NELSON RESERVOIR
1999 RESERVOIR SURVEY

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The Bureau of Reclamation (Reclamation) surveyed Nelson Reservoir in May 1999 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The underwater survey was conducted near reservoir elevation 2,218 feet (project datum). The underwater survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portions of the reservoir covered by the survey vessel. The above-water topography was determined by digitizing the water surface contour line from the U.S. Geological Survey quadrangle (USGS quad) maps of the reservoir area. The new topographic map of Nelson Reservoir was developed from the combined 1999 underwater measured topography and the digitized water surface contour. As of May 1999, at maximum conservation water surface elevation (feet) 2,221.6, the surface area was 4,331 acres with a total capacity of 78,950 acre-feet.

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NELSON RESERVOIR

1999 RESERVOIR SURVEY

by

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Denver, Colorado

July 2001

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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Ronald Ferrari and James Melena of the TSC conducted the hydrographic survey. Ronald Ferrari completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes of the TSC completed the final map development. James Melena performed the technical peer review of this documentation.

U.S. Department of the Interior Mission Statement

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.

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INTRODUCTION

Nelson Reservoir is an offstream storage facility of the Milk River Project located about 19 miles northeast of Malta, Montana (figure 1). The reservoir is formed by five dikes designated as Nelson Dikes A, B, C, D, and DA, with DA being the largest with a structural height of 28 feet and a hydraulic height of 21.6 feet. Dikes C and DA were originally constructed in 1915 by the U.S. Reclamation Service. In 1922, Dikes C and DA were raised around 11 feet and Dikes A, B, and D were constructed to enlarge the reservoir. The five dikes are homogeneous earth embankments with structural heights varying from 5 to 28 feet. The dikes have crest width that vary from 18 to 26 feet and a crest length of 9,900 feet at elevation 2,228.0 (feet)[1]. Numerous surveys have been conducted over the years indicating settlement at some dike locations with measured elevations below the design crest elevation 2,228.0. The reservoir had an original total storage capacity of 79,224 acre-feet at elevation 2221.6 with a dead storage capacity of 18,650 acre-feet at elevation 2200.0. The reservoir has a maximum design capacity at elevation 2223.0, but it has never operated above elevation 2221.6.

Nelson is an offstream storage reservoir with no designed spillway. All reservoir releases are through the outlet works requiring the dam tender to prevent dike overtopping while preventing discharges from overtopping the canal banks. The reservoir has two outlet works, one through Dike C with discharges up to 550 cubic feet per second (cfs) to the Nelson North Canal that discharges into the Milk River and through Dike DA with discharges up to 250 cfs to the Nelson South Canal used for project irrigation.

The drainage area above the Nelson Reservoir dikes is around 35.2 square miles with normal base inflow from the drainage area being essentially zero. Nelson Reservoir has an average width of 0.7 miles and a length of 9 miles at elevation 2221.6.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1999 results of the survey of Nelson Reservoir. The primary objectives of the survey were to gather data needed to develop reservoir topography and compute present area-capacity relationships. Prior to the underwater survey in May of 1999, a static global positioning system (GPS) control survey was conducted by a private contractor to establish horizontal and vertical control points around the reservoir (see table 1). The horizontal control was established in Montana State plane coordinates in the North American Datum of 1983 (NAD83). The vertical control for the established points was in the National Geodetic Vertical Datum of 1929 (NGVD29) and the North American Vertical Datum of 1988 (NAVD88). The survey determined that for these established points the average elevations in NGVD29 were around 2.46 feet lower than in NAVD88. During the May 1999 underwater survey, the average reservoir water surface recorded by the Reclamation gauge was elevation 2218 which was around 1.7 feet lower than the NGVD29 GPS measured water surfaces at the same time. All computations in this report are based on the Reclamation gauge project datum which is 1.70 feet lower than NGVD29.

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[1]Elevation levels are shown in feet. All elevations in this report are based on the original project datum established by U.S. Bureau of Reclamation which is 1.70 feet lower than National Geodetic Vertical Datum of 1929.

The bathymetric survey was run using sonic depth recording equipment interfaced with a differential global positioning system capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat, as it was navigated along grid lines covering Nelson Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. Water surface elevations recorded by a Reclamation gauge during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations.

Since an above water survey wasn't conducted for this study, the Nelson Reservoir water surface contour (labeled elevation 2,222.0) was digitized from the U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps. To match the Reclamation project datum this contour elevation was reduced 1.7 feet and assigned an elevation of 2,220.3. The new topographic map of Nelson Reservoir is a combination of the digitized and underwater-measured topography. The 1999 reservoir surface areas at predetermined contour intervals were generated by a computer graphics program using this combined reservoir data. The 1999 area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 2 and 3 contains a summary of the 1999 Nelson Reservoir survey. The 1999 survey determined that the reservoir has a total storage capacity of 78,950 acre-feet and a surface area of 4,331 acres at reservoir elevation 2,221.6.

RESERVOIR OPERATIONS

Nelson Reservoir operates in conjunction with several other reservoirs of the Milk River Project to provide irrigation water. The May 1999 area-capacity tables show 78,950 acre-feet of total storage below elevation 2,221.6. The 1999 survey measured a minimum reservoir bottom elevation of 2,174.8. The dead storage below elevation 2,220.0 was measured as 18,140 acre-feet.

The Nelson Reservoir inflow and end-of-month stage records are listed on the second page of table 1 for water year 1947 through May 1999. These records were the only ones readily available of the reservoir operation that actually began in 1916. The estimated average inflow into the reservoir for this available recorded period was 39,600 acre-feet per year. Since 1947, the recorded storage fluctuations of Nelson Reservoir ranged from an end of month elevation 2,200.5 in 1984 to a maximum end-of-month elevation 2,221.4 in 1960.

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. The hydrographic system contained on the survey vessel consisted of a GPS receiver with a built-in radio and an omnidirectional antenna, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting underwater data. Power to the equipment was supplied by an on-board generator. The equipment was also mounted in a smaller flat bottom boat for the shallow water areas, but the rainy and breezy conditions during the time of the survey did not safety allow much use of the small boat setup during the time of this survey.

The shore equipment included an identical second GPS receiver with radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. To obtain the maximum radio transmission range, known datum points with clear line-of-sight to the survey boat were selected. The power for the shore unit was provided by a 12-volt battery.

GPS Technology and Equipment

The hydrographic positioning system used at Nelson Reservoir was Navigation Satellite Timing and Ranging (NAVSTAR) GPS, an all-weather, radio-based, satellite navigation system that enables users to accurately determine three-dimensional position. The NAVSTAR system's primary mission is to provide passive global positioning and navigation for land-, air-, and sea-based strategic and tactical forces and is operated and maintained by the Department of Defense (DOD). The GPS receiver measures the distances between the satellites and itself and determines the receiver's position from intersections of the multiple-range vectors. Distances are determined by accurately measuring the time a signal pulse takes to travel from the satellite to the receiver.

The NAVSTAR system consists of three segments:

- The space segment is a network of 24 satellites maintained in a precise orbit about 10,900 nautical miles above the earth, each completing an orbit every 12 hours.

- The ground control segment tracks the satellites, determining their precise orbits. Periodically, the ground control segment transmits correction and other system data to all the satellites, and the data are then retransmitted to the user segment.

- The user segment includes the GPS receivers which measure the broadcasts from the satellites and calculate the position of the receivers.

The GPS receivers use the satellites as reference points for triangulating their position on earth. The position is calculated from distance measurements to the satellites that are determined by how long a radio signal takes to reach the receiver from the satellite. To calculate the receiver's position on earth, the satellite distance and the satellite's position in space are needed. The satellites transmit signals to the GPS receivers for distance measurements along with the data messages about their exact orbital location and operational status. The satellites transmit two "L" band frequencies (called L1 and L2) for the distance measurement signal. At least four satellite observations are required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time); the time unknown is caused by the clock error between the expensive satellite atomic clocks and the imperfect clocks in the GPS receivers. For hydrographic surveying, the altitude, Nelson's water surface elevation parameter was known, which in theory meant only three satellite observations were needed to track the survey vessel. During the Nelson Reservoir survey, the best available satellites were used for position calculations which usually consisted of 5 or more.

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision and the geometric position of the satellites. Precision is affected by several factors--time, because of the clock differences, and atmospheric delays caused by the effect on the radio signal of the ionosphere. Geometric dilution of precision (GDOP) describes the geometrical uncertainty and is a function of the relative geometry of the satellites and the user. Generally, the closer together in angle two satellites are from the receiver, the greater the GDOP. GDOP is broken into components: position dilution of precision (x,y,z) (PDOP), and horizontal dilution of precision (x,y) (HDOP). The components are based only on the geometry of the satellites. The PDOP and HDOP were monitored at the survey vessel's GPS receiver during the Nelson Reservoir Survey, and for the majority of the time they were less than 3, which is within the acceptable limits of horizontal accuracy for Class 1 and 2 level surveys (Corps of Engineers, 1994).

An additional and larger error source in GPS collection is caused by false signal projection, called selective availability (S/A). The DOD implements S/A to discourage the use of the satellite system as a guidance tool by hostile forces. Positions determined by a single receiver when S/A is active can have errors of up to 100 meters.

A method of collection to resolve or cancel the inherent errors of GPS (satellite position or S/A, clock differences, atmospheric delay, etc.) is called differential GPS (DGPS). DGPS are used during the reservoir survey to determine positions of the moving survey vessel in real time. DGPS determines the position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties. Differential positioning is not concerned with the absolute position of each unit but with the relative difference between the positions of two units, which are simultaneously observing the same satellites. The inherent errors are mostly canceled because the satellite transmission is essentially the same at both receivers.

At a known geographical benchmark, one GPS receiver is programmed with the known coordinates and stationed over the geographical benchmark. This receiver, known as the master or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the necessary corrections or differences are transmitted to the mobile GPS receiver on the survey vessel. For the Nelson Reservoir, position corrections were determined by the master receiver and transmitted via a ultra-high frequency (UHF) radio link every second to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS can result in sub-meter positional accuracies for the survey vessel compared to positional accuracies of 100 meters with a single receiver.

The Sedimentation and River Hydraulics Group began using Real-time Kinematic (RTK) GPS in the spring of 1999. The major benefits of RTK versus DGPS are that precise heights can be measured in real time for monitoring water surface elevation changes along with the precise positions. The basic outputs from an RTK receiver are precise 3D coordinates in latitude, longitude, and height with accuracies in the order of 2 centimeters horizontally and 3 centimeters vertically. This output is on the GPS datum of WGS-84 which the hydrographic collection software converted into Montana's NAD83 state plane coordinate system. RTK GPS system employs two receivers that track the same satellites simultaneously just like with DGPS. The receivers track the L1 C/A code and full cycle L1 and L2 carrier phases. The additional data logged from the second frequency allows the on-the-fly centimeter level measurements.

Survey Method and Equipment

The Nelson Reservoir hydrographic survey collection was conducted on May 8 through May 13, 1999 near water surface elevation 2,218 (Reclamation project datum). The bathymetric survey was run using sonic depth recording equipment interfaced with an RTK GPS capable of determining sounding locations within the reservoir. The survey system continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across close-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run somewhat in a perpendicular direction to the center line of the reservoir at 300-foot spacing (figure 2). Data was also collected along the shore as the boat traversed to the next transects. The figure shows that the western portion of the reservoir was not as densely collected. This was due to the weather and shallow conditions of the reservoir during the time of collection. A small boat set up was used to collect shoreline data in this portion of the reservoirs prior to rain returning to the area. The equipment was transferred back to the larger boat to complete the collection of the interior portion of this portion of the reservoir prior to the heavy rains and winds. To access the western area the boat maneuvered through the narrow portion of the reservoir plowing through the soft reservoir bottom conditions. Once in the larger western body of the reservoir, visual cross sections were run about 1000 feet apart. The collected data found the bottom to be very vegetated and fairly flat from bank to bank. Due to these conditions and deterioration of the weather conditions a decision was made that adequate underwater data was collected. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing.

The 1999 underwater data were collected by a depth sounder that was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. The collected data were digitally transmitted to the computer collection system via an RS-232 port. The depth sounder also produces an analog hard-copy chart of the measured depths. These graphed analog charts were printed for all survey lines as the data were collected and recorded by the computer. The charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the recorded computer bottom depths, the computer data files were modified. The water surface elevations at the dam, recorded by a Reclamation gage at 15-minute intervals, were used to convert the sonic depth measurements to true lake-bottom elevations.

Nelson Reservoir Datums

Prior to the underwater survey in May of 1999, a static global positioning system (GPS) control survey was conducted to establish horizontal and vertical control points around the reservoir by a private contractor. The horizontal control was established in Montana State plane coordinates in

NAD83. The vertical control for the established points was in NGVD29 and NAVD88. The survey found that for the established points the average elevations in NGVD29 were around 2.46 feet lower than in NAVD88. The results from the static survey are listed on table 1.

This control network was used during the May 1999 underwater survey for measuring horizontal and vertical data using RTK GPS measuring techniques. This included periodic water surface measurements. A comparison of the reservoir water surface recorded by the Reclamation gauge every 15 minutes found it was around 1.7 feet lower than the NGVD29 GPS measured water surface at the same time. It must be noted that all computations in this report are based on the Reclamation gauge project datum.

The Montana Area Office of the Bureau of Reclamation performed additional surveys to verify the datum shifts. These surveys determined the original construction datum for Nelson Dikes are 1.7 feet lower then NGVD29 and all USGS quadrangle elevations should be reduced 1.7 feet to match the original construction datum. These surveys also checked the hydromet instrumentation that is located on the Nelson South Control Structure. The hydromet measures the reservoir elevations that are tied to the top of the Nelson South Control Structure whose original construction elevation was 2228.0 (Reclamation datum). The survey measured the top elevation to be within 0.05 feet of the original control datum, confirming it should continue to be used to check the hydromet measurements.

RESERVOIR AREA AND CAPACITY

Topography Development

Using ARC/INFO the topography of Nelson Reservoir was developed from the 1999 collected underwater data and USGS quad maps. ARC/INFO is a software package for development and analysis of geographic information system (GIS) layers and development of interactive GIS applications (ESRI, 1992). GIS technology provides a means of organizing and interpreting large data sets.

The upper contours of Nelson Reservoir were developed by digitizing the water surface contour line from the USGS quad maps that covered the Nelson Reservoir area. These contour lines were compiled from aerial photographs taken in 1977. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Montana's NAD 1983 state plane coordinates using the ARC/INFO PROJECT command. The quad's water surface contour was labeled elevation 2,222 in NGVD29. As noted previously, the 1999 GPS surveys estimated that the Nelson Reservoir Reclamation project datum was around 1.7 feet lower than NGVD29. For map development this digitized contour was assigned a vertical elevation of 2,220.3 (elevation 2,222.0 - 1.7 feet).

U.S. BUREAU OF RECLAMATION

NELSON RESERVOIR

1999 STATIC GPS CONTROL SURVEY

CONTRACT #1425-98-CA-60-00090

					Montana State Plane				
Point #	Latitude	Longitude	Ellipsoid		NAD83(1992)		NAVD 88		NGVD 29
	NAD83(1992)	NAD83(1992)	Height		Northing	Easting	Elevation		Elevation
			Meters		Meters	Meters	Meters		Meters
NEL-1	48°° 29' 1.25705" N	107°° 35' 2.65157" W	664.121		472190.6320	741582.1942	680.839		680.091
NEL-2	48°° 29' 36.08509" N	107°° 39' 11.13578" W	670.309		473143.3166	736457.1524	687.056		686.304
NRD-NDA1	48°° 31' 49.92448" N	107°° 31' 6.26810" W	663.635		477518.2664	746301.6713	680.421		679.677
NRD-NDA2	48°° 31' 17.65837" N	107°° 31' 12.68305" W	663.637		476518.8441	746195.3220	680.407		679.664
US REC BM	48°° 32' 23.37515" N	107°° 31' 4.26759" W	657.475		478551.9740	746316.5512	674.278		673.534
LAKESIDE	48°° 25' 34.92034" N	107°° 40' 24.88469" W	678.555		465662.7213	735117.4895	695.190		694.442
NELSON	48°° 30' 48.80439" N	107°° 33' 18.18278" W	693.904		475563.5849	743643.7325	710.669		709.922
MORAINE	48°° 30' 19.89407" N	107°° 34' 13.65634" W	701.924		474642.9345	742527.9031	718.677		717.930
L439	48°° 35' 2.81217" N	107°° 44' 9.20971" W	666.310		483089.5240	730113.4979	683.175		682.414
M439	48°° 33' 50.84596" N	107°° 45' 41.40358" W	677.701		480825.3718	728274.2890	694.541		693.775
P539	48°° 25' 55.89251" N	107°° 39' 34.05285" W	668.891		466334.5995	736146.6671	685.533		684.788
R539	48°° 26' 17.04019" N	107°° 35' 42.02256" W	679.683		467101.4268	740897.5050	696.318		695.568
T539	48°° 26' 16.82546" N	107°° 33' 3.07303" W	671.183		467175.1427	744162.6299	687.799		687.051
W539	48°° 27' 1.94862" N	107°° 29' 24.96772" W	658.847		468681.3083	748606.8826	675.451		674.717

Notes:

The horizontal coordinates were established by GPS observation and were adjusted to NGS "B" order stations LAKESIDE and NELSON.

Elevation values are based upon GPS observation.

NAVD 88 Elevations are based upon NGS Published values which were held at stations L439, M439, P539, R539, T539, and W539.

NGVD 29 Elevations are based upon the NGS "SUPERSEDED SURVEY CONTROL" value held at station MORAINE.

Table 1 - 1999 Nelson Reservoir Static GPS Control Survey

The elevation 2,220.3 contour digitized from USGS quad maps was used to perform a clip or boundary around the edge of the underwater data set such that interpolation was not allowed to occur outside of this boundary. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. The underwater collected data and digitized 2,220.3 contour from the USGS quad maps are plotted on figure 2.

Contours for elevations 2,220.3 and below were computed from the underwater data set using the triangular irregular network (TIN) surface modeling package within ARC/INFO. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values. TIN was designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation where triangles are formed among all data points within a polygon or the boundary clip. This method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data preserving all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in great detail in the ARC/INFO V7.0.2 *Users Documentation, (ESRI, 1992).*

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Nelson Reservoir TIN. In addition, the contours were generalized by weeding out vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had little bearing on the computation of surface areas and volumes for Nelson Reservoir since the areas were calculated from the developed TIN. The contour topography at 2-foot intervals is presented on figure 3 through 8, drawing numbers 15 -D-282 through 15-D-287.

Development of 1999 Contour Areas

The 1999 contour surface areas for Nelson Reservoir were computed at 1-foot increments, from elevation 2,175.0 to 2,220.0, using the Nelson Reservoir TIN discussed above. The 1999 survey measured the minimum reservoir elevation at 2,174.8. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user specified elevations directly from the TIN and takes into consideration all regions of equal elevation. Due to the lack of 1999 survey data above elevation 2,215, (survey conducted near water surface elevation 2,218), the final 1999 area computations assumed no change in surface area from elevation 2,215 and above from the original measured areas.

As discussed in the previous section the USGS quad water surface contour was used as a clip to develop contours from the underwater data collection in May 1999. To match the Reclamation project datum the assigned water surface contour elevation of 2,222.0 was reduced 1.7 feet and assigned an elevation of 2,220.3. The area of this digitized enclosed polygon, minus the areas of the islands that were located within, was found to be around 4,127 acres. From the April 24, 1922-area-capacity tables, the original surface area for elevation 2,220.3 was listed as 4,124 acres.

1999 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). Starting from the 1999 minimum elevation 2,174.8, the 1999 measured surface areas from elevation 2,176.0 to elevation 2,214.0 and the original surface areas from elevation 2,215.0 to 2,223 were used as control parameters for computing the 1999 Nelson Reservoir capacity. The program can compute an area and capacity at elevation increments 0.01- to 1.0-foot by 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 Nelson Reservoir. The capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from a 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. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

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

where:

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

Results of the 1999 Nelson Reservoir area and capacity computations are listed in table 2 and columns (4) and (5) of table 3. Listed in columns (2) and (3) of table 2 are the original surface areas and recomputed capacity values. A separate set of 1999 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation 1999). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1999 area-capacity curves are plotted on figure 9. As of May 1999, at active conservation elevation 2,221.6, the surface area was 4,331 acres with a total capacity of 78,950 acre-feet and an active capacity of 60,810 acre-feet.

Analyses of Results

The Nelson Reservoir original and 1999 area and capacity values are illustrated on the figure 9 and the results are listed on table 2 and 3. Since Nelson Reservoir operation began in 1916, the measured total volume change at reservoir elevation 2,215.0 was estimated to be 446 acre-feet. These presentations illustrate the little capacity difference that has occurred during the 83 years of reservoir operations. This is a very minimal change for this length of operation, but is reasonable assuming minimum sediment inflow from the diverted flows and due to the different methods used to survey and calculate the original and 1999 surface areas. It must be noted that the 1999 measured surface areas for elevations 2,214.0 and below and the original surface areas for elevation 2,215.0 and above were used to develop the 1999 capacity values. This was due to the fact the reservoir water surface elevation was near 2,218 during time of underwater collection and no above water data was collected in 1999. As indicated previously the digitized surface area of the USGS quad contour labeled 2,222 (adjusted to elevation 2,220.3 to match the project datum) is nearly the same as the original measure surface area at the same elevation. The original surface areas are from a 1921 topography survey and the USGS quads were compiled from aerial photographs taken in 1977. The original capacity in column 3 was recomputed using the original area values for comparison purposes. There were no original area values available below elevation 2,200, but several publications indicated that the original capacity below elevation 2,200 was 18,650 acre-feet.

The area comparison plot of figure 9 illustrates the large jump in surface areas for both the original and 1999 measured surface areas. For the original survey, the jump occurred between elevation 2,213 and 2,214. For the 1999 survey the large jump in measured surface area occurred between elevation 2,211 and 2,212. A datum shift between the surveys is possible, but the original and 1999 surface areas for elevations 2,208 through 2,211 were very close. As illustrated on figure 2 there was limited data collected in 1999 in the western portion of the reservoir due to the shallow water and weather conditions during the survey. There may be some high spots in this area that were not measured and contoured in 1999. Another theory is that the original survey measured larger islands throughout the reservoir that have since been reduced in size, above elevation 2,213 due to reservoir wave action. If this has occurred, the eroded material would have settled in the lower elevations of the reservoir as the 1999 survey measured. This eroded material does not affect the total capacity of the reservoir, just the distribution of the available storage. The best means to resolve this dispute and to obtain more accurate reservoir topography would be to collect above water topography when the reservoir elevation was at elevation 2,210 or below.

REFERENCES

American Society of Civil Engineers, 1962. ***Nomenclature for Hydraulics***, ASCE Headquarters, New York.

Bureau of Reclamation, 1981. ***Project Data,*** Denver Office, Denver CO.

Bureau of Reclamation, 1985. Surface Water Branch, ***ACAP85 User's Manual***, Technical Service Center, Denver CO.

Bureau of Reclamation, 1987(a). ***Guide for Preparation of Standing Operating Procedures for Bureau of Reclamation Dams and Reservoirs***, U.S. Government Printing Office, Denver, CO.

Bureau of Reclamation, 1987(b). ***Design of Small Dams***, U.S. Government Printing Office, Denver CO.

Bureau of Reclamation, May 1999. Denver Office, ***Nelson Reservoir Area and Capacity Tables, Milk River Project***, Great Plains Region, Billings MT.

Corps of Engineers, October 1994. Engineer and Design - ***Hydrographic Surveying***, EM 1110-2-1003 (FR), Department of the Army, Washington DC (www.usace.army.mil/inet/usace.docs/eng-manuals/em.htm).

Environmental Systems Research Institute, Inc. (ESRI), 1992. ***ARC Command References***.

RESERVOIR SEDIMENT
DATA SUMMARY

Nelson Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM off stream	3. STATE Montana
	4. SEC. 14 TWP. 32 N RANGE 32 E	5. NEAREST P.O. Malta	6. COUNTY Phillips
	7. LAT 48° 31' 42" LONG 107° 31' 00"	8. TOP OF DAM ELEVATION 2228[1]	9. SPILLWAY CREST EL [2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	15. DATE STORAGE BEGAN
	a. SURCHARGE					
	b. FLOOD CONTROL					
	c. POWER					1916
	d. WATER SUPPLY	2225.6	4,496	4,410	83,634	16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. CONSERVATION	2221.6	4,320	60,574	79,224	
	g. DEAD	2200.0	1,667	18,650	18,650	1916
	17. LENGTH OF RESERVOIR 9 MILES			AVG. WIDTH OF RESERVOIR 0.7 MILES		

BASIN	18. TOTAL DRAINAGE AREA 35.2 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 13[3] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 35.2 SQUARE MILES	23. MEAN ANNUAL RUNOFF 21.1[4] INCHES
	20. LENGTH MILES AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 39,600[5] ACRE-FEET
	21. MAX. ELEVATION MIN. ELEVATION	25. ANNUAL TEMP. MEAN 42°F RANGE -56°F to 109°F[3]

SURVEY DATA

26. DATE OF SURVEY	27. PER. YRS.	28. ACCL. YRS.	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVAL	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
1916					4,331[6]	79,396[6]	2.0
5/99	83	83	Contour (D)	5-ft	4,331[7]	78,950[7]	2.0

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET			WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
5/99	13[3]	39,600[8]	75,800	2,047,200	39,600	2,047,200

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AV. ANN.	c. /MI.²-YR.	a. TOTAL	b. AV. ANNUAL	c. /MI.²-YR.
5/99	446[9]	5.4	-	446	5.4	-

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	40. SED. DEP. TONS/MI.²-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
5/99				0.01[9]	0.56[9]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION.											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
5/99												

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

Table 2. - Reservoir sediment data summary (page 1 of 2).

45. RANGE IN RESERVOIR OPERATION[10]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1947	2,217.7	2,212.4	35,100	1948	2,217.8	2,214.2	21,000
1949	2,216.5	2,203.5	(-)4,400	1950	2,209.3	2,202.7	30,200
1951	2,217.1	2,207.9	40,800	1952	2,218.1	2,215.1	15,400
1953	2,220.0	2,213.4	22,300	1954	2,220.3	2,215.9	27,000
1955	2,221.2	2,216.8	8,900	1956	2,218.2	2,214.8	39,800
1957	2,221.2	2,218.9	46,500	1958	2,220.6	2,216.7	28,900
1959	2,219.8	2,216.1	36,000	1960	2,221.4	2,216.8	36,800
1961	2,218.0	2,204.0	23,300	1962	2,220.8	2,207.7	64,000
1963	2,220.0	2,216.3	10,000	1964	2,217.5	2,212.4	47,900
1965	2,221.3	2,214.7	52,500	1966	2,221.0	2,218.3	43,300
1967	2,221.0	2,215.1	36,400	1968	2,219.3	2,215.3	59,300
1969	2,220.4	2,217.1	39,100	1970	2,221.1	2,217.6	43,300
1971	2,220.0	2,211.8	37,700	1972	2,219.2	2,215.3	38,800
1973	2,219.8	2,210.2	20,000	1974	2,220.9	2,209.5	53,000
1975	2,220.8	2,217.9	24,200	1976	2,221.4	2,218.2	42,400
1977	2,219.7	2,203.6	(-)2,800	1978	2,219.4	2,203.4	71,900
1979	2,220.2	2,216.7	39,200	1980	2,218.7	2,209.4	26,300
1981	2,214.8	2,208.2	45,500	1982	2,221.0	2,213.1	65,900
1983	2,219.9	2,209.2	24,800	1984	2,211.2	2,200.5	12,900
1985	2,211.5	2,202.7	33,100	1986	2,221.4	2,213.5	75,800
1987	2,220.8	2,216.8	39,100	1988	2,218.8	2,203.1	(-)2,100
1989	2,215.6	2,201.7	72,200	1990	2,220.2	2,215.7	59,800
1991	2,217.4	2,214.7	72,400	1992	2,218.0	2,206.9	25,700
1993	2,221.3	2,206.4	74,300	1994	2,221.3	2,212.9	23,600
1995	2,216.8	2,209.8	51,000	1996	2,221.0	2,212.6	63,800
1997	2,219.1	2,213.9	56,400	1998	2,220.4	2,212.9	68,300
1999	2,218.1	2,215.2	30,400	2000			

46. ELEVATION - AREA - CAPACITY DATA FOR **1999 CAPACITY**[11]								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2174.8	0	0	2176	3	2	2178	116	121
2180	248	485	2182	388	1,121	2184	525	2,034
2186	670	3,229	2188	784	4,683	2190	879	6,346
2192	966	8,191	2194	1,052	10,209	2196	1,226	12,487
2198	1,415	15,128	2200	1,597	18,140	2202	1,763	21,500
2204	1,920	25,184	2206	2,096	29,194	2208	2,286	33,580
2210	2,469	38,337	2212	2,928	43,615	2214	3,312	49,865
2216	3,614	56,816	2218	3,855	64,291	2220	4,085	72,225
2221.6	4,331	78,950	2222	4,398	80,696	2223	4,560	85,175

47. REMARKS AND REFERENCES

1 Design elevation of five dikes was 2228.0. Documented settlement of some dikes of 1.4 feet or greater.
2 Off stream reservoir, no spillway.
3 Bureau of Reclamation Project Data Book, 1981.
4 Calculated using mean annual runoff value of 39,600 AF, item 24, water years 1947-1999. Offstream reservoir, majority of inflows diverted.
5 Computed annual inflows from 1947 through 5/99.
6 Original surface area and capacity at elevation 2,221.6. Original capacity recomputed by Reclamation's ACAP program using original surface areas.
7 Surface area and capacity at elevation 2,221.6 computed by ACAP program using 1999 and original surface areas. 1999 surveyed only underwater portion of reservoir below elevation 2214. Elevation 2215 and above from original survey.
8 Values from water years 1947 through 5/99 (51.7 years).
9 Capacity loss calculated by comparing original recomputed capacity and 1999 capacity at reservoir elevation 2221.6, top of conservation elevation. Portion of capacity difference due to accuracy of two surveys. Majority of inflows from diverted inflows accounting for the small difference and little sediment inflow over the life of the reservoir.
10 Maximum and minimum elevations and inflow values in acre-feet by water year, from October 1946 through May 1999.
11 Capacities computed by ACAP computer program. Areas at elevation 2215 and above from original survey.

48. AGENCY MAKING SURVEY Bureau of Reclamation
49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE March 2001

Table 2. - Reservoir sediment data summary (page 2 of 2).

1	2	3	4	5	6	7	8
					Computed	Percent of	Percent of
Elevations	Original	Original	1999	1999	Sediment	Computed	Reservoir
	Areas	Capacity	Areas	Capacity	Volume	Sediment	Depth
(feet)	(acres)		(acres)		(acre-feet)		
2223	4560	85621	4560	85175	446	100.0	100.0
2222	4398	81142	4398	80696	446	100.0	97.9
2221.6	4331	79396	4331	78950	446	100.0	97.1
2221	4230	76828	4230	76382	446	100.0	95.9
2220	4085	72670	4085	72225	445	99.8	93.8
2219	3964	68646	3964	68200	446	100.0	91.7
2218	3855	64736	3855	64291	445	99.8	89.6
2217	3740	60939	3740	60493	446	100.0	87.6
2216	3614	57262	3614	56816	446	100.0	85.5
2215	3488	53711	3488	53265	446	100.0	83.4
2214	3349	50292	3312	49865	427	95.7	81.3
2213	2822	47207	3130	46644	563	126.2	79.3
2212	2670	44461	2928	43615	846	189.7	77.2
2211	2566	41843	2580	40861	982	220.2	75.1
2210	2473	39323	2469	38337	986	221.1	73.0
2209	2387	36893	2379	35913	980	219.7	71.0
2208	2312	34544	2286	33580	964	216.1	68.9
2207	2232	32272	2195	31340	932	209.0	66.8
2206	2150	30081	2096	29194	887	198.9	64.7
2205	2065	27973	2002	27145	828	185.7	62.7
2204	1986	25948	1920	25184	764	171.3	60.6
2203	1905	24002	1843	23303	699	156.7	58.5
2202	1824	22138	1763	21500	638	143.0	56.4
2201	1742	20355	1680	19778	577	129.4	54.4
2200	1667	18650	1597	18140	510	114.3	52.3
2198	0	0	1415	15128			48.1
2196	0	0	1226	12487			44.0
2194	0	0	1052	10209			39.8
2192	0	0	966	8191			35.7
2190	0	0	879	6346			31.5
2188	0	0	784	4683			27.4
2186	0	0	670	3229			23.2
2184	0	0	525	2034			19.1
2182	0	0	388	1121			14.9
2180	0	0	248	485			10.8
2178	0	0	116	121			6.6
2176	0	0	3	2			2.5
2174.8	0	0	0	0			0.0

1	Elevation of reservoir water surface in feet.
2	Original reservoir surface area.
3	Recomputed original reservoir capacity.
4	1999 reservoir surface areas.
5	1999 reservoir capacity.
6	Sediment volume (col. 3 - col. 5).
7	Percentage of total sediment (446AF).
8	Percentage of total depth (48.2).

Table 3. - Summary of 1999 survey results

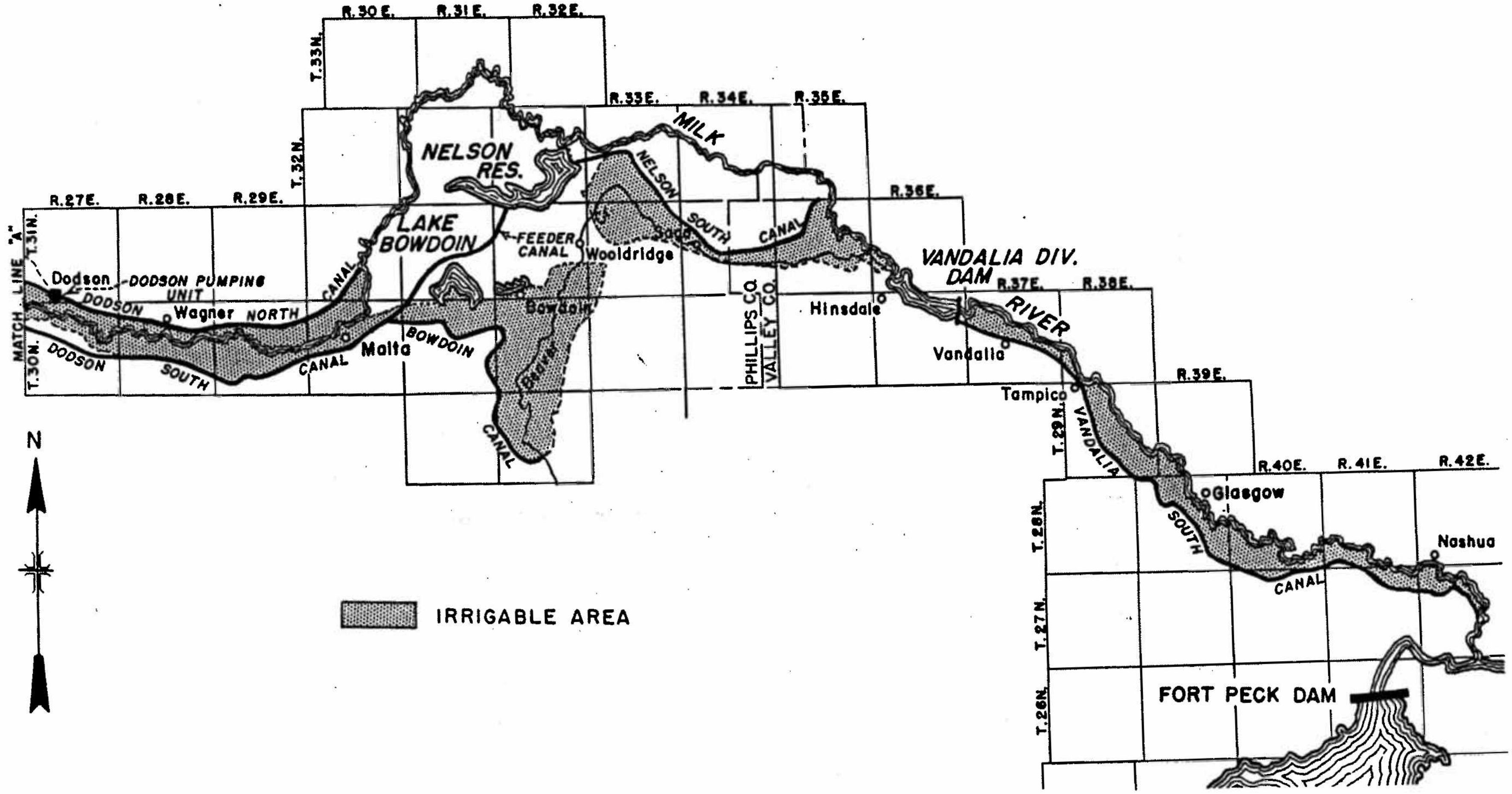

Figure 1. - Nelson Reservoir location map.

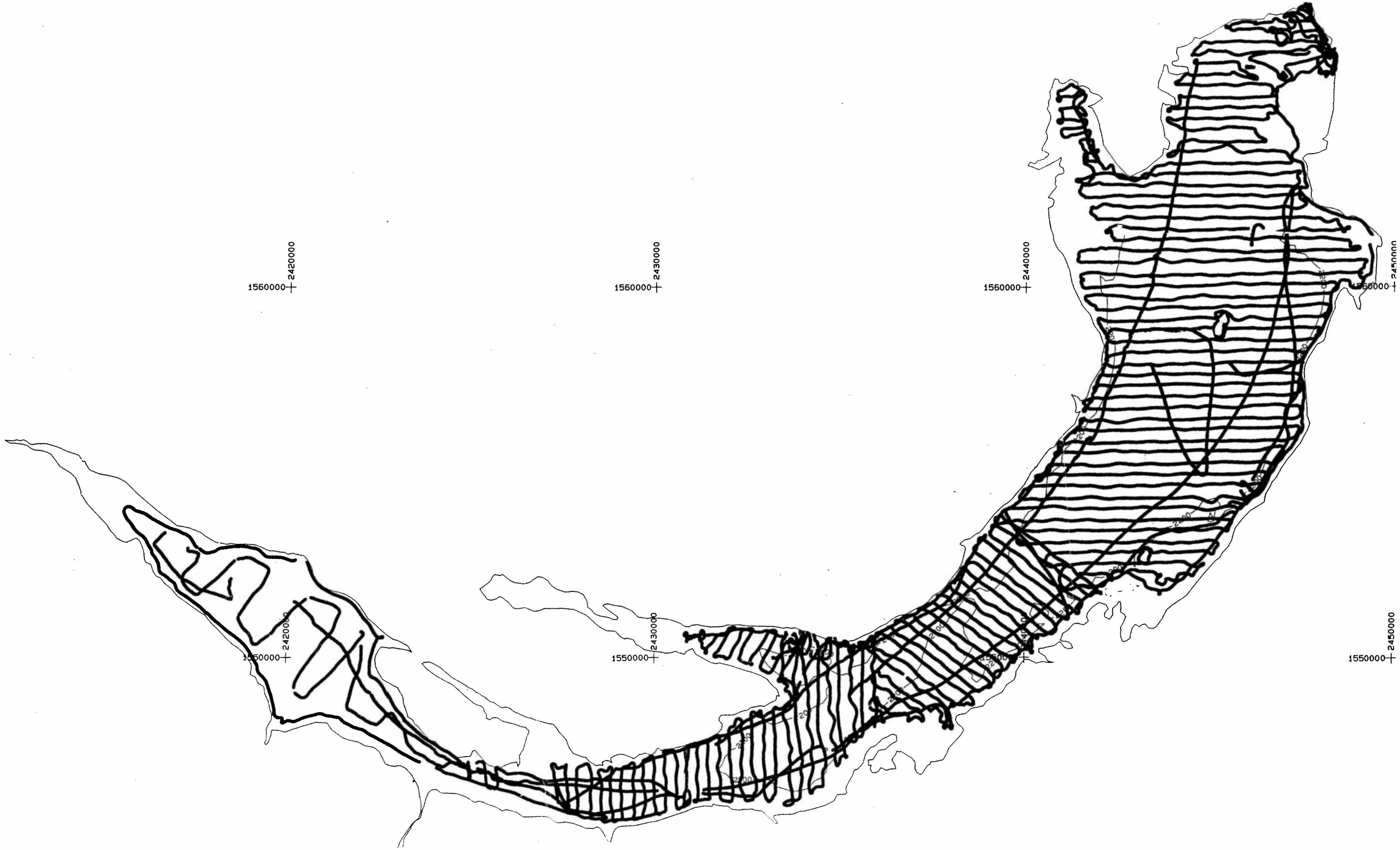

Figure 2. - Nelson Reservoir underwater data collection.

Figure 3. - Nelson Reservoir topology map, No. 15-D-282.

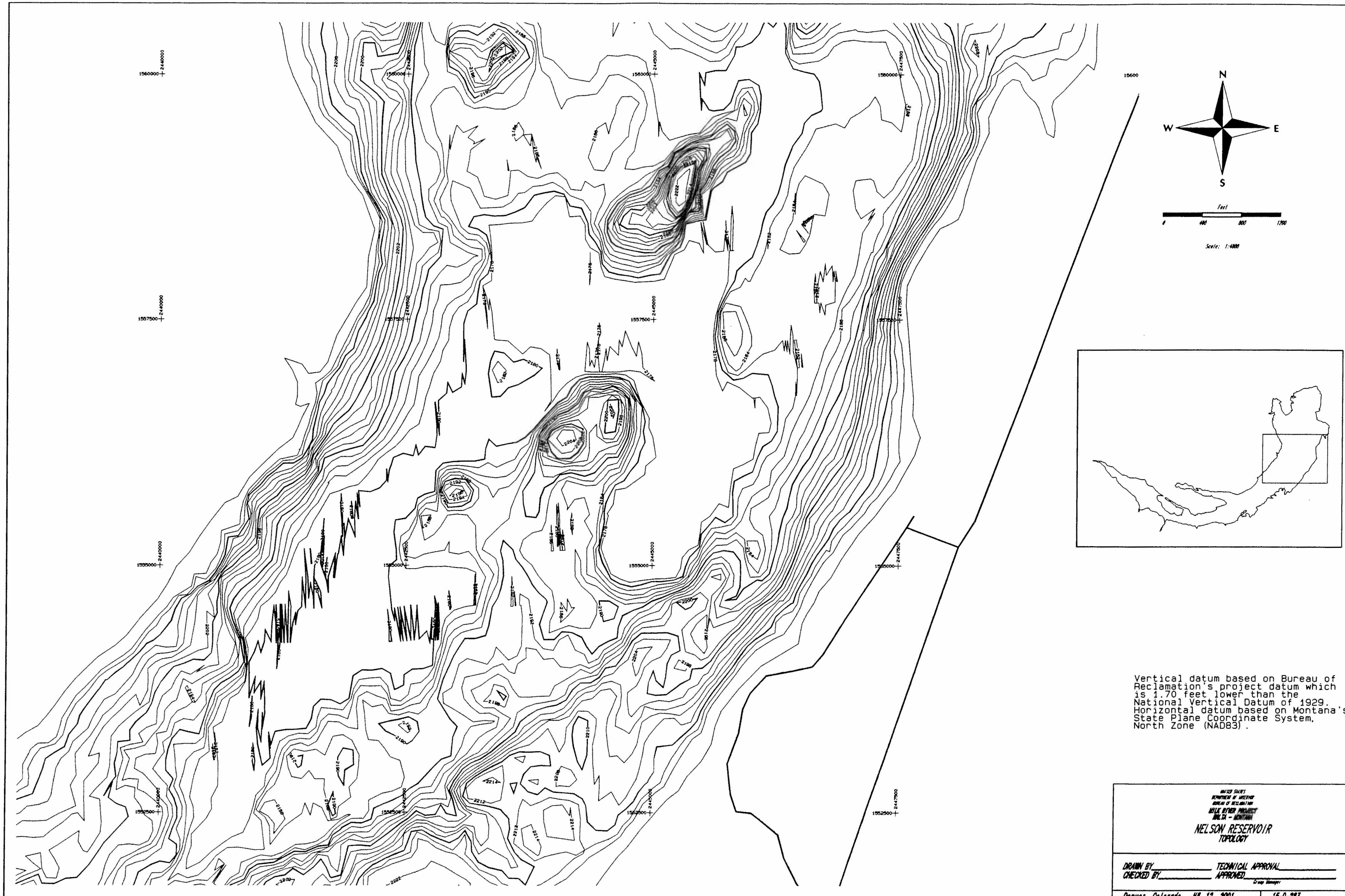

Figure 4. - Nelson Reservoir topology map, No. 15-D-283.

Figure 5. - Nelson Reservoir topology map, No. 15-D-284.

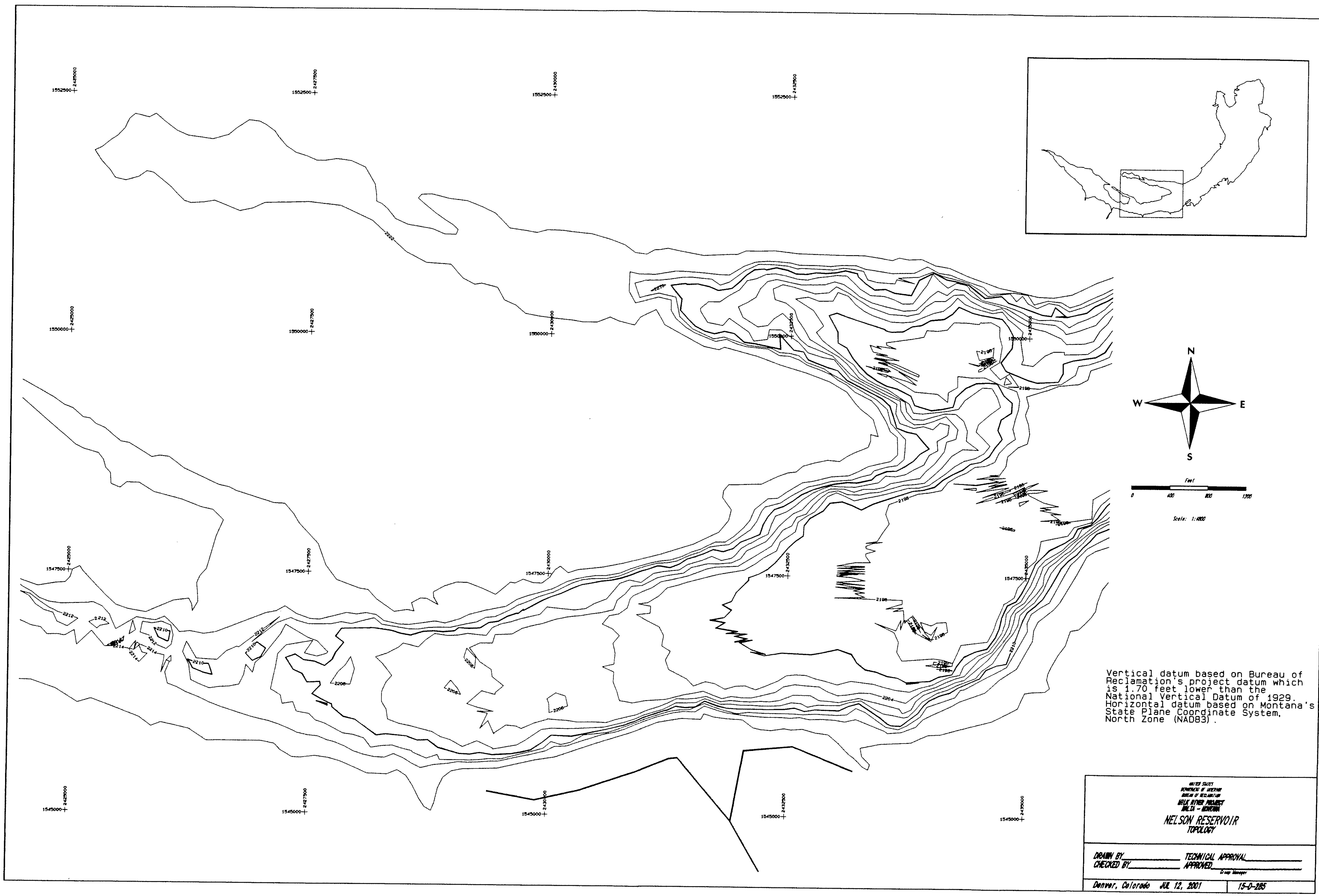

Figure 6. - Nelson Reservoir topology map, No. 15-D-285.

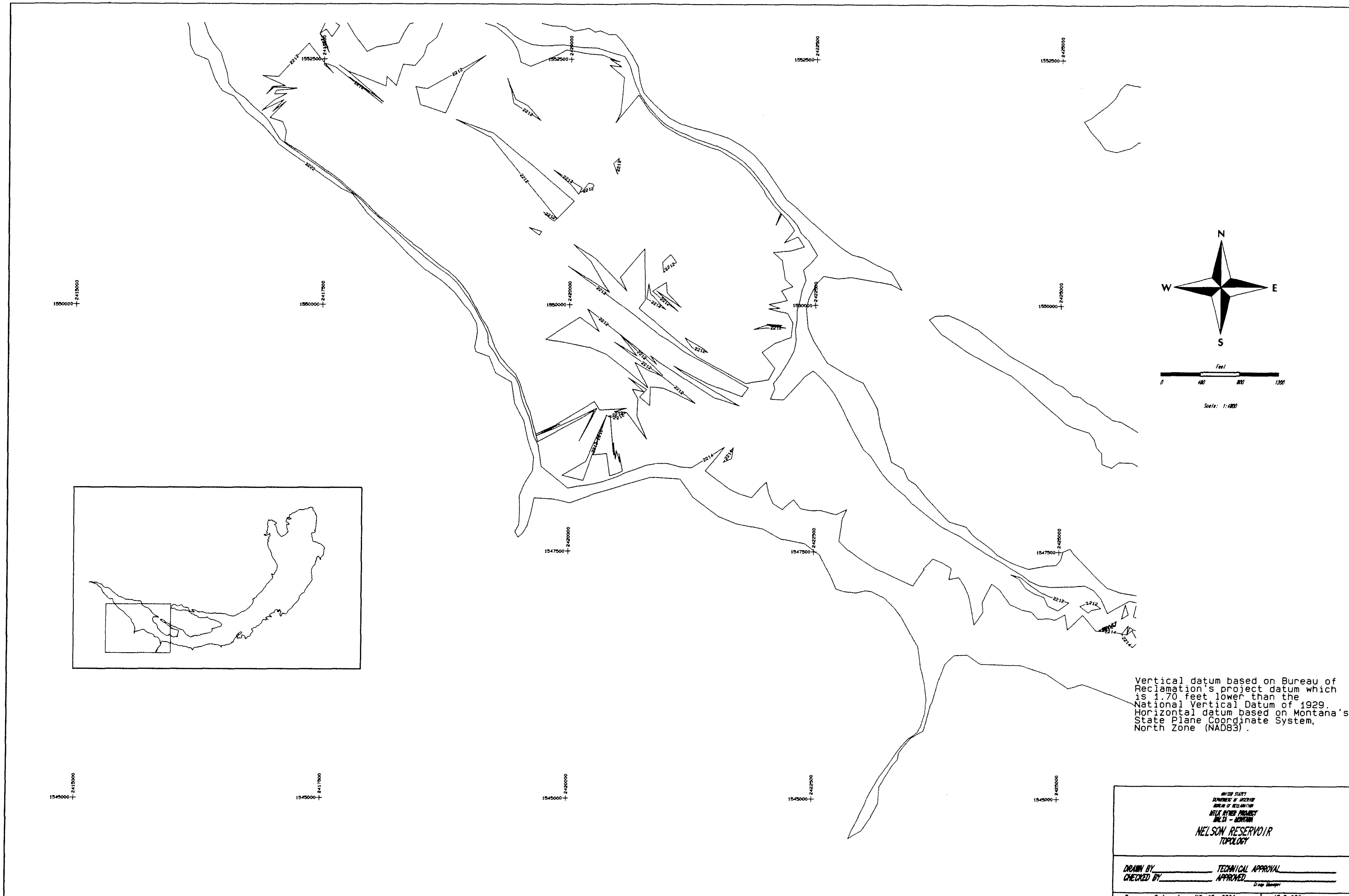

Figure 7. - Nelson Reservoir topology map, No. 15-D-286.

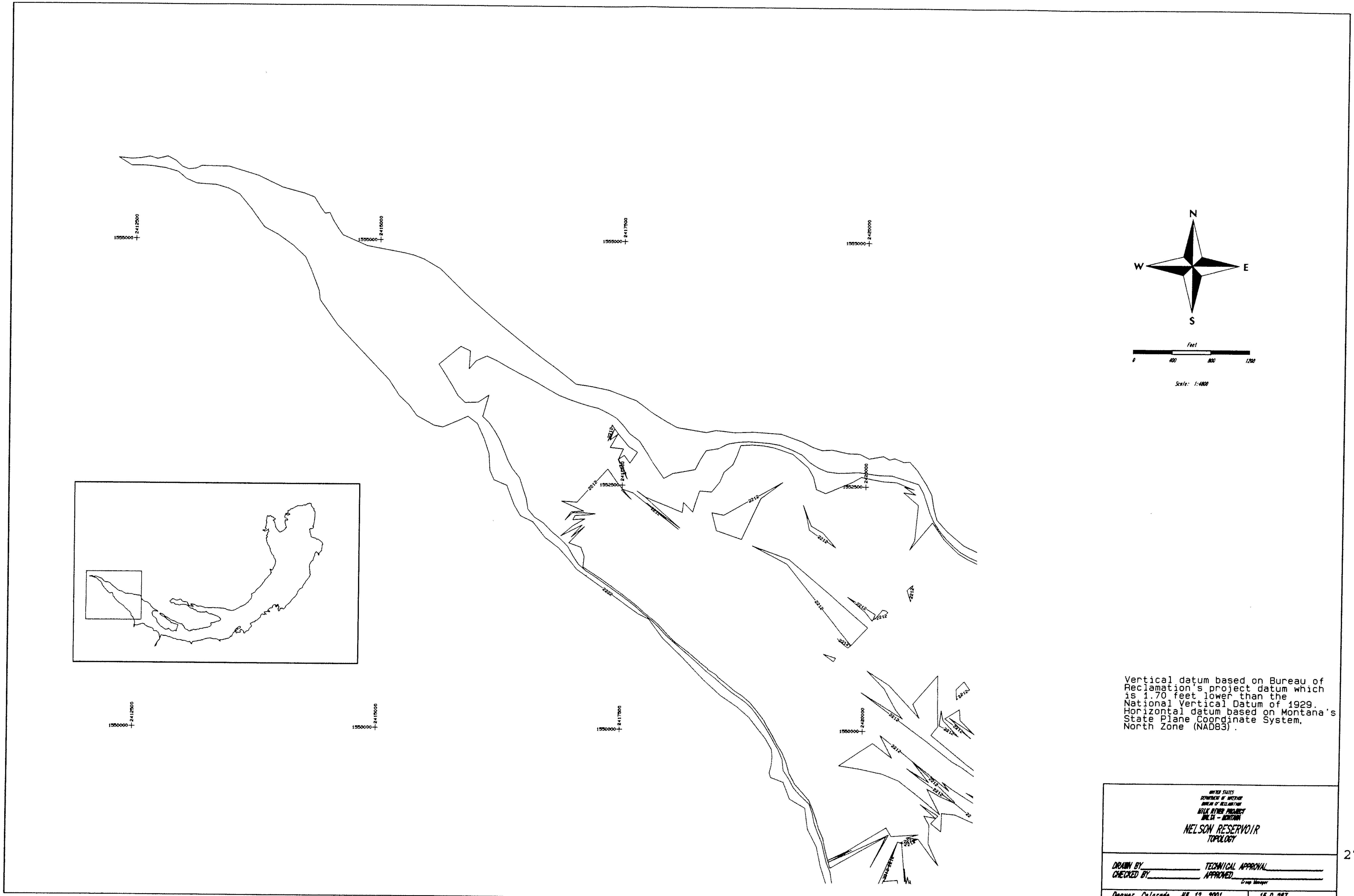

Figure 8. - Nelson Reservoir topology map, No. 15-D-287.

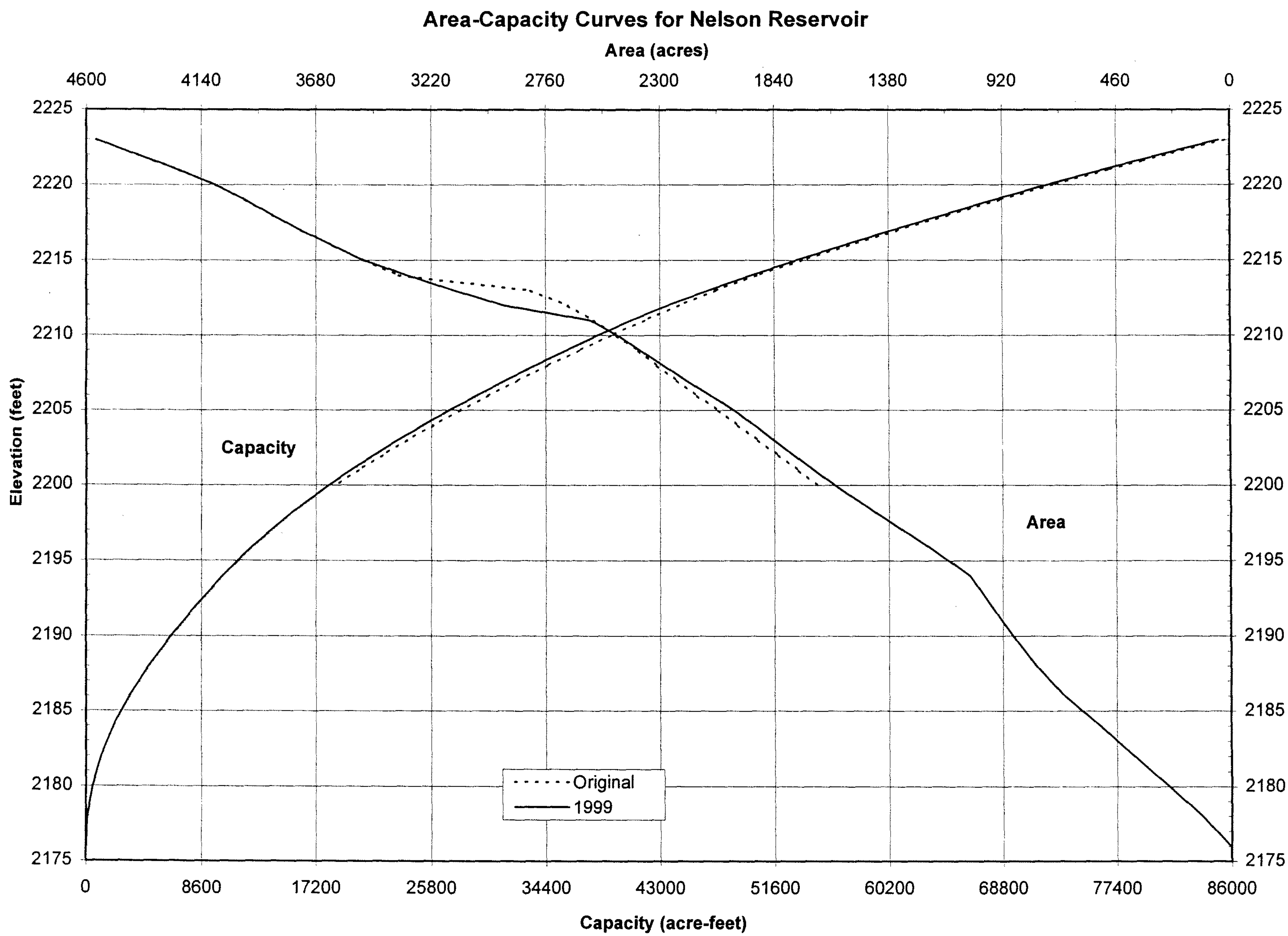

Figure 9. - 1999 area and capacity curves