CHAKACHAMNA HYDROELECTRIC PROJECT
INTERIM FEASIBILITY ASSESSMENT REPORT

VOLUME I
SECTIONS 1-10
APPENDIXES TO SECTIONS 4.0 & 8.0

BECHTEL CIVIL & MINERALS INC.

ENGINEERS – CONSTRUCTORS

MARCH 1983

ALASKA POWER AUTHORITY

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ANCHORAGE, ALASKA

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INTRODUCTION

ALASKA POWER AUTHORITY

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CHAKACHAMNA HYDROELECTRIC PROJECT

INTERIM FEASIBILITY ASSESSMENT REPORT, MARCH, 1983

1.0 INTRODUCTION

This report has been prepared in accordance with the terms of Contract 82-0294 dated August 3, 1981 between the State of Alaska/Department of Commerce and Economic Development/Alaska Power Authority and Bechtel Civil & Minerals, Inc. in connection with services for performing interim feasibility assessment studies of the Chakachamna Hydroelectric Project. As its title indicates, the report is of an interim nature. It is based upon previously published information regarding the project, and on data acquired and derived during a study period extending from the fall of 1981 to December 1982. Its objectives are to summarize the information derived from the studies, to provide a preliminary evaluation of alternative ways of developing the power potential of the project, to define that power potential, and to report on the estimated cost of construction, and to provide a preliminary assessment of the effects that the project would have on the environment.

The initial engineering, geological, and environmental studies were conducted during the fall of 1981, and the findings of these studies were summarized in an interim report dated November 30, 1981. Although the data collected and study period up to that time were rather limited by the short time base, some rather clear indications emerged as to the manner in which it was considered that development of the project should proceed.

One aspect that became evident was that a much more extensive and populous fishery uses the waters in the project area than had been earlier realized or anticipated. This led to an amendment of the above mentioned contract in which the requirements for completion of the feasibility report and application to the Federal Energy Regulatory Commission for a license to construct the project were deleted from the scope of work. Continuing studies of the fishery in the waters of the project area were authorized as were the development of conceptual designs for fish passage facilities at the outlet of Chakachamna Lake plus the preparation of estimates of their construction costs and those of the McArthur tunnel assuming that it could be excavated by tunnel boring machine.

As may be seen by reference to Figure 1-1, Chakachamna Lake lies in the southern part of the Alaska Range of mountains about 85 miles due west of Anchorage. Its water surface lies at about elevation 1140 feet above mean sea level.

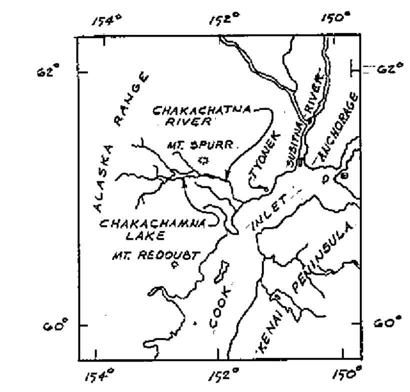
The project has been studied and reported upon several times in the past. The power potential had been estimated variously from about 100,000 kw to 200,000 kw firm capacity, depending on the degree of regulation of the outflow from Chakachamna Lake and the hydraulic head that could be developed.

Two basic alternatives can be readily identified to harness the hydraulic head for the generation of electrical energy. One is by a twelve mile tunnel more or less parallel to the valley of the Chakachatna River. This river runs out of the easterly end of the lake and descends to about elevation 400 feet above sea level where the river leaves the confines of the valley and spills out onto a broad alluvial flood plain. A maximum hydrostatic head of about 740 feet could be developed via this alternative.

The other alternative is for development by diversion of the lake outflow through a ten mile tunnel to the valley of the McArthur River which lies to the southeast of the lake outlet. A maximum hydrostatic head of about 960 feet could be harnessed by this diversion. Various means of development by these two basic alternatives are discussed in the report on the basis of the present knowledge of the site conditions.

The 1982 environmental studies confirmed the importance of the fishery using waters in the project area and expanded the data base concerning it. The basic elements of the recommended mode of development were conceived, these being for development via the McArthur River with a concrete lined machine bored tunnel and with fish passage facilities that would permit fish to ascend into the lake or to travel downstream from the lake into the Chakachatna River. Three samples of rock collected from the surface, two from the general vicinity of the proposed power intake site at Chakachamna Lake and one from near the powerhouse site by the McArthur River, were tested in The Robbins Company laboratory at Kent, Washington. The results indicated that the rock sampled, would be suitable for boring, but since the test data from samples taken at the surface can sometimes be misleading, and since no geological studies have yet been performed along the planned tunnel alignment, it must be assumed at the present time that the tunnel can be bored and additional geological studies will be needed before it can be firmly recommended that the tunnel be bored by machine. The rock test data was used for guidance in estimating the cutter penetration rate in assessing the estimated cost of excavating the tunnel by boring machine.

For the assessment of environmental factors and geological conditions in the project area, Bechtel retained the services of Woodward-Clyde Consultants.



VICINITY MAP

4 0 4 8

SCALE : 1" = 4 MILES

NOTES:

1.) TOPOGRAPHY IS FROM USGS QUADRANGLE MAPS

2.) VERTICAL DATUM IS MEAN LOWER LOW WATER

3.) HORIZONTAL GRID IS UNIVERSAL TRANSVERSE MERCATOR PROJECTION, 1927 NORTH AMERICAN DATUM

No.	DATE	REVISION	BY	CHK'D	ENGR SUPV	PROJ ENGR	PROJ MGR

ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

LOCATION PLAN

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN PRITCHARD	CHECKED [signature]
ENGR SUPV [signature]	PROJ ENGR [signature]	APP'D [signature]

	JOB No.	DRAWING No.	REV.
BECHTEL	14879	FIGURE 1-1	B

SUMMARY

2.0 SUMMARY

2.1 Project Layout Studies

The studies evaluated the merits of developing the power potential of the project by diversion of water southeasterly to the McArthur River via a tunnel about 10 miles long, or easterly down the Chakachatna Valley either by a tunnel about 12 miles long or by a dam and tunnel development. In the Chakachatna Valley, few sites, adverse foundation conditions, and the nearby presence of an active volcano made it rapidly evident that the feasibility of constructing a dam there would be questionable. The main thrust of the initial studies was therefore directed toward the tunnel alternatives without consideration of raising the lake level above the present outlet channel invert, taken as El. 1128, and a minimum drawdown of the water level to El. 1014.

Two alignments were studied for the McArthur Tunnel. The first considered the shortest distance that gave no opportunity for an additional point of access during construction via an intermediate adit. The second alignment was about a mile longer, but gave an additional point of access, thus reducing the lengths of headings and also the time required for construction of the tunnel. Cost comparisons and economic evaluation nevertheless favored the shorter 10 mile 25 foot diameter tunnel.

The second alignment running more or less parallel to the Chakachatna River in the right (southerly) wall of the valley afforded two opportunities for intermediate access adits. These, plus the upstream and downstream portals would allow construction to proceed simultaneously in 6 headings and reduce the construction time by 18 months less than that required for the McArthur Tunnel. Economic evaluation again favored a 25 foot diameter tunnel running all the way from the lake to the downstream end of the Chakachatna Valley.

If all the controlled water were used for power generation, the McArthur Powerhouse could support 400 MW installed capacity, and produce average annual firm energy of 1752 GWh. The effects of making a provisional reservation of approximately 19% of the average annual inflow to the lake for instream flow requirements in the Chakachatna River were found to reduce the economic tunnel diameter to 23 feet. The installed capacity in the powerhouse would then be reduced to 330 MW and the average annual firm energy to 1446 GWh.

If a small rock dike were to be constructed at the outlet of the lake and the maximum lake level is raised to the natural maximum, El. 1155, this would allow 72 feet lake drawdown to accommodate fish passage facilities. If the tunnel diameter remained 23 feet to avoid excessive losses, then the installed capacity in the powerhouse would be 330 MW and the average annual firm energy 1301 GWh. The reduction in firm energy is due to the lesser volume of regulatory storage contained within the narrower range of lake level needed for gravity operation of the fish passage facilities.

For the Chakachatna Powerhouse, diversion of all the controlled water for power generation would support an installed capacity of 300 MW with an average annual firm energy generation of 1314 GWh. Provisional reservation of approximately 0.8% of the average annual inflow to the lake for instream flow requirements in the Chakachatna River was regarded as having negligible effect on the installed capacity and average annual firm energy because that reduction is within the accuracy of the present study.

The reasoning for the smaller instream flow releases considered in this alternative is discussed in Section 2.5.3.

2.2 Geological Studies

At the present level of study, the Quarternary Geology in the Chakachatna and McArthur Valleys has been evaluated and the seismic geology of the general area has been examined though additional work remains to be done next year. General observations as they may affect the project are as follows:

The move of ice of the Barrier Glacier toward the river may be gradually slowing. However, no material change in the effect of the glacier on the control of the Chakachamna Lake outlet is anticipated.

The condition of the Blockade Glacier facing the mouth of the McArthur Canyon also appears to be much the same as reported in the previous USGS studies.

There does not appear to be any reason to expect a dramatic change in the state of growth or recession of either of the above two glaciers in the foreseeable future.

Surface exposures on the left (northerly) side of the Chakachatna Valley consist of a heterogeneous mix of volcanic ejecta and glacial and fluvial sediments which raise doubts as to the feasibility of damming Chakachatna River by a dam located downstream of the glacier.

The rock in the right wall of the Chakachatna Valley is granitic, and surface exposures appear to indicate that it would be suitable for tunnel construction if that form of development of the project were found to be desirable.

No rock conditions have yet been observed that would appear to rule out the feasibility of constructing a tunnel between the proposed locations of an intake structure near the outlet of Chakachamna Lake and a powerhouse site in the McArthur Valley. It must be noted, however, that in the vicinity of the proposed powerhouse location in the McArthur Canyon, the surface exposures indicate that rock quality apppears to improve significantly with distance upstream from the mouth of the canyon.

The Castle Mountain fault, which is a major fault structure, falls just outside the mouth of the McArthur Canyon and must be taken into account in the seismic design criteria of any development of the project whether it be via the McArthur or Chakachatna Canyons. Other significant seismic sources are the Megathrust Section of the Subduction Zone and the Benioff Zone.

2.3 Environmental Studies

2.3.1 Hydrology

Field reconnaissances were conducted in Chakachamna Lake, several of its tributary streams, the Chakachatna and McArthur Rivers. Records of mean daily flows were initiated in mid-August 1982 at the site of the previously operated U.S. Geological Survey gage site and in the Upper McArthur River downstream from the powerhouse location. Data collected and developed are typical of glacial rivers with low flow in late winter and large glacier melt flows in July and August.

The water level in Chakachamna Lake when measured in 1981 was elevation 1142 and is typical of the September Lake stage records in the 12 years preceding the major flood of August 1971. Lake bottom profiles were surveyed at the deltas of the Nagishlamina and Chilligan Rivers, and the Shamrock Glacier Rapids.

Reaches of the McArthur and Chakachatna Rivers vary in configuration from mountainous through meandering and braided. All except the most infrequent large floods are mostly contained within the unvegetated flood plan. Sedimentation characteristics appear to be typically those of glacial systems with very fine suspended sediments and substantial bed load transport.

2.3.2 Aquatic Biology

Field observations identified the following species in the waters of the project area:

Resident:	Rainbow trout	Artic grayling
	Lake trout	Slimy sculpin
	Dolly Varden	Ninespine stickleback
	Round Whitefish	Threespine stickleback
	Pygmy Whitefish	
Anadromous:	Chinook salmon	Pink salmon
	Chum salmon	Sockeye salmon
	Coho salmon	Dolly Varden
	Eulachon	Rainbow smelt
	Longfin smelt	Bering cisco

Salmon spawning in the Chakachatna River drainage and its tributaries occurs primarily in tributaries and sloughs. A relatively small percentage of the 1982 estimated escapement was observed to occur in mainstem or side-channel habitats of the Chakachatna River.

The largest salmon escapement in the Chakachatna drainage was estimated to occur in the Chilligan and Igitna Rivers upstream of Chakachamna Lake. The escapement of those sockeye in 1982 was estimated to be approximately 41,000 fish, or about 70 percent of the escapement within the Chakachatna drainage. Chakachamna Lake is the major rearing habitat for these sockeye. It also provides habitat for lake trout, Dolly Varden, round whitefish, and sculpins.

In the McArthur River over 96 percent of the estimated salmon escapement occurred in tributaries during 1982. The estimated escapement of salmon of all species was slightly greater in the McArthur than the Chakachatna drainage. Other anadromous fish including eulachon, Bering cisco, longfin smelt and rainbow smelt have been found in the McArthur River.

The contribution of salmon stocks originating in these systems to the Cook Inlet commercial catch is presently unknown. Although some commercial and subsistence fishing occurs, the extent to which the stock is exploited is also not known.

Rearing habitat for juvenile anadromous and resident fish is found throughout both rivers, although the waters within the Chakachatna River canyon below Chakachamna Lake and the headwaters of the McArthur River do not appear to be important rearing habitat. There appears to be extensive movement of fish within and between the two drainages, and seasonal changes in distribution have also been noted.

2.3.3 Terrestrial Biology

On the basis of their structural and species compositions, eight types of vegetation habitats were delineated. These range from dense alder thickets in the canyons to vast areas of coastal marsh. The riparian communities are the most prevalent varying from rivers with emergent vegetation to those with broad flood plains scattered with lichen, willow and alder.

Evaluation of wildlife communities in the project area identified seventeen species of mammals. Moose, coyote, grizzly bear and black bear ranges occur throughout the area.

Birds also are abundant, fifty-six species having been identified with the coastal marshes along Trading Bay containing the largest diversity.

None of the species of plants, mammals and birds that were found are listed as threatened or endangered although in May 1981 it was proposed that the tule whitefronted goose, which feeds and may nest in the area, be considered for threatened or endangered status.

2.3.4 Human Resources

These studies were organized into the following six elements:

- Archaeological and historical resources
- Land ownership and use
- Recreational resources
- Socioeconomic characteristics
- Transportation
- Visual resources

Many contacts were made with both State and Federal Agencies and native organizations, as well as a limited reconnaissance of the project area.

No known cultural sites have been identified and the field reconnaissance indicates that the proposed sites for the power intake and powerhouses have a low potential for cultural sites.

Land owners in the area comprise federal, state, and borough agencies, Native corporations and private parties. Land use is related to resource extraction (lumber, oil and gas), subsistence and the rural residential village of Tyonek.

Recreational activity takes place in the project area, but with the exception of Trading Bay State Game Refuge, little data is available as to the extent or frequency with which the area is used.

Regional data on population, employment and income characteristics are relatively good. Employment level and occupational skill data are limited and need to be developed together with information on local employment preferences.

Transportation facilities in the area are few and small in size. There are airstrips at Tyonek and on the shoreline at Trading Bay. A woodchip loading pier is located near Tyonek. Several miles of logging roads exist between Tyonek and the mouth of the Chakachatna Valley; many of these roads and bridges are being removed as timber activities are completed in specific areas. The Chakachatna River was bridged near its confluence with Straight Creek until 1982. There is no permanent road linking the project area with any part of the Alaska road system.

The project area's scenic characteristics and proximity with BLM lands, Lake Clark National Park and the Trading Bay State Game Refuge make visual resource management a significant concern.

2.4 Economic Evaluation

The studies demonstrate that the project offers an ecomonically viable source of energy in comparison with the 55.6 mills/kWh which is the estimated cost of equivalent energy from a coal fired plant, apparently the most competitive alternative source. Taking that figure as the value of energy, the Chakachamna Hydroelectric Project could begin producing 400 MW at 50% load factor (1752 GWh) in 1990 at 37.5 mills/KWh if all stored water is used for power generation. If approximately 19 percent of the water is reserved for instream flow release to the Chakachatna River, the powerplant could still produce 330 MW at 50% load factor (1446 GWh) at 43.5 mills/KWh, which is still significantly more economical than the coal fired alternative. Assuming that the power tunnel were to be machine bored, if the maximum pool level of the lake is raised to El. 1155 and can be drawn down to El. 1083, the powerplant will produce 330 MW (1301 GWh) at 44.5 mills/KWh with 45% load factor. In all the cases above, the powerhouse would be located on the McArthur River. A powerhouse on the Chakachatna River as described in the report is barely competitive with the alternative coal fired source of energy.

2.5 Technical Evaluation and Discussion

Several alternative methods of developing the project were identified and reviewed in 1981. Based on the analyses performed in 1982, the most viable alternative has been identified for further study. That is Alternative E in which water would be diverted from Chakachamna Lake to a powerhouse located near the McArthur River.

2.5.1 Chakachatna Dam Alternative

The construction of a dam in the Chakachatna River Canyon approximately 6 miles downstream from the lake outlet, does not appear to be a reasonable alternative. While the site is topographically suitable, the foundation conditions in the river valley and left abutment are poor as mentioned earlier in Section 2.2. Furthermore, its environmental impact specifically on the fisheries resource will be significant although provision of fish passage facilites could mitigate this impact to a certain extent.

2.5.2 McArthur Tunnel Alternatives A, and B

Diversion of flow from Chakachamna Lake to the McArthur Valley to develop a head of approximately 900 feet has been identified as the most advantageous as far as energy production at reasonable cost is concerned.

The geologic conditions for the various project facilities including intake, power tunnel, and powerhouse appear to be favorable based on the limited 1981 field reconnaissances. No insurmountable engineering problems appear to exist in development of the project.

Alternative A, in which essentially all stored water would be diverted from Chakachamna Lake for power production purposes could deliver 1664 GWh of firm energy per year to Anchorage and provide 400 MW of peaking capacity. Cost of energy is estimated to be 37.5 mills per KWh. However, since the flow of the Chakachatna River below the lake outlet would be adversely affected, the existing anadromous fishery resource which uses the river to gain entry to the lake and its tributaries for spawning, would be lost. In addition the fish which spawn in the lower Chakachatna River would also be impacted due to the much reduced river flow. For this reason Alternative B has been developed, with essentially the same project arrangement except that approximately 19 percent of the average annual flow into Chakachamna Lake would be released into the Chakachatna River below the lake outlet to maintain the fishery resource. Because of the smaller flow available for power production, the installed capacity of the project would be reduced to 330 MW and the firm energy delivered to Anchorage would be 1374 GWh per year. The estimated cost of energy is 43.5 mills per KWh. The cost estimate included an allowance for facilities for downstream flow release and for passage of fish at the lake outlet. Layouts of these facilities were not prepared. Obviously, the long term environmental impacts of the project in this Alternative B are significantly reduced in comparison to Alternative A.

2.5.3 Chakachatna Tunnel Alternatives C and D

An alternative to the development of this hydroelectric resource by diversion of flows from Chakachamna Lake to the McArthur River is by constructing a tunnel through the right wall of the Chakachatna Valley and locating the powerhouse near the downstream end of the valley. The general layout of the project would be similar to that of Alternatives A and B for a slightly longer power tunnel.

The geologic conditions for the various project features including intake, power tunnel, and powerhouse appear to be favorable and very similar to those of Alternatives A and B. Similarly no insurmountable engineering problems appear to exist in development of the project Alternative C, in which essentially all stored water is diverted from Chakachamna Lake for power production, could deliver 1248 GWh of firm energy per year to Anchorage and provide 300 MW of peaking capability. Cost of energy is estimated to be 52.5 mills per KWh. While the flow in the Chakachatna River below the powerhouse at the end of the canyon will not be substantially affected, the fact that no releases are provided into the river at the lake outlet will cause a substantial impact on the anadromous fish which normally enter the lake and pass through it to the upstream tributaries. Alternative D was therefore proposed in which a release of 30 cfs is maintained at the lake outlet to facilitate fish passage through the canyon section into the lake. In either of Alternatives C or D the environmental impact would be limited to the Chakachatna River as opposed to Alternatives A and B in which both the Chakachatna and McArthur Rivers would be affected. Since the instream flow release for Alternative D is less than 1% of the total available flow, the power production of Alternative D can be regarded as being the same as those of Alternative C at this level of study (300 MW peaking capability, 1248 GWh of firm energy delivered to Anchorage). Cost of power from Alternative D is 54.5 mills per KWh.

The cost of energy from Alternative D is 25% greater than that for Alternative B and E and is close to the cost of alternative coal-fired resources. Therefore, it was decided to concentrate further studies on the McArthur River alternatives.

2.5.4 Alternative E

In the development of Alternative B, no specific method was developed for release of instream flows into the Chakachatna River immediately downstream from the lake outlet, and no specific facilities were developed for the passage of upstream and downstream migrant fish at the lake outlet. Instead a lump sum cost allowance was provided to cover these items for Alternative B.

However, in Alternative E which is a refinement of Alternative B, development by tunnel to the McArthur River, specific facilities for providing instream flow releases and fish passage facilities were developed and incorporated into the proposed project structures. To facilitate the arrangement of these facilities, it became evident that a more limited reservoir drawdown was essential. The range of reservoir level adopted was maximum level El. 1155 near the historical maximum level, and minimum level El. 1083 to permit gravity discharge of water through the facilities at the lowest operating water level.

With this operating range in the reservoir and with an installed capacity of 330 MW, the project can produce 1301 GWh per annum at a 45% load factor. If a 50% load factor were to be retained, the installed capacity of the powerhouse would reduce to approximately 300 MW, which would reduce the overall project cost by about 5-10%. However, at this stage of the project development, such a refinement was not considered warranted, and the same installed capacity as developed for Alternative B was retained for Alternative E, i.e. 330 MW. Significant project data for Alternative E are set forth in Table 2-1.

Alternative E is also based on the power tunnel being driven by a tunnel boring machine which resulted in a significant reduction in cost compared with conventional "drill and shoot" methods previously adopted for Alternatives A through D. In addition, the power tunnel profile in Alternative E was modified to a uniform grade from the intake at Lake Chakachamna to the powerhouse in the McArthur valley. The estimated cost of energy is 44.5 mills per kWh.

It should be noted that the significant saving in tunnel cost for Alternative E, as compared with Alternative B, is offset by the increased cost of the fish passage facilities and slightly lower energy production, thereby yielding a firm energy cost slightly higher for Alternative E than for Alternative B.

TABLE 2-1

RECOMMENDED ALTERNATIVE E

PROJECT DATA

Chakachamna Lake

Maximum water level, natural conditions, (ft.)	1,155
Minimum water level, natural conditions, approx. (ft.)	1,128
Surface area at elevation 1155 (sq. mi.)	27
Total volume at elevation 1155 (Ac. ft.)	4,483,000
Drainage area (sq. mi.)	1,120
Average annual inflow, 12 years (cfs)	3,606
Correlated average annual inflow, 31 years (cfs)	3,781

Reservoir Operation

Normal maximum operating water surface elevation (ft.)	1,155
Normal minimum water surface elevation (ft.)	1,083
Active storage (Ac. ft.)	1,105,000

Dike

Type	Overflow rockfill
Length, (ft.)	600
Crest elevation (ft.)	1,177
Maximum height (ft.)	49
Volume (Cu. yd.)	250,000

Spillway

Type	Free overflow
Crest elevation (ft.)	1,155
Discharge capacity (cfs)	55,000

Power Tunnel

Type	Circular, concrete lined
Diameter, internal (ft.)	24
Hydraulic capacity (cfs)	7,200
Surge chamber (Dia. x Ht. Ft.)	48 x 450

TABLE 2-1 (cont'd)

<u>Penstock</u>	
Number/Type	1-Circular, concrete lined 4-Circular, steel lined
Diameter, internal (ft.)	
Concrete lined	24
Steel lined	10
<u>Powerhouse</u>	
Type	Underground
Cavern size (L x W x H Ft.)	250 x 65 x 130
Turbines	4 Vertical Francis
Generators	Synchronous
Unit output (MW)	82.5
Maximum net head (ft.)	938
Minimum net head (ft.)	866
Maximum discharge (cfs)	7,200
Distributor centerline elevation (ft.)	190
Installed capacity (MW)	330
Average annual firm energy (GWh)	1,301
Average annual secondary energy (GWh)	290
Load factor	.45
<u>Fish Passage Facilities</u>	
Maximum release (cfs)	1,094
Minimum release (cfs)	343
Fish passage tunnel (L x W x H Ft.)	7800 x 18 x 20
<u>Economic Parameters</u>	
Estimated total cost $ billion	1.31
Cost of energy (mills per kWh)	44.5
Cost per installed kW ($)	3,985
Construction period (Mos.)	76

PROJECT DEVELOPMENT STUDIES

3.0 PROJECT DEVELOPMENT STUDIES

3.1 Regulatory Storage

The existing stream flow records show a wide seasonal variation in discharge from Chakachamna Lake with 91 percent of the annual discharge occurring from May 1 through October 31 and 9 percent from November 1 through April 30 when peak electrical demands occur. The storage volume required to regulate the flow has been reported to be in the order of 1.6 million acre-feet (USBR, 1962). The elevation of the river bed at the lake outlet has been reported as 1127-1128 feet (Giles, 1967). This elevation is thought to have varied according to the amounts and sizes of solid materials deposited in the river bed each year by the melting toe of the glacier, and the magnitude of the annual peak outflow from the lake that is available to erode the solid materials away and restore the river channel.

The above-mentioned volume of regulatory storage can be developed by drawing down the lake by 113 feet to Elevation 1014. The original studies performed in 1981 adopted such a reservoir operating range in developing project alternatives A, B, C and D. However, when the 1982 studies for development of suitable fish passage facilities at the lake outlet were initiated, it became evident that a lake drawdown to El. 1014 was not suited to the provision of such facilities. Therefore a modified range of reservoir operating level was adopted as discussed below.

If the maximum lake level is raised to El. 1155 and 72 feet drawdown is considered, then a regulatory storage of 1,105,000 acre-feet is provided with increase in head. Although previous studies of the project have discredited the possibility of locating a control structure at the lake outlet because its left abutment would have lain on the toe of the Barrier Glacier, it is believed that a relatively low dike with 27 feet of hydraulic head plus freeboard could be constructed and maintained at this location. This is discussed further in Section 3.5.1.

The Barrier Glacier ice thickness was measured in 1981 by the USGS using radar techniques. The data has not yet been published but verbal communication with the USGS staff has indicated that the ice depth is probably 500-600 feet in the lower moraine covered part of the glacier near the lake outlet. Thus it would appear that the outlet channel from the lake may be a small gravel and boulder lined notch in a deep bed of ice.

3.2 Chakachatna Dam

The possibility of gaining both storage and head by means of a dam on the Chakachatna River was first posed in 1950 by Arthur Johnson (Johnson, 1950) who identified, though was unable to inspect, a potential dam site about 6 miles downstream from the lake outlet. Three years later, during the 1953 eruption of Mount Spurr, a mud flow descended the volcano slopes and temporarily blocked the river at this location, backing it up for about 4 miles until it overtopped the debris dam. At this location, the river today is still backed up almost 2 miles despite the occurrence of the August 1971 lake breakout flood estimated to have peaked at about 470,000 cubic feet per second (Lamke, 1972). This flow is about twenty times larger than the maximum daily discharge that occurred during the 1959-1972 period of record.

Examination of aerial photographs taken after the 1953 eruption between 1954 and 1981 indicate that subsequent mud flows, though of smaller magnitude, may have occurred but probably did not reach the river. The source of this activity has been Crater Peak, an active volcanic crater on the southerly flank of Mount Spurr. It lies directly above and in close proximity to the postulated dam site and thus poses serious questions on the safety of this site for construction of any form of dam. At this location, generally from about 6 miles to 7 miles downstream from the lake outlet, the river is confined within a canyon. Both upstream and downstream, the valley substantially widens and does not appear to offer any topographicaly feasible sites for locating a dam.

Within the canyon itself, conditions are rather unfavorable for siting a dam. Bedrock is exposed on the right abutment, making this the most likely site for a spillway, but the rock surface dips at about 40-degrees toward the river channel. At this location, the peak discharge of the probable maximum flood calculated according to conventional procedures would be in the order of 100,000 cubic feet per second. The crest length of a spillway would have to be in the order of 200 feet and siting it on the steeply dipping right abutment rock surface would be difficult and costly.

Surface examination of the left abutment conditions, as discussed in section 5.2.3.2 of this report, indicates that they consist of deep unconsolidated volcanic materials. These would require a deep diaphragm wall or slurry trench cutoff to bedrock, or an extensive upstream foundation blanket to control seepage through the pervious materials lying on this abutment. Very high costs would also be attached to their construction.

The presence of the volcano and its potential for future eruptions accompanied by mud flows as well as pyroclastic ash flows is probably the overriding factor in discrediting the feasibility of constructing a dam in this canyon location. Consequently, this concept has been temporarily set aside from further consideration at the present stage of the studies, and the main thrust has been directed toward development by gaining regulatory storage by drawing down the lake water level and diverting water from a submerged intake in Chakachamna Lake through a tunnel to the McArthur river, or through a tunnel to the mouth of the Chakachatna Valley, as discussed in the next two sections of this report.

3.3 McArthur Tunnel Devlopment

3.3.1 Alternative A

Initial studies have been directed toward development by means of a tunnel to the McArthur River that would maximize electrical generation without regard to release of water into the Chakachatna River for support of its fishery. Two arrangements have been studied, the first being a tunnel following an alignment about 12 miles long designated Alternative A-1 and shown in Figure 3-1. This alignment provides access for construction via an adit in the Chakachatna Valley about 3 miles downstream from the lake outlet.

As discusssed in section 9.0 of this report, the tunnel would be 25 feet internal diameter and concrete lined throughout its full length.

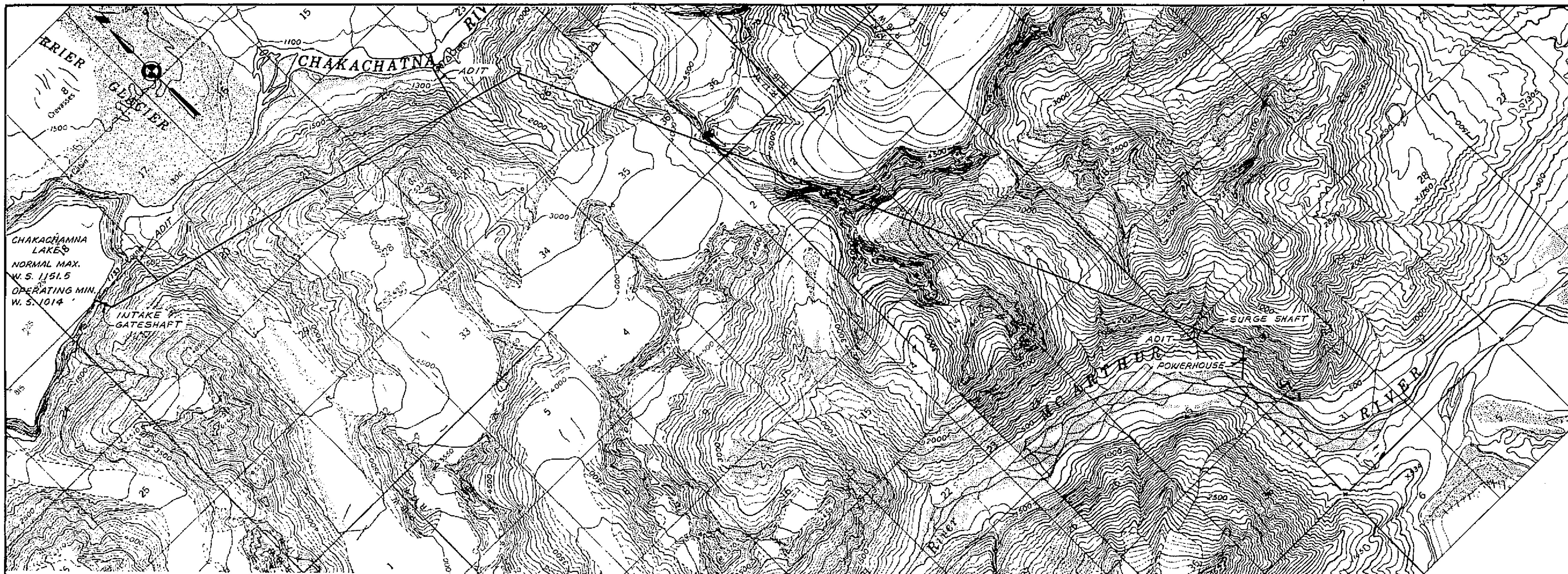
The second tunnel studied is designated Alternative A-2 and follows a direct alignment to the McArthur Valley without an intermediate access adit as shown on Figure 3-2. As further discussed in Section 9.0 of this report, this tunnel would also be 25 feet diameter and concrete lined.

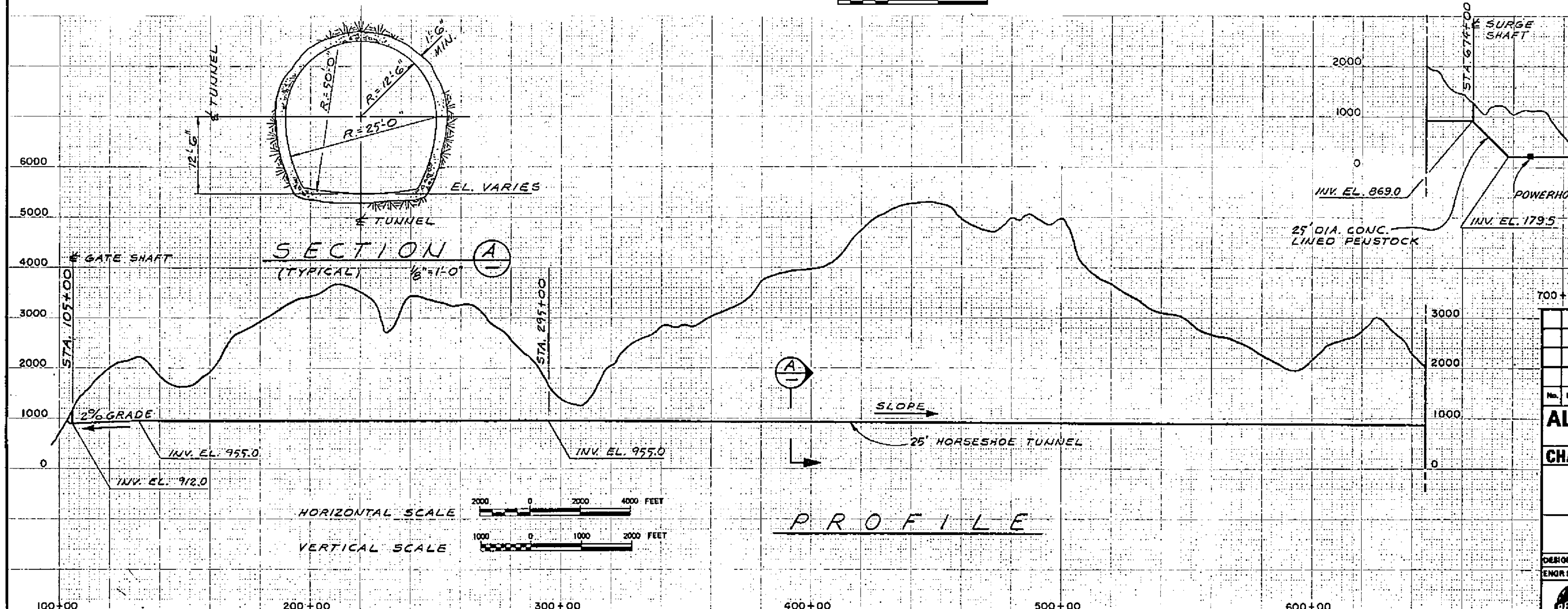
Although the tunnel for Alternative A-1 is about 1 mile longer than that for Alternative A-2, it would enable tunnel construction to proceed simultaneously in four headings thus reducing its time for construction below that required for the shorter tunnel in Alternative A-2. Nevertheless, the studies show that the economics favor the shorter tunnel and no other significant factors that would detract from it have been identified at this stage of the studies. Therefore the direct tunnel route was adopted and all further references in the report to Alternative A are for the project layout with the direct tunnel shown on Figure 3-2.

Typical sketches have been developed for the arrangement of structures at the power intake in Chakachamna Lake and these are shown on Figure 3-4 with typical sections and details on Figure 3-5. Similarly, layouts have been developed for structures located beyond the downstream end of the tunnel. These include a surge shaft, penstock, manifold, valve gallery, powerhouse, transformer gallery, access tunnel, tailrace tunnel and other associated structures as shown on Figure 3-6.

For Alternative A, the installed capacity of the powerhouse derived from the power studies discussed in Section 4.0 of this report is 400 MW. For purposes of estimating costs, the installation has been taken as four 100 MW capacity vertical shaft Francis turbine driven units.

It is to be noted that the layout sketches mentioned above and those prepared for other alternatives considered in this report must be regarded as strictly typical. They form the basis for the cost estimates discussed in Section 8.0 but will be subject to refinement and optimization as the studies proceed. For example, the lake tapping for the power intake is laid out on the basis of a single opening about 26- feet in diameter. This is a very large underwater penetration to be made under some 150-170 feet of submergence, and the combination of diameter and depth is believed to be unprecedented. In the final analysis, it may prove advisable to design for multiple smaller diameter openings. The information needed to evaluate this is not available at the present time.





NOTES:

1) TOPOGRAPHY IS FROM USGS QUADRANGLE MAPS.
2) CONTOUR INTERVAL IS 100 FEET.
3) VERTICAL DATUM IS MEAN SEA LEVEL.
4) HORIZONTAL GRID IS UNIVERSAL TRANSVERSE MERCATOR PROJECTION, 1927 NORTH AMERICAN DATUM.
5) SEE FIGURES 3-4 AND 3-5 FOR GATE SHAFT DETAILS AND FIGURE 3-6 FOR SURGE TANK, PENSTOCK AND POWERHOUSE GENERAL ARRANGEMENT.

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ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

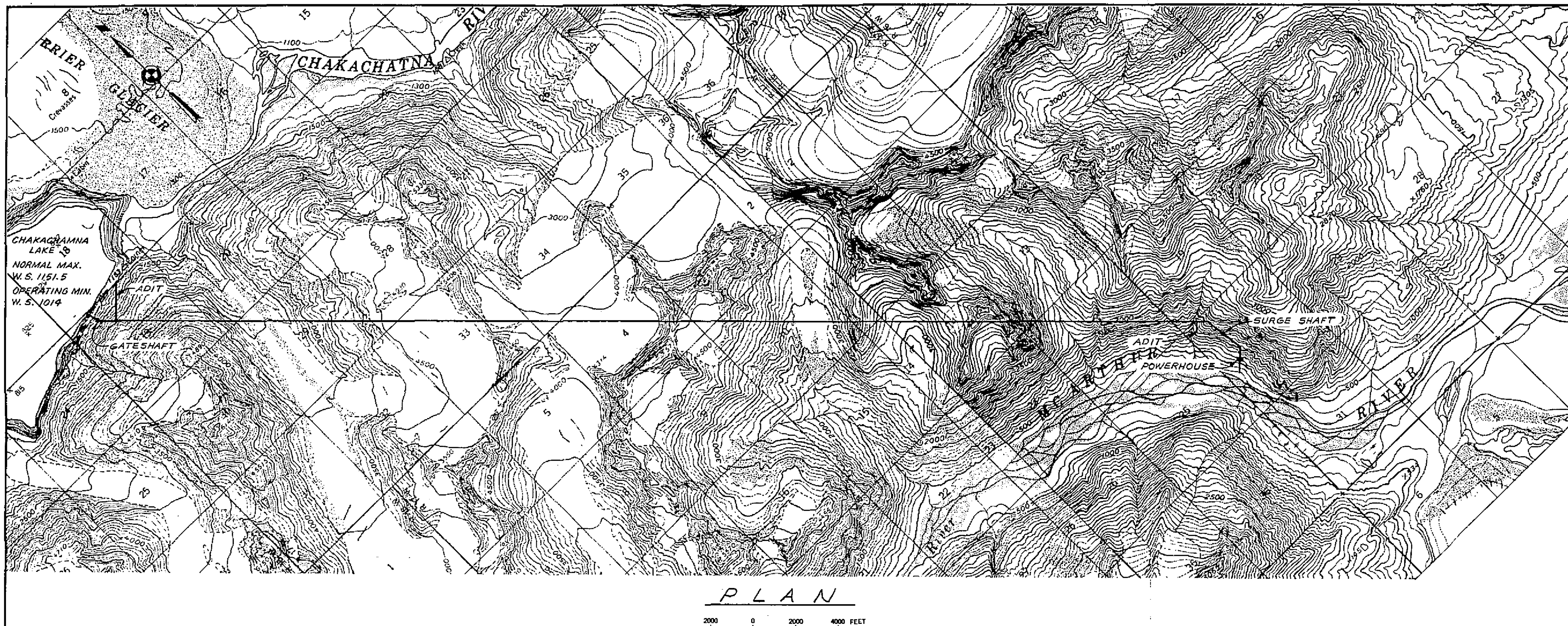
CHAKACHAMNA HYDROELECTRIC PROJECT

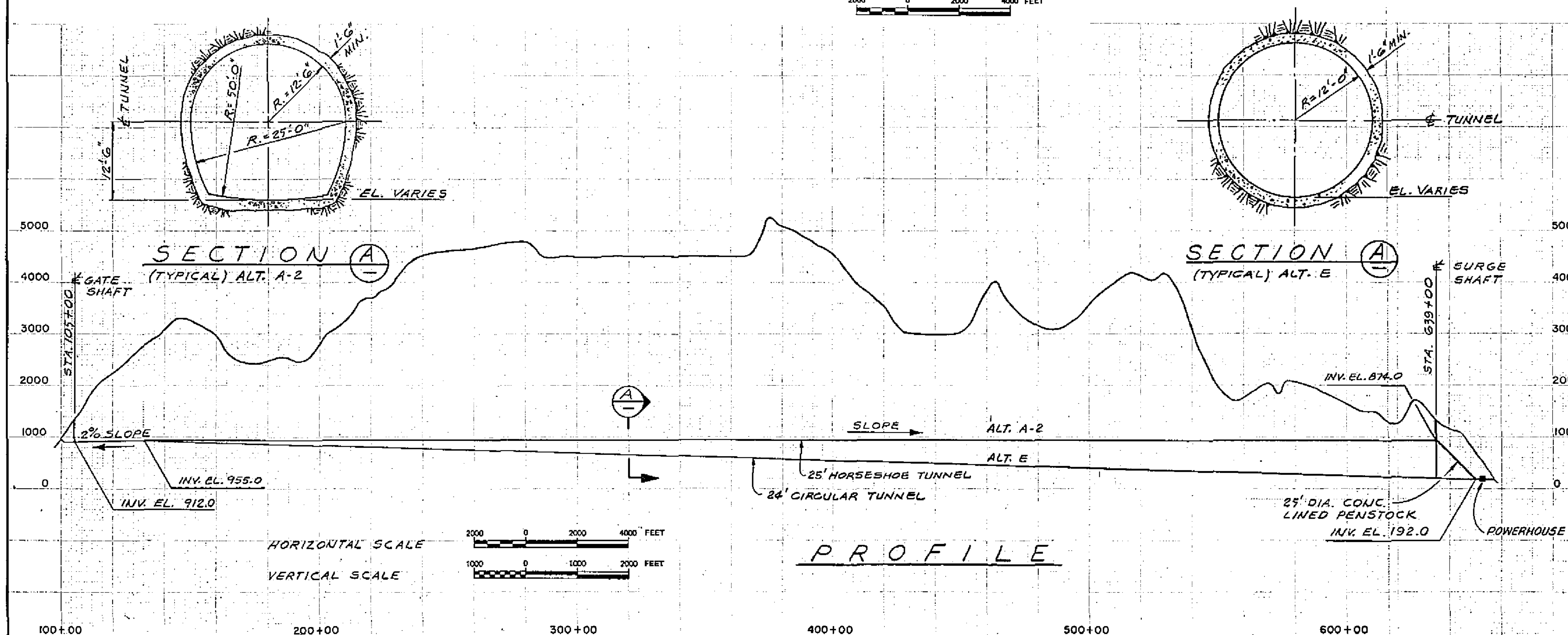
McARTHUR TUNNEL
ALTERNATIVE A-1

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN PRITCHARD	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-1	





NOTES:

1) TOPOGRAPHY IS FROM USGS QUADRANGLE MAPS
2) CONTOUR INTERVAL IS 100 FEET
3) VERTICAL DATUM IS MEAN SEA LEVEL.
4) HORIZONTAL GRID IS UNIVERSAL TRANSVERSE MERCATOR PROJECTION, 1927 NORTH AMERICAN DATUM.
5) SEE FIGURES 3-4 AND 3-5 FOR GATE SHAFT DETAILS AND FIGURE 3-6 FOR SURGE TANK, PENSTOCK AND POWERHOUSE GENERAL ARRANGEMENT.

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CHAKACHAMNA HYDROELECTRIC PROJECT

McARTHUR TUNNEL
ALTERNATIVES A-2 & E

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

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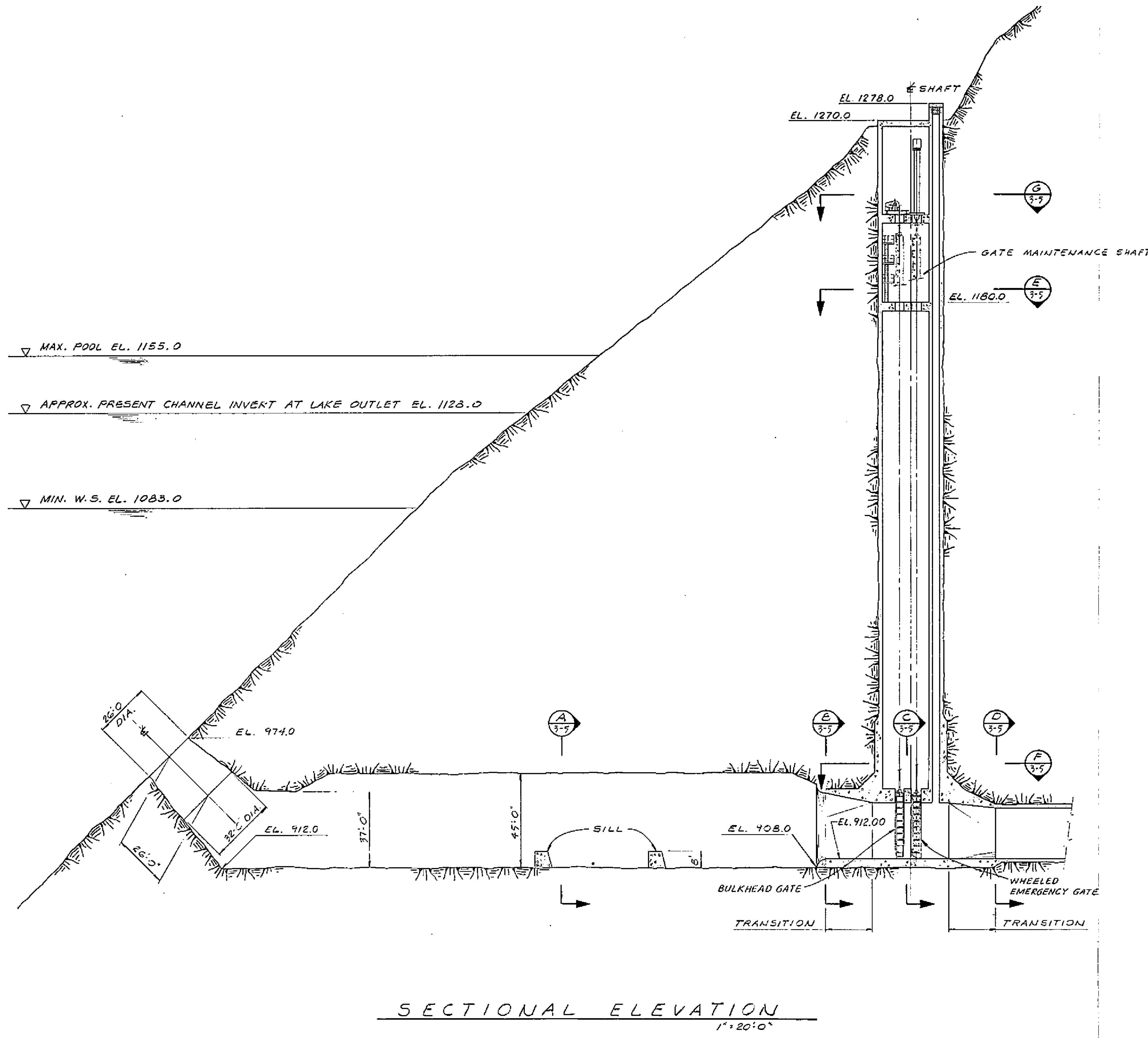
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-2	



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CHAKACHAMNA HYDROELECTRIC PROJECT

GATE SHAFT SECTION
SHEET-1

BECHTEL CIVIL & MINERALS, INC.
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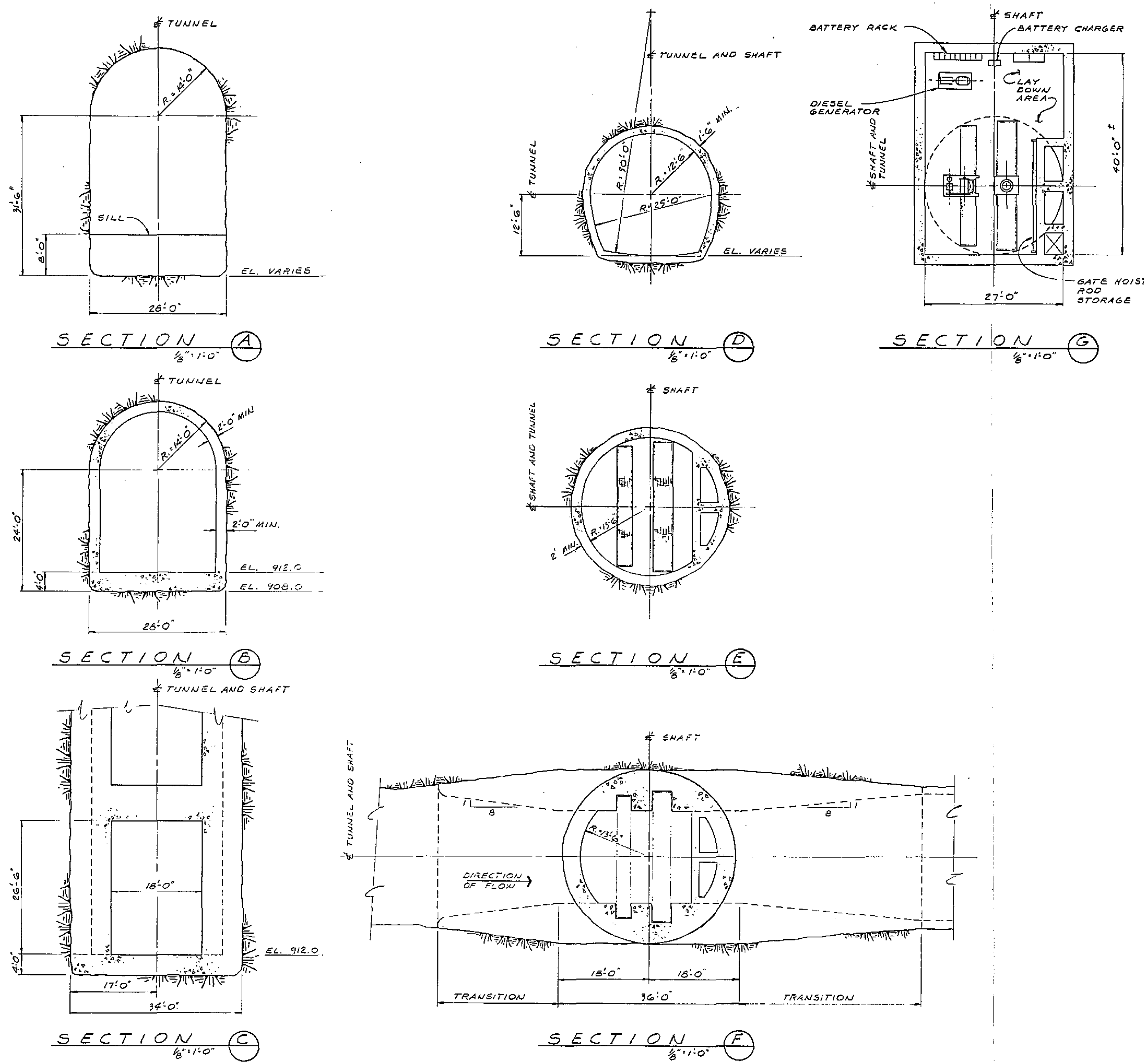
ENGR SUPV | PROJ ENGR | APP'D

JOB No. 14879 | DRAWING No. FIGURE 3-4 | REV.



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CHAKACHAMNA HYDROELECTRIC PROJECT

GATE SHAFT SECTIONS
SHEET-2

BECHTEL CIVIL & MINERALS, INC.
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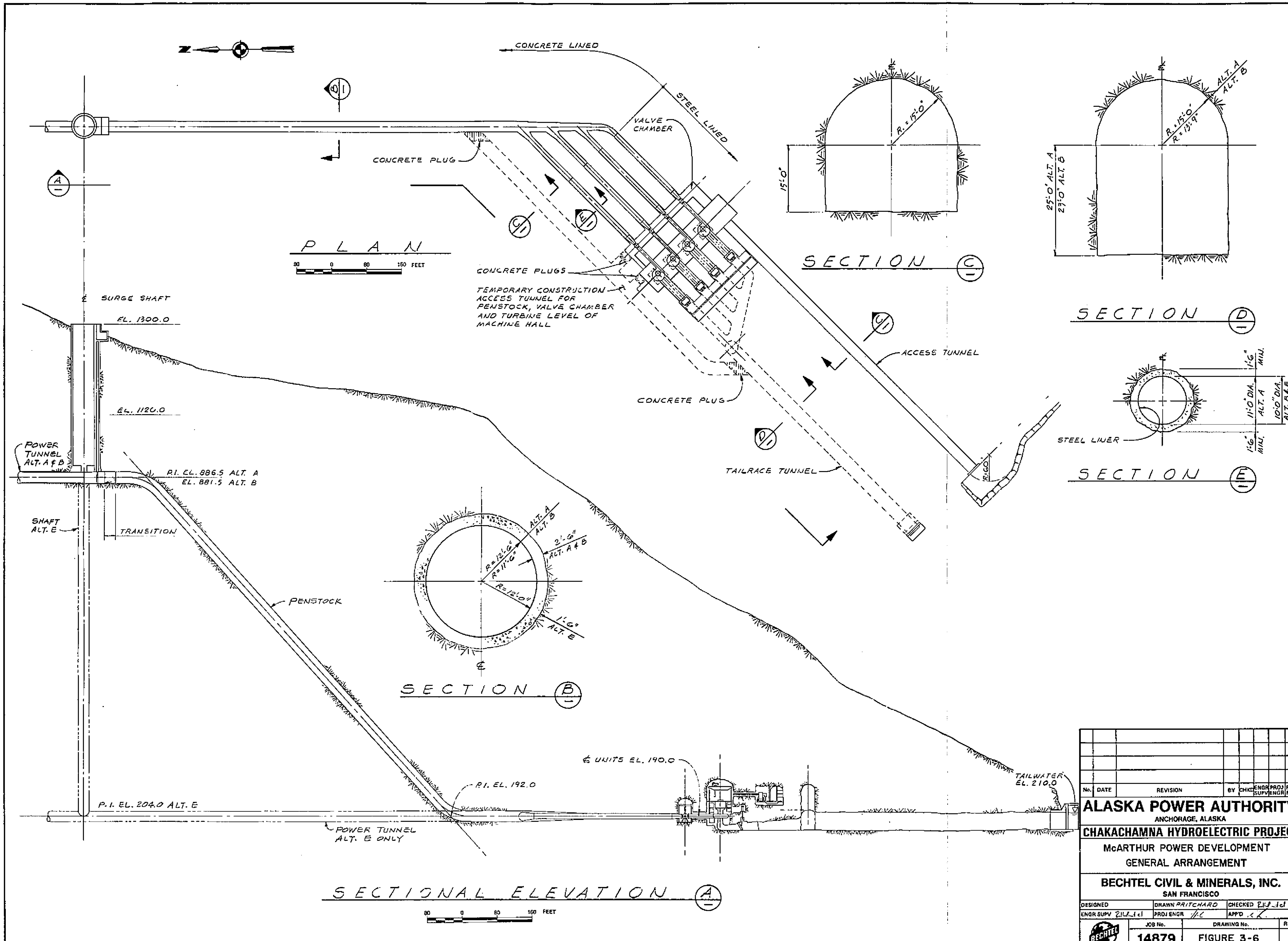
ENGR SUPV	PROJ ENGR	APP'D
JOB No. 14879	DRAWING No. FIGURE 3-5	REV.



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CHAKACHAMNA HYDROELECTRIC PROJECT

McARTHUR POWER DEVELOPMENT
GENERAL ARRANGEMENT

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED | DRAWN PRITCHARD | CHECKED
ENGR SUPV | PROJ ENGR | APP'D

JOB No. 14879 | DRAWING No. FIGURE 3-6 | REV.

In similar vein, the penstock is shown as a single inclined pressure shaft descending to a four-branched manifold at the powerhouse level with provisions for emergency closure at the upstream end. Again, this is a very large pressure shaft, but the combination of pressure and diameter is not unprecedented in sound rock. Other considerations, such as unfavorable hydraulic transients in the manifold, or operational flexibility, may support the desirability of constructing a bifurcation at the downstream end of the tunnel with two penstocks, each equipped with an upper level shutoff gate, provided to convey water to each pair of turbines in the four-unit powerhouse. Such an arrangement would cost more than the single penstock shaft.

Turbine shutoff valves are shown located in a valve chamber separated from the powerhouse itself. Optimization studies should be made in the future to evaluate whether these valves can be located inside the powerhouse at the turbine inlets, or whether a ring gate type installation inside the turbine spiral cases might be preferable.

The powerhouse is shown as an underground installation. This appears to be the most logical solution for development via the McArthur River because of the steep avalanche and rock slide-prone slopes of the canyon wall. For the same reason, the transformers are shown in a chamber adjacent to the powerhouse cavern. A surge chamber is shown near the upstream end of the tailrace tunnel. It may prove more advantageous for this relatively short tailrace tunnel to make it freeflowing in which case the tailrace surge chamber would not be required.

The object of the above comments is to point out some of the options that are available. The arrangement of structures shown provides for a workable installation. Because of the limited engineering studies performed to date, it is not to be regarded as the optimum or most economical. Optimization will be performed at a later date. The layout is a workable arrangement that gives a realistic basis on which to estimate the cost of constructing the project, and a separately identified contingency allowance is provided in the estimate to allow for costs higher than those foreseen at the present level of study.

3.3.2 Alternative B

This alternative considers what effect a tentative allocation of water to meet instream flow requirements in the Chakachatna River would have on the amount of energy that could be generated by Alternative A which would use all stored water for energy generation. The tentative instream flow schedule is discussed in Section 7.3.2 of this report. For diversion to the McArthur River, and reservation of water for instream flow releases, the tunnel diameter would be about 23 feet. Based on the power studies discussed in Section 4.0, the installed capacity of the powerhouse would be reduced to 330 MW. The tunnel alignment and basic layout of structures generally is the same as that shown for Alternative A in Figure 3-2. The diameters of hydraulic conduits and the dimensions of the 330 MW powerhouse would be smaller than for the

400 MW powerhouse in Alternative A and appropriate allowances for these are made in the cost estimates.

When the various alternative arrangements of the project were developed in the 1981 study, no specific plan had been developed for the provision of releases of flow into the Chakachatna River immediately downstream from the lake outlet nor for the provision of fish passage facilities at the lake outlet for upstream and downstream migrants. It was recognized that suitable structures would be difficult to develop and would be very expensive. It was also planned that, due to the presence of the glacier at the lake outlet, the fish passage facility would have to be constructed inside a tunnel within the massive rock mountainside forming the right side of the lake outlet. Since no plan for such facility had been developed at that stage of the studies, a provisional allowance of $50 million was shown in the estimate for fish passage facilities.

During the second phase of the study in 1982, the concept of fish facilities and operation of the lake has been further developed for this alternative and it is described at the end of this section as Alternative E, the recommended alternative.

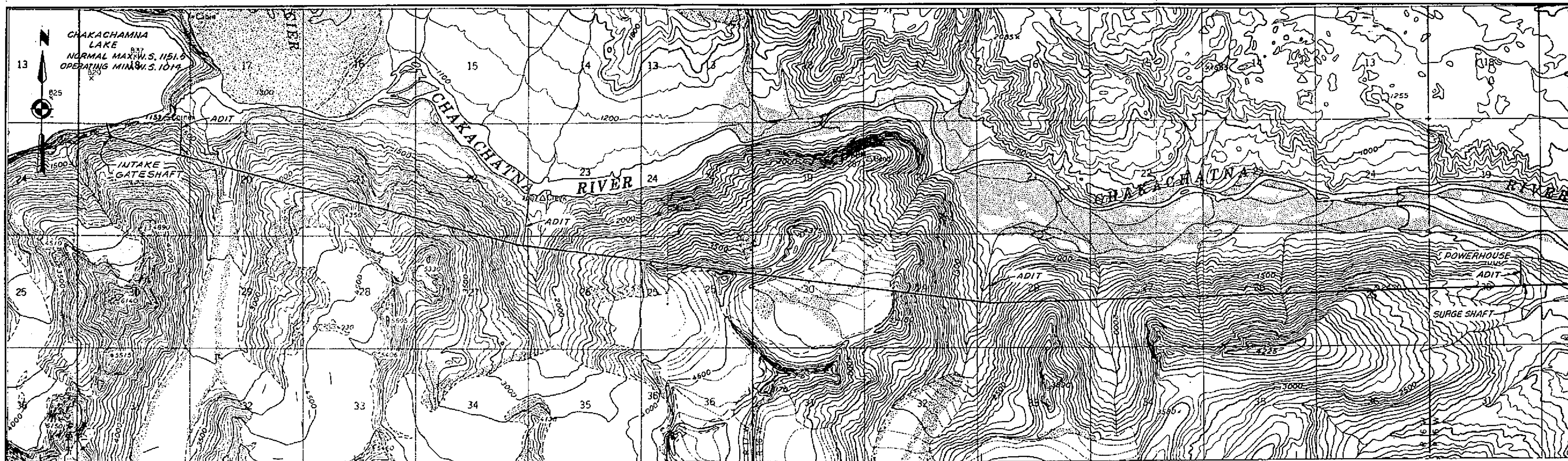
3.4 Chakachatna Tunnel Development

3.4.1 Alternative C

The initial studies of this alternative focused on development of the power potential by means of a tunnel roughly paralleling the Chakachatna River without release of water for instream flow requirements between the lake outlet and the powerhouse where the water diverted for power generation would be returned to the river. The tunnel alignment is shown on Figure 3-3.

This alignment offers two convenient locations for intermediate access adits during construction. The first is about 3 miles downstream from the lake outlet in the same location as discussed in Section 3.3.1 above for Alternative A. The second adit location is about 7 miles downstream from the lake outlet. The total tunnel length in this arrangement is about 12 miles and the adits would make it possible for construction of the tunnel to proceed simultaneously in six different headings.

The arrangement of the power intake is essentially the same and in the same location as for Alternative A as shown on Figures 3-4 and 3-5. The tunnel is also 25 feet internal diameter, concrete lined, and penetrates the mountains in the right wall of the Chakachatna Valley. The arrangement for the surge shaft, penstock, valve gallery, powerhouse and asssociated structures is similar to that for development via diversion to the McArthur River but is modified to fit the topography and lower head. The layout is shown on Figure 3-7. The head that can be developed in Alternative C is roughly 200 feet less than in Alternatives A and B and the installed capacity in the powerhouse is only 300 MW as determined from the power studies discussed in Section 4.0 of this report.

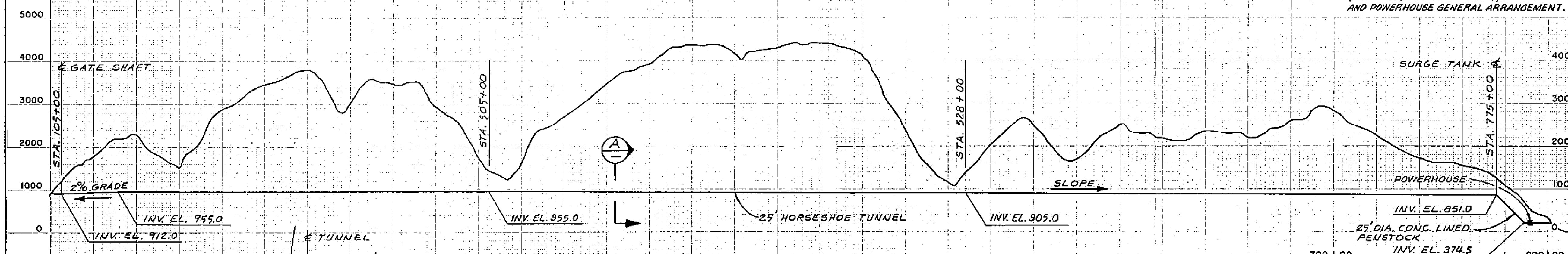


PLAN

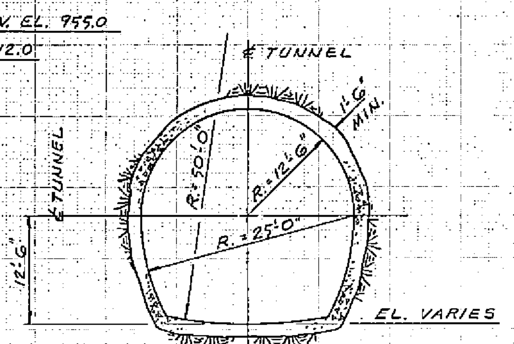
2000 0 2000 4000 FEET

NOTES:

1.) TOPOGRAPHY IS FROM USGS QUADRANGLE MAPS.
2.) CONTOUR INTERVAL IS 100 FEET
3.) VERTICAL DATUM IS MEAN SEA LEVEL
4.) HORIZONTAL GRID IS UNIVERSAL TRANSVERSE MERCATOR PROJECTION, 1927 NORTH AMERICAN DATUM.
5.) SEE FIGURES 3-4 AND 3-5 FOR GATE SHAFT DETAILS AND FIGURE 3-6 FOR SURGE TANK, PENSTOCK AND POWERHOUSE GENERAL ARRANGEMENT.



PROFILE



SECTION (A)
(TYPICAL) 1/8" = 1'-0"

HORIZONTAL SCALE 2000 0 2000 4000 FEET

VERTICAL SCALE 1000 0 1000 2000 FEET

100+00 200+00 300+00 400+00 500+00 600+00

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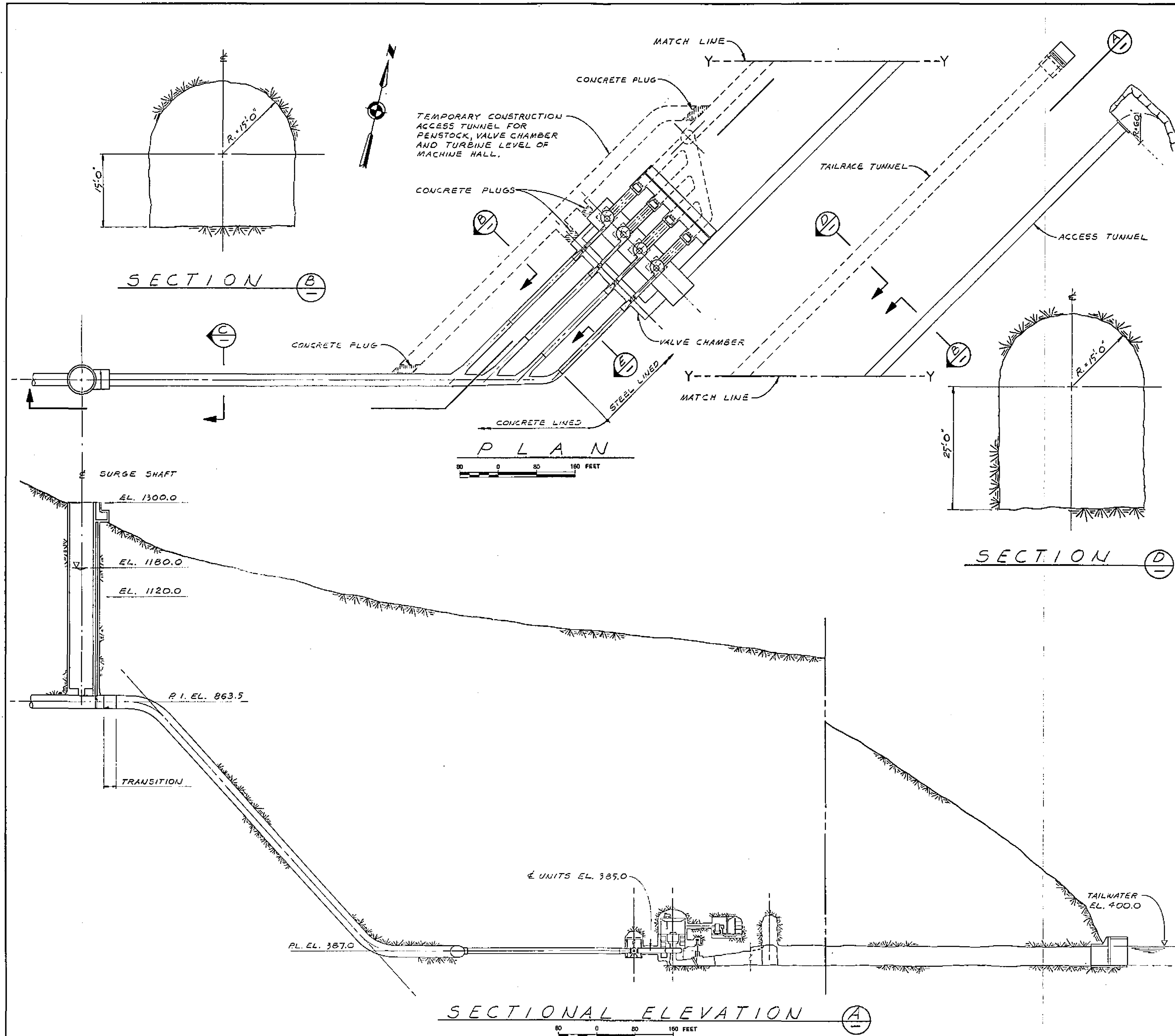
CHAKACHAMNA HYDROELECTRIC PROJECT

CHAKACHATNA TUNNEL
ALTERNATIVES C & D

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN PRITCHARD	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-3	



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ALASKA POWER AUTHORITY
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CHAKACHAMNA HYDROELECTRIC PROJECT

CHAKACHATNA POWER DEVELOPMENT
GENERAL ARRANGEMENT

BECHTEL CIVIL & MINERALS, INC.
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DESIGNED	DRAWN PRITCHARD	CHECKED
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JOB No.	DRAWING No.	REV.
14879	FIGURE 3-7	

For purposes of estimating the present costs of construction, the powerhouse is taken as being located underground. If this Alternative were to be pursued, future studies would be made to determine if economy can be attained by locating it outside on the ground surface. Comments made in Section 3.3.1 regarding the layout sketches for the McArthur powerhouse in Alternative A apply equally to the powerhouse and associated structures for the Chakachatna Powerhouse considered in Alternative C.

3.4.2 Alternative D

Studies of this alternative take account of the effect on electrical generation of reserving water to meet instream flow requirements in the Chakachatna River. The tentative water release schedule is less than that condidered for development by power diversions to the McArthur River as discussed in Section 7.1.5 of this report. The reason for this is that in the lower reaches of the river, downstream from the proposed powerhouse location, the river flow will include those waters that were diverted for electrical generation. These lower reaches of the river are probably more important to the fishery than the reach of the river between the lake outlet and the proposed powerhouse location. This probability is suggested, though not fully confirmed, by observations made of fish runs during the 1981 and 1982 field studies. These have indicated that the Chakachatna River, between the lake outlet and the proposed location of the powerhouse, serves primarily as a travel corridor for fish passing through the lake to spawning areas further upstream. The river itself, in this reach does not appear to offer much in the way of suitable spawning and juvenile rearing habitat. On the other hand, significant numbers of fish and spawning areas were observed in the lower reaches of the river downstream from the proposed powerhouse locations. Consequently, the tentative instream flow releases are small when compared with those considered for development via power diversions to the McArthur River, as discussed in Section 7.1.5 of this report. The tunnel diameter for development of the power potential via the Chakachatna Tunnel with provision for instream flow releases, is 25 feet, the same as that mentioned in Section 3.4.1 without such releases. The installed capacity in the powerhouse also remains the same at 300 MW. The layout sketches shown in Figures 3-3 and 3-7 for Alternative C are equally applicable to Alternative D as are the comments set forth in Sections 3.3.1 and 3.3.2 regarding the layout sketches for de- velopment via the McArthur River.

3.5 McArthur Development - Recommended Alternative E

3.5.1 General

This alternative is basically similar to Alternative B, but modified to include water release facilities into Chakachatna River, fish passage facilities at the lake outlet and modification of lake operating levels to accommodate these facilities. The power tunnel would have a 24-foot internal diameter circular section and the diameters of other hydraulic conduits, the powerhouse arrangement, sizing and location will be the same as described for Alternative B except as shown in Figures 3-2 and 3-6. It is to be noted that the emergency closure gate located at the head of the penstock in Alternative B cannot be retained in the layout for Alternative E. This results in a loss of a certain amount of operating flexibility to the extent that the penstock, upstream of the valve chamber, cannot be dewatered for inspection without dewatering the power tunnel. Likewise, in the event of a failure in the valves or the conduits upstream of the valves, the whole station would have to be shut down and the tunnel dewatered, before the rupture could be repaired.

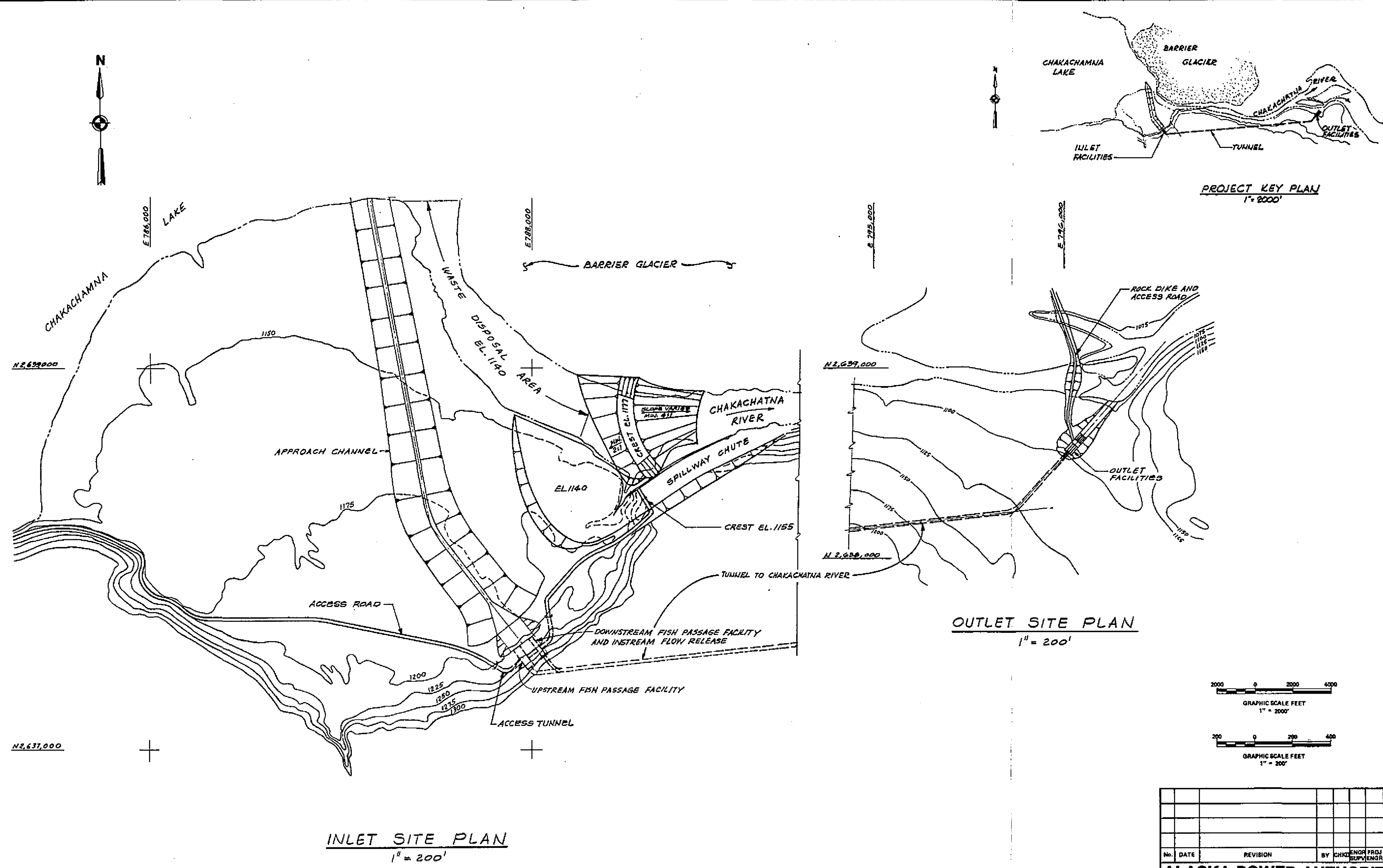
The operating range of the lake will be modified. The maximum level will be taken as the historical maximum evidenced by a white mark on the rock slopes of the lake shoreline at approximately El. 1155. A wide rockfill dike will be constructed at the lake outlet from the spoil material available from the spillway excavation described below to raise the lake outlet by approximately 27 feet. The reservoir level control will be established by an unlined spillway channel at El. 1155 excavated into the rock on the right side of the outlet. The layout is shown in Figure 3.8. The lake level operating range will be 72 feet down to El. 1083 rather than the 113 feet that was previously available in the studies for Alternatives A through D. The power tunnel intake level is maintained at the level previously used to provide even greater submergence to reduce potential problems of attracting downstream migrant fish into the power tunnel. Most flood waters will be released via the unlined spillway channel cut through the granite in the right abutment. This unlined channel has a capacity of 55,000 cfs, and will therefore handle all flood releases up to 55,000 cfs. Flows greater than this up to the presently estimated probable maximum flood of

100,000 cfs will pass both through the spillway and over the rockfill dike. It should be noted that the maximum peak discharge in the period of record of 1959-1971 was 23,400 cfs if the "dam-break" type of flood which occurred in August 1971 is disregarded. Future studies of the required spillway size may indicate that a reduction in size below the 55,000 cfs capacity may be possible.

It is considered that since overtopping of the rock dike will be a very infrequent occurrence, repair of the dike after such an event would be an acceptable maintenance procedure. Such repair can be scheduled in the spring before the lake rises to the level of the dike in July or August. Periodic maintenance will also probably be required to repair damage to the dike caused by movement of the ice in the toe of the glacier.

3.5.2 Water Releases and Fish Passage Facilities

To provide instream releases into the Chakachatna River and arrange for both upstream and downstream migration of fish between the river and the Chakachamna Lake, a concept for a conveyance system was developed which consisted basically of fish ladders at the upstream and downstream ends of two interconnecting channels located in a tunnel. The system is a gravity flow system and does not rely on any pumping for its operation. The layout is shown in Fig. 3-8. The facilities will be located in the right bank granitic rock abutment to provide a secure structure protected against avalanches and rockfalls and to minimize the length of the tunnel. A deep



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CHAKACHAMNA HYDROELECTRIC PROJECT

CHAKACHAMNA LAKE OUTLET
GENERAL ARRANGEMENT

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

	JOB No.	DRAWING No.	REV.
BECHTEL	14879	FIGURE 3-8	

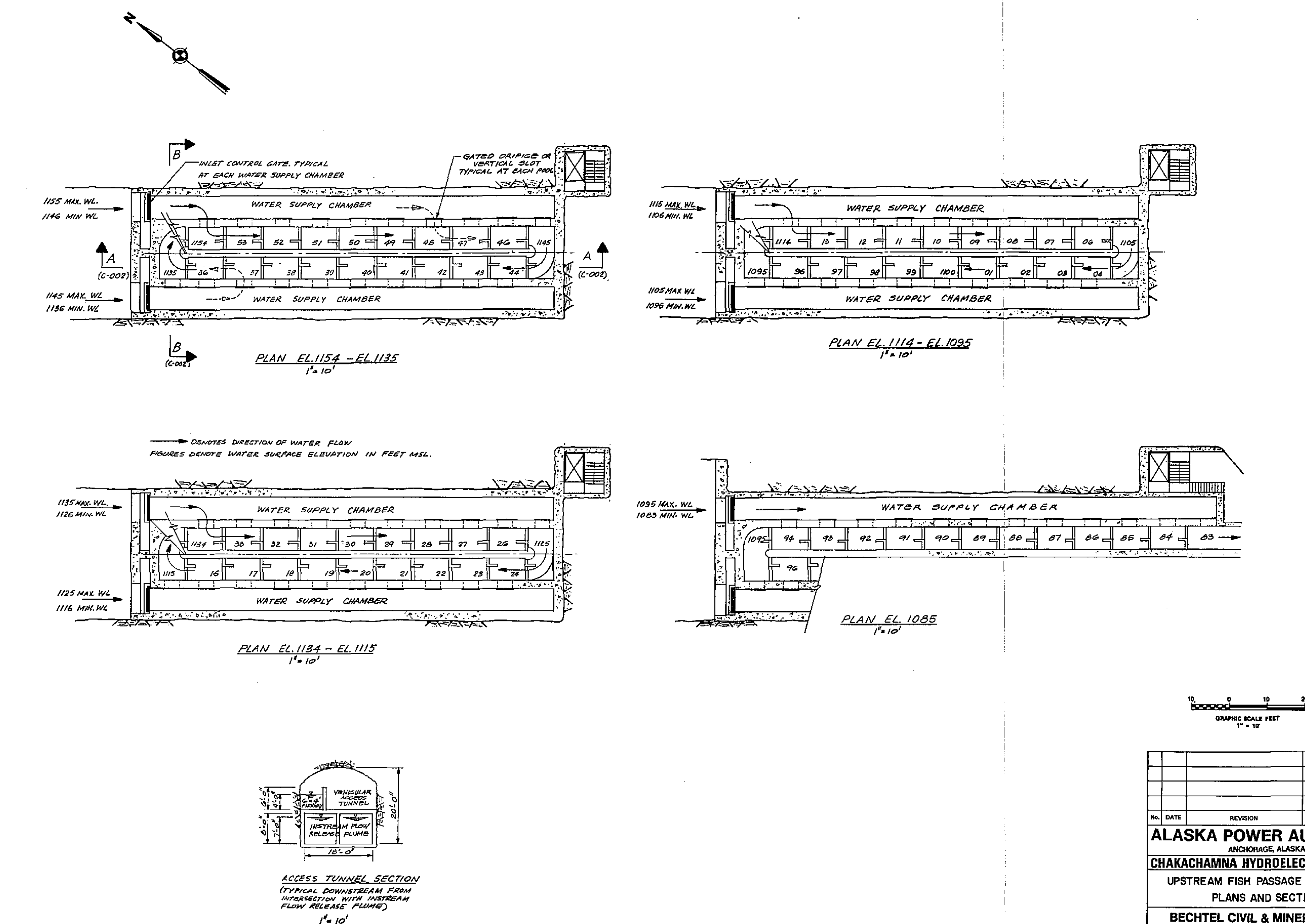
approach channel will be excavated in the alluvial deposits on the right side of the lake outlet to convey water from the lake to the fish release facilities located in an excavated cavern in the right abutment near the lake outlet.

3.5.3 Upstream Migrants Facility

The facility for upstream passage of adult migrant fish would consist of a conventional fish ladder with overflow weirs having 1 foot difference in elevation between each pool. Alongside each tier of ladder pools is a water supply chamber that serves a 10 foot interval in the range of lake level. Each pool in a given tier would have a gated connection to the water supply chamber, so that for a given lake level, the gate leading to the pool whose water level is 1 foot lower than the reservoir would be open, thus letting water run from the supply chamber into the ladder. All other gates between the supply chambers and pools would be closed. As the lake level changes, the gates would be manipulated accordingly. At this stage it is assumed that these gates would be operated manually although it would be possible to automate their operation, with the selection of "open" gate tied to lake level. A control gate is also shown between each water supply chamber and the lake. Fish ascending the ladder would rise through the pools until they reached the one receiving water from its supply chamber. The fish would then pass into the supply chamber and exit into the lake through the control gate opening. This upstream migrant structure would be constructed in an underground chamber excavated in the rock mountainside adjacent to the existing natural lake outlet. The concept is shown in Figures 3-9 and 3-10.

3.5.4 Downstream Migrants Facility

The facility for downstream passage of out-migrants and for provision of minimum downstream flow releases is shown in Figure 3-11. The concept consists of three, 15 feet wide fixed wheel type gates stacked one above the other. The proposed mode of operation is that when the water level is between El. 1155 and El. 1127, the top gate would be lowered the amount necessary to discharge the desired amount of water that would plunge into a stilling basin and return to the river through the discharge tunnel. The middle and bottom gates would be closed. When the lake level falls to El. 1127, the top gate would be raised above the water surface and the middle gate would be lowered to discharge the desired amount of water. As the water level descends below El. 1001, the middle gate would be raised and the lowest gate would take over the control of discharge. This gate will be progressively lowered below the invert of the outlet channel as the lake level falls. Manipulation of the gates would be in the reverse sequence during the condition with a rising lake water level. The depth of flow in the stilling basin immediately downstream from the gates is relatively shallow in order to prevent entrainment of air at depths and pressures which could result in nitrogen saturation harmful to the fish.



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CHAKACHAMNA HYDROELECTRIC PROJECT

UPSTREAM FISH PASSAGE FACILITIES
PLANS AND SECTION

BECHTEL CIVIL & MINERALS, INC.
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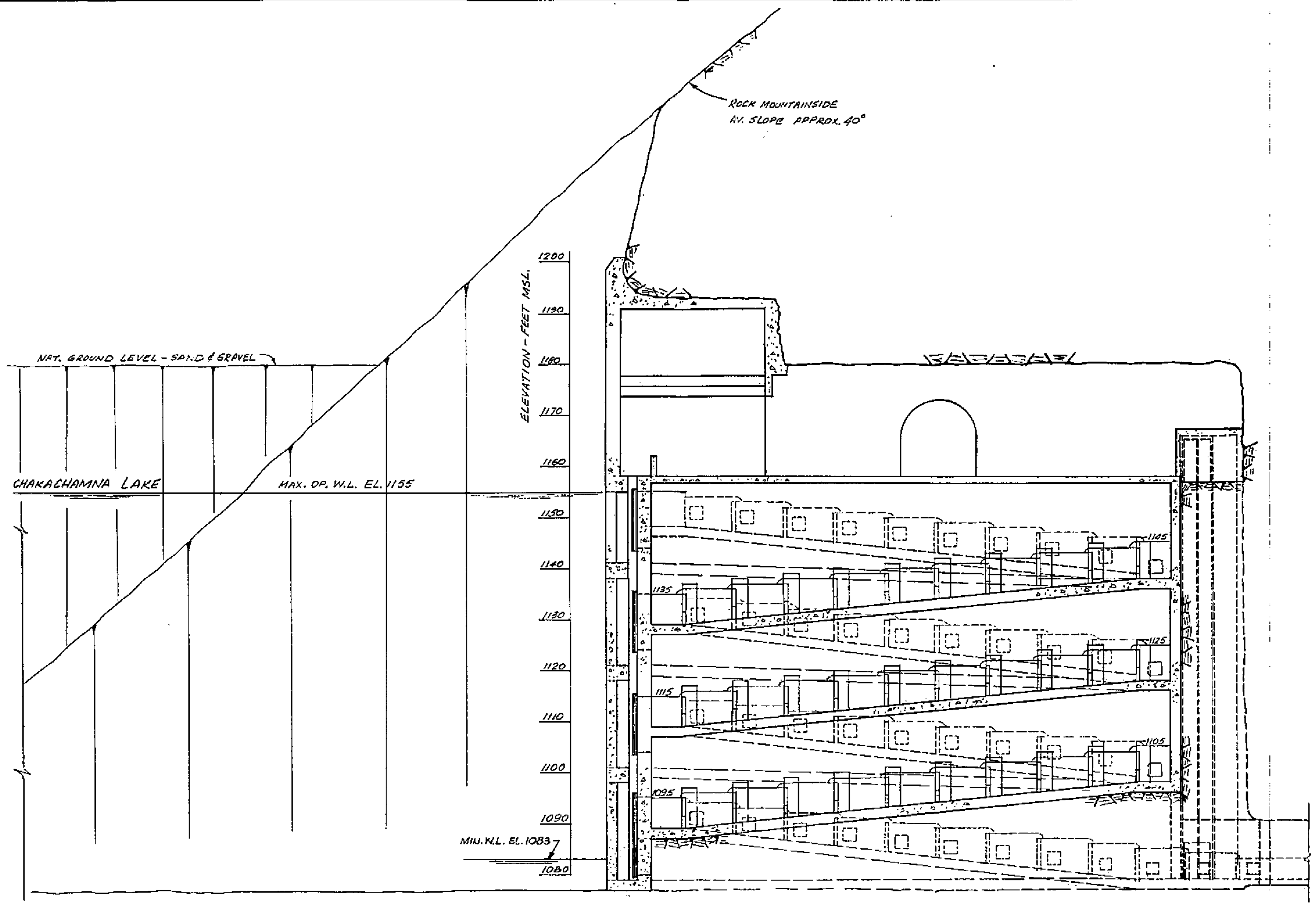
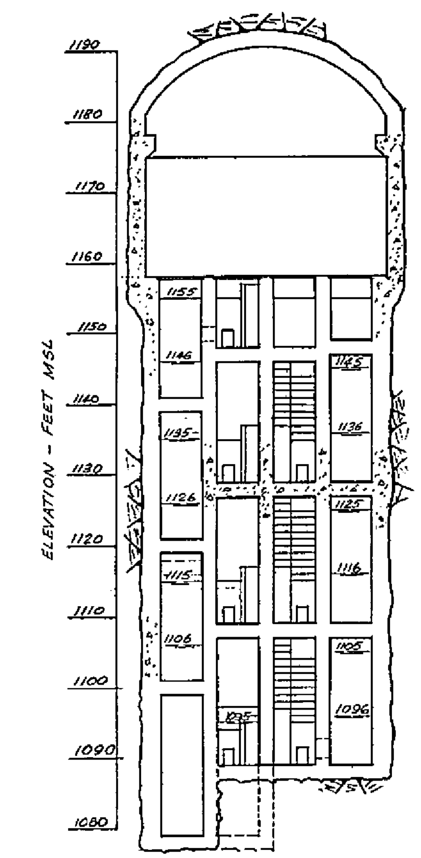
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-9	



SECTION (A)
1" = 10'



SECTION (B)
1" = 10'

GRAPHIC SCALE FEET
1" = 10'

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ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

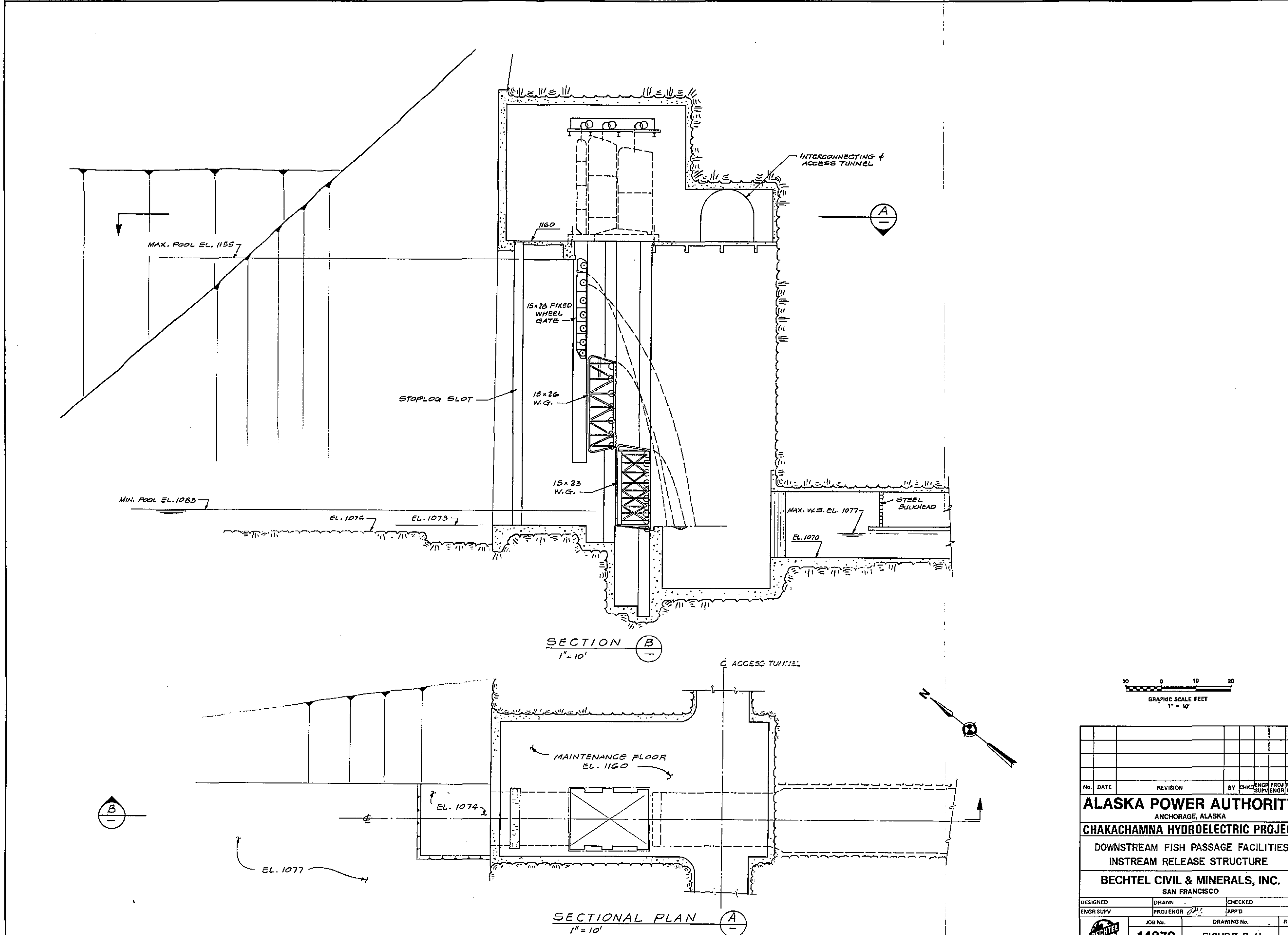
CHAKACHAMNA HYDROELECTRIC PROJECT

UPSTREAM FISH PASSAGE FACILITIES
SECTIONS

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-10	



No.	DATE	REVISION	BY	CHKD	ENGR SUPV	PROJ ENGR	PROJ MGR

ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

DOWNSTREAM FISH PASSAGE FACILITIES
INSTREAM RELEASE STRUCTURE

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-11	

3.5.5 Conveyance Channel

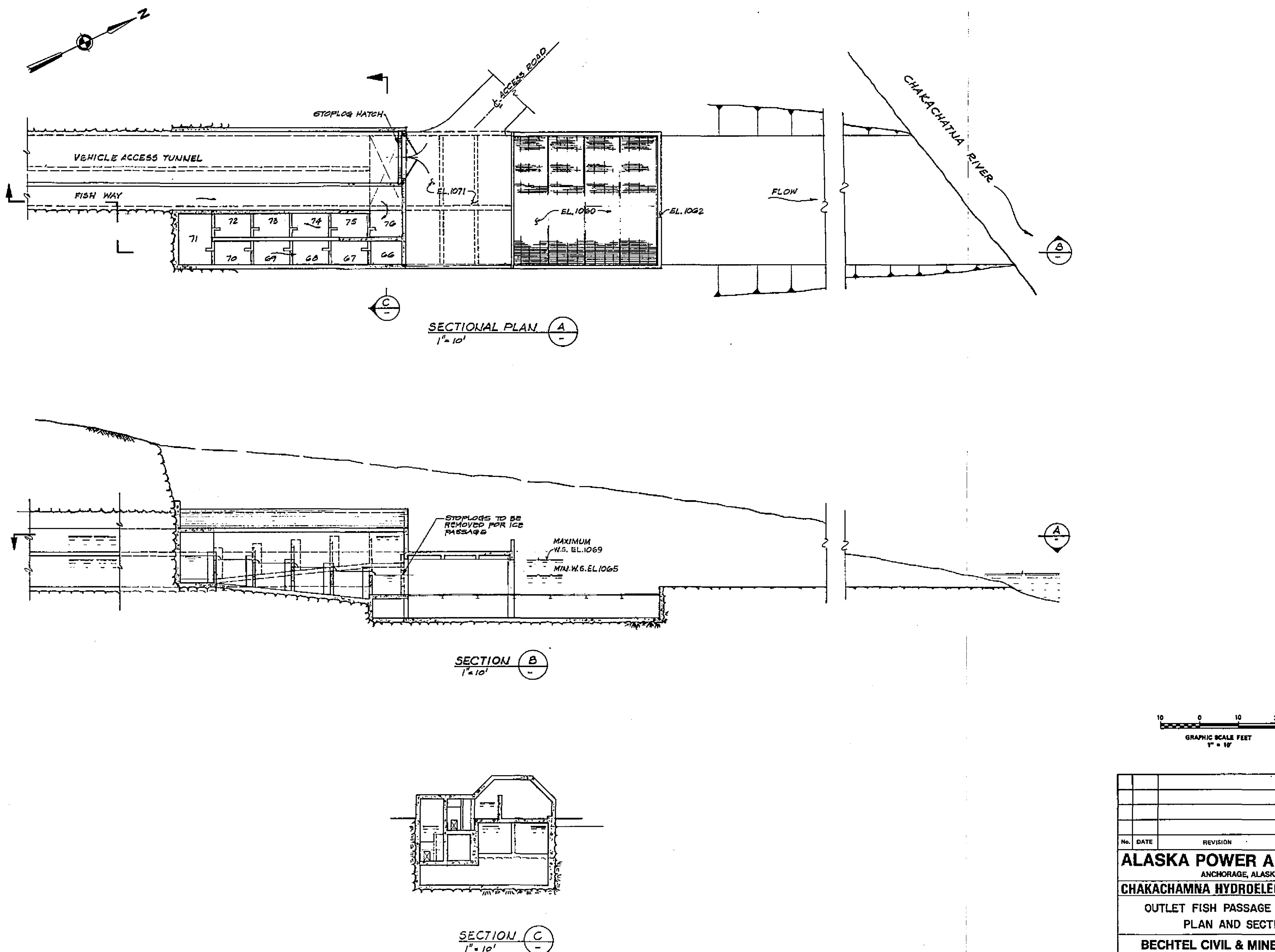
Both upstream and downstream migrants will travel in separate channels located in a common tunnel. The upstream migrants would utilize a 6' x 4' channel dimensioned for the fish ladder discharge of 40 cfs. The out-migrants would use the main channel 18' x 7' dimensioned for maximum required monthly release minus the flow in the small channel. (This maximum downstream release as presented in Section 4 has been set tentatively at 1094 cfs.) The small channel would be located at one side of the tunnel above the main channel with a road access provided on the other side. A typical section of the tunnel is shown in Fig. 3-9. Both channels would be free flowing with freeboard provided. Only the main channel which has a maximum velocity of 8 feet/sec., would be fully lined to reduce head loss. In order to keep velocity in the small channel for the upstream migrants at 2 feet/sec., the floor of the channel would have a slightly less gradient than the large channel and 5 drops of 1 foot each will be provided at regular intervals down the tunnel.

3.5.6 Outlet Structure

A ladder is required at the downstream end of the tunnel to provide a means for the upstream migrants to reach the upper transportation channel inside the tunnel. This ladder will be partially submerged at high releases since the river level rises by an estimated 4 feet when the discharge from the facility is increased from the minimum flow of 343 cfs to the maximum of 1094 cfs. Another 6 ft vertical rise in the ladder is provided to accommodate the difference between the water surfaces in the two channels in the tunnel so that a total of 10 ladder pools would be provided. A horizontal submerged screen would allow the out-migrants to reach the main discharge channel while its presence and a velocity of around 1/2 ft/sec through the bars would prevent the large fish from entering the main tunnel discharge channel. The attraction flow coming down the ladder would be 40 cfs. The layout is shown in Figure 3-12.

A floating ice barrier installed in the approach channel just upstream of the fish passage facility will prevent most of the ice from passing into and through the facility during the breakup period. However, as a precaution, since it will be very difficult to ensure the complete elimination of the entrance of ice into the facility, it is planned to remove a stoplog barrier which normally diverts the flow through the horizontal screen, thus allowing the flow and ice to continue straight into the side outlet channel and the Chakachatna River, and thereby by-passing the horizontal screen through which the flow normally passes. This should be an acceptable procedure because the upstream migrants do not travel upstream until after breakup occurs.

A small rockfill dike will be constructed across the river channel just upstream of the downstream entrance to the outlet facility so that the upstream migrants will be prevented from entering the section of the river between the fish facility and the lake outlet. Any small inflow into the river between the lake



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ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

OUTLET FISH PASSAGE FACILITIES
PLAN AND SECTIONS

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-12	

outlet and the fish facilities outlet will filter through the rock dike.

3.6 Transmission Line and Submarine Cable

At the present stage of the project development studies, no specific evaluation has been made of transmission line routing. Whether development should proceed via the proposed McArthur or Chakachatna Powerhouse locations, it is assumed for the purposes of the costs estimates that the transmission lines would run from a switchyard in the vicinity of either powerhouse site to a location in the vicinity of the existing Chugach Electric Association's Beluga Powerplant. The general routing of the proposed lines is shown on Figure 3-13. At Beluga, an interconnection could be made through an appropriate switching facility with the existing Beluga transmission lines if a mutually acceptable arrangement could be negotiated with the owners of those lines. This would enhance reliability of the total system, but for purposes of this report no such interconnection has been assumed. Beyond Beluga, it is assumed for purposes of the estimate, that the new transmission lines for the Chakachatna or McArthur Powerhouses would parallel the existing transmission corridor to a terminal on the westerly side of Knik Arm and cross that waterway by submarine cables to a terminal on the Anchorage side. Beyond that point, no costs are included in the estimates for any further required power transmission installations.

In the project alternatives thus far considered, the cost estimates are based on power transmission via a pair of 230 KV single circuit lines with capacity matching the peaking capability of the respective power plants. Optimization studies to determine whether transmission should be effected in that manner or by a single line of double circuit towers should be performed in the future.

3.7 References

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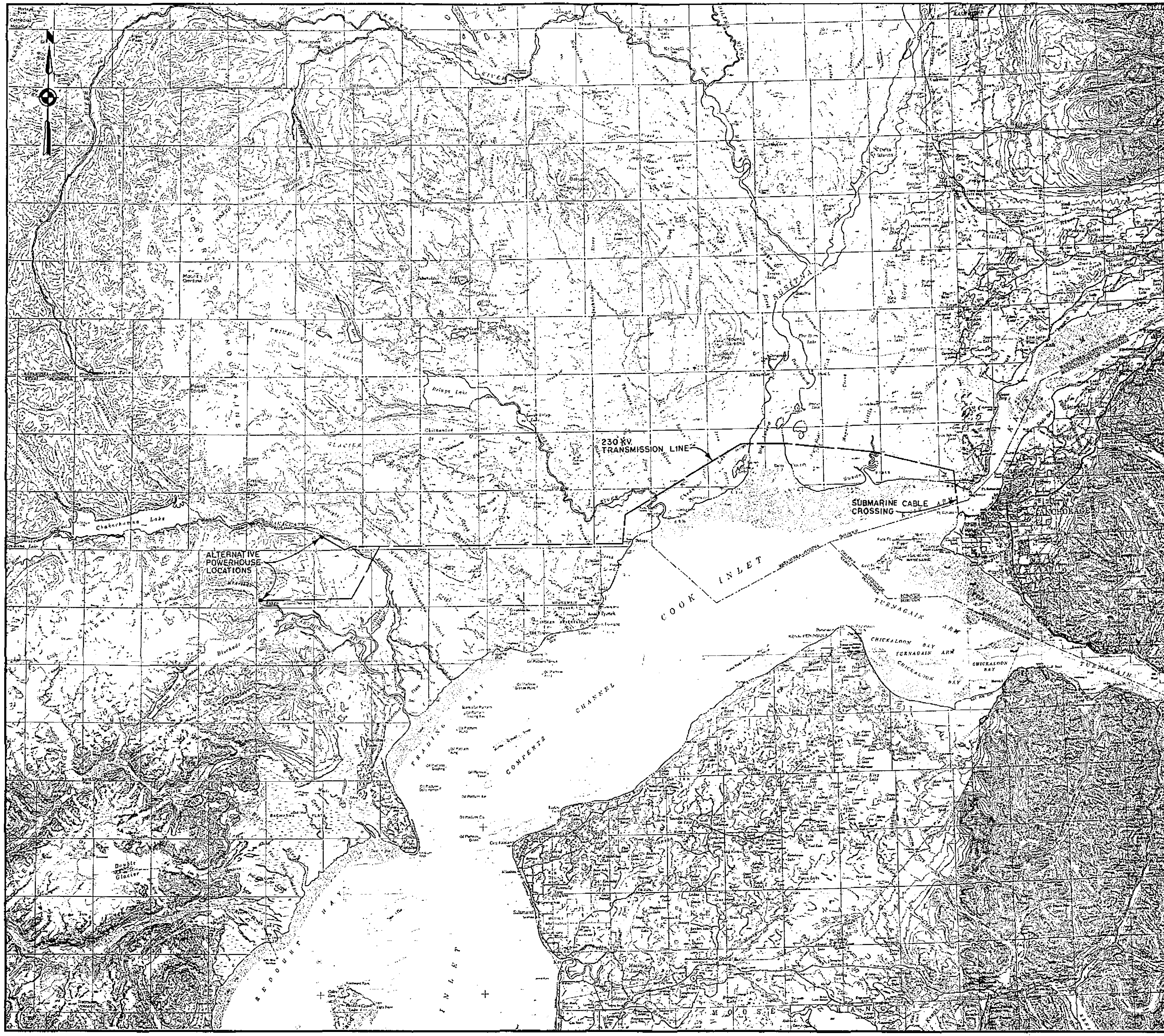


4 0 4 8 MILES

SCALE : 1" = 4 MILES

NOTES:

1.) TOPOGRAPHY IS FROM USGS QUADRANGLE MAPS

2.) HORIZONTAL GRID IS UNIVERSAL TRANSVERSE MERCATOR PROJECTION, 1927 NORTH AMERICAN DATUM.

3.) VERTICAL DATUM IS MEAN LOWER LOW WATER.

No.	DATE	REVISION	BY	CHKD	ENGR SUPV	PROJ ENGR	PROJ MGR

ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

TRANSMISSION LINE
ROUTE LOCATION

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN PRITCHARD	CHECKED [illegible]
ENGR SUPV [illegible]	PROJ ENGR [illegible]	APP'D [illegible]

JOB No.	DRAWING No.	REV.
14879	FIGURE 3-13	

United States Department of the Army, Corps of Engineers, 1950

Survey report on Harbors and Rivers in Alaska. Interim Report No. 2, Cook Inlet and Tributaries.

HYDROLOGICAL AND POWER STUDIES

4.0 HYDROLOGICAL AND POWER STUDIES

4.1 Introduction

River flow records from a gaging station are usually accepted as the best indicator of future runoff from a drainage basin. The longer the period of record is, the more reliable it is assumed to be in forecasting future runoff. For Chakachamna Lake, the records of a gage located near the lake outlet cover only a relatively short period of time, May 1959 to September 1972. During that time some periods occurred during which flow rates were not obtained, reducing the continuous record to a period dating from June 1959 to August 1971.

There are no records of inflow to Chakachamna Lake, and since that information is needed to perform reservoir operation and power studies, inflows were calculated for the continuous period of record by reverse routing of outflows and making appropriate adjustments for changes in water levels. Calculated inflows for the 11 calendar years 1960 through 1970 were used in the power studies conducted during 1981 for Alternates A, B, C and D.

In order to develop a longer series of inflows to Chakachamna Lake, the lake inflows were statistically correlated with hydrometeorological records from other stations. Using the resulting correlation, inflows were calculated to produce a total period of 31 years of recorded and synthesized records. That 31-year sequence was used to determine the energy-generating potential for the recommended project, Alternative E, during the studies conducted during fiscal year 1982.

4.2 Historical Data

Hydrometeorological data from several stations in the Cook Inlet Basin were used for the derivation and extension of estimated lake inflow records. Streamflow records included the following furnished by U. S. Geological Survey:

Station No.	Description
15294500	Chakachatna River near Tyonek (the lake outlet gage)
15284000	Matanuska River near Palmer
15284300	Skwentna River near Skwentna
15292000	Susitna River at Gold Creek

Gaging Station No. 15294500 is located on the right bank of the Chakachatna River close to the outlet of Chakachamna Lake. The gage records include 13 years and 5 months from May 21, 1959 to September 30, 1972. The gage however, was destroyed by a lake outbreak flood on August 12, 1971 and the records between that date and June 20, 1972 are estimated rather than recorded flows. Thus, the period of actual record extends only from May 21, 1959 to August 12, 1971 and from June 20, 1972 to September 30, 1972. Furthermore, during that period, several of the winter-month flows were estimated because of icing conditions and instrument failure. Inaccurate winter records are not a serious engineering concern, because only 11% of the average annual flow normally occurs during the seven months from November through May.

In addition to the streamflow data, records of the water surface elevation at Station No. 15294500 were also obtained from the U. S. Geological Survey in Anchorage.

Available meteorological data consist of daily temperature and precipitation data obtained from the U. S. National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, N.C. for stations at Kenai, Anchorage, and Sparrevohn.

The locations of these three meteorological stations are shown on Figure 4-1. A bar chart showing the periods of record for these stations is plotted on Figure 4-2.

4.3 Derived Lake Inflows

Chakachamna Lake with its surface area of about 26-square miles stores runoff and provides natural regulation of flow to the Chakachatna River. In order to derive a record of inflows to the lake, the regulating effects of the lake were removed from the outflow records using a reverse routing procedure which uses the basic continuity equation

$$I_t - O_t = \Delta s$$

Where

I_t is the inflow volume during month t

O_t is the outflow volume during month t

Δs is the change in lake storage during month t

For all practical considerations, the Chakachatna River near Tyonek gage is, in effect, located at the lake outlet and field observations confirmed that gage readings closely represent the lake water-surface elevation. Hence, it was assumed for the reverse routing computations that the two were the same. Evaporation, seepage and other losses of water from the lake were assumed to be small and effectively compensated for by direct precipitation onto the lake surface.

The lake stage-storage curve used in the computations is shown on Figure 4-3. This is based on data measured by the USGS and recorded on the USGS maps Chakachatna River and Chakachamna Lake Sheets 1 and 2, dated 1960.

Average monthly inflows were calculated for the period June 1, 1959 through August 31, 1971, and are presented in Table 4-1. The calculated inflows for the 11 calendar years January 1, 1960 through December 31, 1970 were used in the power studies for Alternates A, B, C and D of the project layouts during 1981.

4.4 Synthesis of Long-Term Lake Inflows

In order to develop a long-term estimate of energy-production, methods for extending the inflow record were investigated. Transposition of records from other rivers in the region, correlation with meteorological data from nearby long-term stations, and combinations of both, were studied using regression analysis.

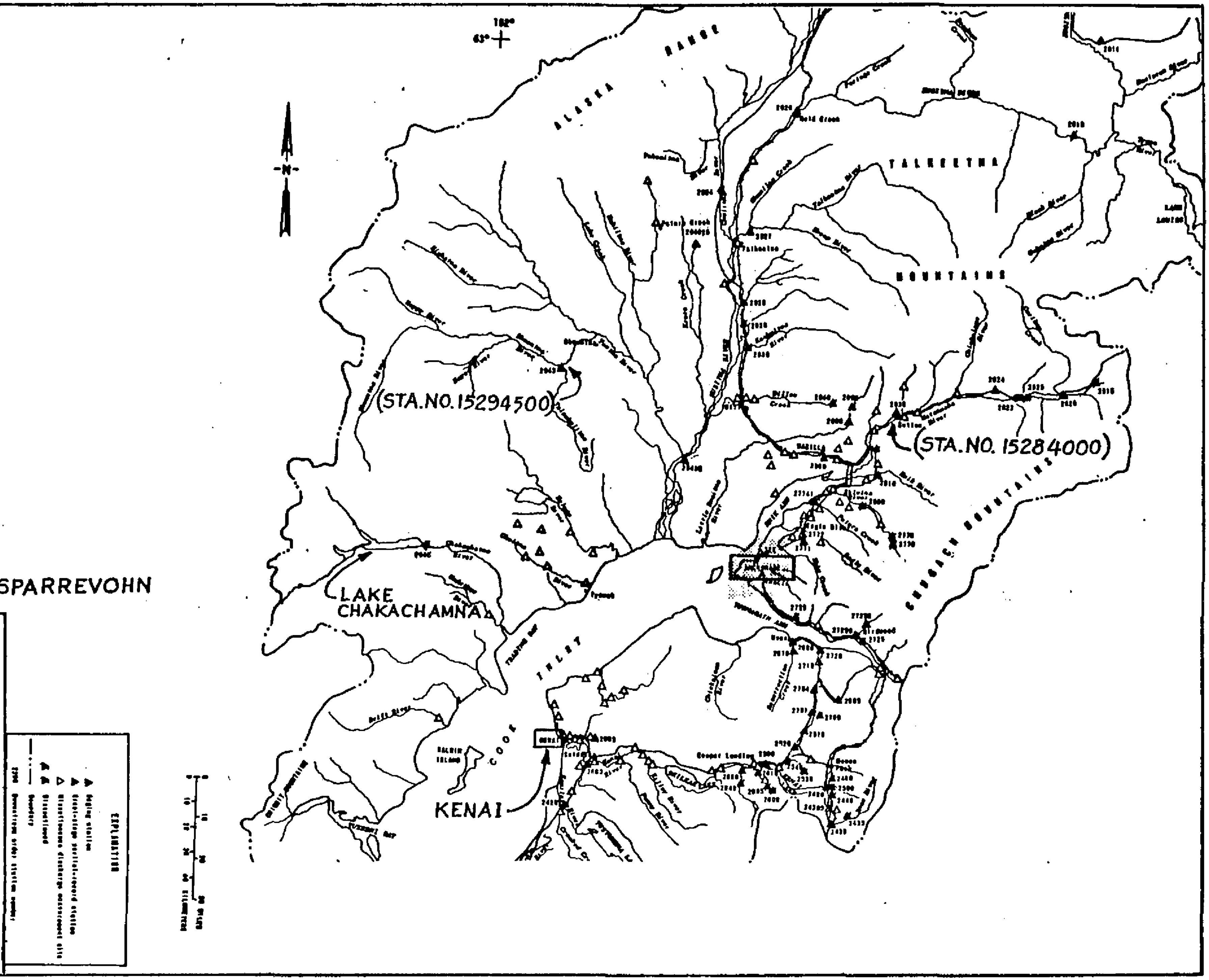


FIGURE 4-1
HYDROMETEOROLOGICAL STATION LOCATIONS

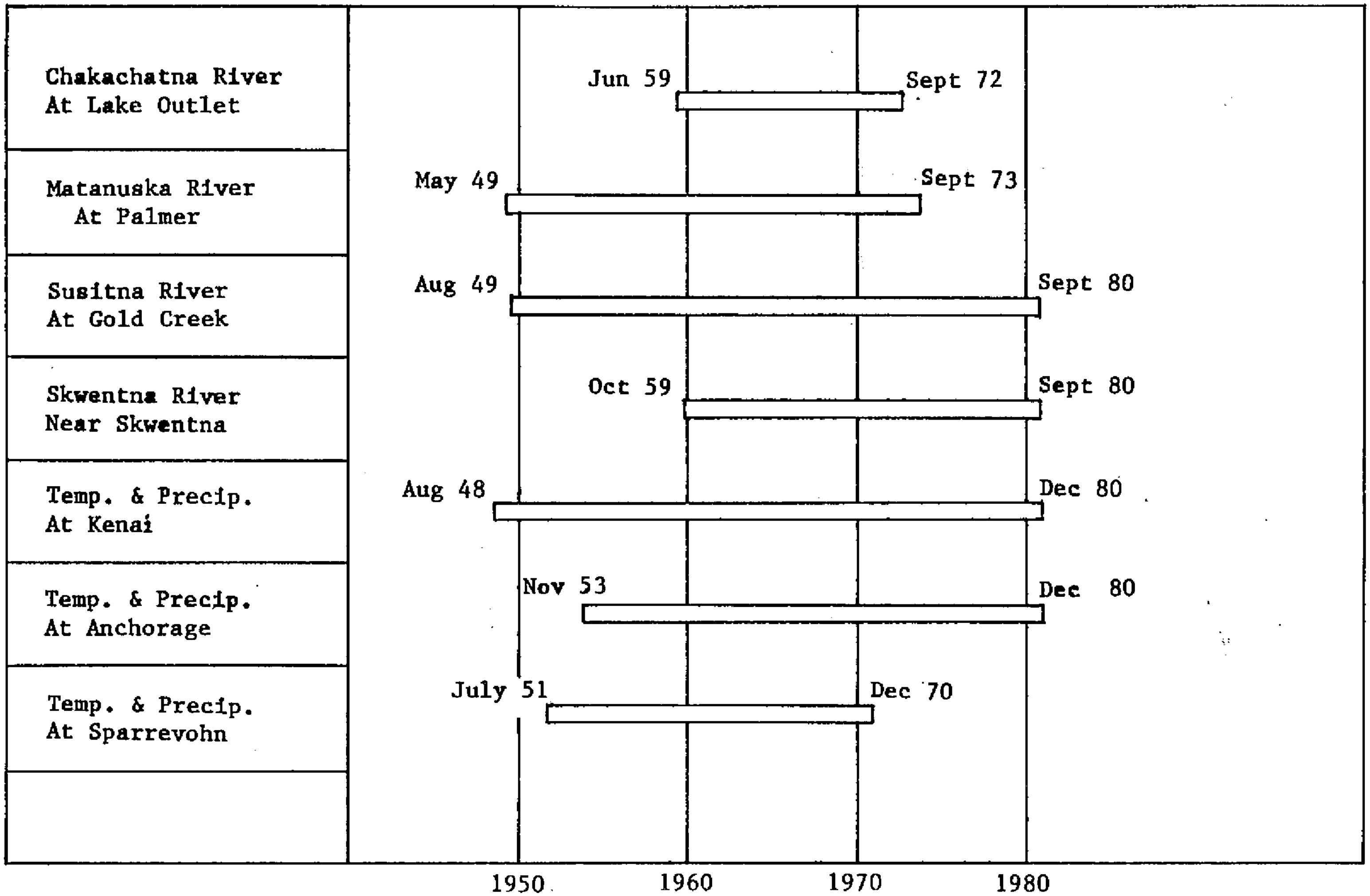
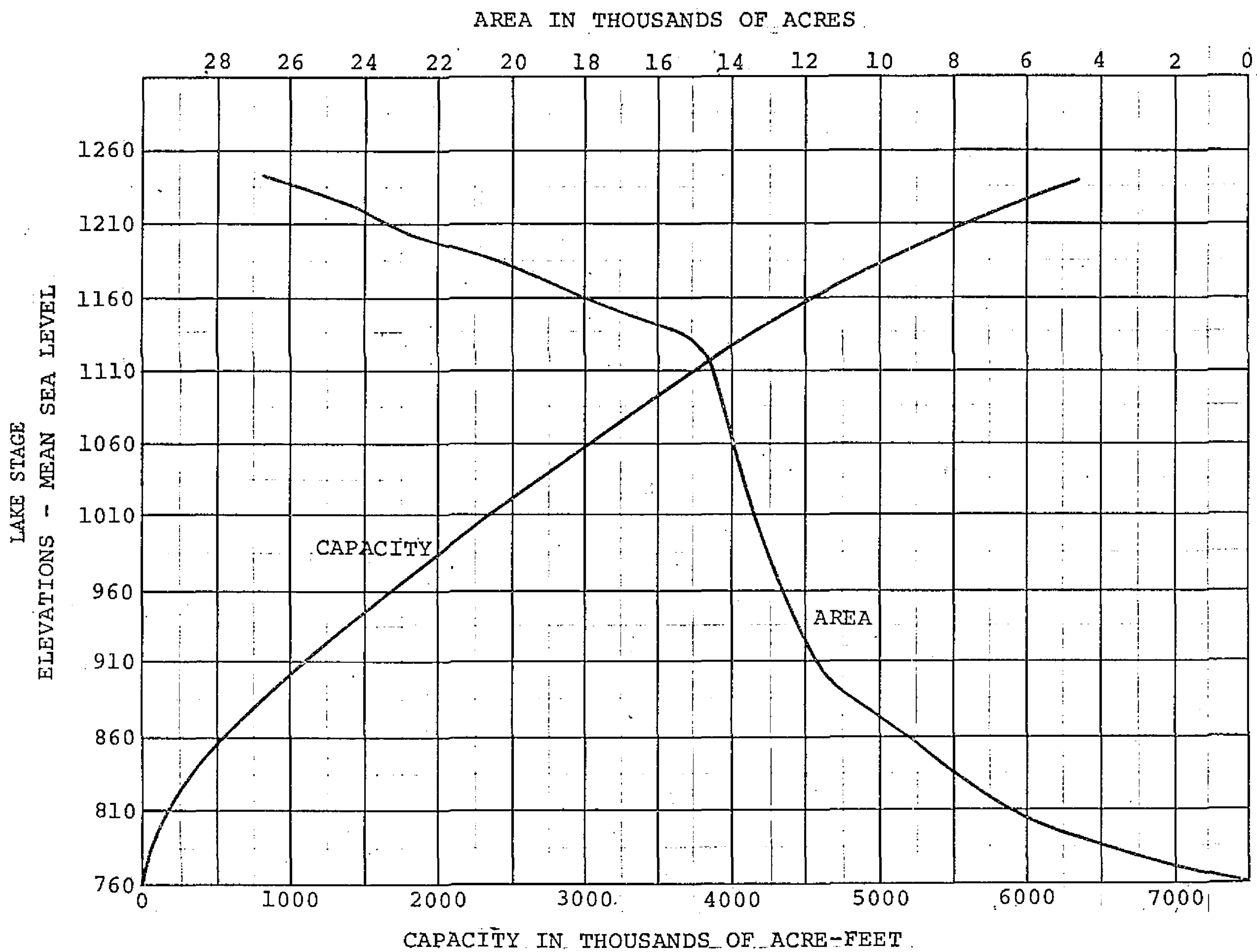


FIGURE 4-2

HYDROMETEOROLOGICAL STATIONS
PERIODS OF RECORD



CHAKACHAMNA
LAKE
AREA & CAPACITY DATA

ELEV. M.S.L.	AREA IN ACRES	CAPACITY ACRE FEET
760	0	0
765	810	2,025
770	1,300	7,300
780	2,690	27,200
800	5,670	111,000
20	7,320	241,000
40	8,270	397,000
60	9,280	572,000
80	10,400	769,000
900	11,590	988,000
20	11,960	1,224,000
40	12,320	1,467,000
60	12,650	1,717,000
80	12,980	1,973,000
1000	13,280	2,236,000
20	13,520	2,504,000
40	13,740	2,776,000
60	13,960	3,053,000
80	14,170	3,335,000
1100	14,390	3,620,000
20	14,620	3,910,000
40	16,100	4,218,000
42	16,780	4,250,000
60	18,250	4,572,000
80	19,900	4,953,000
1200	22,956	5,382,000
20	24,104	5,852,000
40	26,038	6,354,000

CHAKACHAMNA LAKE
LAKE STAGE-AREA AND CAPACITY

FIGURE 4-3

TABLE 4-1

LAKE CHAKACHAMNA INFLOWS (cfs)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	MEAN
1959						9459.	10388.	11731.	3662.	1370.	654.	508.	
1960	400.	307.	267.	393.	3637.	6837.	11209.	9337.	3145.	1439.	799.	870.	3220.
1961	877.	589.	470.	346.	1881.	7983.	12808.	10899.	6225.	1586.	843.	696.	3767.
1962	633.	541.	471.	470.	1265.	7925.	13149.	10411.	5542.	1197.	863.	613.	3590.
1963	498.	357.	315.	337.	1801.	4735.	13249.	12208.	5847.	2056.	930.	710.	3587.
1964	364.	435.	332.	477.	1830.	8093.	10700.	11798.	4246.	1245.	909.	662.	3424.
1965	419.	219.	337.	398.	1286.	3490.	13046.	10516.	10802.	2114.	597.	466.	3641.
1966	388.	336.	350.	410.	1893.	8072.	10303.	9974.	6608.	1953.	910.	313.	3459.
1967	531.	449.	384.	880.	2930.	8761.	14931.	15695.	6191.	2040.	1215.	571.	4473.
1968	534.	510.	467.	630.	2996.	7808.	13117.	11257.	2793.	976.	689.	612.	3532.
1969	485.	486.	500.	652.	1948.	9271.	12510.	7297.	2793.	3057.	1215.	541.	3396.
1970	497.	504.	550.	899.	2265.	6789.	10360.	7986.	2734.	1359.	742.	460.	2929.
1971	394.	441.	513.	1275.	4063.	12672.	13695.	16680.					
MEAN	502.	431.	413.	597.	2241.	7838.	12261.	11215.	5049.	1699.	864.	585.	3606.

Examination of the inflows to Chakachamna Lake in Table 4-1, indicated that, for this watershed, the hydrological year (water year) should be defined as the period from May to April to minimize the overall basin-storage effects. The majority of the lake inflow, 93% of the annual runoff volume, occurs during May through October, while flow recession starts in November. Flows recorded at the lake outlet from November to May were, in general, estimated by USGS personnel using personal judgment because ice cover prevented proper functioning of the stage recorder during that period. The accuracy of the recorded winter streamflow is, therefore, questionable, but estimated total outflow volume during the low-flow winter months is thought to be reasonable. Because of their different hydrologic characteristics, it was decided that regression analyses should be performed separately for the periods, May to October, and November to April. In so doing, the less-accurate monthly-flow estimates for the winter period would not unduly influence calculations for flows during the remainder of each year.

The initial selection of independent variables to be used in the regression analyses was based on the lengths of the available hydrometeorologic records in the region, as well as the potential physical relationship with the inflow regime of Lake Chakachamna. Since Chakachamna Lake is glacially-fed, a heat-input index, such as monthly degree-days above $32^{o}F$ recorded at Kenai and Anchorage, could be an important independent variable. Monthly streamflow records from nearby watersheds which are considered to have hydrologic characteristics similar to that of the

Chakachamna basin were also incorporated in the study. These include the streamflows of Matanuska River at Palmer, Susitna River at Gold Creek and Skwentna River near Skwentna. In addition, monthly precipitation at Kenai and Anchorage were also considered. The final selection of the independent variables used for the lake-inflow synthesis was based on the results of the preliminary analyses.

The final regression analyses were performed systematically using different combinations of the pre-selected independent variables in a step-wise regression-analysis program (Bechtel TM 750). The regression equations obtained were evaluated on the basis of probable physical relationships to topographic, meteorological and hydrologic conditions as well as the computed level of statistical significance of the correlation. It was found that for both the high and low-flow periods, May to October and November to April respectively, the monthly streamflow records for the Matanuska River at Palmer correlate well with the historical monthly Chakachamna lake inflows. The regression equations obtained were:

May - October: $Q_{Lake} = 595.0 + 0.8967\ Q_{Palmer}$

November - April: $Q_{Lake} = 265.3 + 0.4597\ Q_{Palmer}$

Correlation coefficients for these two regression equations were found to be 0.89 and 0.40 respectively and are well within the 95 percent significance level. However, the Matanuska gage was discontinued in September of 1973. Another set of regression equations was therefore required for the flow synthesis for the period after September 1973. New correlation studies were performed. It was found that recorded streamflows for Skwentna River near Skwentna were a good substitute for those at the Matanuska gage. The regression equations obtained were:

$$\text{May - October:} \quad Q_{Lake} = 674.67 + 0.5233\ Q_{SK}$$
$$\text{November - April:} \quad Q_{Lake} = 283.27 + 0.2690\ Q_{SK}$$

The correlation coefficients for these two regression equations were found to be 0.73 and 0.45 respectively and are well within the 95 percent significance level.

The correlation coefficients for the regression equations for the low-flow season are relatively low. This was to be expected, because, as discussed earlier, streamflow values for this period were known to be inaccurate since they had to be estimated by personnel from the U.S. Geological Survey on the basis of regional streamflow data and/or personal judgment because of frequent malfunctioning of gages during winter. However, the streamflow volume in this period represents only about 7 percent of the total annual runoff volume. Because the operation study used monthly flow volumes, inaccuracies inherent in the flow synthesis for the winter months do not significantly affect the overall accuracy of the study and the respective regression equations are therefore regarded as acceptable for use in the derivation of the long-term streamflow record. Table 4-2 presents the lake inflows synthesized by using these equations and the reverse-routing procedure. The 31 year sequence of inflows includes the June 1959 through August 1971 inflows calculated by reverse-routing of outflows plus the May 1949 through May 1959 and the

TABLE 4-2

CHAKACHAMNA PROJECT OPERATION STUDY
H/H,H&CF,BECHTEL CIVIL&MINERALS INC.,SF.

PROJECT 14879001 | ALASKA POWER AUTHORITY | DATE 11783 | PAGE 3

ALTERNATIVE E: MCARTHUR SHORT TUNNEL, WITH FISH RELEASES

INFLOWS TO THE LAKE IN CFS

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	AVEYR	CALYR
1	4513.	10728.	15220.	11615.	6305.	2689.	802.	636.	542.	488.	493.	541.	4548.	1950
2	2055.	8572.	13194.	10548.	4521.	1761.	569.	532.	495.	472.	450.	631.	3650.	1951
3	3801.	10719.	13095.	8831.	8635.	3216.	842.	699.	630.	495.	467.	510.	4328.	1952
4	2027.	8204.	12575.	9431.	3562.	2712.	865.	642.	523.	477.	477.	641.	3511.	1953
5	3992.	13247.	13355.	10808.	4505.	2002.	629.	550.	527.	472.	458.	541.	4257.	1954
6	3434.	9002.	12091.	12046.	6075.	2787.	755.	619.	578.	507.	466.	487.	4071.	1955
7	2193.	6826.	12996.	9983.	5068.	1988.	595.	532.	504.	475.	449.	496.	3509.	1956
8	2936.	7475.	14601.	10235.	5940.	2053.	583.	565.	569.	536.	505.	598.	3883.	1957
9	4393.	14817.	13149.	10405.	6910.	2707.	793.	562.	569.	510.	489.	675.	4665.	1958
10	2496.	9930.	10163.	8691.	3452.	1896.	526.	483.	426.	468.	449.	526.	3292.	1959
11	3120.	9459.	10388.	11731.	3662.	1370.	654.	508.	400.	307.	267.	393.	3522.	1960
12	3637.	6837.	11209.	9337.	3145.	1439.	799.	870.	877.	589.	470.	346.	3296.	1961
13	1881.	7983.	12808.	10899.	6225.	1586.	843.	696.	633.	541.	471.	470.	3753.	1962
14	1265.	7925.	13149.	10411.	5542.	1197.	863.	613.	498.	357.	315.	337.	3539.	1963
15	1801.	4735.	13249.	12208.	5847.	2086.	930.	710.	364.	435.	332.	477.	3598.	1964
16	1830.	8093.	10700.	11798.	4246.	1245.	909.	662.	419.	219.	337.	398.	3405.	1965
17	1286.	3490.	11633.	11929.	10802.	2114.	597.	466.	388.	336.	350.	410.	3650.	1966
18	1893.	8072.	10303.	9974.	6608.	1953.	910.	313.	531.	449.	384.	880.	3523.	1967
19	2030.	8761.	14931.	15695.	6191.	2040.	1215.	571.	534.	510.	467.	630.	4465.	1968
20	2996.	7808.	13117.	11257.	2793.	976.	689.	612.	485.	486.	500.	652.	3531.	1969
21	1948.	9271.	12478.	7297.	2793.	3057.	1215.	601.	497.	504.	550.	899.	3426.	1970
22	2265.	6789.	10360.	7986.	2734.	1359.	742.	460.	394.	441.	513.	1275.	2943.	1971
23	4063.	12672.	13695.	16680.	5075.	3181.	1090.	736.	581.	531.	492.	479.	4940.	1972
24	3468.	8228.	13490.	9263.	5012.	2396.	679.	514.	495.	492.	480.	586.	3759.	1973
25	2131.	7457.	8850.	7809.	2794.	2527.	740.	623.	558.	526.	501.	554.	2923.	1974
26	4215.	6248.	6781.	6159.	6850.	3059.	909.	530.	498.	485.	485.	489.	3059.	1975
27	4784.	10649.	10889.	6802.	5107.	3136.	814.	622.	544.	524.	498.	625.	3750.	1976
28	5283.	8587.	8304.	6494.	4947.	3917.	1058.	1055.	1044.	773.	606.	606.	3556.	1977
29	5335.	19864.	13898.	11224.	6059.	3709.	922.	700.	609.	537.	509.	558.	5327.	1978
30	5387.	7917.	10146.	7865.	4513.	3258.	708.	701.	597.	562.	547.	713.	3576.	1979
31	6776.	8514.	8958.	9157.	4572.	4471.	1412.	882.	762.	718.	647.	810.	3973.	1980
MEAN	3201.	8996.	11928.	10147.	5177.	2383.	828.	621.	551.	491.	465.	588.	3781.	
MAX	6776.	19864.	15220.	16680.	10802.	4471.	1412.	1055.	1044.	773.	647.	1275.	5327.	
MIN	1265.	3490.	6781.	6159.	2734.	976.	526.	313.	364.	219.	267.	337.	2923.	

September 1971 through April 1979 inflows calculated from the regression equations.

4.5 Power Studies

During the 1981 project studies four basic alternative project layouts were developed and designated Alternatives A, B, C and D as described in Section 3.3 of this report. Power studies also performed during 1981 for these four alternates were based on the 11 complete calendar years (January 1, 1960 through December 31, 1970) of Chakachamna Lake inflow set forth in Table 4-1. During the 1982 studies, the recommended Alternative E, also described in Section 3.3, was developed, as was the 31 year sequence of inflow to Chakachamna Lake which was used during the 1982 power studies for each of the alternatives A through E. The power operation studies were performed to determine generated firm and secondary energy, flow releases, and the fluctuations in the water surface elevation of Chakachamna Lake for a range of installed capacities for each of the five project alternatives. The studies were made using a computer program that performs sequential routing of the derived monthly inflows while satisfying power demands, projected in-stream flow requirements, and physical system constraints. Power demands were in accordance with a plant load factor of 0.5, and the monthly variations in peak demand listed in Table 4-3. As advised by APA, these demands are those being used in the evaluation of sources of power alternative to that of the Chakachamna Hydroelectric Project.

The in-stream flow requirements, listed in Table 4-4, represent provisional minimum monthly flows to be

TABLE 4-3

MONTHLY PEAK POWER DEMANDS USED IN POWER STUDIES

MONTH	MONTHLY PEAK DEMAND (Percent of Annual Peak Demand)
January	92
February	87
March	78
April	70
May	64
June	62
July	61
August	64
September	70
October	80
November	92
December	100

Source: Susitna Hydroelectric Project Development Selection Report Appendix D, Table D.1 (Second Draft, July 1981)

TABLE 4-4

PROVISIONAL MINIMUM RELEASES FOR INSTREAM FLOW IN CHAKACHATNA RIVER DOWNSTEEAM FROM CHAKACHAMNA LAKE OUTLET FOR USE IN POWER STUDIES

MONTH	MC ARTHUR TUNNEL DEVELOPMENT ALTERNATIVE B (CFS)*	CHAKACHATNA TUNNEL DEVELOPMENT ALTERNATIVE D (CFS)	MCARTHUR TUNNEL DEVELOPMENT ALTERNATIVE E (CFS)*
January	365	30	365
February	343	30	357
March	345	30	358
April	536	30	582
May	1,094	30	1,094
June	1,094	30	1,094
July	1,094	30	1,094
August	1,094	30	1,094
September	1,094	30	1,094
October	365	30	365
November	365	30	365
December	360	30	363

* Criteria used to determine fish instream flow release:
April through September - 1094 cfs or inflow to lake whichever is less
October through March - 365 cfs or inflow to lake whichever is less

released into the Chakachatna River near the lake outlet as further discussed in Sections 7.3.2 and 7.3.3 of this report.

The physical system constraints, set forth in Table 4-5, are the overall plant efficiency, tailwater elevation, and head loss for the hydraulic conduits.

In the power studies water was drafted from lake storage whenever the monthly inflows were insufficient to meet the power demand. It was assumed that spill, or discharge of water from the lake into the Chakachatna River in excess of the tentative instream requirements would occur whenever the lake water level exceeded elevation 1,128 feet, for alternatives A through D, and 1155 for alternative E. The secondary energy is that which can be generated by plant capacity in excess of that needed to meet the load carrying capability, using water which otherwise would have spilled.

For each of the alternatives considered for development of the project, a range of installed powerplant capacities was tested in order to establish the installed capacity that would make the most use of all water available for power generation without drawing the lake level below a given minimum elevation. This minimum was taken as elevation 1,014 feet for alternatives A through D and elevation 1,085 for alternative E respectively. The lake was assumed to be full at the beginning of each run.

4.6 Results

The results of the power studies listed in Table 4-6 show that, on the basis of the 11 calendar years of

TABLE 4-5

POWERPLANT SYSTEM CONSTRAINTS FOR ALTERNATIVE PROJECT DEVELOPMENTS

ALTERNATIVE	PLANT EFFICIENCY (%)	PLANT FACTOR	AVERAGE TAILWATER ELEVATION (FT.)	HEAD LOSS IN HYDRAULIC CONDUITS (FT.)
A	85	0.50	210	$0.0000024 \times Q^2$
B	85	0.50	210	$0.0000024 \times Q^2$
C	85	0.50	400	$0.0000028 \times Q^2$
D	85	0.50	400	$0.0000028 \times Q^2$
E	85	0.45	210	$0.0000024 \times Q^2$

Note: Q = Flow in cubic feet per second.

TABLE 4-6

POWER STUDIES SUMMARY

Development Alternative	Installed Capacity (MW)	Average Annual Energy Firm (GWh)	Average Annual Energy Secondary (GWh)	Average Annual Flow Power Diversion (CFS)	Average Annual Flow Provisional Instream (CFS)
A	400	1752	153	3322	0
B	330	1446	124	2701	679
C	300	1314	139	3230	0
D	300	1314	130	3239	30
E	330	1301	290	2274	685

Note: Period of record January 1, 1960 to December 31, 1970
Average annual inflow to Chakachamna Lake 3547 cfs (2.6 million AF)
Alternatives A, B - Development via McArthur tunnel
Alternatives C & D - Development via Chakachatna tunnel

Period of record May 1, 1949 to April 30, 1979
Average annual inflow to Chakachamna Lake 3781 cfs (2.7 million AF)
Alternative E - Development via McArthur Tunnel

Power diversion flows are the flows needed to meet firm energy requirements.

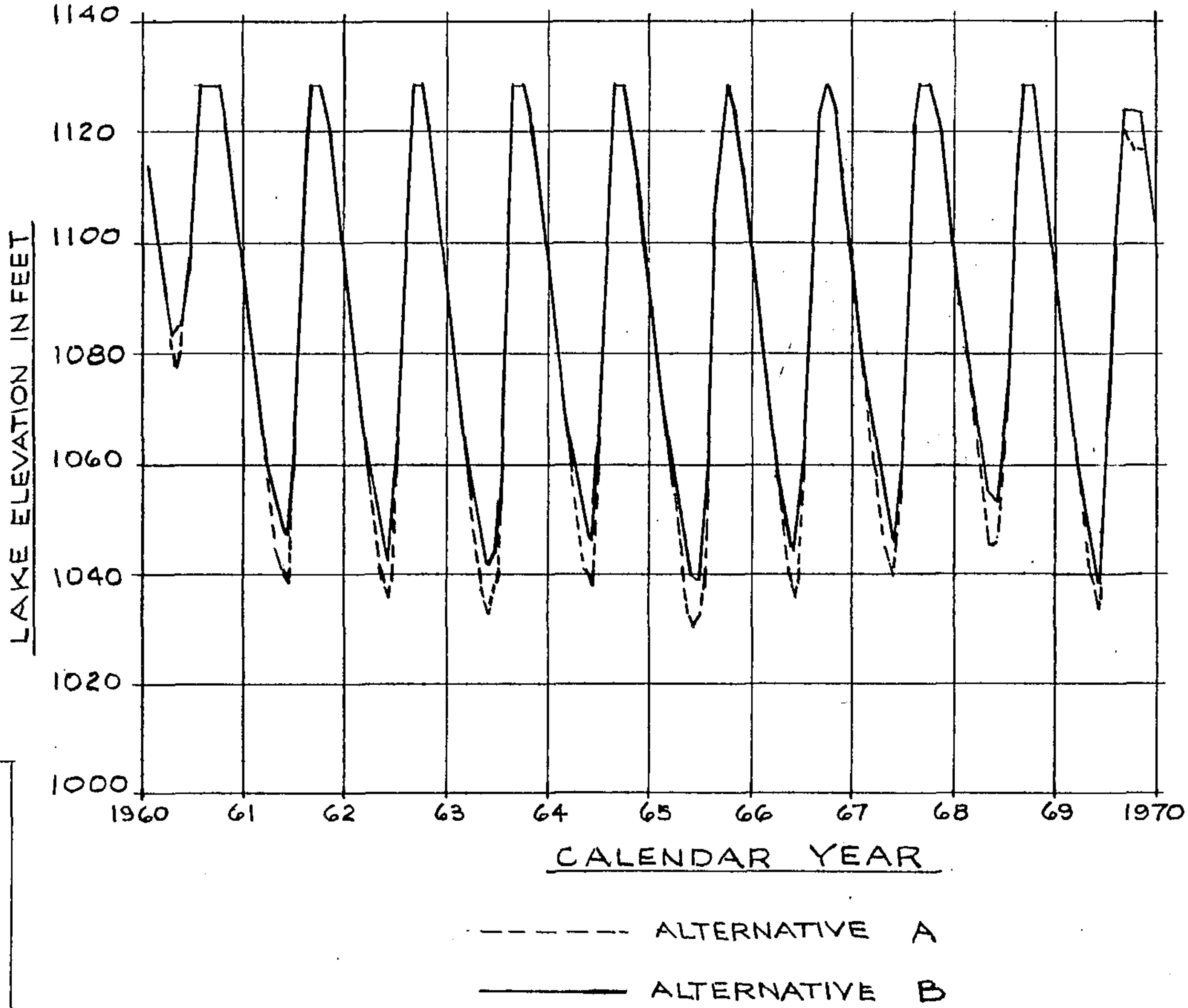
inflow, and with the parameters used in the studies, the optimum development via the McArthur Tunnel could support a powerplant of 400 MW installed capacity when all controlled water is used for power generation as in Alternative A. At 50% plant factor, this provides an average annual 1,752 GWh of firm energy. The provisional instream flow requirements of Alternative B discussed in Section 7.3.2 of this report represent about 19% of the average annual flow in the Chakachatna River during the period of record. If that amount of water is reserved for instream flow, the installed capacity of powerplant that could be justified at the McArthur River would be reduced to 330 MW and the firm average annual energy would be 1446 GWh.

For development via the Chakachatna tunnel, the optimum power development using all controlled water for power generation, Alternative C, would have an installed capacity of 300 MW and firm annual average energy would be 1314 GWh for a 50% plant factor. The provisional minimum instream flow reservations in Alternative D, discussed in Section 7.3.3 of this report, represent less than 1% of the average annual flow during the period of record. Thus, the installed capacity and firm energy in Alternative D for practical purposes would remain the same. There would however be about 15% reduction in the amount of secondary energy that could be generated.

Alternatives A through D cannot firmly support the capacities determined from the 11 years of inflow during the 1981 studies and the recommended Alternative E cannot firmly support 330 MW at 50% plant factor due to two consecutive dry years (1973-74) that occur during the 31 years of correlated lake inflow. These two years do not occur in the 11 calendar years (1960-1970) of inflow used in the 1981 power studies for Alternates A through D and some additional analyses should be made in future studies of the project. Using the 31 years of inflow, and 330 MW installed capacity, Alternate E could produce 1301 GWh at 45% load factor.

4.7 Variations in Lake Water Level

The variations in lake water-surface elevation calculated at the end of the month during the course of the power studies for each of the five alternatives and cases listed in Table 4-6 are shown in the computer output included in the Appendix to Section 4.0, and are also plotted in Figures 4-4 and 4-5.



ALTERNATIVES A & B
LAKE LEVEL VARIATIONS

FIGURE 4-4

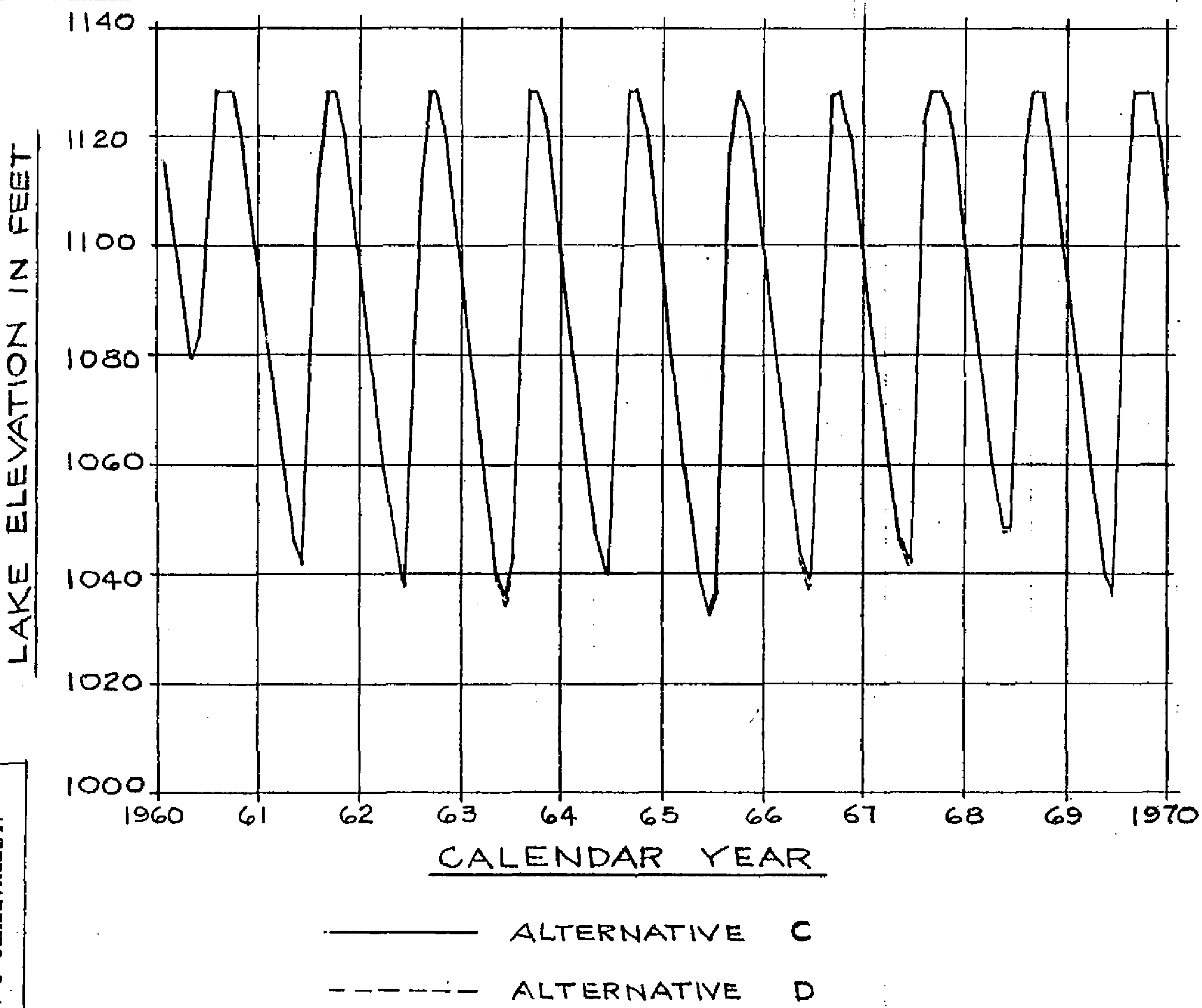


FIGURE 4-5

ALTERNATIVES C & D
LAKE LEVEL VARIATIONS

GEOLOGIC INVESTIGATIONS

5.0 GEOLOGIC INVESTIGATIONS

5.1 Scope of Geologic Investigations

5.1.1 Technical Tasks

The scope of the geologic investigations planned for the Chakachamna Hydroelectric Project Feasibility Study includes five technical tasks:

(1) Quaternary geology,

(2) Seismic geology,

(3) Tunnel alignment and powerplant site geology,

(4) Construction materials geology, and

(5) Road and transmission line geology.

These tasks were identified and scopes defined so that, upon completion of the investigations, the information needed to assess the potential impact of a range of geologic factors on the feasibility of the proposed project will be available. If the Chakachamna Project is judged to be feasible, additional geologic investigations will be required subsequent to the feasibility study in order to provide the detailed information appropriate for actual design.

At the feasibility level, it is appropriate to gather information regarding the general character of the geologic environment in and around the project area, with particular attention to geologic hazards and the geology of specific facilities siting locations. The Chakachamna Project, as presently conceived, does not include facilities such as large dams that would increase the risks associated with geologic hazards that are naturally present in the project area. The geologic tasks were planned in recognition of the above and were designed to focus on geologic factors that may influence the technical feasibility, the operating reliability, and/or the cost of the proposed project.

The work on the geology tasks began in August 1981 but the majority of the work will take place in future feasibility level investigations. This report includes a summary of the work planned for the geologic investigations (Section 5.1.1) and the schedule for each geology task (Section 5.1.2), summaries of the work completed for the Quaternary geology (Section 5.2) and seismic geology (Section 5.3) tasks, and some preliminary commentary on geologic conditions in the project area in Section 7.0. The commentary and any tentative conclusions presented here are subject to revision as the project work continues in the future.

5.1.1.1 Quaternary Geology

The Quaternary geology task was designed to include an assessment of the glaciers and glacial history of the Chakachamna Lake area, an investigation of the Mt. Spurr and associated volcanic centers, and a study of the slope conditions near sites proposed for project facilities.

A study of the glaciers was judged to be appropriate because:

(1) movement of the terminus of Barrier Glacier influences the water level in Chakachamna Lake and any structures to be built near the lake outlet;

(2) the possibility that changes in the terminal position of Blockade Glacier could alter the drainage at the mouth of the McArthur River Canyon; and

(3) questions regarding the influence of other glaciers in the study area on the size and hydrologic balance of Chakachamna Lake.

In addition, knowledge of the ages of geomorphic surfaces is important to the assessment of possible seismic hazards and such knowledge depends on an understanding of the glacial geology.

The simple presence of Mt. Spurr, an active volcano, at the eastern end of Chakachamna Lake provides a clear rationale for investigating the volcanic history and potential volcanic hazards of the project area. Of particular interest is the possibility that lava flows or volcanic mudflows (a possibility increased by the glacier ice on Mt. Spurr) could enter the lake and produce large waves, an increase in lake level, and/or a change in conditions at the lake outlet or on the upper reaches of the river. In addition, the possible impact of a dark, heat-absorbing layer of volcanic ejecta on the glaciers' mass balance, and thus the lake's hydrologic balance is of interest.

Chakachamna Lake, Chakachatna River Canyon, and McArthur River Canyon are all bordered by steep slopes that may be subject to a variety of types of slope failure. A large landslide into the lake could change the usable volume of water stored in the lake and could alter conditions at the proposed lake tap and at the natural outlet from the lake. Potential outlet portal and surface powerhouse sites in the river canyons are all on or immediately adjacent to steep slopes. Both the integrity of and access to these facilities could be impaired in the event of landslide and rockfall activity.

Because of the concerns indicated above, the Quaternary geology task was designed to investigate the timing and size of past glacial fluctuations, the frequency and type of volcanic activity, and the slope conditions in order to provide an estimate of possible future events that could influence the costs and operating performance of the proposed hydroelectric project. In addition, this task should provide information regarding the possibility of the project destabilizing the lake outlet by producing or allowing changes in Barrier Glacier.

5.1.1.2 Seismic Geology

The seismic geology of the Chakachamna Lake area is of interest because southern Alaska is one of the most seismically active areas in the world. Potential seismic hazards of direct concern to the proposed hydroelectric project include surface faulting, ground shaking, seismically-induced slope failure, lake seiche, and liquefaction. Specifically, the seismic geology task was designed to investigate the possibility of active faults in the immediate vicinity of the proposed facilities, to assess the location and activity of regional faults (e.g., Castle Mountain, Bruin Bay), and to estimate the type and intensity of seismic hazards that may be associated with these faults and with the subduction zone.

The seismic geology investigations were planned to maximize the use of existing information by following a sequence of subtasks that become increasingly site specific as the work proceeds. The primary elements in the sequence are:

- literature review
- remote sensing imagery analysis
- field reconnaissance
- low-sun-angle air photo acquisition and analysis
- detailed field studies

The data produced by the above sequence is required to assess directly the surface faulting hazard and for input to the probabilistic assessment of ground motion parameters.

In order to develop approximate ground motion spectra for the various elements of the project, existing ground motion information developed for other projects in southern Alaska will be reviewed and modified, as appropriate. A simplified evaluation of the liquefaction potential of the transmission line alignment should also be carried out.

5.1.1.3 <u>Tunnel Alignment and Powerplant Site Geology</u>

The scope of work for this task should be based on the need to assess the feasibility of constructing a lake tap in Chakachamna Lake, a long tunnel, and a powerhouse as the primary components of the proposed hydroelectric development. Because of the steep mountainous terrain above the tunnel alignment, the tunnel feasibility study should be planned around the mapping of bedrock exposures in the mountains and production of a strip map; drilling would be limited to the powerhouse site during the feasibility investigations. The strip map should focus on those bedrock characteristics that determine the technical and economic feasibility of tunnelling. Geophysical techniques should be used to assess the lake bottom bedrock and sediment characteristics at and near the proposed lake tap and subsurface conditions at the proposed powerhouse site.

All reasonably possible surface powerplant and outlet portal sites are on or adjacent to high, steep slopes. Hazards such as landslides, rockfalls, and avalanches, which are a particular concern in seismically active areas, should be assessed during the feasibility study.

5.1.1.4 <u>Construction Materials Geology</u>

The proposed Chakachamna Hydroelectric Project will, if constructed, require aggregate for concrete, road construction, and construction of the transmission line. In addition, rockfill will be required for the low dike at the lake outlet and boulder rip-rap may be required at the outlet portal and outfall from the powerhouse. This task should be planned to yield information about potential aggregate sources at the powerhouse-outlet portal site, along the road, and along the transmission line alignment.

5.1.1.5 Road and Transmission Line Geology

Geologic considerations will be important in the assessment of the road and transmission line routes. This task will use aerial photograph analysis and reconnaissance-level field studies in order to provide information on the general character of the alignments. The task plans should give particular attention to river crossings, which may be subject to large floods, and to wetland areas where special construction techniques may be required.

5.1.2 Schedule

The 1981 geologic field program did not commence until late August that year and was therefore relatively limited in scope, covering only the Quaternary geology and part of the seismic geology tasks. Future investigations should concentrate on the remaining geologic tasks as discussed below.

5.1.2.1 Quaternary Geology

All of the Quaternary geology field studies were either of a regional nature or directed at targets that would not vary as a function of final configuration of the project facilities. Therefore, it was possible to complete the field work planned for this task. Some additional review of unpublished data, such as that held by the U.S. Geological Survey in Fairbanks, and discussions with geologists who have worked in the

Chakachamna area remain to be completed. Although several important implications with respect to the proposed hydroelectric project have been identified and some tentative conclusions may be drawn, additional analyses and discussions are needed before the conclusions can be finalized.

5.1.2.2 Seismic Geology

As discussed in Section 5.1.1.2, the seismic geology task is designed around a sequence of investigations, each of which builds on the preceding ones. Because of this characteristic, the seismic geology task demands a certain amount of elapsed time and cannot be speeded up by adding additional staff.

During 1981 it was possible to complete the literature review, analysis of existing remote sensing imagery, field reconnaissance, and the acquisition and initial analysis of the low-sun-angle aerial photography. The detailed field studies and ground motion assessment will be conducted during future feasibility study work.

5.1.2.3 Tunnel Alignment and Powerplant Site Geology

No field investigations were conducted for this task in 1981 because the various tunnel alignment locations and configurations to be studied were not identified prior to completion of the 1981 field season. All of the geologic and geophysical investigations planned for this task should be completed during future feasibility study work.

5.1.2.4 Construction Materials Geology

The work for this task will be conducted during future feasibility study work.

5.1.2.5 Road and Transmission Line Geology

The work for this task will be conducted during future feasibility study work.

5.2 Quaternary Geology

The Quaternary, approximately the last 2 million years of geologic time, is commonly subdivided into the Pleistocene and the Holocene (most recent 10,000 years). Although the Pleistocene is generally equated to the glacial age and the Holocene with post-glacial time, such a distinction is less clear in southern Alaska where the mountains still contain extensive glaciers.

The Quaternary was a time of extreme and varied geologic activity in southern Alaska. In addition to the extensive glacial activity and associated phenomena, the Quaternary was also a time of mountain building and volcanic activity. The products of these and other geologic processes that were active during the Quaternary, and are still active today, are broadly present in the Chakachamna Lake area. Although the geologic investigations for this feasibility study consider a broad range of topics that fall under the general heading of Quaternary geology, this task was planned to address three specific topics:

(1) glaciers and glacial geology;

(2) Mt. Spurr volcano; and

(3) slope conditions.

In addition, the seismic geology task (Section 5.3) is designed to focus on Quaternary and historic fault activity and seismicity and is highly dependent on an understanding of the glacial history of the area for temporal data.

For the Quaternary geology task of the Chakachamna study, field work consisted of a twelve-day reconnaissance during which all three primary topics of interest (above) were studied. When combined with information available in the open literature and that gained through interpretation of aerial photography, the field reconnaissance provides a basis for assessing the potential impact of the glaciers, volcano, and slope conditions on the proposed hydroelectric project.

5.2.1 Glaciers and Glacial Geology

5.2.1.1 Regional Glacial Geologic History

At one time or another during the Quaternary, glaciers covered approximately half of Alaska (Pewe, 1975). Previous investigations have demonstrated that the Cook Inlet region has had a complex history of multiple glaciation (Miller and Dobrovolny, 1959; Williams and Ferrians, 1961; Karlstrom, 1964; Karlstrom and others, 1964; Trainer and Waller, 1965; Pewe and others, 1965;

Schmoll and others, 1972). The current understanding of the region's glacial history is based on interpretation of the morphostratigraphic record in association with relative and absolute age dating and other Quaternary studies. The complex history is recorded in glacial, fluvial, lacustrine, marine, and eolian sediments that have been studied primarily in their surface exposures where they can be associated with specific landforms. Although more recent work has led to modification and refinement of Karlstrom's (1964) history of glaciation in the Cook Inlet region, that work still provides a good general overview and, except where noted, serves as the basis for the following summary.

On at least five separate occasions during the Quaternary, the glaciers in the mountains that surround Cook Inlet have expanded onto the Cook Inlet lowlands where they coalesced to cover much or all of the lowland with ice. Evidence for the two oldest recognized glaciations (Mt. Susitna, Caribou Hills) consists dominantly of erratic boulders and scattered remanants of till at high elevation sites around the margins of the lowland. Evidence for the next glaciation, the Eklutna, includes moraines and till sheets that demonstrate the coalescence of ice from various source areas to form a Cook Inlet piedmont glacier. The available evidence suggests several thousand feet of ice covered virtually all of the Cook Inlet lowland during these early glaciations.

The next two glaciations, the Knik and the Naptowne, correspond to the Early Wisconsin and Late Wisconsin glaciations of the midwestern United States, respectively. Thus, the Naptowne glaciation of the Cook

Inlet region correlates, in general, with the Donnely (Pewe, 1975) and McKinley Park (TenBrink and Ritter, 1980; TenBrink and Waythomas, in preparation) glaciations reported from two areas on the north side of the Alaska Range. During the Knik and Naptowne glaciations ice again advanced onto the Cook Inlet lowland, but the ice did not completely cover the lowland as it apparently did during the earlier glaciations. Even at the glacial maxima, portions of the lowland were ice free; such areas were commonly the sites of large ice-dammed lakes that have been studied in some detail (Miller and Dobrovolny, 1959; Karlstrom, 1964).

The maximum ice advance during the Naptowne glaciation is recorded by distinct end moraine complexes located near the mouths of the major valleys that drain the Alaska Range and by moraines on the Kenai lowland. The moraines on the Kenai lowland are of particular interest because they were, at least in part, formed by the Trading Bay ice lobe, which originated in the Chakachatna-McArthur rivers area and advanced across Cook Inlet at the time of the Naptowne maximum. Karlstrom (1964) reported on these features on the Kenai lowland in some detail.

Karlstrom (1964) used a combination of radiocarbon dates and relative-age dating techniques to develop a chronology for the Cook Inlet glaciations. According to Karlstrom, the Naptowne glaciation continued, although with decreasing intensity, past the Pleistocene-Holocene boundary (generally taken as being near 10,000 years before present [ybp]), through the Climatic Optimum, to the beginning of Neoglaciation (see Porter and Denton, 1967). Recent work on the north side of the Alaska Range has produced a well-dated chronology for the McKinley

Park glaciation (TenBrink and Ritter, 1980; TenBrink and Waythomas, in preparation). That chronology shows major stadial events at:

(1) 25,000-17,000 ybp (maximum advance at about 20,000 ybp);

(2) 15,000-13,500 ybp;

(3) 12,800-11,800 ybp; and

(4) 10,500-9,500 ybp.

Recognizing the differences in ice extent and other factors between the Cook Inlet region and the north side of the Alaska Range, the TenBrink chronology is probably reflective of the timing of the primary Naptowne stadial events. Dates from the Cook Inlet region proper have yet to yield such a clear picture, probably because of the greater complexity of the conditions and thus the record there.

Following the Naptowne glaciation (about 9,500 ybp by TenBrink's chronology, as late as 3,500 ybp according to Karlstrom, 9164), glacial advances in the Cook Inlet region have been limited to rather small-scale fluctuations that have extended only up to a few miles beyond present glacier termini. Karlstrom (1964) referred to these Neoglacial advances as the Alaskan glaciation, which he divided into two distinct periods of advance (Tustumena and Tunnel) and further subdivided into three and two short-term episodes, respectively. According to Karlstrom (1964) these Neoglacial events range in age from approximately 3,500 ybp to historic fluctuations of the last several decades.

Two points of particular interest regarding Neoglaciation in Alaska emerged from the literature review:

(1) the idea that "... the youngest major advance typically was the most extensive of the Neoglaciation" (Porter and Denton, 1967, p. 187), and

(2) Karlstrom's (1964) suggestion that, at least in the mountains around the margins of the Cook Inlet region, there was no distinct hiatus between the last small Naptowne readvance and the first Neoglacial advance.

These points will be addressed in the following section.

5.2.1.2 Project Area Glacial Geologic History

The reconnaissance-level investigations conducted for the Chakachamna study confirm the general picture for the project area presented by Karlstrom (1964). The area examined during the field reconnaissance is indicated on Figure 5-1. Although a rather broad area was included in the study area, most of the field work took place in the Chakachamna Lake basin, along the Chakachatna River, and on the southern slopes of Mt. Spurr.

Most of the study area was covered by glacier ice during the maximum stand of the Naptowne-age glaciers. Based on Karlstrom's (1964) work, it would appear that only high, steep slopes and local elevated areas were not covered by Naptowne ice. Within the area examined in the field, the upper limit of Naptowne ice is generally clearly defined, particularly in the area between Capps Glacier and

EXPLANATION

PLACE NAMES AND LOCATIONS WITHIN THE QUATERNARY GEOLOGY RECONNAISSANCE AREA INVESTIGATED BY WOODWARD-CLYDE CONSULTANTS DURING THE 1981 FIELD SEASON.

0 5 10 15

SCALE IN MILES

No.	DATE	REVISION	BY	CHK'D	ENGR SUPV	PROJ ENGR	PROJ MGR

ALASKA POWER AUTHORITY

ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

QUATERNARY GEOLOGY
SITE LOCATIONS

BECHTEL CIVIL & MINERALS, INC.

SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

	JOB No.	DRAWING No.	REV.
BECHTEL	14879	Figure 5-1	

Blockade Glacier, at and east of the range front (Figure 5-1). In this area lateral moraines produced during the maximum stand of Naptowne ice (25,000-17,000 ybp) are distinct and traceable for long distances; younger Naptowne lateral and terminal moraines are also present. The largest area that was not buried by Naptowne ice and which was observed during field reconnaissance is located high on the gentle slopes east of Mt. Spurr, between Capps Glacier and Straight Creek. The two older surfaces (Knik and [?] Eklutna) observed in this area (Figure 5-1) correspond well to the ideas presented by Karlstrom (1964).

Not only are moraines marking the Naptowne maximum present, but a large number of moraines produced during subsequent stadial advances or recessional stillstands are also present. These features demonstrate that even at the Naptowne maximum, ice from Capps Glacier and other glaciers to the north did not coalesce with ice coming from the Chakachatna canyon, except possibly near the coast. The Chakachatna ice and that issuing from the McArthur River Canyon and Blockade Glacier did join, however, to produce Karlstrom's (1964) Trading Bay ice lobe. That ice lobe covered the alluvial flat that, at the coast, extends from Granite Point to West Foreland. From the present coast, the Trading Bay lobe (according to Karlstrom, 1964) extended across Cook Inlet to the Kenai lowland.

The complex of moraines located between Blockade Glacier and the Chakachatna River area allow one to trace the slow retreat of Naptowne ice. As the Trading Bay lobe retreated westward across the inlet and then across the Trading Bay alluvial flats to the mountain front, separate ice streams became distinct. As the Naptowne ice continued to retreat up the Chakachatna Canyon more and more individual glaciers became distinct from one another. For example, Brogan Glacier (informal name, Figure 5-1), separated from the Chakachatna River by a low volcanic ridge, produced a recessional sequence that is independent of that formed by ice in the Chakachatna canyon. Such a sequence of features is less distinct or absent for the other glaciers between Brogan Glacier and Barrier Glacier.

Within the Chakachamna Lake basin, the evidence of Naptowne and older glaciations is largely in the form of erosional features and scattered boulders. Naptowne-age till apparently occurs only in isolated pockets within the lake basin and its major tributary valleys. The Naptowne-age surfaces in the basin are mantled with a sequence of volcanic ashes that averages two to three feet in thickness. The solids are typically developed on these volcanics rather than on the underlying glacially-scoured granitic bedrock or till.

In contrast to the erosional topography that characterizes the Naptowne and older surfaces within the Chakachamna Lake basin, Neoglacial activity produced prominent moraines and outwash fans. Neoglacial features were examined at or near the termini of the following glaciers;

(1) all glaciers along the south shore of the lake from Shamrock Glacier to the lake outlet;

(2) Barrier Glacier;

(3) Pothole and Harpoon Glaciers, where they enter the Nagishlamina River Valley;

(4) all of the glaciers that flow to the south, southeast, and east from the Mt. Spurr highland (Alice Glacier to Triumviarte Glacier, Figure 5-1); and

(5) Blockade Glacier.

The Neoglacial history of several of these glaciers is discussed in more detail in Sections 5.2.1.3 through 5.2.1.5. The Neoglacial record is of particular importance to an assessment of possible glacier fluctuations over the next several decades.

Returning to the two points raised at the end of Section 5.2.1.1:

(1) In most cases observed in the study area, it appears that the latest Neoglacial advance was an extensive or more extensive than earlier Neoglacial advances. This is in agreement with the Porter and Denton (1967) general conclusion for southern Alaska.

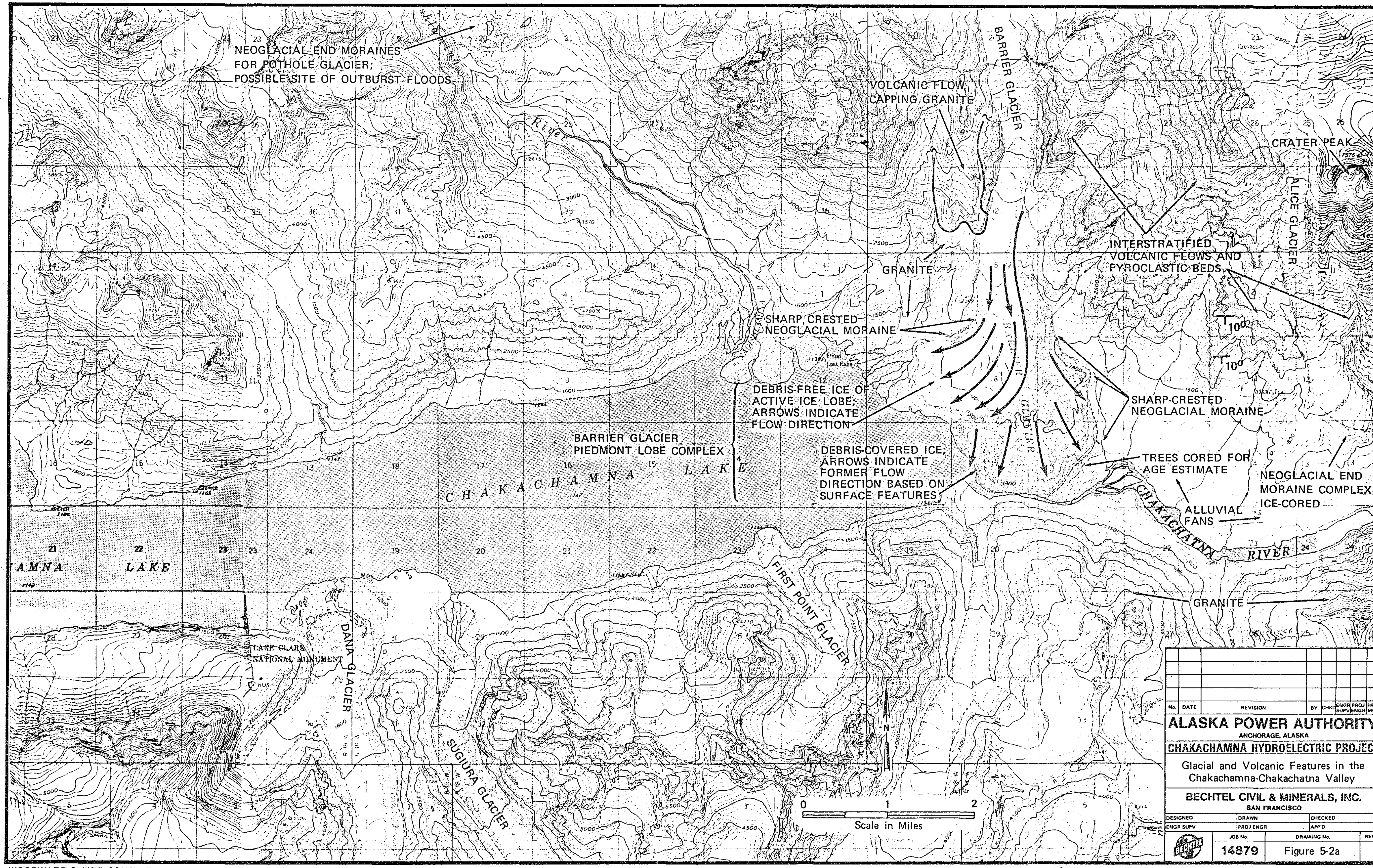
(2) Karlstrom's (1964) chronology suggested a continuous sequence of decreasing glacial advances leading from Naptowne to Neoglacial time. In most parts of the study area it was not possible to assess this suggestion. However, the morainal sequence produced by Brogan Glacier (Figure 5-1) and the difference in the topographic characteristics of those moraines suggest that there was little, if any, hiatus between the youngest Naptowne moraine and the oldest Neoglacial moraine.

5.2.1.3 Barrier Glacier

Barrier Glacier originates in the snow and ice field high on the slopes of Mt. Spurr. From there it flows down a steep, ice-carved canyon to the shore of Chakachamna Lake where its piedmont lobe forms the eastern end of the lake (Figures 5-2a, 5-2b). Barrier Glacier is of particular interest to this study because the glacier forms the eastern end of the lake and influences the size and character of the outlet from the lake.

Barrier Glacier was described by Capps (1935) in his report on the southern Alaska Range and was considered in several reports on the hydroelectric potential of Chakachamna Lake (Johnson, 1950; Jackson, 1961; Bureau of Reclamation, 1962). Giles (1967) conducted a detailed investigation of the terminal zone of Barrier Glacier. Most recently, the U.S.G.S. investigated Barrier Glacier as a part of a volcanic hazards assessment program at Mt. Spurr (Miller, personal communication, 1981).

Giles' (1967) investigation of Barrier Glacier was the most comprehensive to date and was specifically designed to assess the possible impact of the glacier on hydroelectric development of Chakachamna Lake, and vice versa. That work, which took place between 1961 and 1966, included mapping of the lake outlet area and measurements of horizontal and vertical movement and of ablation on various portions of the glacier. Those measurements indicated that:



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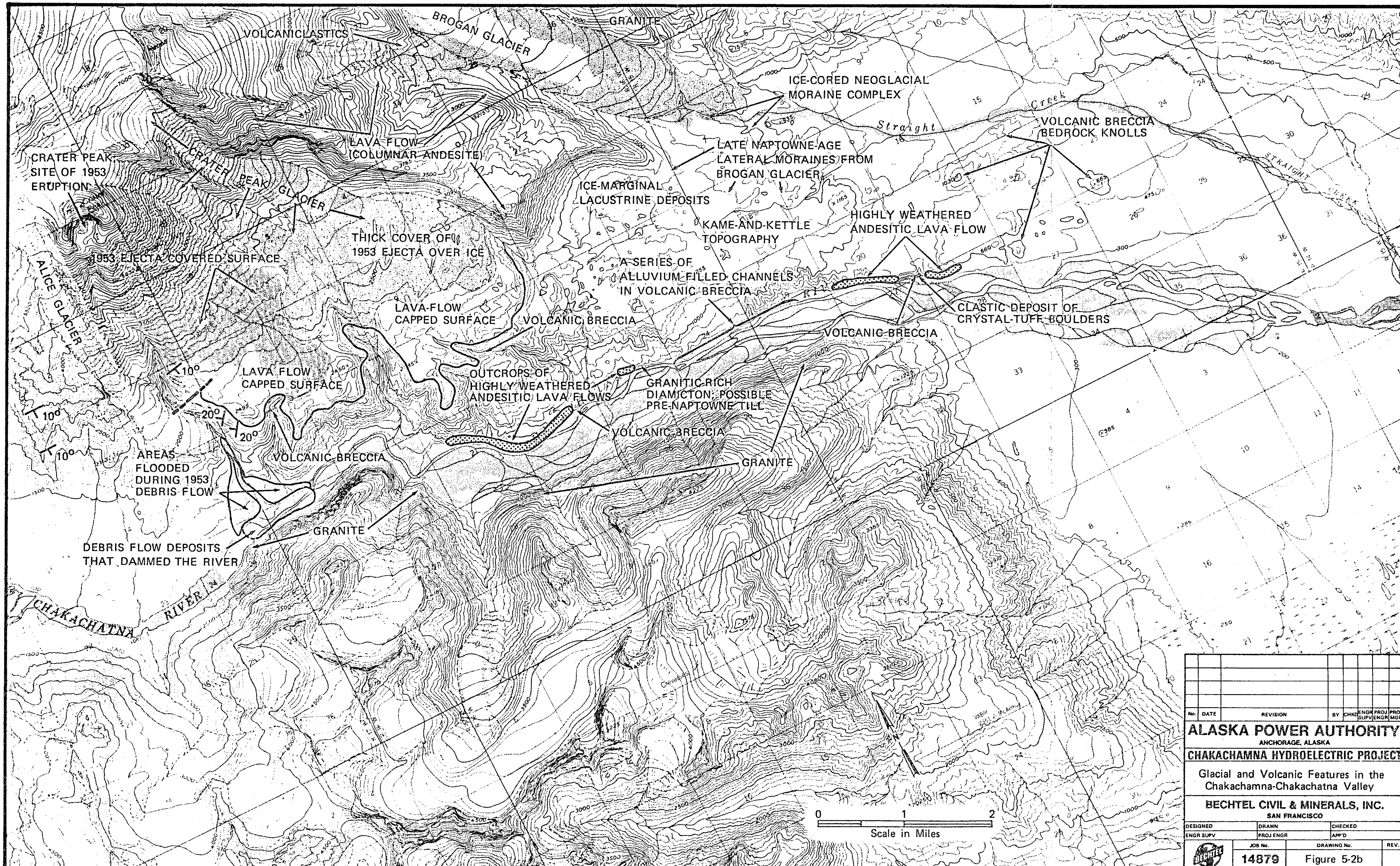
VOLCANICLASTICS
BROGAN GLACIER
GRANITE
ICE-CORED NEOGLACIAL MORAINE COMPLEX
Straight Creek
VOLCANIC BRECCIA BEDROCK KNOLLS
LAVA FLOW (COLUMNAR ANDESITE)
LATE NAPTOWNE-AGE LATERAL MORAINES FROM BROGAN GLACIER
CRATER PEAK SITE OF 1953 ERUPTION
CRATER PEAK GLACIER
ICE-MARGINAL LACUSTRINE DEPOSITS
KAME-AND-KETTLE TOPOGRAPHY
HIGHLY WEATHERED ANDESITIC LAVA FLOW
THICK COVER OF 1953 EJECTA OVER ICE
1953 EJECTA COVERED SURFACE
A SERIES OF ALLUVIUM-FILLED CHANNELS IN VOLCANIC BRECCIA
ALICE GLACIER
LAVA-FLOW CAPPED SURFACE
VOLCANIC BRECCIA
CLASTIC DEPOSIT OF CRYSTAL-TUFF BOULDERS
VOLCANIC BRECCIA
LAVA FLOW CAPPED SURFACE
OUTCROPS OF HIGHLY WEATHERED ANDESITIC LAVA FLOWS
GRANITIC-RICH DIAMICTON; POSSIBLE PRE-NAPTOWNE TILL
10°
20°
20°
10°
10°
VOLCANIC BRECCIA
AREAS FLOODED DURING 1953 DEBRIS FLOW
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GRANITE
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DEBRIS FLOW DEPOSITS THAT DAMMED THE RIVER
CHAKACHATNA RIVER
0 1 2
Scale in Miles
No. DATE REVISION BY CHKD ENGR SUPV PROJ ENGR PROJ MGR
ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA
CHAKACHAMNA HYDROELECTRIC PROJECT
Glacial and Volcanic Features in the Chakachamna-Chakachatna Valley
BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO
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ENGR SUPV PROJ ENGR APP'D
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(1) horizontal movement is in the range of 316 to 125 ft/yr on the debris-free ice and 28 to 1 ft/yr on the debris-covered lobe of ice that forms the southernmost component of the glacier's piedmont lobe complex; and

(2) surface elevation changes were generally small (+0.8 to -2.9 ft/yr), but ablation on the relatively debris-free ice averaged about 35 ft/yr in the terminal zone.

Giles (1967) identified five ice lobes, two on the debris-covered ice and three on the exposed ice, in the terminal zone of Barrier Glacier. Examination of color infrared aerial photographs for the current study suggests that he defined topographic, but not necessarily glaciologically-functional lobes or ice streams. For example, on the debris-covered portion of the piedmont zone, Giles identified two lobes on the basis of a deep drainage that cuts across that zone. On the air photos it is clear that the drainage in question parallels and then trends oblique to the curvilinear flow features preserved in the debris mantle. The drainage does not appear to mark the boundary between two ice streams.

Giles (1967) concluded that the level of Chakachamna Lake is controlled by Barrier Glacier, specifically by one 900-ft wide portion of debris-covered ice along the river; that zone reportedly advances southward, into the river channel, at a rate of about 25 ft/yr. Although the rate of ice movement was apparently relatively constant throughout the year, the low stream discharge in the winter allows the glacier to encroach on the channel but the ice is eroded back during the summer. Thus, Giles suggested that there is metastable equilibrium in the annual cycle. The annual cycle appears to be superimposed on a longer-term change such as that suggested by Giles' measurements.

Observations made during analysis of the color infrared (CIR) aerial photographs and during the 1981 field reconnaissance lead to general agreement with the conclusions produced by previous investigations. Nonetheless, the CIR air photos and extensive aerial and ground-based observations have allowed for the development of several apparently new concepts regarding Barrier Glacier; those new ideas may be summarized as follows:

(1) All of the moraines associated with Barrier Glacier are the products of late Neoglacial advances of the glacier and subsequent retreat. The large, sharp-crested moraines that bound the glacier complex on the eastern and a portion of the western margin (Figure 5-2a) mark the location of the ice limit as recently as a few hundred years ago (maximum estimate) and perhaps as recently as the early to middle part of this century. Cottonwood trees, which are the largest and among the oldest of the trees on the distal side of the moraine are approximately 300 to 350 years old based on tree ring counts on cores collected during the 1981 field work (location of trees on Figure 5-2a). Those dates provide an upper limit age estimate. The vegetation-free character of the proximal side of the moraine and the extremely sharp crest suggest an even more youthful ice stand.

(2) When Barrier Glacier stood at the outermost moraine (no. 1 above), the terminal piedmont lobe was larger than that now present and probably included a portion that floated on the lake; the present river channel south of the glacier could not have existed in anything near its present form at that time. The extent of the piedmont lobe, as suggested here, is based on interpretation of the flow features preserved on the debris-mantled portion of the terminal lobe and the projected continuation of the outermost moraine (no. 1 above).

(3) The most recent advance of Barrier Glacier did not reach the outermost moraine. It appears that the flow of ice was deflected westward by pre-existing ice and ice-covered moraine at the point where the glacier begins to form a piedmont lobe. This pulse was responsible for the vegetation-free zone of till that mantles the ice adjacent to the debris-free ice and for the large moraines that stand above the delta at the northeast corner of the lake.

(4) The presently active portion of Barrier Glacier has the same basic flow pattern as that described in no. 3, above, but the terminus appears to be retreating. The flow of ice is deflected westward as it exits the canyon through which the glacier descends the slopes of Mt. Spurr. The flow pattern is clearly visible on and in the debris-free ice and is further demonstrated by the distribution of the distinct belt of volcanic debris present along the eastern margin of the glacier.

(5) All of the above may be combined to suggest that the large debris-mantled (ice-cored) lobe that forms the most distal portion of the glacier complex, and which borders the river, is now, at least in large part, decoupled from the active portion of the glacier. This interpretation in turn suggests that the movements measured by Giles (1967) are due to adjustments within the largely independent debris-mantled lobe and to secondary effects transmitted to and through this lobe by the active ice upslope.

(6) In spite of the fact that disintegration of the debris-mantled lobe is extremely active locally, the lobe appears to be generally stable because remnant flow features are still preserved on its surface. The debris cover shifts through time, thickening and thinning at any given location as topographic inversion takes place due to melting of the ice and slumping and water reworking of the sediment. It appears that the rate of melting varies as a function of the thickness of the debris cover, with a thick cover insulating the ice and a thin cover producing accelerated melting. Removal of the covering sediment along the edge of the river leads to slumping and exposure of ice to melt-producing conditions. Thus the distal portion of the debris-mantled lobe that borders the river is one site of accelerated melting. Other areas of accelerated melting are concentrated along drainages that have developed within the chaotic ice-disintegration topography.

(7) There is no ice now exposed along the lake shore or around the lake outlet, at the head of the Chakachatna River, as was the case as recently as a few decades ago (Giles, 1969). These areas are rather uniformly vegetated and the debris mantle over the ice appears to be relatively thick compared to areas where accelerated melting is taking place. These areas appear to be reasonable models of what to expect when melting of the ice and the associated sorting and readjustment of the overlying debris have produced a debris cover thick enough to insulate the ice.

(8) If the debris-mantled ice lobe is functionally decoupled from the active ice, as suggested above, the move of ice toward the river is likely to gradually slow in the near future. The Giles' (1967) data suggest that this slowing may be underway; the 1971 flood on the Chakachatna suggests that the ice movement is still occasionally rapid enough to constrict the river channel, however. Nonetheless, it appears likely that, barring a dramatic or catastrophic event, the degrading portion of the ice lobe along the river will slowly stabilize to a condition similar to that along the lake shore. This will probably lead to a channel configuration somewhat wider than at present but the channel floor elevation is unlikely to change significantly. This scenario assumes that the discharge will remain relatively similar to that today. If discharge increases, then a channel deepening, as suggested by Giles (1967), may occur. If discharge decreases, the available data suggest that the outlet channel is likely to become more

narrow and perhaps more shallow as the debris-covered ice continues to stabilize (see Section 7.0).

(9) Over the long term the possible changes along the uppermost reaches of the Chakachatna River, where the lake level is controlled, are potentially more varied and more difficult to predict. One reason for this is that the longer time frame (i.e., centuries vs. decades) provides an increased probability for both dramatic (e.g., marked warming or cooling of the climate) and catastrophic (e.g., large volcanic eruption) events. In this regard, it should be noted that Barrier Glacier and the lake outlet appear to be within the zone of greatest potential impact from eruptions of Mt. Spurr volcano (see Section 5.2.2).

Post and Mayo (1971) listed Chakachamna Lake as one of Alaska's glacier-dammed lakes that can produce outburst floods. They rated the flood hazard from the lake as "very low" unless the glacier advances strongly. The 1971 flood on the Chakachatna (Lamke, 1972) was attributed to lateral erosion of the glacier terminus at the lake outlet. This flood may have, in fact, been triggered by waters from an outburst flood at Pothole Glacier, a surging glacier (Post, 1969) in the Nagishlamina River Valley (Section 5.2.1.5).

5.2.1.4 Blockade Glacier

Blockade Glacier (Figure 5-1) originates in a very large snow and ice field (essentially a mountain ice cap), high in the Chigmit Mountains south of Chakachamna Lake. This same ice cap area is also the source of several of the glaciers that flow to the south shore of Chakachamna Lake (e.g., Shamrock, Dana, and Sugiura Glaciers; Figure 5-1). Blockade Glacier flows southward out of the high mountains into a long linear valley, which trends NE&SW and which is apparently fault controlled (Section 5.3). Once in the linear valley, Blockade Glacier flows both to the northeast and to the southwest. The southwestern branch terminates in Blockade Lake, which is one of Alaska's glacier-dammed lakes that is a source of outburst floods (Post and Mayo, 1971). The northeastern branch of the glacier terminates near the mouth of the McArthur River Canyon and melt water from the glacier drains to the McArthur River.

Blockade Glacier is of specific interest to the Chakachamna feasibility study because one of its branches does terminate so near the mouth of the McArthur River Canyon, and a likely site for the powerhouse for the hydroelectric project is in the lower portions of the canyon (Section 3.0). Changing conditions at the northeastern terminus of Blockade Glacier could conceivably change the drainage of the McArthur River to a degree that may influence conditions in the canyon, i.e., at the proposed powerhouse sites in the canyon.

Blockade Glacier has not been the subject of previous detailed studies such as those for Barrier Glacier (Section 5.2.1.3). Observations made during the 1981 field reconnaissance covered the lower-elevation portions of the source area and both terminal zones, but were concentrated around the northeastern terminus, near the McArthur River.

At its northeastern terminus Blockade Glacier is over two miles wide. Over about half of that width (the northern half) the glacier terminates in a complex of melt water lakes and ponds that are dammed between the ice and Neoglacial moraines. The melt water from the lake system drains to the McArthur River via one large and one small river that join and then flow into the McArthur about 2.5 miles downstream from the mouth of the McArthur River Canyon. A complex of recently abandoned melt water channels formerly carried flow to the McArthur at the canyon mouth. A small advance of the ice front would reinstitute drainage in these now dry channels.

Melt water issuing from the southern half of the ice front flows to the McArthur River in braided streams that cross a broad outwash plain. Whereas the northern portion of the terminus is very linear, the southern portion includes a distinct lobe of ice that is more than a half mile wide and protrudes beyond the general ice front by more than three-quarters of a mile. Another notable characteristic of this zone is that the Neoglacial moraines, which are so prominent to the north, have been completely eroded away by melt water along the southern margin of the glacier.

On the basis of the above observations and the report that Blockade Lake produces outburst floods (Post and Mayo, 1971), it appears that the distinct features in the southern portion of the northeast terminal zone are present because this is the area where the outburst floods exit the glacier front. The broad outwash plain and the removal of the Neoglacial moraines are probably both due to the floods; the vegetation-free (i.e., active) outwash plain is much larger than the size of the melt water streams would suggest. The distinct lobe of ice that protrudes beyond the general front of the glacier probably marks the location of the sub-ice channel through which the outburst floods escape.

The outermost Neoglacial moraines present near the northeastern terminus lie about three-quarters of a mile beyond the ice front. With the exception of the distinct ice lobe, the general form of the ice front is mirrored in the shape of the Neoglacial terminal moraines. The outermost end moraine, which stands in the range of 20 to 40 ft above the surrounding outwash plain (distal) and ground moraine (proximal), is in the form of a continuous low ridge with a gently rounded crest. Three or four less distinct and less continuous recessional moraines are present between the ice and the Neoglacial maximum moraines. Distinct glacial fluting is present in the till in this area.

The Neoglacial end moraine can be traced to a distinct, sharp-crested Neoglacial lateral moraine that is essentially continuously present along the glacier margins well up into the source area for Blockade Glacier. The proximal side of the lateral moraine is steep and vegetation-free, suggesting ice recession in the very recent past. The crest of the lateral moraine stands about 40 or 50 ft (estimate based on observations from the helicopter) above the ice along the lower portions of the glacier.

A readvance of Blockade Glacier's northeastern terminus on the order of one-quarter to one-half a mile would reestablish drainage through the abandoned channels near the mouth of the McArthur River Canyon. Such a change is unlikely to significantly impact conditions within the canyon but would disrupt facilities (e.g., roads) on the south side of the McArthur River, immediately outside the mouth of the canyon. The glacier will have to advance about three-quarters of a mile before conditions in the canyon are likely to be seriously affected. An advance of a mile and a half would essentially dam the mouth of the canyon and would flood a major portion of the lower reaches of the canyon, including the sites under consideration for the powerhouse. Such a glacier-dammed lake would likely produce outburst floods.

There is no evidence that any of the Neoglacial advances of Blockade Glacier were extensive enough to dam the McArthur River Canyon. The outmost of the Neoglacial moraines lies at least one-quarter of a mile short of the point where ice-damming of the canyon would begin, however. Outwash fans on the distal side of the moraine may have produced minor ponding in the lowermost reaches observed in the field and on the color infrared air photos suggest that the last time that Blockade Glacier may have dammed the McArthur Canyon was in late Naptowne time, approximately 10,000 years or more ago.

The only reasonable mechanism that could produce an advance of Blockade Glacier that would be rapid enough to impact on the proposed hydroelectric project is a glacier surge; a surging glacier could easily advance a mile or more within a period of a few decades. Evidence for surges in the recent past might include an advancing glacier front in an area where glaciers are generally in recession and/or distorted medial moraines or longitudinal dirt bands on the glacier surface (Post, 1969; Post and Mayo, 1971). It is clear that Blockade

Glacier's recent history has been one of recession, as is the case for all other glaciers examined during the 1981 field reconnaissance. There are many distinct longitudinal dirt bands and small medial moraines visible on the surface of Blockade Glacier. If one or more of the individual ice streams that comprise Blockade Glacier had recently surged, such activity should be reflected in contortions in the dirt bands and medial moraines. Visible deformation of the surface features on the glacier is very subtle and not suggestive of recent surging of even individual ice streams in the glacier. Thus, there is no evidence of a general surge of Blockade Glacier in the recent past.

In summary, it appears that Blockade Glacier began to withdraw from its Neoglacial maximum within the last few hundred years. At that maximum stand, melt water drainage joined the McArthur River at the canyon mouth and outwash may have produced some ponding and sediment aggradation in the lower reaches of he canyon, but the glacier was not extensive enough to have dammed the canyon. Surging is the most reasonable mechanism that could produce a future advance large enough and rapid enough to impact on the proposed powerhouse sites in the McArthur Canyon. No evidence suggestive of surging of Blockade Glacier was identified during this study.

Currently, melt water is carried away from the canyon mouth. Even markedly accelerated melt water production from Blockade Glacier is unlikely to change this condition or to have a negative impact on the proposed hydroelectric project.

5.2.1.5 Other Glaciers

In order to get a reasonably broad-based sense of the glacial record and history of recent glacier behavior in the Cakachamna Lake region, the field reconnaissance included aerial and ground-based observations of a number of the glaciers in the region in addition to Barrier and Blockade Glaciers. Those glaciers included:

(1) Shamrock Glacier, Dana Glacier, Sugiura Glacier, and First Point Glacier along the south shore of Chakachamna Lake (see figure 5-1 for locations);

(2) Harpoon Glacier and Pothole Glacier in the Nagishlamina River Valley;

(3) Alice Glacier, Crater Peak Glacier, and Brogan Glacier on the slopes of Mt. Spurr, above the Chakachatna River;

(4) Capps Glacier and Triumvirate Glacier on the eastern slopes of Mt. Spurr; and

(5) McArthur Glacier in the McArthur River valley.

Post (1969) surveyed glaciers throughout western North America in an effort to identify surging glaciers. Four of his total of 204 surging glaciers for all of western North America are in the Chakachamna study area (Figure 5-1). Three, including Pothole Glacier and Harpoon Glacier, are located in the Nagishlamina River Valley, tributary to Chakachamna Lake, and one, Capps Glacier, is on the eastern slope of Mt. Spurr. Surface features indicative of surging are clearly visible on the color infrared aerial photographs used in this study and were observed during field reconnaissance.

Specific observations pertinent to an understanding of the glacial history of the area include:

(1) All of the glaciers listed above appear to have only recently withdrawn from prominent Neoglacial moraines, which in most (if not all) cases mark the Neoglacial maximum advance positions of the glaciers. These moraines and younger recessional deposits are generally ice-cored for those glaciers in groups 1 through 3 (above), but have little or no ice core in groups 4 and 5, which terminate at slightly lower elevations.

(2) Ponding and sudden draining of the impoundment upstream of the Pothole Glacier (a surging glacier) end moraine complex in the Nagishlamina River valley may be an episodic phenomena that can produce flooding in the lower portions of that valley and thus a pronounced influx of water into Chakachamna Lake. Published topographic maps (compiled in 1962) show a small lake upstream of the end moraine, which with the exception of a narrow channel along the western valley wall, completely blocks the Nagishlamina River Valley. That lake is no longer present but there is clear evidence for its presence and the presence of an even larger lake in the recent past. Features on the floor of the lower Nagishlamina River Valley suggest recent passage of a large flood. Such a sudden influx of water into

Chakachamna Lake could produce significant changes at the outlet from the lake. It may be that the 1971 flood on the Chakachatna River (U.S.G.S., 1972) was triggered by such an event, the stage having been set by the slow increase in the level of Chakachamna Lake in the years prior to the flood (Giles, 1967).

(3) Only glaciers south and east, and in the immediate vicinity at Crater Peak on Mt. Spurr retain any evidence of a significant cover of volcanic ejecta from the 1953 eruption of Crater Peak. On both Crater Peak Glacier and Brogan Glacier (see Figure 5-1) the ice in the terminal zone is buried by a thick cover of coarse ejecta. The volcanic mantle, where present, appears to be generally thick enough to insulate the underlying ice. The ejecta cover on Alice Glacier is surprisingly limited. Areas where the volcanic cover formerly existed, but was thin enough so that its presence accelerated melting, have probably largely been swept clean by the melt-water. In any case, the only areas where there is now evidence that the dark volcanic mantle has or is producing more rapid melting is on the margins of the thickly covered zones on the two cited glaciers.

(4) Highly contorted medial moraines on Capps Glacier, Pothole Glacier, and Harpoon Glacier suggest that several of the individual ice streams that comprise those glaciers have surged in the recent past. No comparable features were observed on any of the other glaciers in the Chakachamna study area.

5.2.1.6 Implications with Respect to the Proposed Hydroelectric Project

Implications derived from the assessment of the glaciers in the Chakachamna Lake area, with respect to specific project development alternatives, are included in Section 7.2 while project risk evaluation is disucssed in Section 7.4. General implications, not directly tied to any specific design alternative, may be summarized as follows:

(1) In the absence of the proposed hydroelectric project, the terminus of Barrier Glacier is likely to continue to exist in a state of dynamic equilibrium with the Chakachatna River and to produce small-scale changes in lake level through time; the terminal fluctuations are likely to slow and decrease in size in the future, leading to a more stable condition at the lake outlet.

(2) If development of the hydroelectric project or natural phenomena dam the Chakachatna River Valley and flood the terminus of Barrier Glacier, the rate of disintegration is likely to increase. If the level of the lake is raised, the rate of calving on Shamrock Glacier is likely to increase.

(3) If hydroelectric development lowers the lake level, the debris-covered ice of Barrier Glacier is likely to encroach on and decrease the size of the river channel; a subsequent rise in lake level could yield conditions conducive to an outburst flood from the lake. A lowering of the level of Chakachamna Lake will also cause the stream channels that carry water from Kenibuna Lake and Shamrock Lake into

Chakachamna Lake to incise their channels, thereby lowering the levels of those upstream lakes over time.

(4) There is no evidence to suggest that Blockade Glacier will have an adverse impact on the proposed hydroelectric project or that the project will have any effect on Blockade Glacier.

(5) Glacier damming of the Nagishlamina River Valley may result in outburst floods that influence conditions at the outlet from Chakachamna Lake.

(6) With the exception of Shamrock Glacier, the terminus of which may be affected by the lake level, there is no evidence to suggest that the proposed project will influence the glaciers (other than Barrier Glacier) in the Chakachatna-Chakachamna Valley. Changes in the mass balance of the Glaciers will influence the hydrologic balance of the lake-river system, however.

5.2.2 Mt. Spurr Volcano

5.2.2.1 Alaska Peninsula-Aleutian Island Volcanic Arc

Mt. Spurr is an active volcano that rises to an elevation above 11,000 ft at the eastern end of Chakachamna Lake. Mt. Spurr is generally reported to be the northernmost of a chain of at least 80 volcanoes that extends for a distance of about 1,500 miles through the Aleutian Islands and along the Alaska Peninsula; recent work has identified another volcano about 20 miles north of Mt. Spurr (Miller, personal communication, 1981). Like Mt.

Spurr, about half of the known volcanoes in the Aleutian Islands-Alaska Peninsula group have been historically active.

The volcanoes of this group are aligned in a long arc that follows a zone of structural uplift (Hunt, 1967), and that lies immediately north of the subduction zone at the northern edge of the Pacific Plate. The volcanoes on the Alaska Peninsula developed on a basement complex of Tertiary and pre-Tertiary igneous, sedimentary, and metasedimentary rocks. The pre-volcanic rocks are poorly exposed in the Aleutian Islands. At the northern end of the chain, such as at Mt. Spurr, the volcanoes developed on top of a pre-existing topographic high. Mt. Spurr is the highest of the volcanoes in the group and the summit elevations generally decrease to the south and west.

The Alaska Peninsula-Aleutian Islands volcanic chain is, in many ways, similar to the group of volcanoes in the Cascade mountains of northern California, Oregon, Washington, and southern British Columbia. In general, both groups of volcanoes developed in already mountainous areas, both consist of volcanoes that developed during the Quaternary and include historically active volcanoes. In both areas the volcanic rocks encompass a range of compositions but are dominantly andesitic, and both groups contain a variety of volcanic forms. The Alaskan volcanoes include low, broad shield volcanoes, steep volcanic cones, calderas, and volcanic domes. Much of the present volcanic morphology developed in late- and post-glacial time.

5.2.2.2 Mt. Spurr

Capps (1935, p. 69-70) reported, "The mass of which the highest peak is called Mt. Spurr consists of a great outer crater, now breached by the valleys of several glaciers that flow radially from it, and a central core within the older crater, the highest peak of the mountain, from vents near the top of which steam sometimes still issues. One small subsidiary crater, now occupied by a small glacier, was recognized on the south rim of the old, outer crater."

Subsequent work has shown that Capps' observations were, in part, in error. The error is specifically related to the suggestion that the peaks and ridges that surround the summit of Mt. Spurr mark the rim of a large, old volcanic crater. Why Capps had this impression is clear because as one approaches the mountain from the east or southeast, the view strongly suggests a very large crater; such a view has suggested to many geologists that Capps was correct in his observations. It is only when one gets up on the mountain, an opportunity made practical by the helicopter, that it becomes clear that most of the "crater rim" consists of granitic and not volcanic rocks. The most recent and comprehensive report on the distribution of lithologies present on Mt. Spurr is found in Magoon and others (1976). The U.S. Geological Survey plans to issue an open file report on Mt. Spurr in 1982 (Miller, personal communication, 1981).

Field work aimed at assessing the potential impact of volcanic activity from Mt. Spurr on the proposed hydroelectric development at Chakachamna Lake was concentrated in the area bounded by the Nagishlamina River on the west, the Chakachatna River on the south, a north-south line east of the mountain front on the east, and the Harpoon Glacier-Capps Glacier alignment on the north (Figure 5-1). Most of the observations at the higher elevations were from the helicopter; landing locations high on Mt. Spurr are few and far between and many of the steep slopes are inaccessible to other than airborne observations. It was possible to make numerous surface observations in the Nagishlamina River and Chakachatna River valleys and on the slopes below 3,000 ft elevation to the south and southeast of the summit of Mt. Spurr.

Observations made during the 1981 reconnaissance indicate that the Quaternary volcanics of Mt. Spurr, with the exception of airfall deposits, are largely confined to a broad wedge-shaped area bounded generally by Barrier Glacier, Brogan Glacier, and the Chakachatna River (Figures 5-1, 5-2a and 5-2b); the distribution of Quaternary volcanics north of the summit, in areas that do not drain to the Chakachamna-Chakachatna basin, was not investigated.

The bedrock along the western margin of Barrier Glacier is dominantly granite. The only exception observed during the field reconnaissance, which focused at elevations below about 5,000 ft, was an area where the granite is capped by lava flows (Figure 5-2a). East of Barrier Glacier the slopes above about 2,000 ft consist of interstratified lava flows and pyroclastics, which are exposed in cross section. The slopes of Mt. Spurr in this area are not the product of triginal volcanic deposition but are erosional features. Thus, it is clear that the volcanics once extended farther to the south and southwest into what is now the Chakachamna Lake basin and

Chakachatna River Valley. The lower slopes immediately east of Barrier Glacier and south of Mt. Spurr consist of a broad alluvial fan complex.

Between Alice Glacier and the mountain front, the upper slopes of Mt. Spurr, where not buried by glacier ice or Neoglacial deposits, expose interbedded lava flows (often with columnar jointing), pyroclastic units, and volcaniclastic sediments. As is the case near Barrier Glacier, most of the slopes in this area are steep, often near vertical erosional features that expose the volcanic sequence in cross-section. The primary exception to this is found on and adjacent to Crater Peak where some of the slopes are original depositional features.

Crater Peak was the site of the most recent eruption of Mt. Spurr. That eruption, which took place in July, 1953, was described by Juhle and Coulter (1955). The 1953 eruption produced an ash cloud that was observed as far east as Valdez, 100 miles from the volcano; the distribution of ejecta on Mt. Spurr demonstrates that virtually all of the airborne material traveled eastward with the prevailing winds. The thick debris cover on Crater Peak and Brogan Glaciers (Figure 5-2b) is largely the product of this eruption.

Any lava that issued from Crater Peak in 1953 was limited to the slopes of the steep-sided cone. The eruption did produce a debris flow, which began at the south side of the crater where volcanic debris mixed with water from the glacier that reportedly occupied the crater (Capps, 1935) and the outer slopes of the cone began to move downslope toward the Chakachatna River. The debris flow, which was probably more a flood than a debris flow initially, eroded a deep canyon along the eastern margin of Alice Glacier, through the Neoglacial moraine complex at the terminus of Alice Glacier, and through older volcanics and alluvium adjacent to the Chakachatna River. When it reached the Chakachatna River, the debris flow dammed the river and produced a small lake that extended upstream to the vicinity of Barrier Glacier. The dam was subsequently partially breached, lowering the impoundment in the Chakachatna Valley to its present level. Evidence for the high water level includes tributary fan-deltas graded to a level above the current water level and a "bath tub ring" of sediment and little or no vegetation along the southern valley wall.

East of the 1953 debris flow, the Chakachatna River flows through a narrow canyon within the broader valley bounded by the upper slopes of Mt. Spurr on the north and the granitic Chigmit Mountains on the south. The southern wall of the canyon (and valley, as whole) consists of glacially-scoured granitic bedrock. With the exception of remnant deposits of the 1953 debris flow that are present against the granitic bedrock (Figure 5-2b), the 1981 reconnaissance yielded no evidence of volcanic or volcaniclastic rocks on the southern wall of the Chakachatna Valley. The northern wall of the Chakachatna Canyon exposes a complex of highly weathered (altered ?) andesitic lava flows, pyroclastics, volcaniclastic sediments, outwash, and in one location, what appears to be an old (pre-Naptowne) till.

Although the general late-Quaternary history of the Chakachatna River Valley is reasonably clear, the details of that history are very complex and would require an extensive field program to unravel. The observations made during the 1981 reconnaissance suggest the following:

(1) Late-Tertiary and/or early-Quaternary volcanic activity at Mt. Spurr built a thick pile of lava flows, pyroclastics, and volcaniclastic sediments on top of a granitic mountain mass of some considerable relief.

(2) Interspersed volcanic and glacial activity occurred during the Pleistocene, with alternating periods of erosion and deposition. The width of the valley at Chakachamna Lake is maintained downstream to the area of Alice Glacier (Figure 5-2a). From that point to the mountain front, where the same broad valley form seems to reappear, the overall valley is plugged by a complex of volcanic (and glacial) deposits. This, along with the volcanic cliffs high on the slopes of Mt. Spurr, suggests that volcanics once largely filled what is now the Chakachatna Valley, that glaciers then eroded a broad, U-shaped valley (such as is still present in the lake basin), and that subsequent volcanic activity produced the bulk of the deposits that form the valley "plug".

(3) The age of the volcanics in the "plug" is not clear. Some of the characteristics of the basal volcanic rocks exposed along the river suggest some antiquity. For example, many lava flows are so deeply weathered (or altered ?) that the rocks disintegrate in one's hand. These volcanics appear to be overlain by outwash and may be interbedded with till, which is also deeply weathered

(altered?). These and other features suggest that at least some of the volcanics in this area were deposited in pre-Naptowne time. Glacial deposits, including moraines, a large area of kame and kettle deposits,and glacier-marginal lake deposits interpreted to be a late-Naptowne age overlie portions of the volcanic valley plug. [See Section 7.2 for discussion of implications with respect to a dam in the Chakachatna Canyon.]

In contrast, it is difficult to understand how the apparently easily eroded volcanics in this area survived the Naptowne-age glaciers that filled the Chakachatna Valley and were large enough to extend across Cook Inlet (Karlstrom, 1964). In addition, there are many landforms, such as volcanic pinnacles, that clearly are post glacial as they could not have survived being overriden by glacier ice. Such landforms demand the removal of several tens of feet of volcanics over large areas.

Although the evidence is conflicting and an unambiguous interpretation difficult, it does appear that much of the volcanic valley plug is of pre-Naptowne age. The basis for this conclusion is most clearly documented by the presence of outwash on top of volcanics, a sequence exposed at several sites in the canyon. The outwash is capped by a three-to-four foot thick cap of volcanic ash (many discrete depositional units) as is typical of Naptowne-age surfaces in the area. Just how these volcanics survived the Naptowne glaciation is not clear.

(4) Following the withdrawal of the Naptowne ice from the Chakachatna River Valley, Holocene volcanic activity, glacial activity, and fluvial and slope processes have produced the present landscape. Most, if not all of the present inner canyon, through which the Chakachatna River flows, appears to be the product of Holocene downcutting by the river.

Given that many of the details of the Quaternary history of Mt. Spurr are not well understood, it is nonetheless clear that Mt. Spurr is an active volcano that may produce lava flows, pyroclastics, and volcaniclastic sediments in the immediate vicinity within the life of the project. Airfall deposits can be expected to influence a larger area. Considering the size and type of volcanic events for which there is evidence at Mt. Spurr and the present topography, the area of interest to the proposed hydroelectric project most likely to be affected is the area between Barrier Glacier and the 1953 debris flow. The topography of the valley plug volcanics appears to afford some, but certainly not total protection to the canyon portion of the river valley; an example of this "protection" is provided by a second debris flow produced in 1953 that was prevented from reaching the river by intervening topography on the valley "plug".

The types of volcanic event judged to be most likely to impact the Chakachatna River Valley in the near future are:

(1) 1953-type debris flows which could inundate a portion of the valley and re-dam the river,

(2) lava flows, which could enter and dam the valley, and

(3) large floods that would be produced by the melting of glacier ice during an eruption.

Post and Mayo (1971) suggested that melting of glacier ice on Mt. Spurr during volcanic activity may present a serious hazard. Significant direct impact on Barrier Glacier would demand a summit eruption that included the flow of hot volcanics at least into the upper reaches of the glacier or the development of a new eruptive center (such as Crater Peak) west of the present summit. Of course the character of the volcanoes in the Aleutian Island-Alaska Peninsula chain make it clear that a very large event (i.e., a Mt. St. Helens--or even a Crater Lake-type event) is possible at Mt. Spurr; such an event has a very low annual probabilty of occurrence at any given site, however.

5.2.2.3 Implications with Respect to the Proposed Hydroelectric Project

The potential impact of Mt. Spurr on the proposed hydroelectric project will, in part, vary as a function of the project design (see Sections 7.2 and 7.4), but some potential will always exist because of the location of Mt. Spurr relative to Chakachamna Lake and the Chakachatna River. The amount of negative impact on the project is clearly a function of the size of volcanic event considered; larger events, which would have the greatest potential for adverse impact, are, in general, less likely to occur than smaller volcanic events. Some general possibilities that might be associated with low- to medium-intensity events (such as a Crater Peak event or slightly larger) include:

(1) Damming of the Chakachatna River by lava or debris flows, with the most likely site being in the vicinity of the 1953 debris dam. Flooding of the terminus of Barrier Glacier may increase the rate of ice melt and possibly alter the configuration of the current lake outlet. Any project facilities on the valley floor of the upper valley would be buried by the flow and/or flooded.

(2) Flooding of the Chakachatna River Valley as a result of the melting of glacier ice on Mt. Spurr during an eruption. Project facilities near or on the valley floor would be flooded.

(3) Accelerating the retreat of Barrier Glacier due to the flow of hot volcanic debris onto the glacier. In the extreme, Barrier Glacier could be eliminated if enough hot material flowed onto the ice. A less dramatic scenario could include destabilization of the lake outlet due to accelerated melting in the terminal zone of Barrier Glacier. In contrast, a large lava flow at the present site of Barrier Glacier could replace the glacier as the eastern margin of the lake, providing a more stable dam than that provided by Barrier Glacier.

Each of the design alternatives (Section 3.0) includes a lake tap in the zone between the lake outlet and First Point Glacier. Although it is generally true that a site farther from Mt. Spurr is less likely to be subject to volcanic hazards than a site closer to the volcano, there is no apparent reason to favor one particular site in the proposed zone over any other site in that zone. A large eruptive event, apparently substantially larger than any of the Holocene events on Mt. Spurr, would be required before the proposed lake tap site would be directly threatened by an eruption of Mt. Spurr.

5.2.3 Slope Conditions

The Chigmit Mountains, south of Chakachamna Lake and the Chakachatna River, and the Tordrillo Mountains, to the north, contain many steep slopes and near-vertical cliffs. This landscape is largely the product of multiple glaciation during the Quaternary, including Neoglaciation which continues in the area today. The proposed hydroelectric project is likely to include facilities in the Chakachamna Lake basin and either or both of the McArthur and Chakachatna River valleys. Any above-ground facilities in these areas will be on or immediately adjacent to steep slopes, and thus subject to any slope processes that may be active in the area. Because of this fact, the 1981 field reconnaissance included observations of slope conditions in the areas of interest. Future field work should include detailed assessment of bedrock characteristics, such as joint orientations, that influence slope conditions.

5.2.3.1 Chakachamna Lake Area

Chakachamna Lake sits in a glacially overdeepened basin that is generally bordered by steep slopes of granitic bedrock that was scoured during Naptowne and earlier glaciations. Locally, such as along the southern valley wall west of Dana Glacier (Figure 5-2a), distinct bedrock benches are present. In other areas, the slopes rise, with only minor variation in slope, from the lake level to the surrounding peaks. All principal valleys along the southern side of the lake presently contain glaciers. The principal valleys tributary to the north side of the lake, the Chilligan and Nagishlamina, are larger than those on the south side of the lake and are currently essentially ice-free, although their present form is clearly the product of glacial erosion.

No evidence of large-scale slope failures of the slopes in the Chakachamna Lake basin was observed during the 1981 field reconnaissance. Most of the slopes are glacially-scoured bedrock and are essentially free of loose rock debris, although talus is locally present. The orientation of joint sets in the granitic bedrock varies somewhat from area to area. In many areas a near horizontal out-of-slope joint set is present, but it tends to be poorly expressed relative to more steeply-dipping joints. Field work indicates that this and cross-cutting joints have formed boulder-size pieces and small slabs that produce rockfall as the only common type of slope failure for which any evidence was found. This condition is apparently most pronounced along the southern valley wall, between Sugiura Glacier and the lake outlet.

5.2.3.2 Chakachatna River Valley

The Chakachatna River, from its origin at Chakachamna Lake to the mountain front, flows through a valley that is rather variable in its form and characteristics along its length and from side to side. Throughout the valley, the south side consists of steep glaciated granitic bedrock slopes that rise essentially continuously from the river to the adjacent mountain peaks. All major tributary valleys on the southern valley wall, many of which are hanging valleys, now contain glaciers. The comments regarding slope conditions on the slopes above the lake (Section 5.2.3.1) apply to the southern wall of the Chakachatna River Valley.

The north side of the valley differs from the south side in virtually every conceivable way. On this side bedrock is volcanic, and glacial and fluvial sediments are also present. In the westernmost portion of the valley, the river is bordered by the Barrier Glacier moraine and alluvial fans; steep volcanic slopes above the alluvial fans are subject to rockfall activity. Between Alice Glacier (the area of the 1953 debris flow) and the valley mouth, the river flows through a narrow canyon, the north side of which consists of a variety of interbedded volcanics, glacial deposits, and fluvial sediments (Figure 5-2b). The north canyon wall has been the site of several landslides that range in size from small slumps to large rotational slides. Such activity is likely to continue in the future. Its impact will most frequently be limited to the diversion of the main river course away from the north canyon wall; there are several examples of this now present in the canyon. A large landslide, which appears to be unlikely given the height of the slopes, could completely dam the canyon; partial damming with temporary ponding appears to be a more likely possibility.

Volcanic activity on Mt. Spurr could directly influence conditions along the Chakachatna River (Section 5.2.2), or could, by slowly altering conditions along the north wall of the canyon, have a secondary impact on the valley.

5.2.3.3 McArthur River Canyon

The McArthur River Canyon is a narrow, steep-walled glaciated valley. A possible powerhouse site has been identified along the north wall of the canyon (Section 3.0) and the following comments specifically refer to the north wall of the McArthur River Canyon. The valley walls, which consist of granitic bedrock, expose a complex of cross-cutting joint sets and shear zones. The character and dominant orientations of the joints and shears vary along the length of the canyon and the character of the slopes also varies, apparently in direct response.

Except near the canyon mouth, there is no evidence of large-scale slope failure and rockfall is the dominant slope process. Between the terminus of McArthur Glacier and Misty Valley (Figure 5-1) the joint sets are of a character and orientation such that rockfall has been active and the bedrock on the lower slopes on the north valley wall are uniformly buried beneath a thick talus. The vegetation on the talus suggests that the bulk of talus development took place some time soon after deglaciation and rockfall has been less active recently. The slopes between Misty and Gash Valleys (Figure 5-1) consist of glacially-scoured bedrock that is essentially talus free, suggesting little or no rockfall in this area.

From Gash Valley to the canyon mouth, the granitic bedrock appears to become progressively more intensely jointed and sheared and thus more subject to rockfall and small-scale slumping. Talus mantles the lower slopes in much of this area. A large fault zone (Section 5.3) is present at the canyon mouth. The fault has produced intense shearing over a broad zone that is now subject to intense erosion and is the site of several landslides.

5.2.3.4 Implications with Respect to the Proposed Hydroelectric Project

As in the case for volcanic hazards, there is no apparent reason with respect to slope conditions to favor one site over any other in the zone between the lake outlet and First Point Glacier for the lake tap. Rockfall appears to be the only potential slope hazard in that zone; there was no evidence observed in the field to suggest other types of slope failure.

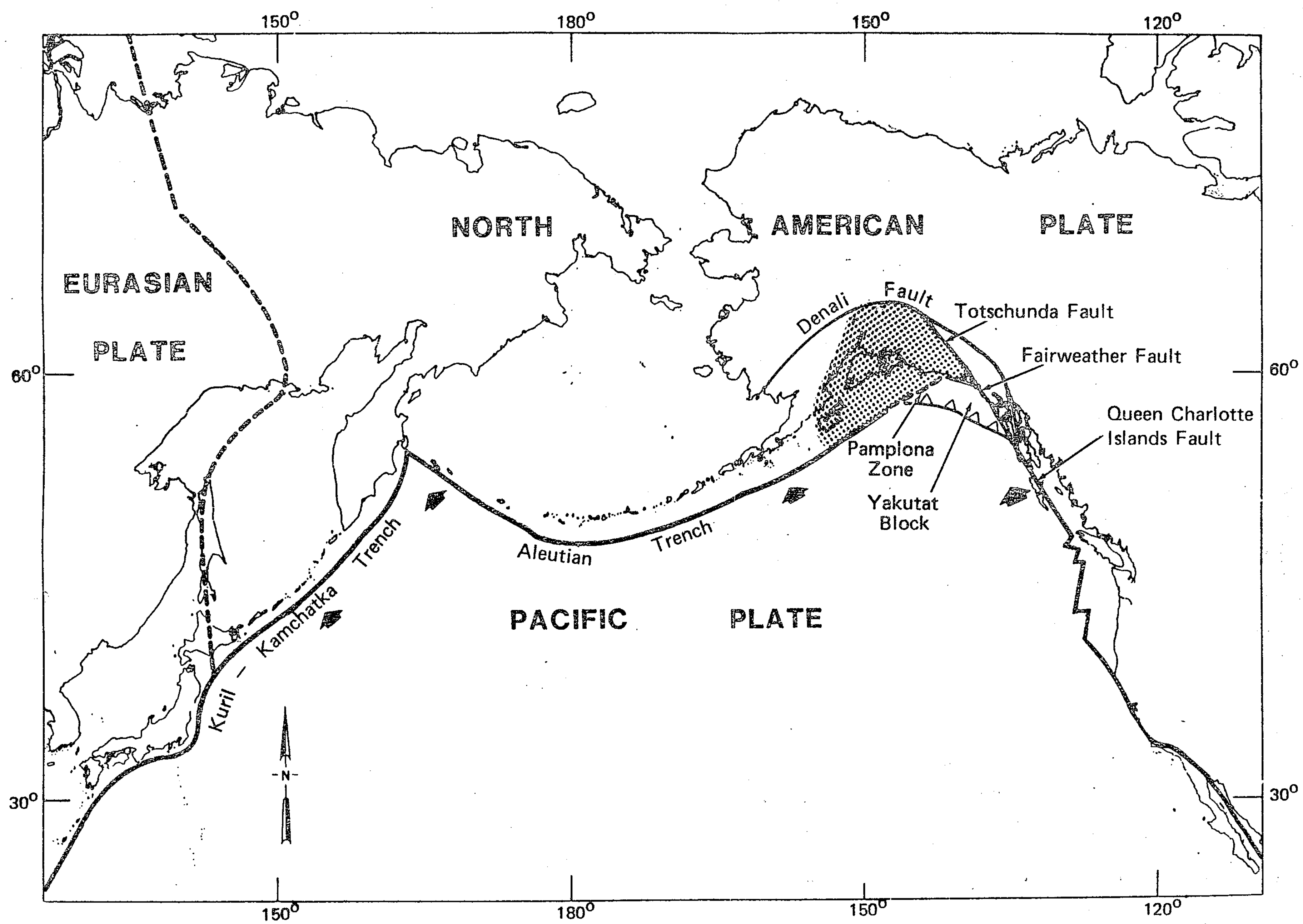
As indicated on Figure 5-9, the Castle Mountain fault (Section 5.3), which is a major fault, crosses the McArthur River just outside the canyon mouth (Section 7.4) where the granitic bedrock has been badly shattered by fault movement. Surface examination reveals that the rock quality progressively improves with distance upstream from the canyon mouth and the best quality rock lies between Gash Valley and Misty Valley (Figure 5-1), beginning about 1-1/2 miles upstream from the powerhouse location presently shown on the drawings. This location is based on economic considerations alone, without taking account of the higher excavations costs that would be associated with the poorer quality rock. A critical evaluation of the rock conditions in this area should be included in future studies and a site should be selected for drilling a deep core hole.

A powerhouse site at or immediately outside the canyon mouth, as has been considered in other studies, is likely to be in the fault zone and subject to fault rupture as well as high ground motions. In addition, facilities outside the canyon will be in Tertiary sedimentary rocks and glacial deposits, not granite.

5.3 Seismic Geology

5.3.1 Tectonic Setting

The active faulting, seismicity, and volcanism of southern Alaska are products of the regional tectonic setting. The primary cause of the faulting and seismic activity is the stress imposed on the region by the relative motion of the Pacific lithospheric plate relative to the North American plate along their common boundary (Figure 5-3). The Pacific plate is moving northward relative to the North American plate at a rate of about 2.4 inches/year (Woodward-Clyde Consultants, 1981 and references therein). The relative motion between the plates is expressed as three styles of deformation. Along the Alaska Panhandle and eastern margins of the Gulf of Alaska, the movement between plates is expressed primarily by high-angle strike-slip faults. Along the northern margins of the Gulf of Alaska, including the Cook Inlet area, and the central and western portions of the Aleutian Islands, the relative motion between the plates is expressed by the underthrusting of the Pacific plate beneath the North American plate. At the eastern end of the Aleutian



LEGEND

- Wrangell Block
- Relative Pacific Plate Motion
- Plate Boundary, dashed where inferred
- Shelf Edge Structure with Oblique Slip
- Intraplate Transform or Strike-Slip Fault

NOTES

1. Base map from Tarr (1974).
2. After Packer and others (1975), Beikman (1978), Cormier (1975), Reed and Lamphere (1974), Plafker, and others (1978).

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Plate Tectonic Map

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14879	Figure 5-3	

Islands, the relative plate motion is expressed by a complex transition zone of oblique thrust faulting.

The Chakachamna Lake area is located in the region where the interplate motion is producing underthrusting of the Pacific plate beneath the North American plate. This underthrusting results primarily in compressional deformation, which causes folds, high-angle reverse faults, and thrust faults to develop in the overlying crust. The boundary between the plates where underthrusting occurs is a northwestward-dipping megathrust fault or subduction zone. The Aleutian Trench, which marks the surface expression of this subduction zone, is located on the ocean floor approximately 270 miles south of the Chakachamna Lake area. The orientiation of the subduction zone, which may be subdivided into the megathrust and Benioff zone (Woodward-Clyde Consultants, 1981), is inferred at depth to be along a broad inclined band of seismicity that dips northwest from the Aleutian Trench.

The close relationship between the subduction zone and the structures within the overlying crust introduces important implications regarding the effect of the tectonic setting on the Chakachamna Lake Project. The subduction zone represents a source of major earthquakes near the site. Faults in the overlying crust, which may be subsidiary to the subduction zone at depth, are sources of local earthquakes and they may present a potential hazard for surface fault rupture. This is of special concern because the Castle Mountain, Bruin Bay, and several other smaller faults have been mapped near to the Chakachamna Lake Hydroelectric Project area

(Detterman and others, 1976; Magoon and others, 1978). Future activity on these faults may have a more profound affect on the seismic design of the project structures than the underlying subduction zone because of their closer proximity to proposed project site locations.

5.3.2 Historic Seismicity

5.3.2.1 Regional Seismicity

Southern Alaska is one of the most seismicially active regions in the world. A number of great earthquakes (Richter surface wave magnitude Ms 8 or greater) and large earthquakes (greater than MS 7) have been recorded during historic time. These earthquakes have primarily occurred along the interplate boundary between the Pacific and North American plates, from the Alaskan panhandle to Prince William Sound and along the Kenai and Alaska Peninsulas to the Aleutian Islands. Among the recorded earthquakes are three great earthquakes that occurred in September 1899 near Yakutat Bay, with estimated magnitudes Ms of 8.5, 8.4, and 8.1 (Thatcher and Plafker, 1977). Ground deformation was extensive and vertical offsets ranged up to 47 ft. (Tarr and Martin, 1912); these are among the largest known displacements attributable to earthquakes. Large parts of the plate boundary were ruptured by these three earthquakes and by twelve others that occurred between 1897 and 1907; these included a magnitude Ms 8.1 event on 1 October 1900 southwest of Kodiak Island (Tarr and Martin, 1912; McCann and others, 1980) and a nearby magnitude Ms 8.3 earthquake on 2 June 1903, near 57° north latitude, 156° west longitude (Richter, 1958).

A similar series of major earthquakes occurred along the plate boundary between 1938 and 1964. Among these earthquakes were the 1958 Lituya Bay earthquake (Ms 7.7) and the 1972 Sitka earthquake (Ms 7.6), both of which occurred along the Fairweather fault system in southeast Alaska; and the 1964 Prince William Sound earthquake (Ms 8.5), which ruptured the plate boundary over a wide area from Cordova to southwest of Kodiak Island and which produced up to 39 ft. of displacement (Hastie and Savage, 1970). Figure 5-4 shows the aftershock zones of these and other major earthquakes in southern Alaska and the Aleutian Islands. The main earthquakes and aftershocks are inferred to have ruptured the plate boundary in the encircled areas.

Three zones along the plate boundary which have not ruptured in the last 80 years have been identified as "seismic gaps" (Sykes, 1971). These zones are located near Cape Yakataga, in the vicinity of the Shumagin Island, and near the western tip of the Aleutian Chain as shown in Figure 5-4. The Yakataga seismic gap is of particular interest to the project because of its proximity to the site region. The rupture zone of a major earthquake filling this gap has the potential to extend along the subduction zone to the north and northwest of the coastal portion of the gap near Yakataga Bay.

5.3.2.2 Historic Seismicity of the Project Study Area

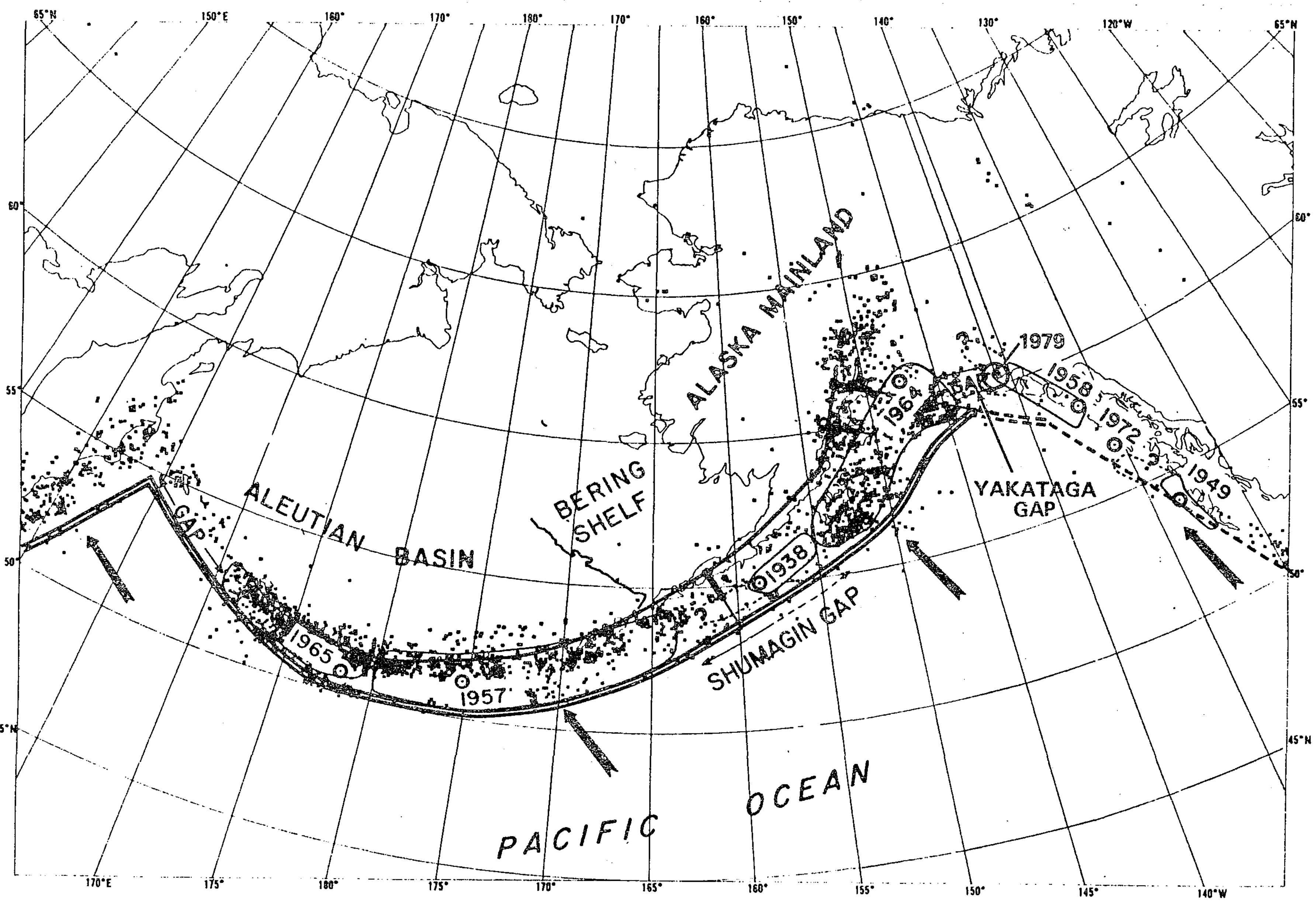
The historic seismicity within 90 miles of the project area, approximately centered on the east end of Chakachamna Lake, is shown in Figures 5-5, 5-6, and 5-7. The earthquake locations are based on the Hypocenter Data

File prepared by NOAA (National Oceanic and Atmospheric Administration, 1981). The Hypocenter Data File includes earthquake data from the U.S. Geological Survey and other sources and represents a fairly uniform data set in terms of quality and completeness since about 1964.

Based on Figures 5-5, 5-6, and 5-7 and data available in the open literature, the seismicity of the project area is primarily associated with four principal sources: the subduction zone, which is divided into two segments--the Megathrust and Benioff zone (Woodward-Clyde Consultants, 1981,; Lahr and Stephen, 1981); the crustal or shallow seismic zone within the North American Plate; and moderate to shallow depth seismicity associated with volcanic activity. The seismic sources are briefly discussed below in terms of their earthquake potential.

The Megathrust zone is a major source of seismic activity that results primarily from the interplate stress accumulation and release along a gently inclined boundary between the Pacific and North American plates. This zone is the source area of many of the large to great earthquakes, include the Ms 8.5 1964 Prince William Sound earthquake, which ruptured along the inclined plate boundary from the eastern Gulf of Alaska to the vicinity of Kodiak Island. The maximum magnitude for an earthquake event along the Megathrust zone is estimated to be Ms 8.5 (Woodward-Clyde Consultants, 1980, 1981).

The Benioff zone portion of the subduction zone is believed to be restricted to the upper part of the descending Pacific plate, which lies beneath the North American plate in southern Alaska. This zone is the source of smaller magnitude and more continuous



LEGEND

- ⊙ 1964 — Location and year of major earthquake; rupture zones including aftershock areas are outlined
- Inferred direction of motion of Pacific plate
- Trench axis
- Approximate transform plate margin

NOTE

1. Modified after Davies and House (1979)

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CHAKACHAMNA HYDROELECTRIC PROJECT

Major Earthquakes and Seismic Gaps in Southern Alaska

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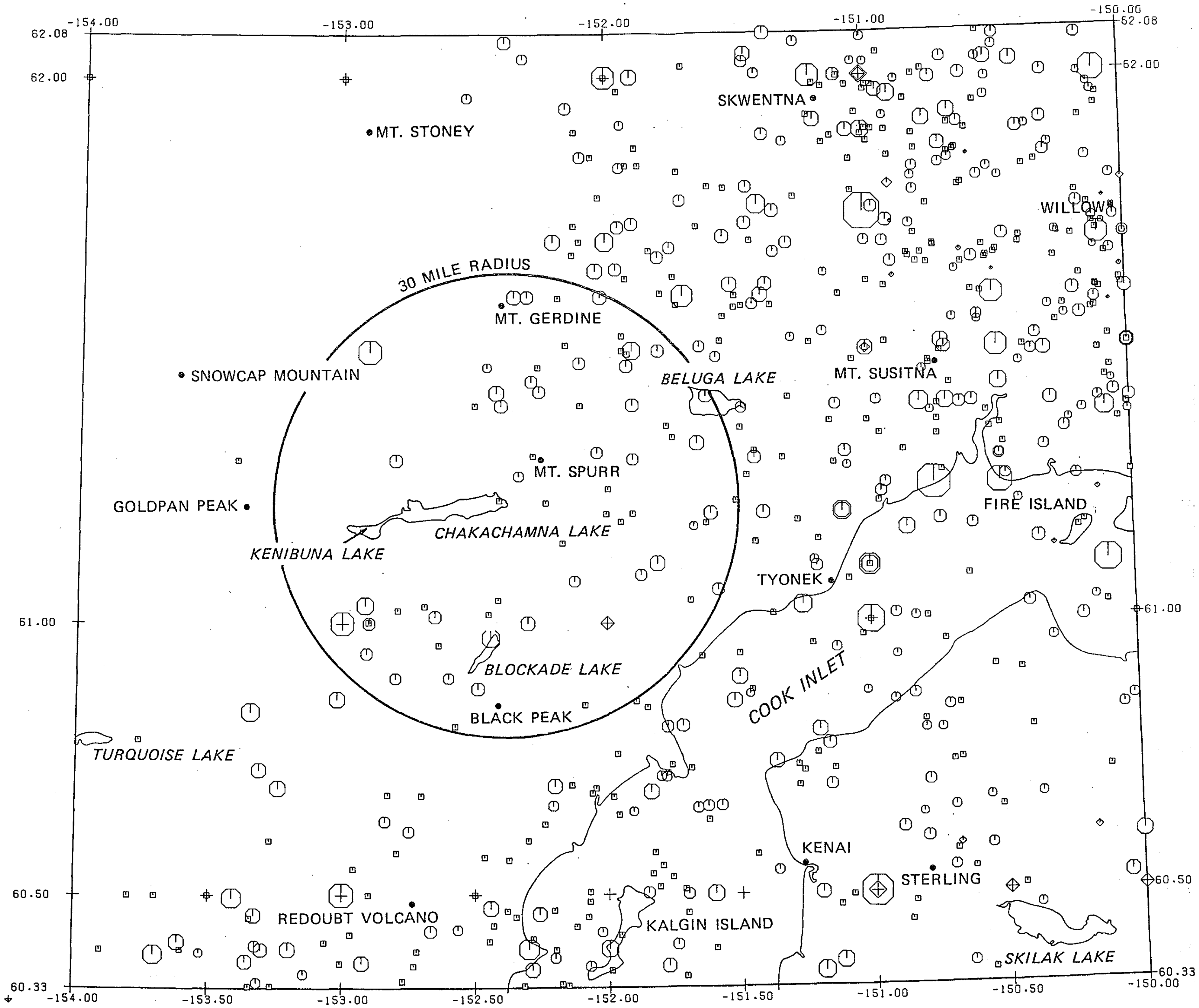

LEGEND

REPORTED MAGNITUDE

8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
No Reported Magnitude

INTENSITY

XII
XI
X
IX
VIII
VII
VI
V

NOTE

1. Magnitude symbol sizes are shown on a continuous nonlinear scale

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CHAKACHAMNA HYDROELECTRIC PROJECT

Historic Earthquakes of All Focal Depths in the Site Region from 1929 Through 1980

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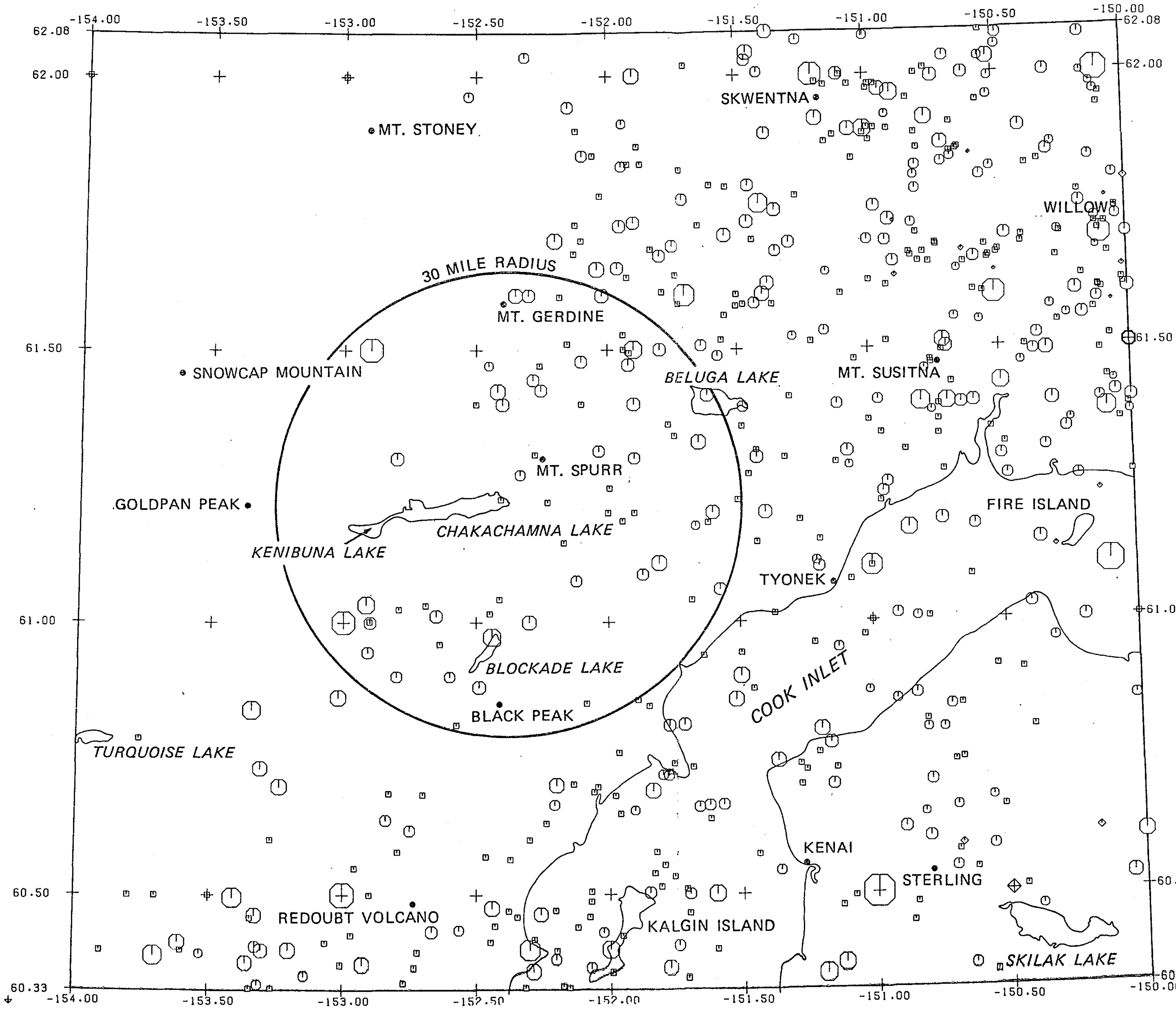

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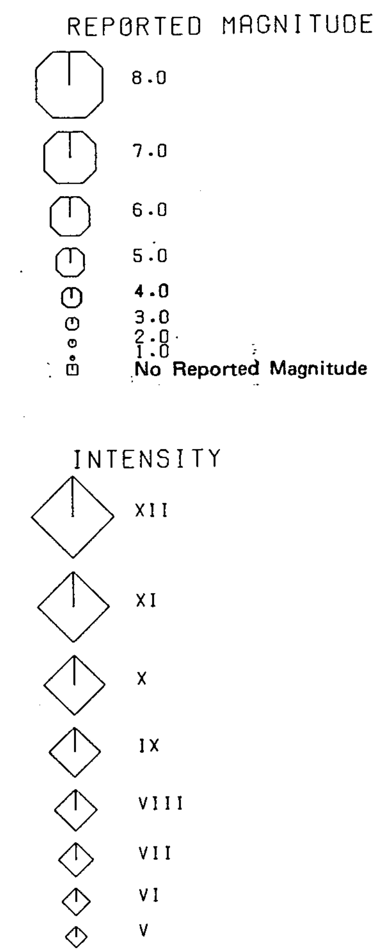

NOTE

1. Magnitude symbol sizes are shown on a continuous nonlinear scale

0 5 10 15 20 Miles

0 5 10 15 20 25 Kilometers

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Historic Earthquakes of Focal Depth Greater Than 20 Miles in the Site Region from 1929 Through 1980

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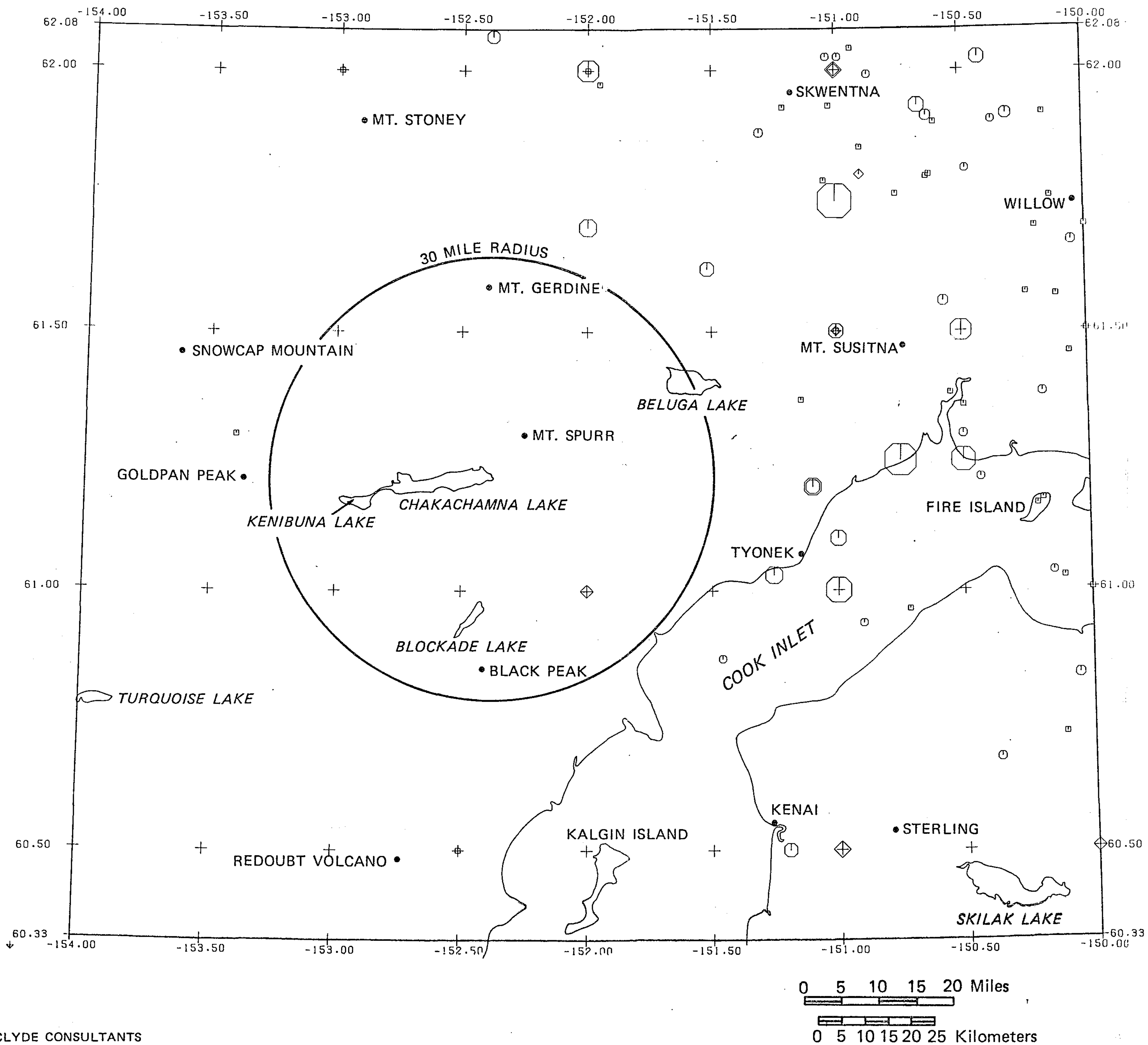

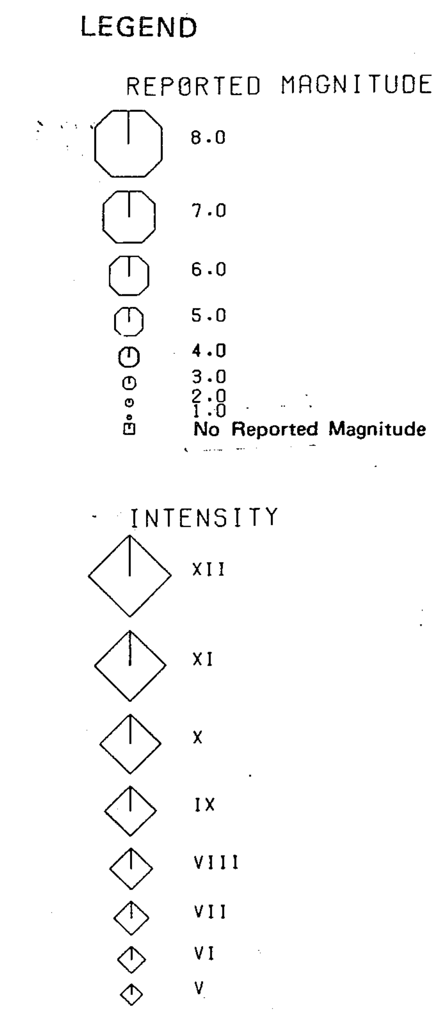

NOTE

1. Magnitude symbol sizes are shown on a continuous nonlinear scale

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Historic Earthquakes of Focal Depth Less Than 20 Miles in the Site Region from 1929 Through 1980

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earthquake activity relative to the Megathrust zone. No earthquakes larger than about Ms 7.5 are known to occur along the Benioff zone and therefore, a maximum magnitude earthquake of Ms 7.5 is estimated for this zone (Woodward-Clyde Consultants, 1981).

The primary source of earthquakes in the crustal or shallow seismic zone is movement along faults or other structures due to the adjustment of stresses in the crust. As shown in Figure 5-7, the historic seismicity of the crustal zone within a large part of the project study area is low. The data base used to compile the historic seismicity of the crustal zone for this study has no recorded earthquakes in the vicinity of Chakachamna Lake.

The majority of the recorded earthquakes shown in Figure 5-7 are located along the eastern and southern margins of the project study area. Most of these events have not been correlated or associated with any known crustal structures, with the possible exception of one event that is associated with the Castle Mountain fault. As discussed in Section 5.3.3.3, the Castle Mountain fault is one of the two major faults present in the project study area. It passes within a mile or less of the proposed project facilities in the McArthur River drainage and within 11 miles of the proposed facilities at Chakachamna Lake. Evidence for displacment of Holocene deposits has been reported in the Susitna lowlands, in the vicinity of the Susitna River (Detterman and others, 1976a). Although a number of recorded earthquakes are located along the trend of the Castle Mountain fault (Figure 5-7), only one event, an Ms 7 earthquake in 1933, has been associated with the fault

(Woodward-Clyde Consultants, 1980b). A maximum magnitude earthquake of Ms 7.5 has been estimated for the Castle Mountain fault (Woodward-Clyde Consultants, 1981).

Further studies are needed to assess the possible association of other historic earthquakes shown in Figure 5-7 with candidate significant features identified in the fault investigation phase of the project study.

Because of the proximity of the project site to active volcanoes of the Aleutian Islands-Alaska Peninsula volcanic chain, including Mt. Spurr which is located immediately northeast of the Chakachamna Lake, volcanic-induced earthquakes are considered a potential seismic source. Active volcanism can produce small-to-moderate magnitude earthquakes at moderate-to-shallow depths due to the movement of magma or local adjustments of the earth's crust.

Occasionally, severe volcanic activity such as phreatic explosions or explosive caldera collapses may be accompanied by significant earthquake events. Because such large volcanic events are rare, there is little data from which to estimate earthquake magnitudes that may be associated with them. However, because of the similarities in characteristics of the Mount St. Helens volcano to those of the Aleutian chain (including Mt. Spurr), it is reasonable to assume that earthquakes associated with the recent Mount St. Helens eruption of May 1980 may also occur during future volcanic activity of Mt. Spurr and others in the Aleutian chain. The largest earthquake associated with the Mount St. Helens explosive eruption that occurred on 18 May 1980 had a magnitude of 5.0. Numerous smaller earthquakes with magnitudes ranging from 3 to 4 were recorded during the period preceding the violent rupture of Mount St. Helens (U.S. Geological Survey, 1980).

As part of a volcanic hazard monitoring program, the U.S. Geological Survey has been operating several seismograph stations in the vicinity of Mt. Spurr to assess its activity. Data acquired by these stations are not presently available but will be released in 1982 as an Open-File Report (Lahr, J. C., personal communication, 1981).

5.3.3 Fault Investigation

5.3.3.1 Approach

The objectives of the Chakachamna Lake Hydroelectric Project seismic geology task are:

(1) to identify and evaluate significant faults within the project study area that may represent a potential surface rupture hazard to project facilities and

(2) to make a preliminary evaluation of the ground motions (ground shaking) to which proposed project facilities may be subjected during earthquakes. In order to meet the specific task objectives and to provide a general assessment of the seismic hazards in the project area, the seismic geology study was designed and conducted in a series of sequential phases (Figure 5-8).

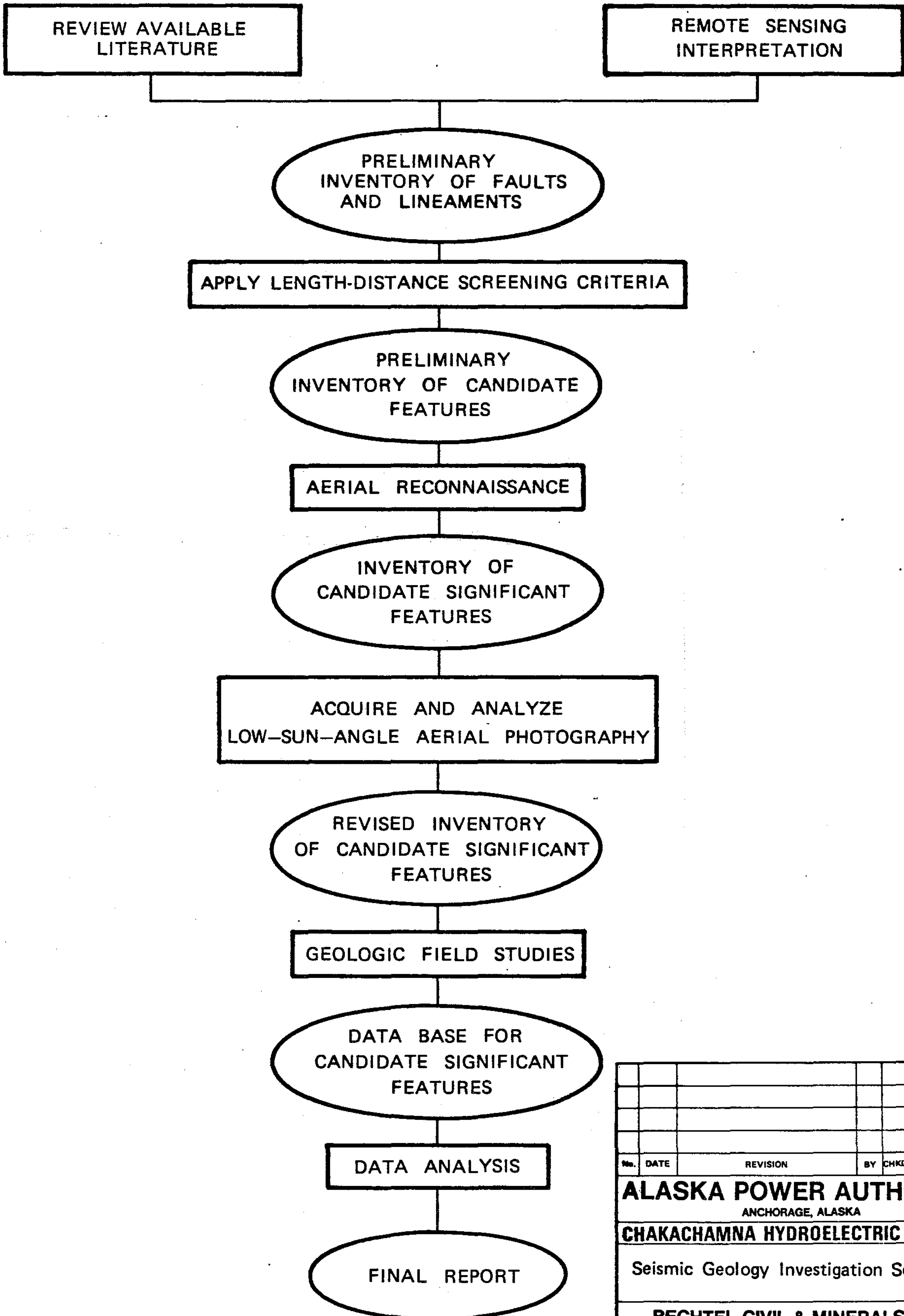
5.3.3.2 Work to Date

The study phases reported here include review of available literature, analysis of remotely sensed data, aerial field reconnaissance, and acquisition of low-sun-angle aerial photographs.

Information of a geologic, geomorphic, and seismologic nature available in the open literature was evaluated to identify previously reported faults and lineaments that may be fault related within the project study area. Geologists presently working in the area or familiar with the study area were also contacted. The locations of all faults and lineaments derived from the literature review and discussions with other geologists were plotted on 1:250,000-scale topographic maps.

Lineaments interpreted to be fault related were also derived from the analysis of high-altitude color-infrared (CIR) aerial photographs (scale 1:60,000) and Landsat imagery (scale 1:250,000) of the study area outlined by the 30-mile diameter circle on Figure 5-9. These lineaments were initially plotted (with brief annotation) on clear mylar overlays attached to the photographs and images on which they were observed. The lineaments were then transferred and plotted on the 1:250,000-scale topographic maps. The faults and lineaments identified from the review of the available literature and interpretation of CIR photographs and landsat imagery comprise a preliminary inventory of faults and lineaments within the study area.

The faults and lineaments in the preliminary inventory were then screened on the basis of a one-third length



No.	DATE	REVISION	BY	CHKD	ENGR SUPV	PROJ ENGR	PROJ MGR

ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

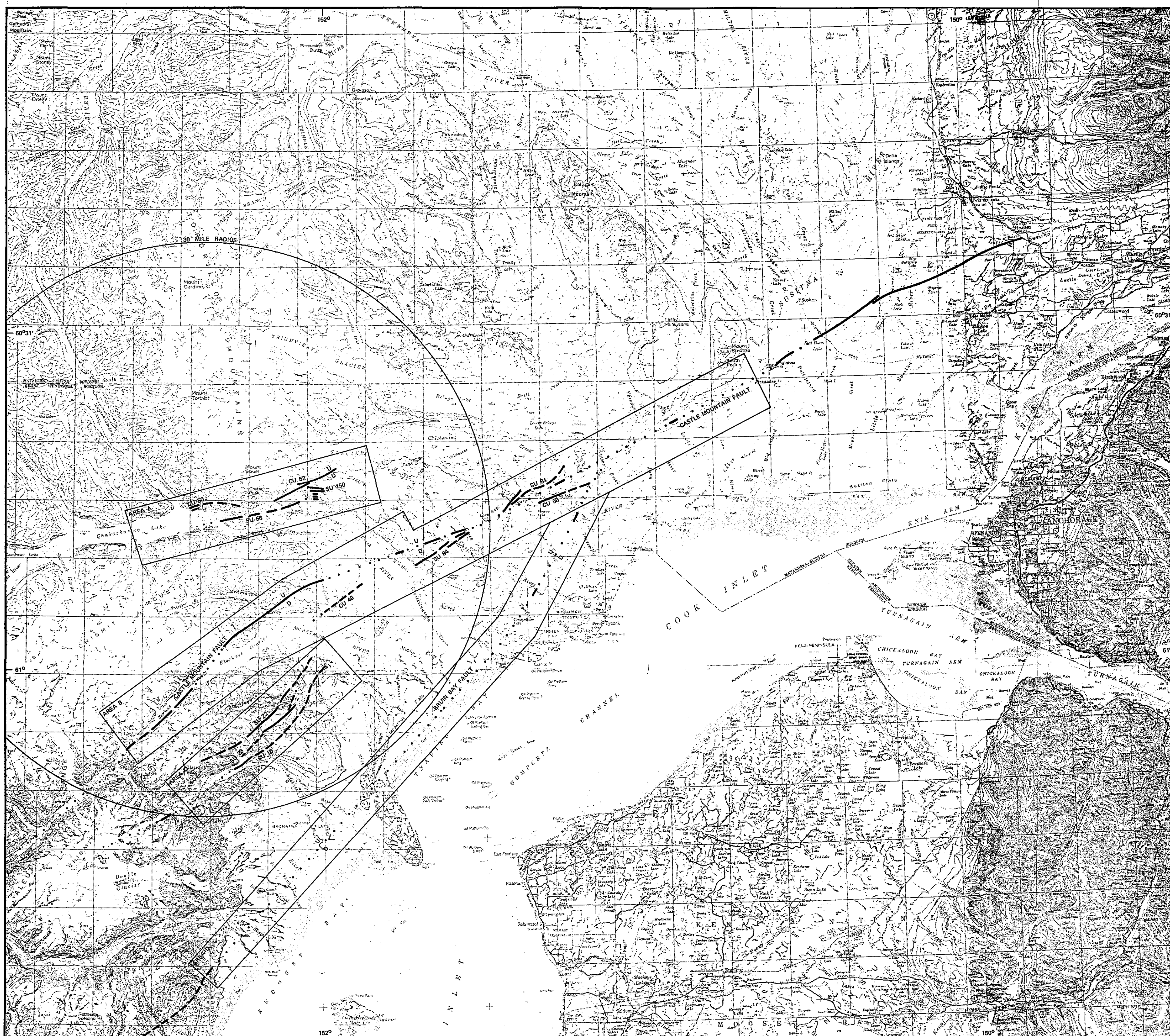
Seismic Geology Investigation Sequence

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	Figure 5-8	

WOODWARD-CLYDE CONSULTANTS



EXPLANATION

— — • ?•	Candidate significant fault or lineament, dashed where approximately located, dotted where concealed, queried where location uncertain or inferred
	Project Study Area. Reconnaissance assessment of surface fault rupture by Woodward-Clyde Consultants during 1981 field season
AREA A	Areas discussed in Section 5.3.3.3

0 5 10 15

SCALE IN MILES

No.	DATE	REVISION	BY	CHKD	ENGR SUPV	PROJ ENGR	PROJ MGR

ALASKA POWER AUTHORITY
ANCHORAGE, ALASKA

CHAKACHAMNA HYDROELECTRIC PROJECT

MAP SHOWING LOCATIONS OF CANDIDATE SIGNIFICANT FEATURES IN THE PROJECT STUDY AREA

BECHTEL CIVIL & MINERALS, INC.
SAN FRANCISCO

DESIGNED	DRAWN	CHECKED
ENGR SUPV	PROJ ENGR	APP'D

JOB No.	DRAWING No.	REV.
14879	Figure 5-9	

length-distance criterion to select those faults and lineaments within the study area that potentially could produce surface rupture at sites proposed for facilities. The length-distance criterion specifies a minimum length for a fault or lineament and a minimum distance from the project site for a fault or lineament to be retained for further study. For example, a fault or lineament that trends toward the project site and has an observed length of 10 miles would be selected for further study if it was less than 30 miles from the project site. A fault or lineament with the same trend and same length, but at a distance of greater than 30 miles from the project site would not be selected for further study.

The one-third length-distance criterion used is based on the empirical data that suggest that fault rupture rarely occurs along the full length of a fault (except for very short faults) during an earthquake (Slemmons, 1977, 1980). The length-distance criterion also takes into account

(1) the possibility of surface rupture within or near to the project site occurring on faults that may be identified only in areas remote from the project site, but which in actuality may extend undetected to the project site, and

(2) the fact that at greater distances from the project site, only longer faults would have the potential of producing rupture at the site.

Regional faults in southern Alaska that are known or inferred to be active but are distant from the project study area were not evaluated for surface rupture potential. These faults, because of their activity, were considered to be potential seismic sources and therefore were evaluated in terms of their potential for causing significant ground motions at the project site.

The faults and lineaments selected for further study on the basis of the length-distance criterion or because they appeared to be potential sources of significant ground shaking were transferred to 1:63,360-scale topographic maps for use during the aerial reconnaissance phase. During the aerial reconnaissance, the faults were examined for evidence (geologic features, and geomorphic expression) that would suggest whether or not youthful activity has occurred. The lineaments were examined to assess:

(1) whether they are or are not faults, and

(2) if they are not faults, what is their origin. For those lineaments that were interpreted to be faults or fault-related, further examination was made to look for evidence that would be suggestive of youthful activity.

After the aerial reconnaissance evaluation of the faults and lineaments, each feature was classified into one of three categories:

(1) a candidate significant feature;

(2) a non-significant feature; or

(3) an indeterminate feature.

Candidate significant features are those that at some point along their length, exhibit geologic morphologic, or vegetational expressions and characteristics that provide a strong suggestion of youthful fault activity. Non-significant features are those, which on the basis of the aerial reconnaissance, apparently do not possess geologic, morphologic, or vegetational characteristics and/or expressions suggestive of youthful fault activity; it was possible to identify non-fault-related origins for many features in this category. Indeterminate features are those lineaments that posses some geologic, morphologic, or vegetational characteristics or expressions that suggest the lineament may be a fault or fault-related feature with the possibility of youthful activity, but for which the evidence is not now compelling.

5.3.3.3 Candidate Significant Features

The candidate significant and indeterminate features identified during the first four phases of this task will require further study in order to evaluate their potential hazard to the proposed project facilities. These features occur in three principal areas, which are designated Areas A, B, and C (Figure 5-9) and are discussed in the following sections. The features presented in each area are discussed in terms of their proximity and orientation with respect to the nearest proposed project facility, previous mapping or published studies in which they have been identified, their expression on CIR photographs, and observations made during the aerial reconnaissance phase of the study.

Area A

Area A is bounded by Mt. Spurr and the Chakachatna River and Chakachamna Lake and Capps Glacier (Figure 5-9). Four candidate significant features, SU 56 and CU 50, CU 52 and SU 150, are located within this area.

Feature CU 50 is a curvilinear fault that trends roughly east-west and extends from the mouth of the Nagishlamina River to Alice Glacier, a distance of about 5 miles. The western end of the feature is approximately 2 miles north of the lake outlet. CU 50 was initially identified on CIR photographs and is characterized by the alignment of:

(1) linear slope breaks and steps on ridges that project southward from Mt. Spurr, east of Barrier Glacier, with

(2) a linear drainage and depression across highly weathered granitic rocks west of Barrier Glacier.

During the aerial reconnaissance, disturbed bedded volcanic flows and tuffs were observed on the sides of canyons where crossed by the feature east of Barrier Glacier. These volcanic rocks are mapped as primarily being of Tertiary age, but locally may be of Quaternary age (Magoon and others, 1976). The possibility of the disturbed volcanic rocks being of Quaternary age suggests that CU 50 may be a youthful fault. The dense vegetation west of Barrier Glacier prohibited close examination of the fault in the granitic terrain.

CU 50 is classified as a candidate significant feature on the basis of its close proximity to proposed project facility sites and because it appears to displace volcanic rocks that may be Quaternary in age.

Feature CU 52 is a composite feature that consists of a fault mapped by Barnes (1966) and prominent morphological features observed on CIR photographs. The feature tends N63°E and extends along the mountain front from Capps Glacier to Crater Peak Glacier, a distance of about 7.5 miles (Figure 5-9). The southwestern end of this feature is approximately 8 miles from the outlet of Chakachamna Lake. Along the northeastern portion of CU 52, from Capps Glacier to Brogan Glacier, the feature is defined by a fault that separates Tertiary granitic rocks from sedimentary rocks of the Tertiary West Foreland formation (Magoon and others, 1976). The southwestern segment, from Brogan Glacier to the Crater Peak Glacier, which extends the mapped fault a distance of 3 miles, was identified on the basis of aligned linear breaks in slope, drainages, and lithologic contrasts. During the field reconnaissance, a displaced volcanic flow was observed at the southwest end of the feature. Over most of its length, the fault was observed to be primarily exposed in bedrock terrain; youthful lateral moraines crossed by the fault did not appear to be affected.

This fault is considered to be a candidate significant feature because of its prominent expression in the Tertiary sedimentary and volcanic rocks crossed by the fault and because of its close proximity to the proposed project facilities. In addition, the fault may extend farther to the west along the mountain front than was observed on the CIR photographs or during the brief reconnaissance. If such is the case, it may connect with feature CU 50.

Feature SU 56 consists of two segments, a fault and a lineament. The combined feature trends N78°E and can be traced from the toe of Barrier Glacier to the edge of the mesa like area between the Chakachatna River and Capps Glacier, a distance of about 11 miles (Figure 5-9). The western extent of the fault segment is unknown, but if the lineament segment, defined by a linear depression across the toe of Barrier Glacier is associated with the fault, it may extend into and along the south side of Chakachamna Lake, very near the proposed lake tap.

SU 56 was recognized on the CIR photographs on the basis of the alignment of morphologic and vegetation features: a linear depression across the piedmont lobe of Barrier Glacier; a narrow linear vegetation alignment across the alluvial fan east of and adjacent to Barrier Glacier; small subtle scarps between Alice and Crater Peak Glaciers; and a prominent scarp and possibly a displaced volcanic flow between Crater Peak and Brogan Glaciers. During the field reconnaissance, all of the characteristics observed on the CIR photographs could be recognized with the exception of the vegetation alignment east of Barrier Glacier. At two locations along the feature, between Alice and Brogan Glaciers, displaced volcanic flows and tuffs were observed. At both localities the sense of displacement was down on the south side relative to the north side. The amount of displacement could not be measured due to the rugged terrain at the two locations. At the eastern end of the fault, near Brogan Glacier, the fault is on trend and appears to connect with one of seven faults observed in ridges along the eastside of Brogan Glacier where Barnes (1966) mapped two prominent bedrock faults.

Feature SU 56 is classified as a candidate significant feature because:

(1) it displaces volcanic rocks that may be of Quaternary age;

(2) the linear depression across the toe of Barrier Glacier is on trend with the fault; and

(3) the westward projection of the feature would pass very close to the proposed project facilities along the south side of Chakachamna Lake.

Feature SU 150 is composed of a series of parallel west-to-northwest-trending faults mapped by Barnes (1966). These faults are located on the Southwest side of the mesa-like area between Brogan and Capps Glacier, approximately 12 miles east of the outlet of Chakachamna Lake (Figure 5-9). These faults are exposed east of Brogan Glacier along a nearly vertical canyon wall that is deeply eroded into Tertiary sedimentary rocks mapped as the West Foreland formation (Magoon and others, 1976).

During the aerial reconnaissance, five additonal faults were observed along the wall of the canyon, south of the two faults mapped by Barnes (1966). Displacement on these faults, as well as on the two mapped by Barnes (1966), appears to be on the order of a few feet to a few tens of feet, with the south side up relative to the north side. An exception to this is the southernmost fault, on which the displacement appears to be relatively up on the north side. During the aerial reconnaissance, the faults could not be traced for any appreciable distance beyond their approximate length of 2 miles mapped by Barnes (1966). The southernmost fault, which is on trend with Feature SU 56, is probably an extension of that feature.

The series of faults associated with Feature SU 150 are included in this report as candidate significant features because of the probable connection of the southernmost fault in the series with Feature SU 56, which consists of morphologic features that are suggestive of youthful fault activity.

Area B

Area B includes the Castle Mountain fault and several parallel lineaments (SU 49, SU 84, and CU 56, Figure 5-9). The Castle Mountain fault is one of the major regional faults in southern Alaska. It trends northeast-southwest and extends from the Copper River basin to the Lake Clark area, a distance of approximately 310 miles (Beikman, 1980). The Castle Mountain fault crosses the mouth of the McArthur River Canyon near Blockade Glacier. The Castle Mountain fault is reported to be an oblique right-lateral fault with the north side up relative to the south side (Grantz, 1966; Detterman and others, 1974, 1976a, b).

The Castle Mountain fault is a prominent feature for most of its mapped length. The segment northeast of the Susitna River is defined by a series of linear scarps and prominent vegetation alignments in the Susitna Lowlands and lithologic contrast in the Talkeetna Mountains (Woodward-Clyde Consultants, 1980; Detterman and others, 1974, 1976a). Between the Susitna and Chakachatna Rivers, the fault is less prominent but is marked by a series of slope breaks, scarps, sag ponds, lithologic contrasts, and locally steeply dipping, sheared sedimentary rocks that are generally flat to gently dipping away from the fault (Schmoll and others, 1981; Barnes, 1966). Southwest of the Chakachatna River, toward the Lake Clark area, the Castle Mountain fault is well defined and expressed by the alignment of slope breaks, saddles, benches, lithologic contrasts between plutonic and sedimentary rocks, shear zones, and a prominent topographic trench through the Alaska-Aleutian Range Batholith (Detterman and others, 1976b).

Displacement on the Castle Mountain fault has been occurring since about the end of Mesozoic time (Grantz, 1966). The maximum amount of vertical displacement is about 1.9 miles or more (Kelley 1963; Grantz, 1966). The maximum amount of right-lateral displacement is estimated by Grantz (1966) to have been several tens of miles along the eastern traces of the fault. Detterman and others (1967 a,b) cited 10 miles as the total amount of right-lateral displacment that has occurred along the eastern portion of the fault and about 3 miles as the maximum amount of right-lateral displacement that has occurred along the western portion, in the Lake Clark area.

Evidence of Holocene displacement has only been observed and documented along a portion of the Castle Mountain fault in the Susitna Lowland (Detterman and others, 1974, 1976a). During their investigation, Detterman and others (1974) found evidence suggesting that 7.5 ft. of dip-slip movement has occurred within the last 225 to 1,700 years. The amount of horizontal displacement related to this event is not known. However, Detterman and others

(1974) cited 23 ft. of apparent right-lateral displacement of a sand ridge crossed by the fault. Bruhn (1979), based on two trench excavations, reported 3.0 to 3.6 ft. of dip-slip displacement, with the north side up relative to the south side, along predominately steeply south-dipping fault traces. He also reported 7.9 ft. of right-lateral displacement of a river terrace near one of the trench locations.

On the CIR photographs, the Castle Mountain fault is readily recognizable on the basis of the alignment of linear morphologic and vegetation features. The most notable features were observed in areas where bedrock is exposed at the surface and include: the prominent slope break that occurs along the southside of Mount Susitna and Lone Ridge; the prominent bench across the end of the Chigmit Mountains, between the McArthur and Chakachatna Rivers; and the alignment of glacial valleys in the Alaska Range, one of which is occupied by Blockade Glacier. In areas covered by glacial deposits, the expression of the Castle Mountain is more subtle and is dominantly an alignment of linear drainages, depressions, elongated mounds, and vegetation contrasts and alignments.

Based on interpretation of the CIR photographs and aerial reconnaissance observations, three lineaments (SU 49 and portions of SU 84 and CU 56) are believed to be traces or splays of the Castle Mountain fault. Lineament SU 49 is approximately 4 miles long, trends northeast, and is on line with the segment of the fault mapped between Lone Ridge and Mount Susitna (Figure 5-9). SU 49 was identified on the basis of the alignment of linear drainages and saddles on a southeast-trending ridge with a vegetation contrast in the Chakachatna River flood plain and by a possible right-lateral affect or the east facing escarpment along the west side of the Chakachatna River.

Lineament SU 84 partially coincides with the mapped trace of the Castle Mountain fault southwest of Lone Ridge. At the Chuitna River, the mapped trace of the Castle Mountain fault bends slightly to the north (Figure 5-9) whereas lineament SU 84 continues in a more southwesterly direction. Features along SU 84 that make it suspect are the alignment of an elongate mound on trend with steeply dipping sedimentary rocks exposed along the banks of the Chuitna River and the eroded reentrant along the high bluff on the northeast side of the Chakachatna River (Nikolai escarpment).

Lineament CU 56 is located east of Lone Ridge; it trends N70°E, is 7 miles long, and is an echelon to the mapped trend of the Castle Mountain fault. CU 56 was identified on the CIR photographs on the basis of the alignment of linear drainages and depressions and vegetation contrasts and alignments. During the aerial reconnaissance, a broad zone of deformed sedimentary rocks was observed on the location where CU 56 crosses the Beluga River. This locality coincides with a zone of steeply dipping sedimentary rocks mapped by Barnes (1966).

Area C

Area C is located south to southeast of the proposed project facilities sites, along the southeastern side of the Chigmit Mountains between the North Fork Big River and McArthur River (Figure 5-9). Three prominent north-east trending parallel features, SU 16, SU 22, and SU 23, are located in this area. SU 16 is an inferred fault that transverses both granitic bedrock and glacial deposits. SU 22 and SU 23 are primarily confined to the granitic bedrock terrain.

Feature SU 16 is the longest of the three northeast-southwest trending features located in ARea C. This feature extends from approximately the intersection of the McArthur and Kustatan Rivers southwestward across a broad bench and along the northeast trending segment of the North Fork Big River, a distance of about 25 miles (Figure 5-9). SU 16 may extend even farther to the west if it follows a very linear glacial valley that is aligned with the northeast trending segment of the North Fork Big River. The northern end of SU 16 approaches to within 10 miles of the proposed project facilities in McArthur River area.

SU 16 was identified on the CIR photographs and aerial reconnaissance on the basis of the alignment of elongate low hills, linear depressions, vegetation contrasts, prominent slope breaks, and a lithologic contrast that form the broad bench like area between the North Fork Big River and Kustatan Rivers. The southwestern segment of the feature is defined by the alignment of a linear portion of the North Fork Big River and a linear glacial valley north of Double Peak. During the aerial reconnaissance, no distinctive evidence, such as displaced lithologic units or bedding or scarps, was observed to confirm that SU 16 is actually a fault. Nonetheless, morphologic features that were observed do suggest that SU 16 is a fault and that it may be a youthful fault.

SU 16 is included in this report as a candidate significant fault because the morphologic features observed on the CIR photographs and during the aerial reconnaissance strongly suggest that it is a fault and may be a youthful fault.

Features SU 22 and SU 23 (Figure 5-9) are both northeast trending linear to curvilinear faults that parallel one another at a distance of about one mile. Feature SU 22 can be traced from about the McArthur River southwestward to Black Peak, a distance of about 16 miles. Feature SU 23 is approximately 8 miles in length and extends from Blacksand Creek southwestward to the north Fork Big River area. The northeastern ends of the two features (SU 22 and SU 23) approach to within 8 miles of proposed project facility sites in the McArthur River area. Both features were recognized on CIR photographs and are defined by the alignment of prominent linear troughs that are partially occupied by small lakes and ponds, scarps, slope breaks, benches, and saddles.

During the aerial reconnaissance, the two features could be readily traced across bedrock terrain (mapped as Jurassic to Cretaceous-Tertiary granitic rock; Magoon and others, 1976) on the basis of their morphologic features. Slicken-sided and polished surfaces were observed at several of the scarps and slope break localities examined; sheared zones were also observed during the reconnaissance. The southwestern portions of both features are located in very rugged terrain and are poorly defined due to the highly jointed granitic rocks that are present along this segment.

At the northern end, in the vicinity of Blacksand Creek, SU 23 appears to splay out with one trace trending toward SU 22 and one trace trending toward SU 16 (Figure 5-9). SU 22 also appears to die out in the vicinity of Blacksand Creek, although there was a subtle tonal alignment observed on the CIR photographs on the north side of the creek that suggests it may extend across Blacksand Creek toward the McArthur River.

SU 22 and SU 23 are included as candidate significant features because their prominent expression suggests that they are major structures and that they may be associated with SU 16 which is considered a fault with possible youthful activity.

Area D

Area D (Figure 5-9) includes the Bruin Bay fault, which is one of the major regional faults in southern Alaska. The Bruin Bay fault is a northeast-trending, moderate-to-steeply-northwest-dipping reverse fault that extends along the northwest side of the Cook Inlet from near Mount Susitna to Bechalaf Lake, a distance of about 320 miles (Detterman and others, 1976b). The fault approaches as close as approximately 30 miles south to southwest of the proposed project facilities at Chakachamna Lake and approximately 20 miles of the project facilities in the McArthur River.

The northern segment of the Bruin Bay fault, from about the Drift River area to Mount Susitna, is projected beneath surficial deposits from its last bedrock exposure north of Katchin Creek. The projection is based on a prominent linear depression across Kustatian Ridge, alignment of linear lakes and depressions in the lowland area west and north of Tyonek, and highly disturbed and faulted Tertiary sedimentary rocks along the Chuitna and Beluga River (Detterman and others, 1976b; Magoon and others, 1976; Schmoll and others, 1981). To the south of Katchin Creek, where the fault is exposed in bedrock areas, the trace of the fault is commonly marked by a zone of crushed rock a few to several hundred meters wide and saddles or notches (Detterman and others, 1976b).

The sense of displacement along the fault is reverse with the north side up relative to the south side (Magoon and others, 1976; Detterman and others, 1976b). Detterman and Hartsock (1966) reported left-lateral displacement of 6 miles or less has occurred along the fault in the Iniskin-Tuxedni region, southwest of the study area. The youngest unit reported displaced by the Bruin Bay fault is the Tertiary sedimentary Beluga formation (Magoon and others, 1976). No displacement of Holocene surficial deposits between Katchin Creek and the probable junction of the fault with Castle Mountain fault near Mt. Susitna has been observed or documented (Detterman and others 1976b; Detterman, personal communication, 1981).

During the analysis of the CIR photographs, several subtle to prominent discontinuous lineaments were identified along the projected trend of the Bruin Bay fault across the McArthur and Chakachatna River flood plains near the Cook Inlet, and along the lowland area west of Tyonek. The lineaments were examined during the aerial reconnaissance and no displacement or disturbed Holocene deposits were observed. Several of the lineaments, however, did coincide with disturbed or faulted sedimentary rocks of the Beluga formation exposed along the Chuitna and Beluga Rivers. Further work is needed to assess whether the glacial and/or fluvial deposits overlying the sedimentary bedrock have been faulted or disturbed.

Although no evidence has been observed or reported that would indicate youthful fault activity along the Bruin Bay fault, several of the lineaments observed on the CIR photographs are suggestive of youthful fault activity. On the basis of the lineaments along the projected trace of the Bruin Bay fault, and the fact that the fault is suspected to intersect with the Castle Mountain fault, the Bruin Bay fault is considered for this report to be a candidate significant feature.

5.3.3.4 Implications with Respect to the Proposed Hydroelectric Project

Based on the results of the work to date a preliminary assessment can be made regarding the potential surface faulting hazards and seismic sources of ground motion (shaking) with respect to the proposed project site.

(1) Within the study area, faults and lineaments in four areas have been identified for further evaluation in order to assess and better understand their potential effect on project considerations. For example, if feature SU 56 is an active fault, its trend is toward the area proposed for the lake tap and the extent and activity of this feature clearly require evaluation. Several of these features may prove to be capable of producing earthquakes, thus both ground shaking and surface rupture in the project area.

(2) The Castle Mountain fault is located along the southeast side of the Chigmit Mountains at the mouth of McArthur Canyon. Although no displacements of Holocene deposits have been observed or reported for the segment of the Castle Mountain fault between the Susitna River and the Lake Clark area, the fault is considered an active fault on the basis of the reported displacement of Holocene deposits east of the project area in the vicinity of the Susitna River.

(3) Based on a review of the available literature and detailed studies conducted for major projects in southern Alaska there are three potential seismic sources that may have an effect on the project site. These include: the subduction zone, which consists of the Megathrust and Benioff zone; crustal seismic zone; and severe volcanic activity. The Castle Mountain fault (crustal seismic source) and the Megathrust segment of the subduction zone are expected to be the most critical to the project with respect to levels of peak ground acceleration, duration of strong shaking, and development of response spectra. (see Section 7.4).

5.4 References

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