Changes in Mirror Lake, Northwestern Washington, as a Result of the Diversion of Water from the Nooksack River

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as a Result of the Diversion of Water
from the Nooksack River

BY

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Accepted in Partial Completion

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MASTER'S THESIS

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Abstract

Mirror Lake, a small lake in northwest Washington, has been used as a settling pond for water diverted from the Middle Fork of the Nooksack River since 1962. In this thesis, I combine bathymetric data and sediment sampling to document the changes in sedimentation that have resulted from this diversion, and compare these results to a previous study conducted in 1991.

To document the change in the bathymetry of Mirror Lake since 1991, I surveyed the lake in the summer of 2000 using a theodolite and sonar depth gauge. I compared a contour map generated from this survey to the map from the survey of 1991. However, inconsistency in measurement of x-y position between the two surveys prevented accurate comparison of the bathymetry except in an area near the delta.

Four cores collected from three locations in the lake, and 14 grab samples from the uppermost bottom sediments allowed analysis of the post-diversion sediments and comparison to the pre-diversion sediments. The deposits since 1962 were analyzed for the thickness of the strata, grain size, organic content and magnetic susceptibility, and compared to the pre-diversion sediments. The sediments from the diverted water have a thickness of about 1.3 meters near the middle of the lake. The sediments are characterized by very fine to medium sand (diameter 0.063 to 0.5 mm) at the delta and by medium to coarse silt (0.016 to 0.063 mm) near the center of the lake. In contrast, the pre-diversion sediment is primarily organic sediment that has a median grain size equivalent to very fine sand (0.063 to 0.125 mm).

Between 1991 and 2000, about 15,000 +/- 2000 cubic meters of sediment have been deposited; this estimate translates to about 1700 +/- 200 cubic meters per year, or about 0.6% of the lake volume. The estimate is based on the change in bathymetry from 1991 to 2000 in the places where this change was significantly greater than measurement error. For the majority of the lake, I estimated sediment thicknesses from water depth and the

sediment thickness at nearby coring sites. My estimate of error for this rate combines errors in estimating the stratigraphic location of the 1991 strata and in estimating sediment thickness where neither coring nor bathymetric comparison provided this information. Five radiocarbon dates from three cores, as well as the presence of Mazama tephra, suggest that organic sediment accumulated at a rate on the order of 40 cubic meters per year prior to the diversion.

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MIRROR LAKE INTRODUCTION

Purpose of Study

The rate at which sediment accumulates in Mirror Lake has increased as a result of diversion of water from the Nooksack River drainage basin. Mirror Lake, which is about 1 kilometer northwest of Wickersham, Washington (Figure 1), is within the Lake Whatcom drainage basin of northwestern Washington and has been used as a settling pond for water that has augmented the city of Bellingham's water supply. The purpose of this thesis was to characterize the changes in sedimentation rates and patterns that have occurred in Mirror Lake since the diversion began.

The first objective of this study was to produce a new map of Mirror Lake bathymetry and compare the new bathymetry with that of the next most recent survey, which was completed in 1991. The rate of sediment deposition was calculated from changes in bathymetry and from sediment coring, both for the lake as a whole, and as a function of position on the lake bed. The cored sediments were analyzed for changes in organic content and magnetic properties so as to identify the boundary between sediments deposited before and after the diversion began. A second objective was to characterize changes in the sizes of sediment deposited in the lake as a function of distance from the location where the diversion discharges into the lake.

Background

Sedimentation in Small Lakes

Sediment in small lakes is usually silt or mud, organic-rich silt or mud, or gyttja, which is a combination of fine organic detritus and fine silicate sediment. The amount and energy of inflow can affect the particle sizes deposited in the lake. In humid low energy, low inflow environments, gyttja or peat usually predominates, depending on whether the lake is shallow enough to allow emergent vegetation (Reeves, 1968). The amount of organic matter depends on the organic productivity of the lake and whether the bottom is anoxic (Reading, 1996). The proportion of clay in lake deposits can be used to determine the climatic history of a lake basin because this proportion reflects the ratio of inflow to lake volume, and therefore residence time (e.g., Campbell, 1998). Campbell (1998) states that an increase in the finest sediments correlated with warmer periods, whereas an increase in aeolian activity should deposit more silts and sands. The deposits in a lake are influenced by the characteristics of both the drainage basin and the lake, and can reflect climate-induced changes in vegetation, such as at Lake Sinnda, in the southern Congo, where an upward grade from muds to organic-rich muds with plant fragments suggests a more humid climatic regime (Vicens et al., 1998). A decrease in organic content, for example in the sediments described by Leonard and Reasoner (1999) in Crowfoot Lake of Alberta, Canada, has been used to infer increases in clastic sedimentation as glacial activity increases in a drainage basin. When lake sediment records are combined with studies of modern lakes and watersheds, they can be used to help reconstruct past physiographic changes and historical ecosystems (Oldfield, 1977). However, the chemical and biological evolution of lakes is currently not as well understood as succession sequences on land (Kling, 2000).

In some lakes, such as those near glaciers, deposition may vary seasonally to produce varves; in modern lakes that contain varves, there is a relationship between the early summer temperature and the thickness of varves (Rittenour et al., 2000). Varves are a type of rhythmite, or alternating pattern of sedimentation; rhythmite sequences are well preserved in lakes that have a high sedimentation rate and a flat bottom (Reading, 1996). Varves can be correlated between different areas, but Coleman (1929) advises caution in matching varve sets solely on the basis of similarities in strata thickness. Varves can also form in areas far from glaciers, such as in the playa lake described by Anderson and Kirkland (1969), where alternating laminae of calcium carbonate and clay were deposited as an alkaline lake contracted and expanded. The post-diversion sediments in Mirror

Lake are rhythmites, but the strata do not clearly represent yearly cycles of deposition.

Effects of the Diversion on Sedimentation

The watershed of Mirror Lake is slightly greater than 0.5 square kilometers (Figure 2). The heavily vegetated character of the drainage area and the lack of input streams comparable in size to the diversion input suggests that production of clastic sediment is low in the drainage area. Therefore, the yearly rate of sedimentation in Mirror Lake is probably substantially greater now than before the diversion from the Middle Fork existed. When the lake was first surveyed in 1946 (Figure 3), it had an area of 5.46 hectares and a volume of about 324,000 cubic meters (Wolcott, 1973).

The drainage area of the Middle Fork of the Nooksack, above the diversion to Mirror Lake, is about 193 square kilometers (Nicholson, 1981). The river originates at the Deming Glacier (Figure 4), and Carpenter et al. (1992) state that this glacier is the main source of fine sediment to the Middle Fork of the Nooksack. Other glaciers are shown on maps of the Middle Fork Basin, and these glaciers account for a third of the total glaciated area in the basin.

According to Bill McCourt (2000, oral communication), water diverted from the Middle Fork is first filtered to remove coarse material by passing it through a set of bars that are spaced 15 cm apart and a 6 1/4 mm hardware cloth screen. The filtered water then enters a 30 meter settling tank, and this removes most material coarser than fine sand. Mirror Lake is used as a natural settling pond for much of the sediment that is not removed in the settling tank. According to Carpenter et al. (1992), this is mostly silt-sized. The silt content of the water at the diversion site is probably highest after heavy rains in the Middle Fork drainage basin. Silt content is also high in late summer, when the debris-rich ice of the Deming Glacier is melting rapidly and the contribution from relatively clean snowmelt and groundwater is low.

From a survey in 1991 (Figure 5) and assumptions about the lake area and water level in the 1946 survey, Carpenter et al. (1992) estimated a yearly sedimentation rate of 250 cubic meters per year for the period 1962 to 1991. The calculation of this value assumed that the volume of sediment deposited each year was negligible before 1962, relative to the sedimentation rate after water diversion, and that the sediment input from the drainage basin of Mirror Lake was also negligible relative to the diversion input. This estimate did not consider compaction and subsidence of the underlying sediments, and coring of the lake in 2001 has shown that the average yearly sedimentation rate in the lake is far greater than 250 cubic meters per year. Since the generation of electricity at the site identified by “Power Plant” in Figure 1 began in 1985, the diversion has been on for longer periods outside the summer months. The change in yearly sediment input to the lake as a result of the operation of the diversion during the fall, winter and spring has probably been less than the increase in operating time would indicate because, as Carpenter et al. (1992) indicated, the silt content of the water is normally much lower outside the period of glacial melting, except after heavy rain.

Deposition of very fine to medium sand where the diverted water enters Mirror Lake has produced a delta (Figure 5). The authors of previous studies did not determine the distribution of grain sizes at this delta or at other locations in the lake. I was not able to determine the degree to which an increase in bedload in the Middle Fork during heavy precipitation events affects the maximum grain size deposited at the delta in Mirror Lake. There is no delta shown on the bathymetric map of 1946 (Figure 3), and the lack of significant tributary steams around the lake suggests that there was no delta in 1946 comparable in size to the present delta.

Diversion History

Demand for water by industrial and residential users has increased in most areas of the United States during the past century. Lake Whatcom is currently the main water source for the City of Bellingham in Whatcom County, Washington (Figure 1). Lake Whatcom has an area of about 2020 hectares (Barrett Consulting Group, 1995). In 1953, a court order was issued that prevented the city from raising the level of Lake Whatcom above an elevation of 96 meters above sea level (Superior Court of the State of Washington, 1953). Because the city has the right to store 24.7 million cubic meters of water, which corresponds to a depth of 1.22 meters when averaged over the 2020 hectare lake area, the lake level has been maintained above 94.78 meters above sea level, even though there is no legal restriction on minimum water level (Barrett Consulting Group, 1995).

In order to satisfy water demand while minimizing fluctuations of the level of Lake Whatcom, the City of Bellingham began diverting water from the Middle Fork of the Nooksack River (Figure 1). After leaving the diversion site (Figure 1), the water flows 2700 meters through a 2.1 by 2.4 meter tunnel, which has a capacity of 7.1 cubic meters per second. The water then flows 15.3 kilometers through a 102 centimeter pipe, which has a capacity of 2.7 meters per second. This water is then discharged 165 meters upstream from Mirror Lake (Barrett Consulting Group, 1995). Turbines, identified by "Power Plant" in Figure 1, were installed in 1985; they are used to generate up to 1000 kilowatts of electrical power. The maximum flow diverted is reduced to 1.9 cubic meters per second while they are in operation (Barrett, 1995). After the turbines were installed, the diversion was often operated in the fall, winter and spring, when no water was required to maintain the level of Lake Whatcom (Carpenter et al., 1992).

Since the year 1962, the diversion has accounted for 20% of the City's water consumption on a yearly basis. However, it may supply as much as 80% of the surface inflow to Lake Whatcom during the summer (Bill McCourt, 2000, oral communication). The volume of the diversion averaged about 3 to 4 million cubic meters per month for most of the 1990s, except for 1999, when the volume was about 1 to 1.5 million cubic meters per month (Bill McCourt, 2000, oral communication).

In 1999, the U.S. Fish and Wildlife Service listed the Chinook salmon as an endangered species, and a minimum flow of water must now be sustained in the Middle Fork of the Nooksack for these salmon. The Lummi and Nooksack Nations, among other groups (Bill McCourt, 2000, oral communication), have also been working to reduce the volume of water diverted in order to provide a minimum flow of 335 cfs for salmon swimming up the Middle Fork to spawn. The diversion has been operated less often in 2000 and 2001. It is probable that the volume of water diverted will remain much lower than pre-1999 levels because of the status of the Chinook salmon.

Site Geology and History Notes

The area of Mirror Lake is underlain by the Jurassic Darrington Phyllite, of the Easton Metamorphic Suite (Lapen, 2000). Schistosity, lineations (intersecting and crenulation) and small folds have been observed in the Darrington Phyllite (Haugerud, 1980). The Darrington Phyllite is exposed in roadcuts near the lake, and in an outcrop at the lake's southwest edge. The lowlands of southwestern British Columbia and northwestern Washington were occupied by the continental Cordilleran ice sheet during the Vashon Stade of the Fraser Glaciation (Easterbrook, 1969). Kovanen and Easterbrook (2001) argue that the Mirror Lake area was occupied by an alpine glacier from the South Fork of the Nooksack River in the latest Pleistocene, although this concept remains controversial. The predominant soil type in the area is part of the Squires Series, which at this site has moderate permeability and moderate available water capacity (Goldin, 1992).

In 1902 the Bellingham Bay and Eastern Railway completed a railroad through the Mirror Lake area (Frank Culp, 2001, oral communication). Logging in the area had begun by 1910, and possibly even earlier (Dan Cozine, 2001, oral communication). Bloedel-Donovan Company was the main timber company in the area (Thompson, 1989). The harvest of timber, along with road and railroad construction, should have caused a greater sediment input to the lake.

BATHYMETRIC SURVEY OF MIRROR LAKE

Methods used in 2000

Field Methods

Reference mark placement

My assistant and I surveyed Mirror Lake during the summer of 2000. This was 9 years after the previous survey of Carpenter et al. (1992) and 54 years after the original survey of 1946, which was described in Wolcott (1973). Because the concrete reference marker constructed for the 1991 survey was not found, and was probably removed in the intervening 9 years, I established a new reference marker on the southern part of the shoreline, at the western edge of an outcrop of phyllite (Figures 6 and 7). The marker, which is a concrete disk about 1 foot in diameter, was cemented to a what appears to be a bedrock outcrop or large boulder. Bathymetric surveying of the lake was based on this reference and on secondary points that were established from this reference. The “V” formed by the insulators of a transmission tower northeast of the lake (Figure 8) was used to establish the azimuth at the start of each day of surveying. This tower is identified by the Bonneville Power Administration as Monroe-Custer (MONE CUST) Line 1, Mile 62, Tower 1 and is located at the center of Figure 8.

Survey of perimeter

I surveyed the perimeter of the lake on August 16, August 17, and September 12 of 2000 with George Mustoe. Bert Rubash also helped me survey on November 4 to fill in gaps in the data set. My survey partner helped by operating a theodolite and recording my x-y-z position while I walked at or near the perimeter of the lake with a reflective prism, which was mounted on a 2 meter staff.

Because the diversion was off when Mirror Lake was surveyed, the level of the lake at the time of the survey, which I designated the low water line, was the most readily identified boundary and was surveyed first. The diversion was on during the spring of

2000, and during this time I observed that the lake level was at the lower edge of shoreline angles on the northeast and southern edges of the lake. This level, which I designated as the high water line, is about 0.85 +/- 0.05 meters higher than the low water line. The position of this high water line was not clearly evident along all reaches of the lake perimeter. I surveyed the topography between the elevations of high water and low water, as well as points above the high water line, to generate a surface upon which I could later set the lake level close to the estimated high water line.

Bathymetry measurements

I surveyed the bathymetry of the lake on August 29, August 31, and September 13 of 2000. While I recorded bathymetric values from a raft (Figure 9), George Mustoe operated an electronic total station (Figure 6). For surveying on the lake, the prism was detached from the staff and mounted on a hard hat. To record each horizontal position on the lake, I held the boat at still as possible and faced the total station. When my survey partner gave a hand signal to indicate that he had recorded an x-y position using the total station, I recorded the value displayed on a Humminbird 100 SX depth gauge (200 kHz, single beam), which was mounted on a board that rested across an inflatable boat. This depth gauge gives readings to the nearest foot (0.3 meters). If the depth gauge was shifting among multiple values, I recorded the value that was displayed most often.

Although this sonar device was not designed for surveying, but rather for locating fish, it produced a bottom profile from which I could recognize the lake bottom. According to a technical support representative of the manufacturer (Tina Conner, 2001, oral communication), the accuracy of this depth gauge should be within 2 percent. The manual provided with the device states that the radius of the cone of dispersal of the sonar is 12 degrees; and, according to Bert Rubash (2000, oral communication), a depth of water is calculated from the first strong pulse that returns to the sonar. A cone of dispersal of 12 degrees returns its reading from an area on the lake bottom that has a radius of about 20 percent of the depth.

I surveyed points on the lake bottom along lines that trend southwest to northeast in the southeastern portion of the lake, and along both southwest to northeast and northwest to southeast trends in the northern portion of the lake (Figure 10). I surveyed fewer points in the middle of the lake, where the lake bottom is nearly flat. I also surveyed points along a path that was about 10 meters from shore. The depths were measured more frequently where the depth changes more rapidly with x-y position than where the lake bottom appears to be flat. The depth reading at each point was later matched with a map position from the theodolite to produce a three-dimensional grid.

Accuracy of Results

The accuracy of the bathymetric map produced for this thesis depends mainly on the accuracy of the depth measurements. The sonar depth gauge used in this survey produced readings that fluctuated by a maximum of +/- 0.3 meters. The 12 degree cone of dispersal covers an area that has a radius of 1.2 meters at a depth of 6 meters, which is about the average depth of the lake. In the study of 2000, the total error of the volume given in the section "Map Calculations" should be no more than 5 percent, based on a vertical error of 0.3 meters and an average lake depth of 6 meters.

Error comes from five known sources: rounding of depth measurements, shape of the lake bottom, inaccurate reflection from the bottom, and two lake level estimates. For each measurement, there was some error associated with instruments and with rounding. The maximum depth of the lake when it was surveyed was between 9 and 10 meters, so the instrument's rounding error of plus or minus 0.3 meters is always greater than the 2 percent error specified by the manufacturer. Western Washington University Mathematics Professor Edoh Ramiran (2000, oral communication) said that if this source of error is separated from other sources of error, it can be considered random, and the Central Limit Theorem could be used. According to the Central Limit Theorem (Johnson and Bhattacharyya, 1992), the distribution of the sample mean is approximately normal for large sample sizes. For the sample of depths for the 2000 Mirror Lake survey, the sample size of 430 is large enough for this theorem to be applied. Given that the depth gauge gives depths that are within 0.3 meters of the actual value, it is reasonable to assume that 95 percent of the depths are within 0.3 meters of the actual value, when only this rounding error is considered. If this is true, the standard deviation of the population (all depth readings) is 0.15 meters (15 centimeters), because two standard deviations include about 95 percent of values (Johnson and Bhattacharyya, 1992). These authors also state that the standard deviation of the sample mean, which is in this case represented by mean lake depth, is the population standard deviation (0.15 meters in this case) divided by the square root of the sample size. Sample size is about 430, so the standard deviation of the sample mean is about 0.0072 meters (0.72 centimeters). The total error from rounding should not be greater than 0.015 meters (1.5 centimeters) at the 95 percent confidence interval.

A second source of error, which is unrelated to instrumental precision, is produced by the shape of the lake bottom. Because the sonar device produces a sounding of the lake bottom based on the intensity of the returning pulse with time (Edgarton et al., 1964) the recorded depth may be less than the actual spot value in areas of steep slopes, where the shortest path from the sonar to the lake bottom may not be vertical. The error from this effect is likely to be no more than 0.1 meters in the majority of locations, because the slope of the lake is less than 15 percent in almost all areas, and the steeper slopes are found in the shallower parts of the lake, where the 12 degree cone of dispersal from the surface covers a relatively small area of the lake floor.

A third possible source of error in this survey is that the surface of the lake sediments may not produce a reflection that is stronger than the threshold signal used by the sonar device for calculating depth. The graphical depiction of the bottom of the lake on the depth gauge was often indistinct, which probably indicated the presence of loose or poorly compacted mud on the floor of the lake. This effect is assumed not to have increased reported depths by more than 0.15 meters, based on the thickness of this indistinct layer on the sonar display.

Because the previous two sources of error should have opposite effects on the calculated volume of the lake, their combined effect should be less than the sum of their absolute values. The fourth and fifth potential sources of error are probably less than the previous two. They involve the estimation of the lake level when depths were recorded, for which the error is on the order of 3 centimeters, and estimation of the level of the lake during the 1991 survey, for which the error should be less than 5 centimeters. The five sources of error produce an approximate error of about 0.3 meters or 5 % in the volume of the lake.

Data Analysis Methods

Map production

The survey points were compiled in a spreadsheet (Appendix). The x-y values given in the appendix are based on the assignment of the position (1000E, 1000N) to the reference marker established in 2000 and the azimuth of N45E to the transmission tower that is shown in Figure 8. The direction of true north is 14.6 degrees east (clockwise) from the orientation of the northing axis that was assigned at the beginning of the 2000 survey.

Depth values were originally given in feet (0.3 meters) by the sonar device. These were converted to meters and subtracted from the measured elevation of the lake surface below the reference marker. Horizontal and vertical positions on the edge of the lake were assigned a precision of 0.01 meters because of slight variations in how far the prism rod sank into mud or duff, and slight inconsistency in holding the rod vertical. Positions for the lake bottom were given a precision of 0.1 meters because the boat moved slightly while its position was being measured, the reflector was not always in the same position relative to the depth gauge, and the precision of the depth gauge was similar to that of the horizontal position. The effect of irregularities in the topography of the lake bottom on precision is difficult to quantify. Because the survey took place when the diversion from the Middle Fork was not operating, the elevation of the lake when the diversion is on was estimated from changes in vegetation on the shoreline (Figure 11) and the depths at each measurement points were increased by 0.85 meters to convert them to depth values for when the diversion is operating.

The program Surfer (Golden Software, 1997) was used to produce a map from the data. This program produces a regularly spaced grid of points from an irregularly spaced data set before it produces a contour map. The X, Y and Z coordinates in the Surfer grid were assigned to the easting, northing and distance below high water, respectively. The line density for this regular grid was 91 lines in the X direction, from 780 to 1125, by 100 lines in the Y direction, from 920 to 1300, for the grid of 2000. These values were used instead of the default density of 50 lines in the longer dimension because the former density produced a grid spacing of about 3.8 meters. This grid spacing is closer to the average spacing between measurement points in the southeast part of the lake, and therefore detail was less likely to be lost in these areas during the calculation of a uniform grid.

Kriging was used as the gridding method because this method was used in the previous survey (Carpenter et al., 1992), and this was the method suggested in the program manual. The values for scale (C) and length (A) were left at the values calculated by Surfer for this data set, which were 9.49 and 236, respectively. A small additive error variance (0.02) was included in the gridding process in an attempt to compensate for the uncertainty in taking measurements on a soft, irregular surface, and for the rounding error that occurred when measurements were expressed in feet (0.3 meters). However, I could see very little change on the final map as a result of the inclusion of this variance, and I could have left this value at zero without significantly affecting the final bathymetry. The micro variance was left at zero and drift was left as none. All data points were used in the search. For the search ellipse radius 1 and radius 2 were left at the computed value 236, and the ellipse angle was left at zero. The resulting grid was smoothed using the spline method, as was the grid generated by Carpenter et al. (1992). Two grid lines were inserted between each of the original grid lines. A contour map at an interval of one meter (Figure 12) was produced from the smoothed grid file, as was a map that shows the density of measurement points (Figure 10).

Map calculations

The version of Surfer that was used for this thesis (Golden Software, 1997) contains programs for estimating the volume between two grid surfaces. The volume of the lake at the estimated level of the lake when the diversion is operating, which is 111.59 +/- 0.15 meters above Bellingham City datum, was calculated by this program as 321,900 cubic meters, and the surface area of the lake was given as 57,510 square meters. At the estimated high water level, the maximum depth of the lake is about 10.05 +/- 0.15 meters.

Problems with map production

A crucial problem encountered in the survey of 2000 was the disappearance of the concrete reference marker that was placed near the edge of the lake in 1991. The absence of this marker resulted in the need to examine the shoreline for a feature that could be used indirectly to compute changes in depth between the two surveys. This is discussed in the section “Estimating lake level of 1991.”

A second problem encountered while producing the contour map was closing the contours in the southeastern portion of the map. When the lake was being surveyed, thick brush prevented sightings into two marshy areas in this location. These areas were slightly below the estimate of high water level and were near the elevation of points closer to the lake, so kriging produced open contours along this reach of the lake perimeter. Additional surveying was required to provide points at a high enough elevation to produce closed contours. When each measurement was recorded by the theodolite, my survey partner gave the vertical component. If this component was below the estimated high water line of the lake, a search was made for a higher location, although sighting to these points from the theodolite was made more difficult by the vegetation around the lake.

Orientation of Mirror Lake

Triangulation was used to position the grid used in the survey of 2000 relative to the Universal Transverse Mercator grid, section 10U, datum of 1983 (Figure 13). The first step in the orientation of the grid used in the 2000 survey involved determining the position of a temporary marker along the edge of Mirror Lake; this point is identified as "peninsula point" in Figure 7. The location of this point was established using a Garmin 45 XL global positioning system and a Garmin GBR 21 differential correction receiver. This device gives individual readings that are accurate to within 5 meters, so the value used in my calculations, which was an average of 27 readings, should have an accuracy of 1 meter; the ratio of error in an individual measurement to error in an average measurement is the square root of the number of points averaged.

The GPS position of "peninsula point" was then matched with its position on the grid used in the 2000 survey, and I calculated the distance from this point to the primary reference used in 2000. The position of a Bonneville Power Administration transmission tower, which is labeled "transmission tower" in Figure 7, was obtained from B.P.A. (Bob Sweet, 2000, oral communication), and an angle was measured at the primary reference between the other two points. This angle and the point measurements were sufficient to triangulate the absolute position of the reference marker of 2000 and the direction of true north on the grid of the 2000 survey.

The elevation of the lake was determined by surveying from the primary reference used in 2000 to a reference marker established by the City of Bellingham. This reference marker, which is identified as “diversion outlet” in Figure 7, is a copper pin above the center of the diversion outlet pipe. Based on an elevation of 112.64 meters above Bellingham City datum provided by the City for this point (Bill McCourt, 2000, written communication), the elevation of the primary reference used in 2000 is 111.94 meters above Bellingham City datum. Bellingham City datum is 1.89 meters below the elevation of mean sea level that was established by the U.S. Coastal and Geodetic Survey (Joe Corbell, 2001, written communication).

Comparison with Previous Surveys

Comparison with 1991 Survey

The volume of sediment deposited in Mirror Lake between 1991 and 2000 could not be estimated for the entire lake based on bathymetric surveys. For most of the lake area, the apparent change in elevation of the lake bed was not significantly greater than the uncertainty in the measurement of vertical position. As a result, I was only able to calculate the amount of sedimentation for an area of 3980 square meters in the southeast portion of the lake (Figure 14a and 14b). The apparent volume of post-1991 deposits in this area is about 3000 +/- 300 cubic meters. However, the actual volume also depends on the amount of compaction or settling that has occurred in the underlying sediments, which could not be determined from the depth survey alone. The sediment volume added to the lake in this area is about 1/5 of the total sedimentation in the lake, based on cores taken from the lake after the survey of 2000 was completed. This is explained in the section “Post-diversion Sedimentation Rates, Volume.” The form of the contours near the edges of the lake differs enough between the two surveys to suggest that there were significant errors in position in the 1991 survey (Figure 15). The inconsistent character of variations between the surveys suggests that the variation does not reflect differences in sedimentation.

Comparison of Survey Techniques in 1991 and 2000

My survey techniques were different than those used in the 1991 survey. In 2000, I used a total station to record positions both at the edge of the lake and for bathymetry. The total station provides more accurate readings than the plane table and alidade used in the 1991 survey. The total station uses the reflection of a laser beam from a prism to calculate distance and can record horizontal rotations and vertical changes with millimeter-scale precision. Because proficient use of the total station gives more accurate readings (millimeter instead of centimeter accuracy), the advantage of an improvement in accuracy outweighs the disadvantage of the change in methods between 1991 and 2000. Most professional surveyors now use either a laser device or a survey-grade GPS in place of the transit.

The locations of depth measurements from my survey do not exactly duplicate those of the 1991 survey. Also, the depth gauge used in the 2000 survey gives readings in feet (0.3 meters), instead of to the nearest 0.03 meters, as in the 1991 survey. Although this produced some error in comparing the maps produced from the two surveys, the increased point density near the delta and other places where the lake bottom has a steeper slope should have compensated for this error. The increase in point density left less area between points over which to interpolate, and therefore irregularities in bathymetry could be measured on a smaller scale. Also, because of errors discussed in the section "Accuracy of Results," the display of readings to the nearest 0.03 meters probably did not reflect the true precision of measurements. The low-organic diversion sediments in Mirror Lake have only a negligible floc bed, and I assumed that the change in depth finders between 1991 and 2000 would not present a significant problem. The expression of depth at a level of precision of 0.3 meters rather than 0.03 meters should not have made a significant difference in the bathymetry map because my x-y position on the lake could not be determined to within 0.03 meters. Although the vertical positions do not directly correlate with the horizontal positions, on steep slopes a horizontal change of several decimeters can result in a change of more than one decimeter. Use of a contour interval on the map that I produced that was smaller in magnitude than the survey precision would have provided no additional information.

Matching Horizontal Locations, 1991 to 2000

The loss of the survey reference marker used in 1991 necessitated the matching of the 1991 and 2000 maps to compute the change at each point on the lake bottom. This was difficult because the lake margins on the two surveys differ by more than two meters in many locations. In an attempt to match the maps, the survey stations used in 1991 were located (or their locations estimated) and resurveyed with respect to the grid established in 2000. Apparent distortion of distances on the 1991 map on the margins of the lake between the delta and the center of the lake, along with larger spaces between depth measurements on the 1991 map (Figure 15), produced errors in the location of depth contours that were two to four times the thickness of the contour lines. This complicated my attempt to match the maps. Consequently, I attempted to match the two maps by establishing the location of the diversion inlet on each, then rotating the maps about the diversion inlet until they were aligned as well as possible near the primary references of 1991 and 2000. Although this method is subjective, my attempt to align the maps by using the survey bases of Carpenter et al. (1992) produced a result that was obviously in error. The areas of the maps near the diversion inlet were given priority during the alignment because this feature is recognizable on both maps and its linear nature made alignment easier.

Estimating Lake Level of 1991

I was only able to estimate the level of the lake in 1991 relative to the reference established in 2000, because the diversion was not operating during the 2000 survey, and the reference used in 1991 is no longer present. Between 1991 and 2000 there may have also been a change in the equilibrium elevation of the lake while the diversion is operating. According to Robin Matthews (WWU Watershed Studies, oral communication, 2000), this level did not change by more than a centimeter while surveys were conducted in 1991. There are small shoreline angles on the shore near the 2000 reference marker, and these are assumed to have been made by wave erosion when lake level was at or near the 1991 level. These shoreline angles are also assumed not to have been present in 1946, because the lake level has consistently been about 0.8 to 0.9 meters below the shoreline angles during my study while the diversion has not been operating. These shoreline angles do not allow the determination of lake elevation within a margin of less than five centimeters, but they are close to the lake level I observed when the diversion was operating in the spring of 2000. If the present lake level were raised to the level that I estimated for 1991, the apparent deposition between 2000 and 1991 would be 5 centimeters.

Calculation of Changes in Bathymetry, 1991 to 2000

The map of net change in lake bed elevation between 1991 and 2000 was computed within the area shown in Figure 14. The change could be calculated by comparing the 1991 and 2000 surveys using Surfer 6.0 (Golden Software, 1997). To compare the surveys in Surfer, I generated a grid of depth values by interpolation from the 1991 map of Carpenter et al. (1992). I first printed a map of the 2000 survey that was accompanied by the easting and northing grid lines of the coordinate system used in 2000; I set grid line spacing at 2 meters for eastings and northings. I then overlaid the 1991 and 2000 maps so that the coordinates (220E, 130N) on the 1991 map coincided with (996E, 1056N) on the 2000 map and (280E, 50N) on the 1991 map coincided with (1060E, 980N) on the 2000 map.

For most of the gridline intersections within the area shown on Figure 14, I interpolated a depth from the 1991 map at a precision of 0.1 meters. I did not record depth values at every intersection in the areas where a visual inspection of the contours of the 1991 and 2000 maps suggested that little information would have been added by completely filling the grid with depth values in these areas. The depth values that I interpolated from the 1991 map were converted to a complete grid in Surfer, and I used the program's grid math function to compute the change between 1991 and 2000.

Although the density of depth measurements in the southeast part of the lake was less in 1991 than in 2000, comparison of the two surveys was possible. The deposits from the diversion have produced a more pronounced lobe in front of the delta and have a more convex view in planform in 2000 than in 1991. Deposits in this area appear to exceed 3 meters for the period 1991 to 2000 (Figure 14b), but problems in aligning the maps prevented the production of an accurate isopach map.

Some sediment appears to have slumped to the north from the delta; this is inferred from an increase in depth (negative isopachs) in this area on Figure 14b, and the area of greater sediment thickness on the right side of the delta. Also, the slope on this portion of the delta was 45 degrees in 1991 (Figure 5). The sediments of the delta do not lie at a 45 degree slope at any location on the 2000 map, nor can such steep slopes be found at any other place on the map of the 1991 survey. The direction of water flow across the delta may have also changed, but a change in flow direction does not appear to have been responsible for the increase in water depth at this isolated location.

The proposed slump may have been triggered by overloading of sediment at this location. The rapid accumulation of sediment may have resulted in an instability in the delta and quicksand conditions in the input channel. The passage of a density current when the diversion was restarted after several weeks is another possible trigger. In a study of sediment deformation in some lakes in Japan (Jones and Omoto, 2000), the authors mention earthquakes, overloading by sediments and subaqueous currents as possible triggers for the deformation they observed. The present delta appears to be unstable enough that an earthquake could trigger a slump, but I did not observe the condition of the delta in 1991.

Comparisons with 1946 Survey

Comparison of the 2000 and 1991 surveys with the 1946 survey of Mirror Lake was complicated by a lack of precision in depth measurements in the 1946 survey. This section describes these problems.

Comparison of 1991 Survey with 1946

Carpenter et al. (1992) estimated the amount of sedimentation in Mirror Lake between 1946 and 1991 as 7500 cubic meters. This comparison was based on changes in bathymetry between the two surveys, and involved the assumption that the lake level was higher in 1946 than in 1991. Carpenter et al. (1992) assumed that the lake level was higher in 1946 because the area given for the lake in 1946 was greater than the area they calculated. This comparison is complicated by lack of knowledge of how the area of the lake was calculated in 1946. The change in lake depth that Carpenter et al. (1992) calculated, 0.3 meters, represents a regression of 1.5 to 2 meters of the shoreline, based on the slope of the lake bottom near shore. This change is about equal to the width of the lake perimeter line that was drawn on the 1946 map. Also, the area of the lake that is given on the 1946 map in Wolcott (1973) is 13.5 acres (5.46 hectares), but the area is listed as 13.8 acres (5.58 hectares). This inconsistency raises questions about how the area of the lake was determined, and what the true area was in 1946.

Carpenter et al. (1992) restated the 1946 volume of Mirror Lake published in Wolcott (1973) as 324,400 cubic meters and the surface area as 5.46 hectares (54,600 square meters). The volume subtracted to compensate for the assumed 0.3 meters drop in lake level from the 1946 survey to 1991 was 389 cubic meters. However, 389 cubic meters is the product of the 0.3 meters change in depth and the change in lake area after the depth was reduced (1,295 square meters smaller), rather than the product of the depth change and the total area of the lake. A change in depth of 0.3 meters over the area of the lake in 1946 yields a volume correction of 16,390 cubic meters, not 389 cubic meters. Carpenter et al. (1992) calculated an adjusted lake volume of 324,000 cubic meters for 1946, and subtracted their 1991 lake volume of 316,500 cubic meters to yield a lake volume change of 7500 cubic meters. A volume correction of 16,390 cubic meters produces a lake volume of 308,000 cubic meters. If the lake level correction of -0.3 meters is accurate, there would have been an increase in lake volume from 1946 to 1991 for the same lake level, i.e. the lake bottom would be lower in 1991 than in 1946. This result clearly seems unlikely. In addition, because the estimate of sedimentation by Carpenter et al. (1992) is well below the volume of sedimentation suggested by the cores taken from the lake in 2001, this question will not be considered further.

Comparison of 2000 Survey with 1946

I attempted to compare the map produced in 2000 with the map produced in 1946. However, the depth contours on the map in Wolcott (1973) are highly generalized, and the depth values from which the contour map was made are not shown on the map. Wolcott (1973) lists the Washington Department of Game as the surveyor of the 1946 map, which later merged with the Washington Department of Fish and Wildlife (Lauren Monday, 2000, oral communication). To locate the original survey data, I needed a report number for the 1946 survey, but no number was listed in Wolcott (1973). Reed Lake and Cain Lake, which are about 6 kilometers from Mirror Lake, were surveyed on February 26, 1946, the same day Mirror Lake was surveyed. Thus the surveyors would not have had time to measure as many points as were measured in subsequent surveys. Therefore, the use of the 1946 survey for comparison at the level of detail that is attempted here will not yield meaningful results unless the data and methods that were used to derive the contours can be located.

SEDIMENT COLLECTION AND ANALYSIS

Sample Collection

Grab Sample Collection

Grab samples were collected from 14 locations in Mirror Lake (Table 1 and Figure 16) in February 2001 to determine how the grain size of near-surface deposits varies with distance from and degree of alignment with the end of the input channel on the delta. The samples were taken from a small boat using an Ekman grab sampler. Grab samples 1 through 10 were not positioned regularly. This was the result of wind drift and error in the position provided by the global positioning system that was used in the sampling. The samples were more closely spaced in the part of the lake closer to the delta, because that is where I assumed that greatest change in sediment size would occur.

The sediments extracted with the Ekman sampler were scraped by hand into plastic bags, air dried on aluminum foil, and stored in plastic bags until analysis. This part of the process was easiest for the sediments that were less cohesive. Each sample was split to produce a subsample of several hundred grams.

Sediment Coring

A Livingstone corer was used to collect cores from the lake in January and March of 2001. Wright (1967) provides a diagram of this apparatus. With the assistance of George Mustoe, I constructed a seven by eight foot platform (Figure 17) for use in coring the lake. According to Douglas H. Clark (oral communication, 2000) the depth of Mirror Lake (about 10 meters) is near the practical limit of this method from a raft. A total of four cores were collected from three different locations on the lake bottom (Table 1 and Figure 16). The cores were all collected from the relatively flat deeper portion of the lake because most complete records are from the deepest portions of lakes. The first coring site, from which two cores were collected, was at the center of the lake. The second site was closer to the delta, but was far enough from the delta to avoid coring in sands. The third coring site was farthest from the delta.

The cores were collected in several segments, which are known as pushes. Each push or segment of a core involves the connection of a column of cylindrical rods above a piston, which has a square central rod that is turned to a locked position prior to coring. This column of rods is held over the sediment to be cored. The core barrel is pushed or twisted a maximum of 1 meter into the sediment, and then is pulled out of the surrounding sediment. The column of rods is disassembled, and the filled piston is set aside on the raft. This is repeated for additional pushes at lower depths at the same site until the desired depth is reached or high resistance to penetrating the sediment is encountered. My field assistants and I completed three to five pushes for each core and collected cores with total lengths between 2.4 and 4.6 meters. The cores were then extruded into split PVC pipe lined with commercial plastic wrap, secured, then transported to the WWU cold room and stored at 5 degrees C.

Sediment Analysis and Discussion

Tests of the loss on ignition, water content and particle size were performed on the grab samples and sediments from the cores after the core logs were produced. An analysis of magnetic susceptibility was also performed on each core before it was split. The first three tests provide information on organic content, compaction, and flow velocity, and the last analysis relates to the organic content and mineral composition of sediment.

Core Logging

Production

After the cores were analyzed for magnetic susceptibility, they were split lengthwise; one set of the core halves was returned to cold storage for archival purposes. Stratigraphic logs were made of the cores, although these logs show only visual changes in the sediment, such as the transition at the onset of the diversion, and are not intended to show all strata that are present. The cores are presented together as a fence diagram in Plate 1 and individually with other measurements in Figures 18 through 21. The cores were photographed before additional tests were performed, but because I took photographs about seven weeks after splitting the cores, the colors recorded in the photos show the sediments in an oxidized condition. Photographs of the different types of sediment in the cores are shown in Figures 22 and 23.

Construction of the logs for each core involved combining the measurements from three to five sections after their lengths have been reconstructed from the original lengths. For each section, I recorded a push length in the field. For the first two cores removed, I also recorded the length of core recovered after each push. After the cores were extruded, I measured the length of each section again. The ends of the sections were often tapered, so I measured the length of the tapered ends and estimated the length they would occupy if restored to their original lengths. I then attempted to correct the lengths of the extruded core sections to their original lengths, by comparing the extruded length to the length recovered (available for the first two cores) or to the estimated push length. The organic-rich sediments appeared to have been compacted varying amounts during core extrusion, whereas there was little if any compaction of the post-diversion sediments. For this reason, when both types of sediment were present in a push, I assumed that all compaction was restricted to the organic-rich sediments and extended the sections accordingly. Table 2 shows the relevant values. The boundaries between each push of a core are identified in Plate 1 by small bars on the right side of each column.

I made two additional adjustments to the core lengths. Analysis of the photographs and particle size tests (referred to in the section on particle size analysis) suggested that part of core ML01-4 included an unintended duplication of part of the sequence, which occurred after the second push entered the sediment at a different angle than the first push. This is the reason for my removal of the bottom 2 centimeters of push 1 and the top 34 centimeters of push 2 from the final log of this core. For the second push of core ML01-2 (Plate 1 and Figure 19) the difference between the push length and recovered length suggested that a part of the core had been lost during the coring process, most likely by falling out of the bottom of the core barrel. I estimated this length to be about 16 cm. Losses of core sediments from this process appear to be negligible in other core segments.

Stratigraphy and Comparison with Other Lakes

The majority of the post-diversion sediment in each core is medium and coarse silt (diameter 0.016 to 0.063 mm). Thickness of strata varies from about 1 millimeter to about 5 centimeters. As might be expected, the thickness and grain size decrease away from the delta. In spite of the presence of distinct strata, I could identify only one distinctive marker bed in the cores. A 2- to 3-centimeter bed of clay and finer silt (<0.016 mm) was deposited about 10 centimeters above the prediversion sediments, and this is shown in the third photograph from the top in Figure 22. Core sediments are described further in the section on particle size analysis.

The pre-diversion sediment in the cores consists primarily of gyttja and peat. Gyttja is composed primarily of fine plant detritus, along with clay, finer silt and remains of plankton. The gyttja is dark brown in color in most of the section, with rare wood fragments. Close to the top of the gyttja in the cores near the delta and near the middle of the lake is a series of clastic laminae at several millimeter intervals, several laminae are about 1 mm in thickness, but others are much thinner and are only faintly visible. I assume these laminae were deposited after logging in the drainage basin about 100 years ago. If sediment from this time actually overlies the uppermost gyttja, the mineralogy of what I assume is the lowermost post-diversion sediment should suggest a Mirror Lake basin provenance rather than a Middle Fork Nooksack provenance. The peat was only encountered in core ML01-4, at slightly more than 2 meters below the post-diversion sediments; I assume that peat was deposited at the other coring sites, because those sites are at a similar water depth to ML01-4, and that peat was present below the bottom of the cores collected at the other sites.

In the lower portion of core 4, about 10 centimeters below the transition from gyttja to peat, there is a pale yellow inorganic layer (Figure 23) that Douglas H. Clark (oral communication, 2001) visually identified as the Mazama tephra, which was erupted about 6850 ^{14}C years B.P. from Crater Lake, OR (Kittleman, 1973). Chemical analysis at Washington State University confirms the tephra as from this Mazama eruption.

Newby et al. (2000) correlate changes in deposition between peat and organic mud to the depth of water at a swamp in Massachusetts. They state that organic mud is deposited during conditions of deeper water, and that peat is deposited when the water is shallower. Deposition of gyttja appears to have predominated during the late Holocene at Mirror Lake. However, peat is present in the lowest portion of core ML01-4, which is farthest from the delta (Plate 1, Figure 16 and Figure 21), and the change from peat to gyttja probably resulted from an increase in water depth that drowned emergent vegetation. This indicates that the deeper portion of Mirror Lake was once a marsh, and that the lake became deeper shortly after the deposition of the Mazama tephra. I did not investigate the cause of this change in water depth. An increase in precipitation may have caused the lake level to rise to the outlet level.

As a result of the diversion, sedimentation in Mirror Lake at present is more rapid than in many lakes that have been cored for studies of glacial history. For example, Crowfoot Lake, a 0.23 square kilometer lake in Alberta, accumulated 1.04 meters of sediment in 6800 radiocarbon years (Leonard and Reasoner, 1999). The sedimentation rate of 0.15 mm/yr in Crowfoot Lake is much lower than the 34 mm/yr in Mirror Lake. There are other lakes where the volumetric sedimentation rate is probably similar to or greater than the rate of Mirror Lake, but if these lakes are small and not very deep, they will probably fill in rapidly to become part of a fluvial system. Deposits in Garibaldi Lake in British Columbia appear to have accumulated at a rate greater than 1 m / 100 yr. (Douglas H. Clark, 2001, written communication), and this rate can be sustained for a period of millennia in a lake that is significantly deeper than Mirror Lake.

Mirror Lake experienced a change from deposition of gyttja during the late Holocene to siliciclastic sedimentation during the past 40 years because the lake has acted as a natural detention basin for the diversion. Most detention basins are constructed; the use of a natural lake is rare. A lake in King County is used as a natural detention basin for water from the Tolt Reservoir, but the sediment accumulation in this lake has been minor because turbid river flows have not normally been diverted to this lake (Sheila Strehle, 2001, oral communication).

Loss on Ignition

Loss on ignition (LOI), which is one method of analyzing the percentage of organic matter, was measured primarily for comparing the change in the amount of organic matter from pre-diversion to post-diversion sediments. This test involves heating a sample in stages and computing mass changes during each stage, i.e., loss of organic matter For tests on the grab samples of loss on ignition, the subsamples mentioned previously were split to produce subsamples between about 7 and 17 grams. These smaller subsamples were then dried at temperatures of about 130 degrees Centigrade for about 6 hours, transferred to ceramic crucibles, and weighed. After being fired at 550 degrees Centigrade for 30 minutes to oxidize the carbon in the sample, they were reweighed. Table 3 shows the results of the loss on ignition tests. Loss on ignition values were usually between 3% and 4% for the grab samples. The organic content of the sediment was as low as 1% in the sand deposited at the delta, and was 4.5% in a sample that contained visible plant fibers.

For the cores, LOI samples were collected at points within five to six centimeters of the boundary between pre-diversion and post-diversion sediments, and at additional locations that were several decimeters above or below this boundary (Figures 18 through 21). These locations were chosen in order to measure how the organic content of sediment changed at the onset of the diversion. A hollow metal cylinder was used to remove samples that were within 5% of one cubic centimeter. The samples were placed in crucibles and weighed, then reweighed after drying at 110 to 120 degrees Centigrade for about 4 hours and firing at 550 degrees Centigrade for 30 minutes to determine loss on ignition. Although I actually fired 12 of the core samples at 650 degrees instead of the standard 550 degrees, dewatering of micas and clays at 650 degrees should not have affected the comparison of pre-diversion and post-diversion sediments. I did not redo the tests on the samples that were fired at 650 degrees.

Results of loss on ignition tests for the cores are shown with the results for the grab samples in Table 3. Loss on ignition for the cores varied from between 1.5% and 5% for the post-diversion sediments and between 30% and 60% for the gyttja (Table 3). Although half of the samples were dried at a temperature that was 100 degrees higher than the standard (550 degrees Centigrade), the results presented here should be close to the actual values. Deposition of clay and silt within the gyttja probably account for LOI values below 100%. The amount of plant ash is probably too small to account for the deficit.

The post-diversion sediments have probably compacted the pre-diversion sediments. Determining the amount of compaction requires a bulk density measurement of undisturbed lacustrine gyttja, which is not easy to obtain. I used four samples of the upper 4 centimeters of uncompacted sediment from Fragrance Lake, in Whatcom County, Washington (Township 37N, Range 3E, Section 30), and compared them to samples from Mirror Lake. Measurements of wet and dry bulk density of 1 cubic centimeter samples from the Mirror Lake cores and from Fragrance Lake sediments are shown in Table 4. I used the samples from Fragrance Lake to estimate the compaction of the Mirror Lake pre-diversion sediments.

I expected to find a trend of increasing density with depth in the Mirror Lake cores, at least for the pre-diversion sediments. However, the main apparent difference in density with position within the cores was greater density for the youngest gyttja deposits; these deposits also have a lower organic content than the rest of the gyttja. Together, these findings suggest a potential increase in clastic sedimentation in the lake, late in its history, which could have been caused by human alteration of the landscape in the watershed. The lack of a clear trend elsewhere in the cores may result from differences in grain packing in the post-diversion sediments or differences in organic content in the pre-diversion sediments. Inaccuracy in estimating the bulk density sample volume was probably another factor; a difference of 0.1 millimeter in length of the cylindrical collected sample translates to a difference of 1% in volume.

In order to assess the compaction of the pre-diversion sediments in Mirror Lake as a result of burial by the diversion sediments, I assumed an average pre-compaction dry bulk density for the pre-diversion sediments that had organic contents similar to those of the sediment in the samples from Fragrance Lake. I compared samples that had similar organic content to simplify the calculation of compaction. The samples I used were from core ML01-3 at 254 and 257 centimeters from the top, and from core ML01-4 at 105 centimeters from the top (Table 4) The organic contents of these three samples are 5% to 15% higher than the average organic content of Fragrance Lake sediments, but these samples were the closest matches. Comparison of the dry bulk densities of sediments from Fragrance and Mirror Lakes (Table 4) suggests that the gyttja in Mirror Lake has been compacted by a factor of about 200% relative to the degree of compaction about 3 or 4 centimeters below the top of sediment in Fragrance Lake. To make this comparison, I assumed that, at the time the samples from the Mirror Lake cores that I mentioned above had been covered by several centimeters of gyttja, they had a bulk density similar to the bulk density of the samples I used from Fragrance Lake. I considered using porosity of the sediments as a basis for comparison, but the magnification of small errors in sample volume for the highly porous organic sediments complicated this comparison.

Dating Control

I collected 5 macrofossil samples from the pre-diversion portions of cores ML01-2, ML01-3 and ML01-4 for radiocarbon analysis. The locations of these samples are identified as “RC” in the column labeled “Other Measurements” of Figures 19 through 21. Table 5 describes these samples. The ages for the samples constrain the pre-diversion sedimentation rates in Mirror Lake. The samples were processed at the Lawrence Livermore National Laboratory’s Center for Accelerator Mass Spectrometry in October 2001. I chose Sample 79714 and Sample 79716 from the bottom of core ML01-4 and Sample 79717 from the bottom of core ML01-3 so that I could establish the long-term sedimentation rate at opposite ends of the lake. Sample 79715 (stratigraphically higher in core ML01-4 than the other two samples from that core) was selected to provide a date for the change from peat to gyttja. Sample 79718 (from core ML01-2) was from the upper portion of the gyttja in the mid-lake core because of the lack of larger fragments of wood or other macrofossils from the bottom of this core. The ^{14}C dates, including the samples in close proximity in core ML01-4, are in stratigraphic order. These dates in ML01-4 are also in agreement with the Mazama tephra.

Particle Size Analysis

Particle sizes in the cores and in the grab samples were determined using a laser particle size analyzer, the Malvern Mastersizer 2000. The size analysis was not intended to show every change in sediment size that occurred along the length of the cores, but rather the general range of sediment sizes present, and whether there was any general trend in grain size in the post-diversion sediments that was not apparent from visual inspection. I also wanted to determine the manner in which sediment size changes with distance from the delta. An additional use of the particle size analysis was to help confirm that there was an unintended duplication of a portion of the strata in core ML01-4.

Samples were collected from cores ML01-1, ML01-3 and Ml01-4 using a cylinder with a cross sectional area of about one square centimeter or a small spatula. A spatula was used to sample from the thinner strata of core ML01-4 (far from delta) because the cylinder diameter is greater then the thickness of these strata. Core ML01-2 was not tested for particle size because the pattern of sedimentation was visibly similar to that of core ML01-1, and the two cores were removed from locations only several meters apart in the center of the lake. One sample for particle size analysis was removed from each grab sample. For tests of sediment size of the grab samples, the subsamples of each grab sample were rewetted with water until they were pliable. They were then kneaded by hand in a bag in the hope that this would remix the samples and reduce bias toward the removal of finer or coarser particles.

To measure particle size of the sediments with the Malvern Mastersizer 2000, I diluted each sample with distilled water in a plastic vial, produced a slurry, and added enough of the vial contents to agitated water in the particle size analyzer to produce an obscuration of at least 10%. Because the gyttja in my cores was cohesive, I added sodium hexametaphoshate to deflocculate the pre-diversion sediments. I did not sonicate the samples because this can cause the fragmentation of plant fragments. The Fraunhofer operating procedure was used to determine particle size, because tests by George Mustoe (oral communication, 2001) produced results that were similar to the results of pipette analysis.

Although the magnitude of error of the particle size analyzer was not determined, the median sizes of the post-diversion sediments that I obtained with the particle size analyzer are usually within 1/4 of a phi size increment (0.005 to 0.015 mm) of the actual grain sizes. The phi size is the inverse of the $\log_2$ of the grain diameter (in mm). Beuselinck et al. (1998) stated that laser diffractometry gives more reproducible results for particles smaller than 63 microns than does pipette analysis, and most of the sediments I analyzed were smaller than 63 microns. The error in the size of the gyttja particles could be more than 1/4 of a phi size (0.01 mm). Incomplete deflocculation of organic sediments and fine clastics may have resulted in an apparent median grain size that was larger than the actual median grain size, and the breaking apart of grains during agitation may have lowered the measured grain size. The particle size of the inorganic portion of the gyttja was not analyzed for this study.

Particle sizes of the grab samples are shown in Table 6 and Figure 24. Graphs of sediment size in the cores are shown in Figures 18 through 21. The variations in post-diversion clastic particle size are greatest in core ML01-3, which is closest to the delta. There is a substantial difference in median grain size between cores at the center of the lake and near the outlet (ML01-1 and ML01-4 respectively). Although these cores contain primarily silt in the post-diversion sediments, the concentration of fine sand in the cores often differed enough within several millimeters to be visible and to be felt as a change in texture. Coarser particles were probably transported to the part of the lake opposite the delta by density currents on the lake floor. Otherwise, they would have settled closer to the delta, as suggested by Stokes' Law.

Particle size data for the gyttja (Figure 23) are shown in the lower part of the grain size graph for each core in Figures 18 through 21 and in Table 7. According to the results of the tests using the particle size analyzer (Malvern Mastersizer 2000), the median size of the organic particles in the gyttja is in the range of very fine sand, which extends from 4 phi (0.063 mm) to 3 phi (0.125 mm). Sand-sized organic particles are probably most common because this lake receives detritus from a lowland temperate forest. The samples from core ML01-4 are probably coarser than those of cores ML01-1 and ML01-3 because core ML01-4 is located close to a shoreline composed of peat. Fragments of peat may have been eroded from the shore at this location.

In core ML01-3, which is closest to the delta, the post-diversion sediments are about 2.5 meters thick. They consist primarily of laminae and 1- to 3-centimeter beds that are about 45% medium and coarse silt, 25% very fine and fine sand, 20% very fine and fine silt, and 10% clay, in the Wentworth classification of grain sizes. In the Wentworth classification, the boundary between sand and silt is at 0.063 mm, the boundary between medium silt and fine silt is at 0.016 mm, and the boundary between silt and clay is at 0.004 mm. Strata of mostly very fine and fine sand (Figure 22), which have a thickness of 5 millimeters to 4 centimeters, are also present but are found mainly in the uppermost 65 centimeters of this core. A lamina or thin bed of fine wood fragments occurs above many of the sand beds (Figure 22). Laminae of clay and silt are common and more evenly distributed than sand in this core; their lower contact is visibly gradational with the predominant strata.

Cores ML01-1 and ML01-2 (middle of lake) also contain laminae and 1- to 3-centimeter beds that are primarily silt. The composition of the characteristic sediments is 50% medium and coarse silt, 25% very fine and fine silt, 15% very fine and fine sand, and 10% clay. Strata of the most common composition, which is medium to coarse silt, alternate with strata that contain up to 25% sand, or almost no sand, and have a thickness of up to slightly greater than 1 centimeter (finer strata are primarily laminae). The sand beds found in core Ml01-3 (near the delta) are absent at this location (Figure 22).

Core ML01-4, which is farthest from the delta, contains less sand (about 8% very fine sand) and more finer silts and clay (30% and 12% respectively) than cores from the center of the lake. Laminae and 1- to 3-centimeter thick beds of medium to coarse silt are separated by laminae that consist of up to 25% sand and are about 5 millimeters thick. The pattern of grain-size distribution appears to repeat near the bottom of the post-diversion sediments (Figure 25), and this was one reason for the elimination of centimeters 98 to 132 on the original log of core ML01-4 (Figure 26).

Magnetic Susceptibility

Results of Tests

The primary purpose of testing the sediments for magnetic susceptibility is to measure the organic content and clastic content of the gyttja and post-diversion sediments in each core, and to provide a tool for stratigraphic correlation of cores. A secondary purpose was to provide a quantitative measurement that could be compared with another sediment property, such as grain size distribution at each point in the core, and more accurately determine the source area of sediments in the post-diversion portion of the core. However, this secondary use is complicated, because the presence of certain clays can influence magnetic susceptibility values; ferromagnetic minerals are not the sole determinant (Verosub and Roberts, 1995). Results of the magnetic susceptibility tests on the cores removed in 2001 might be useful in comparing these cores with cores removed from Mirror Lake in the future, assuming that the patterns are distinct enough to be correlated.

The results of the magnetic susceptibility tests are shown in Figures 18 through 21. The upper portion of each core, which contains sediment deposited after the diversion began from the Middle Fork, is lower in organic content than the pre-diversion sediments. The transition from pre-diversion to post-diversion sediments is readily apparent in the magnetic susceptibility, as this is where the largest changes occur between measurements. This transition is actually sharper than is indicated on the graphs, based on visual and LOI analysis of the cores. The transition probably does not represent clearing of ground cover in the drainage basin 100 years ago because the sediment immediately above the transition does not appear to be weathering products or soil. The change in organic content is sustained.

I needed to alter the graphs of magnetic susceptibility when I transformed the results from the separate pushes into a single graph for each core. Some of the original readings were negative, and this may have been caused by the diamagnetic nature of the PVC plastic that contained the core segments (Bernard Housen, oral communication, 2001). Because of this, I changed the negative readings, which were usually only -1×10^{-5} or -2×10^{-5}, to 0. This change was not enough to be noticeable on the scale at which the graphs are shown. Also, when I extended or compacted a section to approximate its original length, I respectively decreased or increased the magnetic susceptibility values proportionately, so that the area between the curves and the zero line was about the same as before the cores were adjusted. This produces only an approximate correction.

Comparison of Magnetic Susceptibility Results

The magnetic susceptibility of the post-diversion sediments is not consistent between cores nor homogeneous. Aside from the measurements taken near the end of each core segment, the susceptibility values are highest just above the middle of the post-diversion portion of each core. The measurements near the ends of each push are identified by open circles in Figures 18 through 21, and are lower than the actual magnetic susceptibility values because of edge effects. In the Mirror Lake cores, variations exist on two scales: one scale is the difference in magnetic susceptibility between the pre-diversion sediments and the post-diversion sediments, and the other scale is the centimeter-to-centimeter variation in the post-diversion sediments.

The change in magnetic susceptibility from the pre-diversion to the post-diversion sediments is readily apparent. The post-diversion sediments have a much higher clastic content, and this correlates with the large difference in magnetic susceptibility. The loss on ignition values given in Table 3 for each core are 5% or less in the post-diversion sediments, where magnetic susceptibility values are on the order of 400 $x10^{-5}$ to 600 $x10^{-5}$ (Figures 18 through 21). Magnetic susceptibility is rarely greater than 10 $x10^{-5}$ in the pre-diversion sediments. This change in sediment type may not explain the difference, however; the cause of the difference might be redox reactions or bacterial activity in pore water, for example. Additional geochemical tests would be needed.

The changes in magnetic susceptibility within the post-diversion sediments probably relate to the amount of sediment mobilized by storm event erosion in the Middle Fork watershed (Figure 4), although diagenesis in pore-water may also be a factor. The proportions of sediments derived from glaciers and weathered soils may be reflected in sediment bulk magnetic properties (Verosub and Roberts, 1995), because weathering removes elements at different rates. Additional tests would be necessary to determine the minerals contributing to magnetic susceptibility in the Mirror Lake cores (Bernard Housen, 2001, oral communication). These tests would probably involve comparison of magnetic susceptibility with respect to particle size, i.e. bedload and suspended load.

A second possible explanation for the differences in the post-diversion sediments is differences in grain size. This might occur if rocks of different bulk magnetic susceptibility were differentially weathered or transported. There was no apparent correlation between the two parameters on a scale of tens of centimeters within any one core or between individual cores. If grain size correlated with magnetic susceptibility, the magnetic susceptibility values in the upper 60 centimeters of core ML01-3 (close to the delta) would be noticeably greater than in the upper 60 centimeters of core ML01-4 (opposite the delta) because there is a large difference in sediment size between these 2 core segments. However, most magnetic susceptibility values in these two intervals are between 400 $x10^{-5}$ and 500 $x10^{-5}$ (SI units). A third possible cause of changes in magnetic properties was a change in porosity in the post-diversion sediments. There is no conclusive correlation between magnetic susceptibility and water content (Table 4), nor hence porosity, in the post-diversion sediments of cores Ml01-3 and Ml01-4.

DISCUSSION OF SEDIMENTATION RATES

Pre-diversion Rates

The rate of sedimentation in Mirror Lake prior to the diversion is based on radiometric dating of small macrofossils in the gyttja and peat and on the Mazama tephra deposit. As stated in the section "Loss on Ignition," the sediment compaction factor appears to be about 200% in the pre-diversion sediments. The rates given here are after decompaction by 200%. The accumulation rate for the most recent gyttja deposits near the middle of the lake, based on the calibrated age for sample 79718 from ML01-2 (Table 5) is 0.8 mm per year. For the sediments at the end of the lake closest to the delta, sample 79717 indicates a rate of 0.7 mm per year, which is probably not significantly different from 0.8 mm per year. The transition from gyttja to peat, based on sample 79715 in core ML01-4, is 6690 calibrated years B.P., and this yields an accumulation rate of 0.6 mm per year for the core farthest from the delta. Samples 79714 and 79716 from core ML01-4 suggest an accumulation rate for the peat of 0.45 mm per year and 0.5 mm per year respectively, assuming a compaction factor of two. Errors in these values from analytic uncertainty are between 3% and 10%. Potential error from assuming a uniform compaction is difficult to quantify, but is probably between 10% and 20%. The presence of the Mazama tephra at cm 314 to cm 316 suggests that accumulation of peat after deposition of the tephra was 40% of the rate before the tephra was deposited.

The peat and the tephra in core ML01-4 were not present in core ML01-2 (middle of lake) or in core ML01-3 (near delta). If the sedimentation rates in cores ML01-2 and ML01-3 are assumed to be linear, the gyttja-peat boundary should occur at a depth of 406 cm at site ML01-2 and 486 cm deep at site ML01-3. The tephra would probably be about 10 cm lower in each section. By extrapolating sedimentation rates from higher in the cores, the calibrated ages of the gyttja at the bottom of cores ML01-2 and ML01-3 would be about 3640 and 5910 years B.P., respectively.

Post-diversion Sedimentation Rates, Volumes

Data from the cores produce a better estimate of the rate of sedimentation in Mirror Lake than does comparing the surveys of 1991 and 2000. In cores ML01-1 and ML01-2, near the center of the lake (Figures 16, 18 and 19), about 1.3 meters of post-diversion sediments were deposited between 1962 and 2000. In core ML01-3, which is closer to the delta, the thickness of post-diversion sediments is about 2.5 meters. Core ML01-4, which is across the lake from the delta, contains about 1 meter of post-diversion sediment. Although strata of sand and silt are present in the cores, there is no distinct marker bed that could be identified as having been deposited in 1991.

I assumed that sedimentation for the entire lake from 1991 to 2000 is about 25% of the total post-diversion deposits. In core ML01-3, I assumed that the sedimentation was slightly higher for 1991 to 2000 than for 1962 to 1991 and estimated a deposit thickness of about 75 centimeters between 1991 and 2000 (8.4 cm per year), out of a total post-diversion sediment thickness of about 250 centimeters (6.6 cm per year). At the site of cores ML01-1 and ML01-2, I estimated that slightly more 30 centimeters have been deposited from 1991 to 2000 (3.4 cm per year), out of a total post-diversion thickness of about 130 to 135 centimeters (3.5 cm per year). In core ML01-4, thickness for 1991 to 2000 is about 25 centimeters (2.8 cm per year), out of a total thickness of about 1 meter (2.6 cm per year). I assumed a constant sedimentation rate for cores ML01-1, ML01-2, and ML01-4.

I chose a value of sedimentation for the period 1991 to 2000 in core ML01-3 that was greater than 25% of the total. About 10 centimeters of sandy sediment is present in the upper portion of the core (Figure 20) and sand beds with similar grain size and sorting are not present in the middle and lower portion of the core. My interpretation of this higher sand content is that a larger than average turbidity current deposited fine and very fine sand at these locations. This turbidity current may have been generated by transport of sand to the distal end of the input channel. This could have occurred if the diversion was begun while the lake level was low and the delta was exposed, by the collapse of the northern part of the delta, or by higher-density storm currents. However, any conclusion is speculative.

Rates of deposition at the core sites allowed me to produce a map of estimated sedimentation for the central portion of the lake, where sedimentation rates are lower than near the delta. A map of estimated sedimentation between 1991 and 2000 for the entire lake is shown in Figure 27. The map is of the changes from 1991 to 2000 because my knowledge of the form of the lake bottom near the delta before the diversion was constructed is limited.

To produce a total volume of sedimentation, I overlaid graph paper on the sedimentation map so as to cover sectors that were 10 meters on a side, and estimated the sediment accumulation for each sector. Because no cores were removed at the margins of the lake, the locations of isopachs near the lake edge are speculative. Based on this method, about 15,000 +/- 2000 cubic meters of sediment have been deposited between 1991 and 2000, or an average of 1700 +/- 220 cubic meters per year. This infilling represents about 0.6% of the lake volume per year. Because of the sparse cores and the lack of a marker horizon for 1991, quantifying the error in the estimate of sedimentation was difficult. Error sources involve the estimate of the post-1991 sediment thickness and the placement of contours near the margins of the lake. I assumed that sediment thickness near the lake margins was approximately proportional to depth and to distance from the source .

My estimate of sedimentation between 1962 and 2000, based on my assumption of the location of the pre-diversion to post-diversion transition, is about 60,000 +/- 6000 cubic meters, or about 1600 +/-160 cubic meters per year. This estimate is an average rate for 1962 to 2000, and is lower than for 1991 to 2000 because the diversion was operated for a smaller portion of the year before 1985. The error margin is lower than for the period 1991 to 2000 because the boundary between pre-diversion and post-diversion sediment is a good constraint on the lower stratigraphic boundary for this interval; i.e., this source of error is negligible.

CONCLUSIONS AND RECOMMENDATIONS

This study of Mirror Lake has resulted in a follow-up sedimentation map of Mirror Lake about 10 years after the previous study, as was recommended by Carpenter et al. (1992). I attempted to compare the map from the survey of 2000 with the maps from previous surveys of 1991 and 1946, but the accuracy of the combined measurements limited the usefulness of the comparison to the area near the delta, where sediment accumulation was greatest in the past nine years. I tried to establish an accurate survey of the lake, but my methods could be improved in future surveys. The City of Bellingham has established a benchmark that can be used with the reference mark I established for this survey, or in place of it.

The survey was accompanied by coring of the lake at three sites using a Livingstone coring system, as well as grab sampling using an Ekman grab sampler. This was followed by analyzing the cores and the sediments for loss-on-ignition, compaction, sediment size and magnetic susceptibility. Based on the coring, carried out in early 2001, I was able to determine a more accurate rate of sedimentation for the period the diversion has operated than was possible in previous studies, which did not involve coring the sediments. The average sedimentation rate since 1991 has been about 3.5 cm per year near the middle of the lake, or about 1700 +/- 220 cubic meters per year for the entire lake, assuming that the sedimentation rate was constant between 1962 and 2000. Analysis of the core sediments did not permit identification of yearly deposits. Radiocarbon dates from three cores, as well as the presence of the Mazama tephra, permit calculation of the rate of deposition for the pre-diversion gyttja; this averages about 0.7 mm per year for the three cores. The rate of peat deposition appears to have been similar.

The first step in any future survey should be to locate the reference used in the 2000 survey, provided that this marker has not been removed or disturbed. The center of the "V" in the transmission tower immediately north of Park Road (Figure 8) can be used to fix an azimuth for the survey. Finding the position of the reference marker used in 2000 on the UTM grid (1983 datum) directly by using a survey-grade GPS unit would be helpful, although finding enough satellites from the reference marker may take longer than in areas without overhanging vegetation. In the event that the reference marker that I established in 2000 is removed or cannot be found, the benchmark established at the outlet of the diversion by the City of Bellingham can be used to establish an elevation for a new reference marker.

Although it would help to use the same survey points as in the 2000 survey, it is more important to space survey points closely, so that minimal interpolation is needed to produce a map. The use of slightly different locations should still produce a map comparable to the map presented in this thesis. A GPS total station could potentially provide more accurate measurement locations. Another improvement over the study of 2000 and 2001 would be the use of radar, sonar or some other device to produce an image of the sediments on the lake floor, so that the thickness and volume of both the post-diversion sediments and the organic pre-diversion sediments can be determined more accurately than through coring alone. However, coring of the lake down to Pleistocene sediments would be beneficial if this provides information on the thickness of the peat encountered in core ML01-4.

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Table 1. Locations of cores and grab samples collected in Mirror Lake during 2001.

Sample	UTM E	UTM N
Core 1	557449	5390292
Core 2	557449	5390292
Core 3	557504	5390244
Core 4	557357	5390371
Grab 1	557565	5390205
Grab 2	557544	5390235
Grab 3	557542	5390221
Grab 4	557536	5390223
Grab 5	557490	5390227
Grab 6	557472	5390247
Grab 7	557467	5390249
Grab 8	557430	5390308
Grab 9	557355	5390366
Grab 10	557338	5390361
Grab 11	557535	5390248
Grab 12	557546	5390272
Grab 13	557506	5390226
Grab 14	557496	5390207

UTM E is Universal Transverse Mercator Easting

UTM N is Universal Transverse Mercator Northing

Section 10U of UTM, 1983 datum is used for coordinates

Table 2. Adjustments to lengths of core pushes and reconstruction of cores.

Core	Push	Length pushed (cm)	Length recovered (cm)	Length after extrusion	Correction for taper at top of push	Correction for taper at end of push	Length (cm) after taper adjustment	Additional adjustments to length
1	1	96	96	102	3 cm to 2 cm	6 cm to 4 cm	99	compressed 3 cm
1	2	96	93	94	2 cm to 1 cm	2 cm to 1 cm	92	none made
1	3	53	53	40	2 cm to 1 cm	none	39	extended 14 cm
2	1	96	83	82	3 cm to 2 cm	2 cm to 1 cm	80	missing lowest 16 cm
2	2	96	93	88	none	none	87	lowest 49 cm extended 6 cm
2	3	96	93	86	none	2 cm to 1 cm	84	extended 9 cm
3	1	96	NR	96	none	4 cm to 2 cm	94	none made
3	2	99	NR	100	none	2 cm to 1 cm	99	none made
3	3	99	NR	85	none	2 cm to 1 cm	84	top 1 cm slough, lower 27 cm extended 16 cm
3	4	69.5	NR	60	none	none	60	extended 9.5 cm
3	5	96.5	NR	87	none	2 cm to 1 cm	86	extended 10.5 cm
4	1	100	NR	100	none	none	100	lowest 2 cm subtracted
4	2	96.5	NR	80	2 cm to 1 cm	none	79	top 34 cm removed, lower 45 cm extended 17.5
4	3	96.5	NR	84	none	none	84	extended 12.5 cm
4	4	96.5	NR	87	none	2 cm to 1 cm	86	extended 10.5 cm

cm = centimeters

Recovery lengths were not recorded for cores 3 and 4.

Table 3. Loss on ignition results for Mirror Lake grab samples and cores

Grab sample or core number	Centimeters from top (for cores)	Grab sample % loss on ignition	Core sample loss on ignition Pre-diversion	Boundary	Post-diversion	X denotes LOI overfire (At 650^0 C)
GS1		1.0				
GS2		2.4				
GS3		4.5				
GS4		3.6				
GS5		3.4				
GS6		2.9				
GS7		3.6				
GS8		3.3				
GS9		3.5				
GS10		3.0				
GS11		3.0				
GS12		3.2				
GS13		3.5				
GS14		3.3				
ML01-1	28				3.3	X
	86				5.1	X
	129				3.2	X
	133		32.3			X
	214		60.1			X
ML01-2	29				2	X
	125				3	X
	132				2.4	X
	134			10.4		X
	136		32.9			X
ML01-3	13				2	X
	34				1.7	X
	80				3.3	
	141				2.1	
	143				2	
	234				2.8	
	247				1.9	
	249			13.1		
	251		34			
	254		32			
	257		39			
	350		53			
	352		59			
	440		44			
	442		43			
ML01-4	94				2.3	
	96				2.8	
	98			5.9		
	100		32.5			
	102		36.5			
	218		53			
	220		54			
	306		26			
	309		67			
	346		80			
	347		83			

Table 4. Results from bulk density and organic content (LOI) measurements.

Sediment source	Centimeters from top	Wet density (grams/cc)	Dry density (grams/cc)	Water content (grams/cc)	LOI (percent)	Notes
core 3 silt	7	2.08	1.48	0.6	2	
core 3 silt	10	2.14	1.61	0.53	3	
core 3 silt	152	2.15	1.61	0.54	2	
core 3 silt	156	2.01	1.52	0.49	1	
core 3 silt	246	1.81	1.35	0.46	2	
core 3 silt	248	2.25	1.73	0.52	2	
core 3 gyttja	254	1.16	0.25	0.91	32	
core 3 gyttja	257	1.14	0.23	0.91	39	
core 3 gyttja	350	1.08	0.17	0.91	53	
core 3 gyttja	352	1.03	0.17	0.86	59	
core 3 gyttja	440	1.13	0.16	0.97	44	
core 3 gyttja	442	0.99	0.14	0.85	43	
core 4 silt	11	1.88	1.38	0.5	2	
core 4 silt	12	2.08	1.49	0.59	2	
core 4 silt	50	1.93	1.35	0.58	2	
core 4 silt	52	1.77	1.22	0.55	2	
core 4 silt	88	2.08	1.45	0.63	3	
core 4 silt	93	1.89	1.29	0.6	2	
core 4 gyttja	105	1.36	0.34	1.02	29	
core 4 gyttja	108	1.11	0.20	0.91	45	
core 4 gyttja	218	1.18	0.17	1.01	53	
core 4 gyttja	220	0.99	0.13	0.86	54	
core 4 peat	306	1.12	0.31	0.81	26	Sand present
core 4 peat	309	1.03	0.12	0.91	67	
core 4 peat	346	1.00	0.10	0.9	80	
core 4 peat	347	1.13	0.12	1.01	83	
Fragrance Lake 1		1.06	0.20	0.86	22	Sample size
Fragrance Lake 2		1.06	0.15	0.91	29	is 5 cubic cm
Fragrance Lake 3		1.08	0.11	0.97	23	for Fragrance
Fragrance Lake 4		1.10	0.12	0.98	22	Lake samples

Table 5. Location of radiocarbon samples processed at Lawrence Livermore National Laboratory CAMS.

Sample name	Sampled material	Weight in milligrams	CAMS number	Core number	Centimeters from top of core	Relative Location
ML01/4/350	seed	2	79716	ML01-4	350	near bottom of core far from delta
ML01/4/340	twig	15	79714	ML01-4	340	near bottom of core far from delta
ML01/4/304	seed	2	79715	ML01-4	304	at gyttja-peat boundary
ML01/3/432	twig	8	79717	ML01-3	432	near bottom of core close to delta
ML01/2/173	needle	1.9	79718	ML01-2	173	middle of gyttja in mid-lake core

Table 6. Distribution of particle sizes in Mirror Lake grab samples.

Grab sample	Percent clay (<0.004 mm)	Percent very fine & fine silt (0.004 to 0.016 mm)	Percent medium & coarse silt (0.016 to 0.063 mm)	Percent sand (>0.063 mm)	Percent clay	Percent clay to fine silt	Percent clay to coarse silt	Percent clay to sand
1	0	0	0	100	0	0	0	100
2	4	8	22	66	4	12	34	100
3	4	9	27	60	4	13	40	100
4	5	9	23	63	5	14	37	100
5	6	13	35	46	6	19	54	100
6	8	17	38	37	8	25	63	100
7	8	18	42	32	8	26	68	100
8	11	23	46	20	11	34	80	100
9	11	27	49	13	11	38	87	100
10	9	25	53	13	9	34	87	100
11	3	7	27	63	3	10	37	100
12	2	10	37	51	2	12	49	100
13	5	12	32	51	5	17	49	100
14	10	26	41	23	10	36	77	100

Grab sample		Percent clay (<0.004 mm)	Percent very fine & fine silt (0.004 to 0.016 mm)	Percent medium & coarse silt (0.016 to 0.063 mm)	Percent sand (>0.063 mm)	Percent clay	Percent clay to fine silt	Percent clay to coarse silt	Percent clay to sand
Core 1	Centimeters from top								
	1	13	33	44	10	13	46	90	100
	7	13	31	46	10	13	44	90	100
	13	10	26	51	13	10	36	87	100
	16	11	26	50	13	11	37	87	100
	19	7	17	59	17	7	24	83	100
	21	14	33	47	6	14	47	94	100
	22	8	24	53	15	8	32	85	100
	26	10	21	53	16	10	31	84	100
	30	8	19	53	20	8	27	80	100
	34	11	26	55	8	11	37	92	100
	38	12	29	48	11	12	41	89	100
	42	9	24	53	14	9	33	86	100
	46	9	23	55	13	9	32	87	100
	49	10	25	52	13	10	35	87	100
	53	11	28	41	20	11	39	80	100
	57	25	45	29	1	25	70	99	100
	61	10	26	53	11	10	36	89	100
	65	8	23	48	21	8	31	79	100
	69	8	23	48	21	8	31	79	100
	73	13	28	46	13	13	41	87	100
	77	11	27	43	19	11	38	81	100
	80	11	26	48	15	11	37	85	100
	84	11	25	50	14	11	36	86	100
	88	11	21	51	17	11	32	83	100
	92	8	20	49	23	8	28	77	100
	96	12	23	49	16	12	35	84	100
	97	12	24	46	18	12	36	82	100
	101	11	21	52	16	11	32	84	100
	105	12	27	46	15	12	39	85	100
	109	12	27	44	17	12	39	83	100
	113	9	23	46	22	9	32	78	100
	117	9	20	52	19	9	29	81	100
	121	24	53	23	0	24	77	100	100
	125	9	20	56	15	9	29	85	100
	132	2	15	35	48	2	17	52	100
	137	2	13	35	50	2	15	50	100
	157	1	9	29	61	1	10	39	100

Grab sample		Percent clay (<0.004 mm)	Percent very fine & fine silt (0.004 to 0.016 mm)	Percent medium & coarse silt (0.016 to 0.063 mm)	Percent sand (>0.063 mm)	Percent clay	Percent clay to fine silt	Percent clay to coarse silt	Percent clay to sand
Core 3	Centimeters from top								
	2	6	14	33	47	6	20	53	100
	6	7	17	50	26	7	24	74	100
	10	10	23	44	23	10	33	77	100
	12	5	9	29	57	5	14	43	100
	16	5	14	38	43	5	19	57	100
	20	6	13	39	42	6	19	58	100
	22	9	21	51	19	9	30	81	100
	27	11	24	45	20	11	35	80	100
	30	3	6	25	66	3	9	34	100
	34	1	2	8	89	1	3	11	100
	38	4	7	37	52	4	11	48	100
	42	2	2	27	69	2	4	31	100
	46	8	17	45	30	8	25	70	100
	50	8	22	49	21	8	30	79	100
	54	2	4	18	76	2	6	24	100
	58	7	20	39	34	7	27	66	100
	62	3	7	33	57	3	10	43	100
	66	8	22	39	31	8	30	69	100
	70	13	29	44	14	13	42	86	100
	74	13	29	43	15	13	42	85	100
	78	12	26	46	16	12	38	84	100
	82	11	25	44	20	11	36	80	100
	86	7	15	49	29	7	22	71	100
	90	13	25	45	17	13	38	83	100
	96	9	17	42	32	9	26	68	100
	100	7	17	47	29	7	24	71	100
	104	9	21	50	20	9	30	80	100
	108	10	25	43	22	10	35	78	100
	112	8	20	44	28	8	28	72	100
	116	5	12	51	32	5	17	68	100
	120	9	21	44	26	9	30	74	100
	124	9	23	37	31	9	32	69	100
	128	6	15	47	32	6	21	68	100
	132	10	25	44	21	10	35	79	100
	136	8	18	46	28	8	26	72	100
	140	14	24	40	22	14	38	78	100
	144	4	11	51	34	4	15	66	100
	148	8	20	46	26	8	28	74	100
	152	6	17	45	32	6	23	68	100
	156	9	19	43	29	9	28	71	100
	160	9	19	46	26	9	28	74	100
	164	6	15	40	39	6	21	61	100
	168	10	22	50	18	10	32	82	100
	172	6	13	47	34	6	19	66	100
	176	6	18	41	35	6	24	65	100
	180	6	16	42	36	6	22	64	100
	184	8	17	46	29	8	25	71	100

Grab sample	Percent clay (<0.004 mm)	Percent very fine & fine silt (0.004 to 0.016 mm)	Percent medium & coarse silt (0.016 to 0.063 mm)	Percent sand (>0.063 mm)	Percent clay	Percent clay to fine silt	Percent clay to coarse silt	Percent clay to sand
210	6	14	38	42	6	20	58	100
214	7	16	42	35	7	23	65	100
218	6	14	49	31	6	20	69	100
222	5	13	36	46	5	18	54	100
226	6	15	45	34	6	21	66	100
230	4	10	45	41	4	14	59	100
234	41	43	15	1	41	84	99	100
238	6	17	49	28	6	23	72	100
242	6	16	43	35	6	22	65	100
246	5	14	51	30	5	19	70	100
252	2	13	33	52	2	15	48	100
257	2	12	32	54	2	14	46	100
289	2	9	33	56	2	11	44	100
451	1	8	27	64	1	9	36	100

	Grab sample	Percent clay (<0.004 mm)	Percent very fine & fine silt (0.004 to 0.016 mm)	Percent medium & coarse silt (0.016 to 0.063 mm)	Percent sand (>0.063 mm)	Percent clay	Percent clay to fine silt	Percent clay to coarse silt	Percent clay to sand
Core 4	Centimeters from top								
	10	14	35	47	4	14	49	96	100
	20	12	28	52	8	12	40	92	100
	30	15	35	45	5	15	50	95	100
	40	12	28	54	6	12	40	94	100
	50	14	32	47	7	14	46	93	100
	60	15	35	43	7	15	50	93	100
	66	13	28	51	8	13	41	92	100
	68	10	27	43	20	10	37	80	100
	70	11	28	52	9	11	39	91	100
	72	12	28	51	9	12	40	91	100
	74	13	30	50	7	13	43	93	100
	78	8	24	45	23	8	32	77	100
	80	12	29	51	8	12	41	92	100
	85	10	24	52	14	10	34	86	100
	90	9	23	61	7	9	32	93	100
	91	40	51	9	0	40	91	100	100
	94	11	26	50	13	11	37	87	100
	97	12	28	53	7	12	40	93	100
	101	2	7	26	65	2	9	35	100
	105	2	7	26	65	2	9	35	100
	133	1	7	33	59	1	8	41	100
	299	1	4	21	74	1	5	26	100

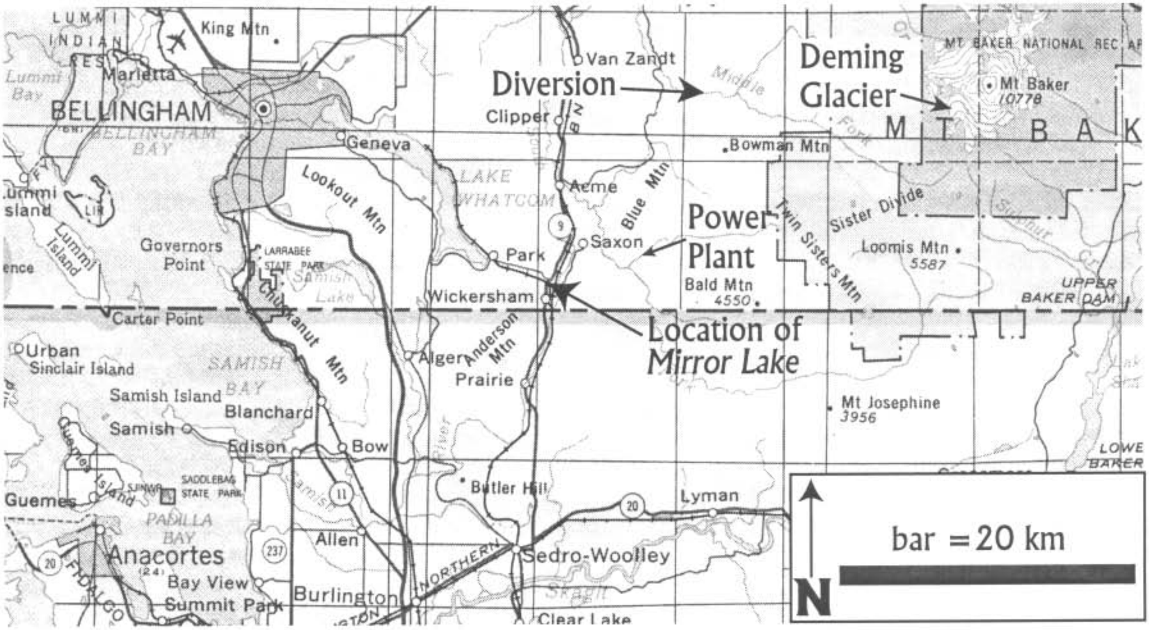
Grab sample	Percent clay (<0.004 mm)	Percent very fine & fine silt (0.004 to 0.016 mm)	Percent medium & coarse silt (0.016 to 0.063 mm)	Percent sand (>0.063 mm)	Percent clay	Percent clay to fine silt	Percent clay to coarse silt	
Deleted portion - positions given are the positions before removal								
102	14	29	47	10	14	43	90	100
104	8	25	47	20	8	33	80	100
108	13	29	49	9	13	42	91	100
110	13	29	50	8	13	42	92	100
113	10	25	44	21	10	35	79	100
119	8	22	54	16	8	30	84	100
124	10	24	58	8	10	34	92	100
125	42	44	12	2	42	86	98	100
128	11	27	55	7	11	38	93	100
131	12	28	53	7	12	40	93	100

Table 7. Sizes of gyttja in pre-diversion sediments.

Core	cm from top	%clay (<0.004 mm)	%very fine &fine silt (0.004 to 0.016 mm)	% medium &coarse silt (0.016 to 0.063 mm)	%sand (0.063 mm)				
1	132	2	15	35	48	2	17	52	100
1	137	2	13	35	50	2	15	50	100
1	157	1	9	29	61	1	10	39	100
3	252	2	13	33	52	2	15	48	100
3	257	2	12	32	54	2	14	46	100
3	289	2	9	33	56	2	11	44	100
3	451	1	8	27	64	1	9	36	100
4	101	2	7	26	65	2	9	35	100
4	105	2	7	26	65	2	9	35	100
4	133	1	7	33	59	1	8	41	100
4	299	1	4	21	74	1	5	26	100

Sediment has high organic content.

Size fractions include all sediment types.



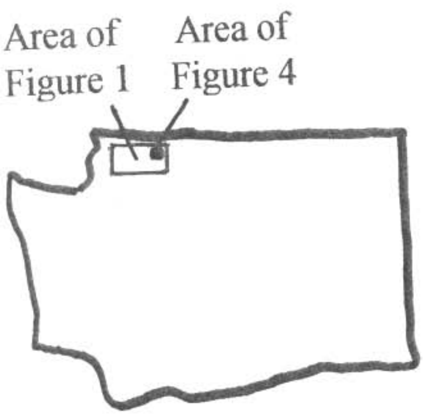


Figure 1. Mirror Lake and other locations mentioned in the introduction. The lower map shows the location of the study area in the State of Washington. Modified from U.S. Geological Survey, 1982.

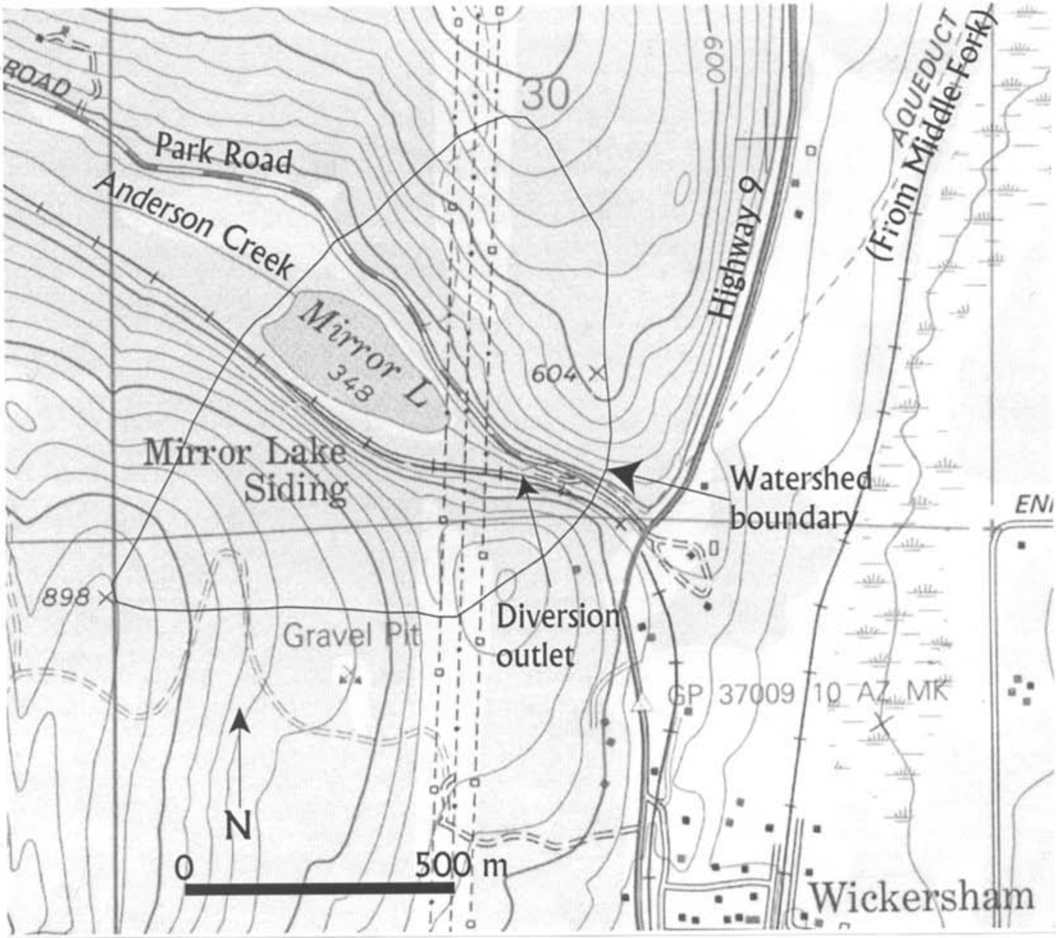


Figure 2. Mirror Lake and its watershed. Modified from U.S. Geological Survey, 1994.

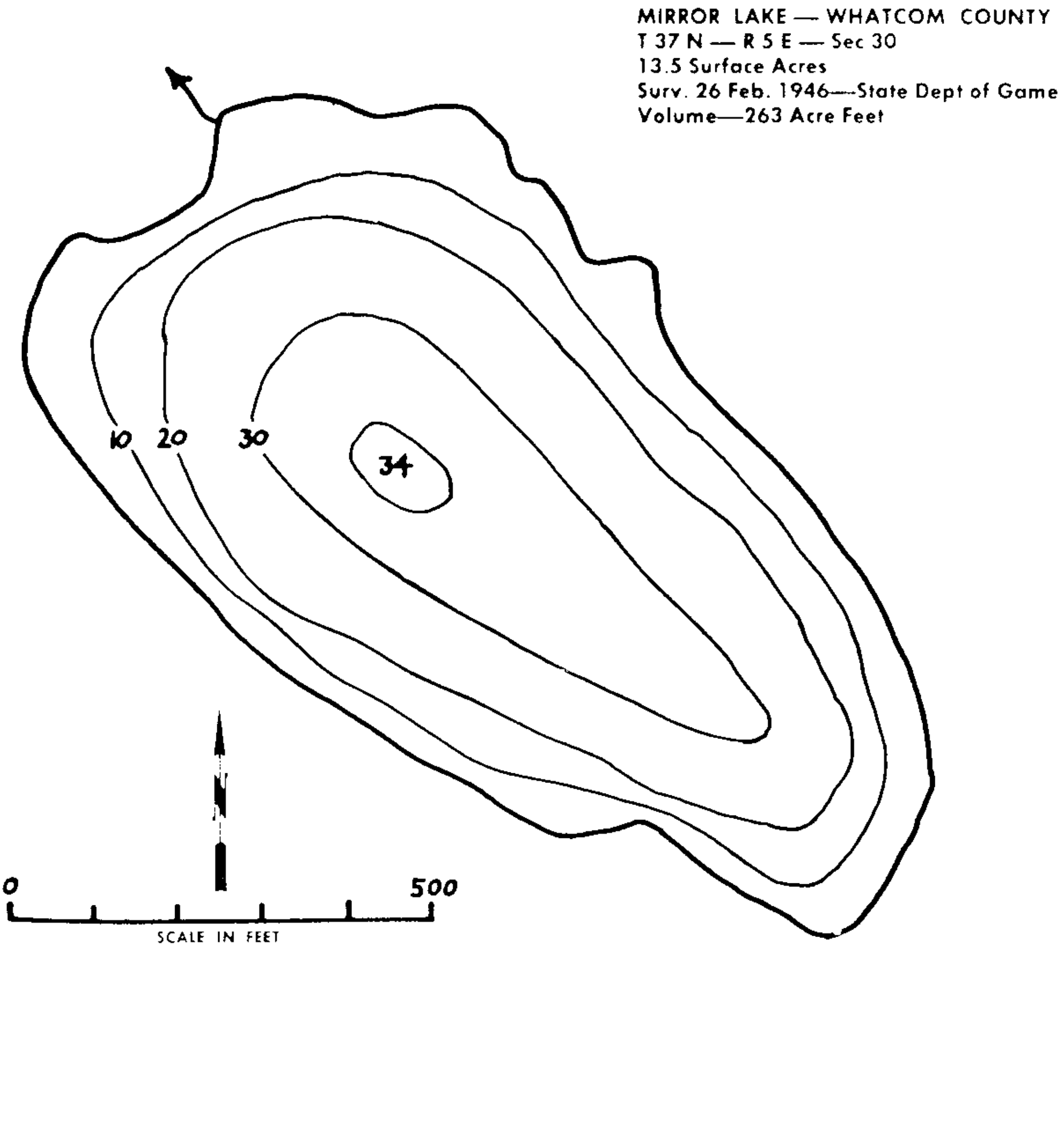


Figure 3. Bathymetric map from the 1946 survey of Mirror Lake. From Wolcott (1973).

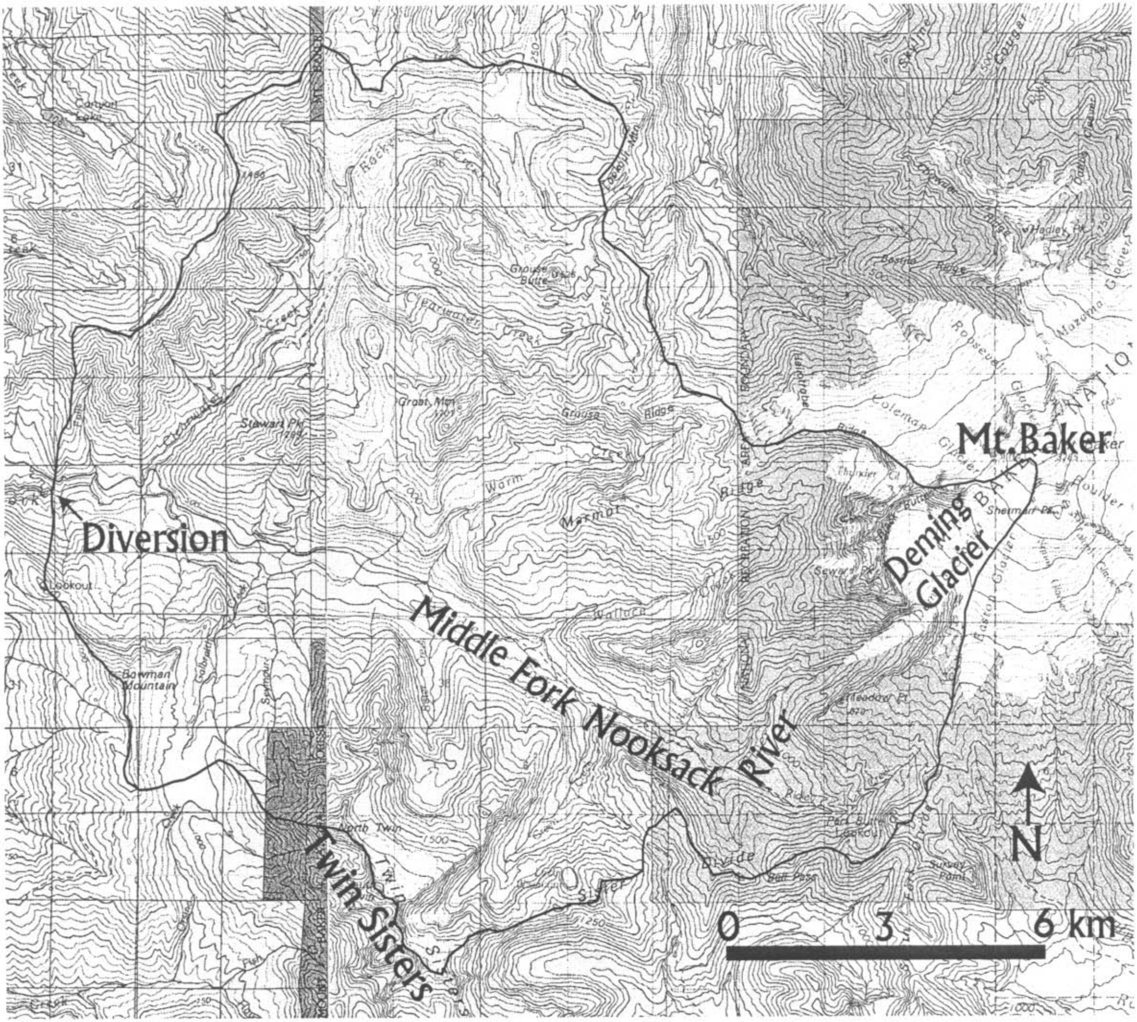


Figure 4. Mount Baker and the drainage basin of the Middle Fork Nooksack River upstream from the diversion to Mirror Lake. Modified from U.S. Geological Survey, 1975 and U.S. Geological Survey, 1979.

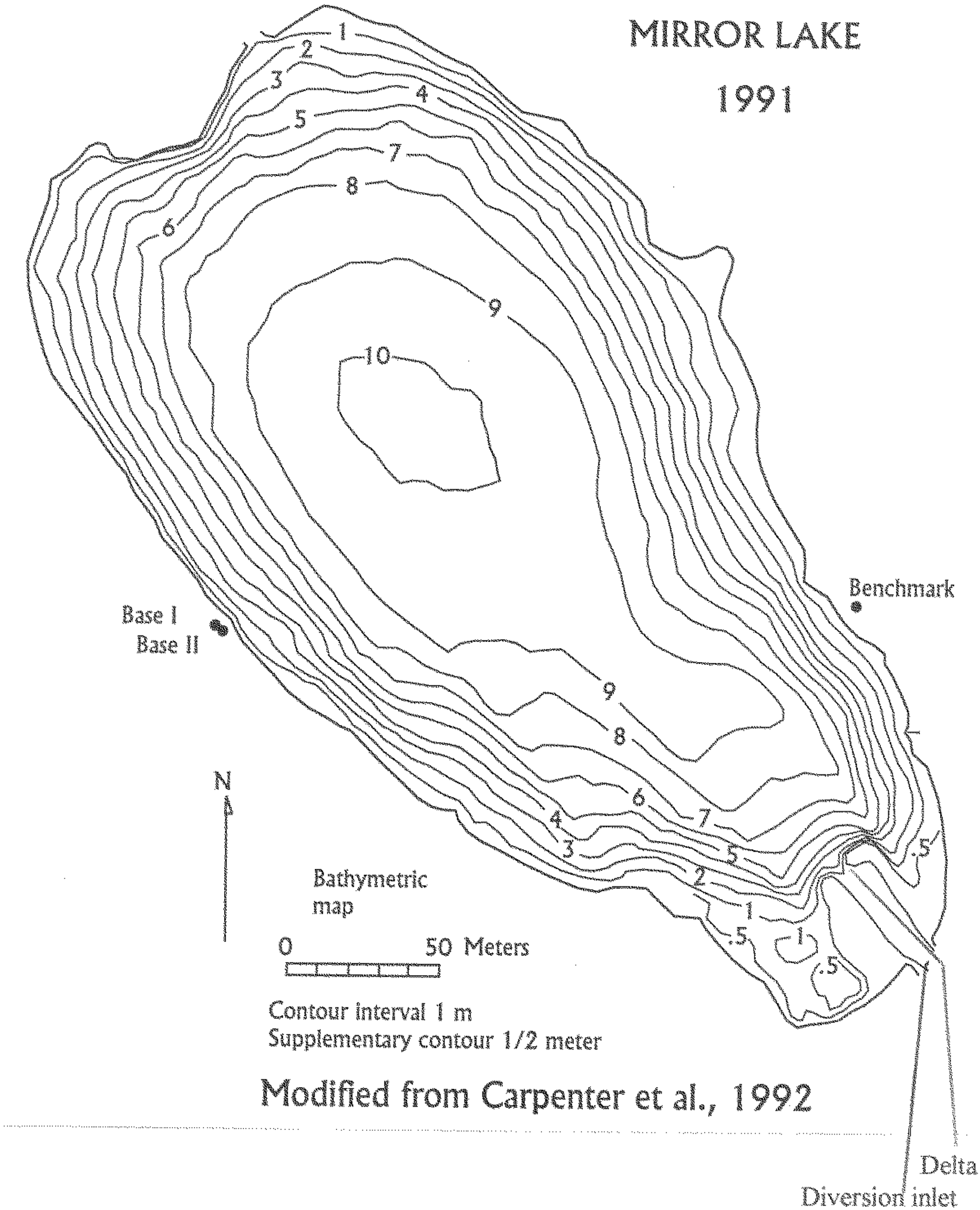


Figure 5. Modified version of map produced in 1991 (Carpenter et al., 1992). Contours are shown at 1 meter intervals.

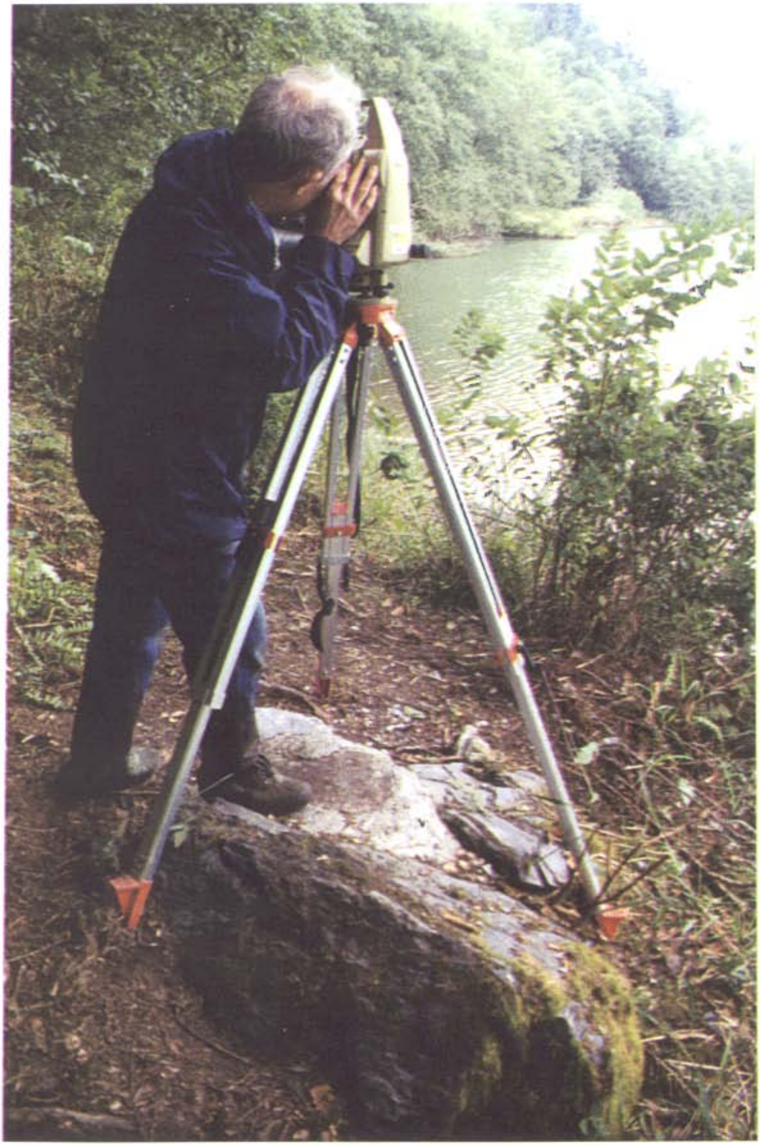


Figure 6. Survey assistant George Mustoe operating a theodolite over the reference marker established in 2000. Photo by Robin Matthews.

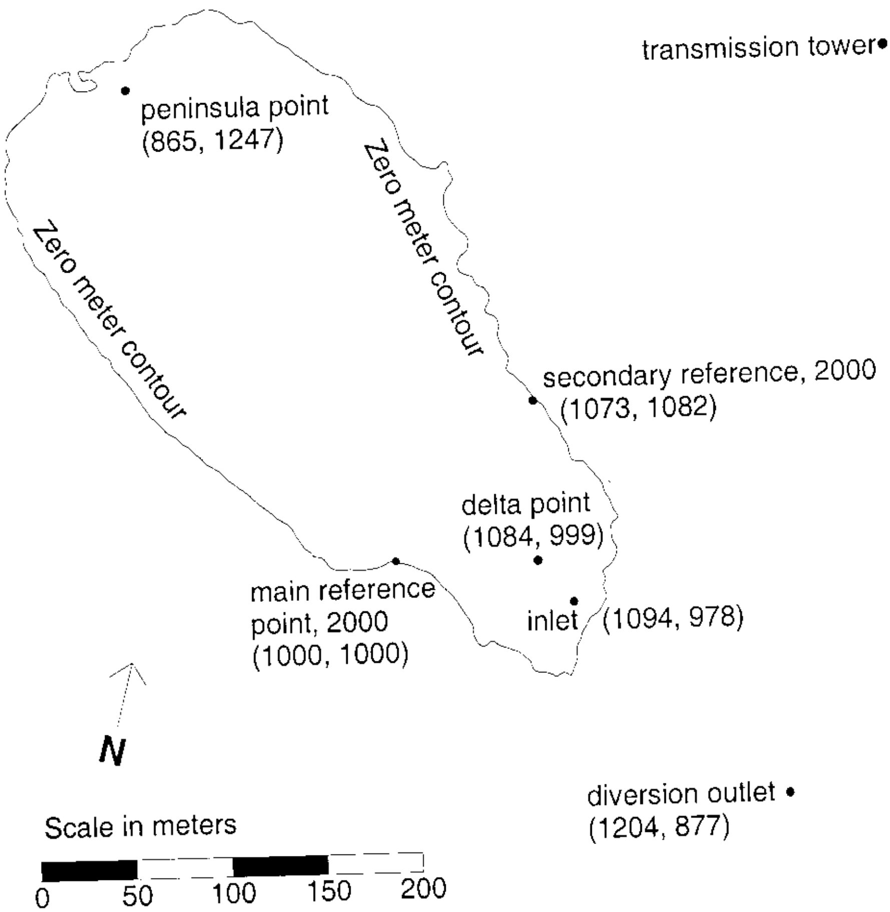


Figure 7. Survey stations and reference points used during the survey of Mirror Lake in 2000. Points identified as "peninsula point," "inlet" and "delta point" are wooden stakes and are unlikely to be present at the time of the next survey after 2000. Numbers in parentheses are the easting and northing positions as surveyed in the grid of 2000.

Figure 8. The transmission tower used in setting a horizontal azimuth from the reference marker in 2000 lies at the center of this photo. The "V" formed by the insulators near the top of the tower at center is about 30.4 degrees east of north when measured from the reference marker established in 2000. The tower is identified by the Bonneville Power Administration as MONE CUST Line 1, Mile 62, Tower 1.

Figure 9. Recording of depth measurements on Mirror Lake in 2000. The theodolite reflector has been mounted on a hard hat to record positions of the depth measurements on the lake. Photo by Robin Matthews.

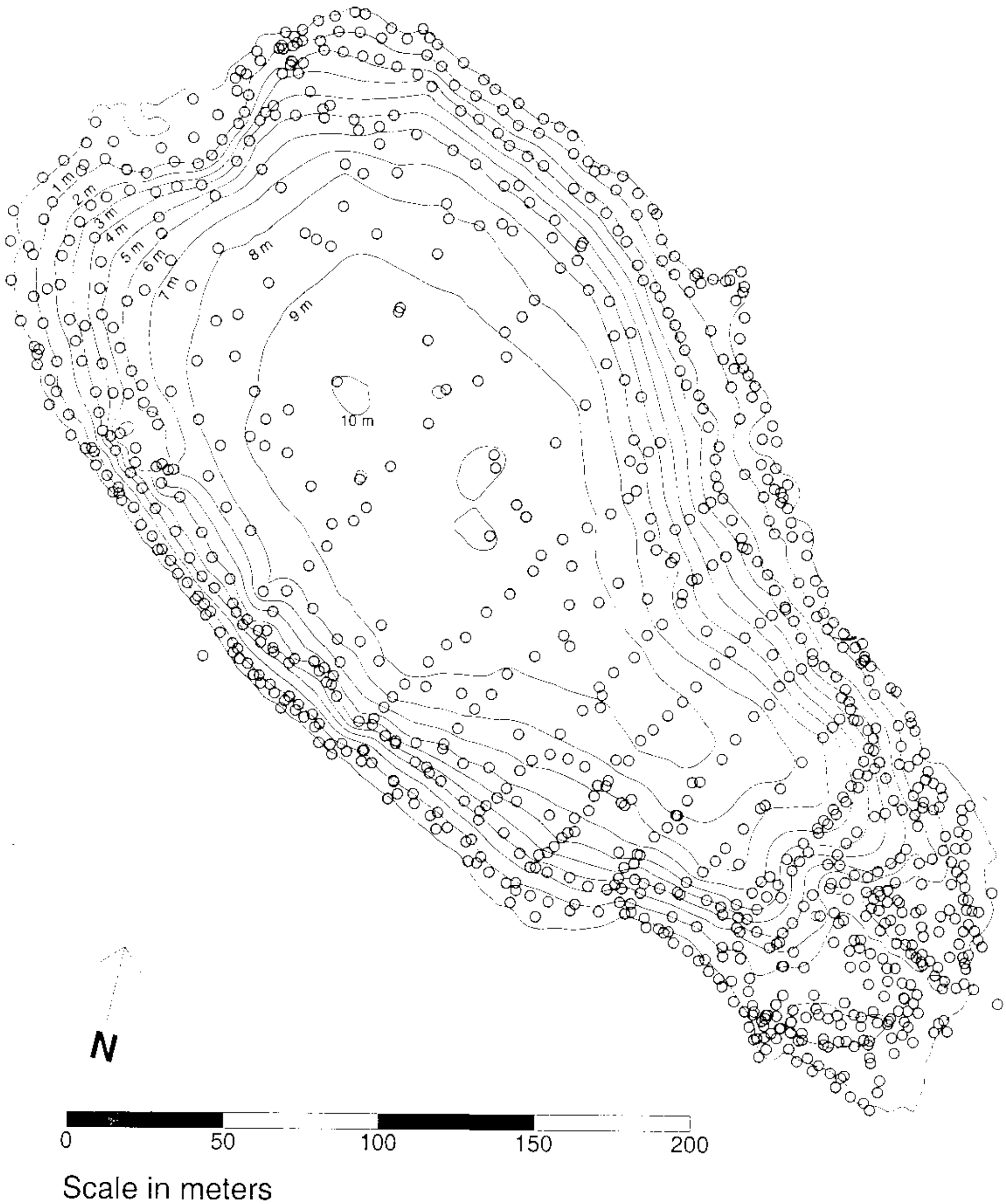


Figure 10. Locations of measurements recorded during the survey of 2000.

Figure 11. Contrast in vegetation that suggests the elevation of the shoreline when the diversion is on. This elevation, referred to in text as the high water line, is about 0.85 meters above the elevation of the low water line.

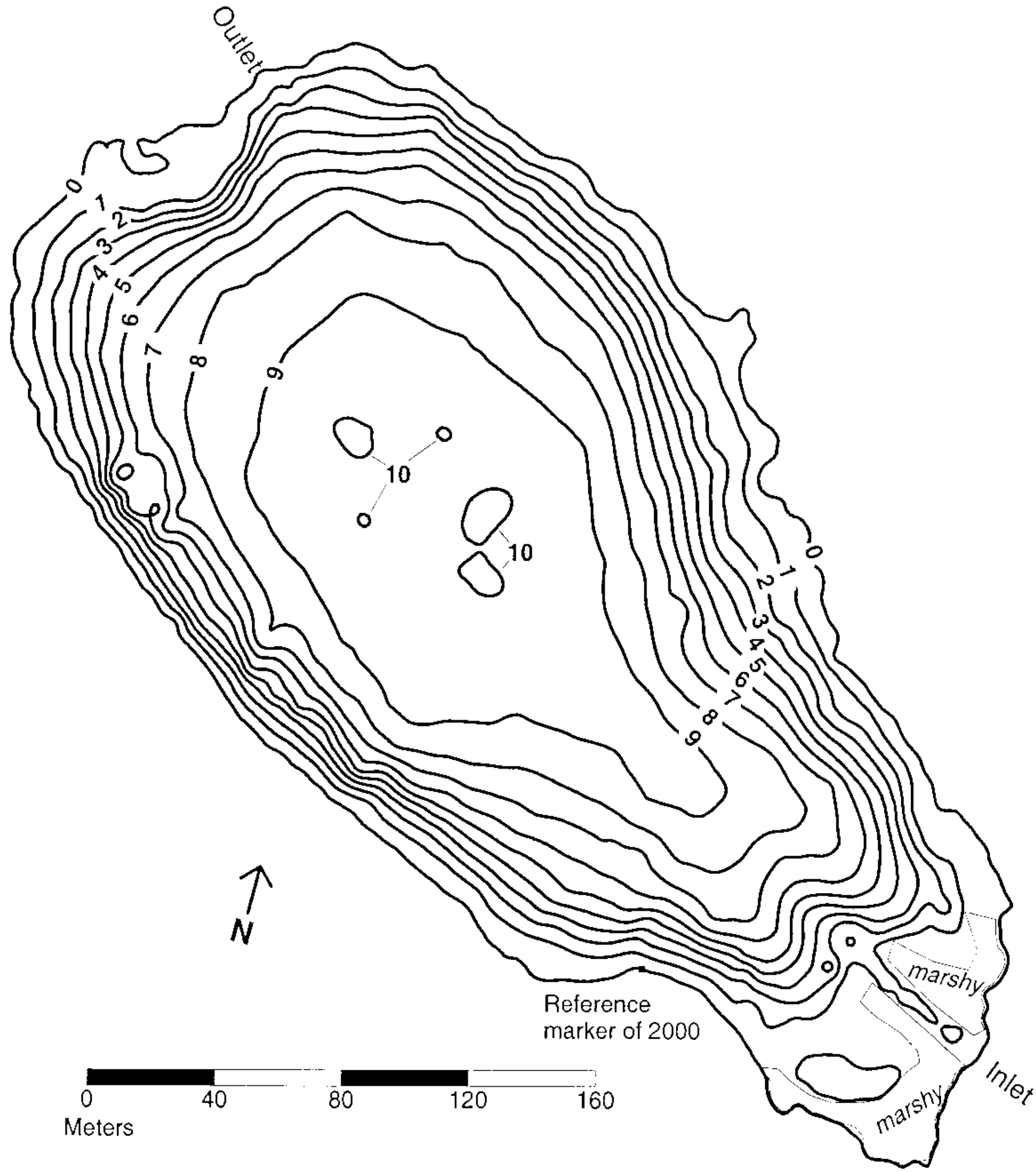


Figure 12. Bathymetric map produced from the survey of Mirror Lake in 2000. Contours are shown in meters. The contour labeled 0 meters has an elevation of 111.59 +/- 0.1 meters above Bellingham City datum. The reference marker established in 2000 has an elevation of 111.94 +/- 0.1 meters above Bellingham City datum.

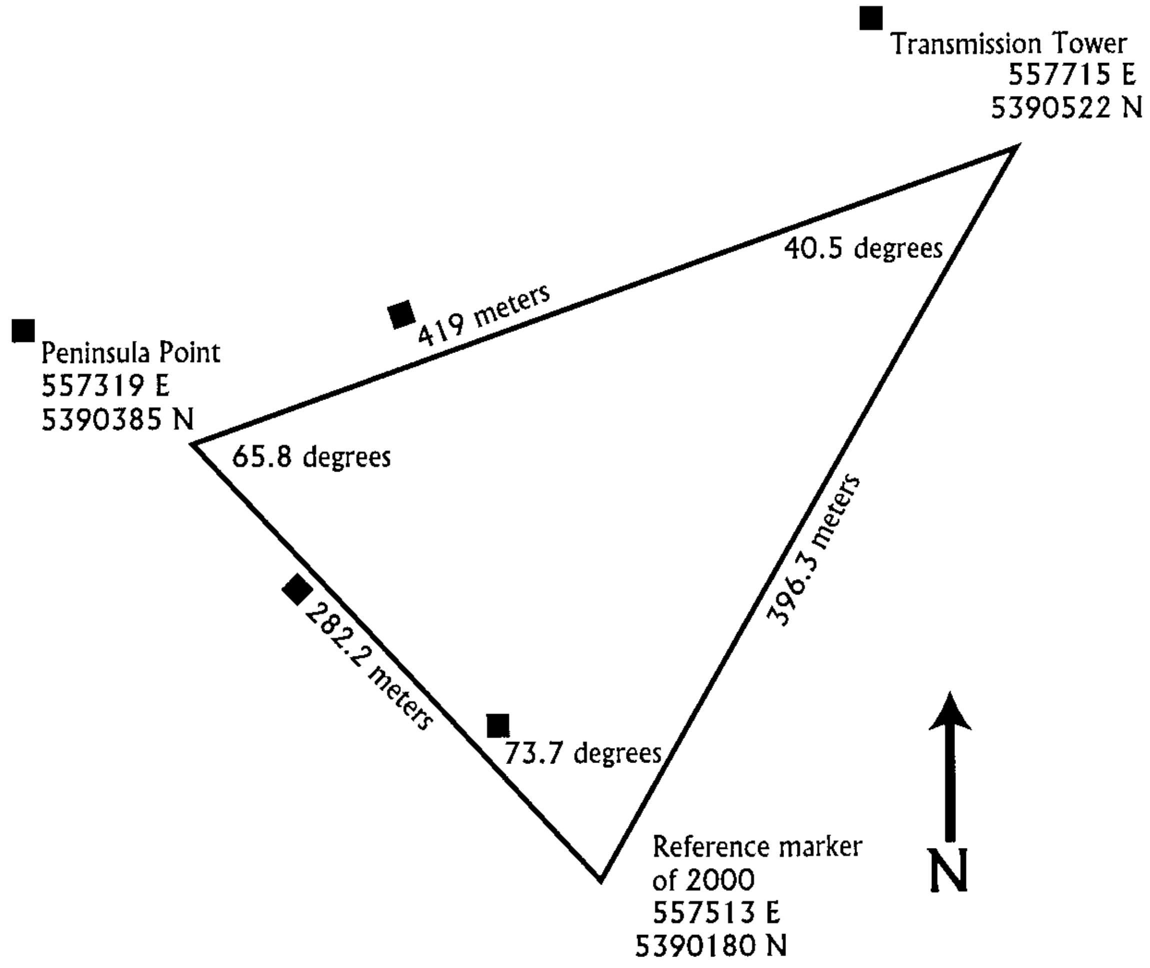


Figure 13. The triangulation diagram for determining the position of the reference marker established in 2000. Positions given are in the Universal Transverse Mercator grid, Section 10U, 1983 datum. The values marked with a square were known prior to triangulation.

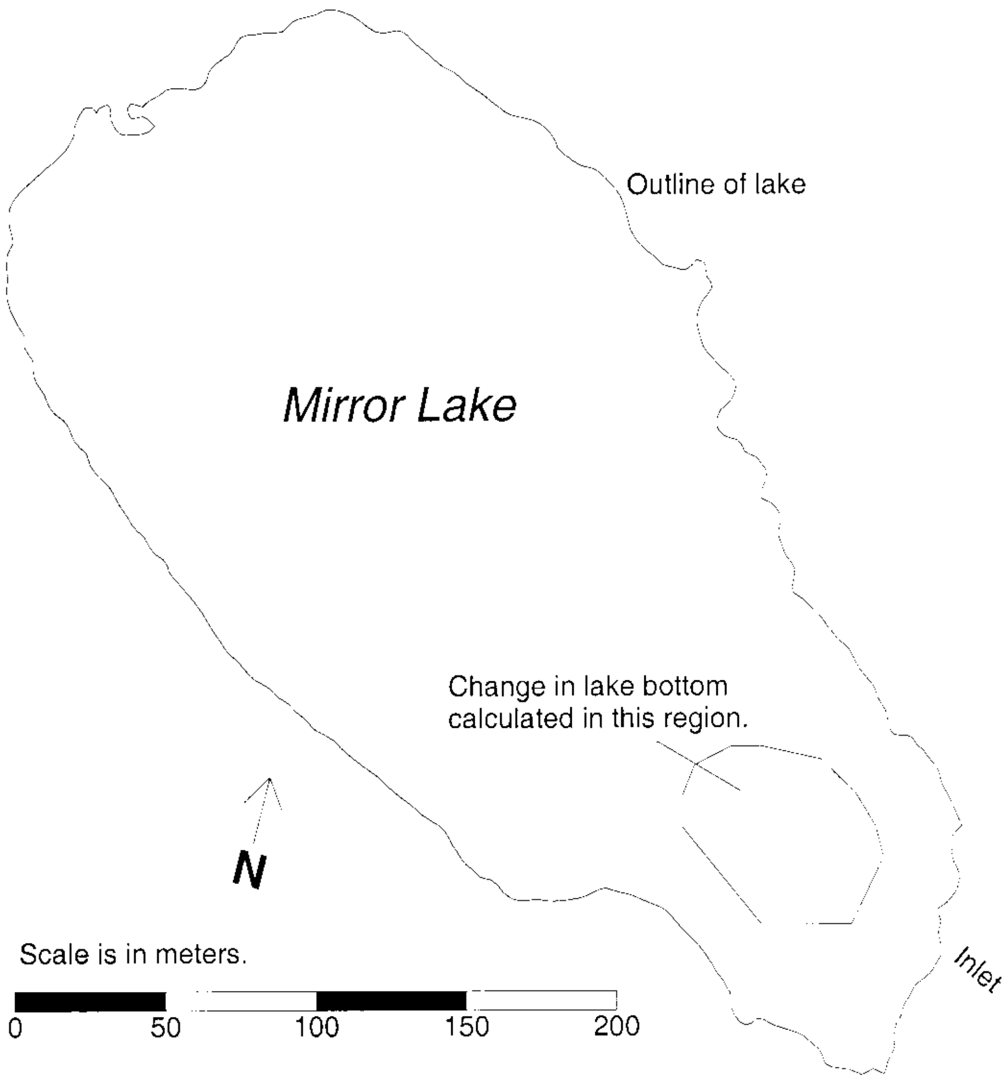


Figure 14a. Area over which the bathymetric maps of 1991 and 2000 were compared. This area is shown enlarged in Figure 14b.

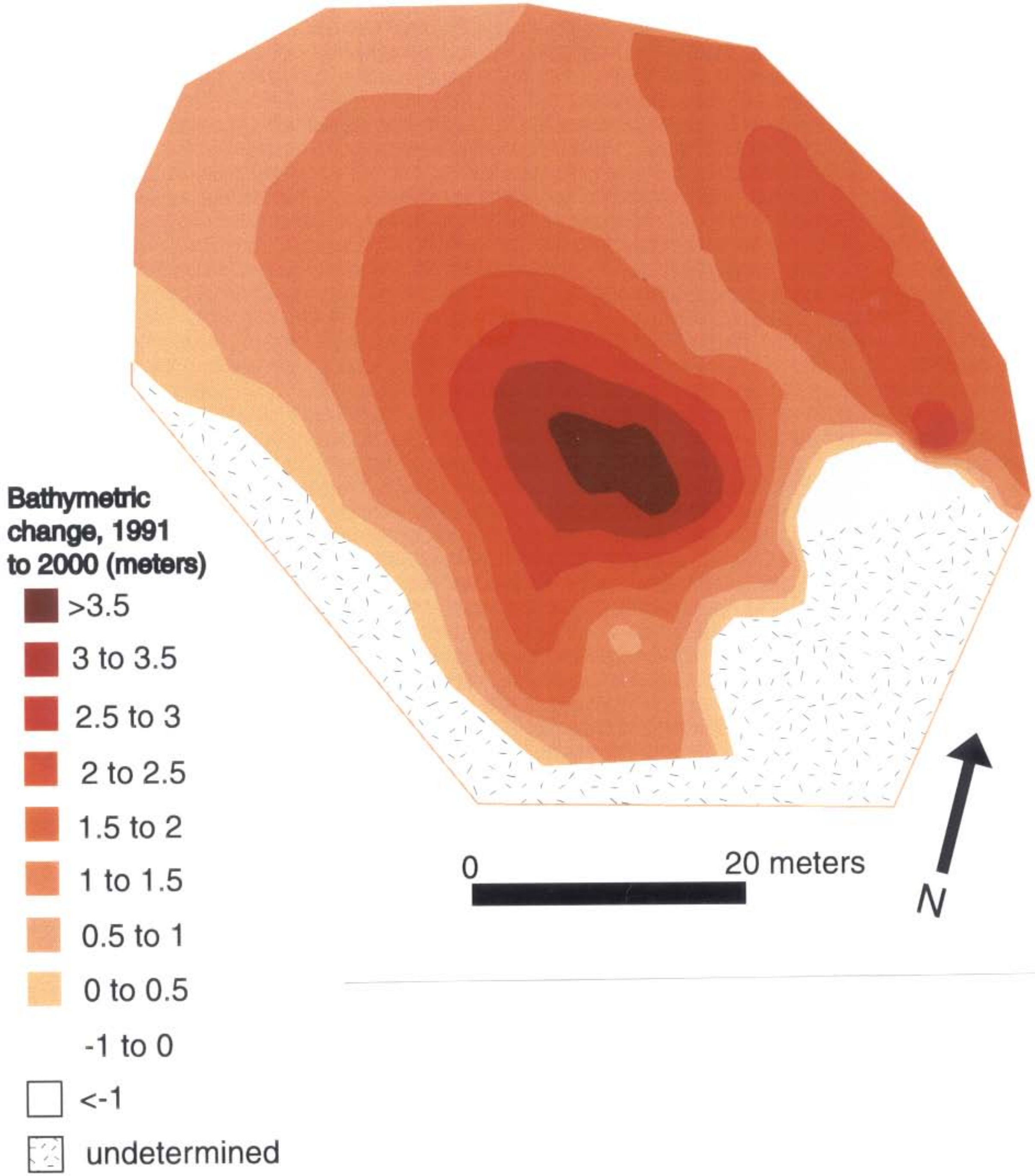


Figure 14b. Change in Mirror Lake bathymetry from 1991 to 2000 for the area outlined in Figure 14a, in meters. Data point densities for each year are shown at the top of Figure 15.

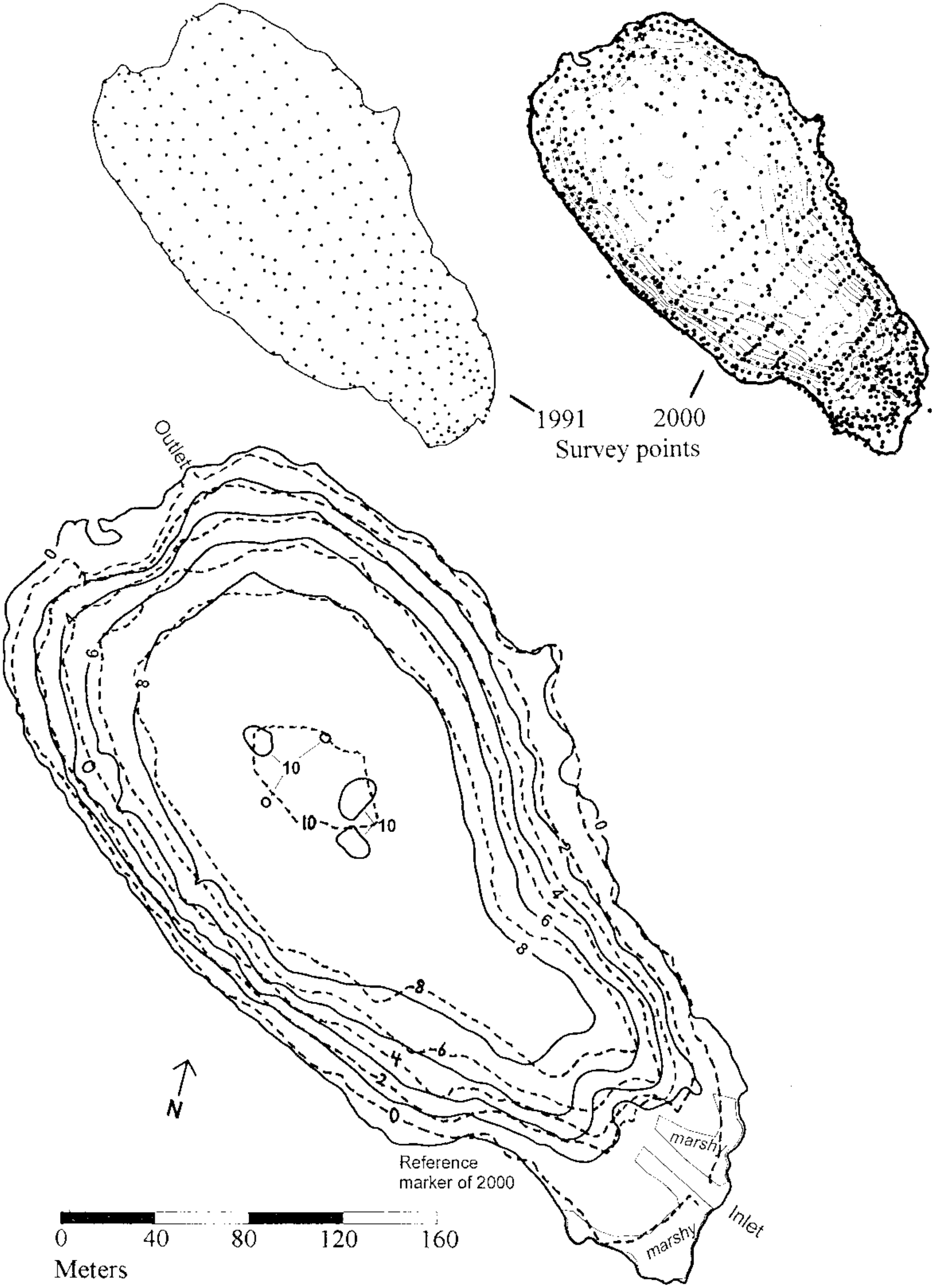


Figure 15. Overlay of bathymetric maps from the survey of 1991 (dashed lines) and the survey of 2000, which illustrates the difficulty in comparing the maps. Survey point densities from 1991 and 2000 are shown at top of figure.

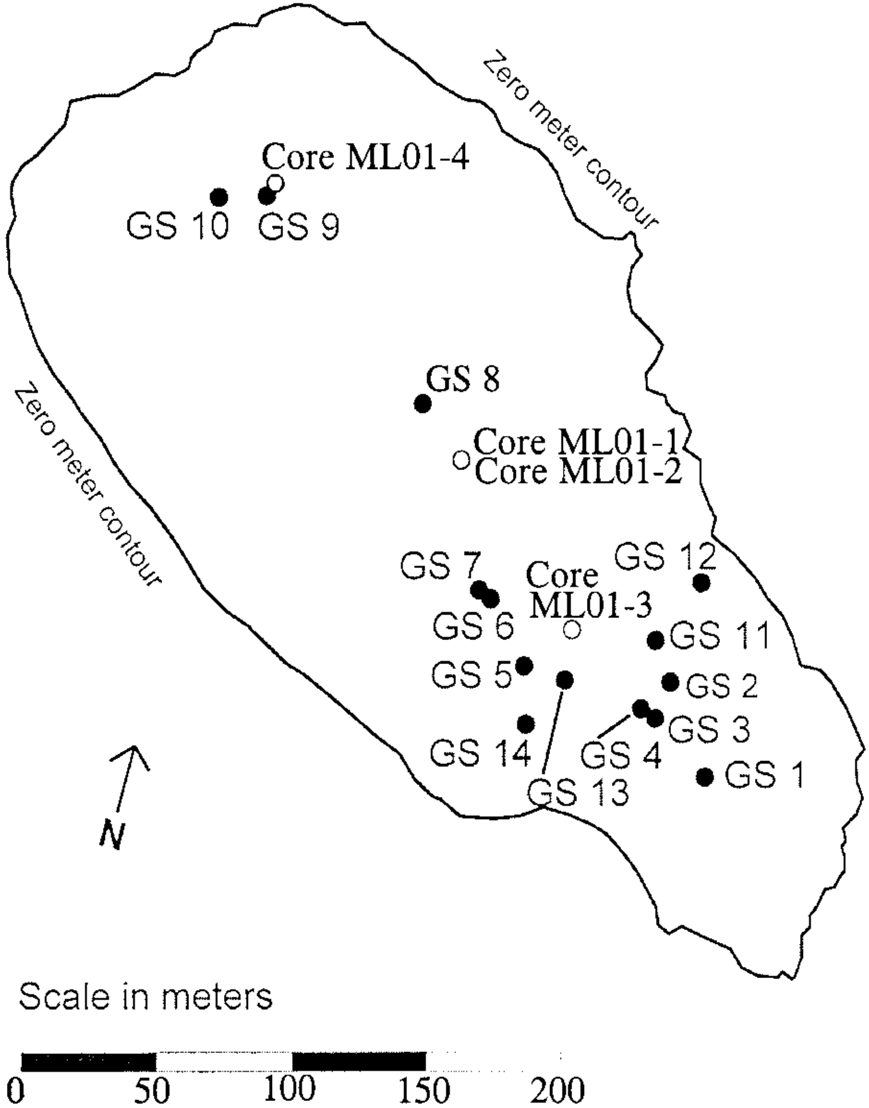


Figure 16. Sites of cores and grab samples collected from Mirror Lake in the winter of 2001. "GS" represents grab sample and "Zero meter contour" is 111.59 +/- 0.1 meters above Bellingham City datum.

Figure 17. Raft used with the Livingstone coring system on Mirror Lake, with field assistant Eric Bilderback.

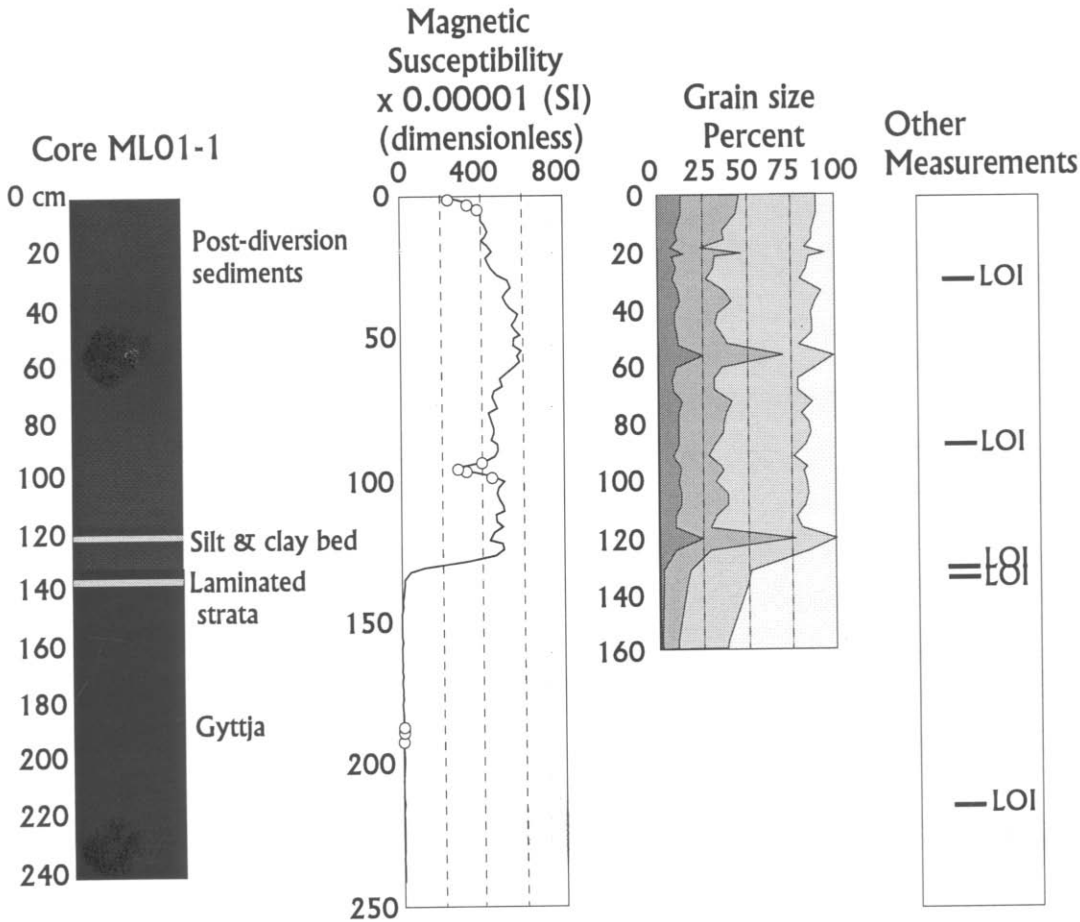


Figure 18. Stratigraphy and measurements on core ML01-1, from near the middle of Mirror Lake. The hollow circles on the magnetic susceptibility graph are values subject to edge effects and are not accurate. Grain size proportions are shown as clay (<0.004 mm), very fine and fine silt (0.004 to 0.016 mm), medium and coarse silt (0.016 to 0.063 mm) and sand sizes (>0.063 mm), from darkest to lightest. LOI indicates sample locations for loss-on-ignition samples.

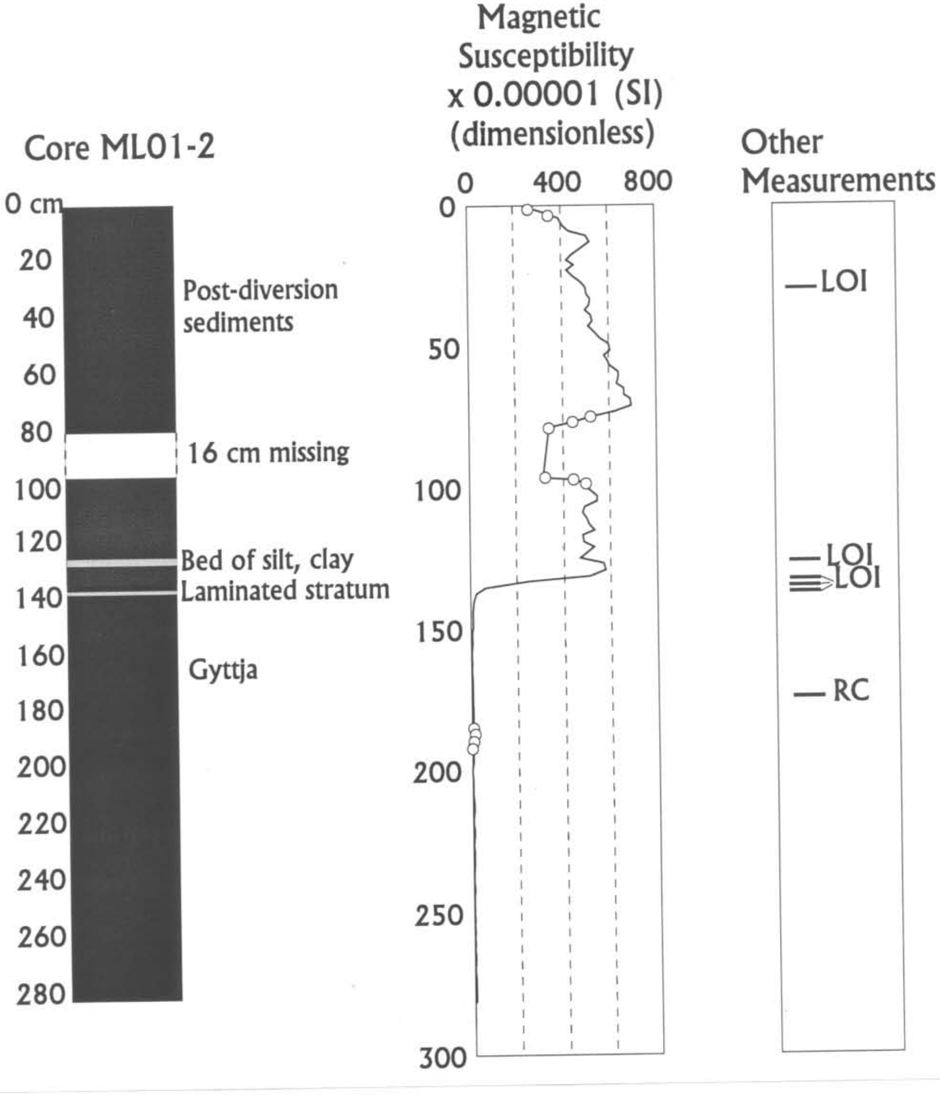


Figure 19. Stratigraphy and measurements on core ML01-2, from near the middle of Mirror Lake. The hollow circles on the magnetic susceptibility graph are values subject to edge effects and are not accurate. Grain size proportions are shown as clay (<0.004 mm), very fine and fine silt (0.004 to 0.016 mm), medium and coarse silt (0.016 to 0.063 mm) and sand sizes (>0.063 mm), from darkest to lightest. LOI and RC indicate sample locations for loss-on-ignition and radiocarbon samples.

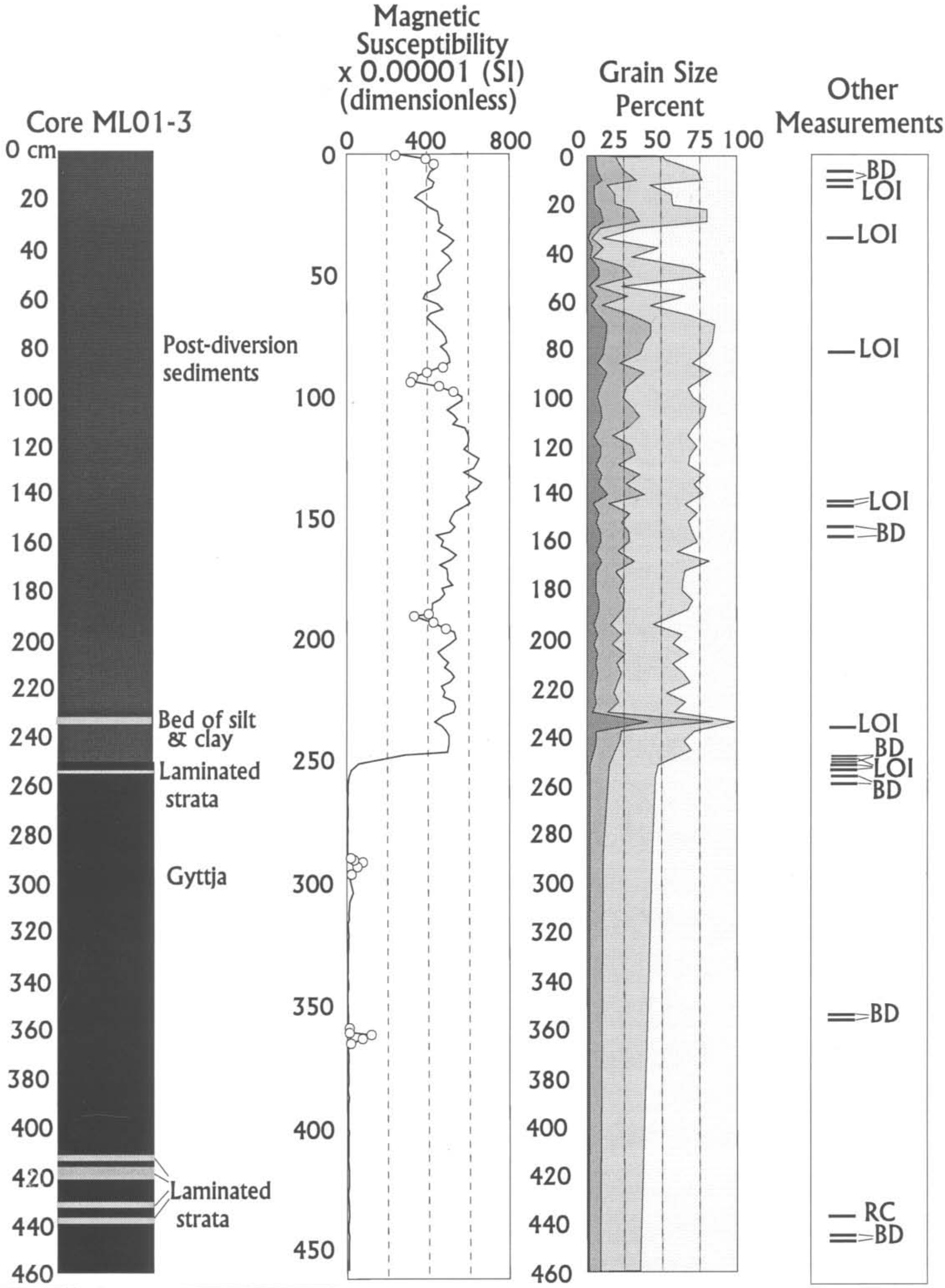


Figure 20. Stratigraphy and measurements on core ML01-3, from the part of Mirror Lake closest to the delta. The hollow circles on the magnetic susceptibility graph are values subject to edge effects and are not accurate. Grain size proportions are shown as clay (<0.004 mm), very fine and fine silt (0.004 to 0.016 mm), medium and coarse silt (0.016 to 0.063 mm) and sand sizes (>0.063 mm), from darkest to lightest. LOI, BD and RC indicate sample locations for loss-on-ignition, bulk density and radiocarbon samples.

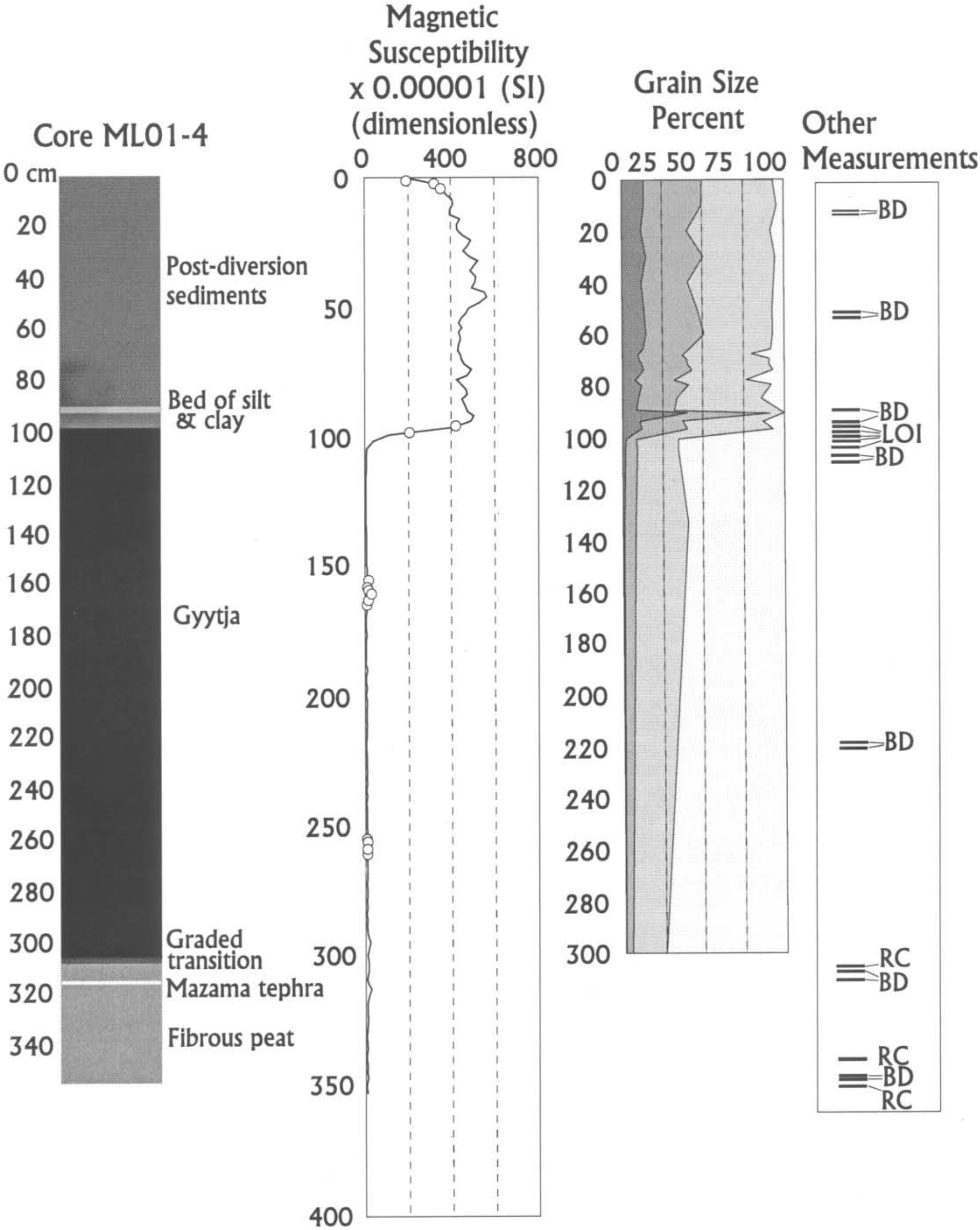


Figure 21. Stratigraphy and measurements on core ML01-4, from the part of Mirror Lake farthest from the delta. The hollow circles on the magnetic susceptibility graph are values subject to edge effects and are not accurate. Grain size proportions are shown as clay (<0.004 mm), very fine and fine silt (0.004 to 0.016 mm), medium and coarse silt (0.016 to 0.063 mm) and sand sizes (>0.063 mm), from darkest to lightest. LOI, BD and RC indicate sample locations for loss-on-ignition, bulk density and radiocarbon samples.

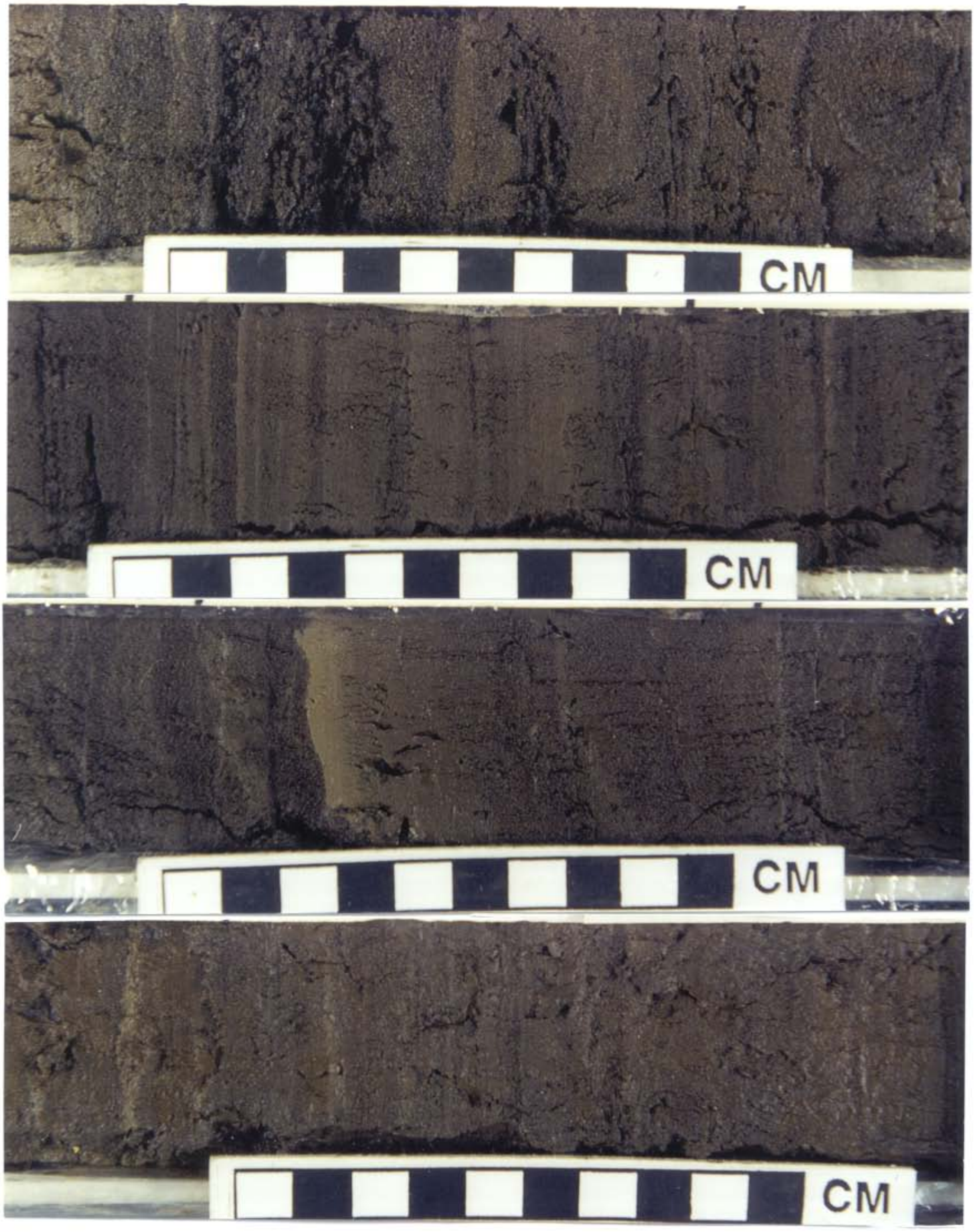


Figure 22. Photographs of post-diversion sediment. Top: sediment near top of core ML01-3 (near delta), with strata of sand, silt and fine woody debris. Second from top: interlamination of sandy silt and silt in core ML01-3. Second from bottom: bed of silt and clay in core ML01-3, near bottom of post-diversion sediments. Bottom: post-diversion sediments in core ML01-2 (middle of lake). Top of core is to left in each photograph.

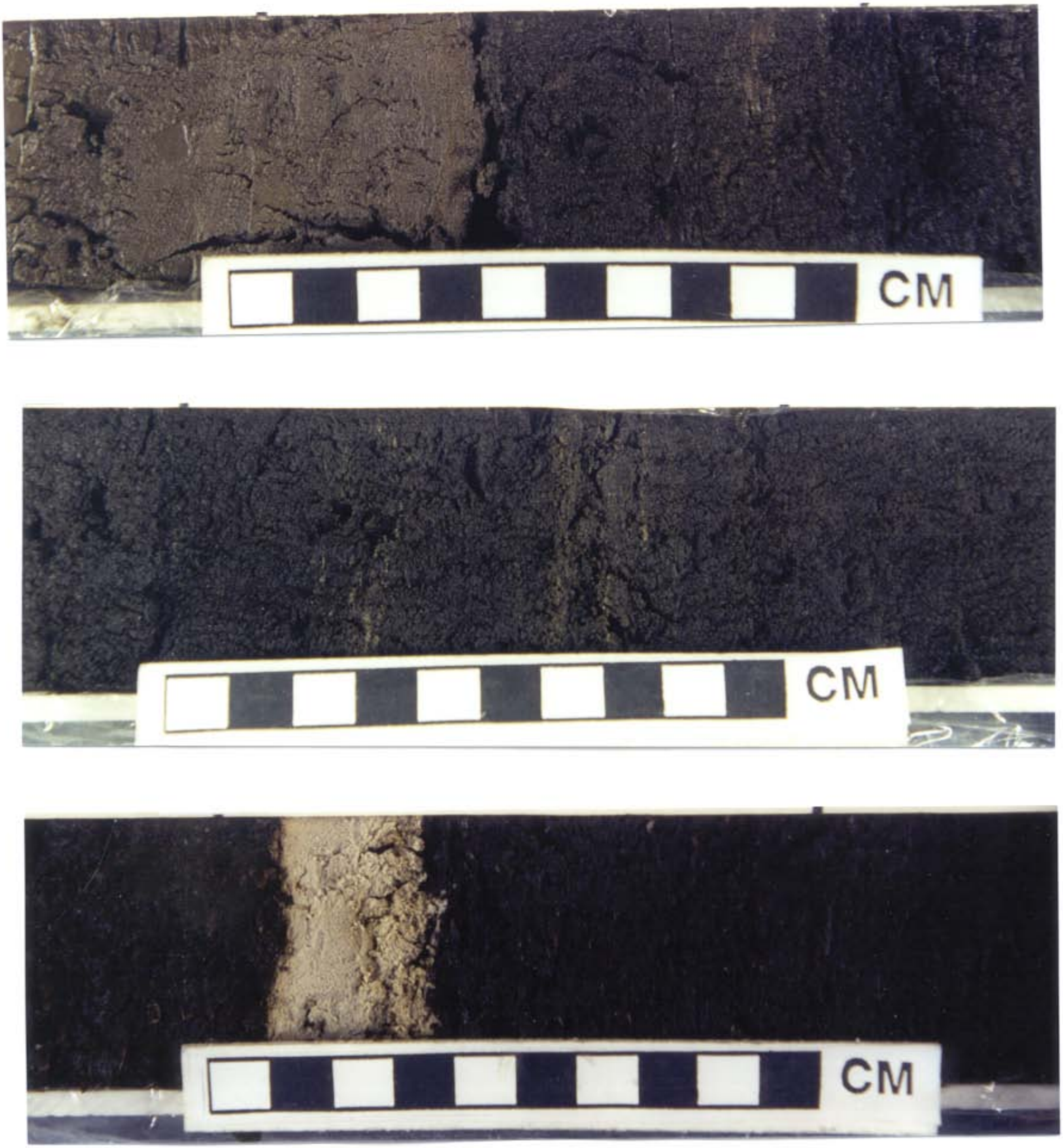


Figure 23. Photographs of pre-diversion sediments. Top: most recent deposits of gyttja from core Ml01-1 (middle of lake). Note laminae at right that appear to have been deposited by a temporary clastic input to Mirror Lake. Middle: laminated gyttja from the bottom portion of core ML01-3 (near delta). Bottom: Mazama tephra in peat at bottom of core ML01-4 (farthest from delta). Top of core is to left in each photograph.

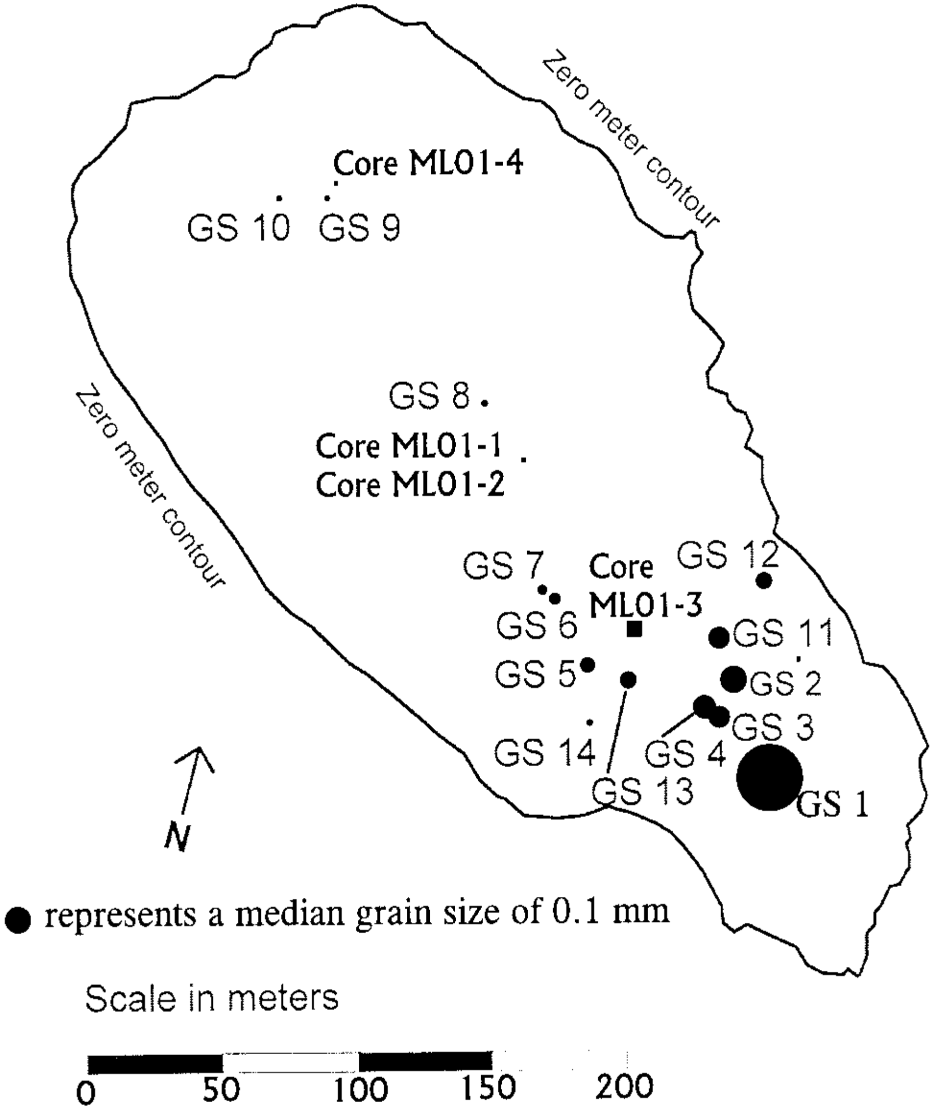
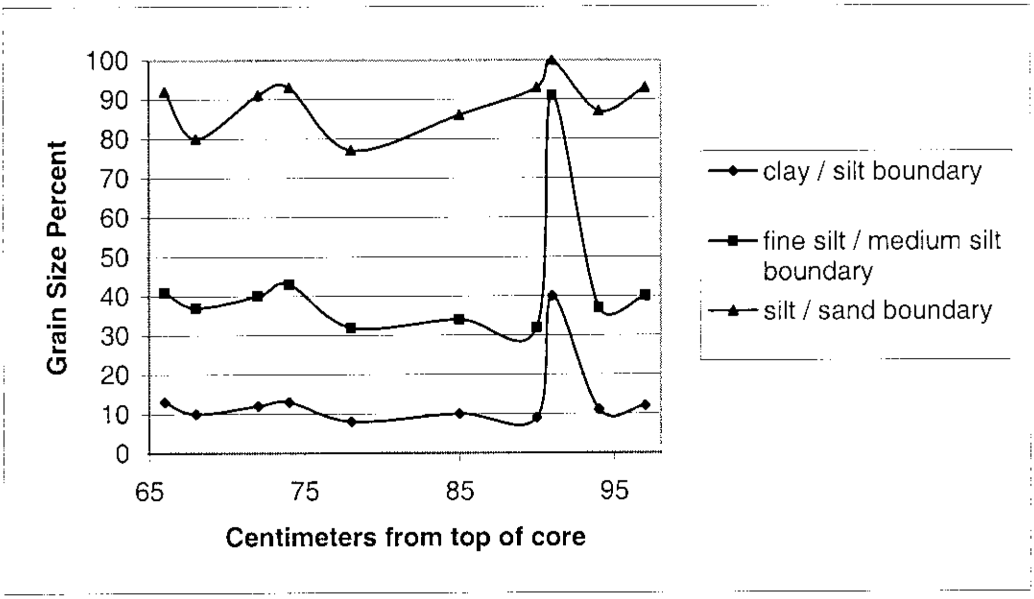


Figure 24. Median grain size of grab samples (GS) and the upper 5 cm of each core removed from Mirror Lake in the winter of 2001. The diameter of each symbol is proportional to the median grain size at the sample site.



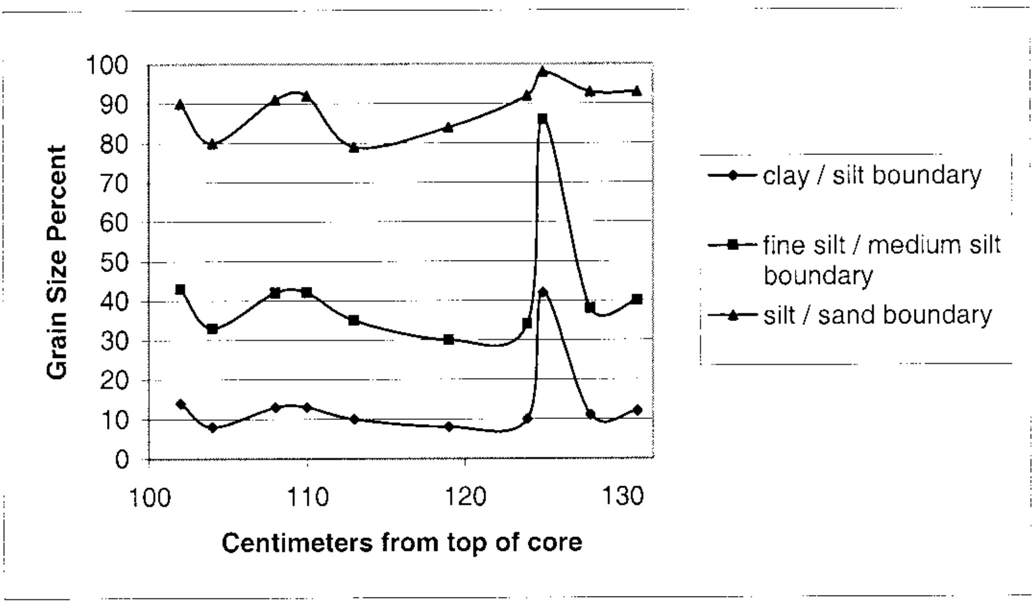


Figure 25. Comparison of grain size distribution in portions of core ML01-4 (farthest from delta). Position in centimeters from top of core is the position before the removal of the lower section.

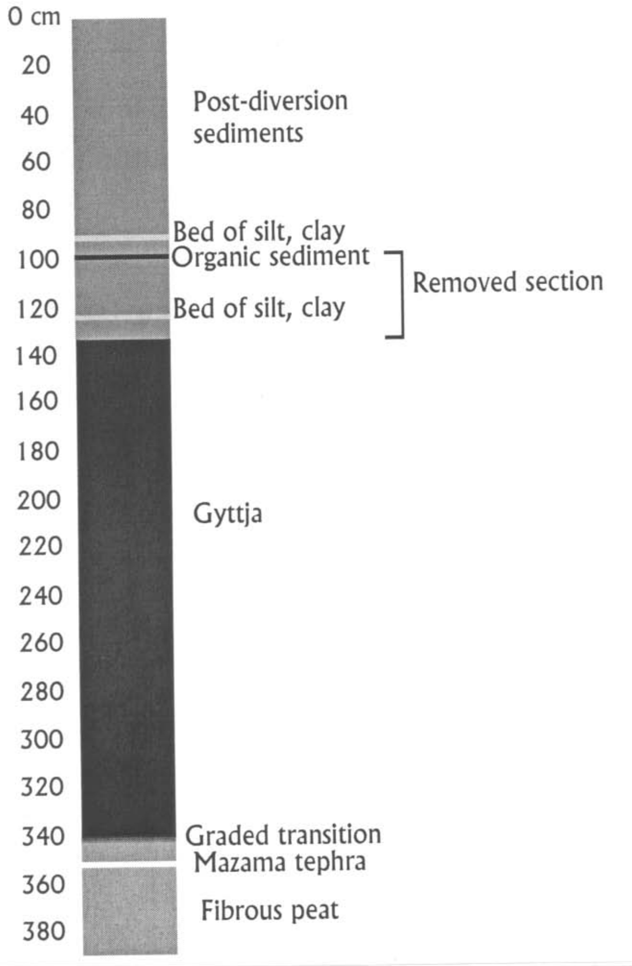


Figure 26. Log of core farthest from delta (core ML01-4) before removal of repeat sequence. Length of removed section is 34 centimeters.

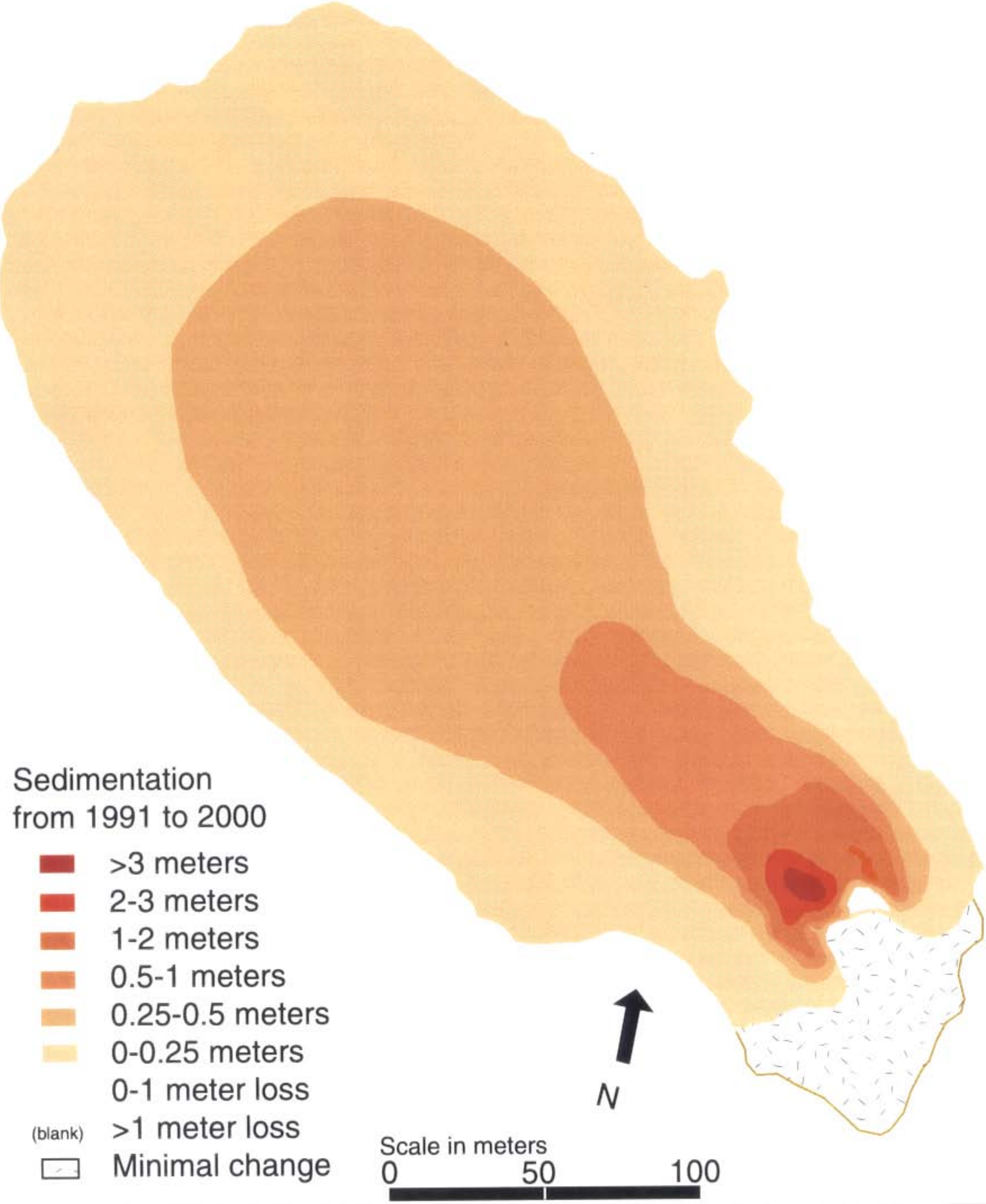


Figure 27. Sedimentation in Mirror Lake from 1991 to 2000. This map is based on comparison of bathymetry and core logs.

Appendix A: Mirror Lake Survey Data of 2000

All values are in meters

Easting	Northing	Distance below high water	Easting	Northing	Distance below high water
883.67	1275.11	1.38	953.80	1047.10	6.08
885.02	1274.99	1.54	962.70	1036.40	5.17
888.17	1275.97	1.31	973.20	1032.10	5.47
889.35	1276.97	1.08	981.40	1026.90	5.47
888.53	1278.86	0.10	995.60	1020.40	5.47
891.17	1277.61	1.06	1002.40	1019.60	5.47
896.84	1277.61	1.06	1000.50	1016.80	3.95
902.69	1280.64	0.96	1000.80	1011.80	2.73
909.59	1280.45	0.98	1003.70	1010.60	3.03
911.26	1286.16	0.05	1008.80	1009.10	3.03
916.56	1278.59	0.97	1015.30	1007.20	3.34
931.39	1273.39	0.94	1023.80	1005.40	3.95
932.21	1278.85	0.23	1028.40	1003.30	3.64
936.12	1269.81	0.97	1033.90	1000.10	3.34
940.38	1263.98	1.16	1039.90	995.60	3.03
947.26	1260.57	0.93	1047.20	992.30	2.73
949.75	1265.75	0.15	1051.60	989.30	1.81
956.03	1256.17	1.02	1060.00	1000.80	3.34
960.86	1251.33	0.97	1047.50	1006.50	4.86
967.58	1248.98	1.04	1041.10	1011.40	6.08
978.63	1242.48	0.93	1033.90	1016.90	7.30
985.50	1236.82	0.99	1015.70	1028.00	7.61
992.43	1230.97	0.92	996.20	1036.20	7.00
999.10	1223.09	0.92	991.30	1041.40	7.00
1004.27	1224.91	0.07	984.40	1047.60	7.61
1007.35	1208.44	0.83	979.00	1050.00	7.61
1011.40	1204.08	0.97	887.29	1269.83	1.51
1016.27	1198.61	0.95	891.46	1270.61	2.42
1019.83	1201.38	0.34	898.11	1274.71	2.12
1029.04	1202.47	0.34	904.26	1274.22	1.81
1031.08	1195.91	0.50	910.55	1272.87	1.81
1023.04	1186.45	0.95	916.00	1271.81	1.51
1027.21	1177.35	0.89	921.65	1269.55	1.81
1030.74	1174.34	0.60	928.51	1267.22	2.42
1033.48	1174.58	0.04	933.11	1263.47	3.64
1029.89	1168.50	0.95	942.51	1255.76	3.34
1036.44	1165.40	0.75	948.31	1253.21	2.73
1032.62	1158.50	0.96	954.46	1248.76	2.73
1039.93	1152.12	-1.35	958.14	1244.80	3.03

1039.62	1144.02	0.75	963.94	1241.41	3.34
1034.40	1140.80	0.97	969.10	1238.51	2.73
1041.77	1139.30	0.72	978.79	1231.37	2.42
1040.52	1133.67	0.96	984.16	1228.54	2.12
1045.95	1135.12	0.67	989.32	1223.52	2.42
1048.16	1137.66	0.10	993.28	1217.86	2.12
1046.69	1133.57	0.55	995.90	1214.39	2.42
1042.40	1126.08	1.00	999.58	1207.04	2.73
1044.11	1121.99	0.98	1001.34	1202.16	3.03
1054.77	1121.12	0.16	1005.30	1199.90	2.12
1049.71	1121.04	0.97	1006.86	1197.07	1.81
1052.01	1106.45	0.97	1009.48	1191.91	1.81
1055.19	1100.60	0.94	1011.74	1188.09	1.81
1059.60	1103.62	0.23	1013.51	1184.34	1.81
1057.81	1095.75	1.02	1014.92	1180.24	1.81
1061.25	1091.82	1.01	1013.51	1173.59	3.03
1063.16	1093.97	0.08	1015.49	1169.07	2.73
1066.26	1086.05	0.98	1019.52	1165.89	1.81
1071.97	1081.09	0.94	1020.86	1161.72	2.12
1073.17	1083.16	-0.14	1022.63	1155.85	2.73
1074.55	1075.55	0.95	1026.09	1149.55	1.81
1073.32	1082.06	-0.04	1024.96	1145.59	1.81
1076.48	1071.19	0.95	1025.10	1140.08	2.12
1083.42	1072.18	-0.37	1025.95	1136.83	1.81
1084.24	1061.36	1.02	1027.58	1133.08	2.12
1085.21	1054.84	0.98	1030.48	1126.22	2.42
1084.78	1049.13	0.91	1033.59	1120.42	2.73
1089.34	1039.10	0.91	1035.43	1117.03	2.73
1092.57	1035.33	0.94	1038.82	1113.07	2.12
1096.10	1034.74	0.97	1042.07	1108.82	1.81
1100.12	1026.31	0.97	1044.41	1103.94	2.73
1099.45	1021.78	0.95	1048.01	1097.93	2.42
1091.59	1017.74	0.96	1050.56	1094.26	3.03
1083.86	1011.53	0.97	1053.03	1088.81	3.03
1074.60	1008.45	0.98	1056.57	1083.86	2.73
1067.74	1011.29	1.00	1060.32	1079.97	2.12
1063.01	1009.54	0.96	1064.21	1076.79	2.12
1064.48	1001.80	0.97	1067.18	1072.69	2.73
1055.07	984.53	0.93	1068.80	1066.40	3.64
1048.55	984.83	0.95	1071.21	1062.86	3.64
1033.92	990.92	0.96	1069.93	1063.14	3.64
1028.97	990.63	0.99	1074.53	1059.82	3.34
1020.72	997.08	0.98	1076.37	1053.32	3.64
1012.88	1000.18	0.96	1080.40	1044.62	3.03
996.08	1004.64	0.96	1083.01	1037.62	3.03
981.62	1003.99	1.00	1085.84	1034.65	2.73

962.69	1010.58	0.99	1090.01	1033.02	2.12
951.44	1018.74	0.98	1091.00	1029.49	2.42
948.42	1024.17	1.05	1095.88	1019.09	3.03
937.47	1032.70	0.95	1087.33	1022.13	2.73
923.11	1042.36	0.93	1085.35	1019.30	2.73
913.35	1052.33	0.98	1082.38	1017.61	3.34
872.31	1084.37	1.18	1078.21	1014.99	2.73
861.45	1098.48	0.95	1075.02	1013.08	2.73
847.94	1115.62	0.97	1070.78	1013.79	2.42
833.84	1135.25	0.99	1066.04	1016.83	2.73
826.06	1146.68	0.95	884.81	1267.07	3.03
813.69	1165.55	0.91	882.05	1256.96	3.95
813.79	1175.11	0.91	877.74	1252.22	3.64
809.20	1187.23	0.97	874.42	1245.65	4.56
806.15	1195.55	0.89	870.39	1239.21	3.95
805.83	1208.97	0.86	859.29	1231.51	3.95
809.17	1220.15	0.88	851.44	1231.01	3.64
811.87	1225.72	0.90	844.86	1229.24	3.64
821.00	1235.87	0.91	836.59	1229.74	2.73
828.64	1239.69	0.99	829.23	1227.48	2.42
835.60	1236.12	1.13	824.28	1224.79	2.12
835.58	1236.46	0.52	820.61	1219.42	2.73
841.91	1235.28	0.89	817.35	1213.48	2.12
850.67	1238.91	0.86	815.16	1208.60	2.42
858.15	1238.37	0.88	814.60	1199.40	2.12
862.48	1241.07	0.85	817.78	1188.44	2.73
865.65	1246.02	0.88	819.69	1181.73	2.42
870.89	1251.15	0.88	821.81	1175.36	2.73
872.74	1254.81	0.92	826.33	1165.60	3.03
873.94	1260.28	0.84	827.47	1159.10	2.73
873.18	1266.90	0.91	828.60	1153.44	2.73
887.90	1270.95	1.14	832.84	1147.08	3.03
887.67	1271.15	0.28	837.72	1139.94	3.34
1088.52	1062.22	-0.20	841.47	1135.06	3.03
1090.70	1050.59	0.11	845.71	1128.55	3.03
1087.84	1048.40	0.46	852.07	1121.34	3.64
1090.95	1041.74	0.42	856.67	1112.92	3.34
1093.46	1044.26	0.07	860.63	1107.13	3.34
1092.79	1037.07	0.58	864.59	1103.45	3.34
1097.97	1035.61	0.80	870.67	1098.64	3.95
1099.08	1038.76	0.07	871.73	1095.88	3.34
1104.51	1027.78	0.02	873.92	1091.99	3.03
1103.54	1022.44	0.80	879.72	1086.48	3.34
1103.97	1015.02	0.33	884.03	1083.30	3.34
1102.30	1011.10	0.82	888.84	1079.90	3.34
1092.50	1011.08	0.78	896.97	1080.40	5.17

1081.42	1009.01	0.88	898.67	1077.43	4.86
1085.41	1005.15	0.70	901.08	1073.89	4.25
1090.73	1002.14	0.47	920.24	1056.99	3.95
1101.72	1003.04	0.65	923.56	1054.52	3.95
1107.21	1003.01	0.27	930.07	1048.72	3.34
1098.40	996.07	0.23	934.59	1045.18	3.03
1092.68	997.57	0.27	938.34	1042.71	3.34
1086.27	1002.20	0.36	945.98	1036.35	3.34
1081.42	1005.39	0.51	951.00	1033.16	3.34
1079.11	1007.31	0.67	958.70	1026.30	3.34
1077.00	1006.21	0.75	963.87	1019.87	2.73
1078.78	1002.67	0.35	969.03	1015.41	2.42
1082.51	999.56	0.18	972.78	1013.93	2.12
1085.75	996.66	0.25	979.85	1012.37	2.73
1089.63	991.85	0.21	985.79	1009.55	2.42
1092.91	988.95	0.16	991.94	1008.63	2.12
1095.34	986.88	0.16	996.68	1008.98	1.51
1098.10	984.85	0.06	1002.62	1007.57	2.12
1093.26	994.63	0.10	863.67	1228.11	5.78
1076.31	1003.35	0.93	864.73	1211.35	7.91
1080.75	998.71	1.08	892.66	1216.37	8.52
1087.34	991.99	1.10	841.61	1197.99	6.69
1091.02	987.96	1.09	836.09	1194.45	6.08
1092.62	986.60	1.07	961.32	1232.14	5.47
999.58	1004.16	0.97	956.09	1219.84	7.61
1048.04	984.86	1.00	935.44	1210.08	8.52
1067.35	999.45	0.95	923.07	1191.63	9.44
1072.99	993.36	0.99	903.41	1169.42	10.05
1080.11	987.51	0.93	887.85	1160.37	9.74
1084.10	984.48	0.32	875.55	1151.89	9.13
1089.21	979.36	0.32	866.07	1148.92	8.22
1091.39	976.16	-0.02	847.55	1136.75	6.69
1090.22	973.45	0.29	849.67	1141.00	5.47
1086.45	979.88	0.28	997.60	1185.54	5.78
1081.44	984.46	0.27	989.89	1175.72	7.61
1076.12	989.01	0.22	983.31	1162.63	8.83
1070.92	993.15	0.21	973.91	1150.54	9.74
1065.90	998.59	0.32	961.60	1130.60	9.74
1064.38	992.50	0.35	953.19	1120.63	10.05
1069.72	984.78	0.36	918.54	1092.07	9.44
1075.64	979.29	0.38	911.75	1086.83	8.22
1080.66	975.58	0.45	905.32	1080.26	7.30
1085.29	970.94	0.58	903.27	1075.94	6.08
1087.29	967.52	0.61	902.63	1073.19	5.17
1082.10	967.68	0.90	878.52	1236.74	6.08
1077.09	970.65	0.76	884.81	1230.87	7.30

1070.99	969.55	0.85	901.01	1212.27	8.83
1067.95	973.47	0.66	923.56	1192.97	9.44
1058.19	975.88	0.85	938.76	1167.16	10.05
1087.05	975.07	0.22	954.82	1142.34	10.05
1076.12	955.92	0.10	964.72	1126.78	9.74
1056.41	955.72	0.08	969.67	1114.62	9.74
1044.74	963.54	0.09	979.14	1085.77	9.44
1038.81	969.30	0.22	989.68	1070.29	9.13
1081.80	966.74	0.97	1021.21	1042.99	8.83
1075.64	960.10	0.96	1040.66	1034.72	7.30
1071.18	959.58	1.02	1014.21	1032.17	7.61
1062.91	959.43	1.00	999.36	1037.26	7.00
1054.59	961.50	1.08	988.54	1041.58	7.00
1050.98	963.82	1.04	973.20	1051.41	7.30
1047.89	965.15	1.09	963.09	1057.70	7.61
1051.15	967.29	0.97	944.77	1070.64	8.52
1046.40	969.00	0.76	933.25	1072.69	8.83
1046.22	972.71	1.01	917.90	1080.68	8.83
1048.35	975.67	0.71	904.40	1087.54	8.22
1051.65	971.00	1.09	896.48	1097.16	8.22
1059.01	971.49	0.98	880.43	1102.46	8.22
1065.74	969.31	1.00	876.11	1121.76	7.91
1073.41	968.80	0.97	868.12	1129.19	7.61
1078.55	967.18	1.61	862.33	1139.23	7.61
1073.32	966.04	1.66	851.30	1141.21	7.30
1066.89	966.51	1.72	839.27	1143.33	6.69
1062.93	968.41	1.86	834.32	1152.52	6.69
1059.74	969.55	1.70	841.18	1167.87	6.39
1055.82	968.76	1.36	837.72	1172.32	6.08
1054.56	963.73	1.27	833.97	1179.61	5.78
1061.43	961.93	1.66	831.78	1186.04	5.47
1066.22	961.11	1.65	828.17	1190.07	5.17
1074.20	961.60	1.57	827.40	1198.34	4.56
1042.84	968.18	0.77	827.61	1206.76	4.56
1038.83	972.39	0.85	825.63	1214.39	3.95
1041.80	967.38	0.24	1014.64	1099.77	6.69
1039.26	970.39	0.31	1018.03	1106.99	6.08
1043.64	969.32	0.51	1012.37	1114.06	6.69
1037.39	976.79	0.61	1004.31	1120.99	7.61
1037.77	980.96	0.99	1004.60	1126.50	7.30
1034.73	987.14	0.65	997.31	1132.94	7.61
1031.95	980.02	0.51	997.81	1144.89	7.61
1028.00	980.56	-0.28	999.01	1151.60	7.00
1029.09	987.73	1.03	1001.20	1165.25	6.08
1023.44	986.72	0.16	995.90	1170.55	7.00
1018.02	989.40	-0.57	992.36	1184.55	6.69

1011.59	995.46	0.27	990.60	1195.37	6.39
1008.57	996.37	-0.20	983.88	1198.98	7.00
1004.01	999.73	0.32	980.27	1208.38	6.39
999.75	1001.61	0.33	972.92	1221.11	5.78
997.71	1001.03	0.05	964.79	1226.70	5.78
989.30	1001.56	0.60	956.58	1231.93	5.78
980.17	1001.93	0.54	947.39	1238.86	6.08
973.13	1004.68	0.54	940.11	1243.17	6.08
967.43	1006.53	0.55	928.30	1248.19	6.39
969.05	999.94	0.22	916.21	1250.53	5.78
962.82	1008.17	0.57	908.01	1252.65	5.17
961.00	1004.38	0.11	898.39	1253.21	5.17
959.60	1010.46	0.64	889.27	1253.99	4.86
954.18	1013.83	0.65	882.69	1253.92	4.56
950.18	1016.77	0.51	879.58	1254.77	3.95
947.38	1017.39	0.04	889.97	1267.29	3.03
946.59	1023.48	0.51	897.96	1256.04	4.86
940.67	1027.91	0.66	905.32	1238.51	7.91
936.98	1027.42	0.26	915.78	1216.30	8.83
935.16	1031.65	0.52	932.75	1182.65	9.74
929.85	1035.47	0.59	954.32	1146.51	10.05
924.40	1038.51	0.48	978.79	1098.99	9.74
921.31	1036.87	-0.18	989.11	1066.33	8.83
921.27	1037.03	-0.20	994.34	1049.78	8.22
912.57	1048.81	0.46	997.31	1035.36	6.69
907.78	1051.98	0.50	831.85	1165.32	4.25
929.44	1038.64	0.97	841.75	1162.35	6.39
922.96	1042.75	0.99	859.07	1157.05	8.22
916.01	1048.39	0.97	880.43	1148.85	9.44
912.87	1052.26	0.92	911.05	1138.31	10.05
906.24	1054.38	1.01	979.49	1111.16	9.44
902.95	1051.02	-0.07	1003.89	1100.90	7.91
902.41	1054.09	0.46	1022.77	1090.93	6.39
898.79	1054.66	-0.15	1043.91	1083.51	5.47
898.93	1060.57	0.97	1004.56	996.79	-0.43
897.46	1059.62	0.49	1010.17	995.05	-0.45
896.64	1063.55	0.99	1013.31	991.95	-0.79
893.95	1062.76	0.44	1021.39	986.37	-0.51
892.10	1066.67	1.08	1024.59	983.02	-0.64
891.12	1064.97	0.45	1028.97	978.22	-0.61
889.31	1069.18	1.00	1032.69	973.51	-0.32
887.72	1067.92	0.52	1036.11	970.38	-0.20
886.54	1065.55	-0.12	1037.67	965.54	-0.10
889.04	1069.31	0.98	1042.65	962.23	0.45
884.43	1070.33	0.49	1040.22	961.84	0.11
882.97	1073.11	1.04	1039.28	961.50	-0.38

879.88	1073.43	0.42	1043.22	958.41	0.40
879.36	1075.94	1.05	1040.88	955.91	-0.24
877.51	1076.09	0.23	1042.43	965.87	0.03
875.55	1079.66	0.97	1046.34	961.91	0.11
872.97	1081.15	0.60	1050.38	958.59	0.01
870.84	1083.07	0.05	1053.00	954.61	-0.02
870.62	1086.13	0.95	1058.00	951.55	-0.06
866.56	1089.41	0.19	1065.42	946.64	-0.24
863.46	1096.01	0.94	1067.97	950.08	0.28
861.94	1094.91	-0.05	1065.36	946.37	-0.28
859.47	1100.85	0.97	1070.05	943.40	0.00
858.71	1099.82	0.21	1074.31	941.48	0.12
855.95	1105.13	0.97	1076.22	939.08	-0.16
853.03	1107.95	0.11	1078.71	944.84	0.24
850.65	1112.08	0.97	1076.50	954.18	0.20
846.61	1115.46	0.06	1079.43	948.59	0.27
844.79	1119.77	0.98	1084.03	957.49	0.23
841.27	1123.32	0.44	1086.67	963.30	0.38
838.88	1128.98	1.03	1088.58	965.90	0.35
835.00	1131.24	0.01	1091.79	970.34	0.38
834.21	1133.49	0.95	1098.51	967.13	0.10
832.09	1133.79	-0.25	1096.96	964.26	0.08
830.21	1139.07	1.00	1102.01	988.13	0.68
826.68	1142.30	-0.10	1104.12	978.35	0.25
825.31	1147.84	0.94	1107.19	984.47	0.07
823.26	1147.69	0.45	1106.24	988.11	0.33
818.49	1151.81	-0.51	1105.01	992.26	0.17
817.73	1158.36	0.98	1106.32	996.25	0.46
811.52	1161.49	-0.34	1110.00	996.49	0.41
811.56	1169.22	0.56	1109.09	1002.66	0.38
807.44	1177.37	0.39	1107.74	1006.24	0.26
807.99	1178.90	0.55	1106.62	1010.08	0.25
804.52	1211.43	0.08	1105.61	1013.10	0.25
821.79	1237.72	0.30	1106.24	1017.13	0.26
825.47	1251.28	0.14	1106.59	1022.45	0.33
856.24	1258.95	0.16	1107.05	1026.65	0.31
869.65	1265.58	0.23	1105.68	1031.52	0.17
1066.00	1070.20	3.34	1105.39	1034.72	0.29
1014.50	1007.90	3.34	1098.46	1041.53	0.24
1017.30	1011.10	5.17	1095.94	1043.07	0.40
1022.50	1014.40	7.00	1093.32	1044.21	0.18
1026.50	1017.80	7.30	1094.10	1046.84	0.12
1029.60	1021.90	7.61	1093.00	1052.57	-0.03
1035.20	1028.10	7.30	1089.78	1059.75	0.08
1042.10	1035.70	7.00	1088.16	1064.27	-0.02
1046.90	1041.00	7.91	1081.68	1073.26	0.07

1053.60	1049.50	7.91	1075.26	1080.14	0.24
1060.20	1057.40	7.00	1072.97	1081.85	0.08
1063.20	1060.70	5.78	807.44	1174.13	-0.22
1065.50	1063.30	4.25	806.45	1179.84	-0.15
1068.40	1068.80	3.03	802.12	1187.80	-0.01
1029.00	1000.90	3.34	798.94	1200.73	-0.21
1033.30	1004.20	5.17	798.64	1213.06	-0.17
1038.30	1007.80	5.78	799.48	1222.77	-0.08
1043.90	1013.00	5.78	808.60	1233.40	-0.15
1049.20	1018.60	4.56	815.40	1239.03	-0.13
1054.40	1023.70	5.17	822.58	1244.73	0.04
1058.80	1028.40	6.08	831.26	1245.16	0.18
1060.80	1031.00	6.69	846.52	1243.28	0.27
1063.80	1034.50	6.69	856.68	1246.72	0.21
1066.80	1038.50	6.69	864.21	1253.91	0.19
1069.30	1042.10	6.08	870.21	1261.57	0.35
1071.50	1045.80	5.47	871.30	1267.92	0.13
1073.20	1049.90	4.86	876.53	1274.21	0.16
1074.70	1054.00	4.25	877.58	1271.18	0.16
1076.20	1057.20	3.34	884.49	1276.11	0.07
1077.00	1060.40	2.73	885.76	1280.23	0.01
1033.50	996.80	2.12	891.17	1281.10	-0.16
1034.40	995.50	2.73	896.17	1283.95	0.11
1036.70	999.60	4.25	901.52	1285.45	-0.06
1039.90	1002.70	5.17	907.89	1286.76	0.15
1043.00	1006.70	5.47	919.70	1281.79	-0.08
1046.50	1010.40	5.17	924.92	1278.49	0.09
1050.90	1015.00	3.95	930.01	1281.72	-0.04
1053.20	1018.00	3.64	934.68	1276.87	-0.05
1056.00	1020.90	4.25	943.14	1271.14	-0.11
1059.10	1027.00	6.08	953.40	1262.79	-0.04
1062.10	1029.90	6.39	960.98	1258.31	-0.10
1064.70	1033.00	6.39	968.88	1253.41	-0.25
1067.70	1037.00	6.39	974.10	1250.97	0.17
1071.60	1041.60	5.78	978.29	1248.20	0.16
1074.40	1045.30	4.86	983.32	1239.93	0.01
1076.80	1047.70	3.95	988.54	1237.26	-0.19
1078.30	1049.60	3.64	994.56	1235.32	0.09
1044.00	990.60	2.12	999.37	1229.95	0.15
1046.20	991.80	2.73	1005.47	1223.37	-0.07
1048.10	995.30	3.03	1007.18	1215.17	-0.06
1051.20	998.50	3.03	1011.33	1209.92	-0.19
1054.70	1003.80	2.73	1017.88	1203.72	0.01
1057.50	1007.40	2.42	1018.75	1204.51	-0.15
1062.20	1017.10	2.73	1023.64	1202.65	-0.07
1065.30	1020.20	4.56	1027.71	1202.22	-0.12

1068.00	1023.80	5.17	1033.19	1198.68	0.04
1071.30	1027.40	5.47	1033.62	1200.48	-0.18
1077.00	1032.40	4.56	1032.58	1205.20	-0.03
1080.40	1033.40	3.95	1033.83	1190.64	-0.58
994.50	1010.10	2.42	1032.41	1183.98	-0.59
995.60	1012.20	3.34	1032.80	1177.43	-0.47
997.30	1015.60	4.56	1035.17	1172.26	-0.13
1001.50	1019.80	5.47	1037.42	1168.90	0.08
1006.90	1025.40	6.69	1040.86	1162.22	0.00
1011.00	1028.40	7.61	1043.18	1156.38	-0.04
1013.60	1032.30	8.22	1044.49	1151.38	-0.09
1017.30	1037.00	8.83	1044.31	1142.80	-0.03
1018.80	1042.70	8.83	1043.94	1136.24	0.33
1028.20	1050.20	8.83	1046.08	1131.93	0.48
1032.40	1056.50	8.83	1048.13	1130.05	0.10
1038.10	1063.90	8.52	1049.29	1125.52	-0.02
1043.10	1067.70	7.61	1054.52	1115.15	0.04
1046.10	1073.50	6.39	1057.30	1107.13	0.12
1049.20	1076.70	5.17	1059.94	1096.87	-0.09
1053.10	1079.10	3.95	1066.49	1090.45	0.11
1056.70	1081.70	2.42	1070.15	1086.04	0.34
967.30	1015.50	2.42	881.70	1090.10	4.04
970.00	1019.40	3.64	883.60	1096.10	5.87
972.70	1020.20	3.95	888.00	1102.70	7.40
974.90	1022.10	4.56	895.00	1110.70	8.62
977.30	1024.90	5.17	900.60	1116.90	9.23
979.10	1026.50	5.47	909.20	1125.10	9.53
981.20	1031.20	5.78	913.20	1129.30	9.84
985.80	1033.60	6.39	921.00	1142.60	9.84
987.50	1038.20	7.00	933.10	1156.30	9.84
992.00	1043.20	7.61	948.90	1169.90	9.53
998.40	1049.60	8.83	957.90	1177.60	9.23
1002.10	1056.00	9.13	957.30	1185.40	8.92
1006.10	1059.40	9.44	962.80	1190.30	8.62
1010.70	1063.90	9.44	966.60	1195.70	8.01
1015.40	1068.30	9.13	974.80	1205.90	7.09
1019.60	1073.20	8.52	981.40	1212.80	5.57
1025.60	1080.40	7.61	981.80	1213.90	5.57
1030.50	1084.30	6.69	972.10	1215.50	6.48
1035.00	1088.80	5.78	959.40	1217.60	7.40
1039.90	1093.60	4.56	948.80	1219.20	8.01
1043.60	1096.10	3.64	939.00	1221.30	8.01
1047.70	1098.70	2.42	938.20	1226.20	8.01
950.60	1030.40	2.73	922.10	1235.90	7.09
953.00	1034.90	3.95	909.50	1249.30	5.57
956.50	1037.40	4.86	900.10	1257.20	4.35

959.40	1040.50	5.78	893.80	1261.50	3.74
963.60	1046.20	6.69	902.20	1124.10	9.23
967.50	1049.50	7.30	895.40	1136.10	9.53
976.40	1057.90	8.22	887.70	1146.70	9.23
983.50	1065.40	8.83	880.60	1157.30	9.23
988.70	1072.80	9.13	876.90	1166.10	8.92
993.30	1077.50	9.44	870.50	1177.20	8.62
999.80	1082.30	9.44	864.30	1188.30	8.31
1003.90	1089.40	8.52	856.20	1199.40	7.70
1008.60	1092.90	7.61	849.80	1207.40	6.79
1015.00	1102.40	6.39	846.90	1215.90	5.87
1019.60	1107.30	5.78	846.00	1221.20	4.96
1024.50	1111.80	4.56	847.70	1142.80	4.96
1028.70	1114.50	3.95	831.20	1151.70	5.26
1033.90	1117.60	2.73	846.20	1155.40	5.57
933.80	1047.10	3.95	844.50	1159.40	5.87
938.90	1052.90	6.08	850.20	1165.90	7.40
943.60	1059.40	7.61	858.40	1175.70	8.31
949.00	1065.70	8.22	871.30	1190.40	8.62
954.30	1070.30	8.83	881.10	1200.50	8.62
959.20	1076.80	8.83	896.30	1214.40	8.31
968.00	1082.50	9.44	904.90	1225.00	8.62
977.10	1089.20	9.74	911.10	1235.50	7.70
988.30	1099.70	9.44	916.30	1245.00	6.48
994.50	1105.90	8.52	920.90	1254.20	4.96
1011.20	1112.50	7.91	1043.00	969.29	0.45
1006.50	1116.50	7.00	1047.41	965.06	0.41
1012.50	1123.10	6.08	1053.45	961.36	0.49
1017.00	1126.40	4.56	1061.53	960.08	0.72
1021.50	1129.90	3.34	1068.59	961.19	0.77
1023.60	1131.80	2.73	1076.04	961.31	0.93
916.00	1060.40	4.56	1082.77	968.43	0.94
916.50	1062.40	5.47	1088.42	970.97	0.82
919.70	1066.00	7.00	1087.31	974.89	0.49
922.50	1069.30	8.22	1081.76	980.31	0.46
926.40	1073.40	8.83	1074.32	984.99	0.41
933.90	1080.50	9.13	1069.36	989.87	0.37
939.70	1086.00	9.44	1072.65	990.79	0.34
945.80	1088.30	9.74	1078.68	1008.78	0.61
952.40	1096.30	9.74	1084.62	1005.95	0.56
959.80	1102.20	9.74	1092.35	1003.13	0.53
967.10	1109.50	10.05	1098.90	1000.98	0.48
976.50	1119.70	9.44	1103.68	1000.27	0.57
984.30	1123.40	9.13	1106.10	1006.39	0.72
991.80	1127.90	8.83	1102.20	1018.15	0.78
999.90	1135.30	7.61	1106.70	979.66	0.25

1001.60	1142.50	7.30	1109.87	977.95	0.00
1003.70	1147.80	6.69	1106.83	986.21	0.01
1007.40	1150.80	5.78	1108.14	988.84	0.14
810.50	1198.00	1.51	1112.49	991.45	-0.19
822.70	1186.50	3.34	1111.17	993.58	-0.37
828.40	1174.60	3.95	1108.02	998.45	-0.02
836.80	1165.10	5.17	1111.19	1002.39	0.26
839.30	1147.90	5.17	1115.38	1008.46	-0.08
845.90	1141.90	4.56	1117.58	973.33	-0.65
853.40	1132.30	4.86	1100.20	968.02	-0.08
860.50	1121.10	4.86	1101.36	964.43	-0.07
863.80	1113.20	4.86	1090.09	961.00	0.14
869.60	1106.30	4.56	1083.18	962.30	0.19
875.30	1093.50	5.17	1059.93	953.36	-0.03
878.90	1090.10	4.25	1063.64	950.96	-0.06
883.70	1084.60	4.25	1067.01	949.32	-0.07
890.80	1081.20	5.17	861.24	1082.04	-0.87
900.30	1078.40	5.47	1072.37	1087.29	-0.37
904.30	1069.40	5.17	1063.35	1011.07	1.14
911.60	1061.50	5.78	1068.81	1006.06	1.21
923.60	1055.30	5.47	1074.56	1000.98	1.16
930.30	1054.80	5.78	1079.21	996.37	1.16
939.20	1054.40	5.78	1084.51	992.36	1.23
945.50	1048.30	5.78	1089.09	989.16	1.26
			1093.18	985.62	1.16
			1097.09	982.20	1.28
			1099.69	978.14	1.24
			1100.36	980.51	1.37