.0	12,681	819,583		47.8
1,060.0	10,085	592,843		43.4
1,040.0	7,973	413,096		38.9
1,020.0	6,193	271,316		34.5
1,000.0	4,550	163,956		30.0
980.0	3,089	88,372		25.6
960.0	1,918	38,390		21.1
940.0	868	11,160		16.7
920.0	171	1,811		12.2
900.0	26	221		7.8
880.0	2	11		3.3
865.0	0	0		0.0

1 Elevation of reservoir water surface. (Project vertical datum, 2.5 feet less than NAVD88).

2 2010-11 reservoir surface area. Areas derived from 2010-11 bathymetric study.

3 2010-11 reservoir capacity computed using ACAP.

4 Reservoir active capacity between elevation 1,208.0 through 1,290.0.

5 Depth of reservoir expressed in percentage of total depth, 449.6 feet, (Top of Dam).

Table 2 – 2010-11 Lake Roosevelt Survey Summary.

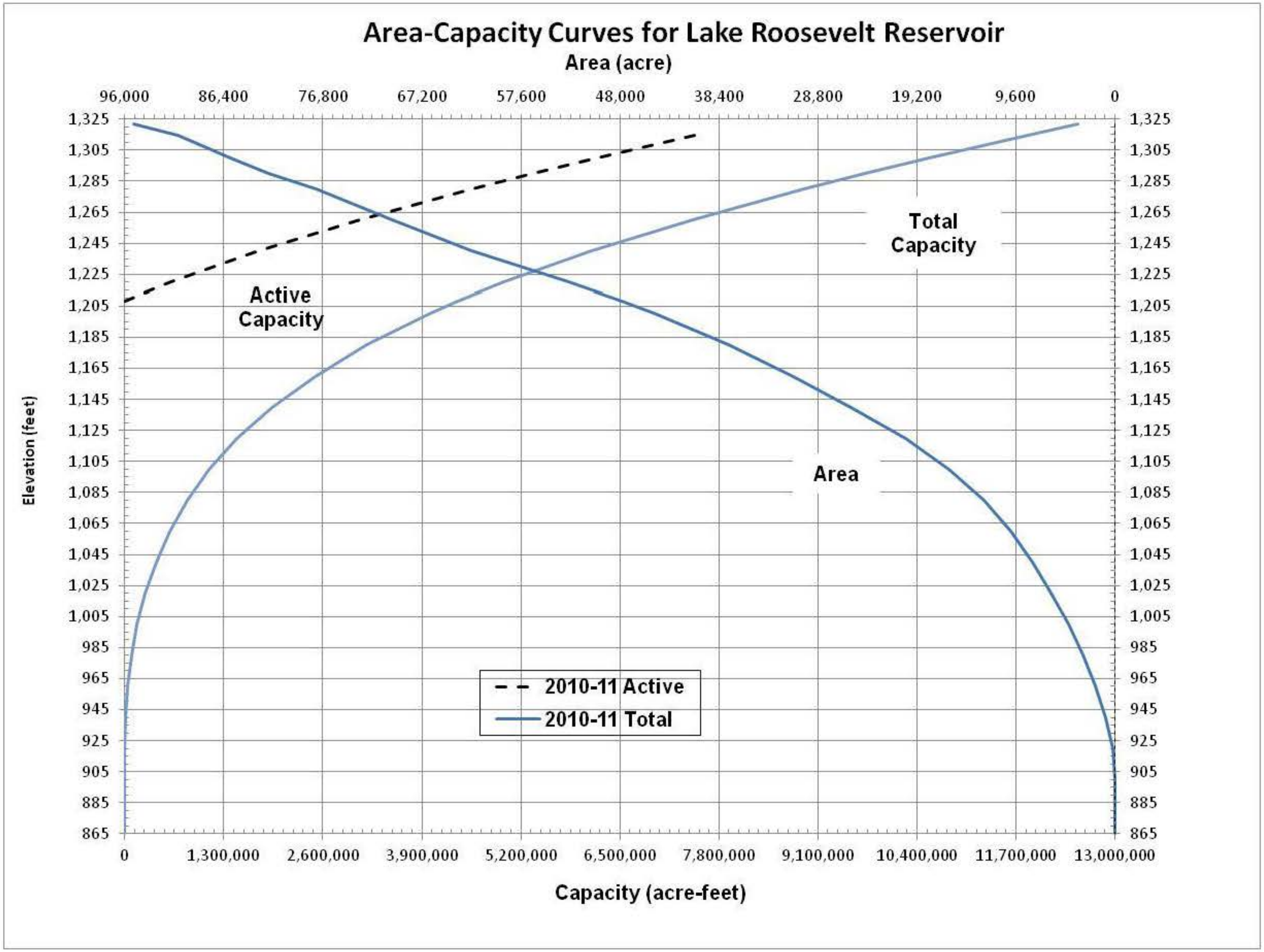

Figure 35 – Lake Roosevelt 2010-11 Area and Capacity Plots.

Summary and Conclusions

This Reclamation report presents the results of a bathymetric survey of Lake Roosevelt that began in October 2010 and was completed in August 2011. The primary objective of the study was to map the reservoir area not covered by a 1974 aerial survey flown near reservoir elevation 1,160. The 2010-11 study was the first survey to develop detailed topography below elevation 1,160. In 2007 the Colville Tribe conducted a bathymetric survey on the upper portion of the reservoir from the Kettle Falls area upstream to near the Canadian border that was part of this analysis. In January 2012, LiDAR data was obtained from the USACE that was collected in November 2009 and March 2010 near reservoir elevation 1,280. These data sets covered the majority of the upper contours of the main body of the reservoir and where this information was lacking, USGS quad contours were digitized to enclose the reservoir. The 1974, 2007, and 2009-10 contours, along with the digitized contours, were combined with the 2010-11 bathymetric data to generate new topography of the total reservoir area.

The primary objectives of the survey were to gather data needed to:

- develop reservoir topography
- provide the reservoir topography in a digital format
- compute area-capacity relationships

A control survey was conducted using the on-line positioning user service (OPUS) and RTK GPS to establish a horizontal and vertical control network of the reservoir for the bathymetric survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The GPS base was set over temporary bench marks throughout the reservoir from the Crescent Bay boat ramp near the dam upstream about 134 reservoir miles to the boat ramp at Northport. The OPUS generated coordinates were used during the bathymetric survey to determine positions and the vertical shift relative to NAVD88 and the measured water surface elevations of the reservoir recorded at the dam.

The horizontal control, in feet, was established in Washington state plane coordinates, north zone, on the North American Datum of 1983 (NAD83). The vertical control, in feet, was tied to the Grand Coulee project vertical datum and NAVD88. RTK GPS water surface measurements were periodically collected and a comparison to the reservoir water surface recorded by the Reclamation gage found they were around 2.5 feet lower than NAVD88 for the area from the dam upstream to Kettle Falls. Above Kettle Falls the measured water surface sloped upward and the shift increased from about 2.8 feet at Onion Creek to about 3.4

feet at Northport. These shifts in the upper reservoir area above Kettle Falls were measured in October of 2010 when the bathymetry was collected for this study. It should be noted that these measured shifts are dependent on the reservoir conditions with the biggest factors affecting the water surface slope being the river inflow capacity and the level of the reservoir. In December of 2010 a difference of around 5.0 feet was measured at Northport. Unless otherwise noted, all elevations in this report are referenced to the project vertical datum that is 2.5 feet lower than NAVD88. The developed reservoir topography presented in this report was tied to NAVD88. The computed surface areas and reservoir volumes from the developed reservoir topography were shifted to the project vertical datum for reservoir water operation purposes.

The October 2010 and June, July, and August 2011 underwater surveys were conducted between reservoir elevation 1,260 and 1,290 feet as measured by the Reclamation gage at the dam. The bathymetric survey used sonic depth recording equipment interfaced with GPS receivers for determining sounding locations within the reservoir navigated by the survey vessels. The system continuously recorded depth and horizontal coordinates as the vessels navigated throughout the reservoir. Grid lines that covered the deeper portions of the reservoir were laid out for the boats to follow for mapping purposes. The positioning system provided information to the boat operator to maintain a course along these lines and the previously collected data. The resulting surface areas from the developed topography were shifted to match the project elevations. The 2010-11 area and capacity tables were produced from a computer program that used the measured surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985). Lake Roosevelt 2010 area and capacity values are illustrated on Figure 35 and listed on Tables 1 and 2. The measured total capacity of the reservoir was 9,715,346 acre-feet at reservoir elevation 1,290.0.

The 2010-11 Lake Roosevelt topography was generated using ArcGIS 10 and will need to be opened or viewed with that version or later if using ArcGIS. The ESRI files of the geodatabase contain feature classes that represent the raster coverage and derived contours developed for the 2010-11 study. The coverages have metadata attached. The data is tied to the Washington state plane north coordinate system in NAD83. The elevations are tied to NAVD88 in feet and need to be shifted downward 2.5 feet to match Grand Coulee and Lake Roosevelt project elevations.

The data coverage is available online under the project gallery for the Sedimentation and River Hydraulics Group, Technical Service Center of the Bureau of Reclamation at:

http://www.usbr.gov/pmts/sediment/

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