SUSITNA
HYDROELECTRIC PROJECT
FEDERAL ENERGY REGULATORY COMMISSION
PROJECT NUMBER 7114

GLACIAL LAKE PHYSICAL LIMNOLOGY STUDIES:

EKLUTNA LAKE, ALASKA

VOLUME 1

MAIN REPORT

PREPARED BY:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS
ANCHORAGE, ALASKA

UNDER CONTRACT TO:

HARZA-EBASCO
SUSITNA JOINT VENTURE
ANCHORAGE, ALASKA

DRAFT REPORT

JUNE 1985

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VOLUME 1 - MAIN REPORT

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GLACIAL LAKE PHYSICAL LIMNOLOGY STUDIES
SUSITNA HYDROELECTRIC PROJECT

TABLE OF CONTENTS

VOLUME 1

GLACIAL LAKE PHYSICAL LIMNOLOGY STUDIES
SUSITNA HYDROELECTRIC PROJECT
LIST OF TABLES

TABLE OF CONTENTS (Continued)

VOLUME 2

GLACIAL LAKE PHYSICAL LIMNOLOGY STUDIES
SUSITNA HYDROELECTRIC PROJECT
LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

GLACIAL LAKE PHYSICAL LIMNOLOGY STUDIES
SUSITNA HYDROELECTRIC PROJECT

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

GLACIAL LAKE PHYSICAL LIMNOLOGY SUDIES
SUSITNA HYDROELECTRIC PROJECT

LIST OF PHOTOS

ACKNOWLEDGMENTS

Field instrumentation was installed and operated at Eklutna Lake by permission of the State of Alaska, Division of Parks, Chugach Division. The cooperation and assistance of the Chugach State Park rangers is gratefully acknowledged. Lake outflow data were provided by Stan Sieczkowski of the Eklutna Project, Alaska Power Administration. Transmissivity data were obtained on two of the 1984 lake trips with a transmissometer loaned from the Institute of Marine Science, University of Alaska, Fairbanks, with special assistance from Gil Mimkin. Suspended sediment analyses were performed by Chemical and Geological Laboratories of Alaska, Inc., in Anchorage and Particle Data Laboratories, Inc., of Elmhurst, Illinois. Special technical assistance throughout the project was provided by Drs. Tom Stuart and C.Y. Wei of Harza-Ebasco Susitna Joint Venture. Field data collection since 1982 was performed by the hydrology staff of R&M Consultants. Brett Jokela and Bill Ashton coordinated the field program and data compilation. Jeff Coffin was responsible for overall coordination and is the principal author of this report.

1.0 EXECUTIVE SUMMARY

1.1 Purpose and Scope

Numerical modelling of the Watana and Devil Canyon Reservoirs in the Susitna Hydroelectric Project was undertaken to refine estimates of the water temperature, turbidity, and suspended sediment levels to be expected within the reservoirs and in the river downstream. The state-of-the-art, one-dimensional DYRESM (Dynamic Reservoir Simulation Model) computer model was selected to simulate the two reservoirs in the glacier-fed Susitna River. Successful application of the model required calibration on an existing glacial lake system. Eklutna Lake, near Anchorage, was chosen as the calibration lake because of its hydraulic and morphologic similarities to Watana Reservoir. Both lakes have similar percentages of their drainage areas covered by glaciers (5.2 and 5.9%), both have similar average residence times within the lake (1.77 and 1.65 years), both have similar climatological conditions, and both are reservoirs operated or to be operated for hydroelectric power production.

For temperature modelling of Eklutna Lake, continuous data were required on inflow volume and temperature, outflow volume and temperature, and on measurements of energy transferred to and from the lake. Sediment modelling required the same thermal data to account for the mixing and circulation processes within the lake. Sediment inflow and outflow quantities were required as well. Periodic profiles and samples were taken at selected stations in the lake to be used in the model verification and to document the lake's mixing environment and sediment dynamics. Supplementary data were collected at the same time to define light penetration relationships in the inflow streams and in the lake. The collection of continuous data began in June 1982 and proceeded until December 1984. The 1982 data were summarized in an interim report (R&M Consultants 1982a); the current report presents the 1983 and 1984 Eklutna Lake data.

The data collection program was designed to provide input data for the DYRESM model, to provide lake data for verification of the model, and to provide information on the lake processes which affect the internal and outflow temperature and sediment characteristics. The methods summarized below were used to document the meteorologic inputs; the water discharge, sediment discharge, and temperature of the lake inflow stream; the temperature and suspended-sediment patterns in the lake; and the water discharge, sediment discharge, and temperature of the lake outflow.

1.2 Equipment and Methods

Meteorologic data were measured by a Weather Wizard (a digital recording weather station) which was located on the brush-covered floodplain at the head of the lake. Instantaneous values were recorded every 15 or 30 minutes for air temperature, relative humidity, solar radiation intensity, and longwave radiation intensity. Cumulative precipitation was measured and recorded at the same time intervals. Average windspeed and wind direction and peak wind gust observed over the preceding 15 or 30 minutes were also reported. Data were recorded onto magnetic cassette tapes, which were replaced once per month during inspection/maintenance visits. The cassettes were computer-processed and summarized on a monthly basis by a hydrologist.

The Eklutna Lake inflow enters the lake at one point at its southeast end. However, two primary tributaries combine to form the Eklutna River a short distance upstream. Each stream was gaged and sampled separately because of the lack of satisfactory access and gaging sites downstream of their confluence. One tributary discharges from Eklutna Glacier and was designated Glacier Fork; the other was called East Fork. A stilling well, float, and strip-chart water level recorder were installed on each creek and operated through the open-water seasons (May-October) of 1982-84. Ryan thermographs were also operated in the streams concurrently, so continuous records were obtained of the water levels and water temperature. Periodic discharge measurements were made to determine stage-discharge relationships. The discharges and temperatures were reported as mean daily values for DYRESM input.

Occasionally in 1982 and frequently in 1984, depth-integrated water samples were collected at the East Fork and Glacier Fork gaging stations and analyzed for turbidity and total suspended solids (TSS) concentration. Field measurements of conductivity and Secchi disk depth were also made on these trips. Sampling in 1984 was done twice per week at each site from early June through freeze-up (about mid-November). Additional suspended sediment samples were taken in July, August, and October and analyzed for particle-size distribution by Particle Data Laboratories in Chicago.

The sampling program in the lake consisted of monthly trips in 1983 and bi-weekly trips in 1982 and 1984. Sediment and turbidity measurements were also made in 1982 and 1984. Temperature-profiling was conducted with a Martek Mark VIII Water Quality Monitor by lowering a sensor to depth and recording from a digital recorder. Conductivity was also recorded using the same instrument on most occasions. Sampling for turbidity and TSS was performed by lowering a brass Kemmerer sampler to the desired depth, capturing the sample, and returning it to the surface. Determinations were then made of turbidity by R&M in the office and of TSS concentration by Chemical and Geological Laboratories of Alaska, Inc. in Anchorage. In mid-1984, a turbidimeter was used which permitted flow-through operation. The sampling procedure was then amended by pumping samples from the desired depth and either into the turbidimeter for analysis or into a sample bottle for subsequent TSS analysis. Light penetration measurements were also made using a quantum sensor and a Secchi disk.

Lake sampling was done at up to 15 different stations on the lake. An inflatable boat was used during the open-water seasons, and winter sampling was done through the ice.

Measurements of lake outflow volume and temperatures on a daily basis were provided by personnel of the Eklutna Hydroelectric Project, Alaska Power Administration, from routine records kept for the hydroelectric plant operation. Lake levels were surveyed weekly by Eklutna Project operators and then starting in 1983 were recorded continuously by the U.S. Geological Survey. Sampling of the outflow in the tailrace was undertaken in 1984 to define the suspended sediment being discharged from Eklutna Lake. Samples were taken twice per week on the same dates the inflow streams were sampled. Determinations were made of turbidity, TSS concentration, conductivity, and Secchi disk depth.

1.3 Summary of Results

Observed lake temperatures ranged from a high of about 15°C at the surface in mid-summer to 0°C just below the ice layer during the winter. Outflow temperatures ranged between 3 and 13°C, remaining very close to 4°C throughout the ice-covered season. The lake experienced overturn twice a year: in May after breakup and in September or October prior to freeze-up. Several instances were noted where temperature fluctuations in the outflow or in the center of the lake (Station 9) could be linked to major wind events experienced at the lake. The inflow stream's presence as a colder, more turbid plume in the lake was detected at varying depths on different dates, depending on its temperature compared to the lake's. It was occasionally seen as an underflow (on the bottom of the lake) but generally appeared as interflow (at mid-depth), and could apparently be detected as far down-lake as Station 9, about three miles.

Measured suspended-sediment concentrations ranged from 0.15 to 570 mg/l in the inflow streams, from 0.1 to 200 mg/l in the lake, and from 0.56 to 36 mg/l in the outflow. Peak values in the inflow occurred in late July or early August, in the lake in about September (as a depth-averaged concentration at Station 9), and in the outflow in late July to mid-August. During the winter, inflow, lake and outflow suspended sediment concentrations were on the order of 0.1 mg/l. During the summer, the average suspended sediment concentration were substantially higher than winter values and were incresed further following large rainfall events or periods of significant glacial melt. Prominent diurnal variation was seen in discharge, water temperature, and TSS concentration on both inflow tributaries, especially during periods of clear weather with warm days and cool nights.

Turbidity values generally followed the trends in the TSS concentration, dropping off in the winter at inflow, lake, and outflow sites and peaking in mid-to-late summer. Values observed ranged from 0.5 to 580 NTU in the inflow streams, from 1.8 to 220 NTU in the lake, and from 3.0 to 46 NTU in the outflow.

2.0 SCOPE OF STUDY

2.1 Purpose

The Alaska Power Authority proposes to develop the Susitna River's power potential by constructing and operating dams and reservoirs at Watana and Devil Canyon damsites in the Susitna Hydroelectric Project. The reservoirs' effects on temperatures and suspended sediment regimes within the reservoirs and in the reaches downstream are of concern for management of fish resources and other environmental issues.

The reservoirs are being mathematically modelled with the Dynamic Reservoir Simulation Model (DYRESM), a state-of-the-art, one-dimensional model developed at the University of Western Australia (Imberger et al. 1981). The original version of the model has been expanded to account for ice formation thermo-dynamics, circulation, and settling properties of suspended sediment. Prior to application of the model on the Susitna reservoirs, the model is being calibrated using data from Eklutna Lake, a glacial lake 100 miles south of the Watana damsite and 30 miles northeast of Anchorage (Figure 2.1).

This report documents the field data collected at Eklutna Lake from December 1982 to December 1984 in support of the modelling efforts. A summary table of all the lake data collected in this period is included in Appendix A as Table A.1. As noted in the Glacial Lake Studies Interim Report (R&M 1982a), the Eklutna data collection program was designed to: (1) provide input data for the DYRESM model; (2) provide lake temperature and sediment data for verification of the DYRESM model; and (3) provide documentation of the lake's mixing environment and sediment dynamics. Little analysis is contained in the report as its function is to present the data collected for subsequent anslyses.

2.2 Summary of Previous Studies and Available Data

Data collected from April through November 1982 at Eklutna Lake were reported in the Glacial Lake Studies Interim Report (R&M 1982a). Profiles at two-to four-week intervals of lake temperature, conductivity, and turbidity from up to 15 stations around the lake intervals were presented, as were daily values of inflow discharge and temperature, outflow discharge and temperature, and local weather parameters. Suspended sediment and light transmittance characteristics were measured at selected stations through the year.

Background data available on Eklutna Lake and the inflow and outflow streams include discharge, lake level, and water quality data from the U.S. Geological Survey (U.S.G.S.); additional lake water quality data from the Municipality of Anchorage; lake outlet geometry and outflow discharge and temperature data from the Alaska Power Administration; and weather data at nearby locations from the National Oceanic and Atmospheric Administration (N.O.A.A.).

The U.S.G.S. data consist of lake inflow discharges from 1960-1962, miscellaneous discharge measurements from 1952-1956, lake level data from 1946-1962, lake outflow discharges below the dam (rather than through the powerplant) from 1946-1962, and stream water quality data from below the dam from 1949-1952.

Lake water quality data were obtained for the Municipality of Anchorage for water supply studies and have been reported by CH2M Hill (1981) and Montgomery Engineers (1984).

Information on the Eklutna Project powerplant and intake characteristics and operating data were obtained from daily records kept by plant personnel (Alaska Power Administration 1982-1985) and from powerplant construction documents made available to R&M.

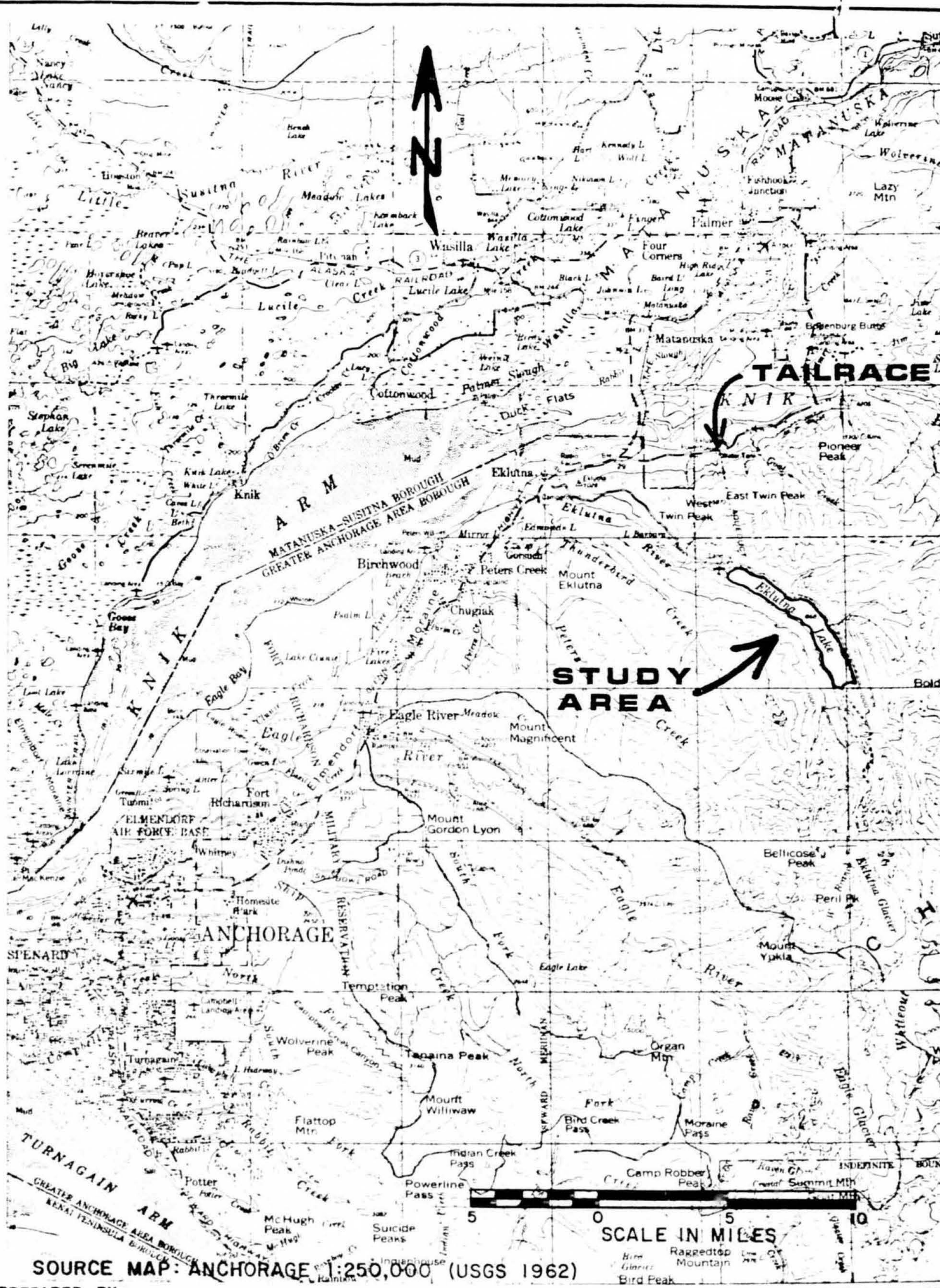
Weather data (precipitation and temperature) are reported by N.O.A.A. (1982-1985) for the Eklutna Project powerplant 5 miles north of Eklutna Lake and for Paradise Haven Lodge in Eagle River 12 miles southwest of the lake, collected by Alaska Power Administration and Chugach State Park personnel, respectively.

These background data are not summarized herein because the emphasis of the present report is the specific period of sampling rather than for historical conditions.

2.3 Report Format

The report provides descriptions of data collection methods, discussions of results, and discussion of the river and lake relationships. Sections are included in Volume 1, the Main Report, for weather monitoring, lake inflow, limnology and lake outflow data, Sections 3 through 6. Relationships of the river and lake systems are discussed in Section 7. Section 8 lists references cited.

Data of a "summary" nature are presented within the main text. This includes plots that show how river and lake parameters vary with time or vary with respect to each other. The appendices, Volume 2, present the supporting data that were used to prepare these plots. Tables which summarize the types of data available are also included in the appendices.



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R&M CONSULTANTS, INC.

EKLUTNA LAKE LOCATION MAP

PREPARED FOR:

HARZA-EBASCO
SUSITNA JOINT VENTURE

FIG. 2.1

3.0 METEOROLOGICAL STATION AND WEATHER MONITORING

3.1 Methodology

By special permission of the Chugach State Park, a weather station was established on June 3, 1982, at the south end of Eklutna Lake near an existing gravel airstrip (Figure 3.1) The station was removed December 14, 1984, following completion of the 1984 open-water season. The weather station consisted of a "Weather Wizard" monitoring system manufactured by Meteorology Research, Inc. (now part of Belfort Instrument Company) and an Eppley Laboratories Precision Infrared Radiometer. The system measured air temperature, precipitation, wind speed and direction, peak gust speed, relative humidity (RH), solar radiation, and longwave radiation. Temperature, relative humidity and radiation levels were recorded as instantaneous values every 15 or 30 minutes on a magnetic tape cassette. Wind data were processed from 15-second interval readings by the data logger and recorded as average winds and peak gust for each 15 or 30 minute interval. Precipitation was recorded as a cumulative amount using a tipping-bucket gage. Raw data from the tapes were edited and summarized in tables and graphs on a monthly basis.

The station layout and photos of the site are shown in Figure 3.2 and Photos 3.1 and 3.2. The sensor configurations are shown in Photos 3.3 and 3.4.

Some of the data used for DYRESM input were not available in the data record from the site. The nearest first-order N.O.A.A. station, Anchorage, was used to estimate Eklutna Lake values for sky cover and vapor pressure. Vapor pressure was computed to fill in gaps in the RH record and was estimated from the Anchorage values of RH and temperature with a regression equation. Sky cover values (in tenths) were taken directly from the Anchorage data.

3.2 Results and Discussion

Graphical summaries of the recorded weather data are presented in a sequential plot of each parameter for 10-month and 15-month periods in Figures 3.3 and 3.4, respectively. Larger copies of each month's plot and a copy of each month's summary data table are contained in Appendix B. Complete reports of monthly data are presented in annual reports for the Eklutna Lake weather station (R&M 1982b, 1984, 1985).

Items particularly worthy of note are the windspeeds and wind directions. Events accompanied by occurrences of high windspeeds during open-water periods, especially if they last for more than a day at a time, are instrumental in causing considerable mixing in the lake. The windspeed patterns can be seen in the bottom graph of each monthly plot in Figures 3.3 and 3.4, when the trace deviates from the zero level and gives consistent values of 4-8 meters per second or higher. Such events were apparent during ice-free conditions for August 6-8, 1983; September 29, 1983; October 9-11, 1983; on three occasions in November 1983; June 28-29, 1984; August 23-24, 1984; October 21-22, 1984; November 19-21, 1984; and December 1-5, 1984. The strong winds were predominantly from the south-southeast, i.e. blowing from the glaciers and down the lake; they caused the air temperature to rise and remain fairly steady through the day; and they were often accompanied by significant rainfall.

The winds in general showed a strong tendency for coming either from the north-northwest or from the south-southeast, due to the alignment of the lake and valley between high mountains along that axis. Winds at Eklutna also frequently showed a diurnal cycle in the summer, when early morning winds flowed down the valley (from the south-southeast) and afternoon and evening winds came up the valley (from the north-northwest), typical of mountain drainage wind patterns (note July 1984, for example).

Air temperature at the lake normally showed a marked diurnal fluctuation, with cool nights and warmer days due to solar heating. The sun's warming is less effective in the winter, so temperature variation then is governed more by movement of regional air masses than by daily fluctuations.

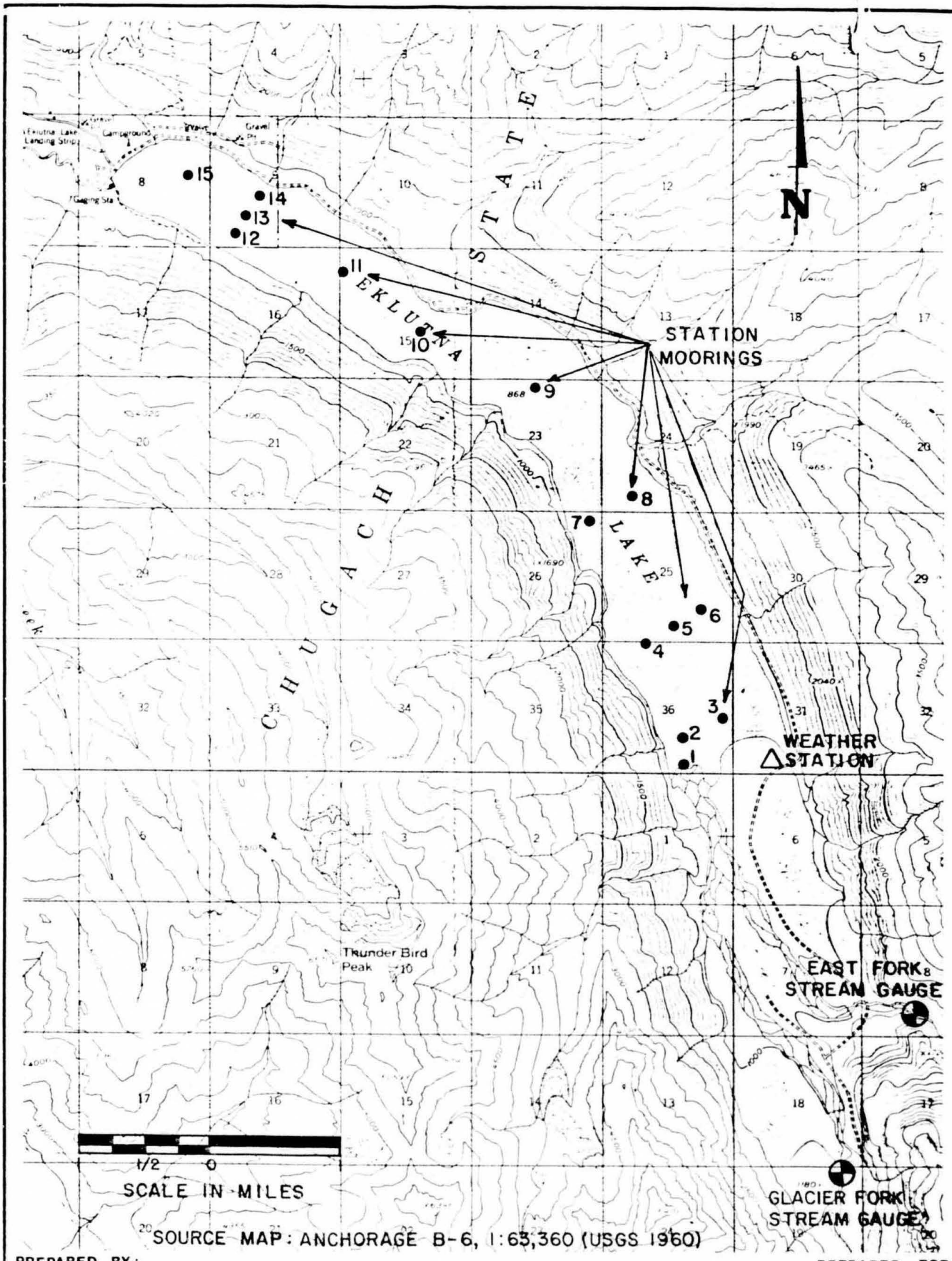
The solar radiation intensity naturally displays a daily and also an annual cycle. The daily peaks in December and January are barely visible on the plots (top graphs), but the summer peaks in May, June, and July are often very high. Daily cycles are quite evident for relative humidity (RH) except during the winter, although several problems in reporting of the RH data were experienced.

More discussion of the meteorologic data collection and detailed data reports are contained in the annual reports (R&M 1984, 1985). The recorded data are felt to be good where reported, with the following comments regarding interpretation:

- precipitation data are not recorded during freezing temperatures so are not reported for winter months (November-March).
- recorded solar radiation data may be lower than actual values at times during the winter due to frost or snow accumulation on the sensor.
- numerous wind speed and wind direction data were lost during winter months when the anemometer and/or the wind vane froze until freed by a strong wind or thawed by warm temperatures or solar heating.
- several periods of intermittent or complete loss of data occurred when electronic or mechanical malfunctions occurred. Intermittent gaps are evident in June and July 1983, and total gaps occurred in January, February, November, and December 1983. Approximately one day of data was lost each in September 1983 and September 1984 when several sensors were removed for annual maintenance.
- the RH plots in Figure 3.3 were not adjusted before plotting, so the daily "peaks" which show up at the bottom of the graphs should actually be plotted at the top, and the traces should be shifted

downward a similar amount. For example, a plotted vaue of 10 percent really corresponds to an RH of 110 percent, indicating the sensor calibration was 10 points too high and should have been adjusted down 10 points. Also, the RH data were all lost from mid-February to early September in 1984 due to a faulty sensor oscillator.

Documentation of the lake conditions through the winter of 1983-84 and during freeze-up in late 1984, as well as a tabulation of weather observations at the lake, are included in Appendix C. The daily weather and wind speed values used as input for the DYRESM model are listed in Appendices N.2 and N.3.



PREPARED BY:

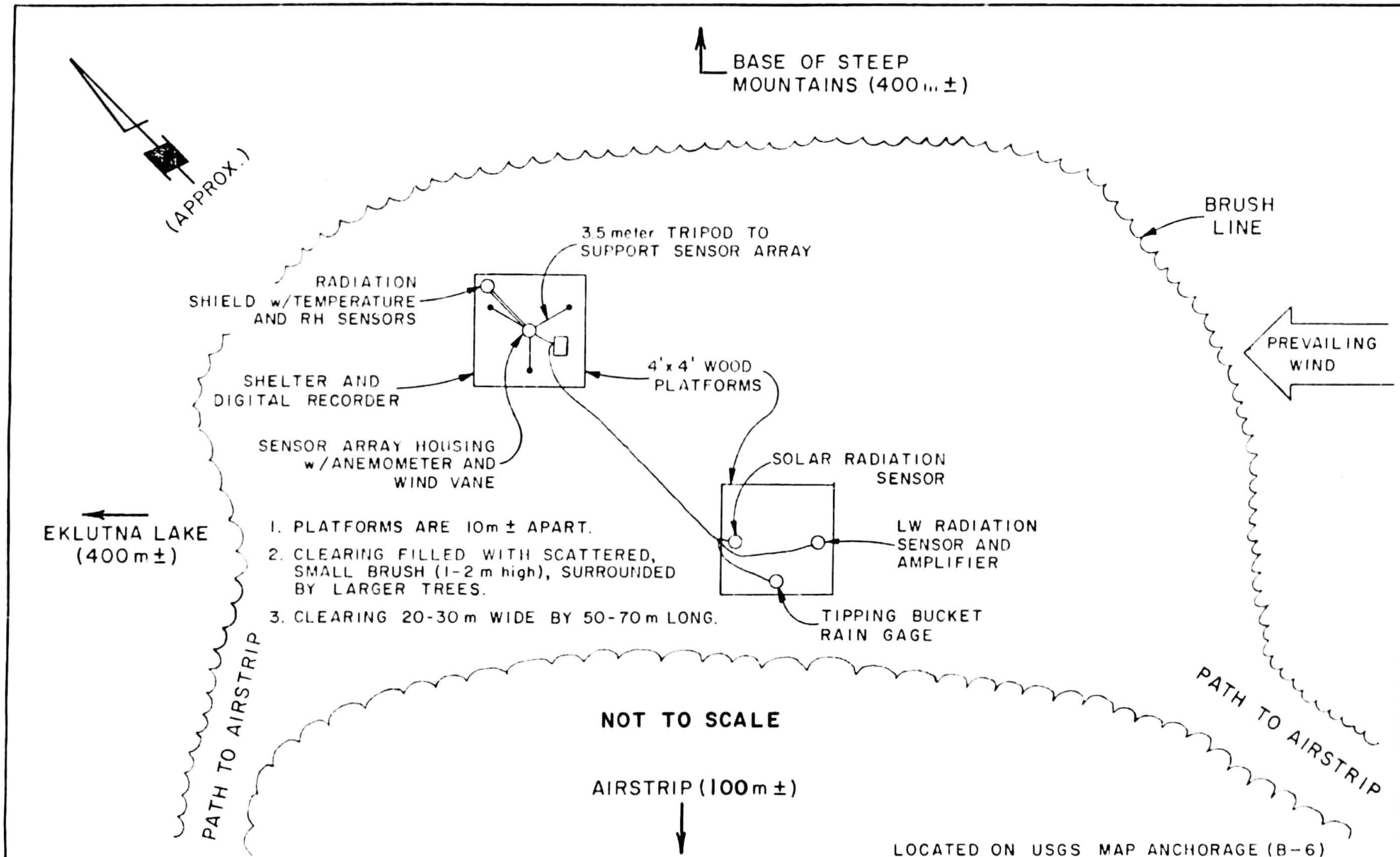
R&M
R&M CONSULTANTS, INC.

PREPARED FOR:

HARZA-EBASCO
SUSITNA JOINT VENTURE

EKLUTNA LAKE STATION LOCATIONS

FIG. 3.1



PREPARED BY:	FIGURE 3.2 - SITE SKETCH	PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	EKLUTNA LAKE CLIMATE STATION ESTABLISHED JUNE 3, 1982 - OWNER: ALASKA POWER AUTHORITY - OPERATOR: R & M CONSULTANTS, INC. UNDER CONTRACT TO HARZA-EBASCO SUSITNA JOINT VENTURE	HARZA-EBASCO SUSITNA JOINT VENTURE

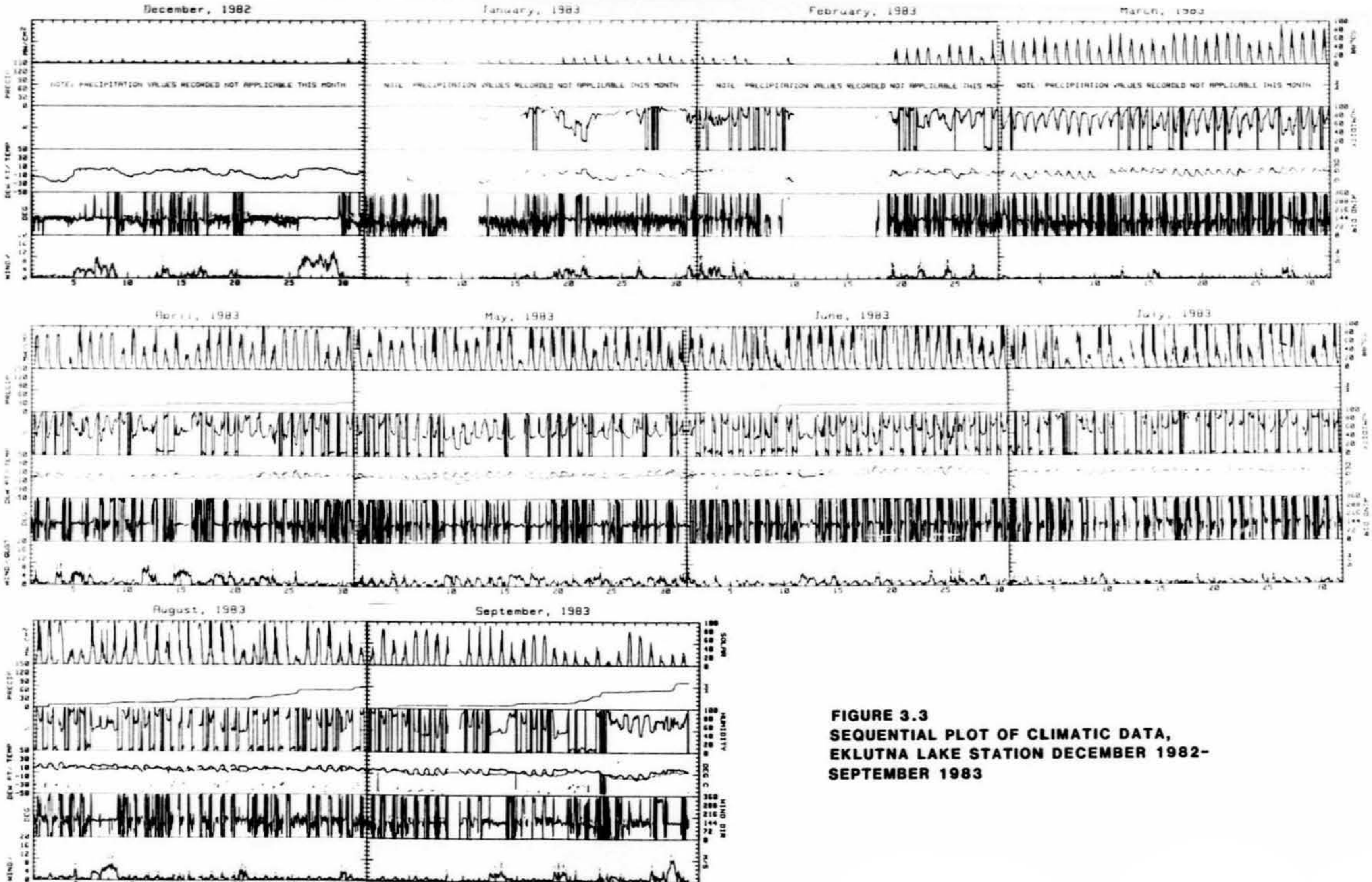
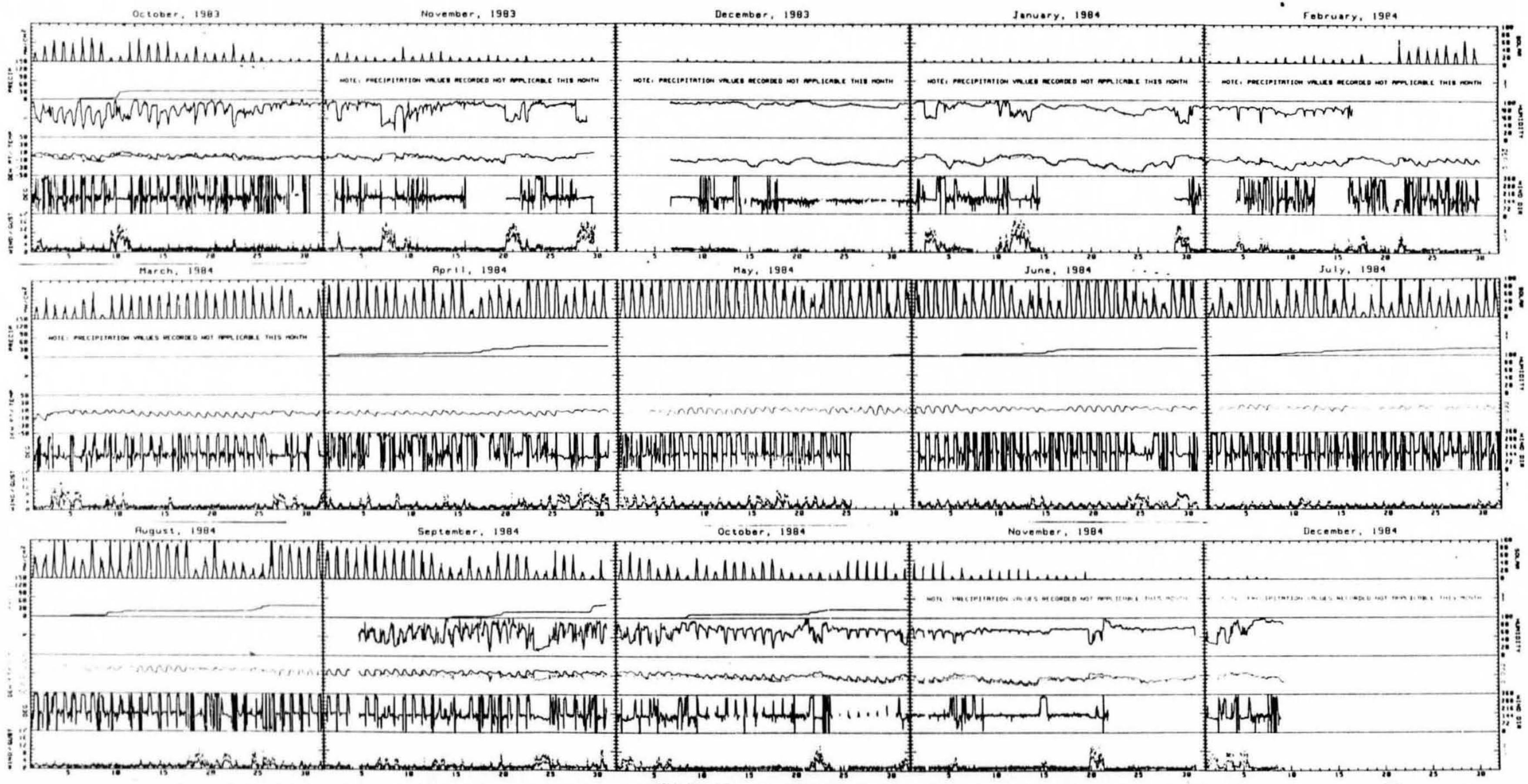


FIGURE 3.3
SEQUENTIAL PLOT OF CLIMATIC DATA, EKLUTNA LAKE STATION DECEMBER 1982-SEPTEMBER 1983



NOTE: A LARGER COPY
PLOT IS INCLUDED IN
APPENDIX B.

FIGURE 3.4
SEQUENTIAL PLOT OF CLIMATIC DATA EKLUTNA LAKE STATION, OCTOBER 1983-DECEMBER 1984

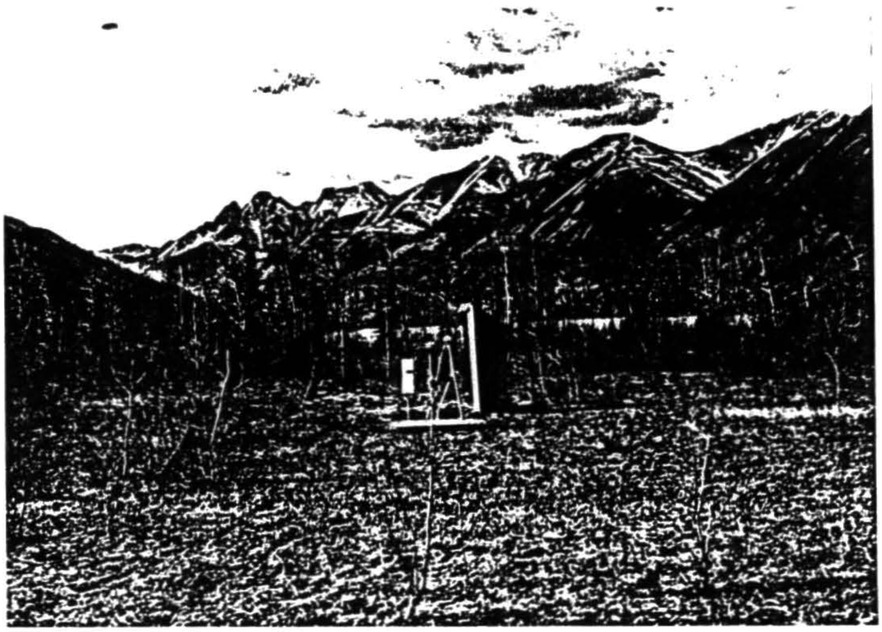


Photo 3.1 Eklutna Lake Climate Station site, looking NW toward Eklutna Lake.

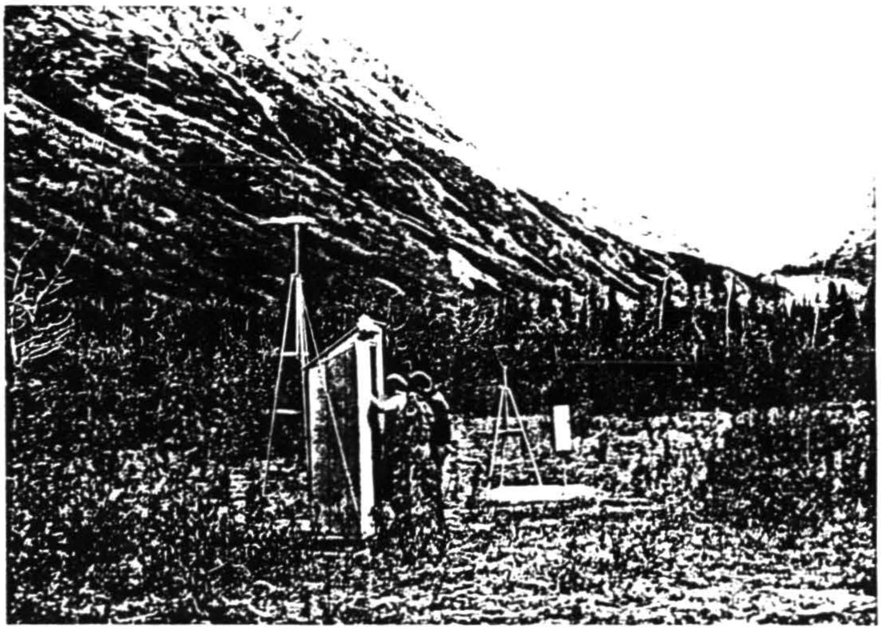


Photo 3.2 Eklutna Lake Climate Station site, looking SE toward upper basin.

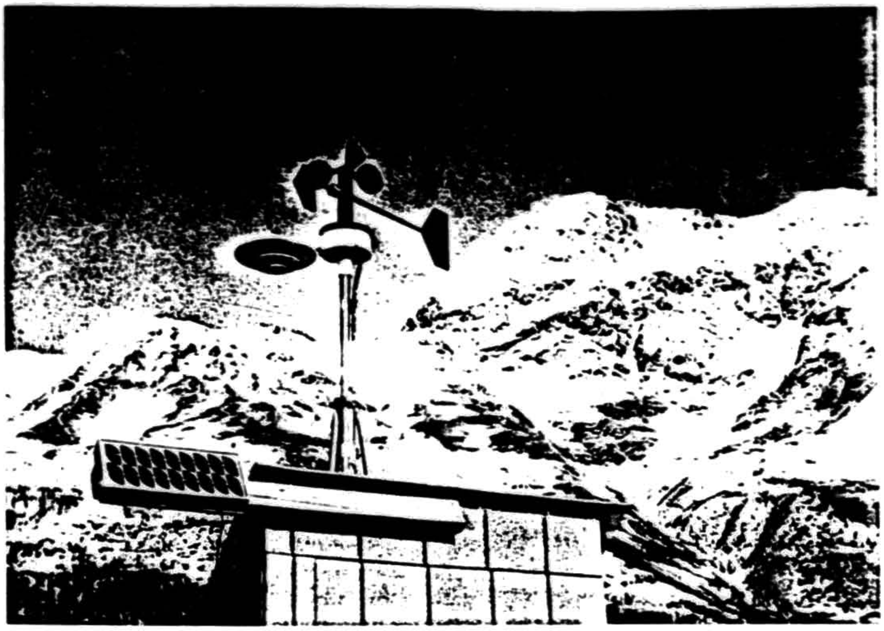


Photo 3.3 Sensor array and solar panel, Eklutna Lake Climate Station. Sensor array contains anemometer, wind vane, and radiation shield with temperature and RH sensors.

Photo 3.4 Auxiliary sensor platform, Eklutna Lake Climate Station. Sensors included (left to right) are solar radiation sensor, longwave radiation sensor, and tipping bucket precipitation gage.

4.0 LAKE INFLOW - EKLUTNA RIVER

4.1 Methodology

Data collection sites were established on each of the two primary inflow streams: East Fork and Glacier Fork of Eklutna River. On each stream, a stream gauge was installed, and water samples were collected. Site locations are shown on Figure 3.1. These two creeks provide the principal inflow to Eklutna Lake, together draining about 50% of the lake's 111-square-mile watershed (R&M 1982a). The two creeks intertwine in braided channels on a broad floodplain before entering the lake. The streams were gaged and sampled separately, several miles from the lake inlet, as the first suitable sections for streamgaging were upstream of their confluence. Very little groundwater flow is expected to augment the stream discharge downstream of the gaging sites.

4.1.1 Streamflow

Stage-discharge relationships were established for both streams. Stevens Type F water level recorders with 30-day charts were utilized to continuously monitor stream stages. The water level recorders were housed in plywood gage houses on 16" diameter polyethylene pipe stilling wells. The stilling wells were installed with 2½" diameter PVC inlet pipes which extended into the channel. Discharge values in cubic feet per second (cfs) were calculated from mean daily stage readings and converted to cubic meters per day (m^3/d) for DYRESM use.

4.1.2 Water Temperature

Inflow temperatures were monitored continuously with Ryan Model J Thermographs, recorded on pressure-sensitive paper charts. These instruments were anchored to rocks placed in the streams such that the sensors remained submerged. Temperatures were also measured every sampling trip with a mercury thermometer. All water temperatures measured with the Ryan thermograph are accurate to the nearest half-degree Celsius.

4.1.3 Light Penetration

Secchi disk depths, as defined by Wetzel (1975), were measured in the inflow streams using a disk painted in alternate quadrants of white and black to facilitate definition when submerged. Secchi disk measurements were reported to the nearest 0.1 foot.

4.1.4 Conductivity

Samples of inflow water were measured for conductivity at the R&M office using a YSI model 33 S-C-T meter (sample collection is described in Suspended Sediment). Exceptions to this were 24-hour sampling trips in July and August 1984 when analyses were performed in the field. In each case, temperature was measured at the same time. Using the temperature, the measured conductivity was corrected to conductivity at 25°C (APHA et al. 1981).

4.1.5 Suspended Sediment

Depth integrated water samples were collected for concentration of total suspended solids (TSS), turbidity and conductivity analyses using a U.S. DH-48 suspended sediment sampler (U.S.G.S, 1978). During periods of low flow, the samples were collected at estimated equal-discharge increments across the stream. Higher flows made this impossible without unacceptable risk to the collector. At these times, a well-mixed location near the edge of the stream was used. Samples were refrigerated immediately after collection until the lab analyses were conducted. Analyses were conducted within three days of sampling and usually within one day.

Concentrations were determined by Chemical and Geological Laboratories of Alaska using standard procedures for detection of total nonfilterable residue (APHA et al. 1981). Filters with a pore size of 0.45 microns (0.45×10^{-3} millimeters) were used for the determinations of TSS concentration. Particle-size distributions and mineralogic analyses were performed by Particle Data Laboratories, Ltd., of Elmhurst, Illinois. The size distributions were determined by the electrozone method (Karuhn and Berg 1982).

4.1.6 Turbidity

Samples taken for suspended sediment analyses were also analyzed for turbidity. Determinations were routinely performed within one day of sampling. A Hach Model 16800 Portalab Turbidimeter was used for this purpose from 1982 until August, 1984, when a Monitek Model 31 Nephelometer was purchased and used thereafter. Both instruments measured nephelometric turbidity (i.e., 90° scattering of light). Standard methods for the measure of nephelometric turbidity were followed (APHA et al. 1981). Calibration standards were supplied by the instrument manufacturers. Some differences were noted in measurements made with the two instruments, so preliminary values were adjusted using an empirical correction relationship.

4.2 Results and Discussion

Plots of mean daily stream discharge and water temperature for the 1983 open-water period are shown for East Fork and Glacier Fork in Figures 4.1 and 4.2. Data for 1984 are shown in Figures 4.3 and 4.4, which plot instantaneous instead of mean daily temperatures, and also plot instantaneous values of turbidity and total suspended solids (TSS).

Both stream basins are heavily glaciated (54% for Glacier Fork's 27 square miles and 20% for East Fork's 40 square miles). The Glacier Fork streamgage is within two miles of the Eklutna Glacier terminus. The glacial influence is quite evident from the low summer water temperatures and from the shape of the annual hydrographs. On frequent occasions while standing in the stream making discharge measurements, the hydrologists' legs were bumped by large (several inches across) chunks of ice floating downstream. The streamflows are characterized by very low magnitudes in the winter and high, variable flows through the summer. The summer rise begins in late May or early June and continues to a peak in late July or August. Summer fluctuations are produced by rainfall or glacial melt events, or a combination of both factors. The melting of the glacier is accelerated by warm air temperatures and solar radiation, especially when accompanied by strong winds. The peaks of the year in 1983 were particularly sharp and high. They occurred on August 8 at each site following several days of warm temperatures, strong winds, and intermittent rainfall.

The suspended-sediment and turbidity data collected in 1984 afford some interesting comparisons with the streamflow and temperature plots, shown in Figures 4.3 and 4.4. High-turbidity and high-TSS events coincide well, with both generally coinciding with rises in the discharge. Some of the sharp peaks on the discharge plots, however, do not appear on the TSS and turbidity plots, and vice versa. There are two reasons for this. First, discharge data are plotted for every day, while TSS and turbidity data are available only from the times sampled, i.e. twice per week. Thus, the streamflow (Q) could rise and fall sharply between sampling trips. The TSS and turbidity levels would also presumably have risen and fallen in the meantime, but this pattern was not sampled.

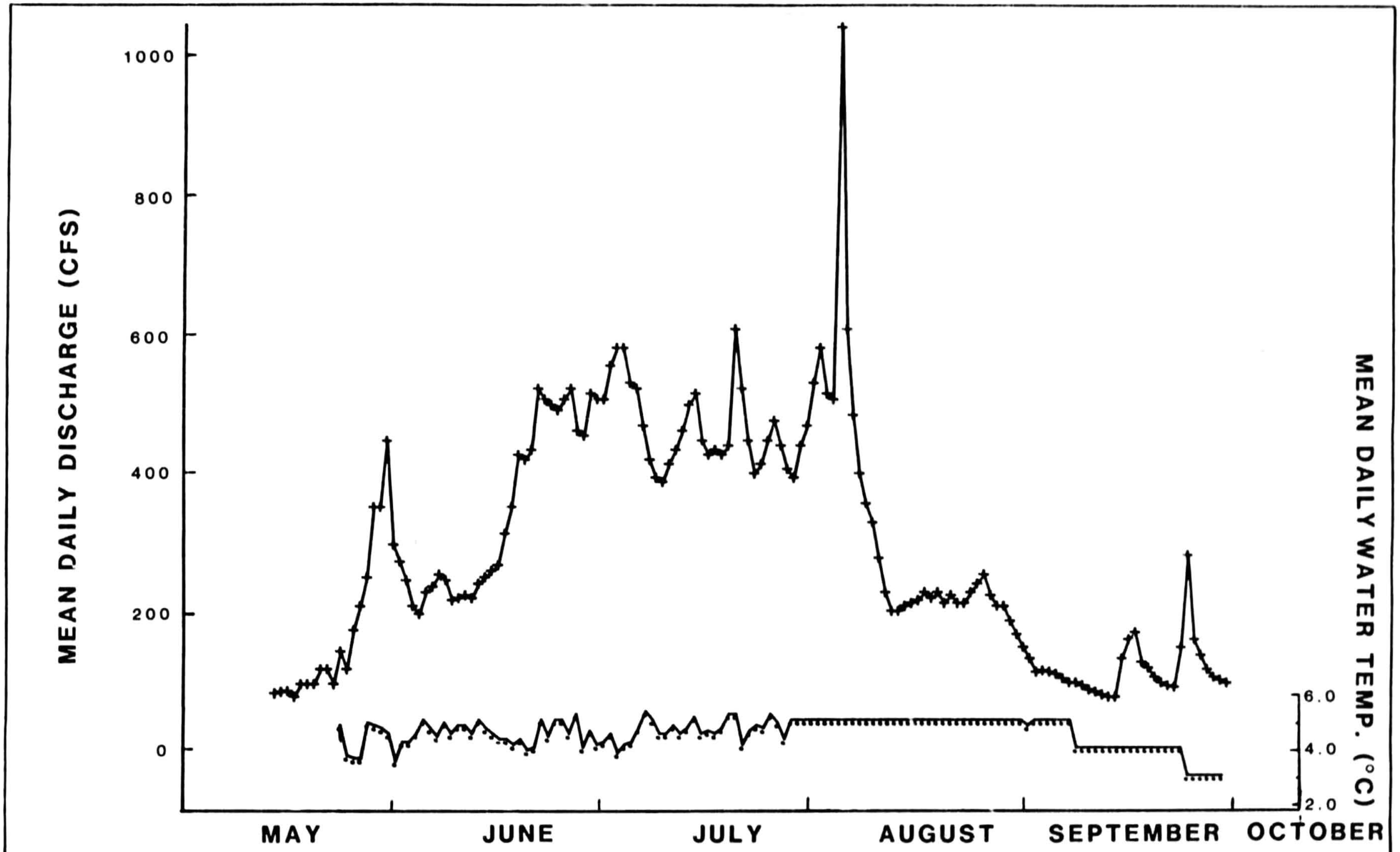
A second factor influencing the apparent Q-TSS-turbidity relationships in Figures 4.3 and 4.4 is the fact that the Q plotted is the mean daily value, while the other parameters are instantaneous values. Continuous records of water level and temperature at both gaging sites have shown a pronounced diurnal variation in both parameters, especially at Glacier Fork. Cool, clear nights reduce glacial melting and runoff and lower the temperature of the water. Warm, sunny days promote melting and increase the runoff and generally increase the water temperature. Thus, levels observed are quite dependent on the time of day. Mean daily values of a parameter may be relatively uniform over a period, with instantaneous values fluctuating significantly about the mean on a particular day. Relationships were derived between parameters of interest to help interpolate between the discrete sampling times. Figures 4.5 and 4.6 show the plots of TSS as a function of discharge at each gaging station. Instantaneous values of each were paired to develop the relationships. The regression equations and correlation coefficients are shown on the figures, indicating that the function is good in each case. These equations permit estimation of stream TSS concentrations when the discharge is known; they were used to provide estimates of daily suspended sediment load for use in the DYRESM model. Computed values of TSS are given in Appendix N.6.

A relationship between TSS and turbidity was determined. Plots for the two gaging sites are shown in Figures 4.7 and 4.8, with their corresponding regression equations. A fairly good relationship is again apparent, indicating that turbidity values in the stream could be estimated from TSS measurements. It should be noted that the relationships are somewhat different for each stream, so application of the equations should be site-specific and are for flowing water only (i.e. not for a lake). Differences between streams arise from differences in sediment size, particle size distribution, shape, density, and color.

Particle-size distribution plots are presented in Figure 4.9 and 4.10 for East Fork and Glacier Fork, respectively. Samples were collected on three dates in 1984: July 20, August 28, and October 23. The median particle size ranges between 5 and 16 microns (10^{-6} meters) at East Fork and between 4 and 17 microns at Glacier Fork. No rationale is apparent to explain the relationship of the three curves at either of the sites. The Glacier Fork samples fit the pattern of decreasing median particle size with decreasing TSS concentration, but this does not apply to East Fork (instantaneous discharge values and corresponding water quality parameters are shown chronologically in Appendix D, Table D.1 for East Fork and Table D.2 for Glacier Fork). The particle-size distribution data are tabulated in Appendix F, Tables F.1-F.6.

The variation in discharge and several of the water quality parameters over a daily cycle was briefly discussed above. The significance of this diurnal variation was investigated by collecting samples from each stream through a continuous 24-hour period. Samples were taken every two hours. The results are plotted in Figures 4.11 and 4.12 for East Fork and Figures 4.13 and 4.14 for Glacier Fork. The first figure in each case (4.11 and 4.13) was from sampling done after several days of overcast weather, while the second sampling trip followed several days marked by clear skies and sunshine. The effect is masked somewhat by a rise in each stream's hydrograph toward the end of the "cloudy" period, caused by the emergence of the sun. However, inspection of the two "cloudy" hydrographs shows a very flat hydrograph between late afternoon and early the next morning. By contrast, the two "sunny" plots have an obvious peak in the flow in the late afternoon or evening and a significant drop overnight. The TSS, turbidity, and water temperature follow patterns similar to that of the streamflows.

Mean daily discharge values for each stream for 1983 and for 1984 are tabulated in Appendix E, Tables E.1-E.4. Table E.5 lists the discharge measurements and corresponding gage heights for each site, and stage-discharge rating curves are presented in Figures E.1 and E.2. Appendices N.4 and N.6 list the daily data for discharge and water temperature (N.4) and suspended-sediment quantities (N.6) for input to the DYRESM model.



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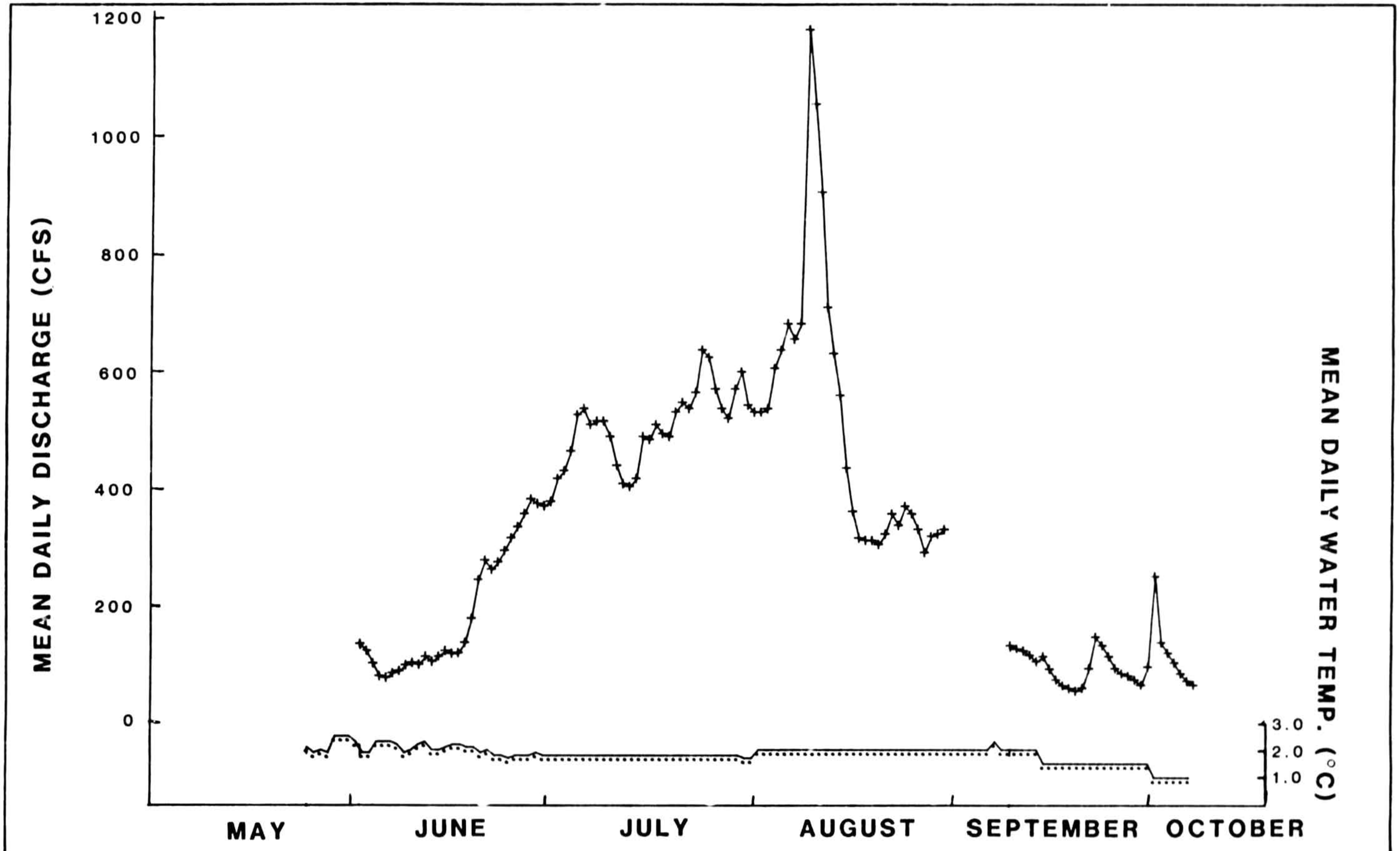
1983 INFLOW DATA
EAST FORK

FIGURE 4.1

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE



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1983 INFLOW DATA
GLACIER FORK

FIGURE 4.2

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

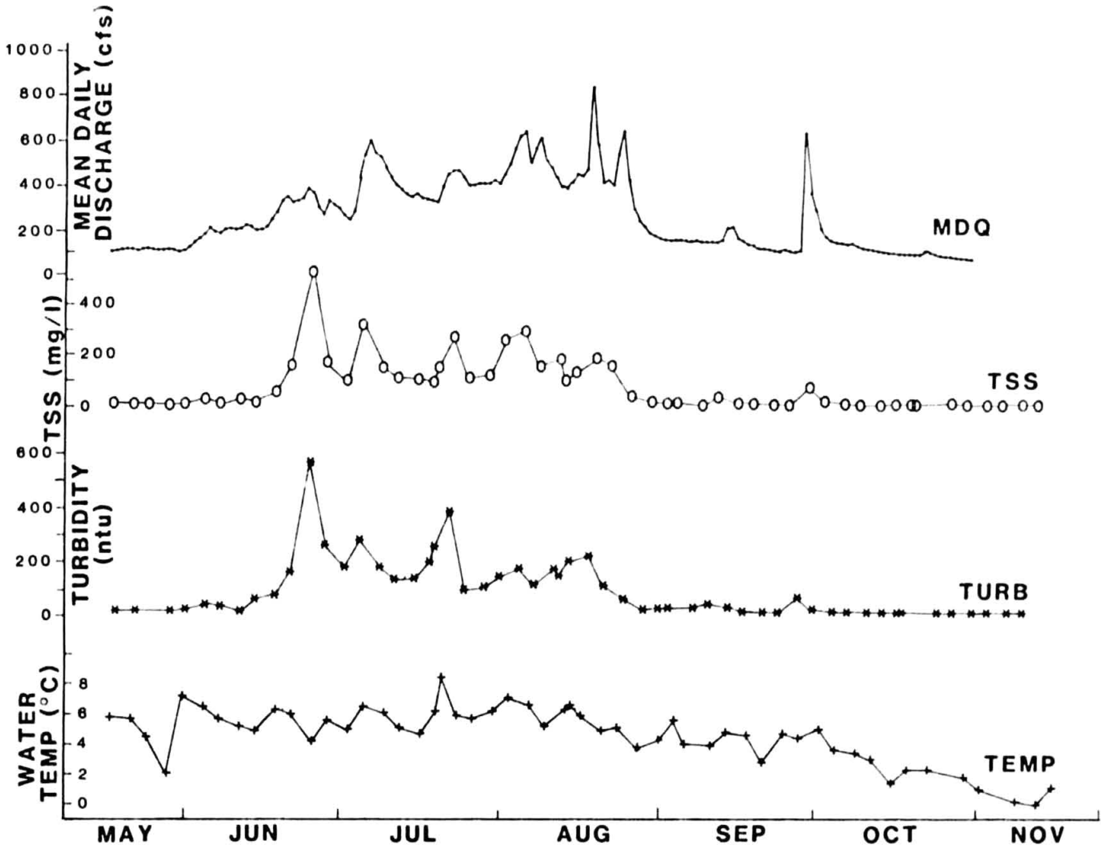

FIGURE 4.3

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	1984 EKLUTNA LAKE INFLOW DATA: EAST FORK	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

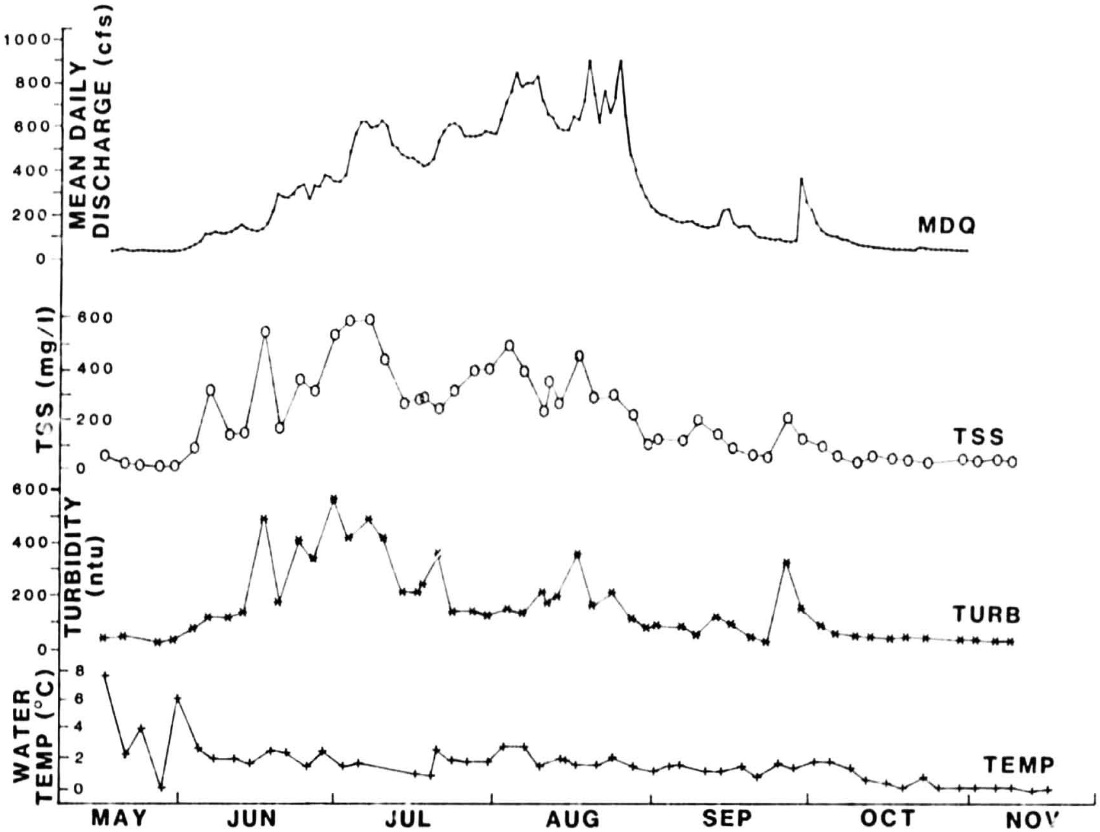

FIGURE 4.4

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R&M R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**1984 EKLUTNA LAKE INFLOW DATA: GLACIER FORK**	HARZA-EBASCO SUSITNA JOINT VENTURE

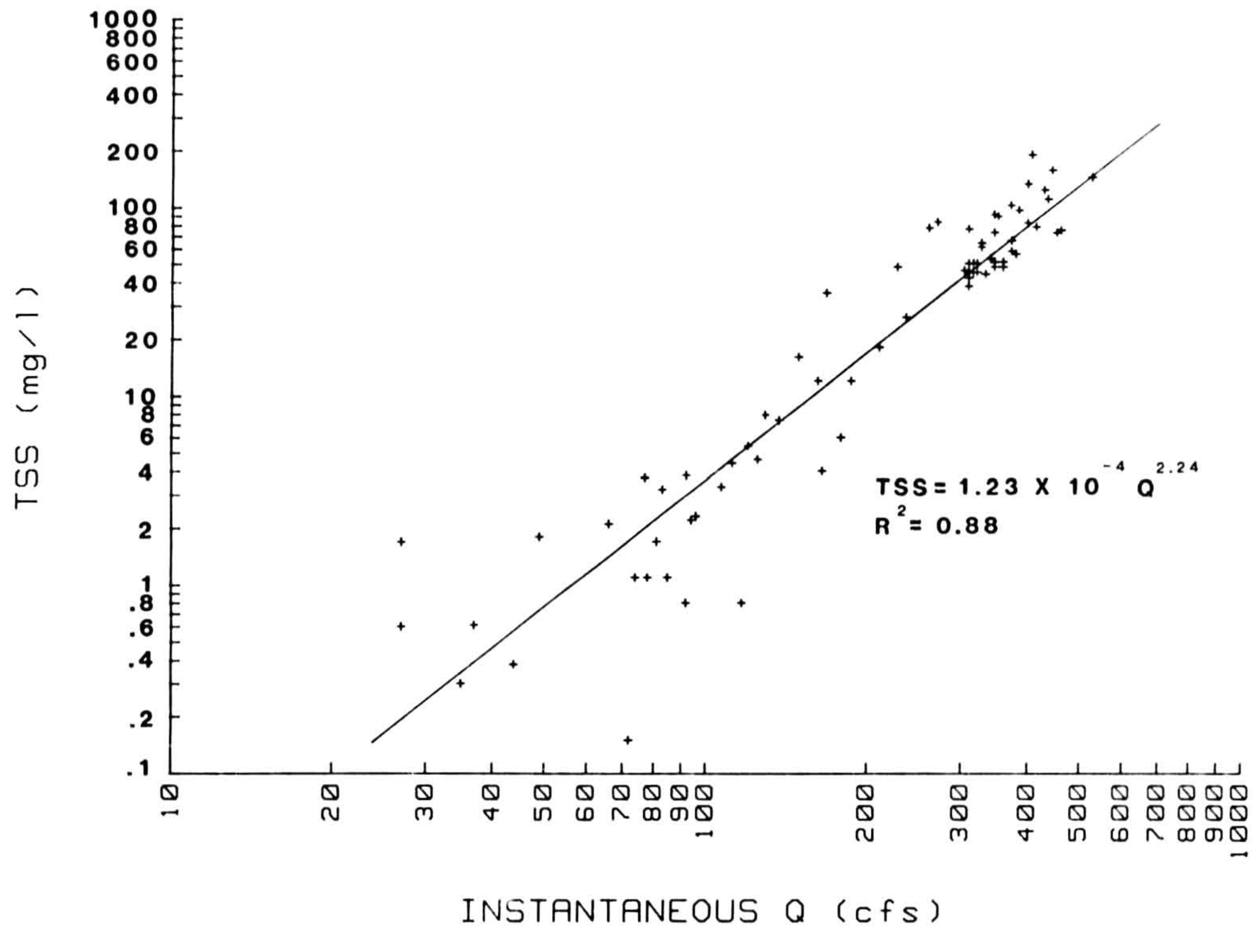

FIGURE 4.5

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1984 EAST FORK DATA:
TSS vs. INSTANTANEOUS FLOW

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

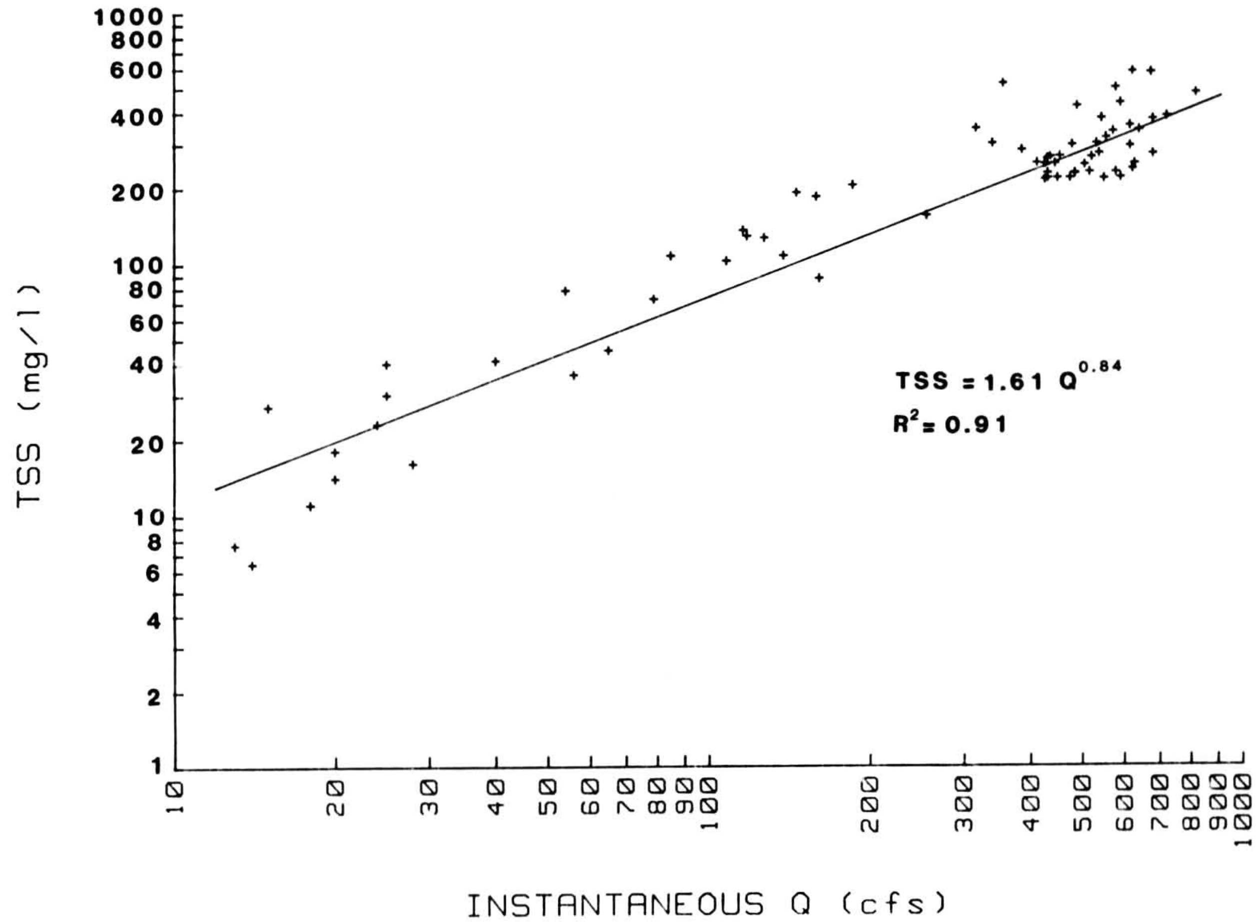

FIGURE 4.6

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R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**1984 GLACIER FORK DATA:** **TSS vs. INSTANTANEOUS FLOW**	HARZA-EBASCO SUSITNA JOINT VENTURE

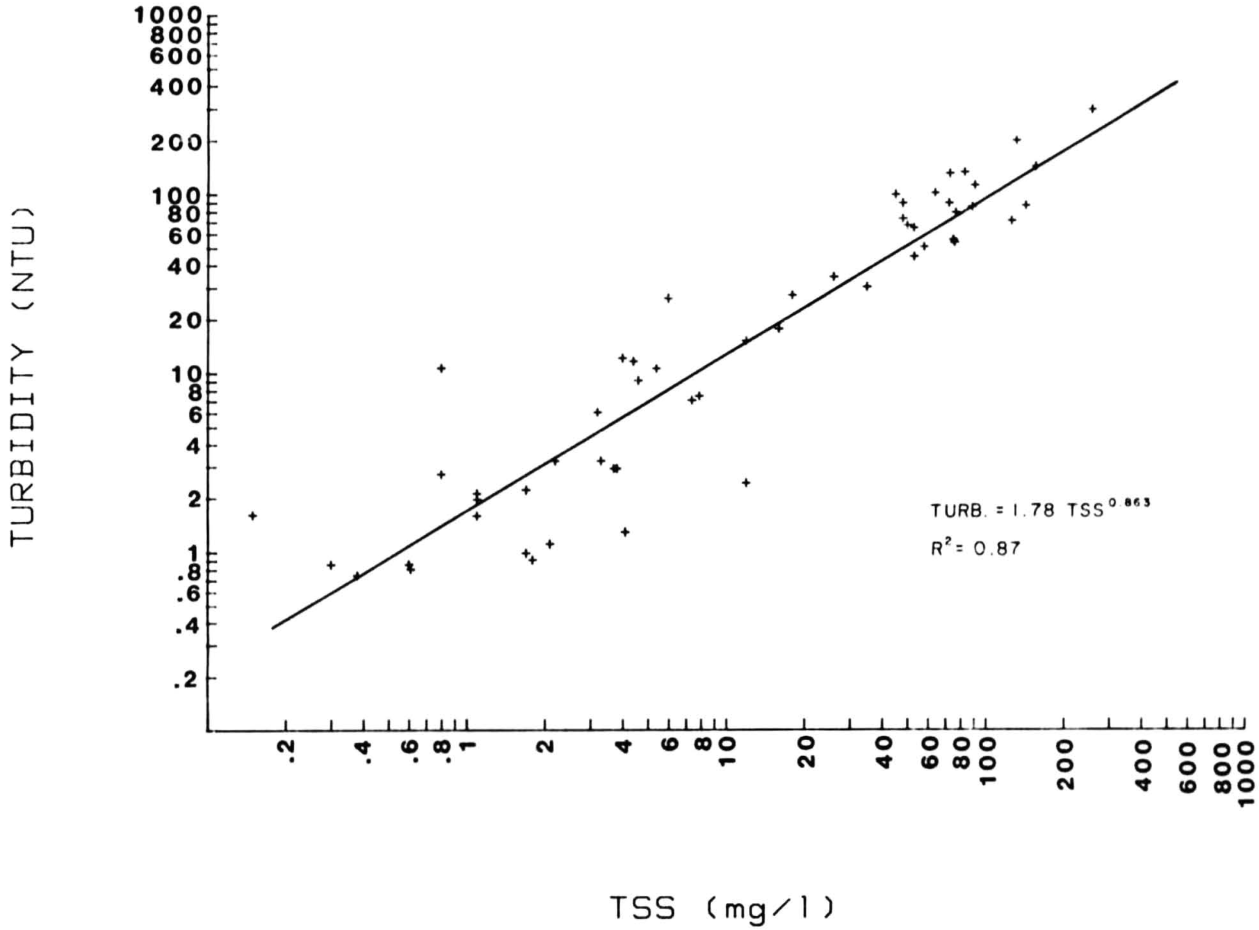

FIGURE 4.7

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1984 EAST FORK DATA: TURBIDITY VS. TOTAL SUSPENDED SOLIDS

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

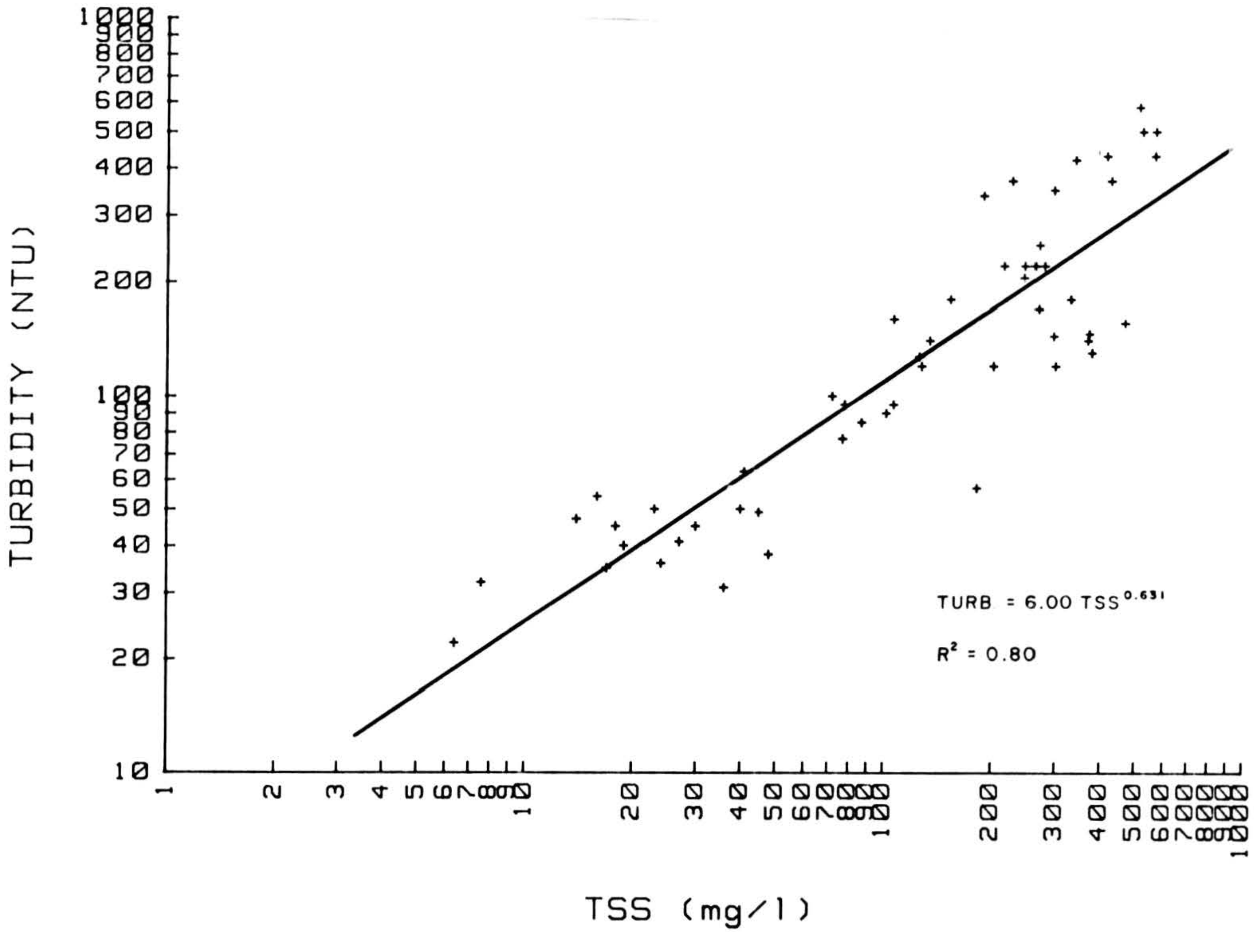

FIGURE 4.8

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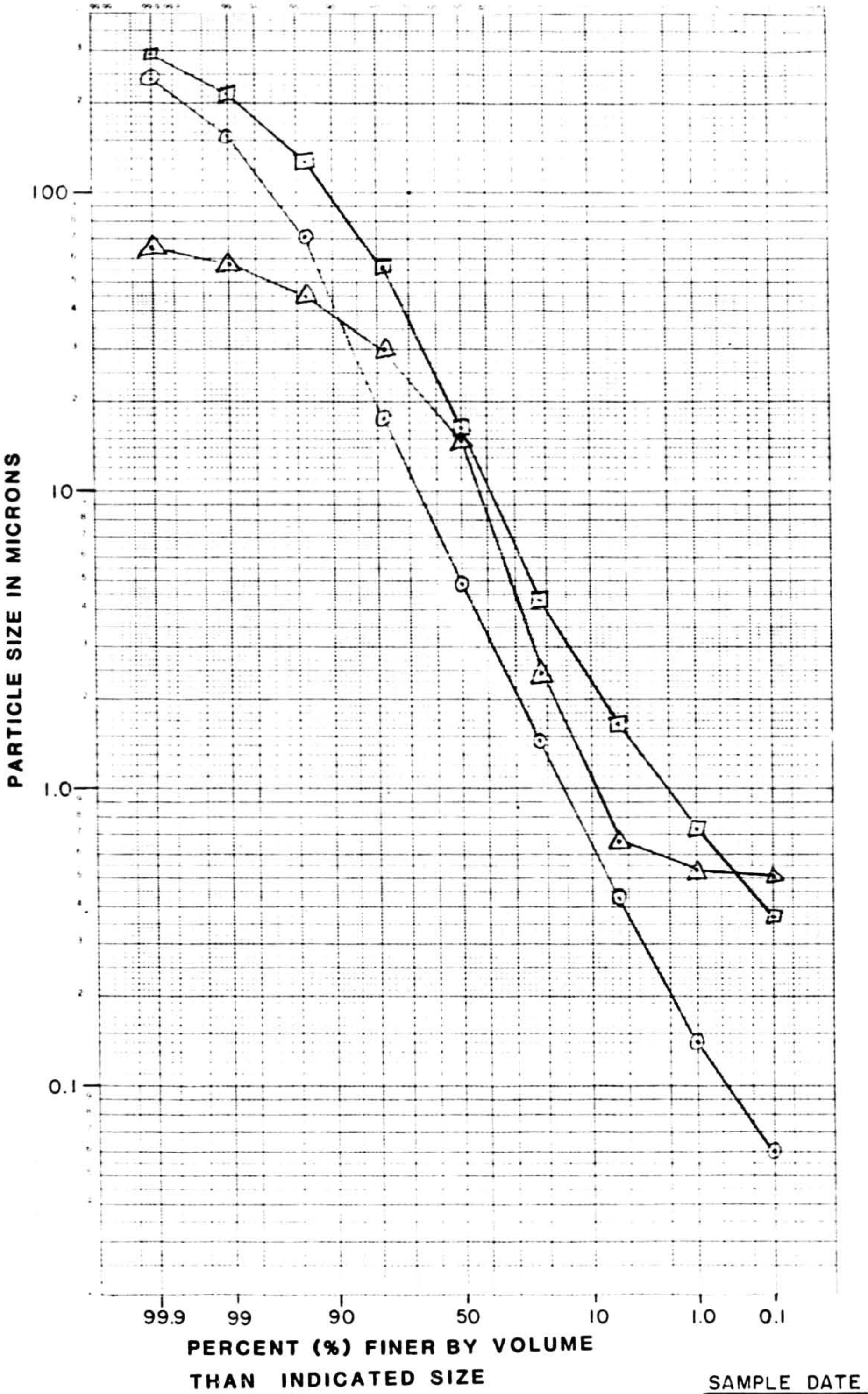
1984 GLACIER FORK DATA: TURBIDITY vs. TOTAL SUSPENDED SOLIDS

PREPARED FOR:

HARZA-EBASCO

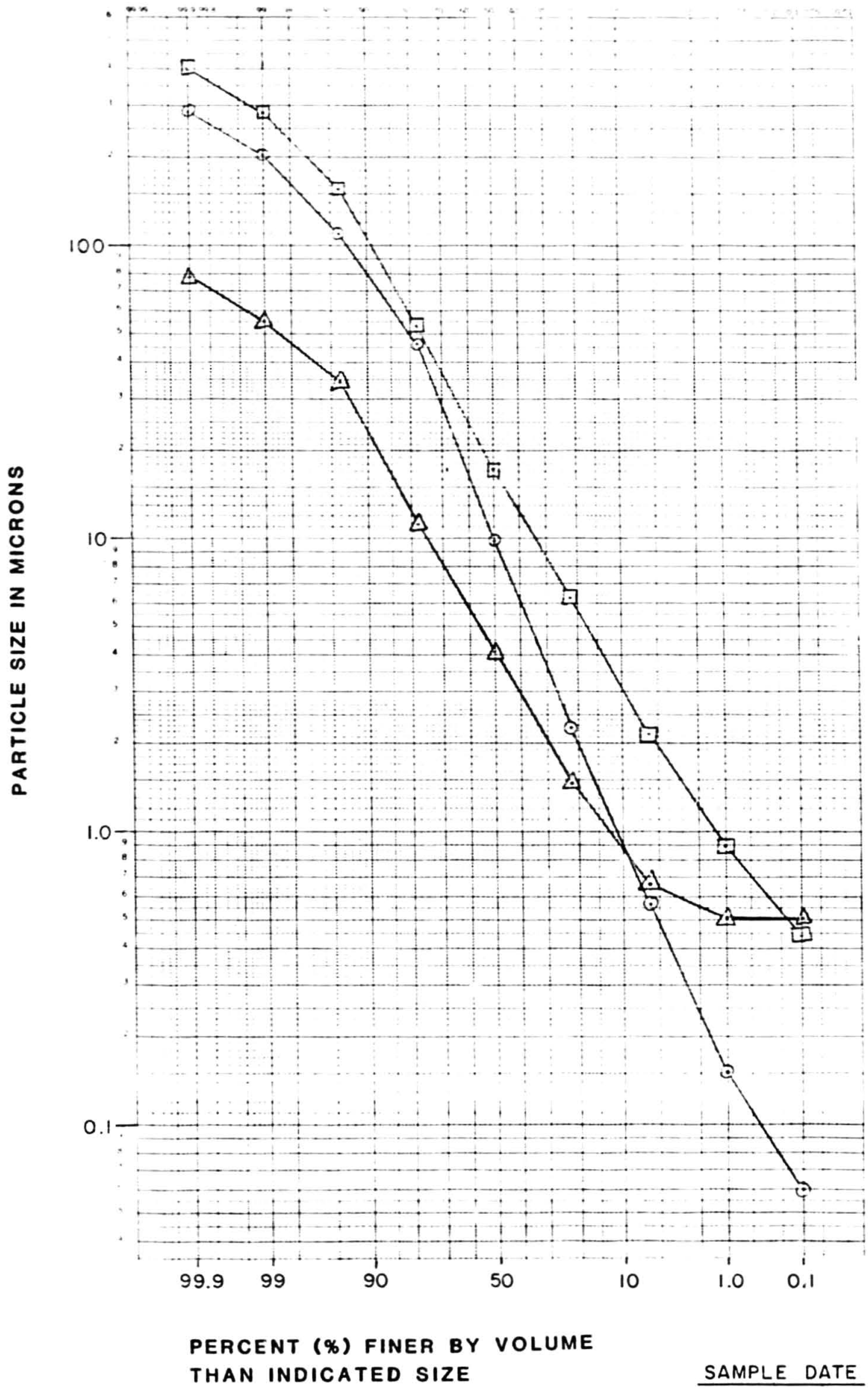
SUSITNA JOINT VENTURE



EAST FORK EKLUTNA CREEK

FIGURE 4.9

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	SUSPENDED SEDIMENT PARTICLE SIZE DISTRIBUTION	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



GLACIER FORK EKLUTNA CREEK

FIGURE 4.10

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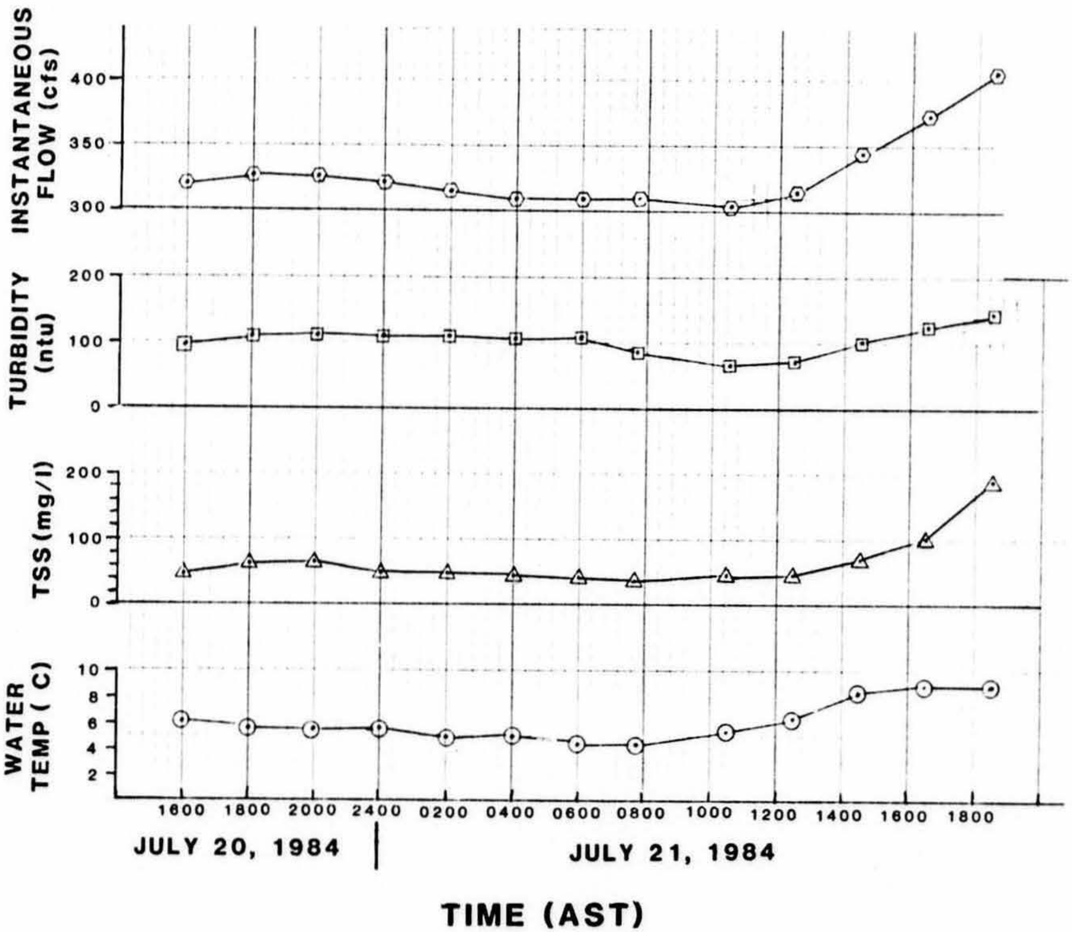

FIGURE 4.11

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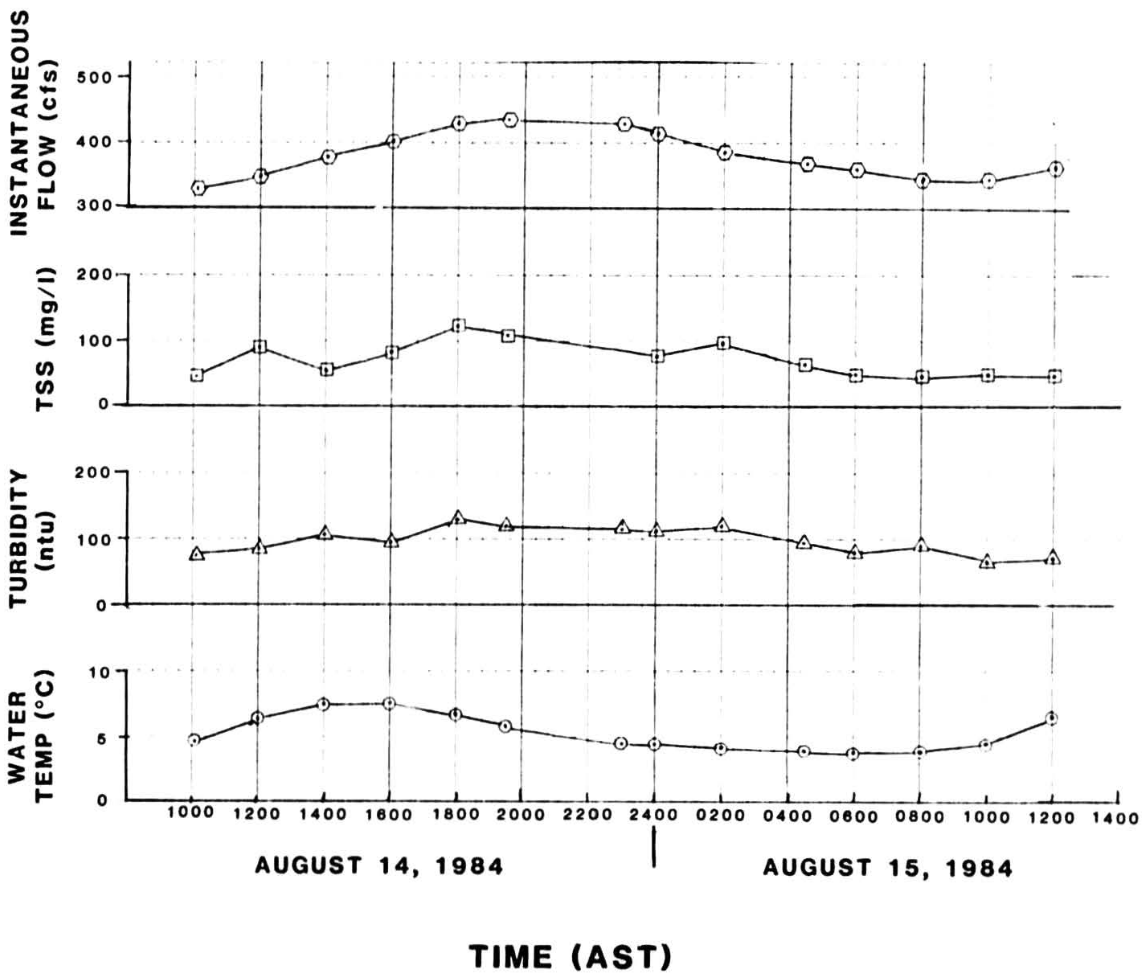

FIGURE 4.12

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R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	DIURNAL VARIATION OF DISCHARGE, TSS, TURBIDITY, AND WATER TEMPERATURE. EAST FORK FOLLOWING A SUNNY PERIOD	HARZA-EBASCO SUSITNA JOINT VENTURE

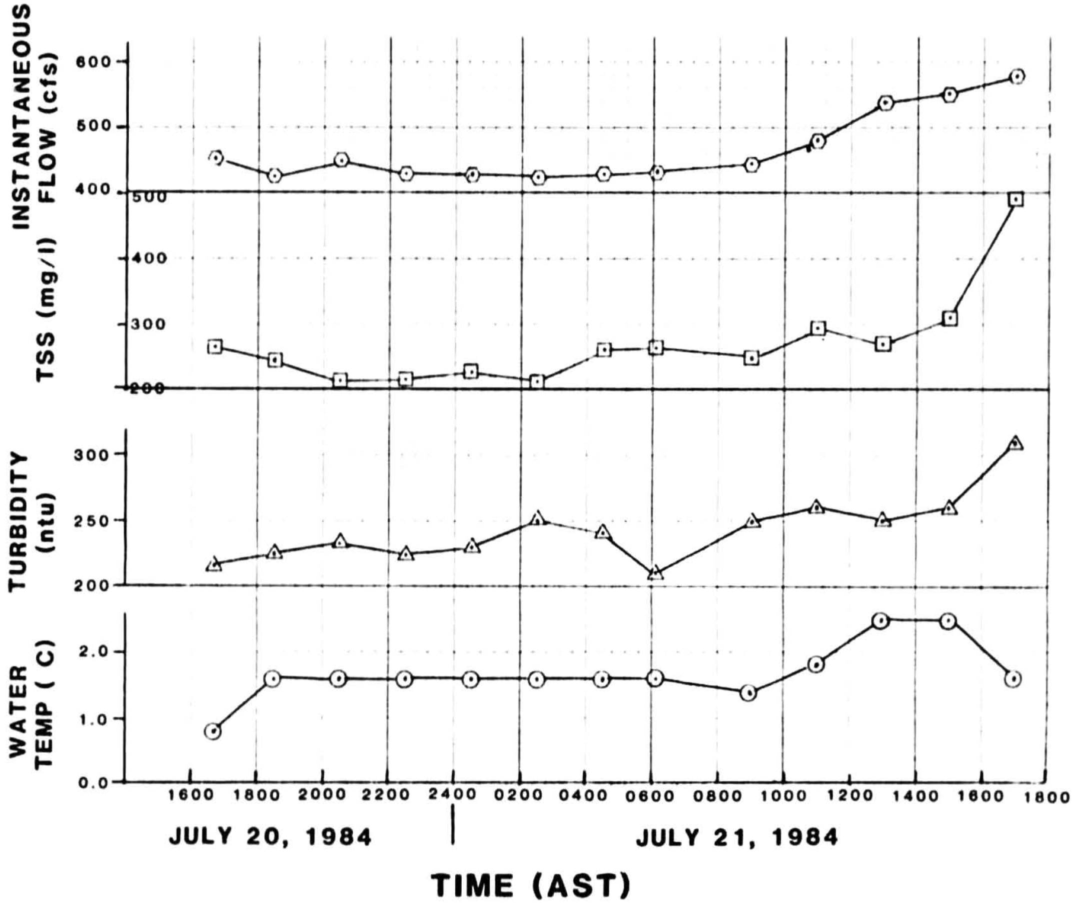

FIGURE 4.13

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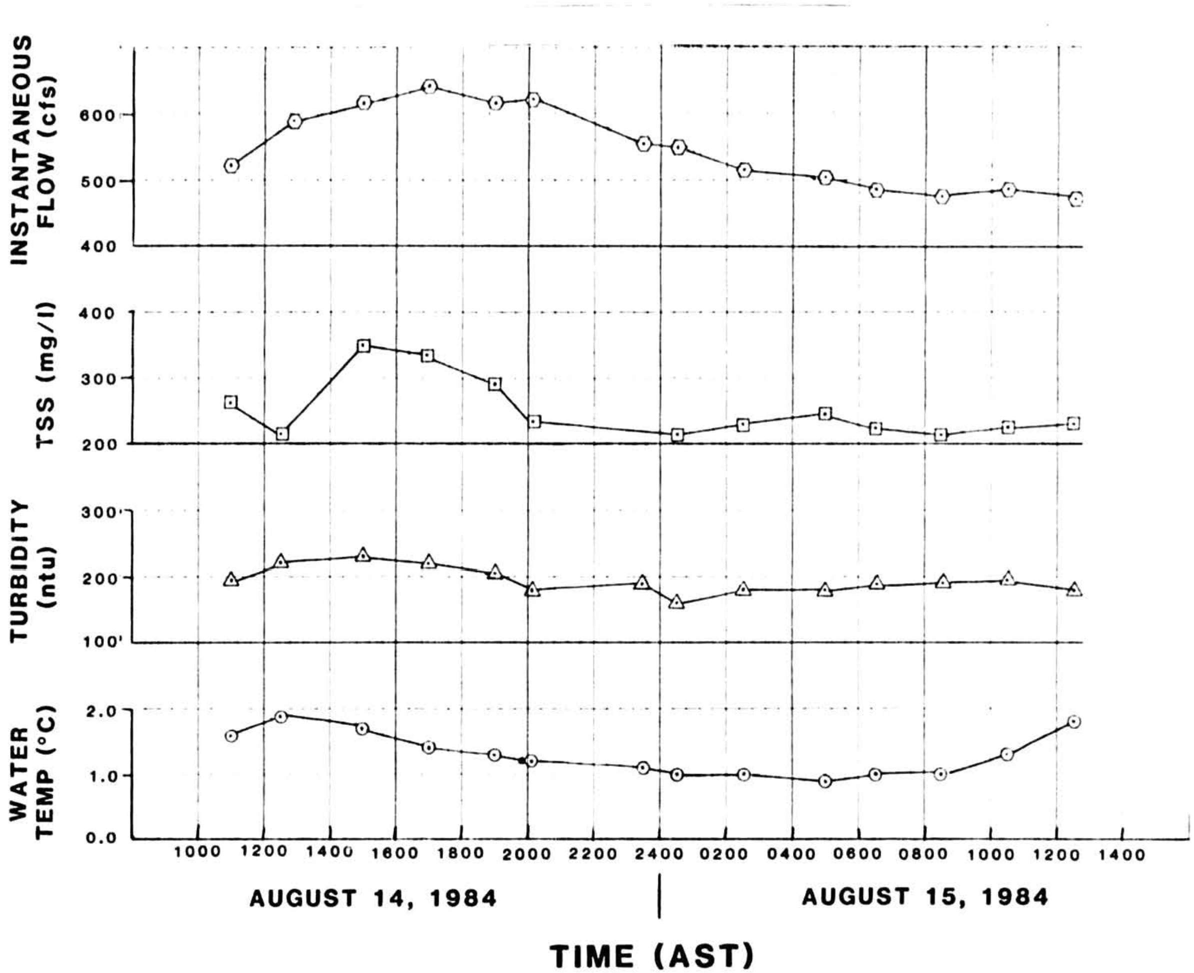

FIGURE 4.14

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5.0 LIMNOLOGY OF EKLUTNA LAKE

5.1 Methodology

Fifteen data-collection stations were selected for the profiling of Eklutna Lake. Station locations are shown in Figure 3.1. Profiling on most dates was done at Stations 1, 2, 5, 9, and 15, in order to sample the lake center and the outlet end and to emphasize the inlet end. The profiling and sampling of Eklutna Lake concentrated on thermal and suspended-sediment measurements for calibrating and verifying the DYRESM model. Data of each type are presented in the interim report (R&M 1982a). Additional lake data collected since 1982 include suspended sediment and light-transmissivity data during 1984 and temperature data during 1983 and 1984.

5.1.1 Temperature and Conductivity

Temperature and conductivity were measured with a Martek Mark VIII Water Quality Monitor. A probe was lowered to depth and readings were taken from the digital display. A mercury thermometer was used for water surface temperature measurements. A Yellow Springs Instrument Company (YSI) Model 33 S-C-T Meter measured conductivity and temperature from 0 to 2 m, and in some cases conductivity from 0-14 m to verify the Martek readings. Conductivity was also measured with the YSI Model 33 on samples taken for TSS and turbidity analyses. The calibration of the Martek Mark VIII was checked prior to making measurements at each station. Temperatures were reported to the nearest 0.1°C and conductivities in micromhos per centimeter at 25°C (APHA et al. 1981).

5.1.2 Continuous Temperature Monitoring

A string of Ryan Model J Thermographs fixed at different depths was suspended from a buoy at Station 9 (Figure 3.1) and provided continuous temperature monitoring. These thermographs were maintained during profiling trips which were performed once every two weeks. Data were reduced to determine mean daily or instantaneous three-hourly temperatures (as needed). Temperatures were adjusted when necessary by comparison with Station 9 temperature profiling measurements.

5.1.3 Light Extinction

Light extinction measurements were performed using a LI-COR Model LI 185B Underwater Photometer, with a model LI-192SB quantum sensor. This instrument measured the number of photons incident per unit time on the surface of a sensor at wavelengths comparable to the visible spectrum (400-700 nanometers or 400-700 x 10^{-9} meters). Readings were taken in the air, just below the water surface (less than 1 cm), and at several depths until complete extinction was reached. The sensor was horizontal, facing vertically upward. Readout from the sensor was via an analog meter in units of micro-Einsteins per square centimeter per second (one Einstein equals 6.02 x 10^{23} photons). The values obtained from point measurements at each station were used to determine the curve:

$$I_Z = I_o e^{-nZ}$$

where I_Z is light intensity or irradiance at depth Z, I_o is irradiance at the surface, and n is an extinction coefficient (Wetzel 1975).

Secchi disk depths were measured to provide backup data with the light extinction measurements made with the photometer. The disk was painted with alternate glossy quadrants of black and white to facilitate definition of the reflective disk surface when submerged. The Secchi depth, as defined by Wetzel (1975), was recorded to the nearest 0.1 foot.

5.1.4 Transmissivity

Transmissivity was measured on two sampling trips using a Sea Tech, Inc., 25-cm Transmissometer. The instrument measured light emitted by an LED (light-emitting diode) at a wave length of 660 nanometers and incident on a synchronous detector. The LED and the sensor were separated by a 25-cm water path. The output signal was read directly as volts, and percent transmittance was calculated from the corrected (calibrated) voltage.

Voltages were corrected through use of a calibration procedure specified by the manufacturer. The percent transmittance was calculated using the following equation:

$$V = (A/B) * (X-Z)$$

where:

V = Corrected output voltage (5 VDC corresponds to 100% Transmission in water)
A = Air calibration value (4.735 VDC)
B = Air calibration (present value)
X = Data value (output voltage measured in water)
Z = Zero offset with the light path blocked (0.000 VDC)

5.1.5 Turbidity

From 1982 until August 1984, turbidity was measured from samples obtained at various depths at selected stations each sampling trip using a brass Kemmerer water sampler (APHA et al, 1981). These samples were analyzed at the R&M office using a Hach Model 16800 Portalab nephelometric turbidimeter, normally within one day of sampling. Samples were kept refrigerated from collection until analysis. From August 1984 to December 1984 turbidity was measured using a Monitek Model 31 Nephelometer. On profiling trips on August 16-19, September 3, September 17, and October 1 in 1984, samples were collected by pumping from depth using a gasoline-powered centrifugal pump and 3/4" and 1" rubber garden hose. The intake was weighted and lowered to the desired depth for sampling. Turbidity was measured in the field with the Monitek Model 31. A 3/8" hose was run from the pump outflow into the nephelometer intake. Most of the flow was directed away from the instrument, taking most air bubbles and gases coming out of the solution with it. The pump was permitted to run long enough at the sampling depth to ensure that the hose was emptied completely of water from the previous depth. Samples were isolated in the instrument by valves, and condensation was wiped off the sample vial when necessary before reading the value from the meter.

When operational, this system provided very reliable data. Its operation was suspended after the October 1 sampling trip because water tended to freeze in the pump at cold temperatures. The Kemmerer sampler was used for the remainder of 1984. Analytical procedures for turbidity were those described in Standard Methods (APHA et al. 1981). Calibration standards were supplied by the instrument manufacturers. Some differences were noted in measurements made with the two instruments, so preliminary values were adjusted using an empirical correction relationship.

5.1.6 Suspended Sediment

Samples analyzed for total suspended solids (TSS) concentration were obtained using the same procedures as those acquired for turbidity testing, described above. Sampling between August 16 and October 1, 1984, inclusive, was performed by retaining one-liter samples from the outflow of the centrifugal pump, after measuring the turbidity. Samples before and after this period were collected by lowering the Kemmerer sampler to the desired depth. After collection, samples were kept refrigerated until delivery to Chemical and Geological Laboratories of Alaska, normally the same day as or the day after sampling. Concentrations were determined by the lab using standard procedures (APHA et al. 1981). Filters with a 0.45-micron pore size were used for the TSS determinations. Particle-size distributions and mineralogic analyses were performed by Particle Data Laboratories, Ltd., of Elmhurst, Illinois. The size distributions were determined by the electrozone method (Karuhn and Berg 1982).

5.2 Results and Discussion

The annual variation of lake temperature at Station 9 is presented in Figures 5.1-5.3 for 1982-1984, respectively. Data were obtained from the periodic lake-profiling trips and from the string of thermographs suspended from a buoy moored at Station 9 at the center of the lake. The position of the lake surface in each plot corresponds to the elevation axis on the right. The depth axis on the left gives the distance from the bottom of the lake to any given point in the lake or on the lake surface. A dashed line indicates the estimated location of an isotherm. Typical of a reservoir operated for hydroelectric power in a northern region, the lake level is highest in September and October (after the summer period of high inflow and low power demand) and lowest in June (following the low-inflow, high-power-demand winter period). The observed annual fluctuation was about 12 meters (40 feet), with the maximum depth at full pool about 62 meters (200 feet). The lake profile data are presented in Appendix G. Profiles of the lake temperature for sampling trips with four or more stations sampled are presented in Appendix H.

Eklutna Lake exhibits two overturn periods annually, indicated by a transition through the 4°C isotherm twice each year - while cooling in the fall and while warming in the spring. The lake becomes isothermal at 6-7°C around October, then cools to maximum density at 4°C until November or early December. Ice formation can begin as soon as a small layer of water at the surface then cools to 0°C, but this is usually delayed by winds which keep the lake mixed and require further cooling of the surface layer. Timing of the freeze-up is dependent on the sequence and magnitudes of winds and air temperatures throughout the period; freeze-up occurred between the first and second weeks of December in each of the past three years. Disappearance of ice on the lake occurred between the second and third weeks of May in 1983-85.

Observed lake temperatures ranged from 0°C immediately below the ice surface during the winter to over 15°C at the lake surface around August 1, 1983. Timing and magnitude of the annual peak temperature in the lake are both dependent on the weather conditions experienced that particular summer. The primary factor would be the amount of wind experienced, as little or no wind would promote formation of a thermocline and allow significant warming of the surface water. The 15°C surface temperature in 1983 occurred during several weeks of little wind activity (see Figure 3.3). The presence of more frequent or stronger winds would tend to mix the warmer surface water with the underlying cooler water. Notice the plunging of the 7° isotherm in mid-September 1982 (Figure 5.1), which followed several days of strong, southeast winds blowing down the lake.

The effects of the weather, especially wind, on the lake thermodynamics are shown in greater detail in Figures 5.4-5.6. Here, a one-week period containing a significant wind event was selected from each year and plotted at enlarged scale. Hourly water temperatures were taken from the thermograph string at Station 9 and shown with 30-minute or 60-minute weather data (air temperature, wind direction, and windspeed) for comparison. Occurrences of the major winds produced a noticeable response: considerable "rippling" and steepening of the isotherms (especially in 1983), indicating mixing in the lake.

Plots similar to the isotherm plots were also prepared for turbidity: "iso-turbidity" lines as functions of time and depth are shown in Figures 5.7-5.9 for Station 9 in 1982-1984. The same conventions apply with the elevation, depth, and lake surface on the plots as were explained above for the isotherm plots. The number and frequency of turbidity samples each year are indicated to provide the reader an indication of the data used to develop these plots.

One noteworthy feature of the iso-turbidity plots is the range of turbidity observed (low values of 10 NTU and less in the spring and early summer before the glacial inflow begins, and high values of 60 NTU and above in August and late September-early October). Another is the time and depth where the high values occur. These data are for the center of the lake, so the effect of the heavy sediment inflow at the head of the lake is delayed several days before it is noticed at Station 9. It is interesting that similar patterns appear in the turbidity values in August and September of both 1982 and 1984 (the data collected in 1983 may have been too sparse to measure it then). The high values (of 60-70 NTU) first occurred in mid-August, about 10-15 meters below the surface. The sediment plume from the inflow stream had apparently reached station 9 at this time, travelling as an interflow. Then the lake experienced some mixing due to wind, and the high concentration dropped to the bottom of the lake by mid-September (1982) or early October (1984). The lake may have become better-mixed thermally by this time, allowing the water density to be governed more by the concentration of suspended sediment and to become initially stratified on that basis. Further cooling of the surface water evidently promoted mixing of the entire lake depth, which diluted the highly-turbid water at the bottom. Settling of the sediment particles undoubtedly occurred as well.

Figures 5.10-5.12 show variation in light-penetration characteristics of the lake surface water through the summer season-one plot for each year. Measurements of quantum extinction coefficient (in m^{-1}) and Secchi disk depth are each plotted versus time on their own axes. Data for 1982 and 1984 are for Station 9 only, while the 1983 data are from various lake stations because of insufficient data at Station 9. Notice that the Secchi disk depth axis increases downward. A direct relationship is quite apparent: as the extinction coefficient increases, the Secchi disk depth decreases, as one would expect. An increasing extinction coefficient means that light is unable to penetrate as far below the water surface. Secchi disk depths ranged from 1.2-8.0 feet, lowest in July and August and greatest in June. Extinction coefficients varied between 0.4 and 2.3 m^{-1}, low in May and high in August. Corresponding euphotic levels, the depths at which only 1% of the incident solar energy is available, ranged from 1.9 to over 9 meters, for the 2.3 and 0.4 extinction coefficients, respectively. The complete set of light-penetration data is presented in Appendix I: Table I.1 gives the lake measurements of quantum extinction, and Table I.2 lists the lake Secchi disk measurements.

Extinction coefficient was compared with Secchi disk depth, surface turbidity (i.e. the turbidity in the euphotic zone), and surface transmissivity (Figures 5.13-5.17). Figure 5.16 compares Secchi disk depth with surface turbidity measurements, and Figure 5.17 relates TSS concentrations with turbidity for all lake values.

Figure 5.13 shows an exponential or hyperbolic relationship between extinction coefficient and Secchi disk depth, asymptotic to a Secchi disk depth of zero for a large coefficient and to a coefficient of zero for a large Secchi disk depth. The plot indicates that a Secchi disk reading could be used reasonably well to predict quantum extinction coefficient in Eklutna Lake, though the relationship was not determined.

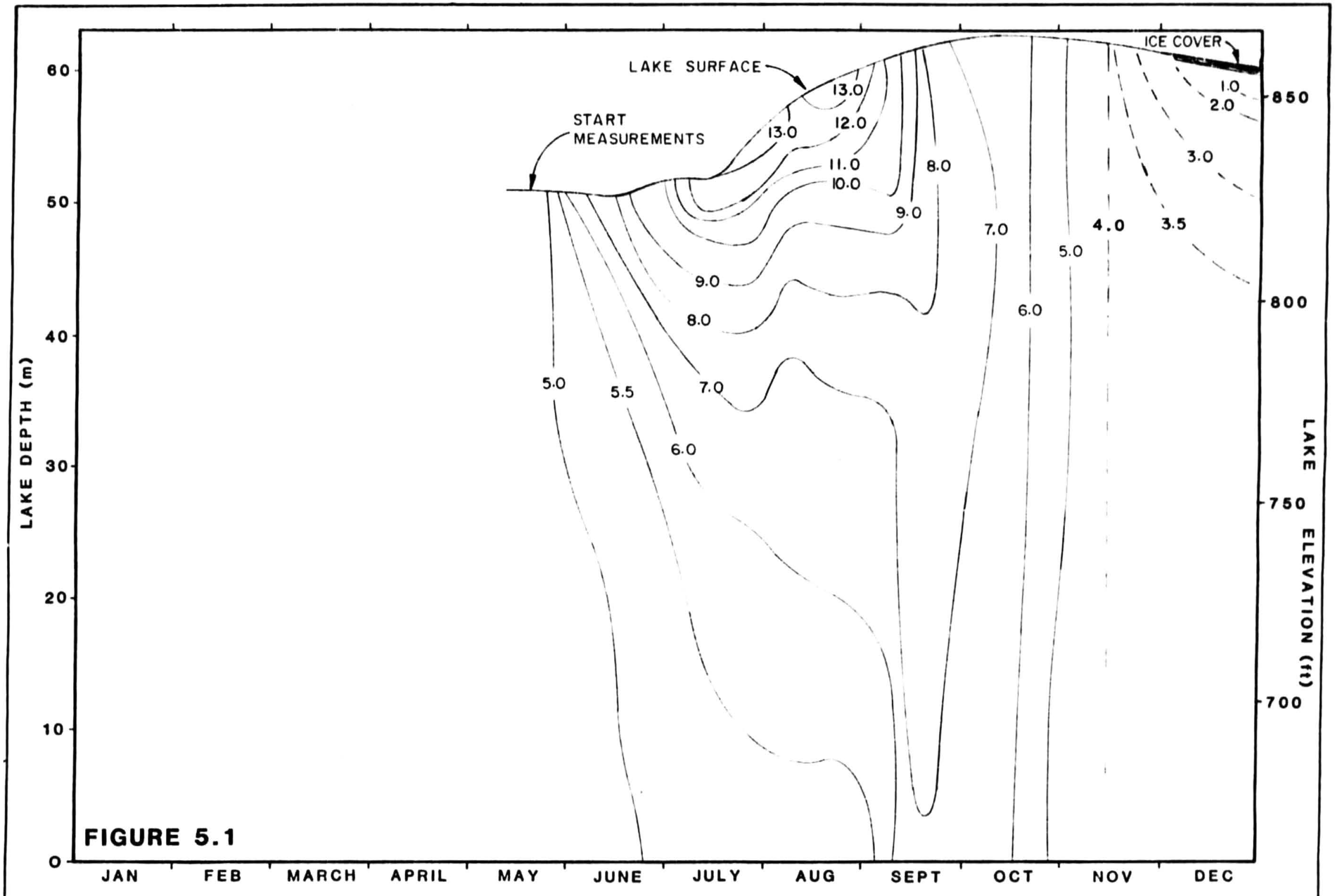
Figure 5.14, lake surface turbidity as a function of extinction coefficient, again indicates a fairly good relationship. There is some scatter in the plot at the higher end, adding uncertainty to prediction of extinction coefficients for higher turbidity values in the lake. There is one point with an extremely high turbidity and extinction coefficient. This point is for data obtained at Station 1, at the mouth of the inflow stream. Data from Station 1 are generally very unreliable to use in relationships between parameters. The inflow plume was often extremely variable in its horizontal position at the junction with the lake, shifting rapidly from side to side. In addition, the stream water immediately begins to entrain lake water in the plume and dilute the sediment concentration. Thus, if one attempts to correlate measurements made on a sample taken from the plume with measurements made **in situ**, there is uncertainty whether the same water conditions are being compared; the plume may be there for the sampling but not for the profiling, or vice versa. Station 1 data were collected to examine the inflow dynamics and to observe the ranges of the parameters experienced there, but the data were normally omitted from regression relationships.

The plot of surface transmissivity as a function of extinction coefficient in Figure 5.15 shows some scatter. There is a scarcity of data, but if the data point in the upper right corner is omitted, a weak exponential relationship is evident. A large extinction coefficient relates to a small transmittance, and vice versa.

The plot of surface turbidity as a function of Secchi disk depth in Figure 5.16 represents another exponential relationship. Finally, the relationship in Figure 5.17 shows all lake values of TSS plotted against corresponding turbidity values. There is quite a bit of scatter evident in the plot (R^2=0.33), due to consolidation of the data for the entire lake. Differences in the relationship come from differences in the time of settling, changes in the sediment characteristics with time, and other factors.

Supporting lake profiling data are included in several of the appendices. Appendix G contains the individual tables from sampling trips, a sheet for each station on each date. Plots of lake isopleths are presented in Appendices H and J. Figures H.1-H.20 show the temperature condition of the lake for each sampling date when profiles were taken at four or more lake stations. Figures J.1 and J.2 present turbidity and light-transmittance isopleths, respectively, for a sampling trip in August 1984 when all 15 lake stations were profiled during a five-day period. In Appendix K, Tables K.1-K.9 provide a summary for each month from

March through November 1984 of all the field data collected at Eklutna Lake.



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ISOTHERM DEPTH vs. TIME
EKLUTNA LAKE at STATION 9
1982

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

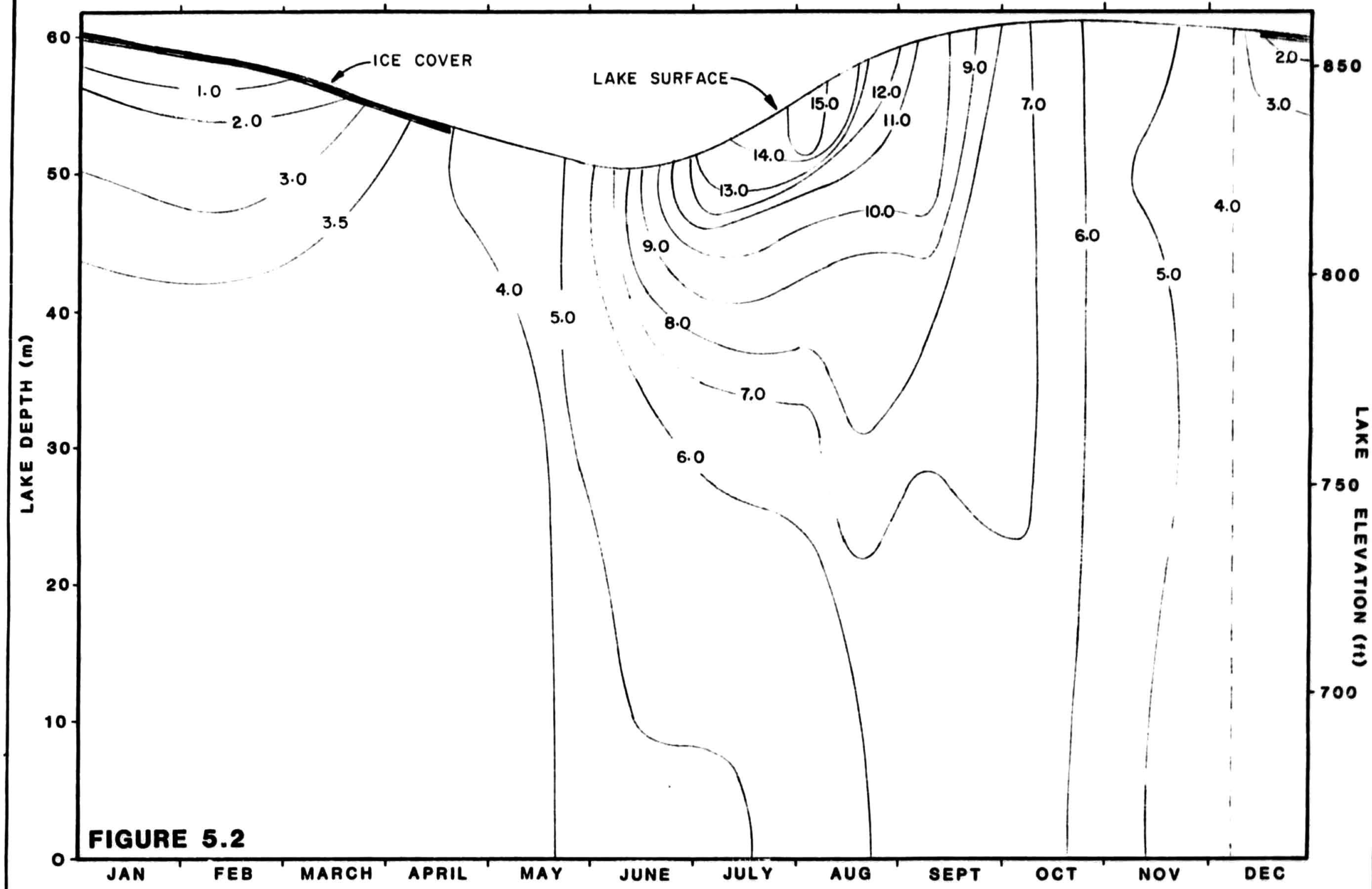

FIGURE 5.2

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ISOTHERM DEPTH vs. TIME
EKLUTNA LAKE at STATION 9
1983

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

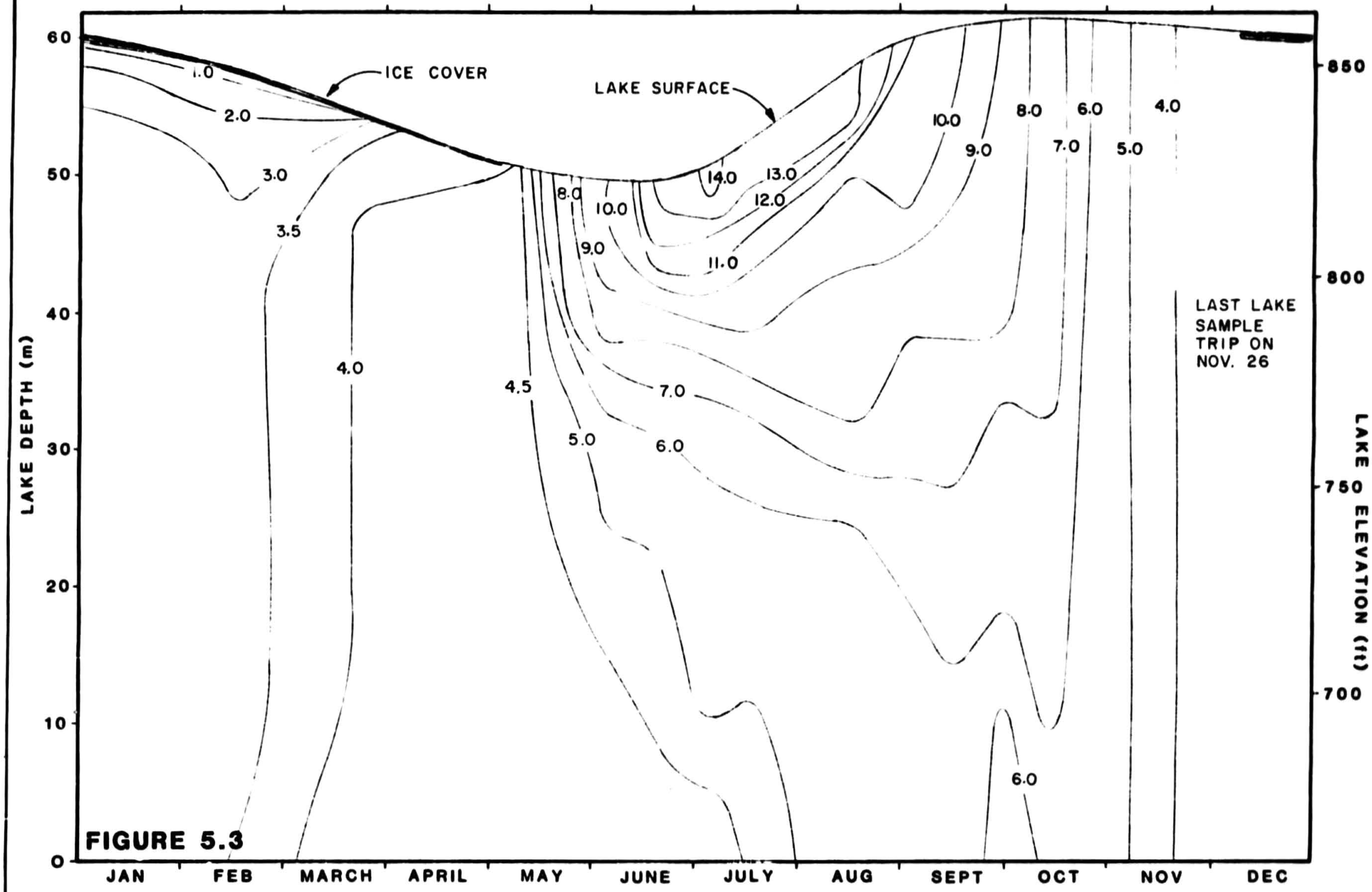

FIGURE 5.3

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ISOTHERM DEPTH vs. TIME
EKLUTNA LAKE at STATION 9
1984

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

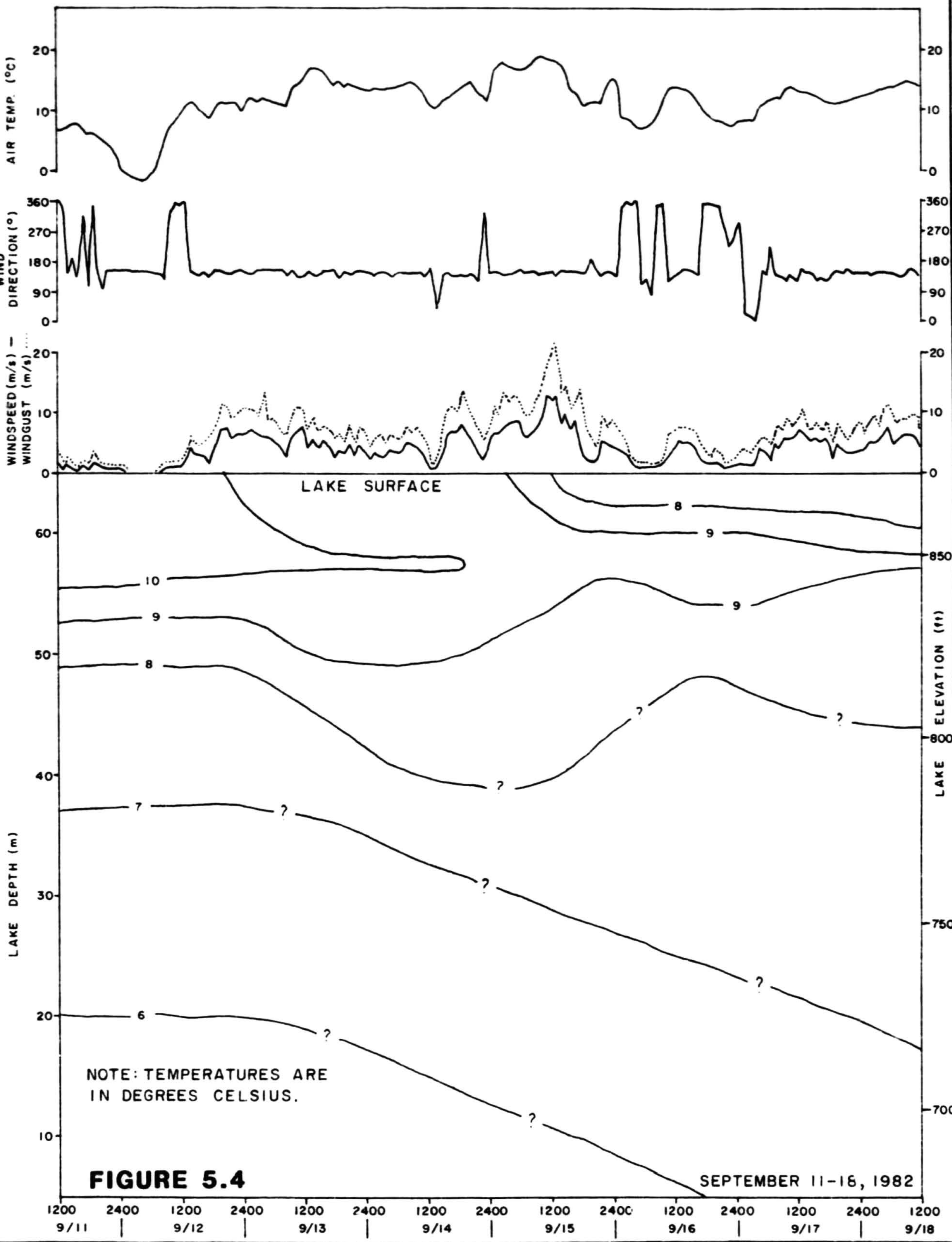

FIGURE 5.4

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

COMPARISON OF STATION 9 LAKE TEMPERATURES WITH WINDSPEED, DIRECTION AND AIR TEMPERATURE

PREPARED FOR:
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SUSITNA JOINT VENTURE

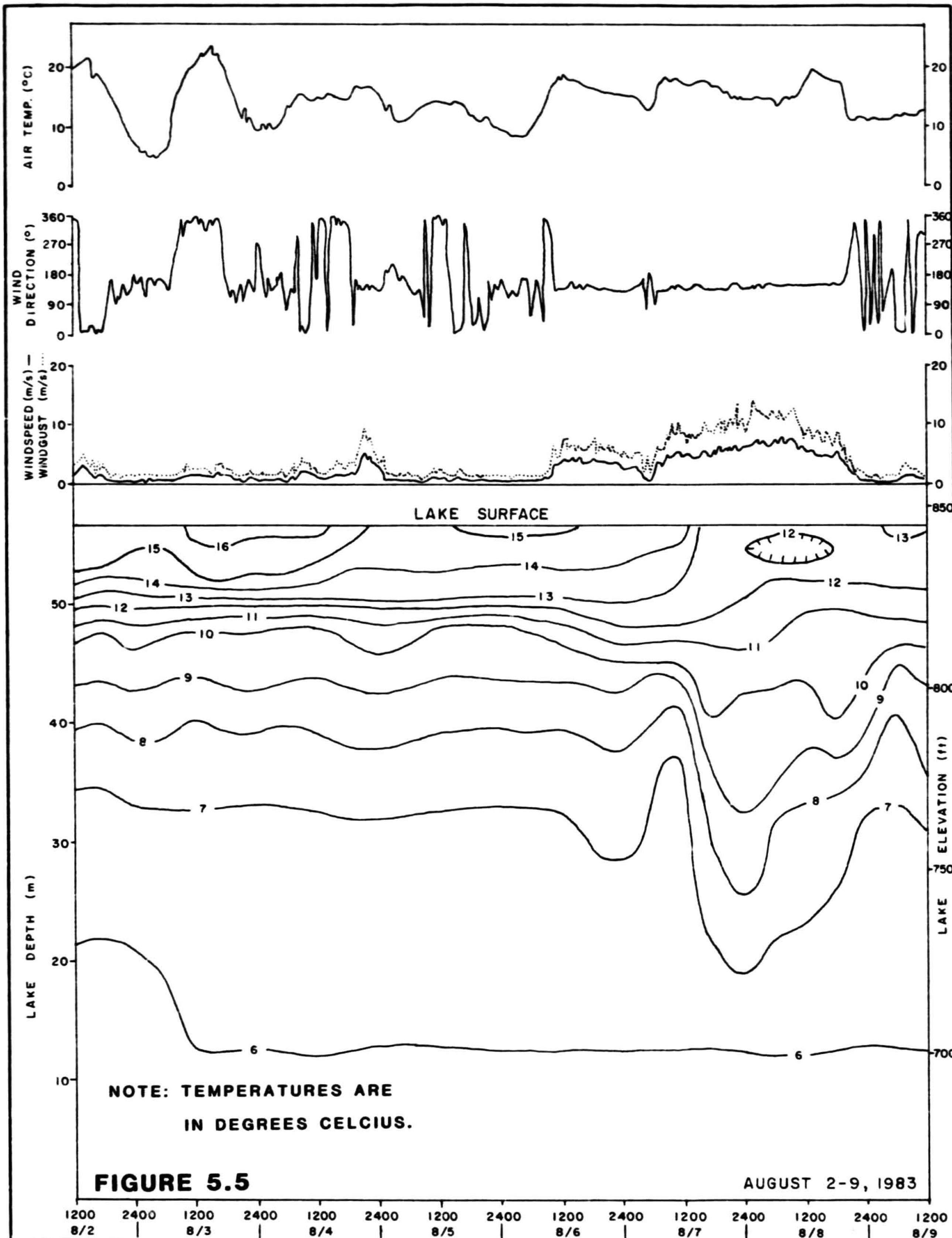

FIGURE 5.5

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC.	COMPARISON OF STATION 9 LAKE TEMPERATURES WITH WINDSPEED, DIRECTION AND AIR TEMPERATURE	HARZA-EBASCO SUSITNA JOINT VENTURE

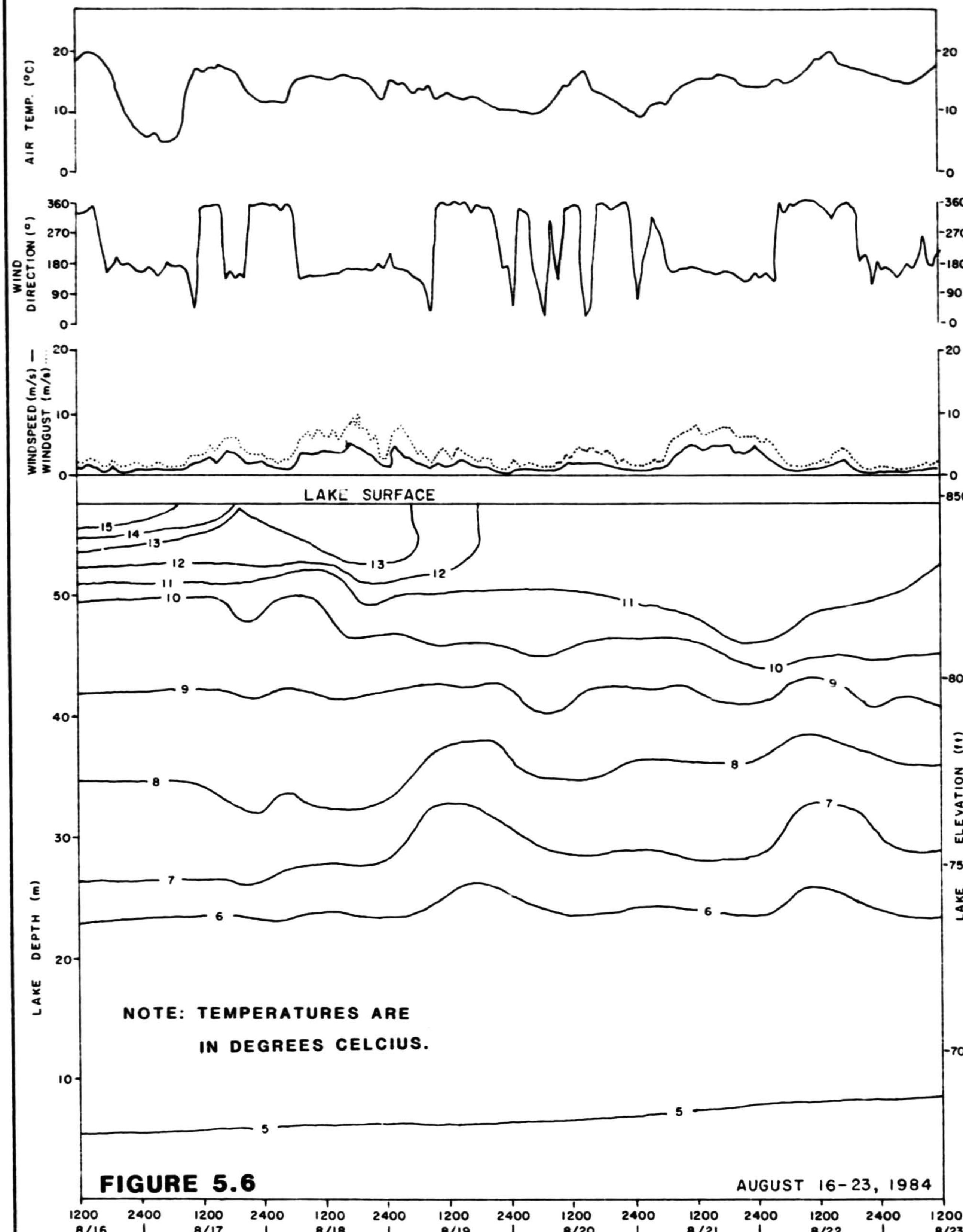

FIGURE 5.6

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	COMPARISON OF STATION 9 LAKE TEMPERATURES WITH WINDSPEED, DIRECTION AND AIR TEMPERATURE	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

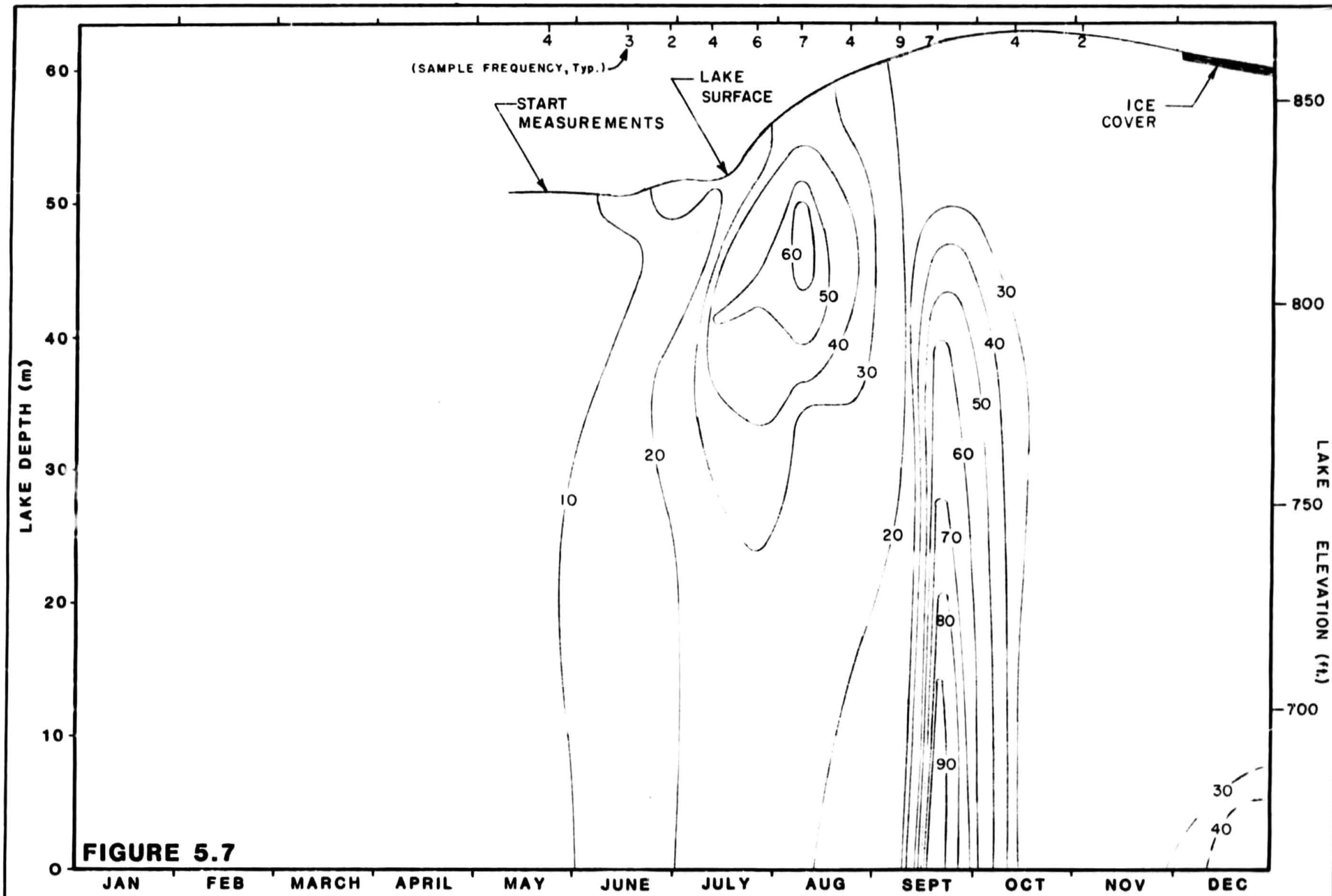

FIGURE 5.7

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ISO-TURBIDITY vs. TIME
EKLUTNA LAKE at STATION 9
1982

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

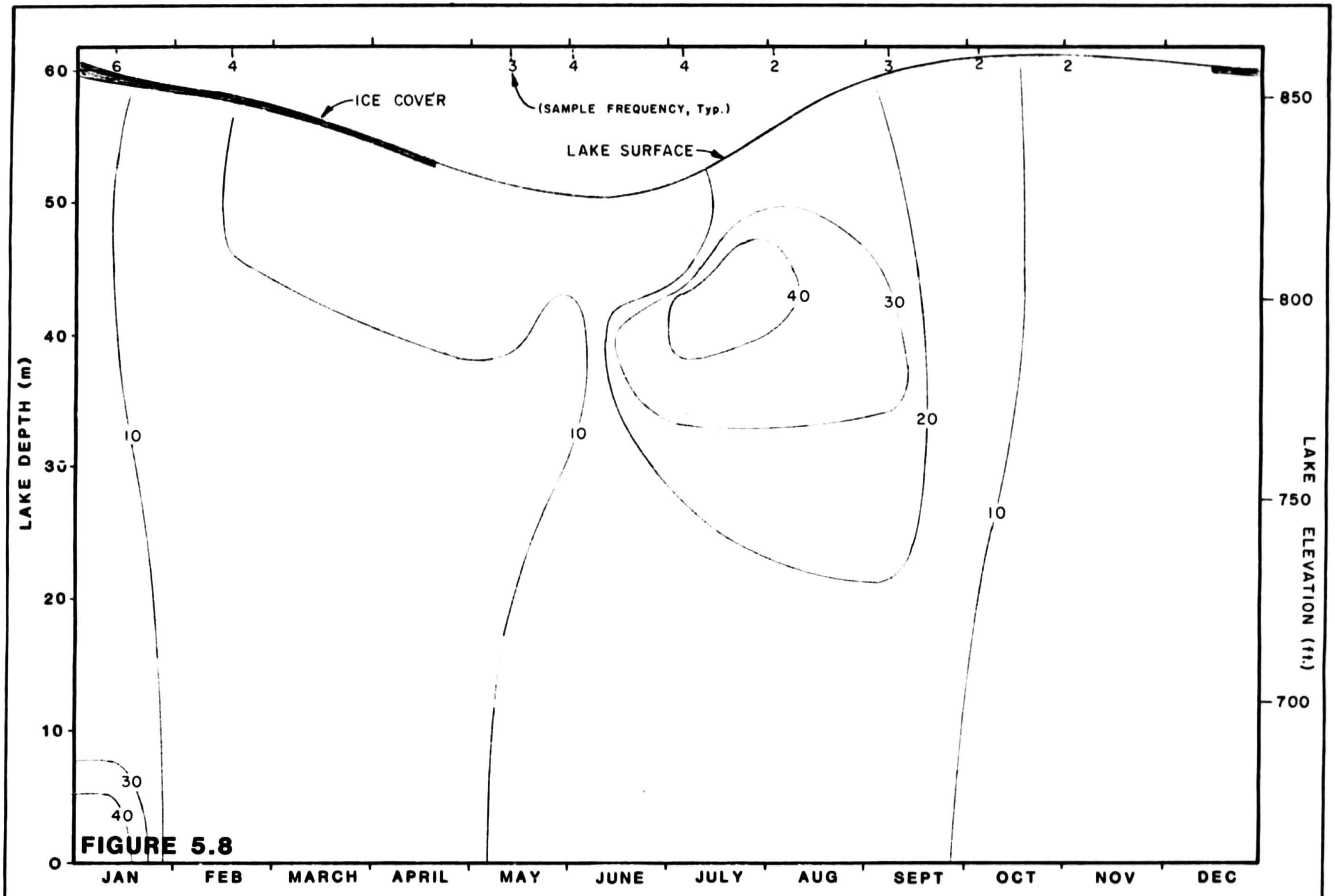

FIGURE 5.8

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**ISO-TURBIDITY vs. TIME EKLUTNA LAKE at STATION 9 1983**	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

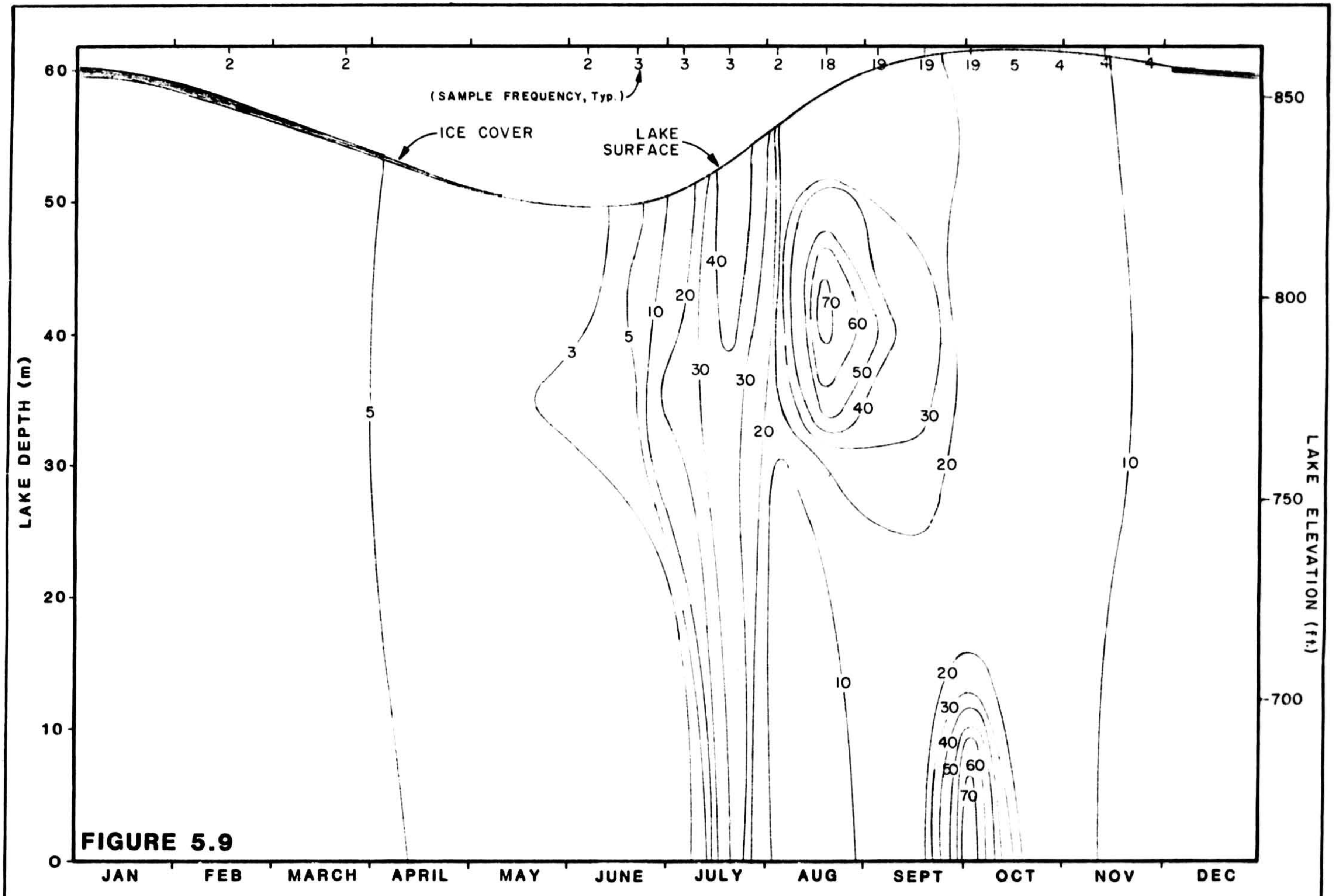

FIGURE 5.9

PREPARED BY:
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ISO-TURBIDITY vs. TIME
EKLUTNA LAKE at STATION 9
1984

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

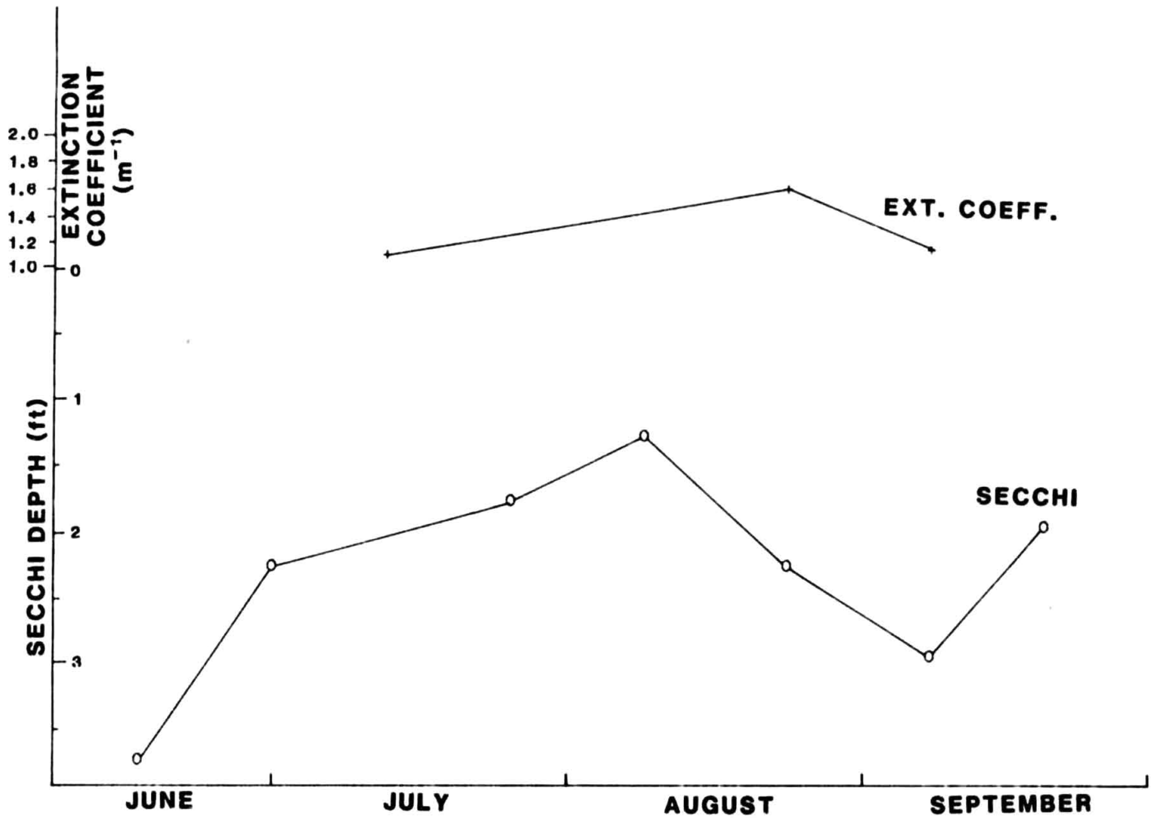

FIGURE 5.10

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	1982 EKLUTNA LAKE SURFACE DATA: STATION 9	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

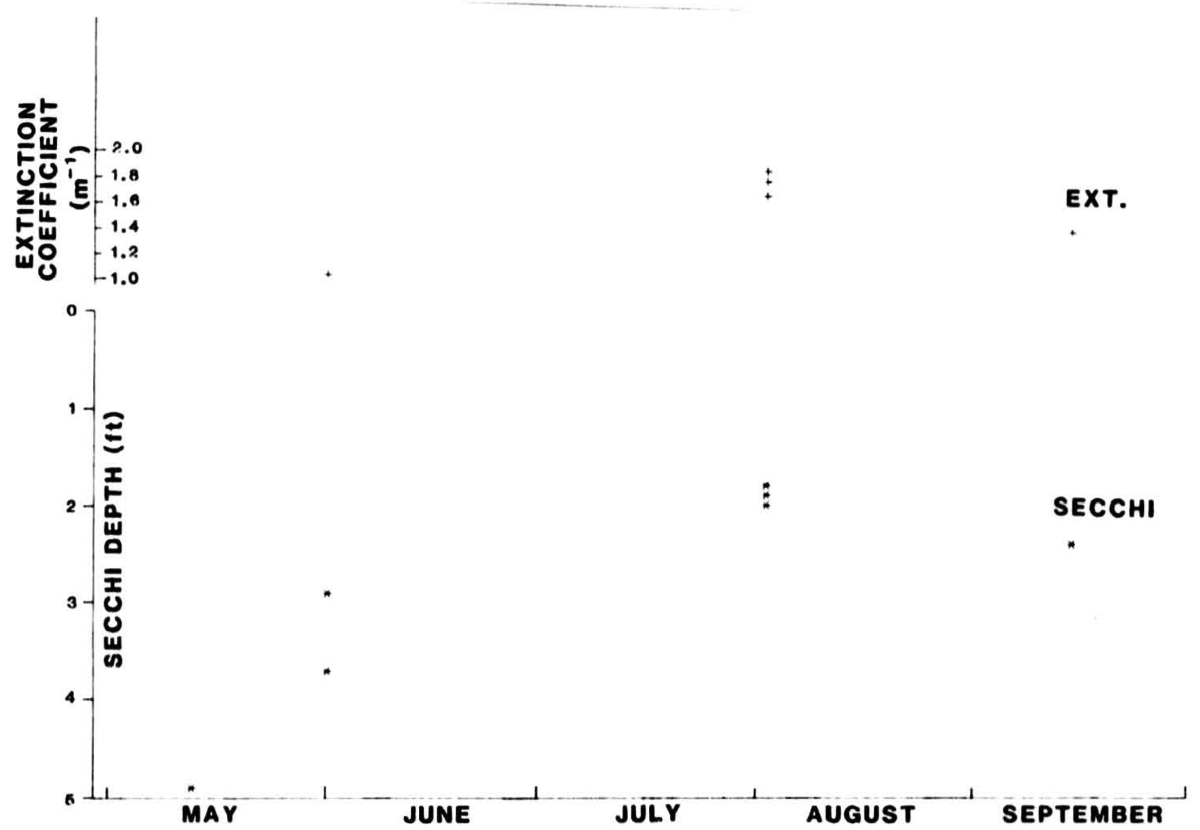

FIGURE 5.11

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1983 EKLUTNA LAKE SURFACE DATA

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

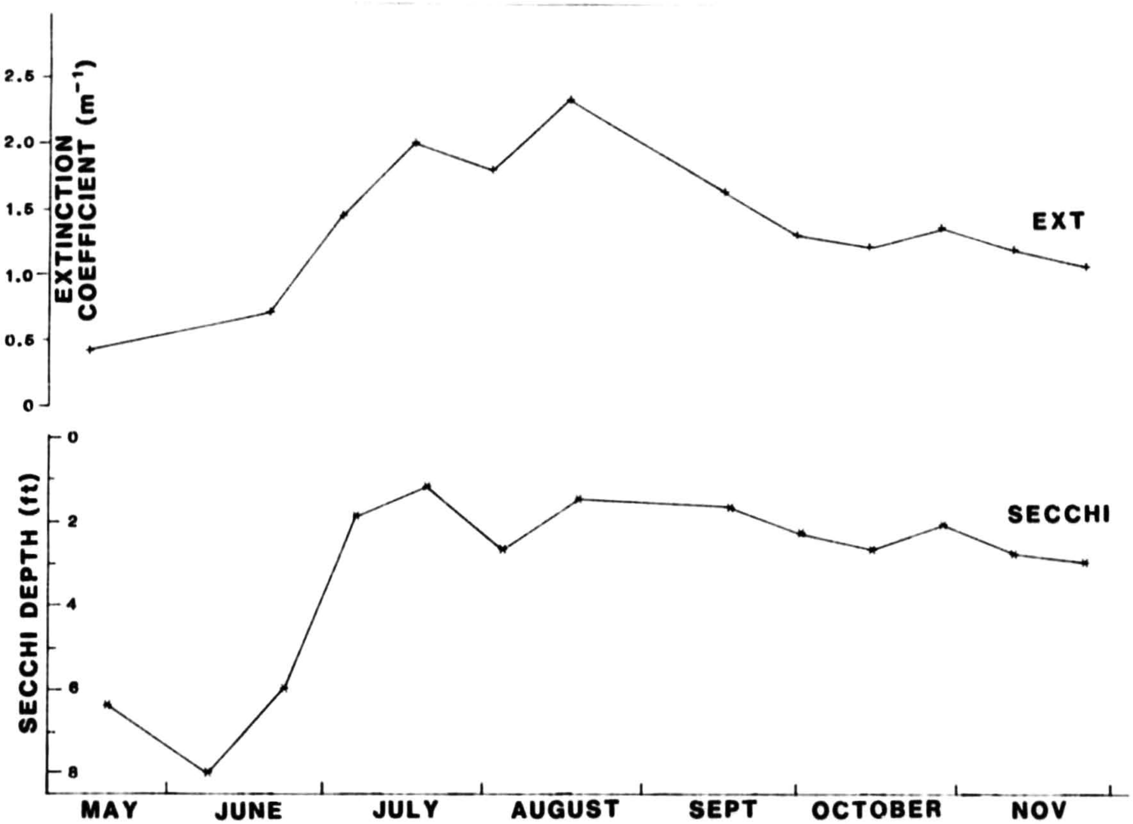

FIGURE 5.12

PREPARED BY:	1984 EKLUTNA LAKE SURFACE DATA: STATION 9	PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS		HARZA-EBASCO SUSITNA JOINT VENTURE

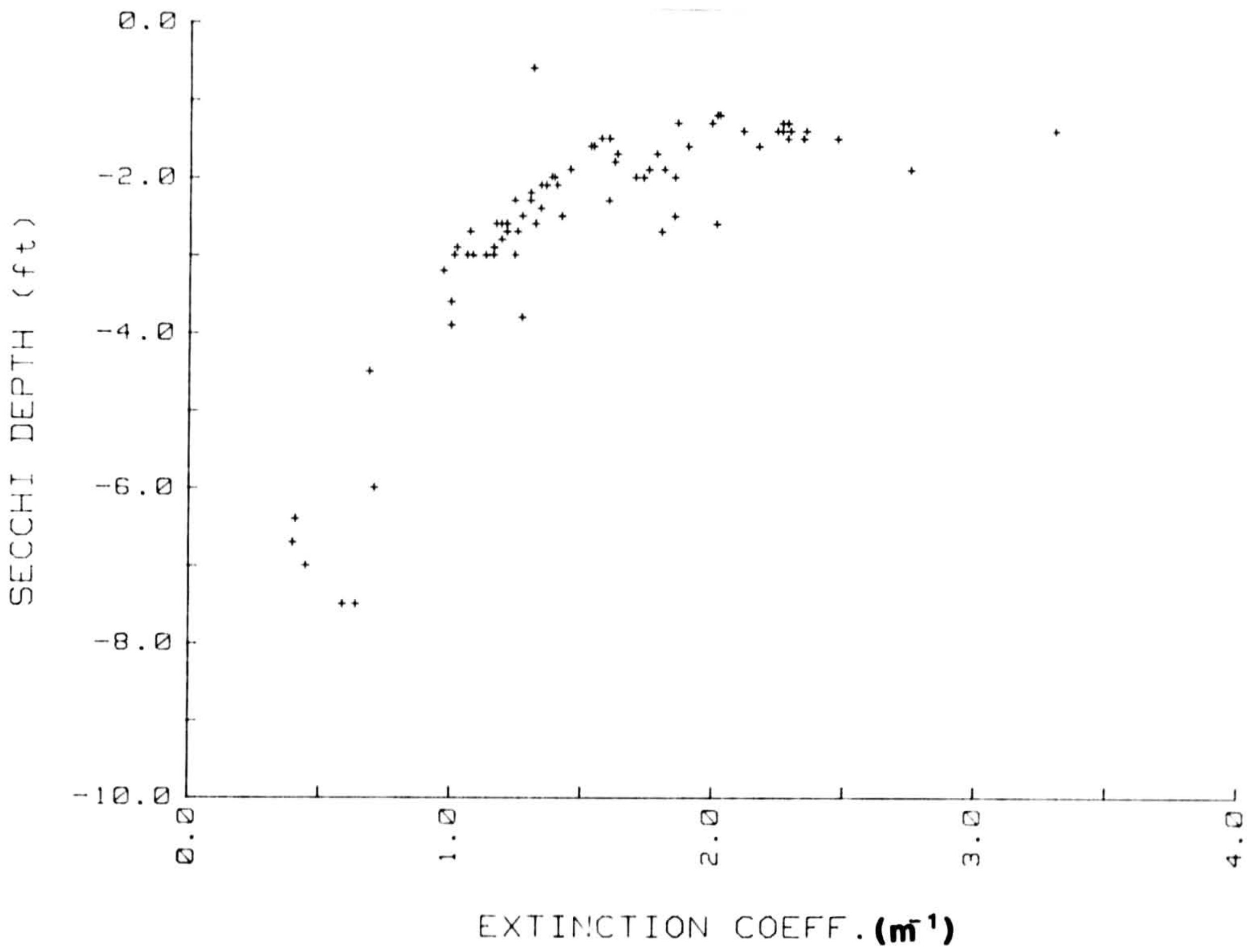

FIGURE 5.13

EKLUTNA LAKE SURFACE DATA:
SECCHI DEPTH
vs.
EXTINCTION COEFFICIENT

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HARZA-EBASCO
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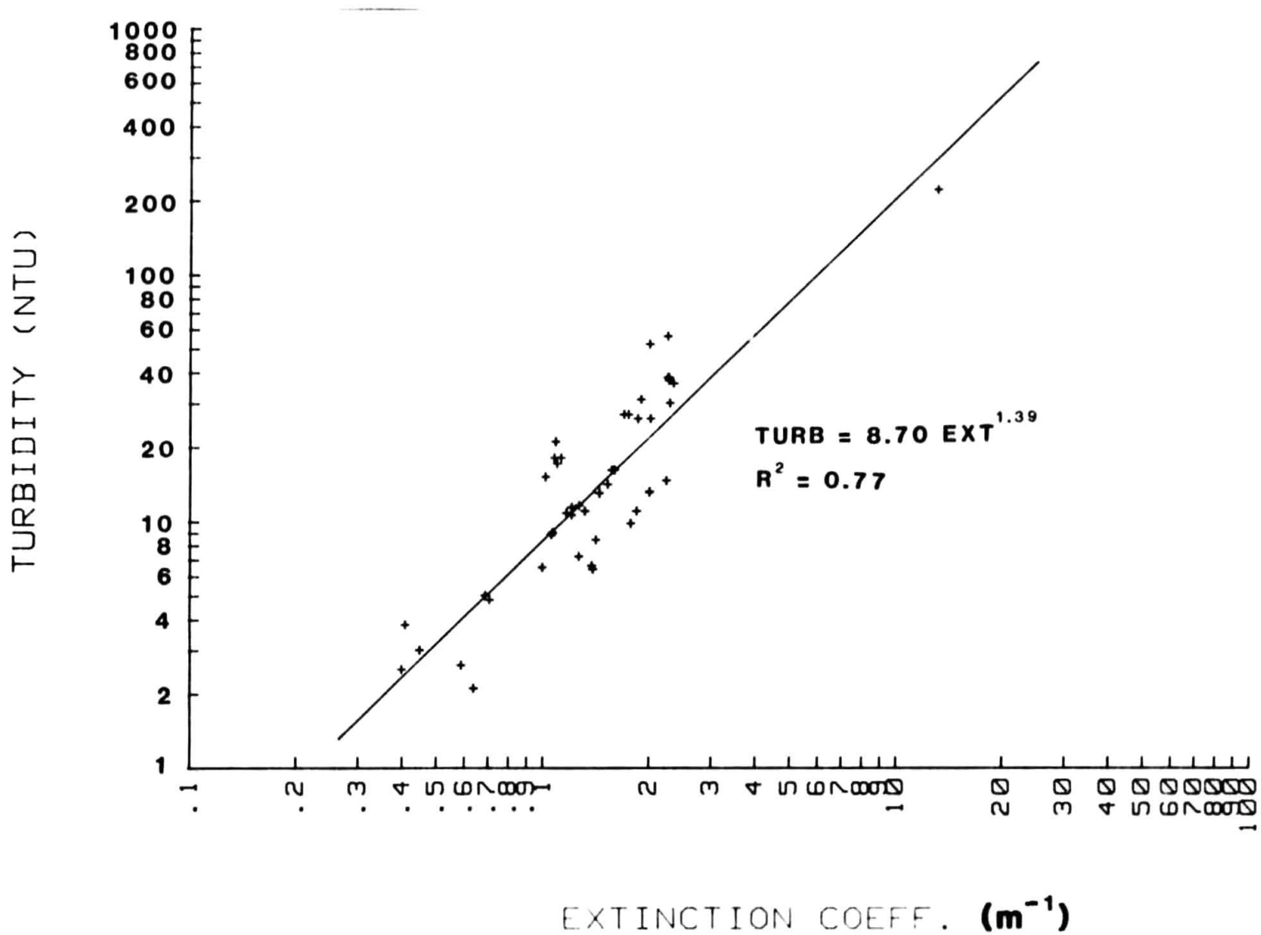

FIGURE 5.14

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**EKLUTNA LAKE SURFACE DATA: TURBIDITY vs. EXTINCTION COEFFICIENT**	HARZA-EBASCO SUSITNA JOINT VENTURE

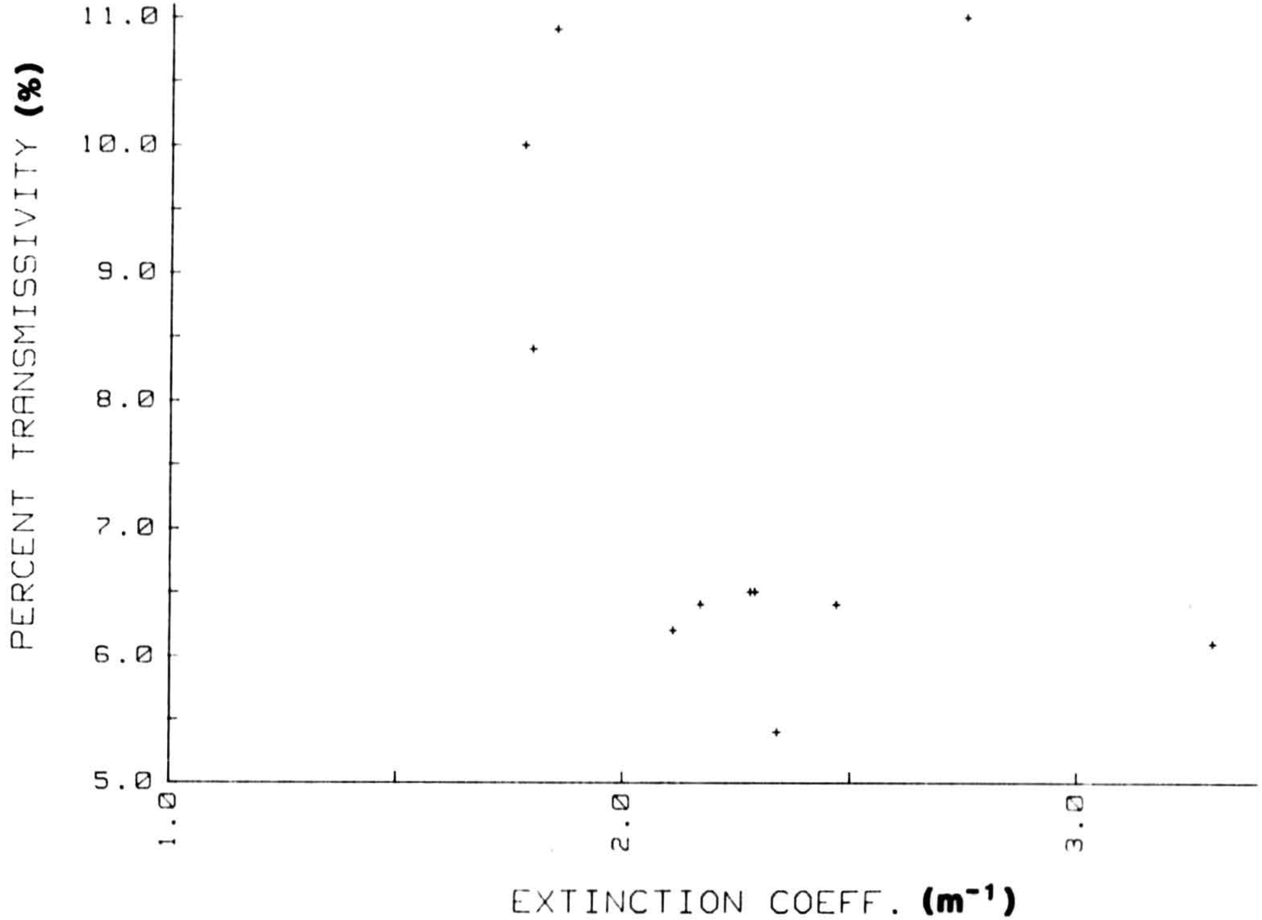

FIGURE 5.15

PREPARED BY:
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ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

EKLUTNA LAKE SURFACE DATA: LIGHT TRANSMISSION vs. EXTINCTION COEFFICIENT

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

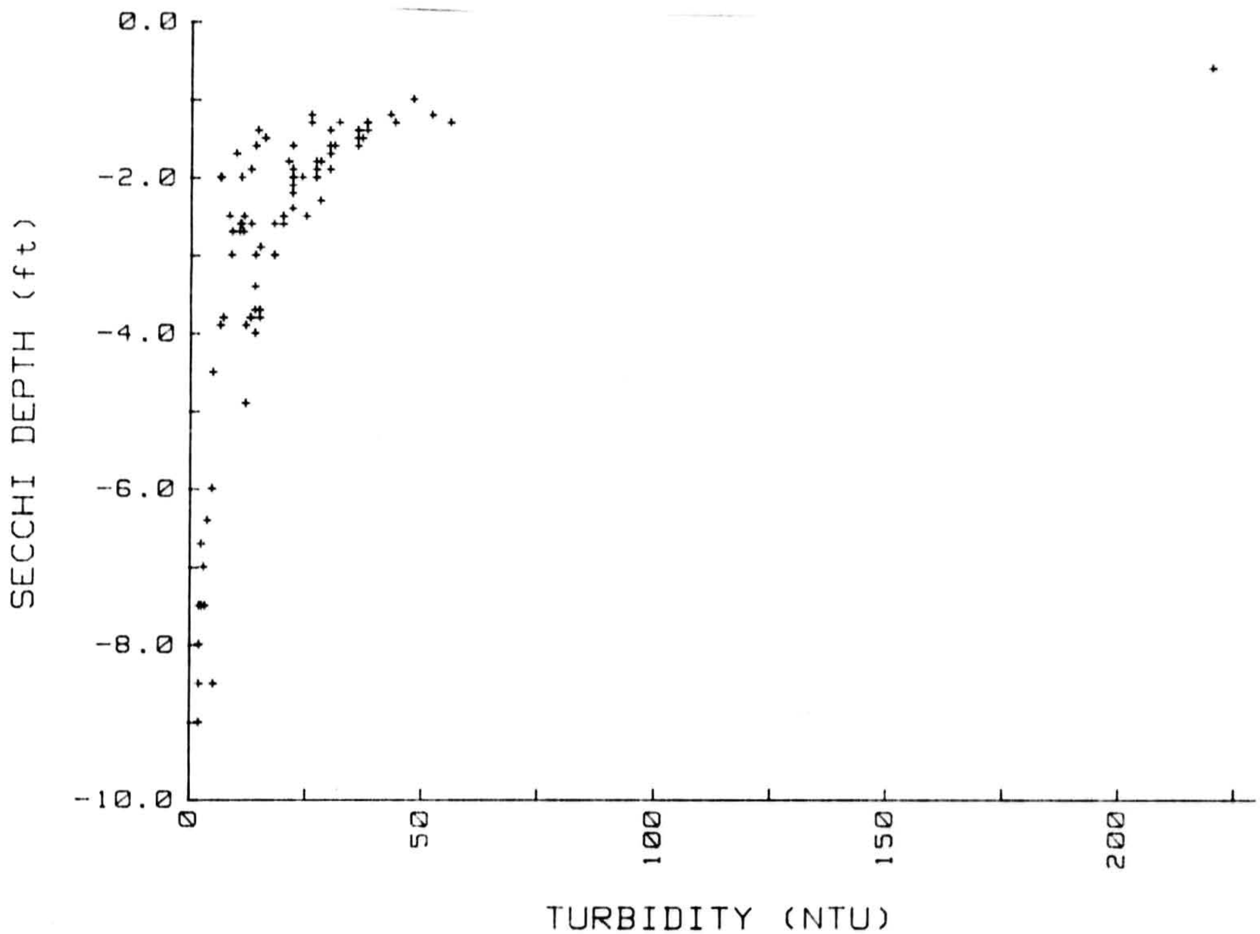

FIGURE 5.16

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**EKLUTNA LAKE SURFACE DATA: SECCHI DEPTH vs. TURBIDITY**	HARZA-EBASCO SUSITNA JOINT VENTURE

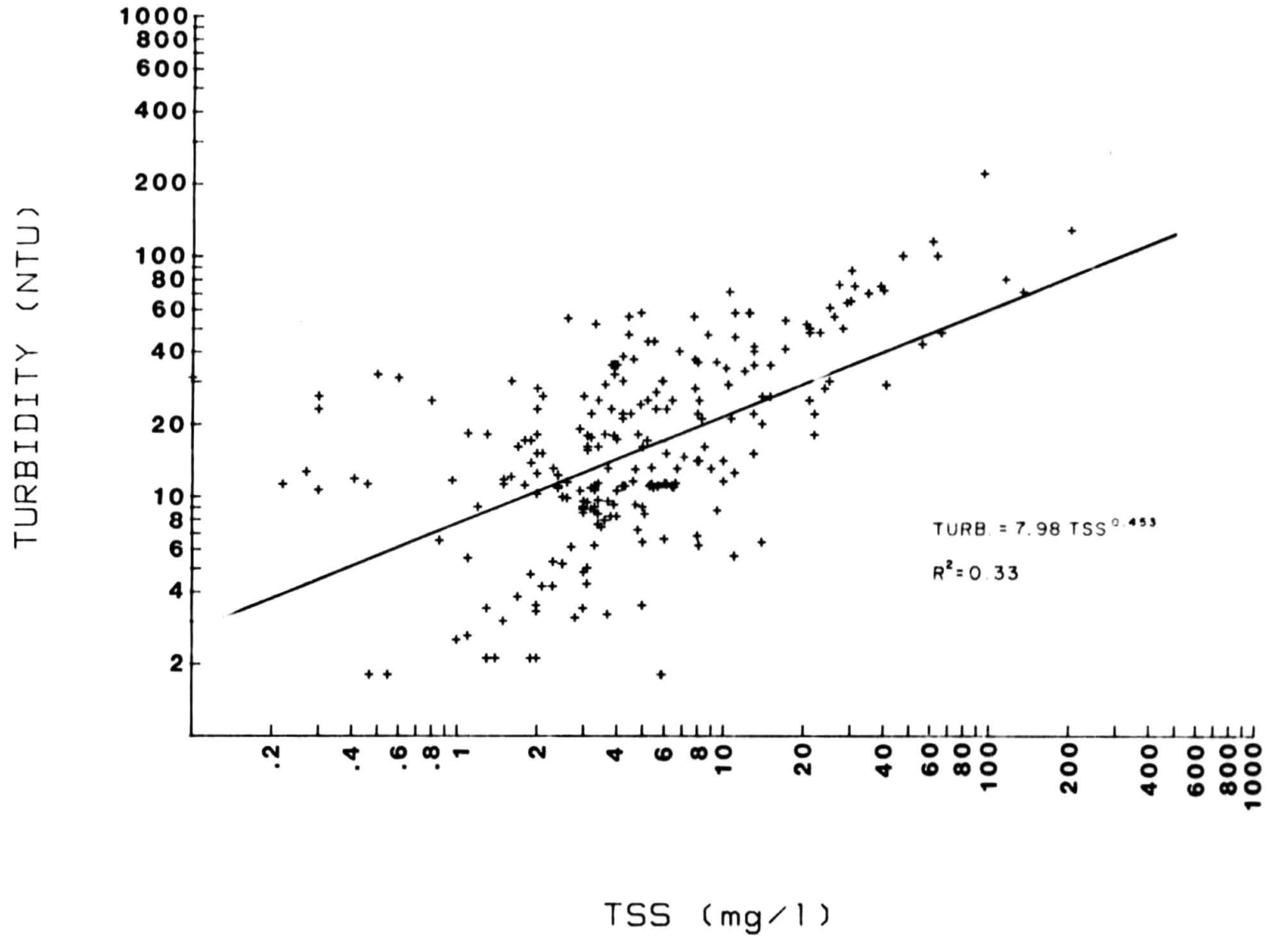

FIGURE 5.17

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**EKLUTNA LAKE DATA: TURBIDITY vs. TOTAL SUSPENDED SOLIDS**	HARZA-EBASCO SUSITNA JOINT VENTURE

6.0 LAKE OUTFLOW

6.1 Methodology

Data on the Eklutna Lake level and outflow quantity and quality were obtained from three sources: 1) Alaska Power Administration surveys and observations, 2) U.S. Geological Survey lake level measurements, and 3) R&M sampling at the tailrace. The Power Administration performed level surveys of the lake elevation once per week until June 1983, when the U.S.G.S installed a water-stage recorder to continuously monitor the level. Outflow data were provided by the Alaska Power Administration, as described below. Sampling and analysis done by R&M at the power plant tailrace (see Figure 2.1 for location) are also described below for each parameter measured. A view of the tailrace is shown in Photo 6.1.

6.1.1 Powerplant Data

Personnel at the Eklutna Project Hydroelectric Plant operated by the U.S. Department of Energy, Alaska Power Administration provided outflow temperature and discharge data to R&M. Temperature was measured routinely three times daily, at 0800, 1600, and 2400 hours with a gage that sensed water temperature in a penstock within the powerplant. The flow passing through each turbine was calculated daily from production performance curves. Total lake outflow was reported by the Alaska Power Administration in acre-feet per day and converted by R&M to cubic feet per second and cubic meters per day for DYRESM model input.

During May to December 1984, twice-weekly samples of tailrace outflow water were collected for analysis of turbidity, conductivity, and suspended sediment concentration. Samples were collected in the tailrace pond as close as possible to the turbine outlet ports, using the DH-48 hand-held, depth-integrated sampler (U.S.G.S 1978). During freezing conditions, the normal site directly above the ports

Illinois. The size distributions were determined by the electrozone method (Karuhn and Berg 1982).

6.1.5 Temperature

A mercury thermometer was used for instantaneous temperature measurements. Temperatures were read to the nearest 0.1 degree Celsius. These measurements compared favorably to those reported by the Alaska Power Administration.

6.1.6 Light Penetration

Secchi disk depths, as defined by Wetzel (1975), were measured using a disk painted in alternate quadrants of black and white to facilitate definition when submerged. Secchi disk measurements were reported to the nearest 0.1 foot.

6.1.7 Powerplant Intake

The layout of the Eklutna Hydroelectric Project works, including the powerplant intake in the lake and the tailrace adjacent to the Knik River are shown schematically in Figure 6.1. The intake works are for withdrawal at a single level in the reservoir (elevation 794 feet) and are located on the north shore of Eklutna Lake near Station 15 (Figure 3.1). The original intake structure extended over 200 feet along the lake bottom and was surrounded by gently-sloping (10:1 slope) sides, as shown in Figure 6.1. However, CH2M Hill (1981) reported that the intake had to be rehabilitated after the 1964 earthquake.

The intake structure as replaced consists of a rectangular, reinforced-concrete box, open and protected by trashracks on its top, front, and two sides. The trashracked portion is about 23 feet wide, 20 feet high, and 22 feet long in the direction of conduit flow, was often too icy and treacherous, so sampling was done at the edge of the pond, within 5 meters of the outlet ports. Temperature and light penetration measurements were also made at sampling times.

6.1.2 Turbidity

The tailrace water samples were refrigerated between time of collection and time of analysis, which was normally within one day of sampling. Turbidity analyses were performed at the R&M office using a Hach Model 16800 Portalab nephelometric turbidimeter until August 1984, when a Monitek Model 31 nephelometer was purchased and used. Analytical procedures for turbidity were those described in Standard Methods (APHA et al. 1981). Calibration standards were supplied by the instrument manufacturers. Some differences were noted in measurements made with the two instruments, so preliminary values were adjusted using an empirical correction relationship.

6.1.3 Conductivity

Samples were analyzed at the R&M office for conductivity using a YSI Model 33 S-C-T meter and adjusted to conductivity at 25°C (APHA et al. 1981).

6.1.4 Suspended Sediment

Analyses of suspended sediment concentration were performed by Chemical and Geological Laboratories of Alaska, Inc. using standard methods for detection of total nonfilterable residue (APHA et al. 1981). The samples were refrigerated after collection until analysis, which was normally the same day as or the day after sampling. Filters with 0.45-micron pore sizes were used for determining the TSS concentrations. Particle-size distributions and mineralogic analyses were performed by Particle Data Laboratories, Ltd., of Elmhurst, Illinois. The size distributions were determined by the electrozone method (Karuhn and Berg 1982).

6.1.5 Temperature

A mercury thermometer was used for instantaneous temperature measurements. Temperatures were read to the nearest 0.1 degree Celsius. These measurements compared favorably to those reported by the Alaska Power Administration.

6.1.6 Light Penetration

Secchi disk depths, as defined by Wetzel (1975), were measured using a disk painted in alternate quadrants of black and white to facilitate definition when submerged. Secchi disk measurements were reported to the nearest 0.1 foot.

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The layout of the Eklutna Hydroelectric Project works, including the powerplant intake in the lake and the tailrace adjacent to the Knik River are shown schematically in Figure 6.1. The intake works are for withdrawal at a single level in the reservoir (elevation 794 feet) and are located on the north shore of Eklutna Lake near Station 15 (Figure 3.1). The original intake structure extended over 200 feet along the lake bottom and was surrounded by gently-sloping (10:1 slope) sides, as shown in Figure 6.1. However, CH2M Hill (1981) reported that the intake had to be rehabilitated after the 1964 earthquake.

The intake structure as replaced consists of a rectangular, reinforced-concrete box, open and protected by trashracks on its top, front, and two sides. The trashracked portion is about 23 feet wide, 20 feet high, and 22 feet long in the direction of conduit flow, and the inlet channel is 100 feet wide and about 720 feet long (CH2M Hill 1981).

6.1.8 Powerplant and Outlet Characteristics

The Eklutna Project was constructed as a single-purpose, 30,000-plus-kilowatt hydroelectric project by the U.S. Bureau of Reclamation in the early 1950's. It is now owned and operated by the Alaska Power Administration, U.S. Department of Energy. The pressure tunnel is a 9-foot diameter, circular, concrete-lined tunnel, 23,550 feet long with a design flow capacity of 640 cfs. The penstock is 1395 feet of steel pipe encased in concrete, and has diameters of 91", 83", and 75" in different portions of its length. The current total installed capacity of the two Francis-type turbines in the powerplant is 33,334 kilowatts, with a maximum gross head of 865 feet. Average annual energy production from the plant between 1955 and 1980 was 156,000 megawatt-hours, ranging from 97,000 to 204,000 megawatt-hours in any year. The tailrace consists of a reinforced-concrete pressure conduit, 209 feet long and of varying width and depth, which discharges into an open channel. The open channel has a 25-foot bottom width, side slopes of 2:1, a depth of 12.5 feet, and a length of about 2000 feet before emptying into the Knik River (CH2M Hill 1981).

6.2 Results and Discussion

The variation of TSS, turbidity, Secchi disk depth, and water temperature of the outflow are shown for 1984 in Figure 6.2. Each data point is an instantaneous value obtained during sampling, which was conducted twice per week during the open-water season. The full data set is summarized chronologically in Appendix L, Table L.1. The outflow water is withdrawn from Eklutna Lake in the vicinity of Station 15, so lake data obtained at Station 15 should be similar to measurements made at the tailrace. Comparison with the isotherm plots in Appendix H shows good agreement with the measured tailrace temperatures. The recorded outflow temperatures appear to be close to or slightly higher (1°C or so) than those observed at the intake level at Station 15. This is reasonable to expect, indicating that either the intake may be drawing warmer water from nearer the lake surface or the water may be warming as it flows through the tunnel and powerplant. The observed water temperatures of the outflow ranged from a low of 3.8°C in November to a high of 12.8°C in late June.

Turbidity and TSS levels measured in the outflow were fairly uniform through the year, with a few upward spikes, likely induced by wind events at the lake. The base level of turbidity also rose during the July-September summer season. Turbidity over the whole period ranged from 3.0 NTU in early June to a peak of 46 NTU in late August and then dropped back down to 6.6 NTU by November before the lake froze up. The TSS values varied from a spring low of 0.5 mg/l in June to a high of 36 mg/l in late July and then a low again of 2.2 mg/l in November. Only minor fluctuations between 2.2 and 7.6 mg/l and 6.6 and 15.5 NTU were observed for TSS and turbidity after mid-September.

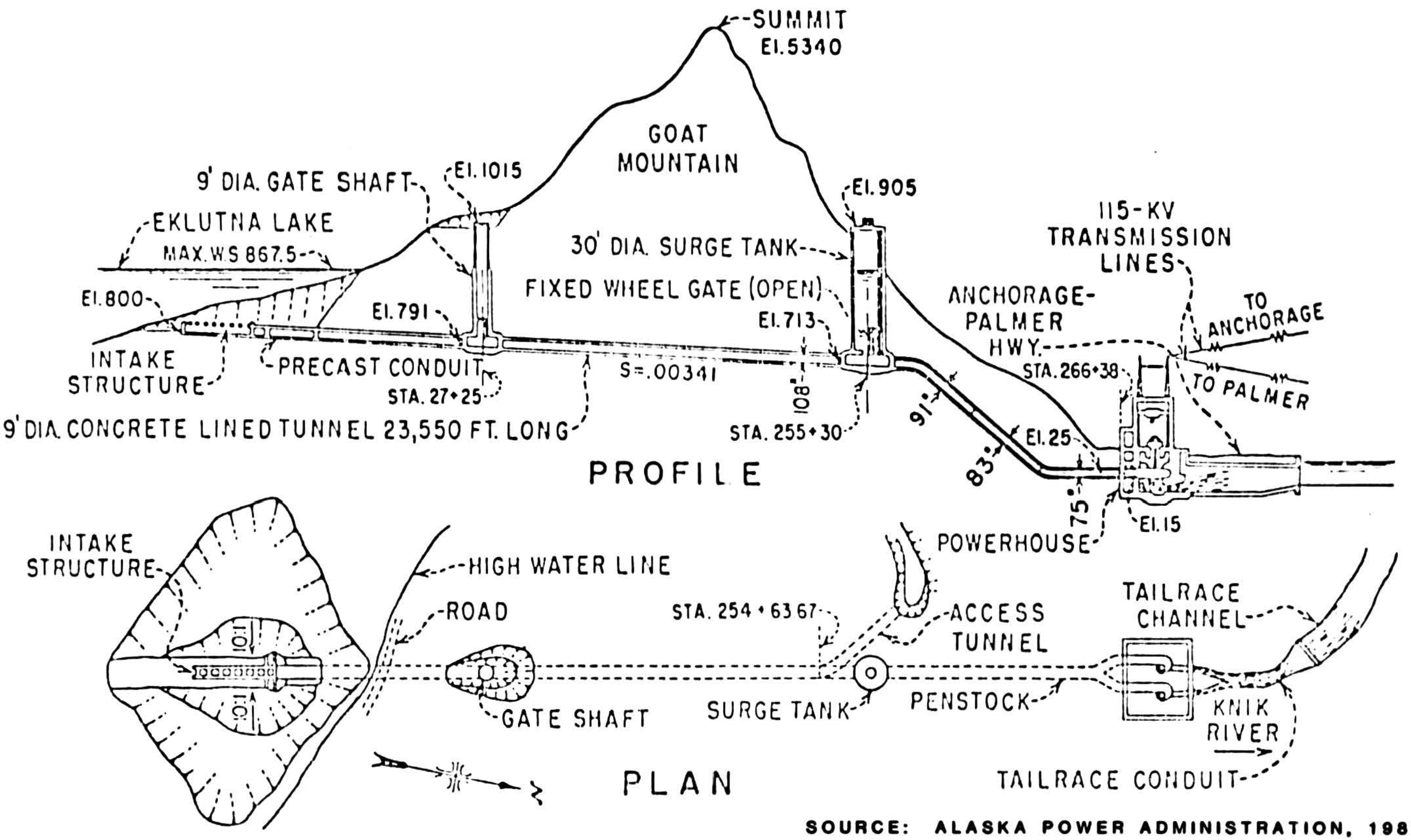
The sharp peak in both plots in late August was probably due to strong southeast winds that blew down the lake and persisted for several days. These winds would tend to transport more surface water down the lake and would also tend to move more of the turbid inflow down the lake. The tailrace temperature also rose slightly at this time, probably due to the presence of additional warm surface water in the outflow. Another possible explanation for the increases in turbidity and TSS is that the winds blowing down the lake develop sizeable waves (up to 2 feet) at the northwest end. These waves beat on the shoreline near the intake works and may entrain sediment in the water from the banks of the lake.

A plot of the comparison between turbidity and total suspended solids for the tailrace data is shown in Figure 6.3. The relationship is weak, with a correlation coefficient of 0.25.

Particle-size distribution plots are presented in Figure 6.4 for three 1984 samples of suspended sediment from the tailrace. The samples were collected on July 20, August 28, and October 23, the same dates the inflow streams were sampled. The data used for plotting the graphs are tabulated in Appendix F, Tables F.7-F.9, which were obtained from Particle Data Laboratories.

Outflow data for use in the DYRESM model are tabulated in Appendix N.5. The table gives daily values of outflow volume, water temperature, and the level of Eklutna Lake, all of which were obtained from the Eklutna Water Project (from the U.S.G.S. for the recent lake levels).

The Eklutna Water Project (EWP), a project to transport drinking water from Eklutna Lake to Anchorage, is currently being developed by the Municipality of Anchorage Water and Wastewater Utility. The engineering contractor for the Municipality prepared a report which presented some newly-acquired water quality and sediment data (Montgomery Engineers, Inc. 1984). These data and supporting information are included in Appendix M in Tables M.1 and M.2, Figures M.1-M.6, and Photos M.1 and M.2. Samples were collected at the powerplant during three six-week phases in 1983: February-March, May-June, and September-October. Table 4.1 gives ranges of numerous water quality parameters that were analyzed during their studies. Plots of turbidity and water temperature are shown in Figure M.1; samples were obtained daily for the entire period of mid-February through late October 1983. The observed temperatures ranged from 39°F (4°C) to 56°F (13°C), and the measured turbidity values varied between 7.5 and 68 NTU. Several particle-size distribution plots are shown, in Figures M.2-M.4. It should be noted, however, that these plots are for **counts** of particles - not particle volume or particle weight - so they may not be directly compared with the distributions in Figure 6.4 and Appendix F. For comparison, the tables of particle-size distributions based on count obtained from Particle Data Laboratories for the 1984 tailrace samples are also shown in Appendix F (particle-size distributions by PDL were determined by count and by volume). Several measurements were made for the EWP of TSS concentrations in various size ranges and on several dates. These data are tabulated in Table M.2 and plotted in Figure M.5. Figure M.6 compares turbidities with TSS concentrations obtained from various filter sizes. Finally, Photos M.1 and M.2 show TEM (transmission electron microscope) and SEM (scanning electron microscope) photographs of particles observed in the water samples.



SOURCE: ALASKA POWER ADMINISTRATION, 1985

FIGURE 6.1 Schematic plan and profile of Eklutna project features.

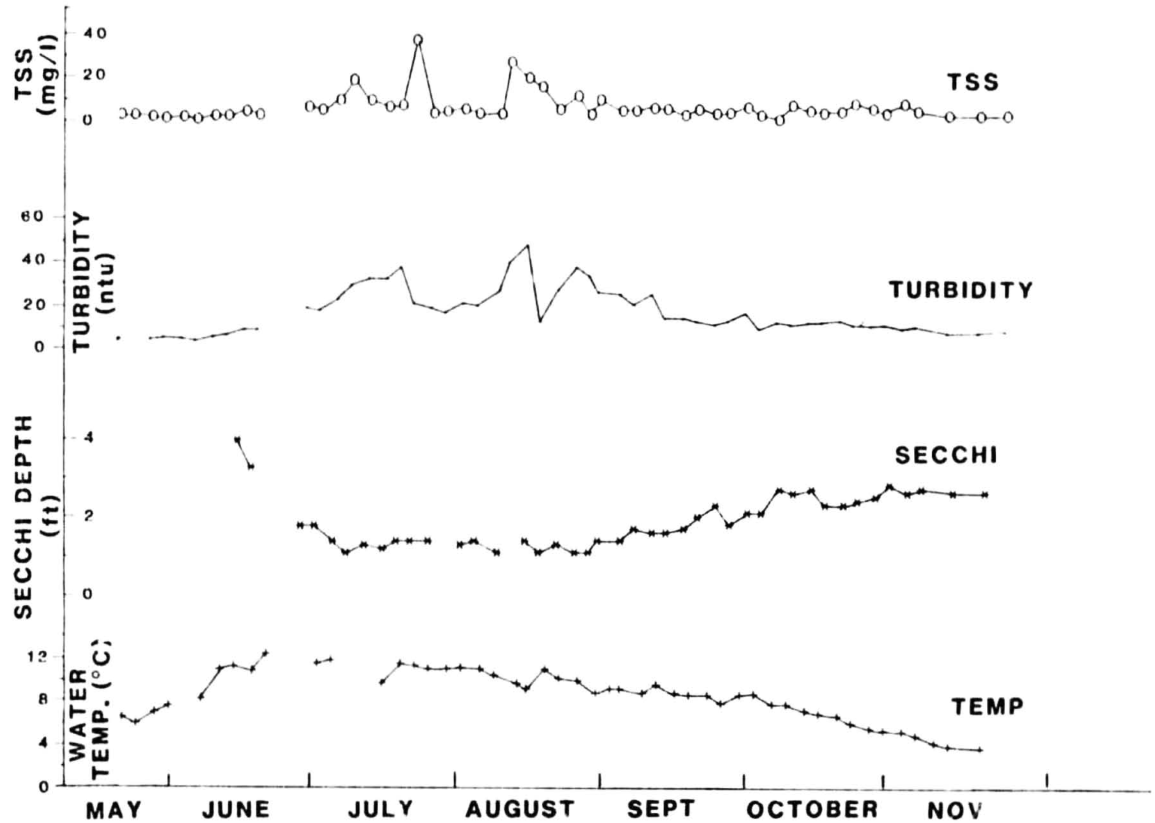


FIGURE 6.2

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	1984 TAILRACE DATA	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

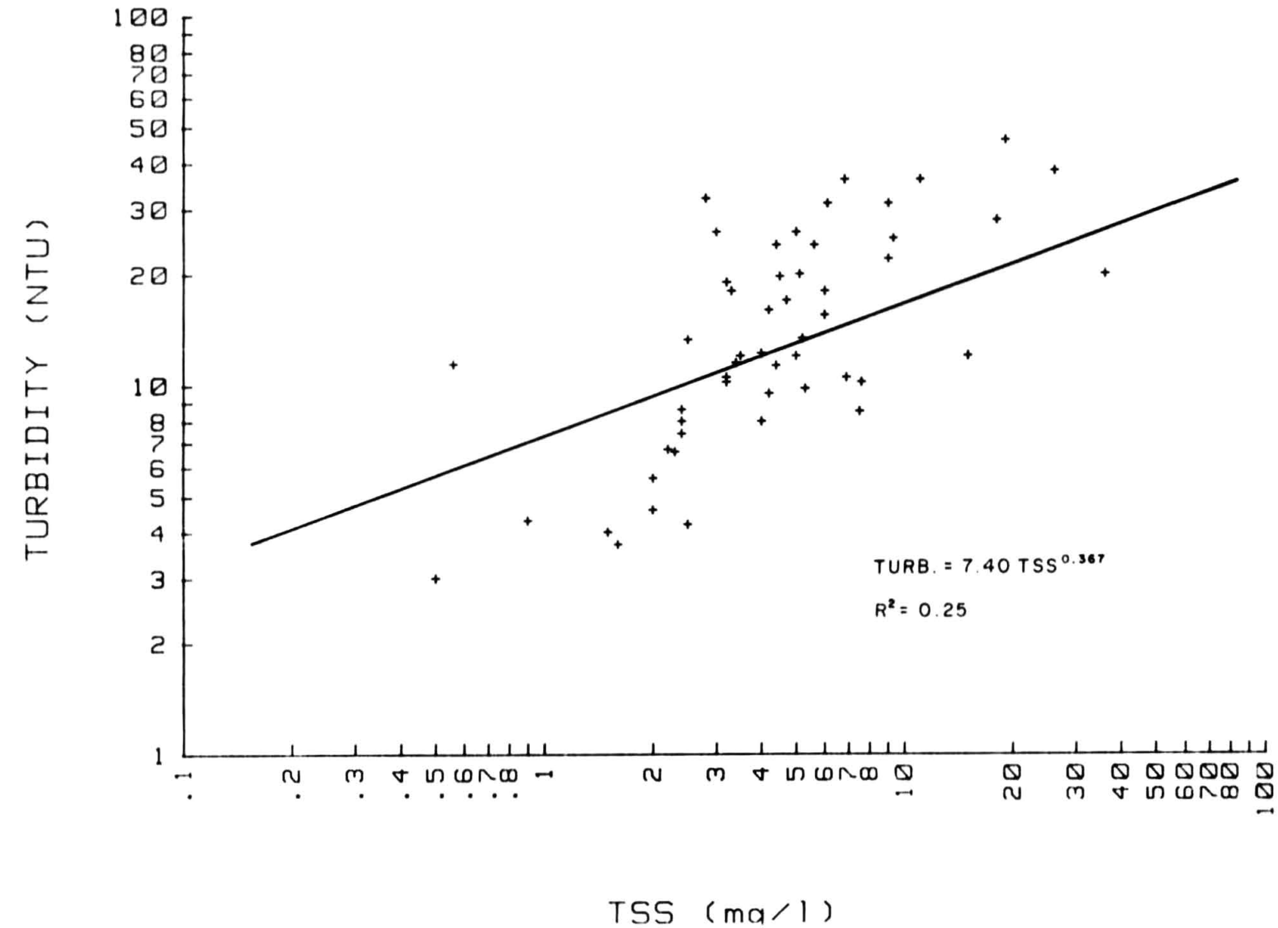


FIGURE 6.3

PREPARED BY:

R&M CONSULTANTS, INC.

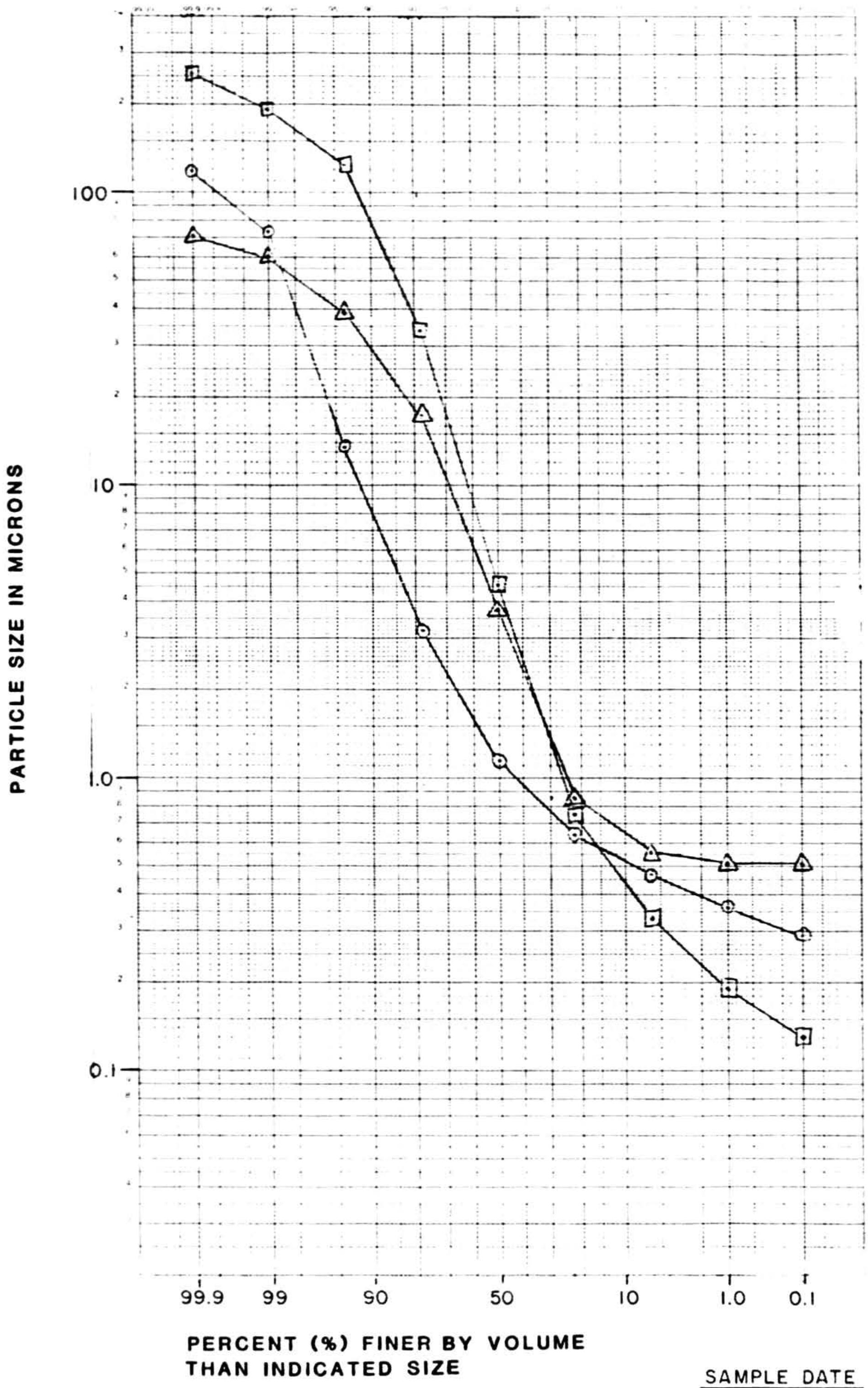
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

1984 TAILRACE DATA: TURBIDITY VS. TOTAL SUSPENDED SOLIDS

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE



EKLUTNA POWER PLANT TAILRACE

FIGURE 6.4

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	SUSPENDED SEDIMENT PARTICLE SIZE DISTRIBUTION	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

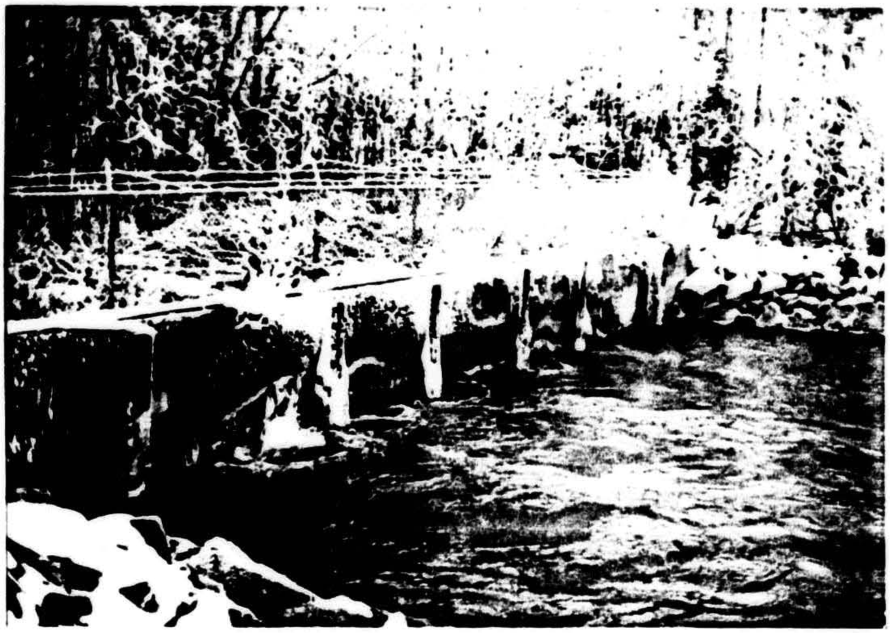


Photo 6.1. Eklutna Hydroelectric Project Tailrace, looking upstream at concrete outlet port structure (winter). Top of concrete wall is approximately 6 feet above the water surface.

7.0 RIVER-LAKE SYSTEM RELATIONSHIPS

Time plots for 1984 which demonstrate the seasonal variation in the parameters and also compare the measured levels in the inflow, in the lake, and in the outflow are shown in Figures 7.1-7.3 for turbidity, TSS, and water temperature, respectively. Inflow (both East Fork and Glacier Fork) and outflow (tailrace) data are plotted from the samples obtained twice per week from mid-May through mid-November. The lake data were measured at the center of the lake (Station 9) during profiling trips performed monthly from mid-March to mid-May and twice per month from early June through late November. Station 9 values from the same depths where sediment samples were obtained for a date were averaged to provide a single value for the plot.

Several trends are evident in Figures 7.1-7.3, indicating that thermal and sediment effects may work their way through the system and out the lake. The turbidity and TSS plots follow each other fairly well in general, so they can be considered together. The minimum turbidity levels in the inflow streams occurred in early June, rose sharply a few weeks later, and reached the observed peak of the year around July 1. Levels fluctuated quite a bit but stayed high for almost all of July. The low turbidity at Station 9 occurred in early June rose gradually through June and July, and did not peak until mid-July, a week or two after the streams' peaks. A lag is expected, considering travel time down the lake, but differences in sampling frequency could also effect the apparent difference in timing of the events. A further lag was seen at the tailrace: the rise in turbidity began in late June and continued until the peak in late July. Secondary rises in turbidity on both streams in late July show up as high turbidity values at Station 9 about 2 weeks later and then in the outflow a week or so after that (late August). There were also some winds in the third week of August which may have affected the turbidity of the outflow.

The peaks in late September initially appear to be out of phase in the wrong direction, i.e. the high turbidity occurs first at Station 9 in the lake, then in the streams, then at the tailrace. However, the high lake and tailrace values were preceded by strong southeast winds which had lasted almost two days and probably produced mixing in the lake. The high stream turbitities and TSS concentrations followed a day where nearly an inch of rain fell in 24 hours, causing a rapid rise in both creeks.

The progress of the temperature changes through the river-lake system is more subtle than the sediment/turbidity changes, likely due to the importance of factors external to the stream in influencing the lake's thermal condition. The suspended sediment in the lake originates almost entirely in the East Fork and Glacier Fork tributaries, but summer warming of the lake comes primarily from atmospheric influences (solar radiation, thermal convection, and thermal conduction). The general shape of the temperature plots through the year is with a broad peak for the average Station 9 temperatures, a similar broad peak in the outflow but with fluctuations up or down a couple of degrees at a time, and generally uniform base stream temperatures but with frequent variations. The Station 9 temperatures plotted were averages of measurements made at the same depths where TSS/turbidity samples were taken; this generally gave a slight bias toward conditions at the lake surface, rather than for the full depth, as can be seen by comparing to Figure 5.3.

Station 9 warmed up fairly quickly in May and June, reaching the observed high for the year in mid-June. The outflow temperatures followed a similar pattern but occurring slightly later, rising in June to peak late in the month. The temperatures in the streams fluctuated considerably early in the summer (May). This was before the glaciers had begun melting significantly, so streamflow was derived chiefly from snowmelt and groundwater inflow. On sunny days, the solar radiation would warm the stream water directly, especially at Glacier Fork where the discharge was still very low. Temperature fluctuations later in the year were due to other environmental factors - air temperature, wind, solar radiation, precipitation, and degree of influence from the glaciers. The proximity of the Glacier Fork gage to the Eklutna Glacier terminus made it particularly sensitive to activities of the glacier. The stream and outflow temperatures plotted were instantaneous measurements made at the time of suspended-sediment sampling. Some fluctuation is due to differences in sampling time, as was discussed in Section 4.

Inspection of the monthly inflow to and outflow from the lake for a one-year period (Table 7.1) shows the total annual contributions for East Fork and Glacier Fork to be nearly identical though Glacial Fork had a higher summer flow and lower winter base flow. Also, the sum of the East Fork and Glacier Fork discharges for the year, 188,000 acre-feet, was 91% of the lake outflow for the same period. Thus, all but a very small share of the lake inflow comes from the East Fork and Glacier Fork drainage areas.

TABLE 7.1 COMPARISON OF EKLUTNA LAKE INFLOW AND OUTFLOW, WATER YEAR 1984

Eklutna Lake Monthly Inflows and Outflows (acre-feet)

Month	East Fork (EF)	Glacier Fork (GF)	Sum (EF&GF)	Powerplant Outflow
October 1983	5,500	4,400	9,900	7,300
November	3,000	1,800	4,800	8,500
December	2,700	300	3,000	13,700
January 1984	2,000	0	2,000	23,700
February	1,800	0	1,800	24,900
March	1,300	0	1,300	28,400
April	1,500	0	1,500	27,300
May	3,900	700	4,600	20,500
June	13,400	10,000	23,400	21,300
July	23,500	30,900	54,400	12,500
August	27,100	38,600	65,700	9,100
September	7,400	8,100	15,500	9,000
TOTAL	93,100	94,800	187,900	206,200

Notes:
1. Inflow data were measured by R&M Consultants (June-September). Values for November-April were estimated, and October and May values were partially estimated.
2. Outflow data were provided by Alaska Power Administration.

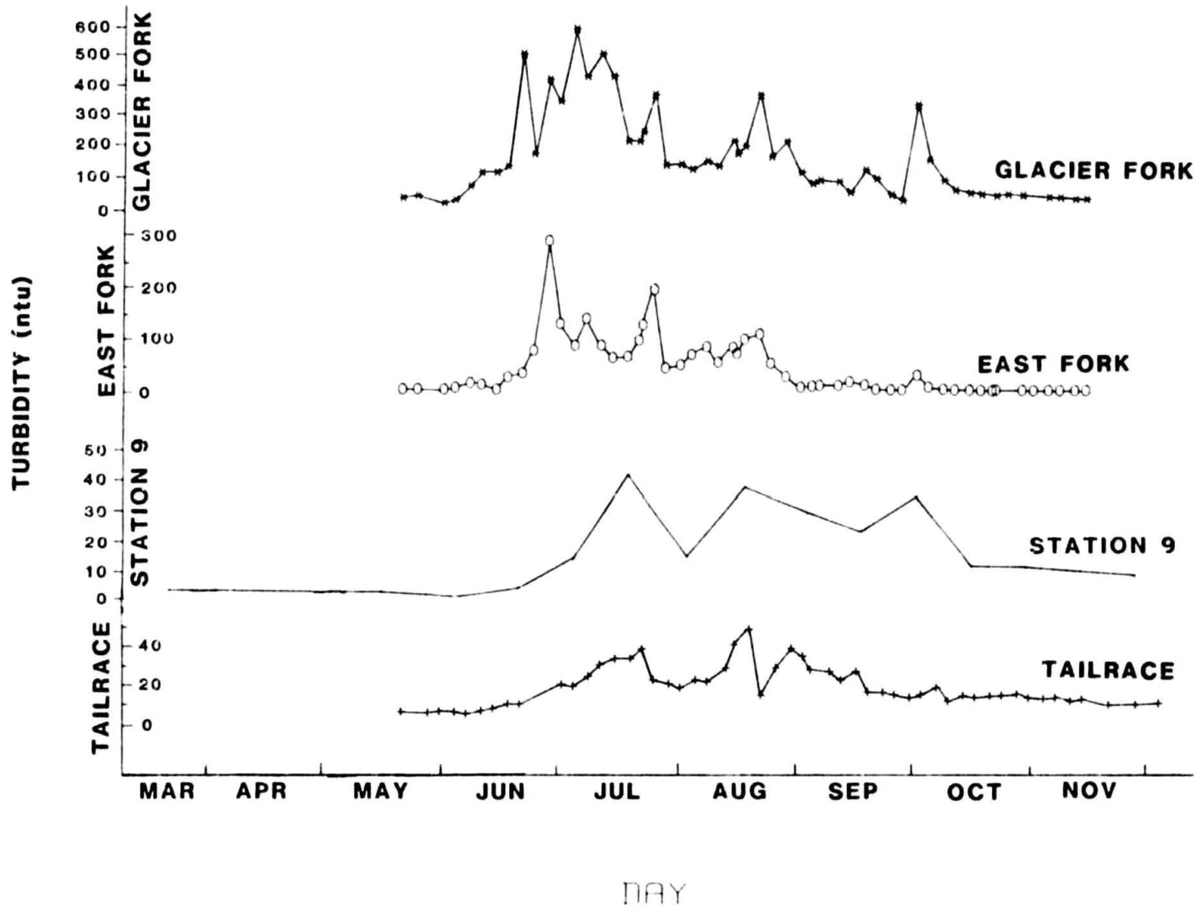


FIGURE 7.1

PREPARED BY:

R&M CONSULTANTS, INC.

ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

1984 EKLUTNA STREAM-LAKE SYSTEM DATA: TURBIDITY

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

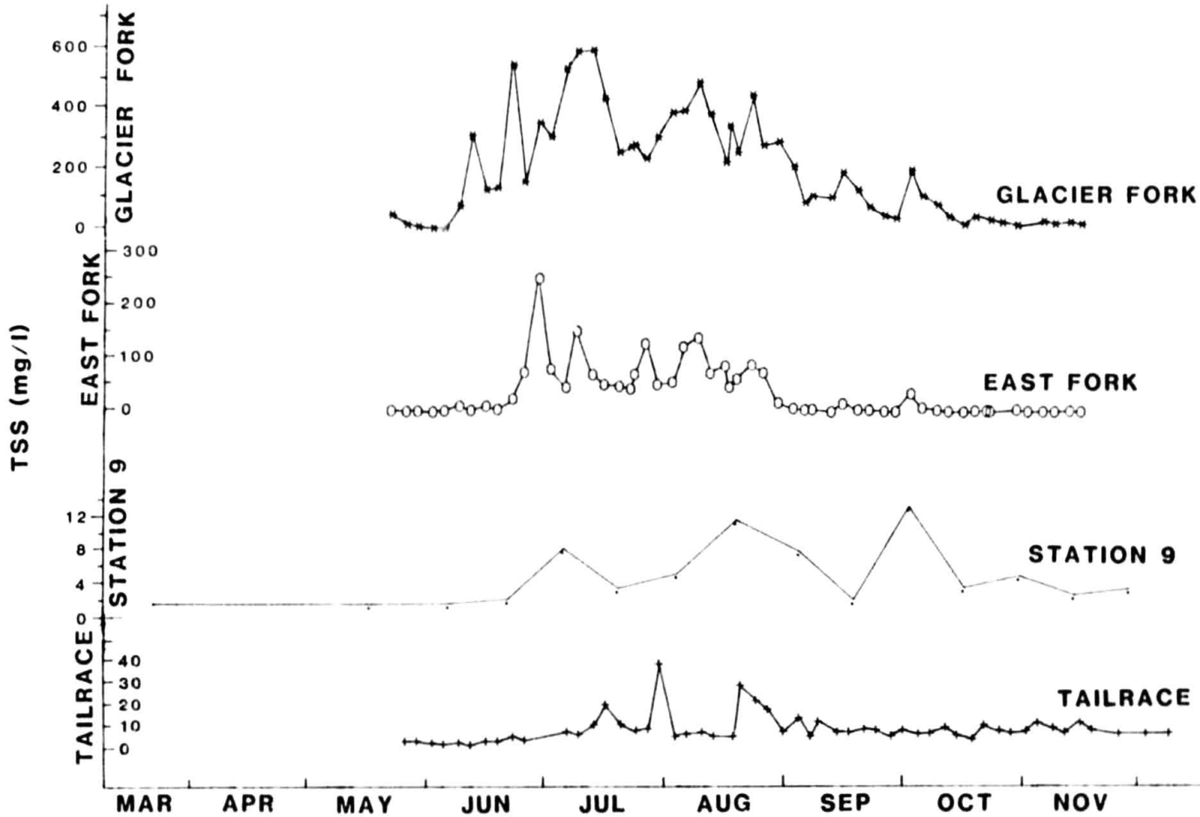


FIGURE 7.2

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1984 EKLUTNA STREAM-LAKE SYSTEM DATA: TOTAL SUSPENDED SOLIDS

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

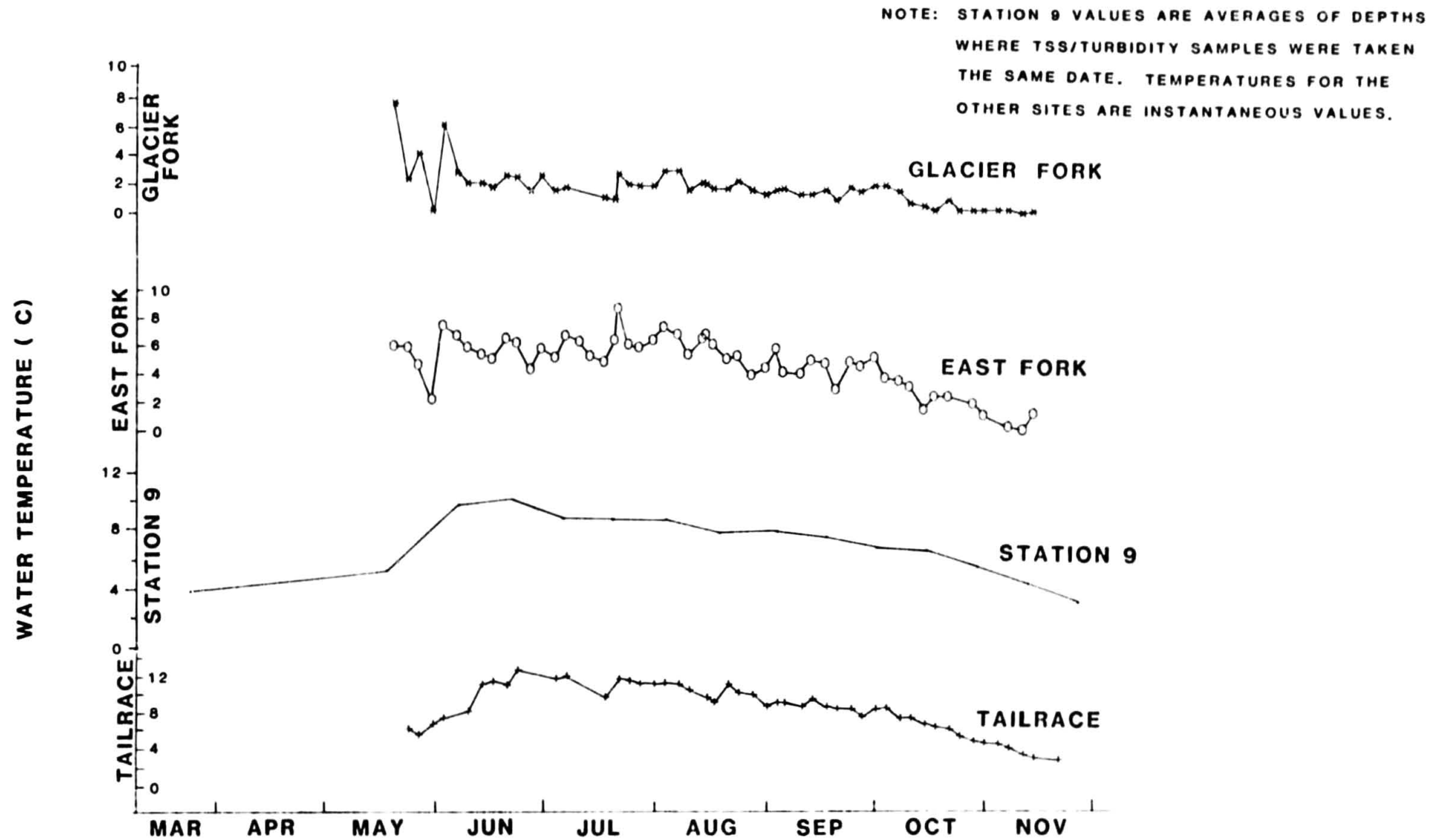

FIGURE 7.3

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	1984 EKLUTNA STREAM-LAKE SYSTEM DATA: WATER TEMPERATURE	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

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