RECLAMATION

Managing Water in the West

Tiber Reservoir – Lake Elwell 2002 Survey

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The Bureau of Reclamation (Reclamation) surveyed Tiber Reservoir in June and July of 2002 to develop new reservoir topography and compute a present storage-elevation relationship (area-capacity tables). The underwater survey, conducted between reservoir elevation 2,991.9 (feet) and 2,995.4, used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was determined by digitizing the developed contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps and the reservoir water surface from a 2003 aerial survey of the reservoir (elevation 2,991.6).

As of July 2002, at joint use elevation 2,993.0, the surface area was 18,275 acres with a total capacity of 925,649 acre-feet. At maximum reservoir elevation 3,020.2 feet, the surface area was 25,407 acres with a total capacity of 1,515,522 acre-feet. Since initial filling in October of 1956, about 42,179 acre-feet of capacity loss has occurred below elevation 2,993.0. A large portion of this loss is due to extensive shoreline erosion throughout the reservoir.

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Tiber Reservoir – Lake Elwell 2002 Survey

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UNITED STATES DEPARTMENT OF THE INTERIOR

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BUREAU OF RECLAMATION

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

Tiber Dam, that forms Lake Elwell, is located in north central Montana on the Marias River in Liberty County about 13 miles west of the town of Chester (figure 1). Lake Elwell is also known as Tiber Reservoir and is referenced as both within this report. These features are part of the Lower Marias Unit of the Pick-Sloan Missouri Basin Program that was designed to provide municipal and industrial water, flood control, and irrigation water to 127,000 acres of land. The original designed irrigation features were not constructed because the irrigation district did not negotiate a repayment contract with the United States.

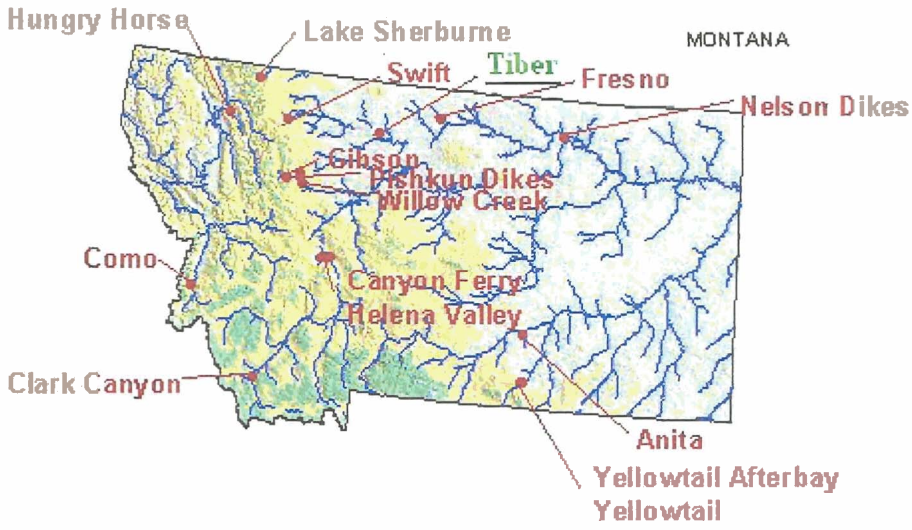

Figure 1 – Tiber Dam Location Map.

Settlement of the spillway crest of Tiber Dam began following initial filling of the reservoir in 1956. Reservoir operating level restrictions were imposed to safeguard the structure until repaired. The rate of settlement became more alarming following a 1964 flood. Measures to protect the structure were approved by Congress and initial construction began in 1967 with completion in 1970. The work consisted of modifying the canal outlet works for use as an auxiliary outlet works and closing the entrance channel of the spillway by a temporary earthfill cofferdam. For additional protection, the reservoir operating criteria was further revised and the active capacity was eliminated. Additional work was completed, 1976-81, that included replacing the upstream section of the spillway and raising the dam 5 feet (figures 2 and 3). Beginning in 1982, and continuing through 1983, Tiber Reservoir was filled to its original design capacity of elevation 2,993.0 feet and normal reservoir operations were restored.

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Tiber Reservoir is formed by Tiber Dam along with a dike that closes a saddle on the south rim of the reservoir near the dam. The earthfill dike is 16,650 feet long and has a maximum height of 65 feet. The dam is a zoned earthfill structure whose dimensions are:

Hydraulic height[1]	189	feet	Structural height	206	feet
Top width	45	feet	Crest length	4,300	feet
Crest elevation	3,026	feet[2]			

The spillway, crest elevation 2,975, is located on the right abutment. The flows are controlled by three 22- by 38-foot radial gates with top of gate elevation 3,012.5. The spillway capacity is 68,470 cubic feet per second (cfs) at reservoir elevation 3,020.2.

The River Outlet Works (ROW) through the right abutment contains two discharge pipes, 22- and 72-inch diameters that are controlled by a 24-inch gate value and a 5.0-foot square high-pressure gate respectfully. The discharge capacity is 65 cfs for the 22-inch pipe and 1,540 cfs for the 72-inch pipe at reservoir elevation 3,020.2.

The 22-inch diameter outlet pipe with 24-inch gate valve and 18-inch butterfly valve (BFV) has not been operational since completion of the dam. The existing hydraulic operating system is inadequate to operate the upstream gate valve due to excessive friction losses in the piping system. The Montana Area Office is planning to convert the 22-inch outlet pipe into a ventilation system in 2006.

In 2003-2004, the ROW underwent extensive modification to incorporate the addition of a Federal Energy Regulatory Commission (FERC) 7.5 MW powerplant, privately owned by Tiber Montana, LLC. A bifurcation pipe was installed in the ROW tunnel at the downstream end to divert flow from the existing 72-inch outlet pipe through a bifurcation and 96-inch BFV to the powerplant. Releases from the regulating gate and powerplant enter directly into the ROW stilling basin.

Under normal operation, river releases up to about 700 cfs will be primarily through the 7.5MW FERC powerplant. River flows greater than 700 cfs will normally be released through the auxiliary outlet works. However, if the auxiliary outlet works is not available for use, flows in excess of the powerplant capacity are released through a combination of the ROW regulating gate and powerplant.

An auxiliary outlet works, constructed as part of the safety of dams modification, is located through the left abutment of the dam. The auxiliary outlet is controlled by a 7.25- by 9.25-foot outlet gate with a capacity of 4,240 cfs at reservoir elevation 3,020.2.

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[1]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*.

[2]Elevations in feet. All elevations based on the original project datum established by U.S. Bureau of Reclamation that was determined to be 2.9 feet lower than the North American Vertical Datum of 1988 (NAVD88).

The drainage area above Tiber Dam is approximately 4,375 square miles and all is considered sediment contributing. The reservoir, at elevation 2,990.0, is about 44 miles in length with an average width of 1.6 miles. The total length includes 35 miles of the Marias River arm and 9 miles of the Willow Creek arm.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 2002 results of the survey of Tiber Reservoir. The primary objective of the survey was to gather data to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion since dam closure

Prior to the underwater collection, the hydrographic survey crew conducted a RTK GPS survey utilizing horizontal and vertical control established by the National Geodetic Survey (NGS) for datum point "Tib1." This point is located near the dam and is not a high-order vertical datum. Other NGS datums in the surrounding area found elevations in NAVD88 to be around three feet higher than elevations in NGVD29. The 2002 hydrographic survey found the vertical project datum established by Reclamation during construction to be 2.9 feet lower than NAVD88 assigned to "Tib1". All elevations are in feet and referenced to Reclamation's project vertical datum.

The underwater survey, June and July of 2002, was conducted between reservoir elevation 2,991.9 and 2,995.4. The bathymetric survey used sonic depth recording equipment interfaced with a RTK GPS capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along grid lines covering Tiber Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. The reservoir's water surface elevations, recorded by the Reclamation reservoir gauge during the time of collection, were used to convert the sonic depth measurements to reservoir bottom elevations. These gauge elevations are tied to the Reclamation project datum.

The above-water area of Tiber Reservoir was developed by digitizing the developed contour lines from the USGS quad maps and the reservoir water surface from rectified aerial photographs flown July 4, 2003 at reservoir elevation 2,991.6. The 2003 aerial survey covered the entire reservoir and provided valuable information about the extensive shoreline erosion that has occurred on Tiber Reservoir.

The final 2002 Tiber Reservoir topography is a combination of the 2003 aerial water surface contour, the USGS quad contours, and the 2002 underwater collected data. A computer graphics program generated the 2002 reservoir surface areas at predetermined contour intervals from these combined data sets. The 2002 area and capacity tables were generated by a computer program that used the measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985).

Tables 1 and 2 contain summaries of the Tiber Reservoir and watershed characteristics for the 2002 survey. The 2002 survey determined that the reservoir has a total storage capacity of 925,649 acre-feet and a surface area of 18,275 acres at joint use reservoir water surface elevation 2,993.0. Since closure in October of 1957, the reservoir has an estimated volume change of 42,179 acre-feet below reservoir elevation 2,993.0. This volume represents a 4.4 percent change in total capacity at this elevation.

RESERVOIR OPERATIONS

Tiber Dam operates to provide regulated flows downstream on the Marias River. The July 2002 capacity table shows 1,515,522 acre-feet of total storage below the maximum water surface elevation 3,020.3. The 2002 survey measured a minimum lake bottom of around elevation 2,839. The following values are from the July 2002 capacity table:

- 186,799 acre-feet of surcharge between elevation 3,012.5 and 3,020.2.
- 403,074 acre-feet of flood control between elevation 2,993.0 and 3,012.5.
- 258,436 acre-feet of joint use between elevation 2,976.0 and 2,993.0.
- 112,883 acre-foot of conservation storage between elevation 2,966.4 and 2,976.0.
- 534,709 acre-foot of inactive storage between elevation 2,870.0 and 2,966.4.
- 19,621 acre-foot of dead storage below 2,870.0.

Tiber Reservoir computed annual inflow and reservoir stage records are listed by water year on table 1 for the operation period 1956 through 2002. The inflow values were computed by the regional office and show annual fluctuations with a computed average inflow of 618,300 acre-feet per year. The maximum reservoir elevation was 3,005.6 in 1965 with a minimum elevation of 2,953.8 in 1968.

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 4). The hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to all the equipment. The shore equipment included a second GPS receiver with an external radio. The GPS receiver and antenna were mounted on a survey tripod over a known datum point and a 12-volt battery provided the power for the shore unit.

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 is from a RTK receiver are precise 3D 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 Montana's state plane coordinates in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

Figure 4 - Survey vessel with mounted hydrographic equipment on Jackson Lake in Wyoming

In 2001, the Sedimentation and River Hydraulics 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 generate a detailed cross section of bottom geometry as the survey vessel passes over the areas to be 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 measured the relative water depth across the wide swath perpendicular to the vessel's track. Figure 5 illuminates the swath of the sea floor that is about 3.5 times as wide as the water depth below the transducer.

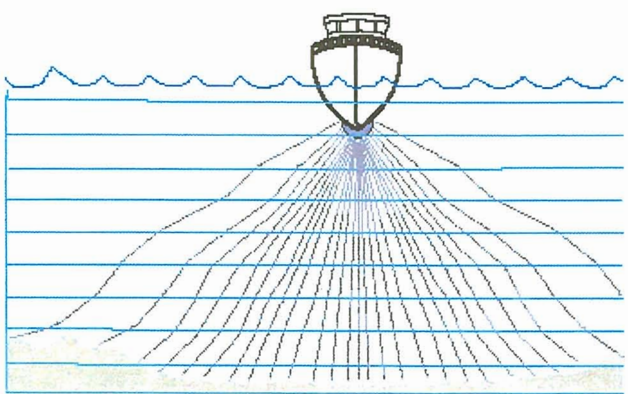

Figure 5 – Multibeam collection system

The multibeam system is composed of several instruments that are all in constant communication with a central on-board notebook computer. The components include the RTK 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 of the reservoir water column. With the proper calibration, the data processing software utilizes all the incoming information to provide an accurate detailed x, y, z data set of the lake bottom.

The Tiber Reservoir bathymetric survey collection was conducted in June and July of 2002 between water surface elevation 2,991.9 and 2,995.4 (Reclamation project datum). The survey was run using the multibeam instrumentation described above where the survey system software continuously recorded reservoir depths and horizontal coordinates as the survey vessel moved across closely spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run along the original river alignment to the reservoir where the multibeam swaths overlapped each other. The multibeam system could have provided full bottom coverage, but time, budget, and access did not allow this to occur in all the shallow portions of the reservoir. The loss of these additional data points did not have a significant impact on the area computations since an extensive above water collection was not conducted for this study.

Additional data in the upper shallow water reaches of the two inlets was also collected using a single beam depth sounder. The depth sounder was calibrated by lowering a weighted cable below the boat with beads marking known depths. 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 a 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 gauge, were used to convert the sonic depth measurements to true lake-bottom elevations.

Shoreline Erosion

The 2002 underwater survey revealed extensive shoreline erosion throughout the reservoir area. During collection, the GPS boat positions were found to be at times outside the digitized USGS quad contour locations indicating the boat was on solid ground. These USGS quad contours were developed from aerial photography flown in the 1960's and at times, the position of the boat was tens of feet outside their boundary. In addition, during the 2002 survey a major windstorm occurred and the crew witnessed vertical sections of the shoreline collapsing into the reservoir for days after. Even with the extensive shore erosion that has occurred since dam closure, the survey vessel was able to hug the vertical banks in deep water conditions where previous shore material had collapsed into the reservoir. It appears that over time the collapsed material is washed further into the reservoir by the wave action, similar to ocean waves smoothing the beaches. This is possible because the material dissipates in the water and consists of little to no rock or large cobble. Following are views showing the shoreline erosion and its affect on the reservoir, figure 6 through 9, from photographs taken by Sharon Nuanes in 2002.

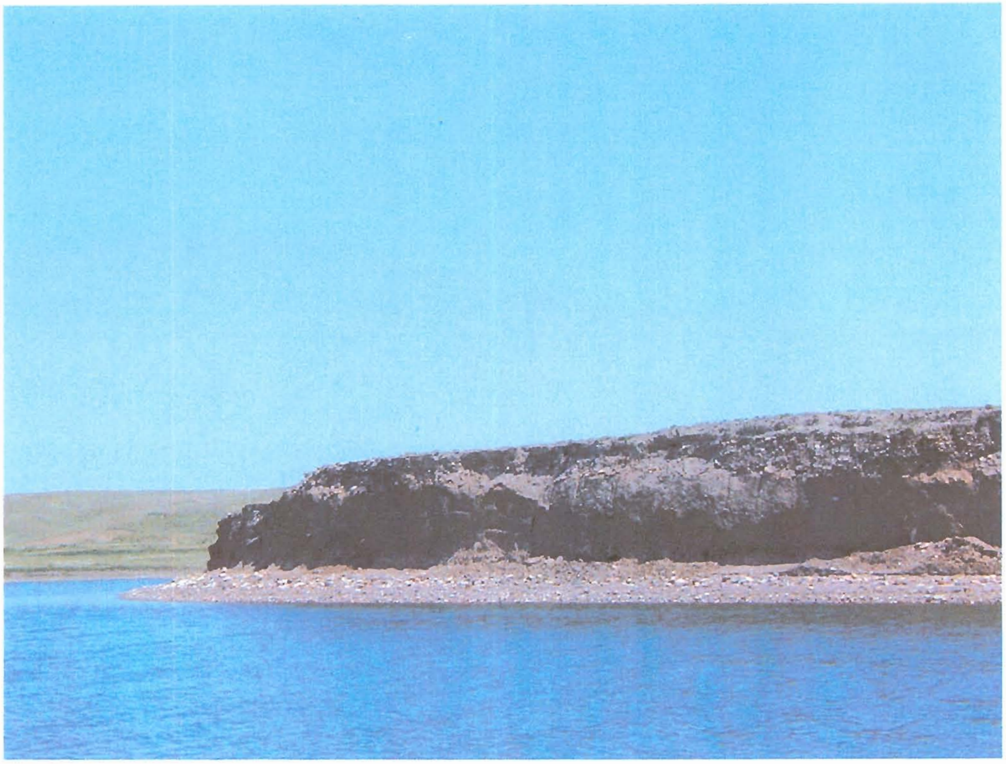

Figure 6 – Eroded Material Forming a Shelf.

Figure 7 – Large Areas of Erosion Occurring Above the Reservoir Maximum Water Surface.

Figure 8 – Recent Eroded Material That Has Not Moved Further Into Reservoir.

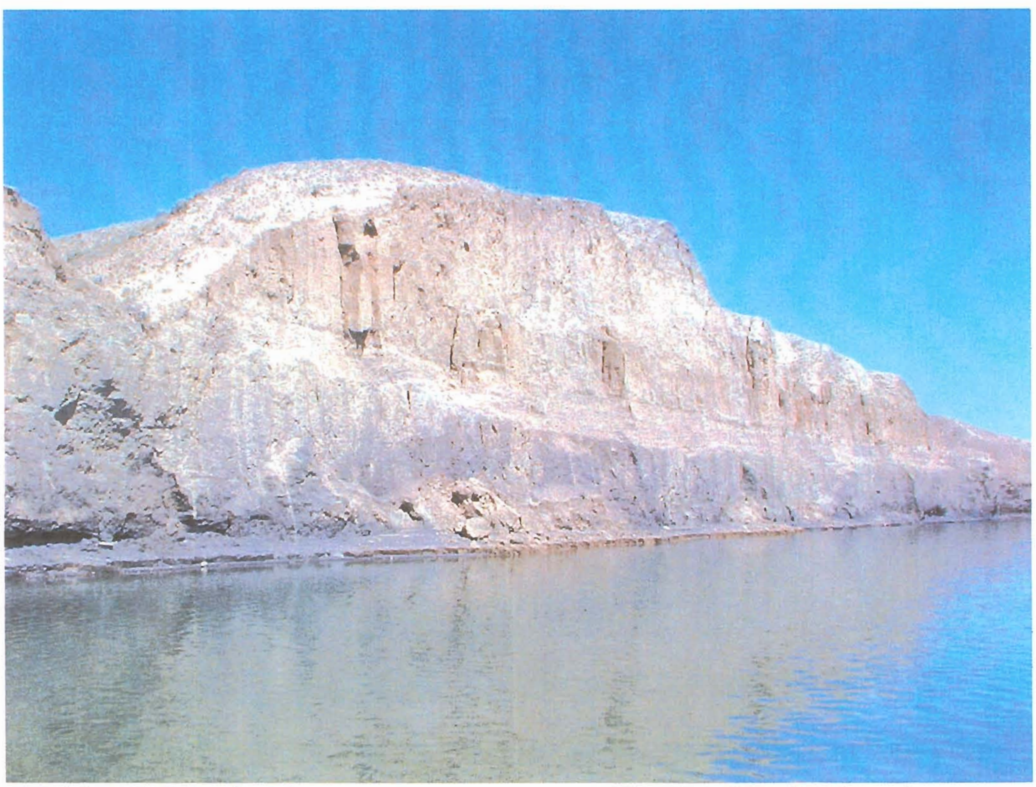

Figure 9 – Eroded Bank Where the Eroded Material Has Deposited Below the Water Line.

The above photographs show several different stages of the shoreline erosion along the Tiber Reservoir banks. If the erosion occurred only below the reservoir high water mark, the total volume of the reservoir would not be greatly affected. In this case, however, the gain in surface area and resulting volume in the upper reservoir elevation zone is offset by the loss of surface area and volume in the lower elevations of the reservoir. The eroded upper elevation shoreline deposits in the lower elevations of the reservoir. The photographs show the large amount of shore erosion above the maximum reservoir elevation, meaning that a portion of the loss of the original total reservoir volume is due to the above reservoir shoreline erosion along with the incoming river sediments. The only means to accurately measure the extent of the shoreline erosion would be by an above water aerial survey.

For a vegetation study, an aerial survey was conducted on July 4 of 2003 at reservoir water surface elevation 2,991.6. The collected digital aerial photos were rectified, but no above water contours were developed. As part of this analysis, the 2003 reservoir water surface image was digitized to compute the surface area at elevation 2,991.6. The 2003 digitized surface area at reservoir elevation 2,991.6 was 17,935 acres compared to the original computed surface area of 17,472 acres at the same elevation. The 2003 surface area was nearly 500 acres greater, illustrating the extent of the shoreline erosion that has occurred throughout the reservoir.

Tiber Dam Datum

Prior to the underwater collection, the hydrographic survey crew conducted a RTK GPS survey utilizing horizontal and vertical control at NGS datum point "Tib1." Tib1 is located near the dam and is not a highly rated vertical control point. Other NGS vertical datums in the surrounding area show the elevations in NAVD88 to be around three feet higher than the elevations in NGVD29. The 2002 hydrographic survey found the vertical project datum established by Reclamation during construction to be 2.9 feet lower than NAVD88 elevation at Tib1. This was an average measured shift from multiple water surface shots compared to the Reclamation gauge readings. All elevations in this report are in feet and referenced to the Reclamation project vertical datum or gauge readings at the time of this survey. Following are the NGS coordinates for "Tib1" used for this survey. The Montana's state plane coordinates are in NAD83 and elevation in NAVD88.

North	1,486855.785
West	1,578,509.929
Elevation	3,025.51

Multibeam Analysis

The analysis started with processing all the collected raw multibeam bottom profile files. This included applying all necessary correction information that was collected, such as the roll, pitch, and yaw effects on the survey vessel. Other corrections included applying the field measured sound velocity of the reservoir water column. All this information was used when converting all the corrected depth data to elevations. All elevations in the final analysis were tied to the Reclamation measured water surface elevation at the time of collection. Due to the massive amount of data, the data set was filtered utilizing procedures within the collection and analysis software that logically removed data points without adversely affecting the results. Quality control and assurance of the data sets were accomplished by conducting field calibration as required by the multibeam system and collecting velocity profile data for the areas being surveyed.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Tiber Reservoir was developed from the 2002 collected underwater data, the digitized contours from the USGS quad maps, and the digitized 2003 aerial water surface contour. The digitized USGS contour lines were used to supplement areas of the reservoir not covered by the survey vessel due to shallow water conditions. The USGS quad maps were developed from aerial photography dated in the 1960's because it was the only available data for certain portions of the reservoir. ARC/INFO 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. This same method was used to digitize the reservoir water surface from the 2003 rectified digital aerial photographs that were flown on July 4, 2003 at reservoir water surface elevation 2,991.6. These rectified photographs were part of a vegetation study and no contours were developed. The aerial water surface image did allow a complete contour to be digitized for the reservoir's water surface elevation 2,991.6. The 2003 digitized surface area at elevation 2,991.6 was 17,935 acres compared to the original computed surface area of 17,472 acres. The 2003 surface area was nearly 500 acres greater due to the extensive shoreline erosion that has occurred throughout the reservoir.

The digitized 2003 reservoir water surface, elevation 2,991.6, was used to perform a clip of Tiber Reservoir triangular irregular network (TIN) such that interpolation was not allowed to occur outside the enclosed polygon. This contour was selected since it was the closest data available to represent the reservoir water surface at the time the 2002 underwater survey was conducted (between reservoir elevation 2,992 and 2,995). The clip was assigned an elevation of 2,991.6.

Contours for the reservoir below elevation 2,991.6 were computed from the 2002 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 the polygon clip. The 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. This method preserves all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in detail in the ARC/INFO *Users Documentation*, (ESRI, 1992).

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Tiber Reservoir TIN. In addition, the contours were generalized by filtering 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 no bearing on the computation of surface areas and volumes for Tiber Reservoir since the areas were calculated from the developed TIN. The areas of the enclosed contour polygons at one-foot increments were developed from the survey data for elevation 2991.0 and below. The contour topography at 10-foot intervals is presented on figures 10 through 18.

Development of 2002 Contour Areas and Reservoir Volume

The 2002 contour surface areas for Tiber Reservoir were computed at 1-foot increments from elevation 2,839.0 to 2991.0. 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. For the purpose of this study, the measured 2002 survey areas at 2-foot increments from elevation 2,839.0 through 2,985.0 were used to compute the new area and capacity tables. Due to the limited amount of 2002 shallow water data, the digitized surface area at elevation 2,991.6 was used to complete the area and volume computations between elevation 2,985.0 and 2,991.6. Due to the absence of above water data, this study assumed no change in original area from elevation 3,005.0 and above. The area and capacity program computes the areas between the elevations by assuming a straight-line interpolation between the input data set. For the 2002 study, this was the only means to compute the areas between elevation 2,991.6 and 3,005.0.

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). The surface area data as described above were used as the control parameters for computing the 2002 Tiber Reservoir capacity. Since this study did not collect above water data, the measured 2003 aerial water surface contour area and the original surface areas from elevation 3,005.0 and above were used to complete the area and capacity tables.

The ACAP85 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 Tiber 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. Differentiating the capacity equations, which are of second order polynomial form, the 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 Tiber Reservoir area and capacity computations are listed in table 1 and columns 4 and 5 of table 2. On table 2, columns 2 and 3 list the original surface areas and recomputed original capacities. A separate set of 2002 area and capacity tables has been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation 2002). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 2002 area-capacity curves are plotted on figure 19. As of July 2002, at maximum reservoir elevation 3,020.2, the surface area was 25,407 acres with a total capacity of 1,515,522 acre-feet.

2002 RESERVOIR ANALYSES

Results of the Tiber Reservoir area and capacity computations are listed in table 1 and columns 4 and 5 of table 2. Columns 2 and 3 of table 2 list the original area and recomputed capacity values. Column 6 lists the capacity differences between the original and 2002 computations. Figure 19 is a plot of the Tiber Reservoir surface area and capacity values and illustrates the differences between the two surveys. Since Tiber Dam closure in 1957, the measured total volume change at reservoir elevation 2,993.0 is 42,179 acre-feet. The estimated average annual rate of capacity lost for this period (44.8 years) was 941.5 acre-feet per year. The storage loss in terms of percent of original storage capacity was 4.4 percent at elevation 2,993.0. The 2002 area and capacity tables were generated assuming no change in area and capacity, since the original survey, from elevation 3,005.0 and above. This is in all probability not the case, but the lack of above water data only allows this assumption. As indicated before, there have been large areas of shoreline erosion that has occurred above elevation 2,993 and in some areas it appears to have occurred above maximum reservoir elevation 3,005. The only means to measure this would be by an aerial topographic survey.

The 2002 survey noted the large areas of shoreline erosion by comparing with the original contours. The 2003 aerial water surface contour was able to measure the erosion at elevation 2,991.6 that this study found to be around 500 acres. The shoreline erosion has enlarged the surface area and volume of the upper elevations while decreasing the surface area and volume of the lower reservoir elevations where the eroded material has deposited. If the shoreline material only occurred within the reservoir boundary, the overall volume of the reservoir would not significantly change due to the shoreline erosion. The volume would have redistributed within the reservoir affecting the reservoir operation levels, but not the total volume. The 2002 survey visually noted significant erosion above the normal maximum reservoir elevation. This material has settled within the reservoir along with the inflowing sediments to reduce the original capacity.

During the original planning of Tiber Reservoir, the estimated loss of total capacity of the reservoir over the first 100 years of operation was 47,000 acre-feet. There is no information on how this sediment inflow value was determined and what factors were used to compute this value. The 2002 survey found a current volume loss of 42,179 acre-feet in the first 44.8 years of reservoir operation below elevation 2,993.0. That is near the total 100-year estimate in less than half the time, 44.8 years. As stated before, a large part of this volume is due to shoreline-eroded material that this study is not able to distinguish from inflowing sediment. The 2002 survey results did measure where the volume loss has occurred as illustrated on item 43 of table 1. The study found that of the total volume of 42,179 acre-feet, 4.9 percent occurred below dead storage elevation 2,870, 50.2 percent below inactive reservoir elevation 2,966.4, 22.1 percent below conservation elevation 2,976.0 and 22.8 percent below joint use elevation 2,993.0. There is no information above elevation 2,991.6 feet to allow computing changes above this elevation.

A resurvey of Tiber Reservoir should be considered in the future if major sediment inflow events are observed or if the average annual rate of sediment accumulation requires further clarification. Due to the extensive shoreline erosion, any new survey should include detailed above water collection. Comparing the aerial data with the original values would make it possible to measure the extent of the reservoir shoreline erosion.

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

RESERVOIR SEDIMENT DATA SUMMARY

<u>Tiber Reservoir</u>
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Marias River	3. STATE Montana
	4. SEC. 33 TWP. 30 N RANGE 5 E	5. NEAREST P.O. Chester	6. COUNTY Liberty
	7. LAT 48° 19' 06" LONG 111 05'27"	8. TOP OF DAM ELEVATION 3,026.0[1]	9. SPILLWAY CREST EL 2,975.0[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	3,020.2[3]	25,414	187,741	1,555,898	
	b. FLOOD CONTROL	3,012.5	23,152	400,838	1,368,157	10/57
	c. POWER					
	d. JOINT USE	2,993.0	17,886	267,994	967,319	16. DATE NORMAL OPERATION BEGAN
	e. CONSERVATION	2,976.0	13,787	121,701	699,325	
	f. INACTIVE	2,966.4	11,741	556,042	577,624	
	g. DEAD	2,870.0	1,535	21,582	21,582	10/81[4]
	17. LENGTH OF RESERVOIR	44[4] Miles		AVG. WIDTH OF RESERVOIR	1.6 MILES	

BASIN		
	18. TOTAL DRAINAGE AREA 4,375 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 10.23[5] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 4,375 SQUARE MILES	23. MEAN ANNUAL RUNOFF 2.65[6] INCHES
	20. LENGTH MILES / AV. WIDTH	24. MEAN ANNUAL RUNOFF 618,300[7] ACRE-FEET
	21. MAX. ELEVATION / MIN. ELEVATION	25. ANNUAL TEMP. MEAN 58.9°F RANGE -53°F to 103°F[5]

SURVEY DATA

26. DATE OF SURVEY	27. PER.	28. ACCL	29. TYPE OF SURVEY	30. NO. OF RANGES OR	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO
10/57			Contour	5-ft	17,896[8]	967,828	1.6
7/02	44.8	44.8	Contour (D)	2-ft	18,275[9]	925,649	1.5

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
7/02		618,300[10]	1,167,600	29,060,900	618,300	29,060,900

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AV. ANN.	c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AV. ANNUAL	c. /MI.^{2}-YR.
7/02	42,179[11]	941.5	0.215	42,179	941.5	0.215

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR. a. PERIOD	b. TOTAL TO	41. STORAGE LOSS, PCT. a. AV.	b. TOTAL TO	42. a.	b.
7/02				0.09[11]	4.4[11]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
		2825-2870	2870-2966	2966-2976	2976-2993						
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
		4.9	50.2	22.1	22.8						

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 1. - Reservoir sediment data summary (page 1 of 3).

45. RANGE IN RESERVOIR OPERATION[10]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1956	2974.1		654,093	1957	2982.5	2969.2	596,675
1958	2984.0	2972.8	568,883	1959	2985.5	2971.3	938,097
1960	2983.8	2969.7	641,166	1961	2984.2	2972.8	432,929
1962	2982.8	2971.6	482,486	1963	2980.0	2971.2	392,538
1964	3001.9	2973.5	973,734	1965	3005.6	2975.2	966,346
1966	2987.4	2969.8	632,795	1967	2984.8	2955.2	931,643
1968	2970.3	2953.8	611,937	1969	2979.2	2956.3	670,260
1970	2984.2	2962.9	692,701	1971	2976.4	2957.4	778,927
1972	2979.1	2960.1	925,408	1973	2970.2	2960.5	341,915
1974	2975.6	2961.8	604,100	1975	2993.9	2960.0	1,167,605
1976	2976.2	2965.1	784,700	1977	2969.4	2960.3	193,573
1978	2976.6	2962.9	788,800	1979	2980.2	2961.2	716,744
1980	2978.3	2960.9	578,796	1981	2972.6	2959.4	601,630
1982	2978.0	2959.7	635,886	1983	2983.7	2975.2	300,728
1984	2983.8	2976.7	254,946	1985	2989.3	2975.2	397,556
1986	2991.6	2977.5	720,083	1987	2988.5	2976.4	508,388
1988	2984.9	2975.0	271,226	1989	2989.4	2973.3	641,313
1990	2992.5	2980.6	740,777	1991	2995.5	2974.9	927,078
1992	2983.3	2974.8	294,349	1993	2991.2	2976.6	513,396
1994	2991.8	2979.7	540,830	1995	2995.3	2979.0	754,503
1996	2991.9	2983.6	977,709	1997	2996.5	2978.6	843,373
1998	2992.7	2981.2	428,512	1999	2990.3	2975.8	434,990
2000	2988.0	2981.9	336,209	2001	2983.4	2976.6	203,948
2002	2995.9	2974.1	766,629				

46. ELEVATION - AREA - CAPACITY DATA FOR **2002 CAPACITY**[12]								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2,839	0	0	2,840	0	0	2,841	0	0
2,842	4	3	2,843	8	9	2,844	30	28
2,845	51	68	2,846	92	140	2,847	134	253
2,848	186	413	2,849	238	625	2,850	290	889
2,851	341	1,204	2,852	405	1,577	2,853	468	2,014
2,854	549	2,523	2,855	629	3,112	2,856	691	3,772
2,857	753	4,494	2,858	812	5,277	2,859	871	6,118
2,860	928	7,017	2,861	986	7,974	2,862	1,046	8,990
2,863	1,106	10,066	2,864	1,183	11,211	2,865	1,260	12,432
2,866	1,338	13,731	2,867	1,416	15,108	2,868	1,477	16,555
2,869	1,536	18,061	2,870	1,582	19,621	2,871	1,628	21,226
2,872	1,677	22,879	2,873	1,725	24,580	2,874	1,773	26,329
2,875	1,821	28,126	2,876	1,889	29,981	2,877	1,956	31,903
2,878	2,023	33,893	2,879	2,090	35,950	2,880	2,164	38,077
2,881	2,238	40,278	2,882	2,327	42,560	2,883	2,417	44,933
2,884	2,517	47,400	2,885	2,618	49,967	2,886	2,701	52,627
2,887	2,785	55,369	2,888	2,852	58,188	2,889	2,919	61,073
2,890	2,992	64,029	2,891	3,064	67,056	2,892	3,134	70,156
2,893	3,205	73,325	2,894	3,271	76,563	2,895	3,336	79,866
2,896	3,405	83,237	2,897	3,473	86,676	2,898	3,549	90,187
2,899	3,624	93,773	2,900	3,708	97,439	2,901	3,792	101,189
2,902	3,867	105,019	2,903	3,942	108,923	2,904	4,020	112,904
2,905	4,098	116,963	2,906	4,178	121,101	2,907	4,258	125,319
2,908	4,327	129,612	2,909	4,397	133,974	2,910	4,473	138,409
2,911	4,550	142,921	2,912	4,627	147,509	2,913	4,703	152,174
2,914	4,785	156,918	2,915	4,867	161,745	2,916	4,966	166,661
2,917	5,064	171,676	2,918	5,168	176,792	2,919	5,272	182,013
2,920	5,377	187,337	2,921	5,483	192,768	2,922	5,580	198,299
2,923	5,677	203,928	2,924	5,777	209,655	2,925	5,877	215,482
2,926	5,962	221,402	2,927	6,048	227,407	2,928	6,147	233,504
2,929	6,246	239,701	2,930	6,350	245,999	2,931	6,454	252,400
2,932	6,567	258,911	2,933	6,680	265,535	2,934	6,792	272,271
2,935	6,904	279,119	2,936	7,009	286,075	2,937	7,114	293,136
2,938	7,224	300,305	2,939	7,334	307,584	2,940	7,444	314,972
2,941	7,553	322,471	2,942	7,657	330,076	2,943	7,760	337,784

Table 1. - Reservoir sediment data summary (page 2 of 3).

2,944	7,970	345,599	2,945	7,981	353,524	2,946	8,122	361,576
2,947	8,264	369,759	2,948	8,400	378,101	2,949	8,536	386,569
2,950	8,669	395,171	2,951	8,802	403,906	2,952	8,929	412,772
2,953	9,054	421,764	2,954	9,170	430,877	2,955	9,283	440,103
2,956	9,403	449,446	2,957	9,523	458,908	2,958	9,659	468,499
2,959	9,795	478,226	2,960	9,925	488,087	2,961	10,054	498,076
2,962	10,183	508,195	2,963	10,313	518,443	2,964	10,451	528,624
2,965	10,589	539,344	2,966	10,753	550,016	2,967	10,918	560,851
2,968	11,093	571,857	2,969	11,258	583,037	2,970	11,515	594,428
2,971	11,761	606,066	2,972	11,947	617,920	2,973	12,132	629,960
2,974	12,321	642,186	2,975	12,510	654,602	2,976	12,710	667,213
2,977	12,910	680,023	2,978	13,152	693,054	2,979	13,393	706,326
2,980	13,727	719,886	2,981	14,061	733,779	2,982	14,288	747,953
2,983	14,516	762,356	2,984	14,729	776,978	2,985	14,941	791,813
2,986	15,396	806,981	2,987	15,848	822,603	2,988	16,302	838,678
2,989	16,755	855,206	2,990	17,209	872,188	2,991	17,662	889,624
2,992	18,032	907,496	2,993	18,275	925,649	2,994	18,517	944,045
2,995	18,760	962,684	2,996	19,003	981,566	2,997	19,246	1,000,690
2,998	19,489	1,020,058	2,999	19,732	1,039,668	3,000	19,975	1,059,521
3,001	20,218	1,079,617	3,002	20,460	1,099,956	3,003	20,703	1,120,538
3,004	20,946	1,141,363	3,005	21,189	1,162,431	3,006	21,451	1,183,750
3,007	21,712	1,205,332	3,008	21,974	1,227,175	3,009	22,235	1,249,279
3,010	22,497	1,271,646	3,011	22,764	1,294,276	3,012	23,031	1,317,174
3,013	23,299	1,340,339	3,014	23,566	1,363,771	3,015	23,833	1,387,471
3,016	24,138	1,411,456	3,017	24,443	1,435,746	3,018	24,747	1,460,341
3,019	25,052	1,485,241	3,020	25,357	1,510,446	3,020.2	25,407	1,515,522

47. REMARKS AND REFERENCES

1 All elevations are in feet on the original project datum established by Reclamation that were found, during 2002 survey, to be around 2.9 feet less then the NAVD88. Original construction 1955-57. Due to settling, construction modifications were conducted, 1976-81, to the spillway and dam that was raised 5 feet.

2 Spillway crest elevation. Controlled by radial gates with top of gate elevation 3,012.5.

3 Original area and capacity values obtain from table dated September 1963.

4 35 miles from dam to upper Marias River plus 9 miles of Willow Creek from confluence of Marias River at elevation 2890.

5 Western Regional Climate Center Data for Station 243489 located at Gibson Dam, Montana

6 Calculated using mean annual runoff value of 618,300 acre-feet, item #24.

7 Average annual computed inflows by water year, from 1956 through 2002.

8 Original surface areas from 1963 table at joint use elevation 2993.0. The original capacity values were recomputed by ACAP program for use of determining capacity loss.

9 2002 area and capacity values computed by ACAP program at elevation 2993.0. 2002 surface area at elevation 2,993 is larger then original due to extensive shoreline erosion.

10 Annual Reclamation computed inflows by water year, from 1956 through 2002. Maximum and minimum elevations available from Reclamation records.

11 Capacity loss calculated by comparing original recomputed capacity and 2002 capacity at reservoir elevation 2,993. 2002 survey had only one above water contour developed from a 2003 aerial survey flown at reservoir elevation 2,992.6 feet. A portion of the measured lower elevation lossses are due to extensive shoreline erosion.

12 Capacities computed by Reclamation's ACAP computer program. Surface areas from elevation 3005 were developed assuming no original surface area change.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE June 2005

Table 1. - Reservoir sediment data summary (page 3 of 3).

Tiber Reservoir
2002 Survey Summary

1	2	3	4	5	6	7
Elevations (feet)	Original Survey (acres)	Original Capacity (acre-feet)	2002 Survey (acres)	2002 Survey (acre-feet)	2002 Volume Change	Percent of Reservoir Depth
3020.2	25407	1555429	25407	1515522	39,907	100.0
3020	25357	1550353	25357	1510446	39,907	99.9
3019	25052	1525148	25052	1485241	39,907	99.4
3018	24747	1500248	24747	1460341	39,907	98.9
3017	24443	1475653	24443	1435746	39,907	98.4
3016	24138	1451363	24138	1411456	39,907	97.8
3015	23833	1427278	23833	1387471	39,807	97.3
3014	23866	1403678	23566	1363771	39,907	96.8
3013	23299	1380246	23299	1340339	39,907	96.3
3012.5	23165	1368630	23165	1328723	39,907	96.1
3012	23031	1357081	23031	1317174	39,907	95.8
3011	22764	1334183	22764	1294276	39,907	95.3
3010	22497	1311553	22497	1271646	39,907	94.8
3009	22235	1289186	22235	1249279	39,907	94.3
3008	21974	1267082	21974	1227175	39,907	93.8
3007	21712	1245239	21712	1205332	39,907	93.2
3006	21451	1223657	21451	1183750	39,907	92.7
3005	21189	1202338	21189	1162431	39,907	92.2
3004	20909	1181288	20946	1141363	39,925	91.7
3003	20629	1160519	20703	1120538	39,981	91.2
3002	20350	1140030	20460	1099956	40,074	90.7
3001	20070	1119820	20218	1079617	40,203	90.2
3000	19790	1099890	19975	1059521	40,369	89.7
2999	19529	1080231	19732	1039668	40,563	89.1
2998	19267	1060833	19489	1020058	40,775	88.6
2997	19006	1041696	19246	1000690	41,006	88.1
2996	18744	1022821	19003	981566	41,255	87.6
2995	18483	1004208	18760	962684	41,524	87.1
2994	18190	985871	18517	944045	41,826	86.6
2993	17896	967828	18275	925649	42,179	86.1
2992	17603	950079	18032	907496	42,583	85.6
2991	17309	932623	17662	889624	42,999	85.0
2990	17016	915460	17209	872188	43,272	84.5
2989	16794	898555	16755	855206	43,349	84.0
2988	16571	881873	16302	838678	43,195	83.5
2987	16349	865413	15848	822603	42,810	83.0
2986	16126	849175	15395	806981	42,194	82.5
2985	15904	833160	14941	791813	41,347	82.0
2984	15660	817378	14729	776978	40,400	81.5
2983	15416	801840	14516	762356	39,484	80.9
2982	15171	786547	14288	747953	38,594	80.4
2981	14927	771498	14061	733779	37,719	79.9

Tiber Reservoir
2002 Survey Summary

1	2	3	4	5	6	7
Elevations (feet)	Original Survey (acres)	Original Capacity (acre-feet)	2002 Survey (acres)	2002 Survey (acre-feet)	2002 Volume Change	Percent of Reservoir Depth
2980	14683	756693	13727	719886	36,807	79.4
2979	14459	742122	13393	706326	35,796	78.9
2978	14235	727775	13152	693054	34,721	78.4
2977	14010	713652	12910	680023	33,629	77.9
2976	13786	699754	12710	667213	32,541	77.4
2975	13562	686080	12510	654602	31,478	76.8
2974	13321	672638	12321	642186	30,452	76.3
2973	13081	659437	12132	629960	29,477	75.8
2972	12840	646477	11947	617920	28,557	75.3
2971	12600	633757	11761	606066	27,691	74.8
2970	12359	621278	11515	594428	26,850	74.3
2969	12182	609007	11268	583037	25,970	73.8
2968	12005	596913	11093	571857	25,056	73.3
2967	11829	584996	10918	560851	24,145	72.7
2966.4	11723	577931	10819	554330	23,601	72.4
2966	11652	573256	10753	550016	23,240	72.2
2965	11475	561693	10589	539344	22,349	71.7
2964	11306	550302	10451	528824	21,478	71.2
2963	11137	539081	10313	518443	20,638	70.7
2962	10968	528028	10183	508195	19,833	70.2
2961	10799	517144	10054	498076	19,068	69.7
2960	10630	506430	9925	488087	18,343	69.2
2959	10455	495887	9795	478226	17,661	68.6
2958	10281	485519	9659	468499	17,020	68.1
2957	10106	475326	9523	458908	16,418	67.6
2956	9932	465307	9403	449446	15,861	67.1
2955	9757	455462	9283	440103	15,359	66.6
2954	9600	445784	9170	430877	14,907	66.1
2953	9443	436262	9056	421764	14,498	65.6
2952	9286	426898	8929	412772	14,126	65.1
2951	9129	417690	8802	403906	13,784	64.5
2950	8972	408640	8669	395171	13,469	64.0
2949	8834	399737	8536	386569	13,168	63.5
2948	8695	390973	8400	378101	12,872	63.0
2947	8557	382347	8264	369769	12,578	62.5
2946	8418	373859	8122	361576	12,283	62.0
2945	8280	365510	7981	353524	11,986	61.5
2944	8164	357288	7870	345599	11,689	61.0
2943	8048	349182	7760	337784	11,398	60.5
2942	7931	341193	7657	330076	11,117	59.9
2941	7815	333320	7553	322471	10,849	59.4
2940	7699	325563	7444	314972	10,591	58.9
2939	7585	317920	7334	307584	10,336	58.4

Tiber Reservoir
2002 Survey Summary

1	2	3	4	5	6	7
Elevations (feet)	Original Survey (acres)	Original Capacity (acre-feet)	2002 Survey (acres)	2002 Survey (acre-feet)	2002 Volume Change	Percent of Reservoir Depth
2938	7471	310392	7224	300305	10,087	57.9
2937	7358	302978	7114	293136	9,842	57.4
2936	7244	295677	7009	286075	9,602	56.9
2935	7130	288490	6904	279119	9,371	56.4
2934	7024	281413	6792	272271	9,142	55.8
2933	6918	274442	6680	265535	8,907	55.3
2932	6813	267576	6567	258911	8,665	54.8
2931	6707	260816	6454	252400	8,416	54.3
2930	6601	254163	6350	245999	8,164	53.8
2929	6503	247610	6246	239701	7,909	53.3
2928	6406	241156	6147	233504	7,652	52.8
2927	6308	234799	6048	227407	7,392	52.3
2926	6211	228539	5962	221402	7,137	51.7
2925	6113	222378	5877	215482	6,896	51.2
2924	5992	216325	5777	209655	6,670	50.7
2923	5871	210394	5677	203928	6,466	50.2
2922	5750	204583	5580	198299	6,284	49.7
2921	5629	198894	5483	192768	6,126	49.2
2920	5508	193325	5377	187337	5,988	48.7
2919	5420	187861	5272	182013	5,848	48.2
2918	5331	182486	5168	176792	5,694	47.6
2917	5243	177199	5064	171676	5,523	47.1
2916	5154	172000	4966	166661	5,339	46.6
2915	5066	166890	4867	161745	5,145	46.1
2914	4974	161870	4785	156918	4,952	45.6
2913	4882	156942	4703	152174	4,768	45.1
2912	4789	152107	4627	147509	4,598	44.6
2911	4697	147364	4550	142921	4,443	44.1
2910	4605	142713	4473	138409	4,304	43.5
2909	4507	138156	4397	133974	4,182	43.0
2908	4409	133698	4327	129612	4,086	42.5
2907	4312	129338	4258	125319	4,019	42.0
2906	4214	125075	4178	121101	3,974	41.5
2905	4116	120910	4098	116963	3,947	41.0
2904	4038	116833	4020	112904	3,929	40.5
2903	3960	112834	3942	108923	3,911	40.0
2902	3882	108913	3867	105019	3,894	39.4
2901	3804	105070	3792	101189	3,881	38.9
2900	3726	101305	3708	97439	3,866	38.4
2899	3664	97610	3624	93773	3,837	37.9
2898	3601	93978	3549	90187	3,791	37.4
2897	3539	90408	3473	86676	3,732	36.9
2896	3476	86900	3405	83237	3,663	36.4

Tiber Reservoir
2002 Survey Summary

1	2	3	4	5	6	7
Elevations (feet)	Original Survey (acres)	Original Capacity (acre-feet)	2002 Survey (acres)	2002 Survey (acre-feet)	2002 Volume Change	Percent of Reservoir Depth
2895	3414	83455	3336	79866	3,589	35.9
2894	3347	80075	3271	76563	3,512	35.3
2893	3280	76761	3205	73325	3,436	34.8
2892	3213	73515	3134	70156	3,359	34.3
2891	3146	70335	3064	67056	3,279	33.8
2890	3079	67223	2992	64029	3,194	33.3
2889	2995	64185	2919	61073	3,112	32.8
2888	2911	61232	2852	58188	3,044	32.3
2887	2828	58363	2785	55369	2,994	31.8
2886	2744	55577	2701	52627	2,950	31.3
2885	2660	52875	2618	49967	2,908	30.7
2884	2583	50254	2517	47400	2,854	30.2
2883	2506	47709	2417	44933	2,776	29.7
2882	2429	45242	2327	42560	2,682	29.2
2881	2352	42851	2238	40278	2,573	28.7
2880	2275	40538	2164	38077	2,461	28.2
2879	2193	38304	2090	35950	2,354	27.7
2878	2110	36152	2023	33893	2,259	27.2
2877	2028	34083	1956	31903	2,180	26.6
2876	1945	32097	1889	29981	2,116	26.1
2875	1863	30193	1821	28126	2,067	25.6
2874	1797	28362	1773	26329	2,033	25.1
2873	1732	26598	1725	24580	2,018	24.6
2872	1666	24899	1677	22879	2,020	24.1
2871	1601	23265	1628	21226	2,039	23.6
2870	1535	21698	1582	19621	2,077	23.1
2869	1471	20195	1536	18061	2,134	22.5
2868	1406	18756	1477	16555	2,201	22.0
2867	1342	17382	1416	15108	2,274	21.5
2866	1177	16073	1338	13731	2,342	21.0
2865	1213	14828	1260	12432	2,396	20.5
2864	1143	13650	1183	11211	2,439	20.0
2863	1072	12542	1106	10066	2,476	19.5
2862	1002	11505	1046	8990	2,515	19.0
2861	931	10539	986	7974	2,565	18.4
2860	861	9643	928	7017	2,626	17.9
2859	796	8814	871	6118	2,696	17.4
2858	731	8050	812	5277	2,773	16.9
2857	667	7351	753	4494	2,857	16.4
2856	602	6717	691	3772	2,945	15.9
2855	537	6148	629	3112	3,036	15.4
2854	508	5625	549	2523	3,102	14.9
2853	478	5132	468	2014	3,118	14.3

Tiber Reservoir
2002 Survey Summary

1	2	3	4	5	6	7
Elevations (feet)	Original Survey (acres)	Original Capacity (acre-feet)	2002 Survey (acres)	2002 Survey (acre-feet)	2002 Volume Change	Percent of Reservoir Depth
2852	449	4669	405	1577	3,092	13.8
2851	419	4235	341	1204	3,031	13.3
2850	390	3830	290	889	2,941	12.8
2849	375	3448	238	625	2,823	12.3
2848	360	3080	186	413	2,667	11.8
2847	344	2728	134	253	2,475	11.3
2846	329	2392	92	140	2,252	10.8
2845	314	2070	51	68	2,002	10.2
2844	285	1771	30	28	1,743	9.7
2843	256	1500	8	9	1,491	9.2
2842	226	1259	4	3	1,256	8.7
2841	197	1048	0	0	1,048	8.2
2840	168	865	0	0	865	7.7
2839	148	707	0	0	707	7.2
2838	128	569	0	0	569	6.7
2837	108	451	0	0	451	6.1
2836	88	353	0	0	353	5.6
2835	68	275	0	0	275	5.1
2834	59	212	0	0	212	4.6
2833	49	158	0	0	158	4.1
2832	40	113	0	0	113	3.6
2831	30	78	0	0	78	3.1
2830	21	53	0	0	53	2.6
2829	17	34	0	0	34	2.0
2828	13	19	0	0	19	1.5
2827	8	8	0	0	8	1.0
2826	4	2	0	0	2	0.5
2825	0	0	0	0	0	0.0

1	Elevation of reservoir water surface.
2	Original reservoir surface area from 1963 area table.
3	Original reservoir capacity recomputed from 1963 surface areas using ACAP.
4	Reservoir surface area from 2002 survey.
5	Reservoir capacity computed from 2002 surface areas using ACAP.
6	Measured volume difference = column (3) - column (5).
7	Depth of reservoir expressed in percentage of total depth of 195.2 feet.

Figure 10. – Tiber Reservoir topographic map, No 1.

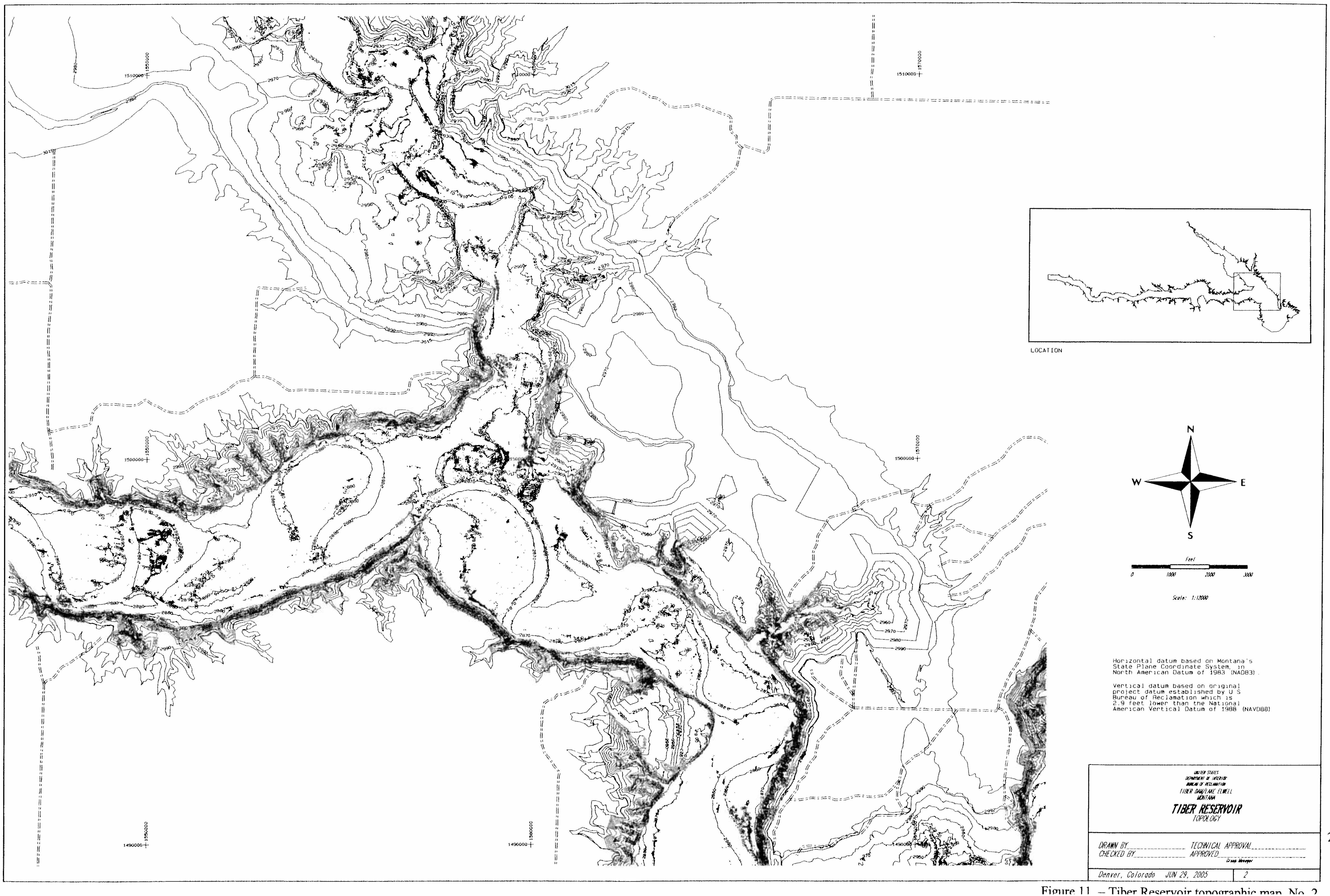

Figure 11 – Tiber Reservoir topographic map No. 2

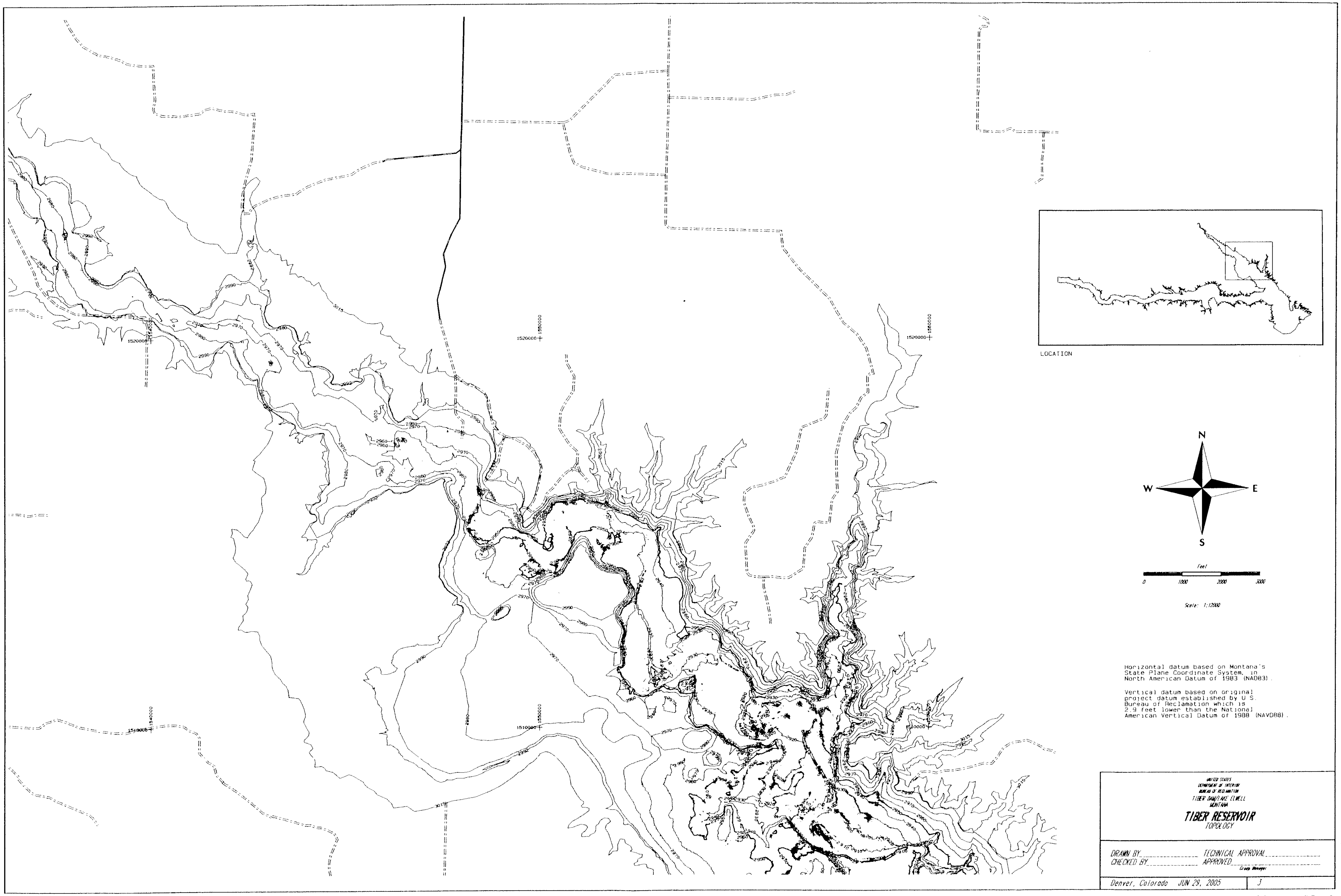

Figure 12 Tiber Reservoir topographic map No. 3

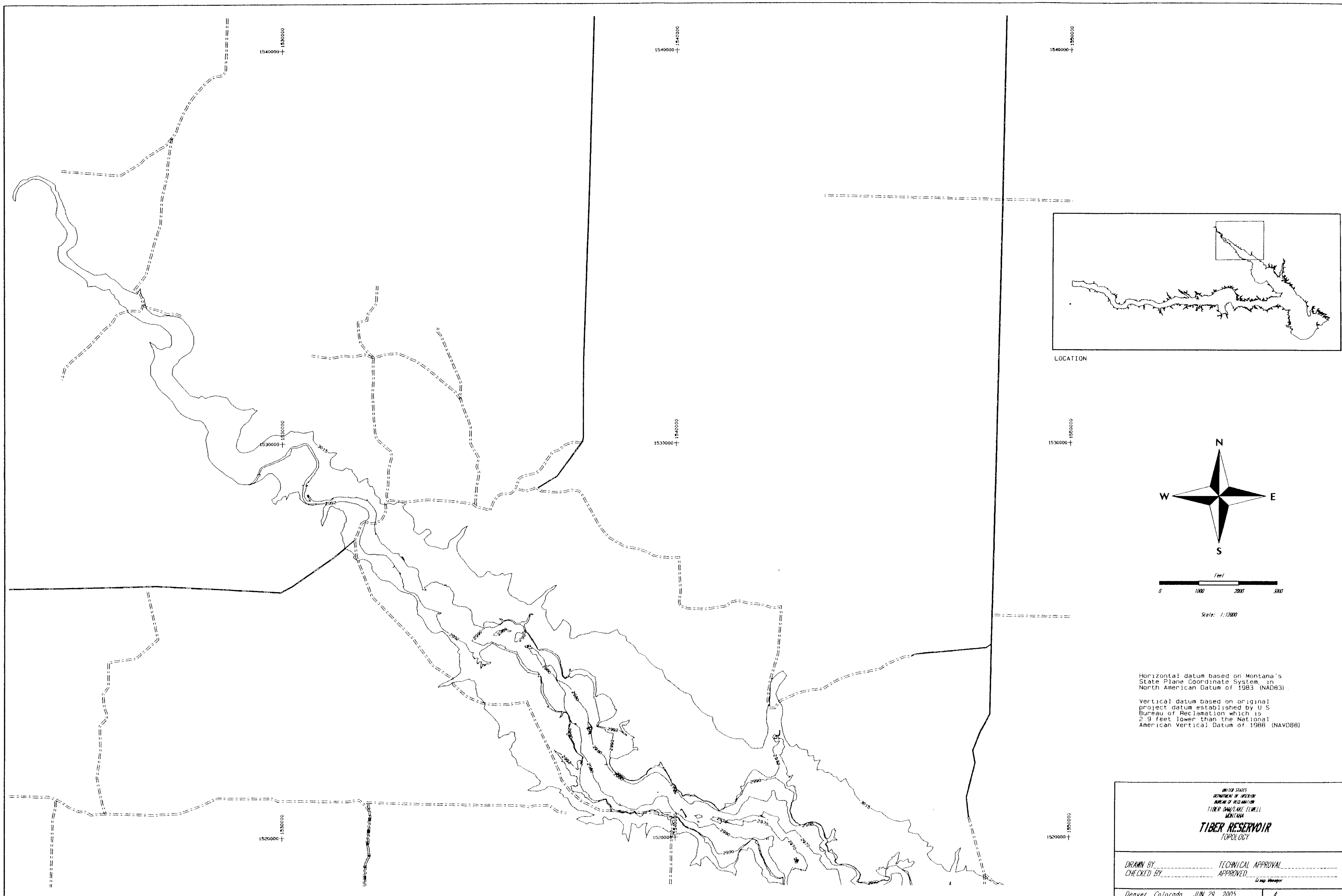

Figure 13. – Tiber Reservoir topographic map No. 4

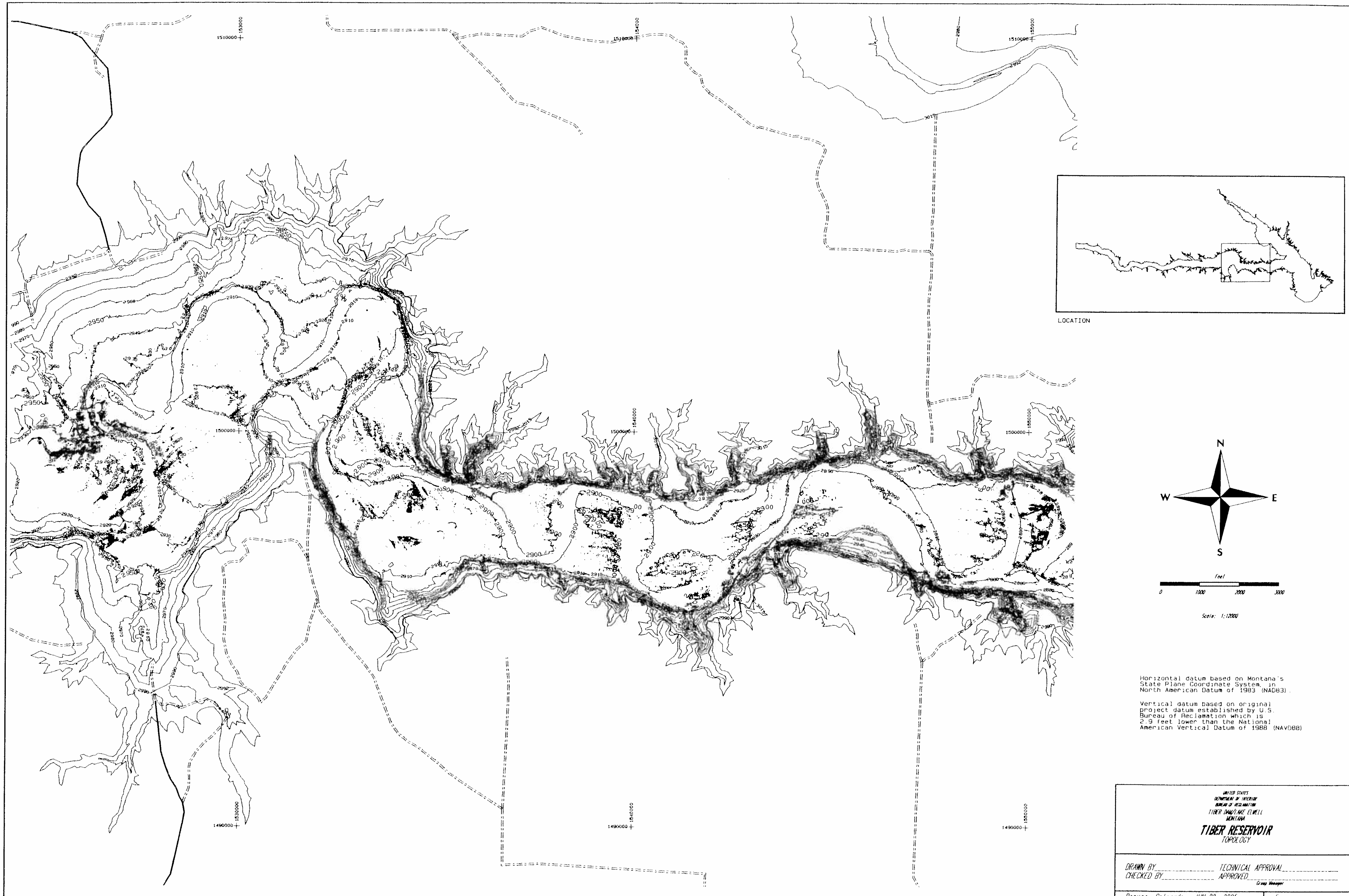

Figure 14. – Tiber Reservoir topographic map. No. 5.

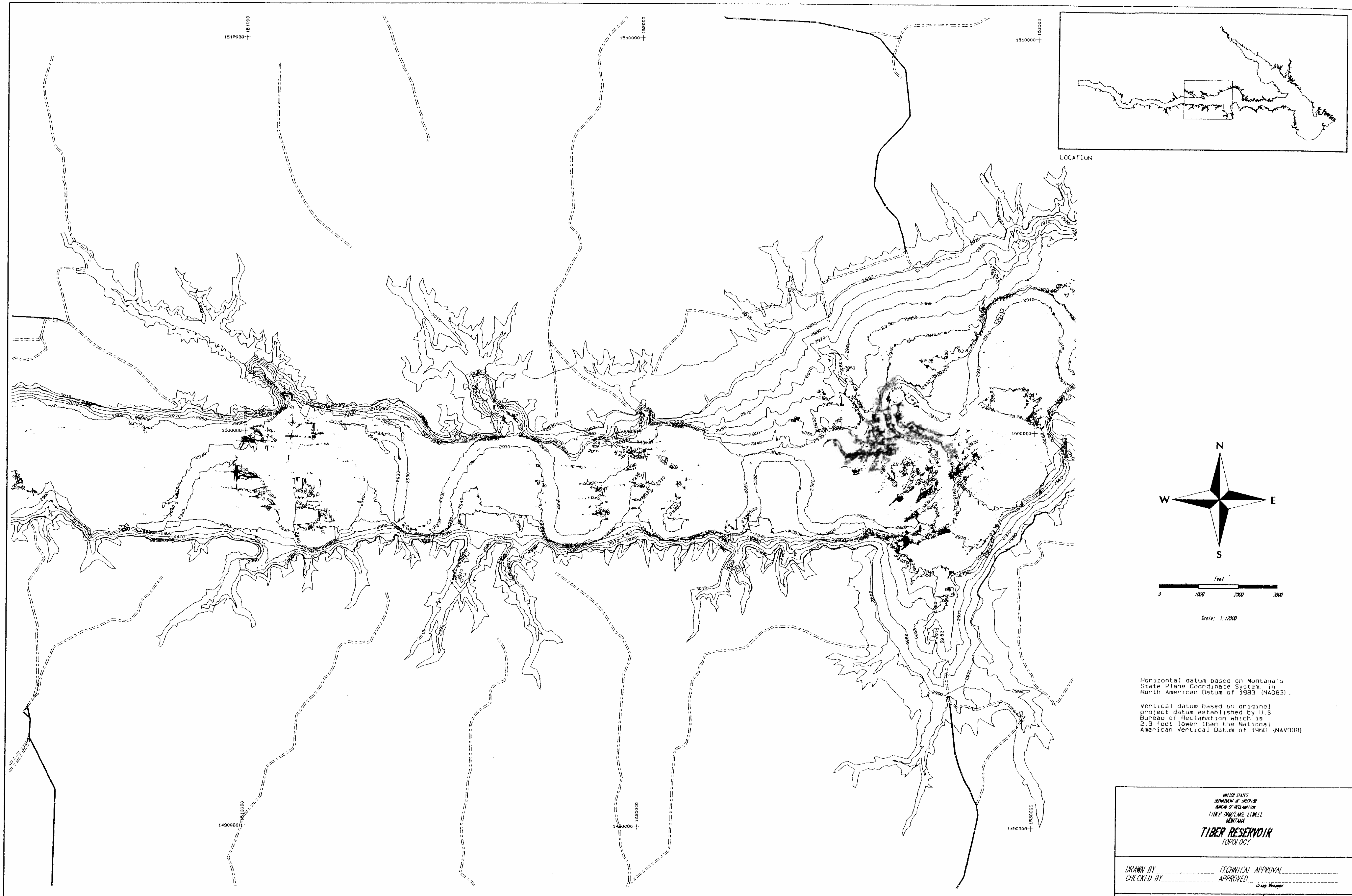

Figure 15. – Tiber Reservoir topographic map. No. 6

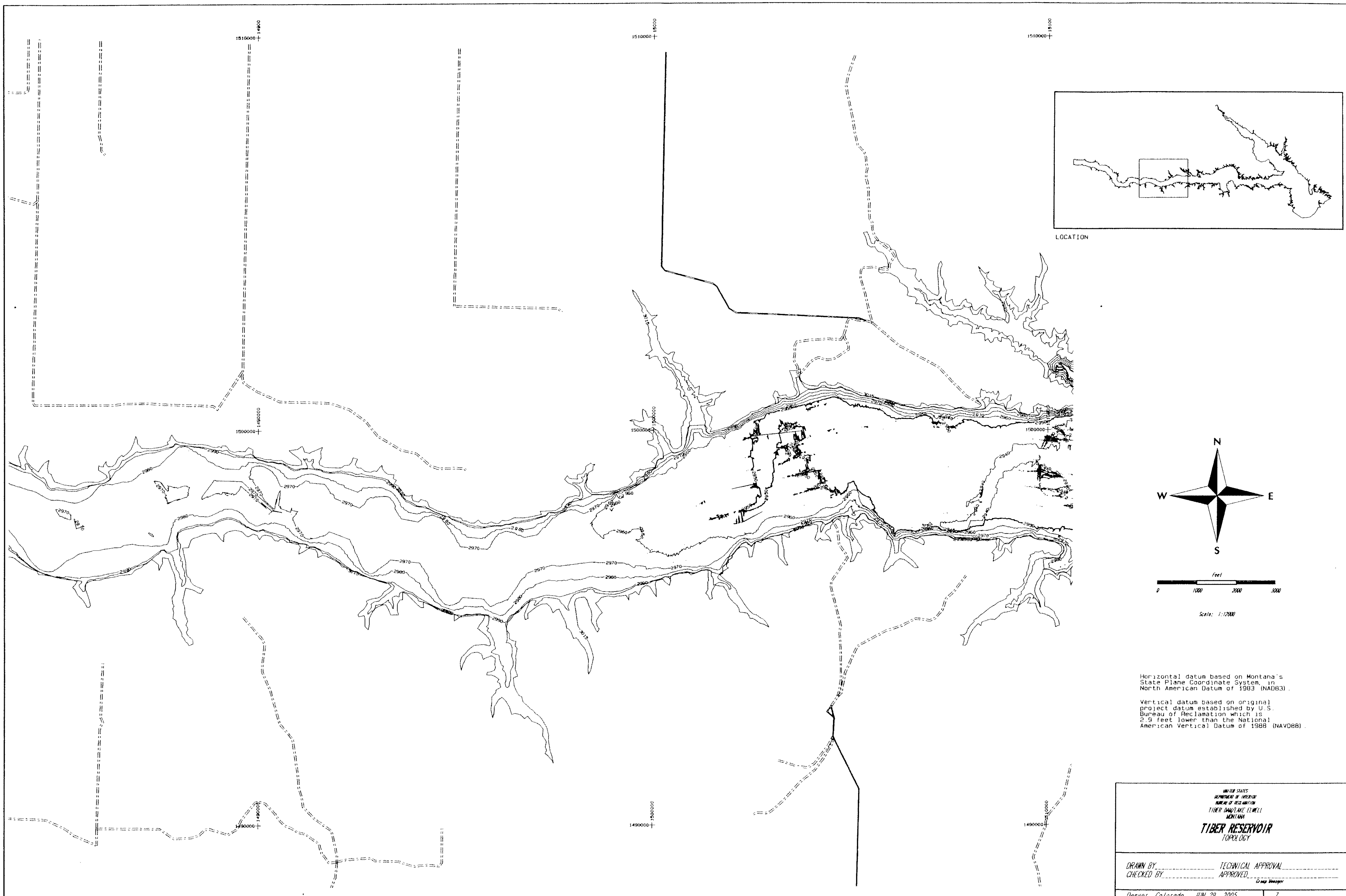

Figure 16. – Tiber Reservoir topographic map, No. 7.

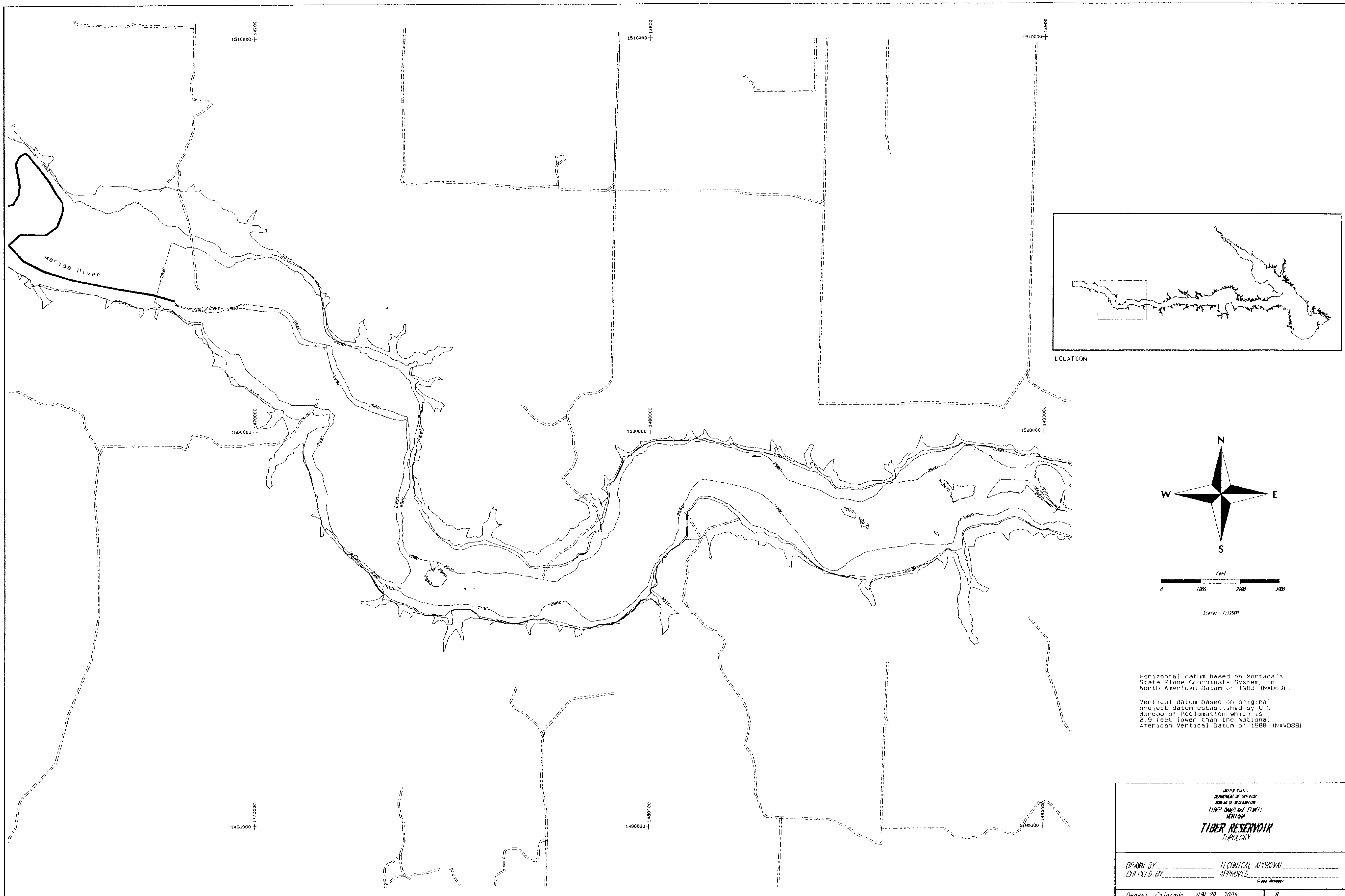

Figure 17. – Tiber Reservoir topographic map, No. 8.

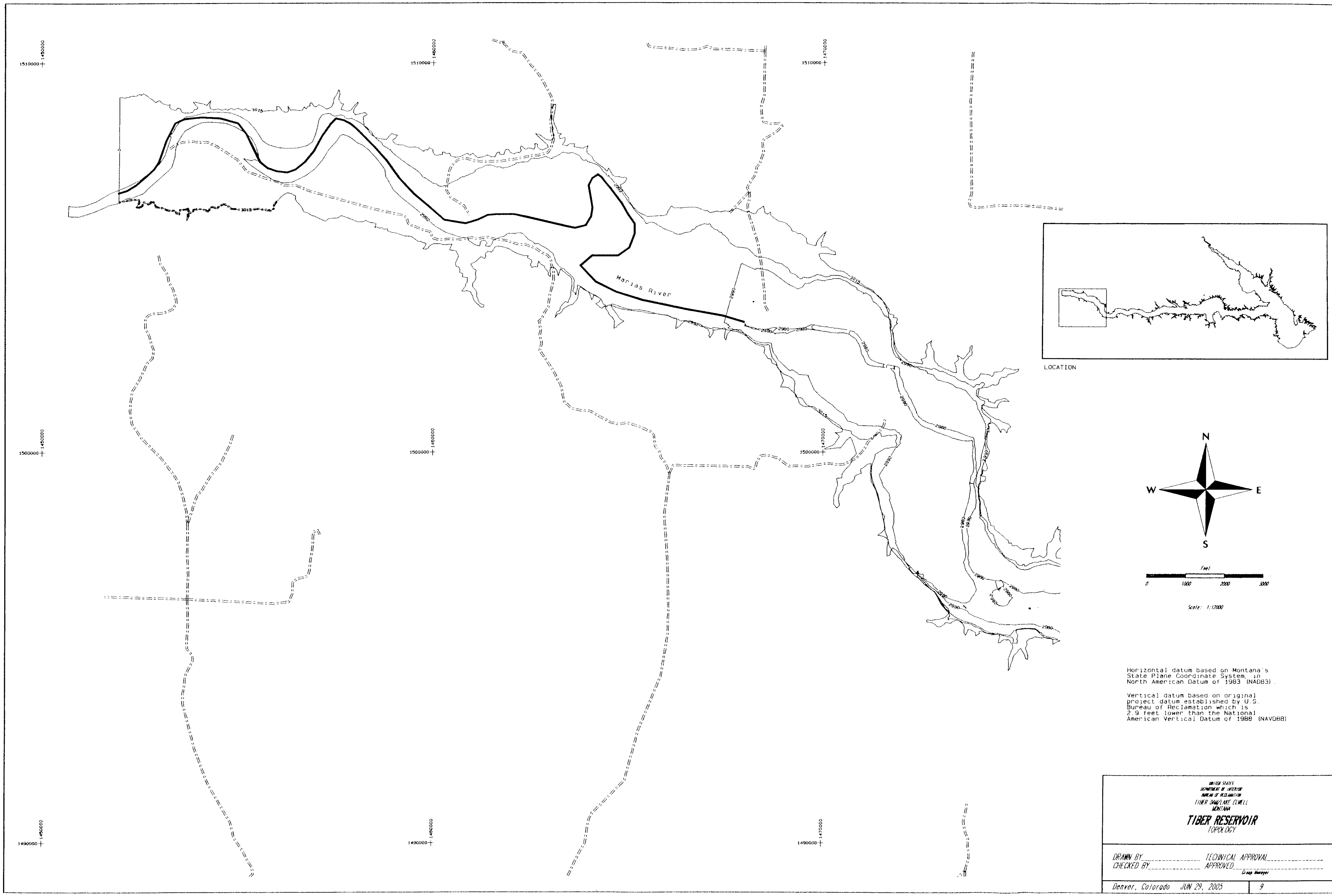

Figure 18. – Tiber Reservoir topographic map No. 9

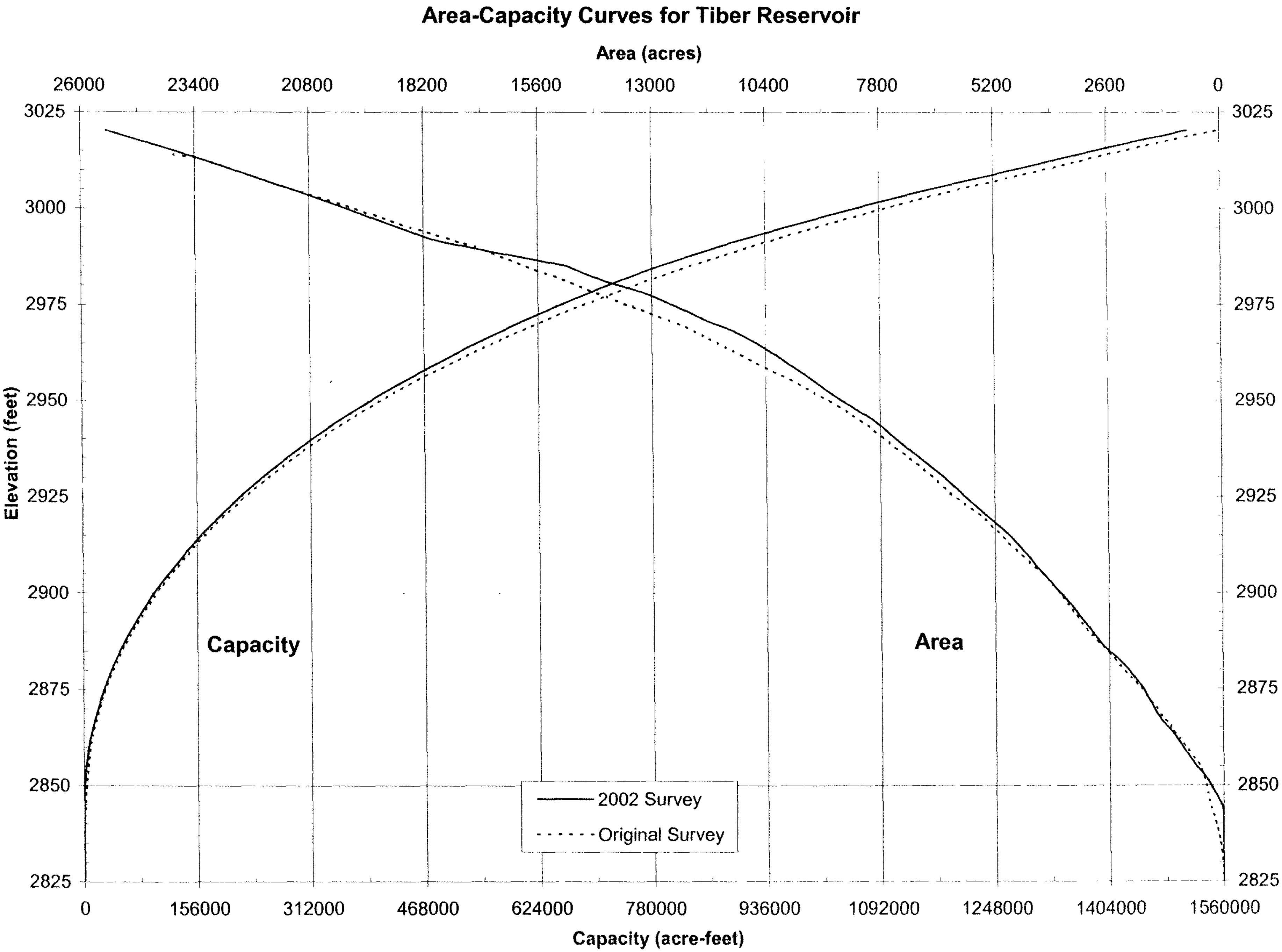

Figure 19. - 2002 area and capacity curves.