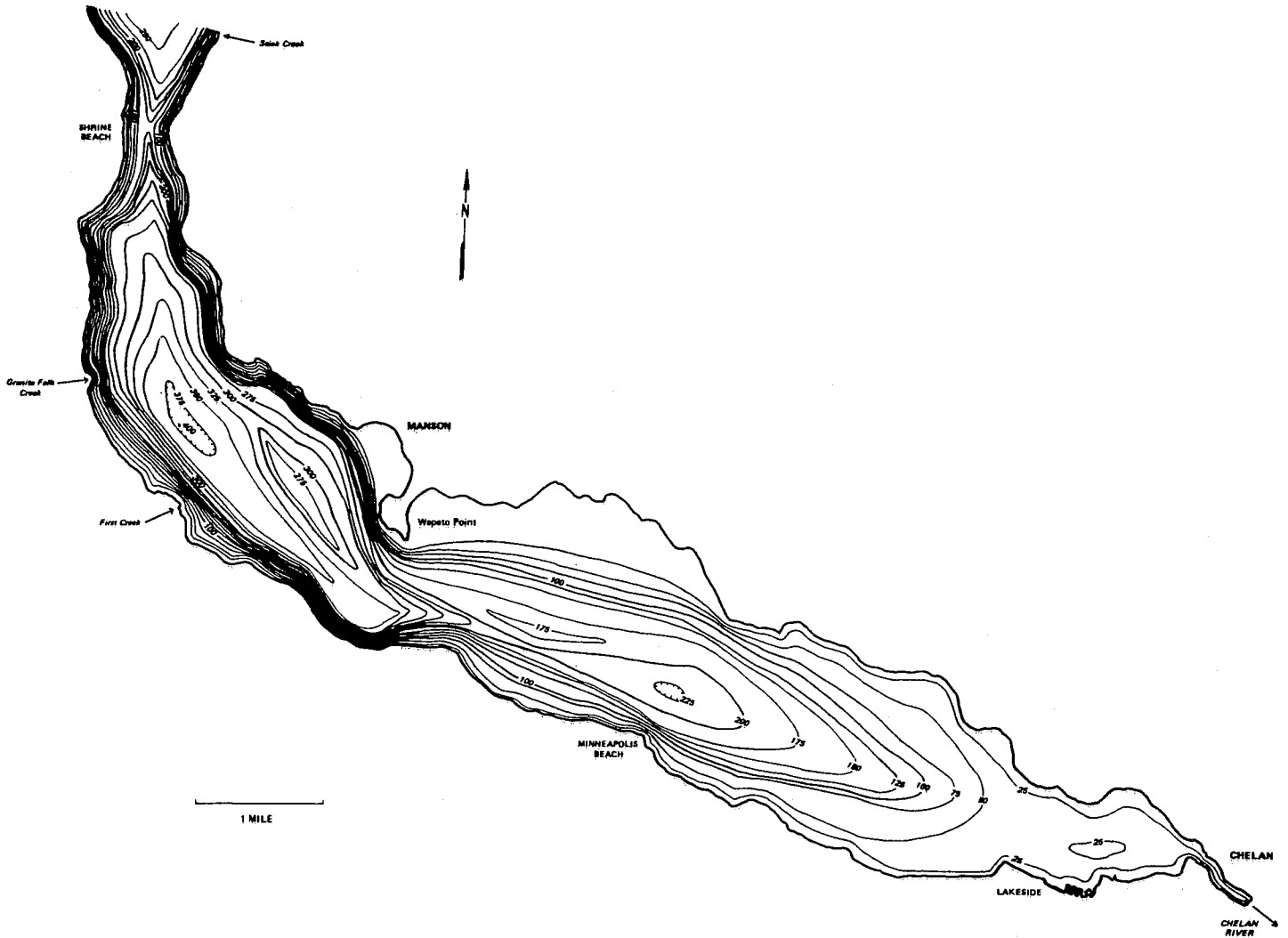


# MORPHOMETRY OF LAKE CHELAN



WASHINGTON STATE DEPARTMENT OF ECOLOGY

JANUARY 1987



BOOTH GARDNER  
Governor

ECOLOGY 87-1

ANDREA BEATTY RINIKER  
Director

Segment No. 21-47-101

MORPHOMETRY OF LAKE CHELAN

by

Will Kendra  
and  
Lynn Singleton

Water Quality Investigations Section  
Washington State Department of Ecology  
Olympia WA 98504-6811

January 1987

Ecology Report No. 87-1

## TABLE OF CONTENTS

| <u>Title</u>           | <u>Page</u> |
|------------------------|-------------|
| List of Tables         | ii          |
| List of Figures        | iii         |
| Acknowledgments        | iv          |
| Abstract               | v           |
| Introduction           | 1           |
| Methods                | 2           |
| Results and Discussion | 5           |
| References             | 29          |
| Appendices             | 30          |

LIST OF TABLES

| <u>Table<br/>Number</u> | <u>Title</u>   | <u>Page</u> |
|-------------------------|--|-------------|
| 1                       | Definition and significance of several morphometric features of lakes.                     | 4           |
| 2                       | Morphometric parameters of Lake Chelan and its two basins (delimited by the Narrows Sill). | 7           |

LIST OF FIGURES

| <u>Figure<br/>Number</u> | <u>Title</u>  | <u>Page</u> |
|--------------------------|---|-------------|
| 1                        | Map of Lake Chelan showing location of 40 echosounding tracks (solid lines) and boundaries of an 11-sheet bathymetric map (dashed lines, numerals).   | 9           |
| 2                        | Bathymetric map of Lake Chelan with 200-foot contour intervals.   | 10          |
| 3                        | Bathymetric map of Wapato Basin, Lake Chelan, with 25-foot contour intervals.   | 12          |
| 4                        | Bathymetric map of Lake Chelan with 100-foot contour intervals (map consists of 11 sheets; key to sheet locations is provided in Figure 1).   | 14          |
| 5                        | Longitudinal profile of the bottom topography of Lake Chelan, with (a) the vertical axis greatly exaggerated, and (b) both axes of same scale.  | 26          |
| 6                        | Relationship between depth maxima observed along echosounding transects common to both the 1966 (Whetten, 1967) and 1986 bathymetric surveys of Lake Chelan. The dashed reference line represents points of 1:1 correspondence. | 27          |
| 7                        | Hypsographic (a) and depth-volume (b) curves of Lake Chelan.  | 28          |

## ACKNOWLEDGMENTS

The authors wish to acknowledge the following individuals for their assistance on this project:

John Milhollin of Ecology's Cartographic Unit offered helpful suggestions concerning bathymetric map construction and provided access to drafting equipment and supplies.

Special thanks are given to Tim Gregg and Patrick Caton of the Resource Mapping Unit of the Washington State Department of Natural Resources, who performed the integration of bathymetric surface areas on a computer-based digitizing system.

## ABSTRACT

A morphometric survey of Lake Chelan, Washington, was conducted in July 1986. Forty echosounding profiles of subsurface topography were used to prepare three bathymetric maps of varying detail. Lake Chelan is the largest natural lake in Washington and the third deepest lake in the United States. Maximum and mean lake depths are 1,486 feet (453 meters) and 474 feet (144 meters), respectively. Lake volume is approximately 25 billion cubic yards (19 billion cubic meters) and hydraulic retention time is 10.6 years. Much of the lake is U-shaped in cross-section, a feature characteristic of glaciated valleys. The hydrographic attributes of Lake Chelan are strongly influenced by the morphometry and bathymetry of Lucerne Basin, which accounts for 74 percent of the lake's surface area and 92 percent of its volume.

## INTRODUCTION

Lake Chelan is the largest natural lake in Washington State and one of the deepest lakes in the world. Located in Chelan County, the lake bears the elongate, subrectangular shape characteristic of glacially carved fjords. From its downstream terminus at the city of Chelan, the lake extends northwesterly more than 50 miles (80 kilometers) to the mouth of the Stehekin River, which headwaters in the Cascade Range and is the principal inlet to the lake. Other major tributaries to Lake Chelan include Railroad, Fish, Prince, and Twenty-five Mile Creeks.

The elevation of Lake Chelan is controlled by a concrete dam at the outlet of the lake. Constructed in 1927, the dam raised the level of the lake 21 feet (6 meters) to its present full-pool height of 1,100 feet (335 meters). Nearly all of the outflow from Lake Chelan is diverted through a penstock for power production by Chelan County Public Utility District (PUD) No. 1. Discharge from the Chelan Falls Power Plant flows immediately into the Columbia River. The elevation of Lake Chelan is maintained at full-pool during the peak recreational season (July through September).

The Chelan watershed drains an area encompassing 924 square miles (2,393 square kilometers). Most (92 percent) of the basin is forested or undeveloped (Dion, *et al.*, 1976). Agricultural and residential uses comprise less than 3 percent of the acreage, while the lake itself accounts for most of the remainder. In addition to hydroelectric production, beneficial uses of Lake Chelan include recreation and water supply (domestic and agricultural).

As part of an ongoing water quality assessment of Lake Chelan, the Water Quality Investigations Section of Ecology initiated a morphometric study of the lake. Morphometry is the branch of limnology that concerns the measurement of the size and shape of a lake basin. Morphometric data are required to evaluate nutrient loading and sedimentation rates, chemical mass, water and energy budgets, thermal stability, biological productivity, and other structural and functional components of a lake ecosystem (Wetzel and Likens, 1979).

Objectives of the morphometric survey were two-fold: (1) to develop a bathymetric map of Lake Chelan, and (2) to quantify the hydrographic features of Lake Chelan in the form of standard morphometric parameters. The work reported here represents the first comprehensive analysis of the morphometry and bathymetry of Lake Chelan.



## METHODS

The subsurface topography of Lake Chelan was surveyed July 15 and 22-24, 1986, using bathymetric techniques common to limnological investigations (Hakanson, 1981). Continuous echosounding profiles of the lake bottom were recorded by a fathometer mounted on a 20-foot motorboat. The boat was operated at constant speed and direction along 40 predetermined sounding track lines (Figure 1; Appendix A). Thirty-five of the sounding tracks were oriented approximately normal to the long axis of the lake. To verify accuracy, four tracks were positioned to cross several of the 35 lines. In general, headings for the track lines were visible from opposite shores and discernible on USGS maps. Occasionally, positions and course headings were fixed with a compass.

The fathometer was a Ross 800-Series Portable Survey Recorder. Powered by 24 volts DC, the fathometer had a range of 2,400 feet (732 meters). A 50-kilohertz, 22-degree transducer was suspended off the side of the boat by a rigid outrigger. Soundings were later adjusted to correct for the one-foot operating depth of the transducer. The stylus motor drive of the chart recorder was preset to function at a fixed sound velocity of 4,800 feet per second (1,463 meters per second). The fathometer was periodically calibrated with a graduated dacron sounding line. The elevation of Lake Chelan remained constant at 1,100 feet (335 meters) for the duration of the echosounding survey (B. Dearing, Chelan PUD, personal communication).

Bathymetric maps were drawn and morphometric parameters were subsequently calculated using the methods of Welch (1948), Hutchinson (1957), Lind (1979), and Wetzel and Likens (1979). Briefly, depth measurements along the sounding tracks were plotted to scale on outline maps of Lake Chelan. Contour lines were then drawn by freehand, using mathematical interpolation where necessary. The area of the plane circumscribed by each 100-foot contour was integrated on a computer-based digitizing system operated by the Washington State Department of Natural Resources. The volume of strata (layers) between contours was calculated using one of the following formulations:

1.  $V = h(a_1 + a_2)/2$
2.  $V = h(a_1 + a_2 + \sqrt{a_1 a_2})/3$
3.  $V = ha_1/3$
4.  $V = ha_1/2$

where:  $V$  = volume of stratum  
 $h$  = depth (thickness) of stratum  
 $a_1$  = area of upper surface of stratum  
 $a_2$  = area of lower surface of stratum

For strata with contours of similar surface area, the rectangular prism formula was used (Equation 1). Where the areas diverged

considerably, the truncated cone formulation was applied (Equation 2). The volume of bottom strata which terminated at a point of maximum depth was calculated as the volume of a cone (Equation 3), while the volume of bottom strata of gradual or no slope was taken as the volume of a wedge (Equation 4). Total lake volume was determined by summing the strata volumes.

Additional morphometric parameters were measured or calculated as described in Table 1. Shoreline length was measured with a cartometer. Maximum depth was determined by intensively sounding the deepest portions of the lake. Hydraulic residence time was calculated as lake volume divided by mean annual outflow.

Table 1. Definition and significance of several morphometric features of lakes.

| Parameter                | Definition   | Significance  |
|--------------------------|--|---|
| Maximum Length           | Open-water distance between the two most remote extremities of a lake.   | This value is commonly reported as "lake length."   |
| Maximum Effective Length | Longest straight-line open-water distance between any two shoreline points.  | Represents the maximum fetch (i.e., effective length for wind to act without interruption by land).               |
| Maximum Width            | Maximum distance between opposite shores, perpendicular to the maximum-length axis.  | --  |
| Mean Width               | Lake surface area divided by maximum length.   | This value is commonly reported as "lake width."  |
| Mean Depth               | Lake volume divided by surface area.   | Important in models describing lake productivity and trophic status.  |
| Shoreline Development    | Ratio of shoreline length (SL) to the length of the circumference of a circle of area (A) equal to that of the lake ( $SL/2\sqrt{A\pi}$ ). | As an index of shoreline irregularity, this ratio reflects the potential for development of littoral communities. |

## RESULTS AND DISCUSSION

Lake Chelan consists of two basins, Wapato and Lucerne (Figures 2 - 4). The lower basin, Wapato, is relatively broad and shallow, with a length of 12.0 miles (19.3 kilometers) and maximum depth of 400 feet (122 meters). Lucerne Basin is 38.4 miles (61.8 kilometers) long and attains a maximum depth of 1,486 feet (453 meters) in the vicinity of Big Goat Creek. Between Twentyfive Mile Creek and Canoe Creek, the walls of Lucerne Basin descend abruptly to depths exceeding 1,000 feet (305 meters). Lucerne Basin is U-shaped in cross-section, a feature characteristic of most glaciated valleys. The two basins are separated by a shallow (127 feet/39 meters) sill located at a constriction of the lake known as the "Narrows" (Figure 5; Appendix A).

Lake Chelan was formed through glacial erosion of its upper and middle portions and deposition at the outlet (Freeman, 1944; Whetten, 1967). During the last major glaciation, the Chelan Glacier advanced down the Chelan Valley to a point near the Narrows. Meanwhile, the Okanogan-Columbia Valley lobe of the Cordilleran Ice Sheet invaded the Chelan Valley at least up to Wapato Point, creating Glacial Lake Chelan between the two glaciers. Recession of the Okanogan-Columbia Valley lobe left the lower Chelan River blocked with glacial deposits, forming Lake Chelan. Contemporary sediment thickness in Wapato Basin is greater than in Lucerne Basin due to the large volume of glacial debris that accumulated in the lower valley between the two glaciers.

At 1,486 feet (453 meters), Lake Chelan is the third deepest freshwater lake in the United States, behind Crater Lake (1,932 feet/589 meters) and Lake Tahoe (1,645 feet/501 meters) (Bue, 1963). Earlier investigators have reported Lake Chelan to be between 1,503 feet (458 meters) and 1,605 feet (489 meters) deep (Freeman, 1944; Hutchinson, 1957; Bue, 1963). However, the methods used to sound the lake were not documented and therefore are suspect. More recently, Whetten (1967) echosounded much of the lake and found a maximum depth of 1,529 feet (466 meters). Seven of Whetten's sounding tracks were the same as those of the present survey. A plot of depth maxima observed along these tracks during the two surveys reveals an interesting trend (Figure 6). As depth increases, Whetten's results deviate from ours by increasingly larger margins.

Our maximum sounding of 1,486 feet was confirmed in late 1986 during sediment coring operations with a metered winch (C. Patmont, Harper-Owes, personal communication). Several factors may explain the error in Whetten's measurements. Fathometer accuracy in the present survey was periodically verified to a depth of 450 feet (137 meters) using bar checks. Whetten did not document calibration procedures, hence the accuracy of his fathometer is uncertain. Further, the differences in depth measurement may reflect 20 years of advancement in echosounding technology. In addition, Whetten's fathometer generated sonar pulses at a frequency of 1 kilohertz, which is optimal for sediment penetration (layering studies) but of questionable utility for measurement of bottom topography. Finally, the echosounding

discrepancies may be attributed to the variable velocity of sound in water.

The speed of sound in water is a function of temperature, salinity, and depth (Albers, 1965):

$$C = 4625 + 7.68(t-32) - 0.0376(t-32)^2 + 3.35s + 0.018d$$

where: C = velocity of sound in water (feet per second [fps])  
t = temperature (<sup>o</sup>F)  
s = salinity (parts per thousand)  
d = depth (feet)

At the surface of a 58<sup>o</sup>F (14<sup>o</sup>C) freshwater lake, the velocity of sound is about 4,800 fps (1,463 m/s). Some fathometers feature a control to adjust sound velocity, but these instruments do not alter the speed of sound in water. Instead, they alter the speed of the motor-driven stylus to compensate for changes in sound velocity caused by density and pressure gradients. In other words, the sound velocity control internally corrects fathometer readings to reflect the true speed of sound under actual study conditions.

Using temperature and depth data from July 1986, the velocity of sound in Lake Chelan was estimated to be 4,723 fps (1,440 m/s). Because our fathometer readings were based on an assumed (preset) sound velocity of 4,800 fps (1,463 m/s), maximum depth measurements may have been overestimated by up to 1.6 percent (24 feet/7 meters). Whetten reported an assumed sound velocity of 4,921 fps (1,500 m/s), thus his maximum depth measurement may have been overestimated by 4.0 percent (61 feet/19 meters), assuming temperature gradients for August 1966 and July 1986 were similar. If Whetten's data are corrected for this error, maximum soundings from the two bathymetric surveys more closely coincide.

The hydrographic characteristics of Lake Chelan are strongly influenced by the morphometry and bathymetry of Lucerne Basin (Table 2). The maximum fetch of Lake Chelan occurs along a 15.4-mile (24.8-kilometer) stretch of Lucerne Basin. The mean depth of Lucerne Basin is considerably greater than that of Wapato Basin, but not unlike the overall lake mean. The shoreline development index suggests that Lucerne Basin has a higher potential than Wapato Basin for the development of littoral communities, but the steep walls of Lucerne Basin negate this potential. In total Lucerne Basin accounts for 74 percent of Lake Chelan's surface area and more than 92 percent of its volume.

The volume of Lake Chelan was calculated in both vertical and horizontal increments (Appendices B and C) to allow greater flexibility in the manipulation and analysis of area/volume data. Lake volume was

Table 2. Morphometric parameters of Lake Chelan and its two basins (delimited by the Narrows Sill).

| Parameter <sup>a</sup>               | Wapato Basin      | Lucerne Basin     | Lake Chelan |
|--------------------------------------|-------------------|-------------------|-------------|
| Maximum Length (mi.)                 | 12.0              | 38.4              | 50.4        |
| Maximum Effective Length (mi.)       | 9.6               | 15.4              | 15.4        |
| Maximum Width (mi.)                  | 1.8               | 1.4               | 1.8         |
| Mean Width (mi.)                     | 1.1               | 1.0               | 1.0         |
| Maximum Depth (ft.)                  | 400               | 1,486             | 1,486       |
| Mean Depth (ft.)                     | 140               | 590               | 474         |
| Shoreline Length (mi.)               | 27.6 <sup>b</sup> | 82.3 <sup>b</sup> | 109.2       |
| Shoreline Development                | 2.1               | 3.7               | 4.3         |
| Surface Area (sq. mi.)               | 13.5              | 38.6              | 52.1        |
| Percent of Lake Surface Area         | 26.0              | 74.0              | 100.0       |
| Volume (cu. yds. x 10 <sup>9</sup> ) | 1.95              | 23.5              | 25.5        |
| Percent of Lake Volume               | 7.6               | 92.4              | 100.0       |

<sup>a</sup>Defined in Table 1.

<sup>b</sup>Distance across lake at the Narrows Sill is included in this value.

approximately 25 billion cubic yards (19 billion cubic meters); in layman's terms, this amount of water is enough to cover an area the size of Washington State to a depth of 4.4 inches. Based on a 79-year average outflow of 2.4 billion cubic yards (1.8 billion cubic meters) per year (USGS, 1985), the hydraulic retention time of Lake Chelan was calculated to be 10.6 years.

Hypsographic (depth-area) and depth-volume curves of Lake Chelan were drawn to show the relationship of lake area and volume to depth (Figure 7). Hypsographic curves permit determination of the absolute and/or relative area circumscribed by a lake basin at any depth level. Similarly, depth-volume curves allow determination of the absolute and/or relative volume of water located above any specific depth. For example the depth-volume curves can be used to estimate the volume of water in Lake Chelan's cryptodepression (that portion of the lake basin beneath sea level). The curves reveal that 1.3 billion cubic yards (1 billion cubic meters) or 5 percent of the lake's volume is located below mean sea level (i.e., a depth of 1,100 feet or 335 meters).

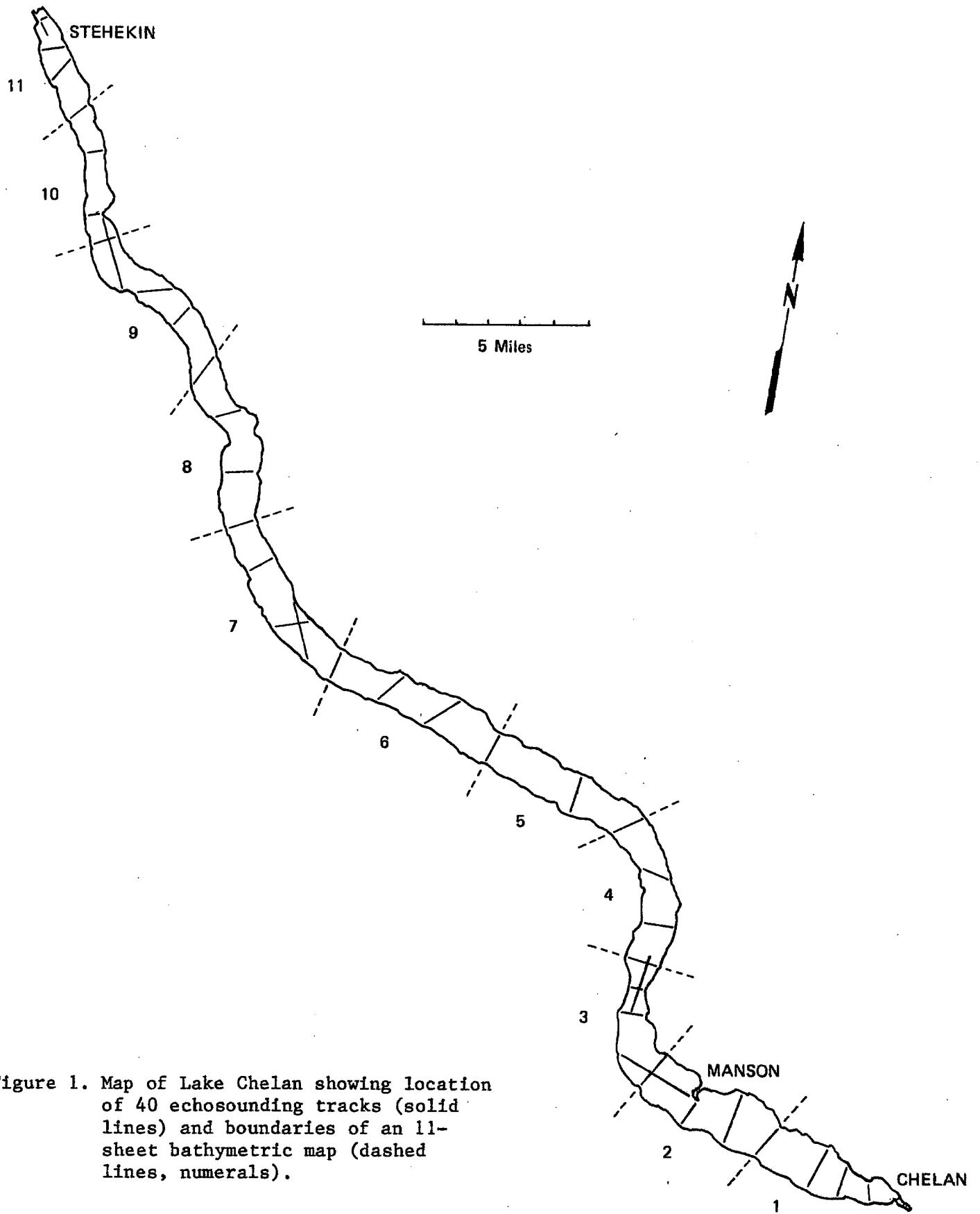


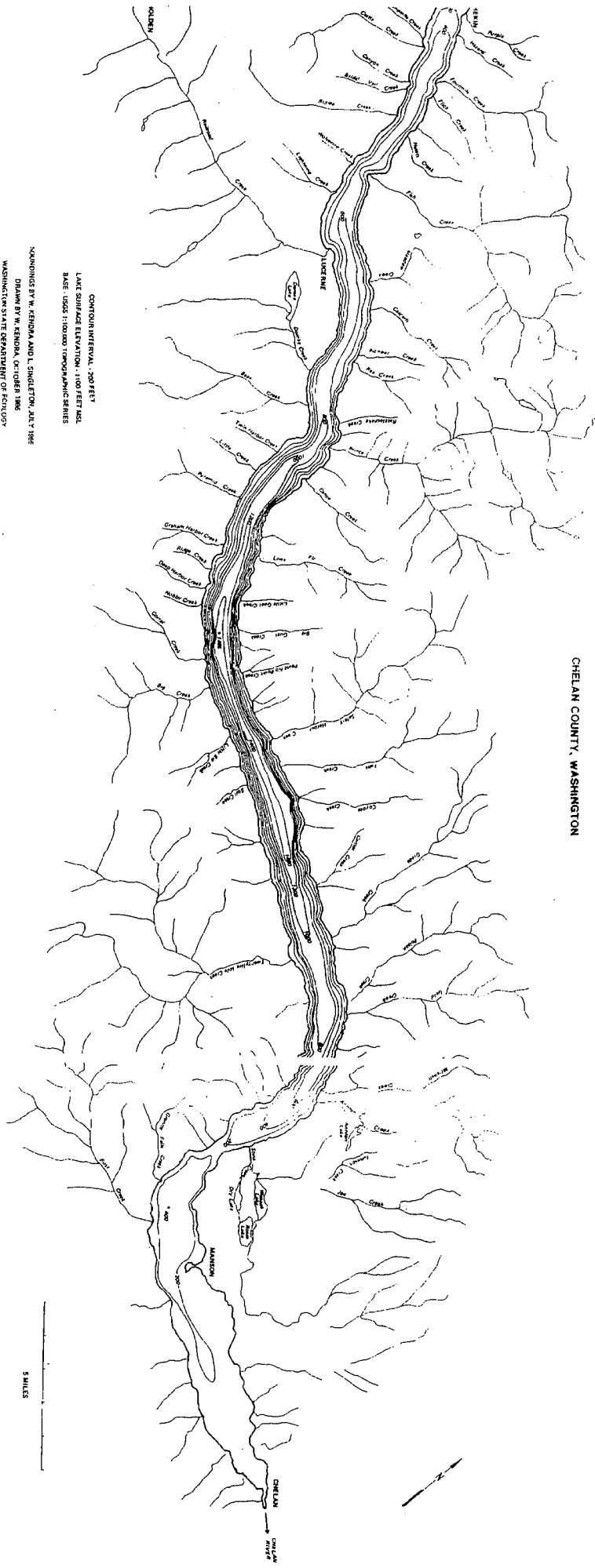
Figure 1. Map of Lake Chelan showing location of 40 echosounding tracks (solid lines) and boundaries of an 11-sheet bathymetric map (dashed lines, numerals).



Figure 2

Bathymetric Map of Lake Chelan with 200-foot Contour Intervals

BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON



CONTOUR INTERVAL: 200 FEET  
LAKE SURFACE ELEVATION: 1100 FEET MSL  
BASE: U.S.G.S. 1:100,000 TOPOGRAPHIC SERIES

SKETCHES BY W. KENDRA AND L. SINGLETON, JULY 1966  
DRAWN BY W. KENDRA, OCTOBER 1966  
WASHINGTON STATE DEPARTMENT OF FISH AND WILDLIFE

Figure 3

Bathymetric Map of Wapato Basin, Lake Chelan,  
with 25-foot Contour Intervals

**BATHYMETRIC MAP OF WAPATO BASIN, LAKE CHELAN  
CHELAN COUNTY, WASHINGTON**

CONTOUR INTERVAL - 25 FEET  
LAKE SURFACE ELEVATION - 1100 FEET MSL  
BASE - USGS 1:25000 TOPOGRAPHIC SERIES

SOUNDINGS BY W. KEMMRA AND L. SINGLETON, JULY 1966  
DRAWN BY W. KEMMRA, OCTOBER 1966  
WASHINGTON STATE DEPARTMENT OF ECOLOGY

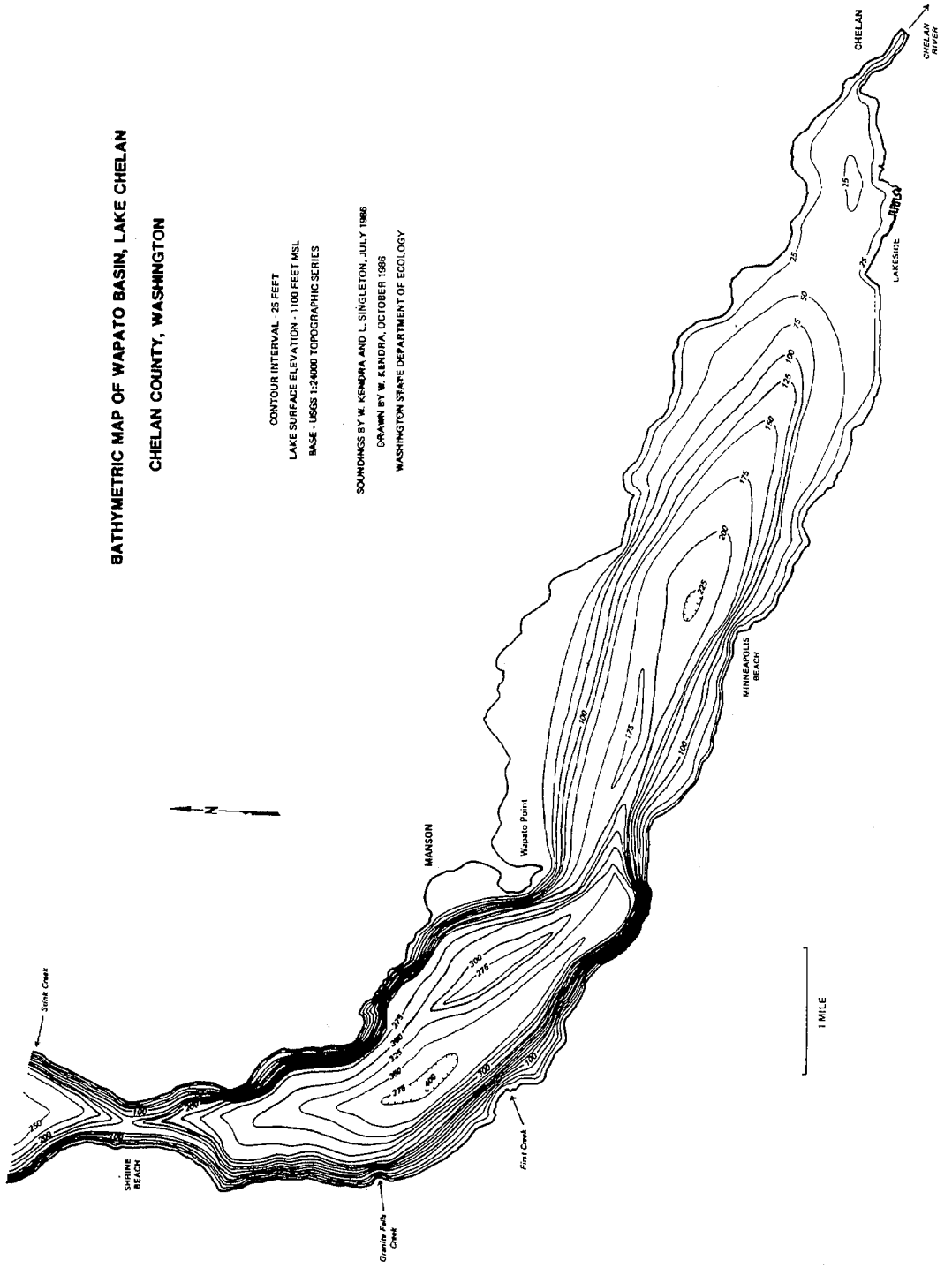
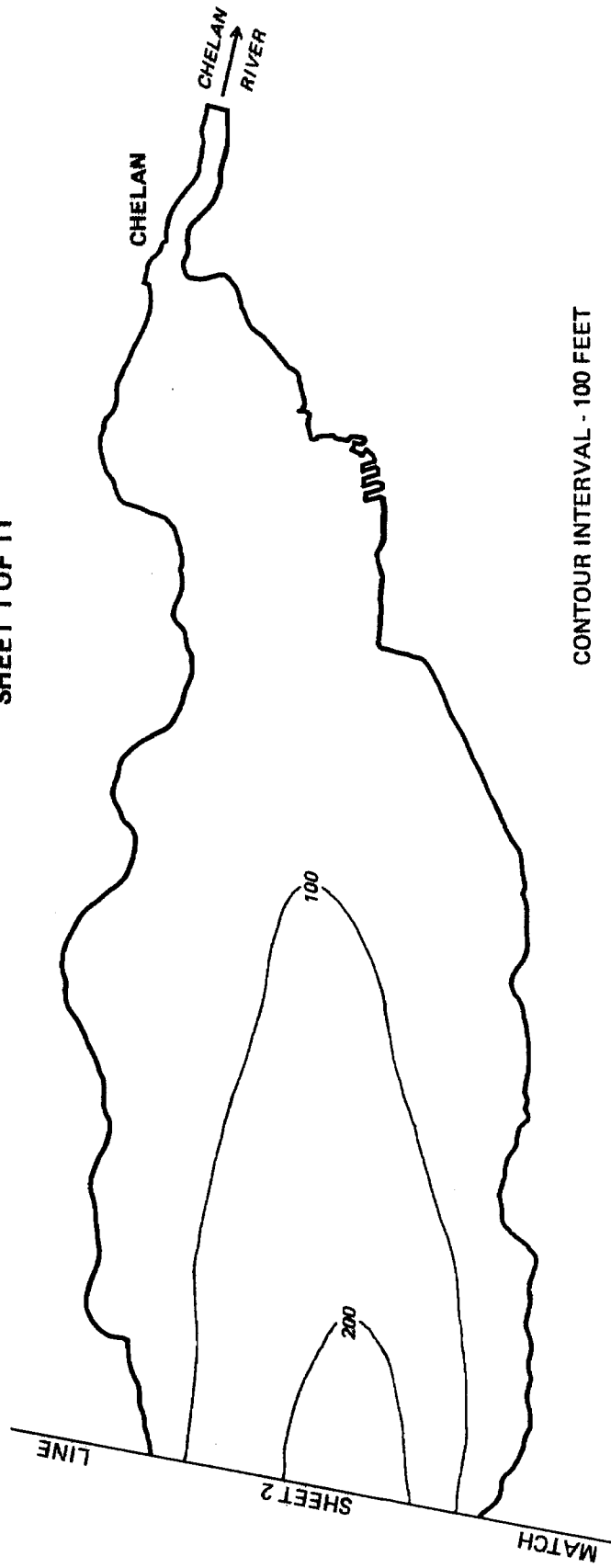


Figure 4

Bathymetric Map of Lake Chelan with 100-foot Contour Intervals  
(map consists of 11 sheets; key to sheet locations  
is provided in Figure 1)

BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

SHEET 1 OF 11



CONTOUR INTERVAL - 100 FEET

LAKE SURFACE ELEVATION - 1100 FEET MSL

BASE - USGS 1:24000 AND 1:62500 TOPOGRAPHIC SERIES

SOUNDINGS BY W. KENDRA AND L. SINGLETON, JULY 1986

DRAWN BY W. KENDRA, OCTOBER 1986

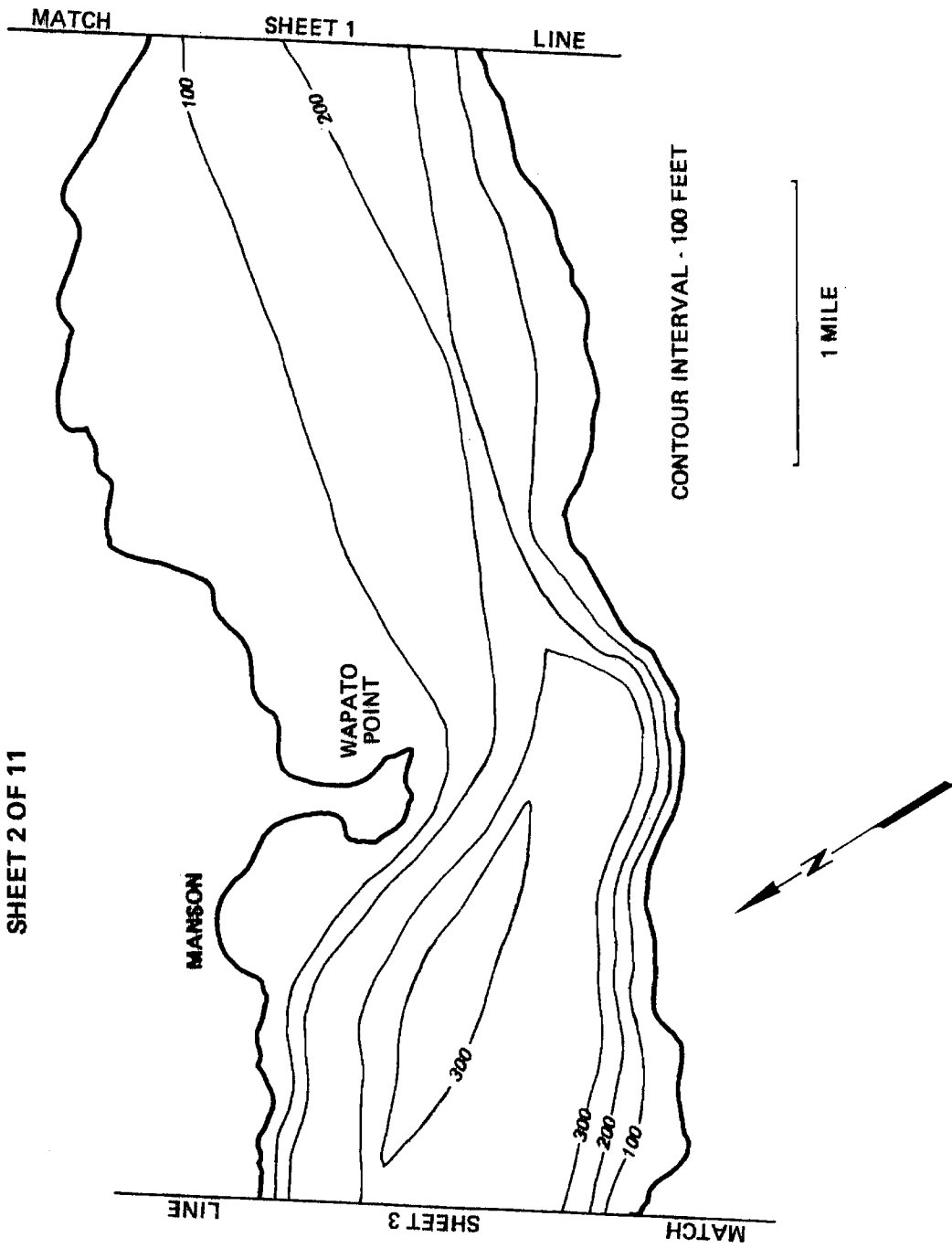
WASHINGTON STATE DEPARTMENT OF ECOLOGY

1 MILE



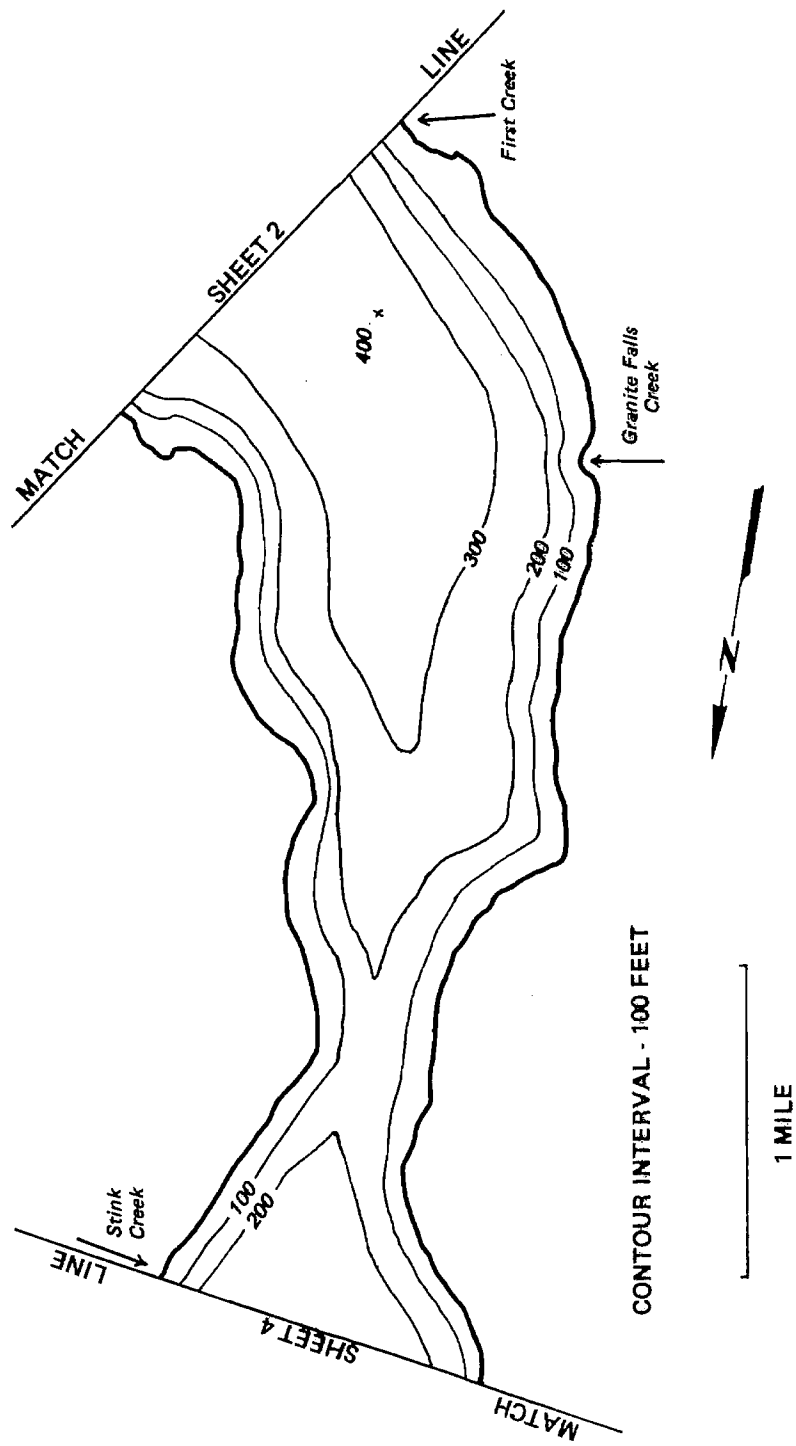
BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

SHEET 2 OF 11



BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

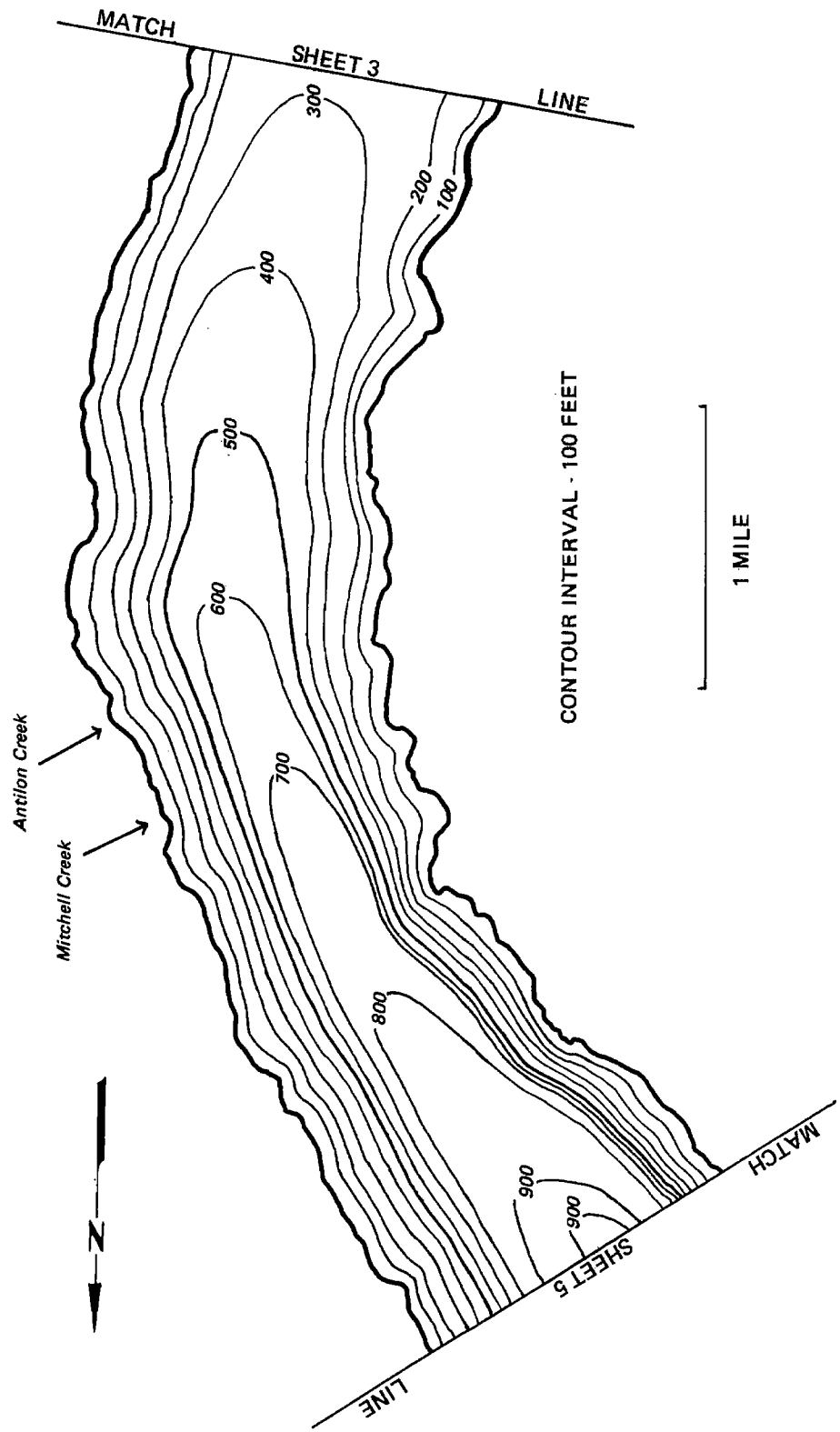
SHEET 3 OF 11





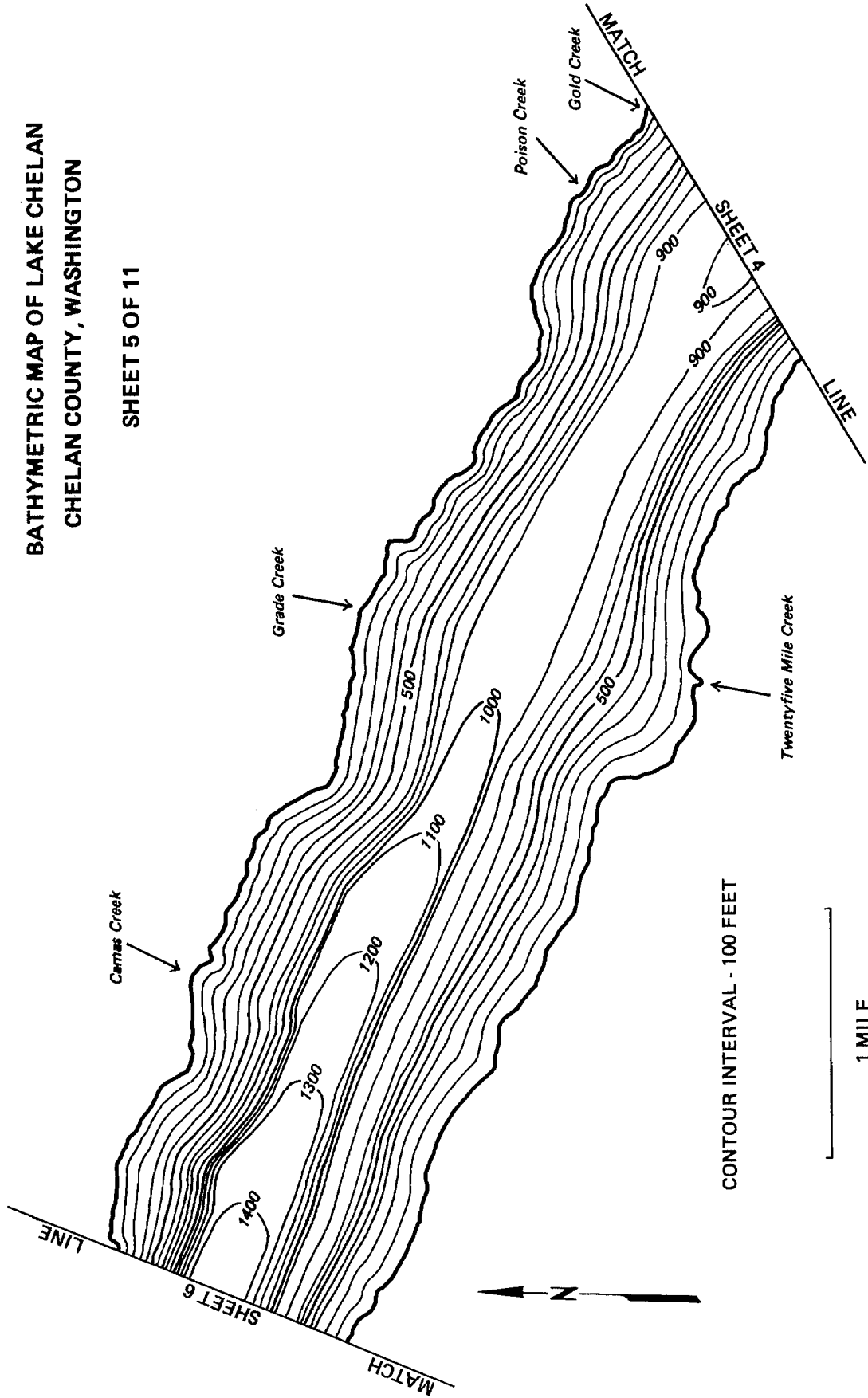
**BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON**

**SHEET 4 OF 11**



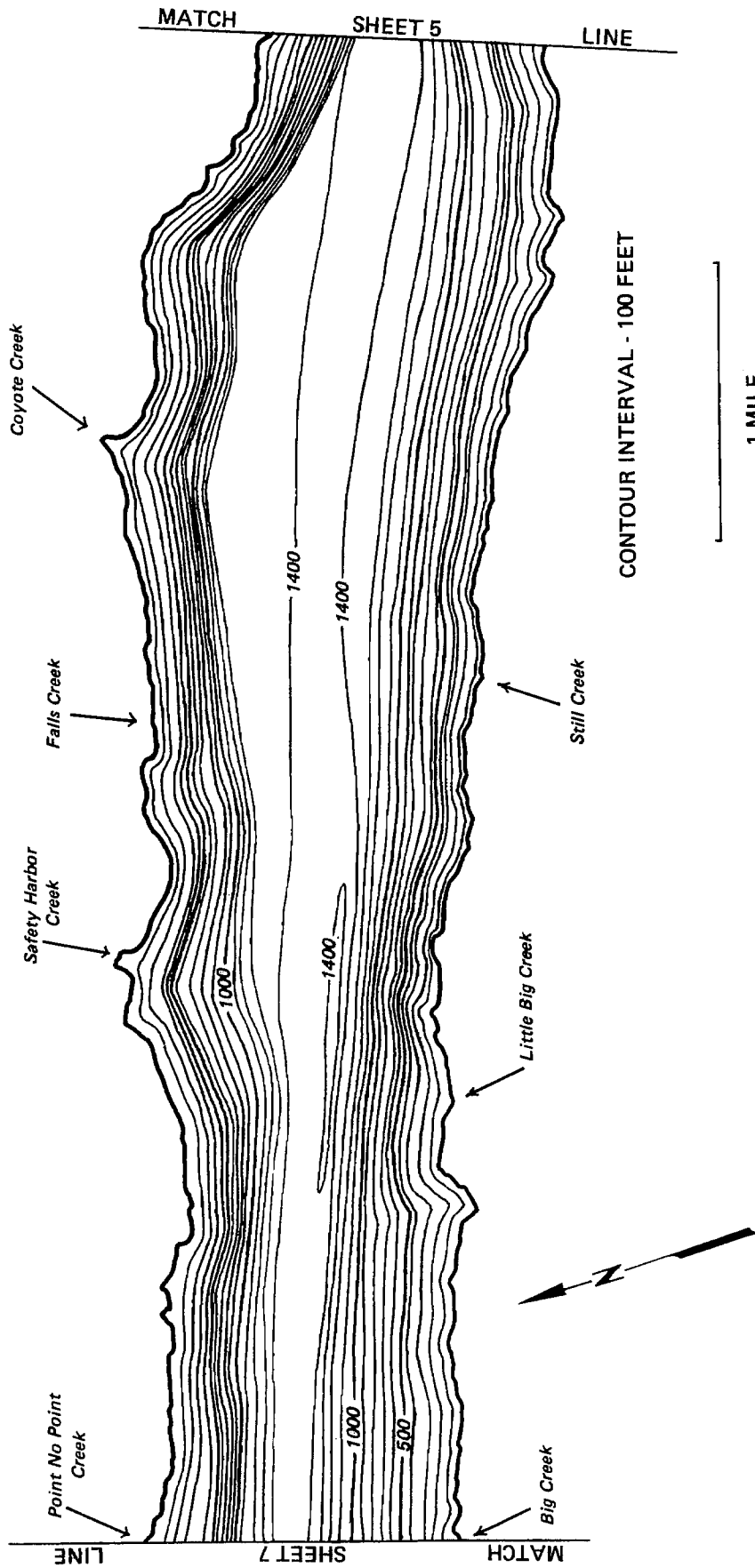
BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

SHEET 5 OF 11



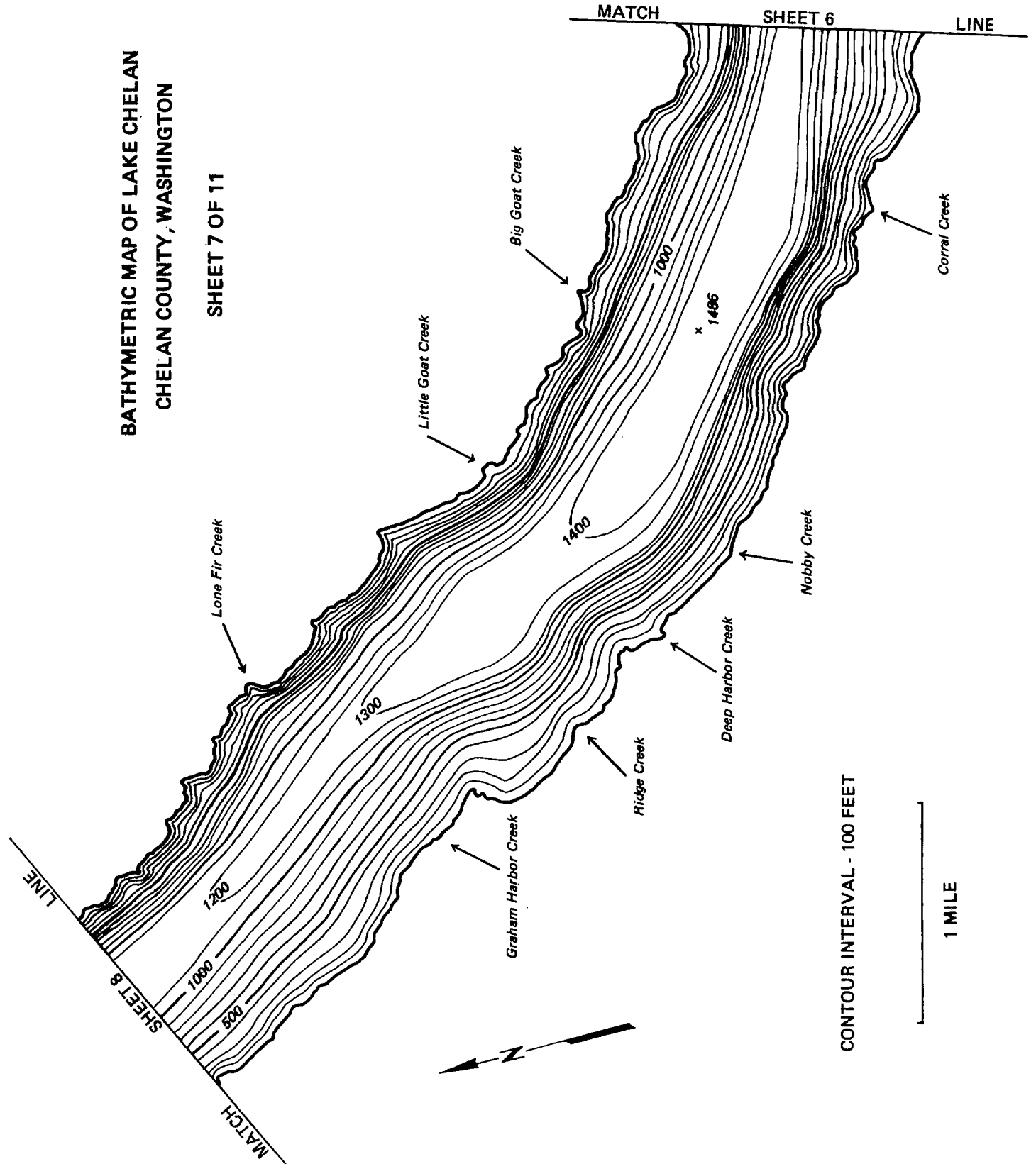
**BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON**

**SHEET 6 OF 11**



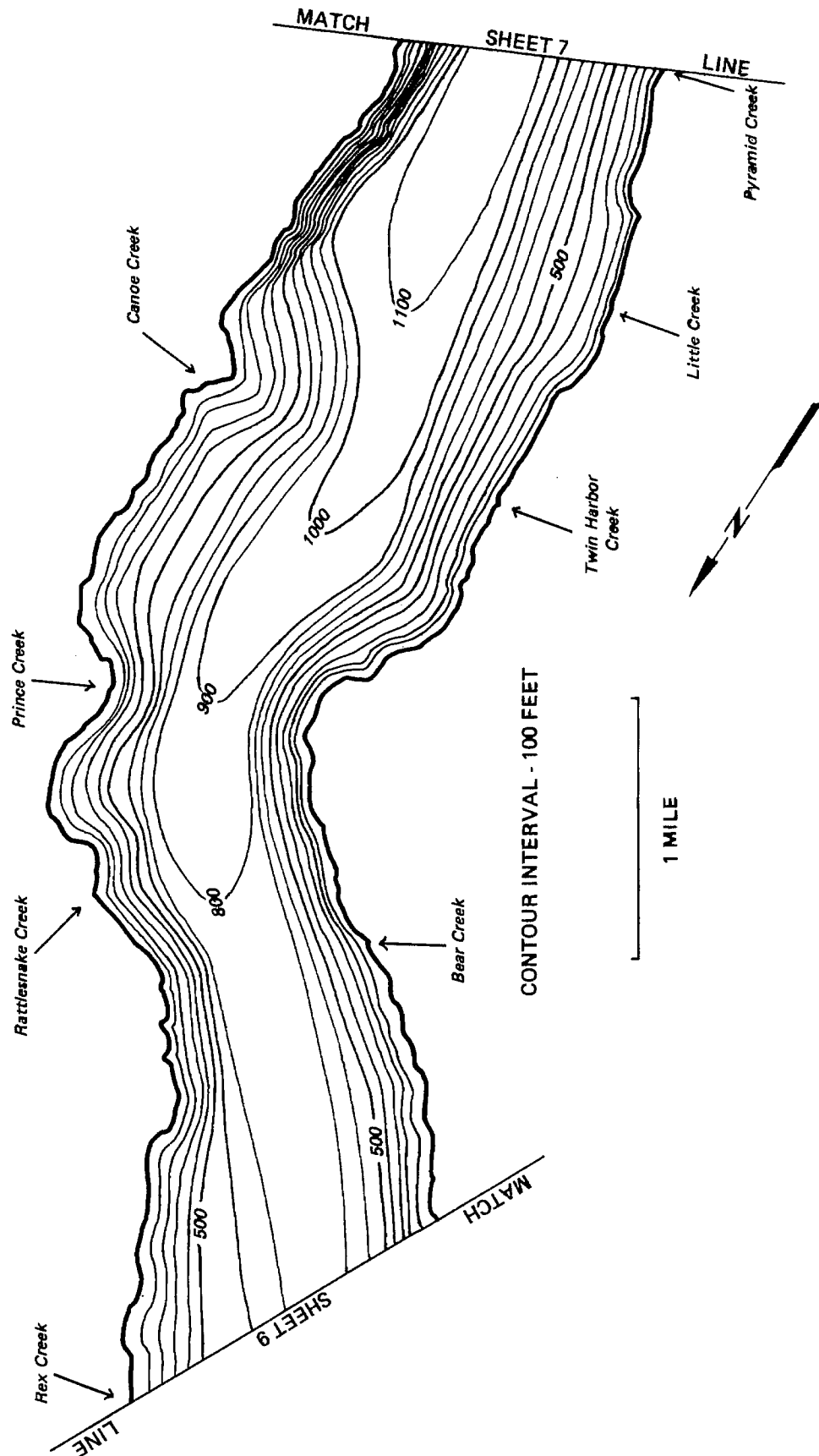
BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

SHEET 7 OF 11



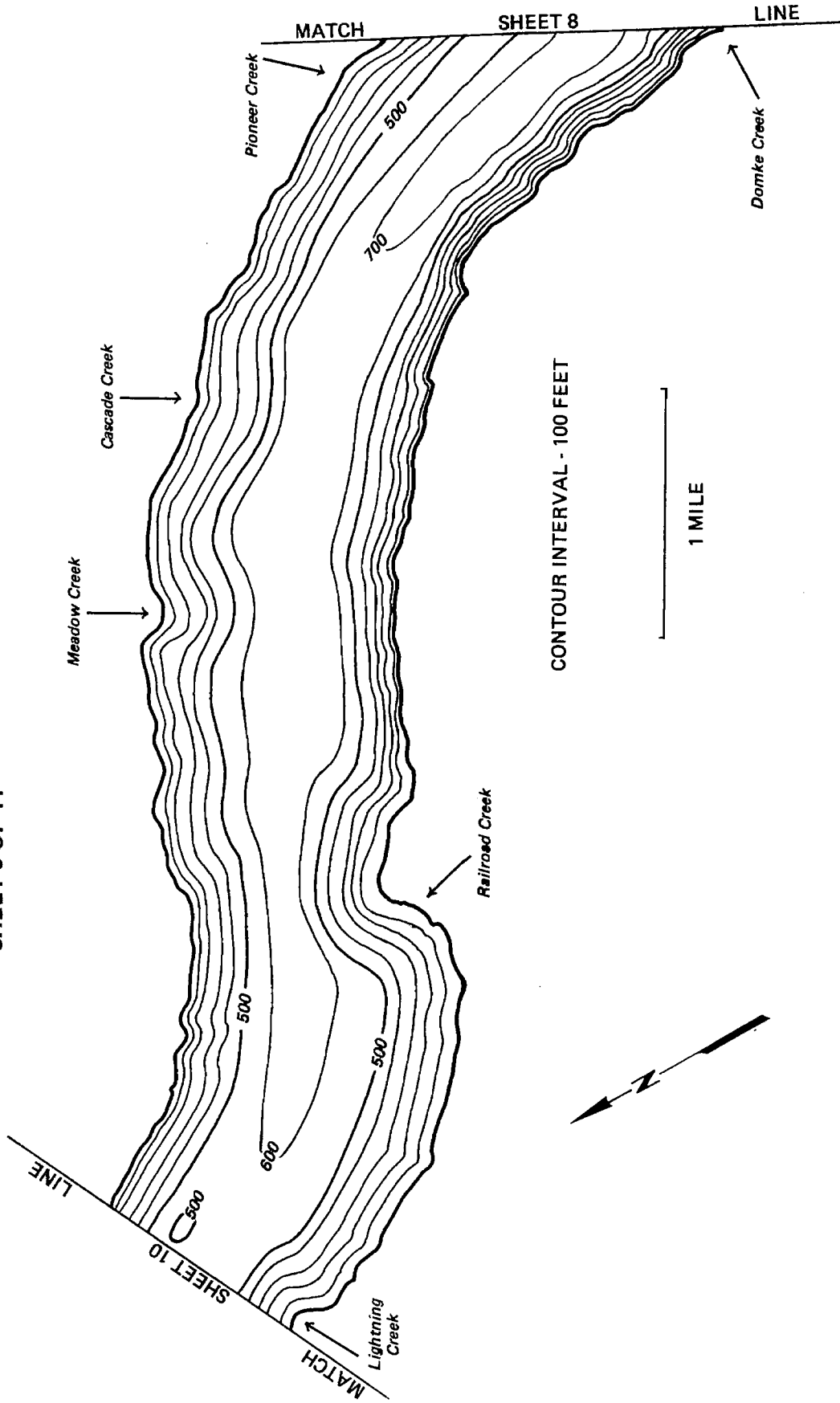
BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

SHEET 8 OF 11



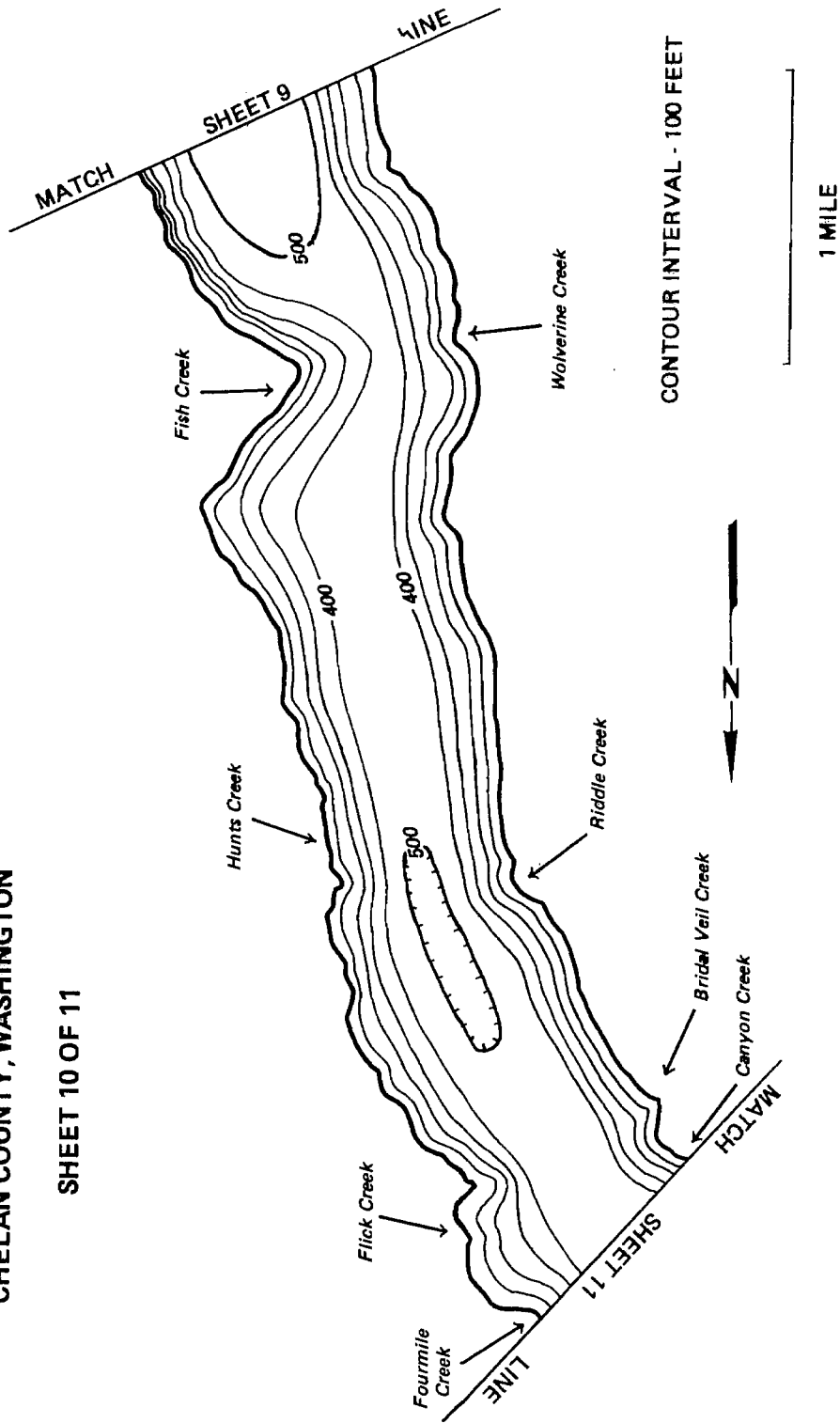
**BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON**

**SHEET 9 OF 11**



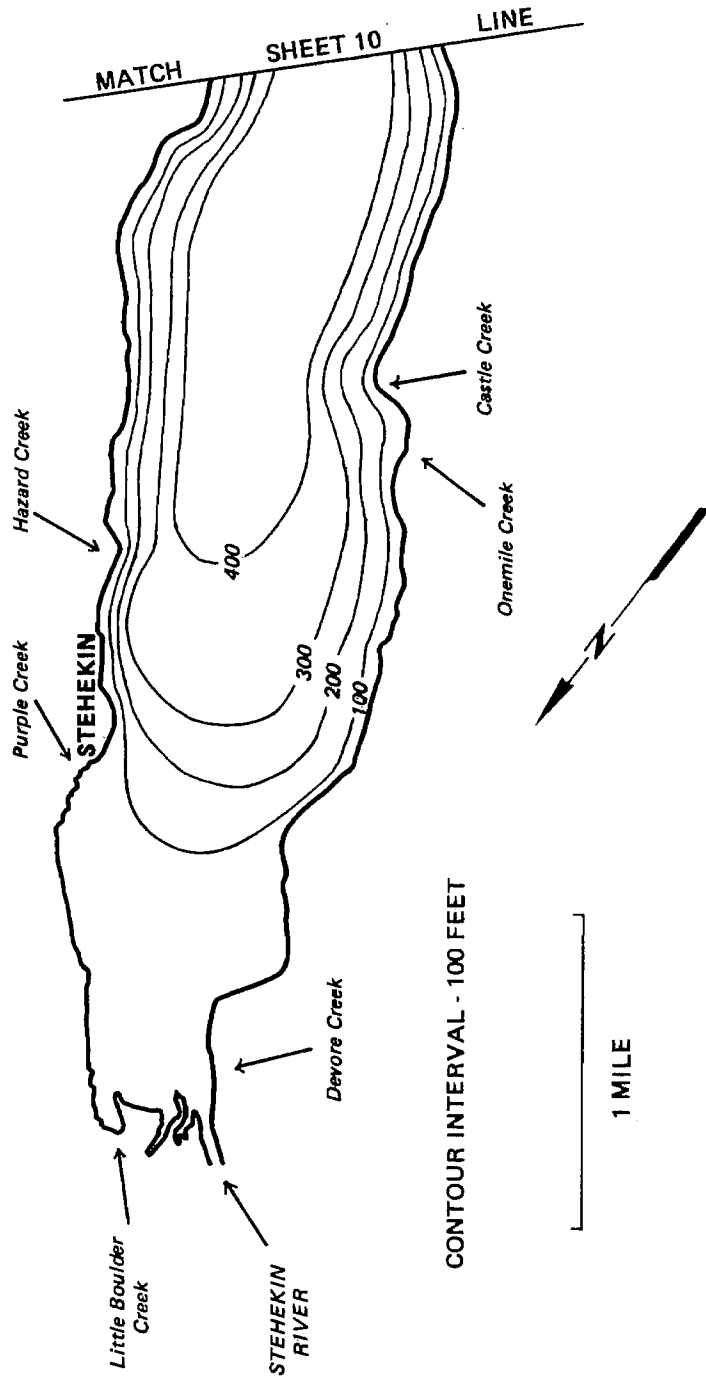
**BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON**

**SHEET 10 OF 11**

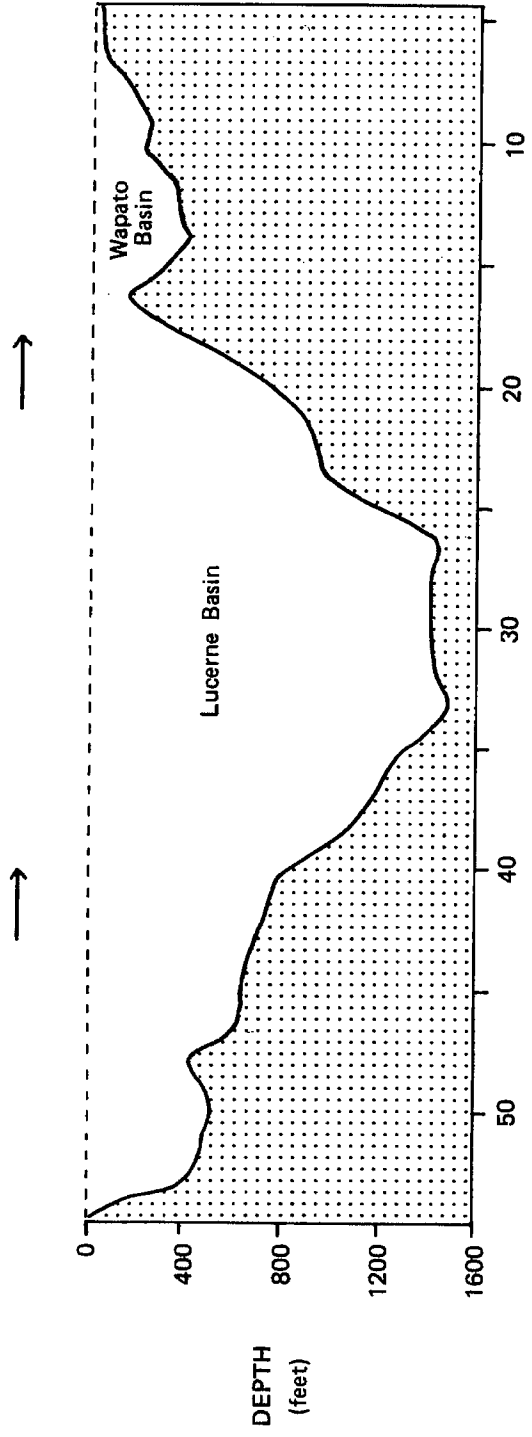


BATHYMETRIC MAP OF LAKE CHELAN  
CHELAN COUNTY, WASHINGTON

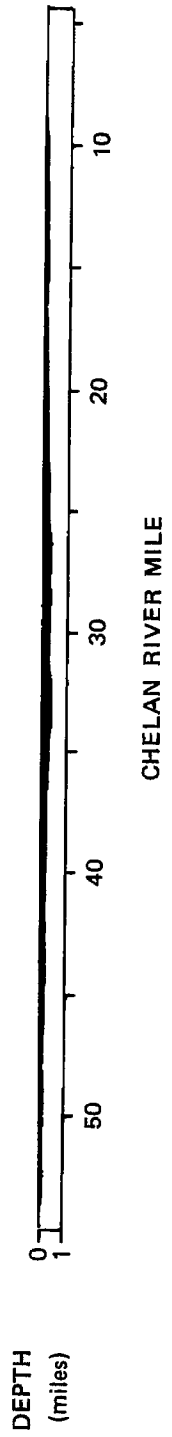
SHEET 11 OF 11







(a)



(b)

Figure 5. Longitudinal profile of the bottom topography of Lake Chelan, with (a) the vertical axis greatly exaggerated, and (b) both axes of same scale.

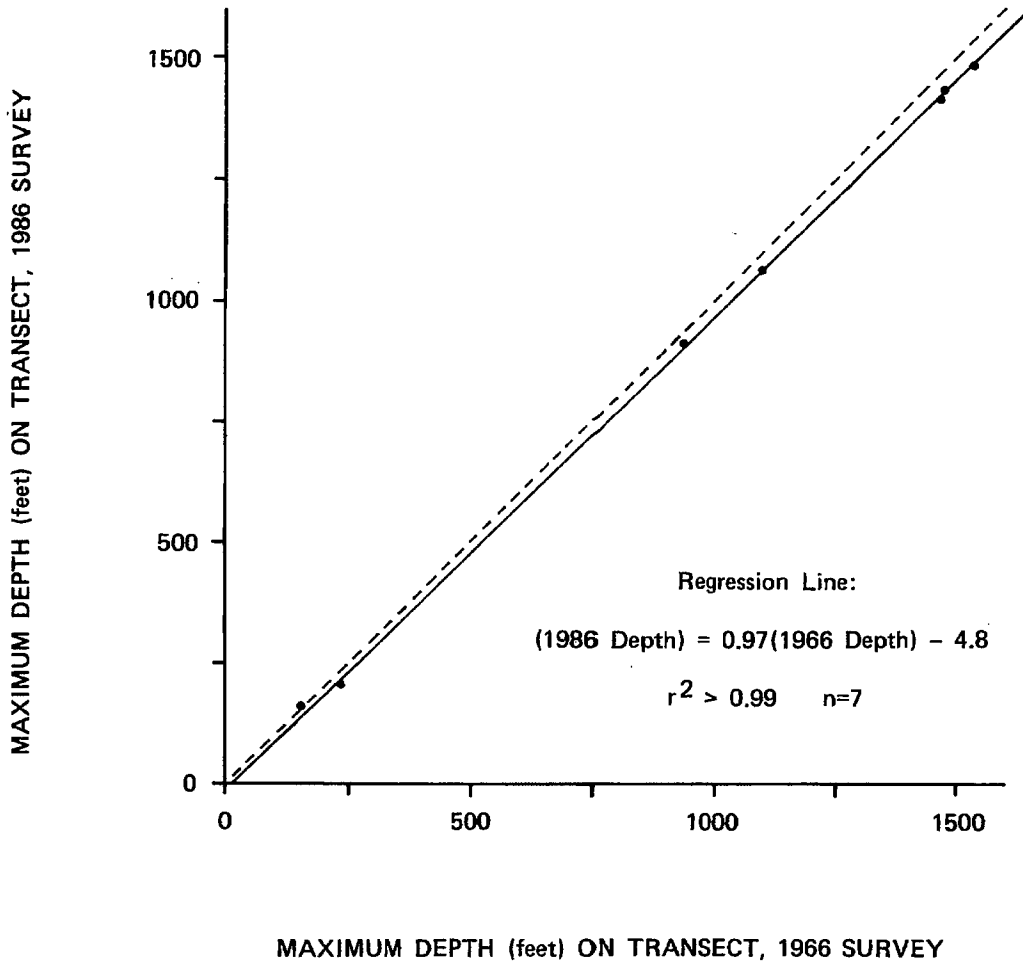
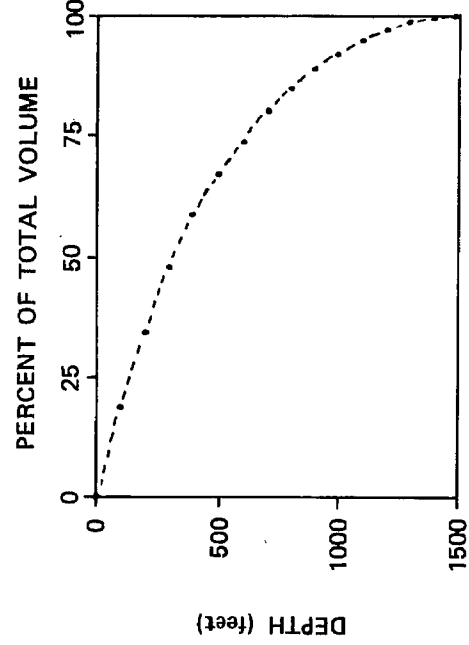
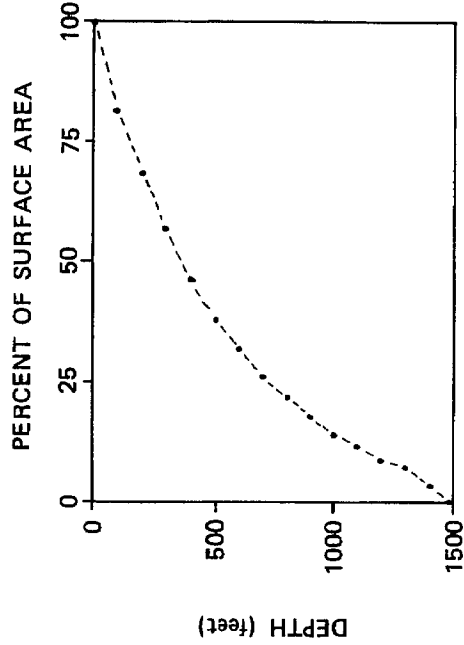
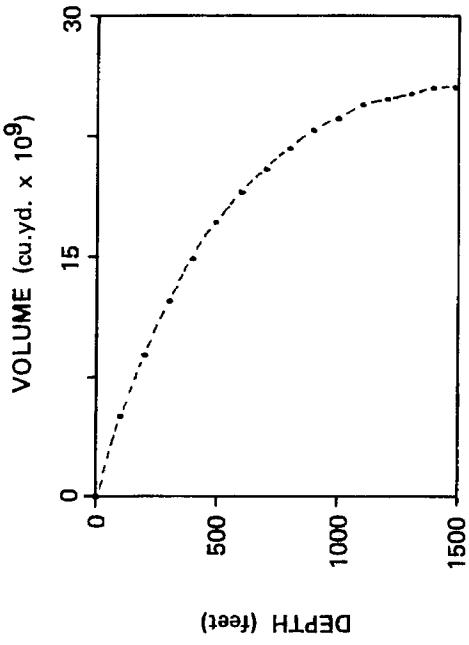
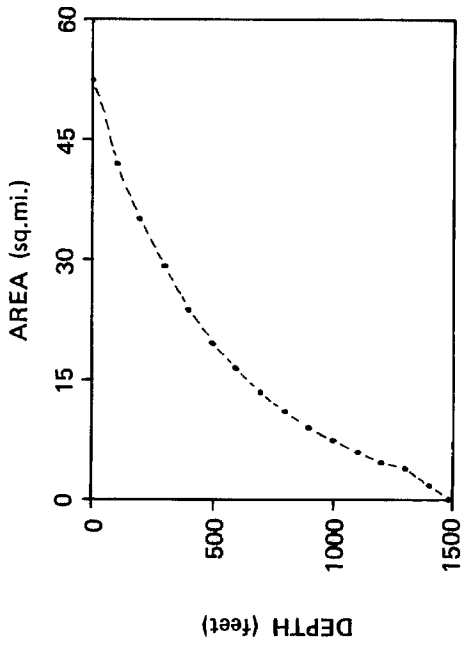


Figure 6. Relationship between depth maxima observed along echosounding transects common to both the 1966 (Whetten, 1967) and 1986 bathymetric surveys of Lake Chelan. The dashed reference line represents points of 1:1 correspondence.



(a)

(b)

Figure 7. Hypsographic (a) and depth-volume (b) curves of Lake Chelan.

## REFERENCES

- Albers, V.M., 1965. Underwater Acoustics Handbook II. Penn. State Univ. Press, University Park, PA. 356 pp.
- Bue, C.D., 1963. Principal Lakes of the United States. U.S. Geol. Surv. Circular 476, Washington D.C. 22 pp.
- Dion, N.P., G.C. Bortleson, J.B. McConnell, and L.M. Nelson, 1976. Reconnaissance Data on Lakes in Washington, Volume 5: Chelan, Ferry, Kittitas, Klickitat, Okanogan, and Yakima Counties. Wa. Dept. of Ecology and U.S. Geol. Surv. Water-Supply Bulletin 43, Vol. 5. 264 pp.
- Freeman, O.W., 1944. Glaciation and some human relationships at Lake Chelan. Northwest Science 18: 59-62.
- Hakanson, L., 1981. A Manual of Lake Morphometry. Springer-Verlag, Berlin. 78 pp.
- Hutchinson, G.E., 1957. A Treatise on Limnology, Volume 1: Geography, Physics, and Chemistry. John Wiley and Sons, New York, NY. 1,015 pp.
- Lind, O.T., 1979. Handbook of Common Methods in Limnology. C.V. Mosby Co., St. Louis, MO. 199 pp.
- USGS (United States Geological Survey), 1985. Water Resources Data for Washington, Water Year 1983. Water-Data Report WA-83-1. 433 pp.
- Welch, P.S., 1948. Limnological Methods. Blakiston Co., Philadelphia, PA. 381 pp.
- Wetzel, R.G. and G.E. Likens, 1979. Limnological Analyses. W.B. Saunders Co., Philadelphia, PA. 357 pp.
- Whetten, J.T., 1967. Lake Chelan, Washington: bottom and sub-bottom topography. Limnology and Oceanography 12: 253-259.

## **APPENDICES**

APPENDIX A. Location of 40 echosounding tracks on Lake Chelan and maximum depth recorded along each. Lake boundaries are river miles 4.3 and 54.7.

| Approx.<br>River<br>Mile | Description of Sounding Track                                      | Maximum<br>Depth (ft) |
|--------------------------|--|-----------------------|
| 4.5                      | SW to NE shore of neck, immediately uplake of new US-97 bridge     | 31                    |
| 4.8                      | SW to NE shore of neck, immediately downlake from old US-97 bridge | 27                    |
| 5.7                      | Point SW of Spaders Bay to ferry landing opposite                  | 29                    |
| 6.6                      | Intermittent stream on N shore to USGS gage opposite               | 51                    |
| 7.4                      | Point W of USGS gage to beachfront park opposite                   | 138                   |
| 9.2                      | Point at Minneapolis Beach to point opposite                       | 229                   |
| 10.4                     | Point SE of Sunnybank to water intake due W of Old Mill Park       | 206                   |
| 11.7                     | Point below cliffs on S shore to S extent of Wapato Point          | 345                   |
| 13.5                     | First Creek to Chelan Reclamation District agricultural drain #6   | 371                   |
| 13.9 <sup>a</sup>        | Granite Falls Creek to S extent of Wapato Point                    | 400                   |
| 15.5                     | Point NW of Willow Point to Cove Marina opposite                   | 277                   |
| 16.3                     | Point opposite Shrine Beach to marina boat ramp                    | 156 <sup>b</sup>      |
| 16.3 <sup>a</sup>        | Mid-lake, NW of Greens Landing, to mid-lake, E of Cove Marina      | 127 <sup>b</sup>      |
| 17.2                     | Missouri Harbor to Stink Creek (Greens Landing)                    | 275                   |
| 18.4                     | Third point N of Missouri Harbor to swale/cliffs opposite          | 482                   |
| 20.1                     | Fields Point to Mitchell Creek                                     | 757                   |
| 21.8                     | Gold Creek to unnamed creek opposite                               | 906                   |
| 23.6                     | Twentyfive Mile Creek to Grade Creek                               | 951                   |
| 26.4                     | Unnamed creek E of Box Canyon to Deer Point opposite               | 1,441                 |
| 28.4                     | Still Creek to Coyote Creek  | 1,412                 |
| 30.1                     | Little Big Creek to Safety Harbor Creek                            | 1,417                 |
| 31.9                     | Big Creek to Point No Point Creek                                  | 1,431                 |
| 33.4 <sup>a</sup>        | Little Goat Creek to Corral Creek                                  | 1,486                 |
| 33.8                     | Big Goat Creek to Nobby Creek                                      | 1,471                 |
| 35.8                     | Graham Harbor Creek to Lone Fir Creek                              | 1,238                 |
| 37.3                     | Point below cliffs to Pyramid Creek opposite                       | 1,157                 |
| 38.5                     | Twin Harbor Creek to Canoe Creek                                   | 1,059                 |
| 40.5                     | Bear Creek to Rattlesnake Creek                                    | 793                   |
| 41.8                     | Domke Creek to Rex Creek   | 745                   |
| 43.8                     | Cliffs opposite Cascade Creek to swale 100 yds NW of Cascade Cr.   | 670                   |
| 45.0                     | USFS residence at Lucerne to Meadow Creek                          | 629                   |
| 46.4 <sup>a</sup>        | Railroad Creek to Moore Point                                      | 620                   |
| 47.2                     | Lightning Creek to opposite shore                                  | 566                   |
| 48.0                     | Point at Wolverine Creek to Moore Point                            | 421                   |
| 49.9                     | Riddle Creek to unnamed creek opposite                             | 509                   |
| 51.2                     | Canyon Creek to Fourmile Creek                                     | 489                   |
| 52.7                     | Onemile Creek to Adams Point                                       | 424                   |
| 53.4                     | Gorge S of Painted Rocks to USGS gage                              | 347                   |
| 53.7                     | Weaver Point to mid-lake, W of Stehekin                            | 133                   |
| 54.3                     | Point NW of Stehekin to Weaver Point opposite                      | 11                    |

<sup>a</sup>Sounding track cross-checks main-scheme line(s); river mile shown corresponds to deepest point on track.

<sup>b</sup>Depth shown is a minimum along the track, which was sounded to locate the Narrows Sill.

APPENDIX B. Description and volume of discrete segments of Lake Chelan. Segment 1 begins at the lake outlet (river mile 4.3).

| Segment | Upstream Boundary  | Approx. River Mile | Volume (cu. yds. x 10 <sup>9</sup> ) |
|---------|--|--------------------|--------------------------------------|
| 1       | Point W of USGS gage to beachfront park opposite           | 7.4                | 0.10                                 |
| 2       | Point at Minneapolis Beach to point opposite               | 9.2                | 0.29                                 |
| 3       | Point below cliffs on S shore to S extent of Wapato Point  | 11.7               | 0.45                                 |
| 4       | First Cr to Chelan Reclamation Dist. agricultural drain #6 | 13.5               | 0.52                                 |
| 5       | Narrows Sill: Shrine Beach to opposite shore               | 16.3               | 0.59                                 |
| 6       | Antilon Creek to point opposite                            | 19.4               | 0.83                                 |
| 7       | Gold Creek to unnamed creek opposite                       | 21.8               | 1.18                                 |
| 8       | Grade Creek to point opposite (NW of Twentyfive Mile Cr)   | 23.9               | 1.41                                 |
| 9       | Unnamed creek E of Box Canyon to Deer Point opposite       | 26.4               | 2.06                                 |
| 10      | Falls Creek to Still Creek                                 | 28.8               | 2.98                                 |
| 11      | Big Creek to Point No Point Creek                          | 31.9               | 2.79                                 |
| 12      | Little Goat Creek to Deep Harbor Creek                     | 34.5               | 2.56                                 |
| 13      | Point below cliffs to Pyramid Creek opposite               | 37.3               | 2.38                                 |
| 14      | Prince Creek to point opposite                             | 39.7               | 2.20                                 |
| 15      | Domke Creek to Rex Creek                                   | 41.8               | 1.19                                 |
| 16      | Meadow Creek to opposite shore                             | 44.5               | 1.13                                 |
| 17      | Lightning Creek to opposite shore                          | 47.2               | 1.15                                 |
| 18      | 48° 15' north latitude                                     | 49.0               | 0.49                                 |
| 19      | Canyon Creek to Fourmile Creek                             | 51.2               | 0.47                                 |
| 20      | Mouth of Stehekin River                                    | 54.7               | 0.68                                 |

APPENDIX C. Area of the plane circumscribed by each contour and volume of the horizontal strata delimited by the areas of sequential depth contours. Where applicable, areas of submerged lake mounts were subtracted from contour areas.

|               | Depth of Contour (ft.) | Area of Contour (sq. mi.) | Percent of Surface Area | Depth of Stratum (ft.) | Volume of Stratum (cu. yd. x 10 <sup>9</sup> ) | Percent of Total Volume |
|---------------|------------------------|---------------------------|-------------------------|------------------------|--|-------------------------|
| Wapato Basin  | 0                      | 13.52                     | 100.0                   | 0 - 100                | 1.043  | 53.6                    |
|               | 100                    | 7.27                      | 53.8                    | 100 - 200              | 0.567  | 29.1                    |
|               | 200                    | 3.86                      | 28.5                    | 200 - 300              | 0.275  | 14.1                    |
|               | 300                    | 1.76                      | 13.0                    | 300 - 400              | 0.061  | 3.1                     |
| Subtotal      |                        |                           |                         |                        | <u>1.946</u>                                   | <u>100.0</u>            |
| Lucerne Basin | 0                      | 38.55                     | 100.0                   | 0 - 100                | 3.779  | 16.1                    |
|               | 100                    | 34.64                     | 89.9                    | 100 - 200              | 3.406  | 14.5                    |
|               | 200                    | 31.33                     | 81.3                    | 200 - 300              | 3.037  | 12.9                    |
|               | 300                    | 27.52                     | 71.4                    | 300 - 400              | 2.650  | 11.3                    |
|               | 400                    | 23.85                     | 61.9                    | 400 - 500              | 2.218  | 9.4                     |
|               | 500                    | 19.56                     | 50.7                    | 500 - 600              | 1.842  | 7.8                     |
|               | 600                    | 16.37                     | 42.5                    | 600 - 700              | 1.508  | 6.4                     |
|               | 700                    | 13.35                     | 34.6                    | 700 - 800              | 1.250  | 5.3                     |
|               | 800                    | 11.07                     | 28.7                    | 800 - 900              | 1.033  | 4.4                     |
|               | 900                    | 9.07                      | 23.5                    | 900 - 1,000            | 0.836  | 3.6                     |
|               | 1,000                  | 7.21                      | 18.7                    | 1,000 - 1,100          | 0.673  | 2.9                     |
|               | 1,100                  | 5.86                      | 15.2                    | 1,100 - 1,200          | 0.532  | 2.3                     |
|               | 1,200                  | 4.62                      | 12.0                    | 1,200 - 1,300          | 0.427  | 1.8                     |
|               | 1,300                  | 3.67                      | 9.5                     | 1,300 - 1,400          | 0.273  | 1.2                     |
|               | 1,400                  | 1.82                      | 4.7                     | 1,400 - 1,486          | 0.040  | 0.2                     |
| Subtotal      |                        |                           |                         |                        | <u>23.504</u>                                  | <u>100.0</u>            |
| Lake Chelan   | 0                      | 52.07                     | 100.0                   | 0 - 100                | 4.822  | 18.9                    |
|               | 100                    | 41.91                     | 80.5                    | 100 - 200              | 3.973  | 15.6                    |
|               | 200                    | 35.19                     | 67.6                    | 200 - 300              | 3.312  | 13.0                    |
|               | 300                    | 29.28                     | 56.2                    | 300 - 400              | 2.711  | 10.7                    |
|               | 400                    | 23.85                     | 45.8                    | 400 - 500              | 2.218  | 8.7                     |
|               | 500                    | 19.56                     | 37.6                    | 500 - 600              | 1.842  | 7.2                     |
|               | 600                    | 16.37                     | 31.4                    | 600 - 700              | 1.508  | 5.9                     |
|               | 700                    | 13.35                     | 25.6                    | 700 - 800              | 1.250  | 4.9                     |
|               | 800                    | 11.07                     | 21.3                    | 800 - 900              | 1.033  | 4.1                     |
|               | 900                    | 9.07                      | 17.4                    | 900 - 1,000            | 0.836  | 3.3                     |
|               | 1,000                  | 7.21                      | 13.9                    | 1,000 - 1,100          | 0.673  | 2.6                     |
|               | 1,100                  | 5.86                      | 11.3                    | 1,100 - 1,200          | 0.532  | 2.1                     |
|               | 1,200                  | 4.62                      | 8.9                     | 1,200 - 1,300          | 0.427  | 1.7                     |
|               | 1,300                  | 3.67                      | 7.0                     | 1,300 - 1,400          | 0.273  | 1.1                     |
|               | 1,400                  | 1.82                      | 3.5                     | 1,400 - 1,486          | 0.040  | 0.2                     |
| Grand Total   |                        |                           |                         |                        | <u>25.450</u>                                  | <u>100.0</u>            |