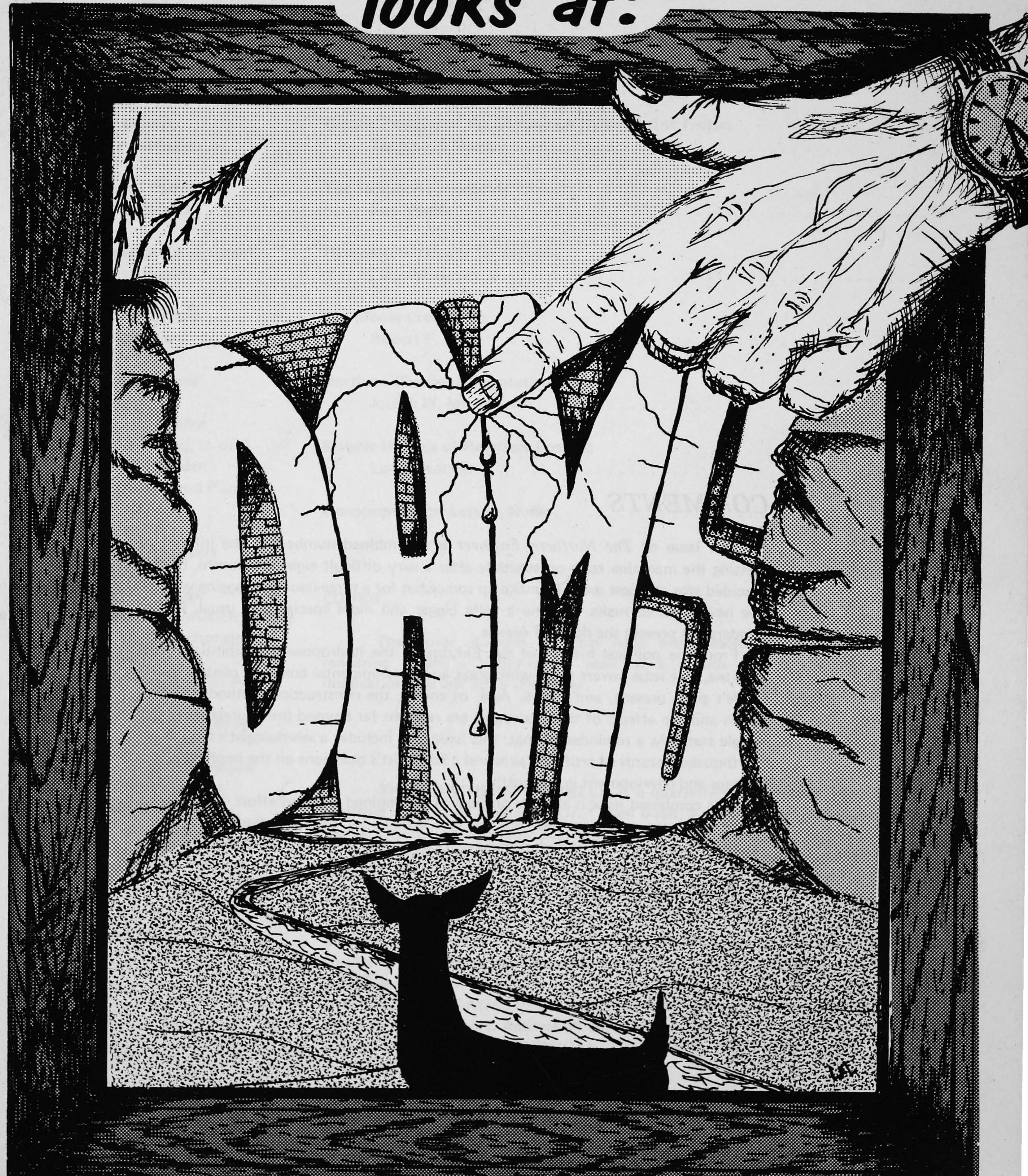
THE NORTHERN ENGINEER looks at:



VOLUME 8, NUMBER 3 and 4

FALL AND WINTER 1976

COMMENTS

This issue of *The Northern Engineer* is a combined number. In the interest of getting the magazine back on schedule after a very difficult eighteen months, this we decided was the best way. To make up somewhat for a three-issue and lagging volume, we have tried to make this one a little bigger and more special than usual. Patient readers, we present the dams of Alaska.

From the political history of the Eklutna to the hydropower possibilities of the Susitna, this issue covers geographic areas and developmental concerns central to this state's past, present, and future. And, of course, the construction methods used for dams and the effects of their existence are relevant far beyond the boundaries of any single state. As a reminder of that, this issue also includes a seismologist's look at the earthquake hazards of artificial lakes and a humanist's questions on the implications of change and development in the north.

This combined issue is also the product of a combined editorial effort. Gina Brown-Wickwar began soliciting and selecting the articles for this long-planned endeavor; Judith Holland continued that process and completed almost all the editing as well; I was charged with seeing that their efforts reached you. So it is on behalf of my skilled predecessors as well as the present staff that I hope you find Vol. 8, No. 3 and 4, worth the wait.

Carla Helfferich, Editor

THE NORTHERN ENGINEER

Volume 8, Number 3 and 4

Fall and Winter 1976

TABLE OF CONTENTS

COVER

The cover drawing for this issue was created by Lee Leonard whose rendering offers a light-hearted look at a serious subject. Further allegorical implications are left up to the reader.

THE NORTHERN ENGINEER is a quarterly publication of the Geophysical Institute, University of Alaska - Dr. T. Neil Davis, Acting Director. It focuses on engineering practice and technological developments in cold regions, but in the broadest sense. We will consider articles stemming from the physical, biological and behavioral sciences, also views and comments having a social or political thrust, so long as the viewpoint relates to technical problems of northern habitation, commerce, development or the environment. Contributions from other polar nations are welcome. We are pleased to include book reviews on appropriate subjects, and announcements of forthcoming meetings of interest to northern communities. "Letters to the Editor" will be published if of general interest; these should not exceed 300 words. Subscription rates for *THE NORTHERN ENGINEER* are $10 for one year, $15 for two years, and $35 for five years. Address all correspondence to THE EDITOR, THE NORTHERN ENGINEER, GEOPHYSICAL INSTITUTE, UNIVERSITY OF ALASKA, FAIRBANKS, ALASKA 99701, U.S.A.

The Snettisham project area. Speel Arm is in the upper left background, and ice-covered Long Lake lies in the lower right foreground.

by Thomas E. Munsey

UNIQUE FEATURES OF THE SNETTISHAM HYDROELECTRIC PROJECT

Modern hydropower development is multipurpose, involving flood control, irrigation, recreation, wildlife management, and a possible host of other concerns. But the Snettisham Project has a sole purpose--generating electric power. The scant population of southeastern Alaska does not require more than this seemingly old-fashioned approach provides. Yet within this single-purpose isolated load power project are contained some of the most advanced design features that required some of the most advanced construction techniques known in the world today. This paper concentrates on three of these unique features: the initial water diversion by lake piercing, the unlined power tunnel, and the underground power station.

GENERAL PROJECT DESCRIPTION

Snettisham is a single-purpose, two-stage hydroelectric project designed to use water from Long and Crater Lakes, perched high above the Speel Arm fjord 28 air miles southeast of Juneau. The latitude is approximately that of Stockholm, but the area is unpopulated and rugged, with some 140 inches of precipitation per year. The only roads are those constructed at the project site.

Ultimate capacity of the three-unit sea level underground power plant will be 74,000 KW. The two first-stage units (23,350 KW each) are powered with water from Long Lake, carried through 8,200 feet of tunnel and 1,700 feet of penstock (Fig. 1). Power is carried to a

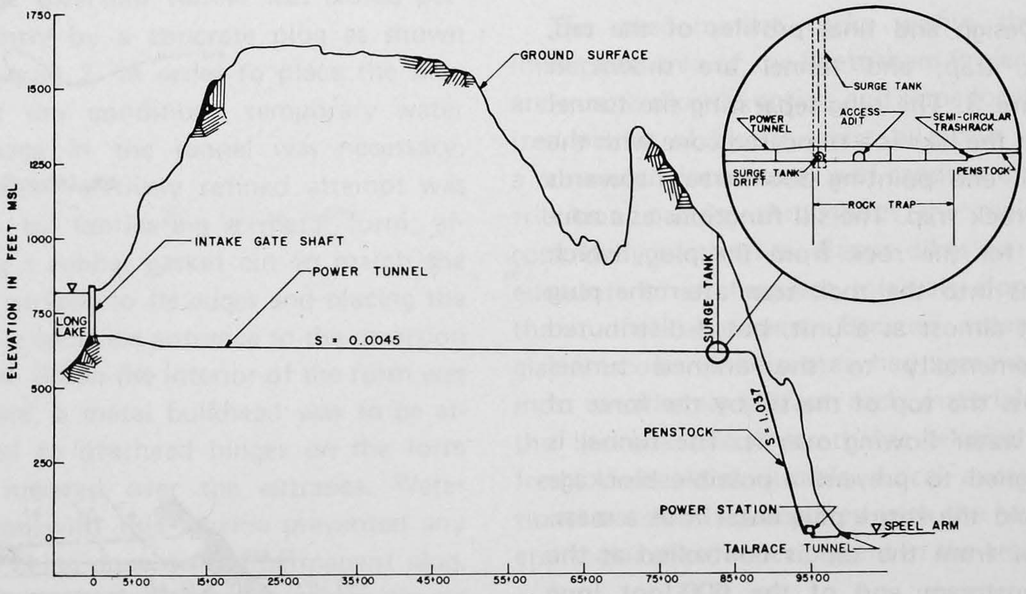


FIGURE 1 – PROFILE OF WATER CONVEYANCE SYSTEM
LONG LAKE TO POWERHOUSE

substation just south of Juneau through 41.6 miles of overhead line energized at 138 KV and 15,400 feet of underwater cable.

DIVERSION PLAN

Long Lake is typical of glacially-formed lakes in Alaska. Its natural water surface is at elevation 815, and the lowest observed lake bottom elevation is 280. Its drainage area is 30.2 square miles, and total storage is 340,000 acre-feet. The Alaska District of the U. S. Army Corps of Engineers wished to use as much of this natural storage as possible, and underwater piercing--sometimes known as the Norwegian Lake Tapping Method--was chosen as the most feasible means of accomplishing this.[1] The process consisted of driving a tunnel lakewards leaving a small rock plug to separate the tunnel and lake. After careful exploration and preparation, the entire plug was blasted through to drain the lake through the tunnel. When the lake water surface dropped to elevation 675 at Snettisham, a power tunnel intake with an entrance invert elevation of 684 was constructed. At the end of construction, a concrete plug was installed to stop flow through the 12-foot diversion tunnel permanently. A general plan of the diversion area is shown in Figure 2.

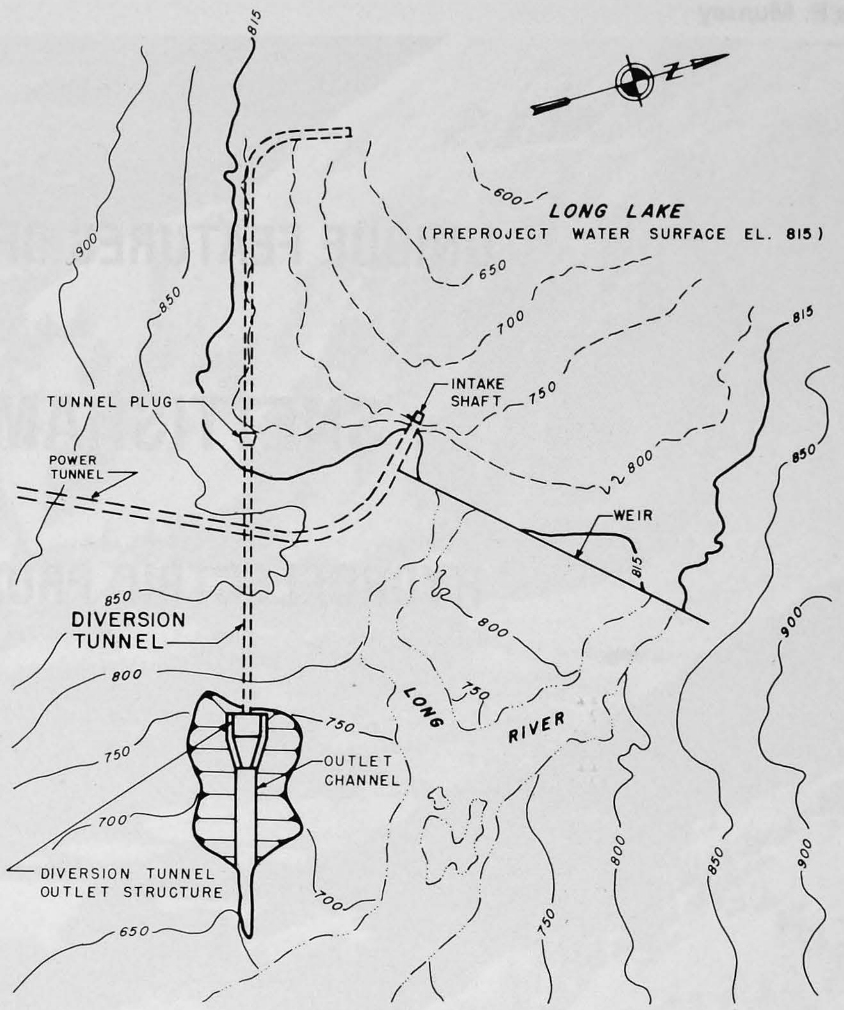


FIGURE 2 – GENERAL PLAN

TAP DESIGN

Design and final profiles of the tap, rock trap, and tunnel are shown in Figure 3. The plug separating the tunnel from the lake is a truncated cone with the small end pointing downstream towards the rock trap. The sill functions as a control for the rock from the plug, which slides into the rock trap after the plug blast almost as a unit, but is distributed incrementally to the unlined tunnel across the top of the sill by the force of the water flowing over it. The tunnel is designed to prevent a possible blockage should the entire plug enter it as a mass. Flow from the tap is controlled at the downstream end of the 600-foot long tunnel by a 12.5- by 6.5-foot slide gate located in a control house structure keyed into the rock and post-tensioned with six vertical tendons at 130 kips each

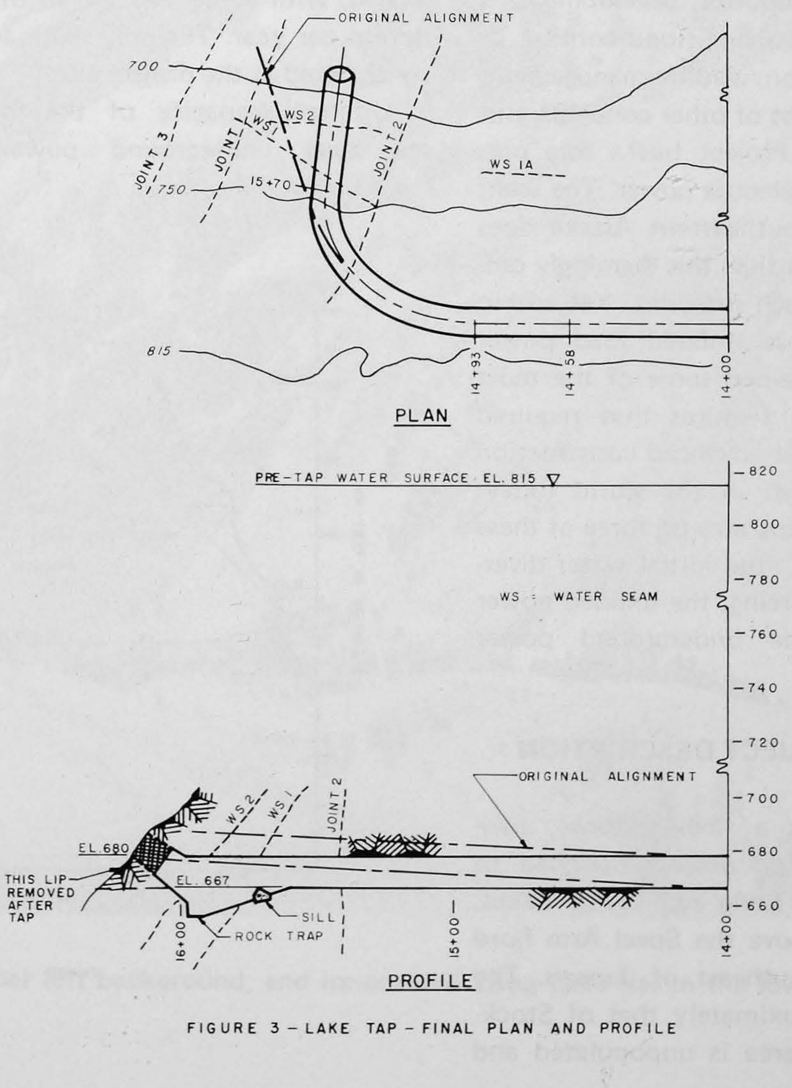


FIGURE 3 – LAKE TAP – FINAL PLAN AND PROFILE

and eight horizontal tendons at 470 kips each. A 35-foot lined transition from the circular tunnel section to the rectangular gate section is located in the tunnel just upstream of the control house. Four piezometer taps located at the upstream end of the concrete-lined transition furnish water pressure readings to gauges located in the control structure.[2,3]

DIVERSION CONSTRUCTION

Before tunnel excavation began two holes were drilled from a barge in the area of the design piercing point. Excellent rock was found and excavation of the tunnel was begun on the original contract drawing alignment shown in Figure 3. But as driving proceeded, several changes were made in the tunnel layout. The most important were:

1. A decrease in the slope of the tunnel upstream of the tunnel plug--this change lowered the rock trap elevation and placed the tap excavation upstream of the trap nearly normal to the rock surface (see profile, Figure 3).
2. A change in the horizontal alignment of a portion of the tunnel to avoid two joints discovered during an underwater investigation of the tap area (see plan, Figure 3).

After the tunnel was excavated, the concrete sill was placed, the gate installed and tested, and in July 1969 the holes for the final tap were drilled.[3] Water was encountered in only one hole during loading and that hole was loaded with an aluminum sleeve around the charge. The final blast was made on July 16.

About 18 seconds after the blast, the first water reached the gate. The gate stayed open for 11 minutes. An estimated 3,800 c.f.s. (cubic feet per second) maximum flow passed through the tunnel with the gate fully opened.

About 90 seconds after the blast a single air bubble, 6 to 10 feet in diameter, was noted on the surface of the lake. Three minutes after the shot a second lake disturbance occurred, consisting of scattered and intermittent bubbles 125 to 150 feet away from the first bubble.

Inspection of the tap after the blast by divers with an underwater TV camera showed that the hole was satisfactory. There were no rocks in the rock trap and no large boulders were in a position to fall or shift position and block the tunnel. On July 24, the gate was opened up to the point where the water velocity in the tunnel was 20 f.p.s. As the lake dropped, the gate was opened wider to maintain this velocity, which corresponds to an outflow of 2,300 c.f.s. A vortex was observed on the lake above the tap inlet during all stages of drawdown. (Note that the maximum depth of water above intake invert was 135 feet.) The vortex formation was intermittent at higher stages but was more or less constant below lake elevation 720. By 28 October 1969 the lake was down to elevation 683.5. This subsequently proved to be a typical winter low lake level, and the water surface dropped no lower until the steep intake portion of the diversion entrance was leveled off prior to closure.

DIVERSION OPERATION AND CLOSURE

After minimum lake elevation was reached and the upper portion of the tap hole inspected, the gate was closed for the winter. During subsequent winters the gate was left fully open. There were no problems with ice blocking the tunnel.

To lower the lake water surface further and enable construction of the intake tower, the steep (intake) portion of the diversion tunnel upstream of the rock trap was lowered to elevation 667, the same as the tunnel control sill (see Figure 3).

The diversion tunnel was closed permanently by a concrete plug as shown on Figure 2. In order to place the plug under dry conditions, temporary water stoppage in the tunnel was necessary. The first relatively refined attempt was made by fabricating a metal form, affixing a rubber gasket cut to match the rock surface to its edges and placing the form around the entrance to the diversion tunnel. When the interior of the form was grouted, a metal bulkhead was to be attached to overhead hinges on the form and lowered over the entrance. Water leakage with this scheme prevented any work being done on the permanent plug. The second closure attempt was simple and successful. The gate was shut, the entrance sandbagged to 5 feet above the existing lake surface, and the gate reopened. Low inflow during this period (November) led to a very slow rise in lake surface. With flow temporarily stopped in the tunnel, the permanent concrete plug was placed under dry conditions, and the lake rose without mishap to its pre-tap elevation.

GENERAL POWER TUNNEL DESCRIPTION

The power tunnel from intake to surge tank is 8,240 feet long; 7,170 feet of that length is unlined. Typical lined and unlined sections are shown on Figure 4. Emergency closure facilities at the intake shaft consist of a 12.5-foot by 6.5-foot slide gate for closure against differential head and a 13.14-foot by 6.5-foot bulkhead for closure under zero flow conditions. A 17-foot diameter restricted orifice surge tank is offset from the power tunnel at the upstream end of the rock trap.[4] The 205-foot rock trap is located at the upstream end of the penstock and consists of:

1. An enlargement of the tunnel section as an 18-foot horseshoe to provide a low velocity reach to capture suspended or saltating particles;
2. A vertical rock face at the downstream end of the trap plus a half circle trash rack over the lower half of the penstock entrance. An access adit for construction and maintenance is also located in the rock trap downstream of the surge tank.

TUNNEL GEOLOGY

The predominant rocks within the immediate area of the Snettisham Project are quartz diorite, gneiss, and some localized phases of biotite schist; all occur in a somewhat interwoven and random distribution pattern throughout the main rock body at the site. Basalt dikes were encountered at frequent intervals along the tunnel alignment. Because recent glacial scour in this area had removed most weathered surface rock materials, the bedrock encountered was relatively fresh, dense, and durable. Local exceptions are chiefly associated with the several major shear zones present in the area.

POWER TUNNEL DESIGN

Energy losses due to rock surface roughness were computed using the

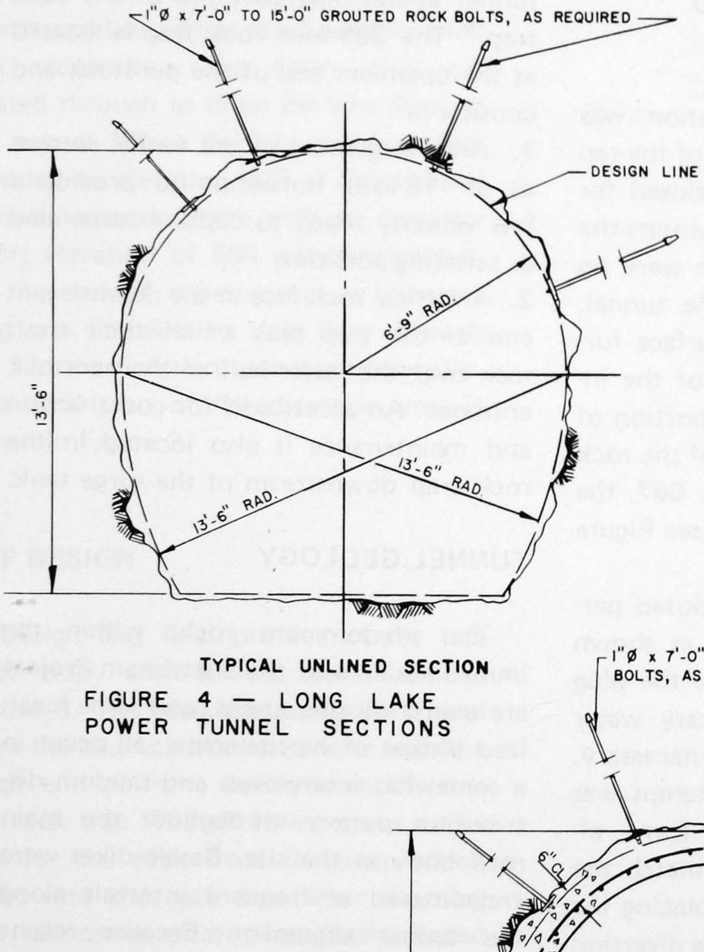
D'Arcy friction factor "f"

$$\left[\text{head loss} = f\ \frac{\text{length}}{\text{equivalent diameter}}\ \frac{(\text{velocity})^2}{2g}\right]$$

as determined from the von Karman-Prantl equation for turbulent flow in rough pipes:

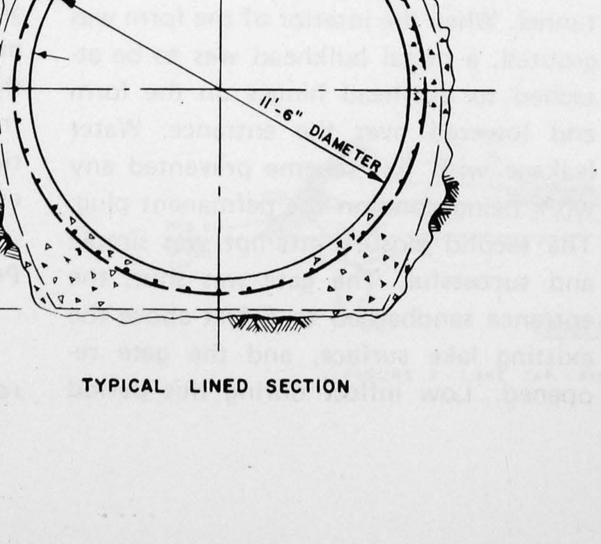
$$\frac{1}{\sqrt{f}} = 2 \log \frac{D_{\text{eqv.}}}{2k} + 1.74$$

An expected absolute roughness height of 6 inches (k) was used for design. Other energy losses were tabulated. The most economic tunnel size was obtained by maximizing the difference between the value of energy head gained by enlarging the tunnel and the cost of enlarging the tunnel to obtain this head increase. The resulting modified double radius horse-shoe section is shown in Figure 4. The perimeter defined by the 13.5-foot arcs represents the clear area inside which no rock can protrude. The actual design area is considered to be 3 inches outside this perimeter and represents half of the expected 6-inch roughness height.



TYPICAL UNLINED SECTION

FIGURE 4 — LONG LAKE POWER TUNNEL SECTIONS



TYPICAL LINED SECTION

POWER TUNNEL CONSTRUCTION

The power tunnel was driven upstream from the access adit. The full face of the tunnel was shot with the average pull length being about 10 feet. Tunnel lining is limited to a 278-foot section across the Glacier Creek Fault and three smaller faults requiring 68 feet of lining each. Approximately 470 feet of additional tunnel lengths involving lesser faults and high angle joints were treated with rock bolts, mine ties, or shot crete, depending on the particular section. The intake section was lined for 470 feet to limit hydraulic pressures on the rock where cover depths were insufficient. Approximately 87 percent of the power tunnel was completed without lining and 83 percent of the tunnel was without additional support of any kind. Less water than anticipated was encountered, with the largest inflow being 40 to 50 g.p.m. at approximate Station 79+00. The tunnel and penstock were filled to lake head in December 1972.

An estimate of the value of "f" was made using 350 tunnel cross sections taken at 20-foot intervals along the unlined portion and the statistical method developed by Dr. Lennart Rahm.[5] The areas are plotted on a normal distribution logarithmic diagram. The resulting curve is approximated by a straight line and the slope of the line is designated as δ. Based on hydraulic studies by Dr. Rahm of existing unlined tunnels:

$$f = 2.75 \times 10^{-3}\ \delta.$$

For Snettisham, the prototype "f" from the Rahm theory is 0.1094. The design "f" used was 0.06155; however, since average excavated area was so much greater than expected design area, the energy losses for design and construction are nearly equal. If the roughness height is computed from the value of "f" obtained from the Rahm theory and used to determine an average "constructed" clear tunnel area, the same value as the original design assumption for clear tunnel cross sectional area is obtained (Fig. 5).

GENERAL POWERHOUSE

The powerhouse is the first underground type to be designed and constructed by the Corps of Engineers. This method was chosen over an above-ground installation because: (a) it is more economical, (b) construction could be carried on year round, and (c) the environmental impact is minimal.

Two 23,350 KW generating units now utilize water from the Long Lake power tunnel; a third may be installed for the planned future tap of Crater Lake so that ultimate capacity would be 74,000 KW. The turbines for generating

SNETTISHAM (LONG LAKE) POWER TUNNEL

Hydraulic Data

Item	As Designed		As Constructed	
	Clear	Expected Average	Computed Clear	Measured Average
Area in Sq. Ft.	155.75	160.94	156.95	199.30
Wetted Perimeter in Ft.	45.22	46.06	45.54	53.01
Hydraulic Radius in Ft.	3.444	3.494	3.446	3.760
Equivalent Diameter in Ft. (= 4 x Hydraulic Radius)	13.776	13.976	13.784	15.039

Item	Max.	Expected	Min.	Computed from Rahm's Value of "f"
k in In. (Absolute Roughness)	12	6	3	20.59

Item	Expected	Computed from Rahm Method
f (D'Arcy-Weisbach)	0.06155	0.1094
n (Mannings)	0.0283	0.0382
Head Loss in Ft. per Ft. of Tunnel Length for 1,000 c.f.s.	0.002640	0.028436
Length of Unlined Tunnel in Ft.	7,200	7,170 (6,940 tunnel +230 expanded car pass sec)

Energy Loss in Ft. for Entire Tunnel from Intake to Surge Tank for 1,000 c.f.s. In parentheses, is the loss coefficient in terms of K, as used in the formula:*

$$\text{Head Loss} = \frac{Kx(\text{unlined tunnel velocity})^2}{2g}$$

Unlined Tunnel	19.07 (31.8)	19.68 (50.34) tunnel 0.29 (0.74) car passes
Lined Tunnel	2.34 (3.89)	1.56 (4.00)
Abrupt Contractions	0.80 (1.34)	.56 (1.42)
Abrupt Expansions	2.42 (4.03)	1.78 (4.59)
Trashrack, Entrance and Misc. Losses	1.06 (1.77)	1.06 (2.72)
Unlined Tunnel Velocity Head in Ft. for 1,000 c.f.s.	0.600	0.391
Total Loss for 1,000 c.f.s.	25.69 (42.83)	24.93 (63.81)

*Velocity in expected average tunnel area for design and in measured average tunnel area for construction.

Figure 5. Tabular comparison of design assumptions and construction results.

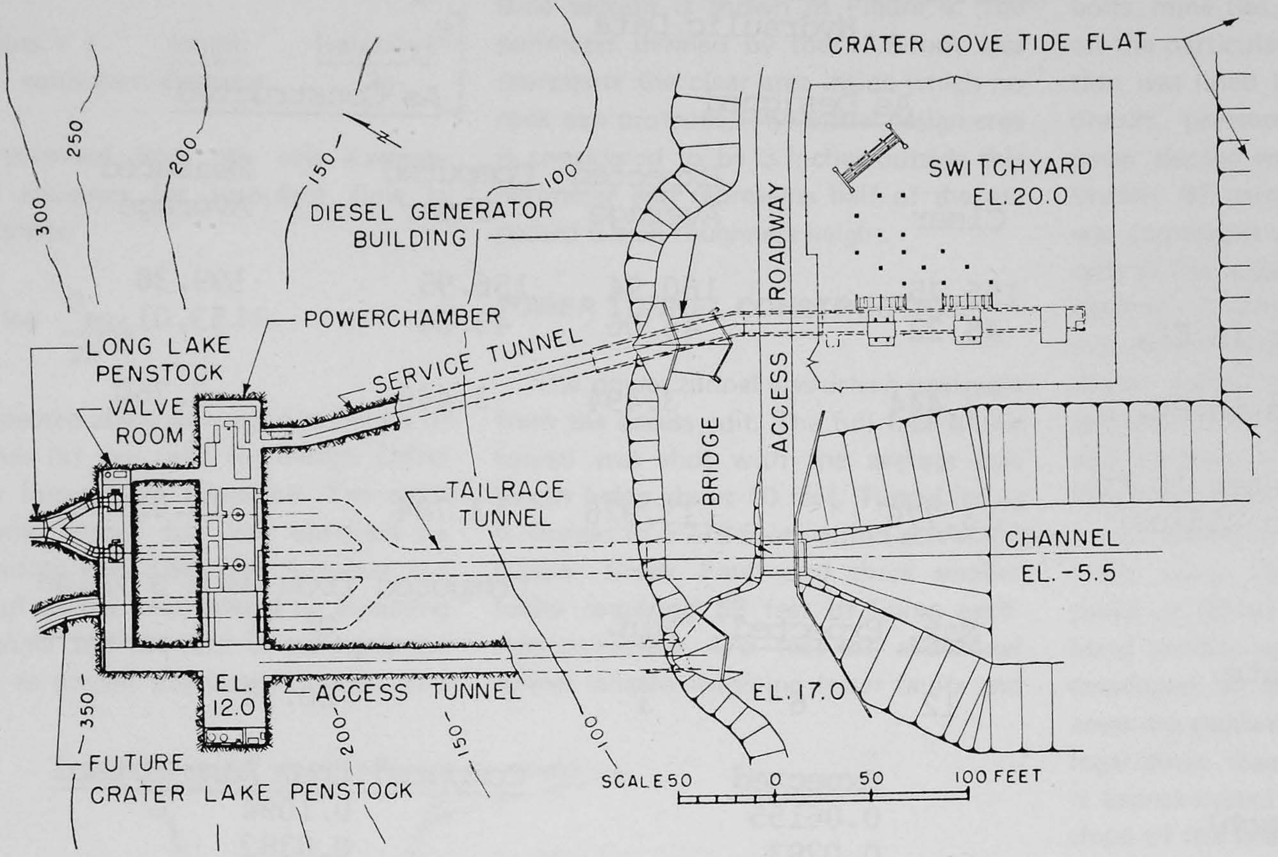


FIGURE 6 - GENERAL LAYOUT OF POWERHOUSE AND SWITCHYARD AREA

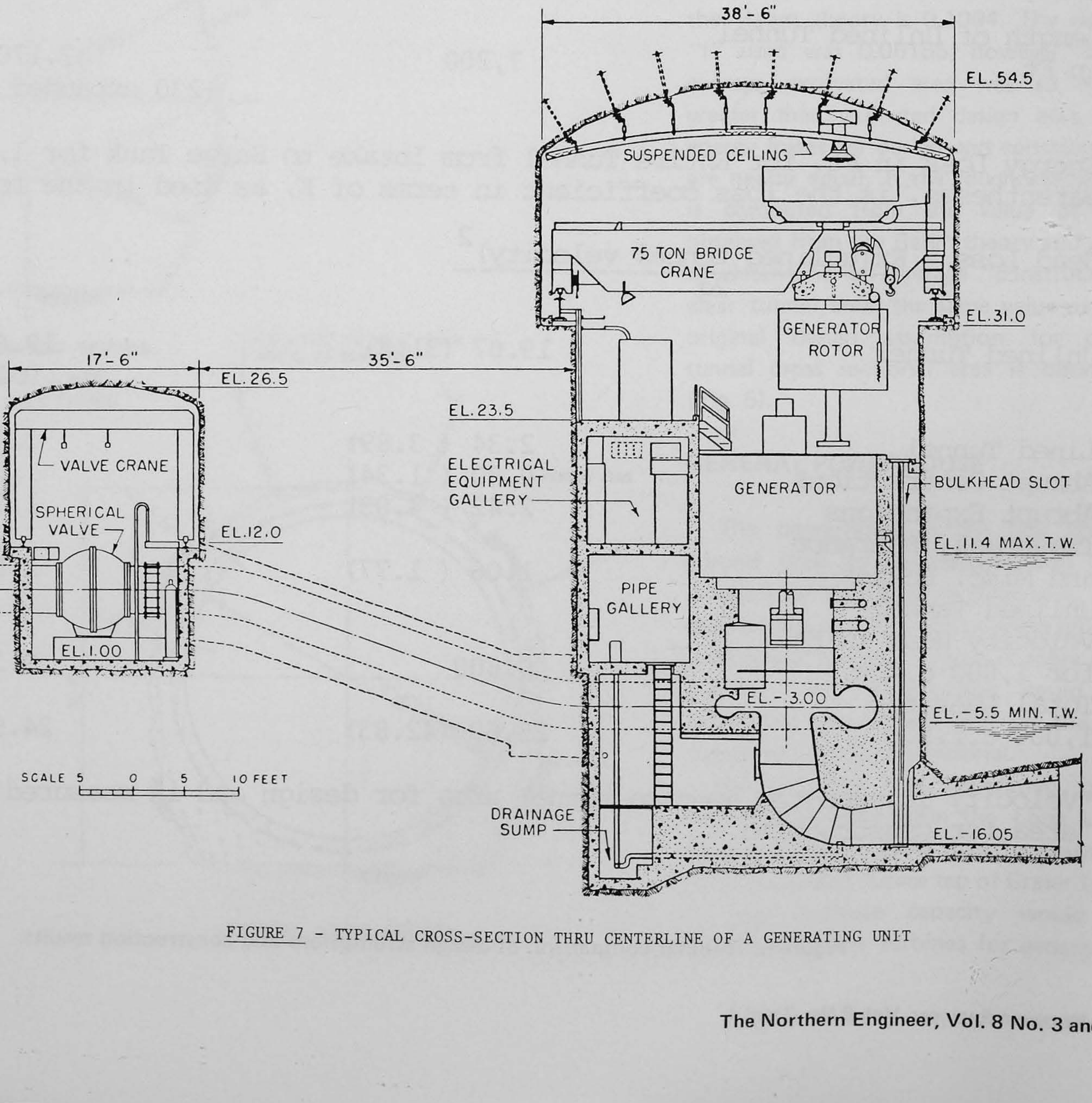


FIGURE 7 - TYPICAL CROSS-SECTION THRU CENTERLINE OF A GENERATING UNIT

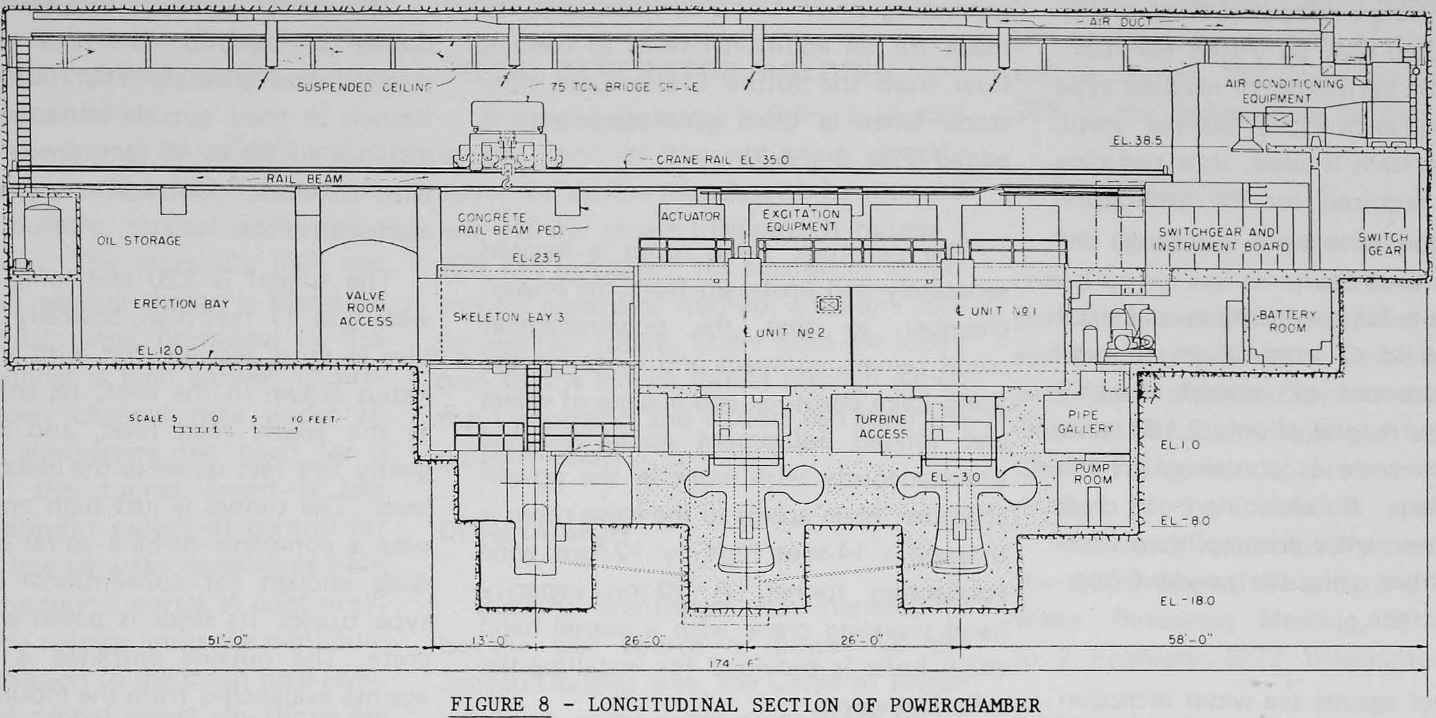


FIGURE 8 - LONGITUDINAL SECTION OF POWERCHAMBER

units 1 and 2 are Francis type, rated at 32,300 horsepower, and operate under a gross head of from 704 to 820 feet. The general layout of the powerhouse and switchyard area is shown in Figure 6.

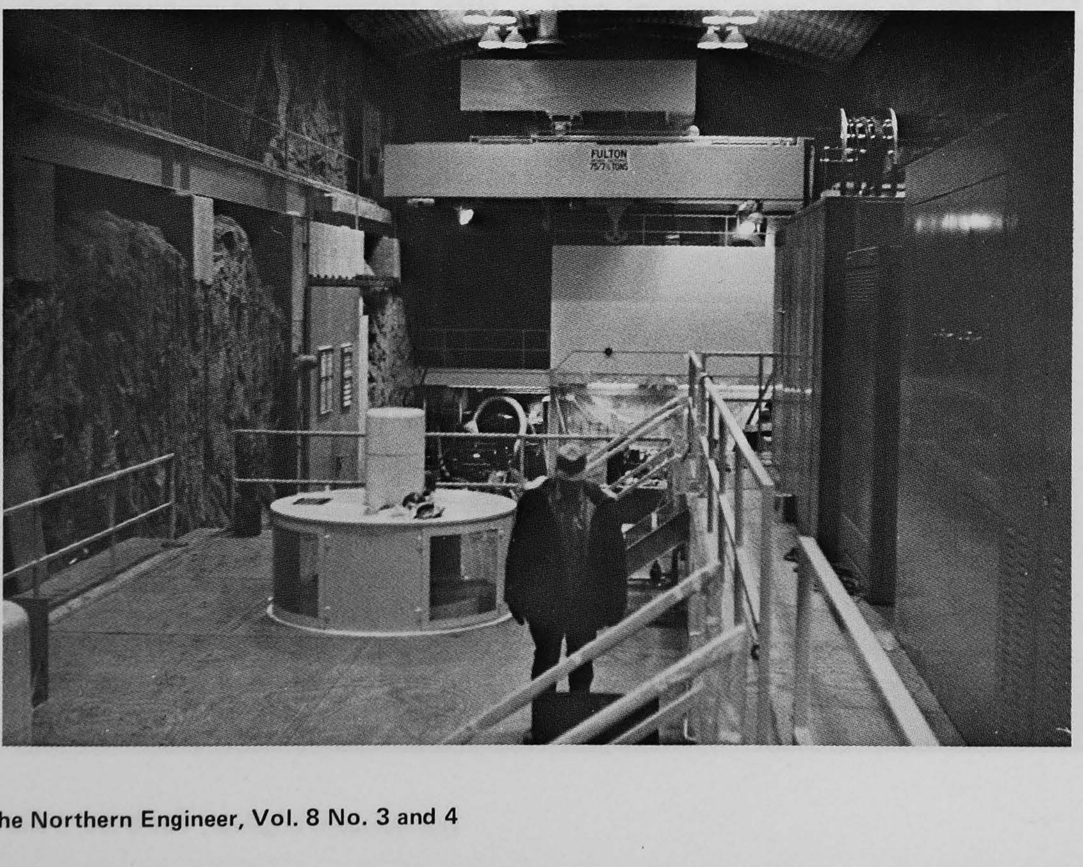
POWERCHAMBER

The powerchamber is located at tidewater level for maximum power benefits, and at a minimum horizontal distance inside the base of the mountain for minimum construction cost. Rock to a depth of 150 to 200 feet covers the roof of the chamber. Adequate but minimal space is provided for all the various features and items in the small (174.5 feet long by 38.5 feet wide by 72.5 feet deep) chamber. A cross section through the centerline of a generating unit is shown in Figure 7, and a longitudinal section of the powerchamber is shown in Figure 8.

The powerchamber was formed by excavating 11,500 cubic yards of rock. Because of the small size of the chamber and the high quality of the quartz diorite bedrock, rigorous mechanical analysis of stresses was not required. Borehole extensometers placed in the side walls to measure rebound from excavation registered no changes. The powerchamber was excavated in lifts from the roof down, with excavated material removed first through the service tunnel and at various later stages through the access and tailrace tunnels. Excavated material was placed in the switchyard fill.

The roof of the powerchamber is crowned on a 33-foot radius and is systematically rock bolted on 5-foot centers with 1-inch diameter hollow cored bolts. The rock bolts are stressed and grouted and are 15 feet long over the length of the chamber in the central half of the roof area and 10 feet long in the remaining edge strips. To prevent loose rock fragments from falling, the entire roof area is covered with galvanized wire fabric fastened to the roof rock bolts. A watertight suspended ceiling also covers the entire roof area as shown in the photograph in Figure 9. The ceiling is constructed of fluted, lightweight steel roof decking spanning between steel arches. This suspended ceiling will control any water seepage; however, the chamber was dry at the time of excavation (September 1970) and has remained dry.

Figure 9. Powerchamber interior, showing Unit 2 and space for future Unit 3.



The generators are set in rectangular spaces formed by integral concrete walls. The generators are spaced as close as possible, separated only by a steel partition. In lieu of the conventional rotating type top-mounted exciters, a bus-fed static excitation system is used, thus reducing the height required for the generators. Access to the generators is through the top of their housings.

Excavation for the turbines and draft tubes was held to a minimum to hold down the amount of concrete backfill around them. A total of only 2,100 cubic yards of concrete is contained in the powerchamber. Bulkheading of draft tubes is conveniently accomplished within the chamber using the pendant operated bridge crane.

To protect against sea water intrusion all areas of the powerchamber are concreted up to 12.0 feet, which is 0.6 feet above expected maximum tailwater. Stainless steel was used for draft tube bulkhead guides and for the turbine runners to protect against corrosion from sea water.

The air conditioning system is primarily a cooling and ventilating system based on a measured ambient temperature of 41°F within the powerchamber cavern. The system is designed to maintain a powerchamber temperature of 50°F minimum and 100°F maximum with outside design temperatures of -4°F in winter and 71°F in summer. Heating is provided by heat gains from the lights and equipment, with outside air heated by electric resistance heaters. Cooling is provided by outside air, with a water cooling coil available for additional cooling and/or dehumidification as required. Air is normally drawn in through the service tunnel and exhausted through the access tunnel. The ventilation system is reversible for clearing smoke in the event of fire.

Escape from fire or other disaster can be made through the access tunnel at one end of the chamber or the service tunnel at the other end.

PENSTOCK VALVE ROOM AND BRANCH PIPES

The 8.5-foot diameter Long Lake penstock forks into two 4.5-foot diameter branch lines at the valve room, where connecting spherical valves can isolate generating units 1 and 2. Provisions are made for an additional valve to control flow from the future Crater Lake penstock when a third generating unit is added (Figs. 6 and 7).

The penstock valve room is located separately and upstream from the powerchamber so that the powerchamber could remain compact and work on the Long Lake penstock and placing of valves and related equipment could progress simultaneously with work in the powerchamber. Main access to the valve room is through a 14-foot high by 12-foot wide connecting tunnel. A 20-ton capacity hand traveling crane with a geared hand chain hoist is provided for installing the spherical valves.

The steel penstock branch pipes leading from the valve room to the turbines are designed to withstand water pressures of 600 p.s.i. Rock tunnels driven to contain the branch pipes are D-shaped, 6.5 feet wide, and 8 feet high. The branch pipes are concreted in position within the tunnels. The branch pipe tunnel for future generating unit 3 and a starter tunnel for the proposed Crater Lake penstock have been excavated to eliminate the need for future blasting in the immediate powerhouse vicinity.

ACCESS TUNNEL

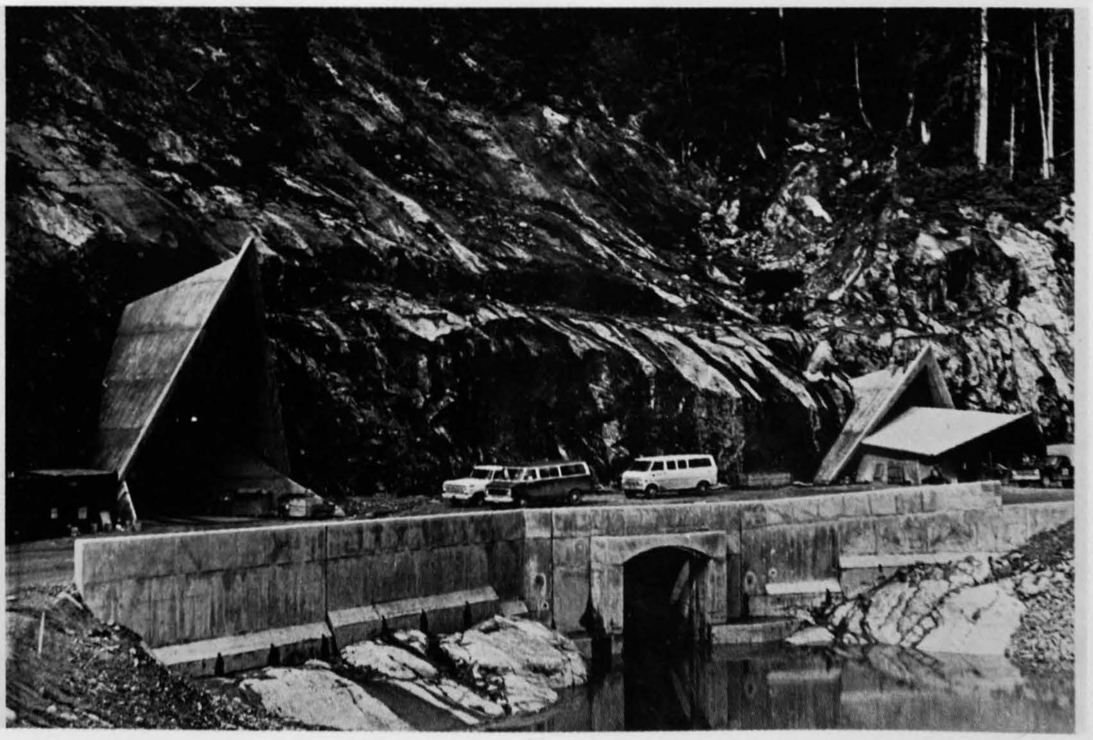
The access tunnel is rock-bolted, randomly as required. The rock bolts are stressed and grouted. The roofs of the tunnels at their outside entrances, for a distance of 30 to 40 feet, are reinforced with structural concrete as a precaution against cave-ins.

The tunnel is 220 feet long, 13 feet wide and 17 feet high, basically rectangular in cross section, but with a 13-foot radius crown in the roof. Its entrance is at the access road level, and it slopes gently five feet down to the erection area level. The tunnel is just high enough to pass a complete turbine spiral case and wide enough for conventional highway type trucks. Its floor is paved with concrete. The outside entrance is guarded against avalanches from the mountainside by a 42-foot high, A-shaped concrete structure (Fig. 10).

TAILRACE TUNNEL

The tailrace tunnel collects the converging draft tube extensions 70 feet downstream from the centerline of the turbines. From that point to the tailrace channel the tunnel is 220 feet long. The last 75 feet of tunnel is outside the base of the mountain and is formed by a channel excavated in rock and covered

Figure 10. Powerhouse entrances, left to right: access tunnel, tailrace tunnel (below vehicles), service tunnel.



with a reinforced concrete arch. The covering protects the channel from possible ice, mud, or snow slides from the mountainside above, and also forms a bridge for the access roadway leading to the powerchamber entrance.

The tailrace tunnel is unlined and is 13.5 feet wide by 39.5 feet high overall, with a flat bottom, vertical sides, and a circular crown. The unusually high and narrow cross section design is based on the large tidal range prevailing in this area. The tunnel is high enough to provide for open channel flow under all conditions, eliminating the need for a surge tank; the tunnel invert is low enough to prevent switch of control for the flow at low tailwater conditions from the sill to the tunnel portal. A control sill located in the tailrace limits the minimum tailwater elevation to the mean tidal level. The sill and tunnel invert elevations are based on the results of economic studies which compared the power benefits attributable to head variations against the powerhouse costs for different turbine settings.

The tunnel can be dried out for inspection by placing bulkheads in a slot provided on the tailrace bridge at the downstream end of the tunnel.

SERVICE TUNNEL

The service tunnel connects the powerchamber with the switchyard. It is 430 feet long overall and has an approximately 10-foot square cross section. The tunnel slopes down on an 8.5 percent grade from the powerchamber to a point approximately 15 feet underground at the foot of the mountain. From that point to the switchyard the tunnel is a level section constructed of reinforced concrete and buried under fill. The portion of the tunnel inside the mountain is unlined rock, but is paved for foot traffic.

The service tunnel carries 13.8 KV generator power leads to the transformers located in the switchyard, and also carries electrical service leads and air and water lines. The generator power leads are insulated copper cables with galvanized steel armor and are carried in ladder type trays. At the switchyard end, the tunnel has a small tower projecting 17 feet above ground level to take in air for the air conditioning system. The tower also has an opening above maximum expected snow level to be used as an alternate escape exit from underground.

DIESEL GENERATOR BUILDING

The diesel generator building is located at the foot of the mountain directly above the service tunnel, with its entrance just off the access roadway. It houses a 200 KW generator, for emergency power and for generator start-up, a visitors' lobby and rest rooms. Stairs from the lobby lead to the service tunnel through which plant personnel and visitors can enter the powerchamber.

CONCLUSION

Because Snettisham was intended to be the sole source of power for the Juneau-Douglas area, the Corps of Engineers took many extra precautions to ensure that once operation began, the project would have a minimum down time. To date the project itself has had a good record in that regard, although the initial location for the transmission line proved to be too vulnerable to the weather; it was relocated to a lower, more sheltered route in 1976.

Balanced against this need for reliability was the need to keep construction costs low so that the operators, the Alaska Power Administration (a federal agency under the Department of the Interior), could market the power as inexpensively as possible, even though construction in Alaska is more expensive than in any other area of the United States. In order to design and construct with the requisite economy and reliability, the Corps used the most innovative design and advanced construction procedures available. The wholesale rate at which the APA sells power is inexpensive; the design did win a national award in a competition within the Corps; and, as the features discussed in this paper illustrate, the result has been a unique hydropower project which can serve as a prototype for future power development in Alaska.

Currently Snettisham provides some three-quarters of the power used in the Juneau-Douglas area; peak load demands average 10 to 15 megawatts, and the highest recorded has only been a little over 16. The Alaska Power Administration has estimated it will be 1985 at the earliest--and that depending on the fate of Alaska's planned capital move--before the Crater Lake portion of the project will be needed. The Corps has completed 20% of the design phase for that portion.

Acknowledgment

The information on the project described herein was compiled by the writers during the course of their duties as Engineers for the U. S. Army Corps of Engineers, North Pacific Division and Alaska District. The permission granted by the Chief of Engineers to present this information to the public is appreciated.

This paper was originally presented at the ASCE Annual Meeting and National Water Resources Meeting, 29 January to 2 February, 1973, Washington, D. C.

REFERENCES

1. Grøner, C. F., "Underwater Piercing of Lakes," *Water Power*, July, 1960, pp. 265-268.

2. Munsey, Thomas E., "Diversion by Lake Piercing, Snettisham Project," *Civil Engineering*, October 1969, pp. 48-52.

3. Munsey, Thomas E. and Neilson, F. M., *Prototype Observations of Snettisham Project Diversion Tunnel, Long Lake, Alaska*, U. S. Army Corps of Engineers, Waterways Experiment Station, Miscellaneous Paper H-71-7, April 1971.

4. Munsey, Thomas E., "Snettisham Surge Tank is Result of Revolutionary Design," *USCOLD Newsletter*, September 1969, pp. 14-15.

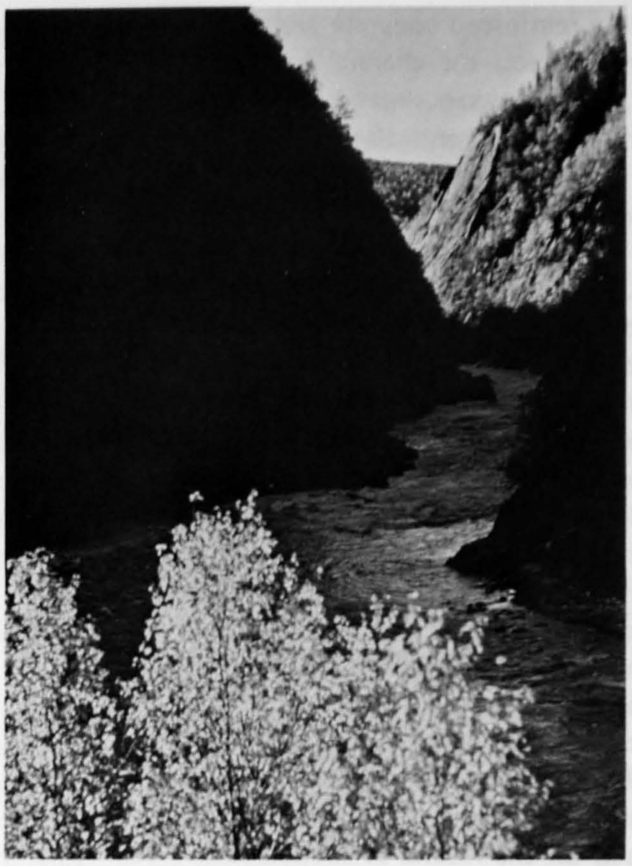
5. Rahm, Lennart, "Friction Losses in Swedish Rock Tunnels," *Water Power*, December 1958, pp. 457-464.

* * *

Formerly a hydraulic engineer with the U. S. Army Corps of Engineers, Tom Munsey is currently Civil Projects Coordinator with the Corps' Anchorage District Office. He received his B. S. from Virginia Tech and a postgraduate degree after completing the International Hydraulic Engineering course in Delft, The Netherlands.

by Eric Yould

THE SUSITNA HYDROELECTRIC PROJECT



A downstream view of Devil Canyon.

In response to a request for a feasibility study from the U. S. Senate Public Works Committee, the Alaska District Corps of Engineers recently recommended building two dams on the Susitna River as an efficient, environmentally sound way to meet the future power needs of Alaska's fastest growing region, the Southcentral Railbelt. In October 1976, the 94th Congress authorized $25 million for Phase 1 of the proposal for advanced engineering and design.

HYDROPOWER–NEEDS AND POTENTIAL

Concentrated along the railroad are the communities which now consume roughly 85 percent of Alaska's energy. Projections of future demand indicate that by 1985 the area will require 5500 gigawatt hours (GWH) of energy and 1270 megawatts (MW) of capacity annually, an increase of about 100% over what is now used.

Centrally located between the load centers of Anchorage and Fairbanks, the hydropower potential of the Susitna River has been recognized for many years. In 1972, when the U. S. Senate Public Works Committee requested the Corps to assess the feasibility of developing hydroelectric power on the Upper Susitna, it was asking for an update of a task that had been done before in that both the Corps of Engineers and the Bureau of Reclamation had already studied the river's potential. In the late 1950's and early 1960's, the Bureau of Reclamation proposed a four-dam development of the river. Their study was backed up by reservoir operation studies, foundation exploration for three of the dam sites, and an economic analysis which showed that the development would be economically feasible.

The 1972 Senate resolution asked the Corps to reassess the Bureau's four-dam proposal to determine its present technical, economic, and environmental feasibility. To do this, the Corps wanted to know if a need actually existed for the river's tremendous energy potential and, almost as important, to review the many energy sources available in Alaska to decide which kind offered the best long-range advantages in cost and which would have minimum adverse social and environmental impacts.

In conjunction with the Corps study, the Department of Interior's Alaska Power Administration (APA) conducted a power marketability analysis and a transmission line study. As a result of APA's requirement for close coordination with railbelt area utilities, energy and power demand projections were developed which determined the need for a particular project. Their projections were based primarily on the results of the 1974 Alaska Power Survey which was compiled for the Federal Power Commission.

In 1974, energy use within the Anchorage and Fairbanks areas amounted to roughly 2,000 gigawatt hours (GWH), only one third of the annual energy capability of the Upper Susitna River. The Susitna could be termed a small producer compared to a single dam on the Yukon River at Rampart Canyon which could produce as much as 34,000 GWH or a dam on the Copper River at Wood Canyon, which would be capable of producing 22,000 GWH. But the Susitna River is centrally located between the Anchorage and Fairbanks load centers and, by comparison, the overall impact of developing the Susitna appears to be considerably less than that of the Yukon or Copper Rivers.

The power and energy projections were broken down into the three demand categories of utilities, national defense, and industrial. The composite projections indicated that the market area would be demanding 5,500 GWH of energy and

1,270 MW of capacity by 1985, the earliest that Susitna could be brought on line, with increases to 15,000 GWH and 3,170 MW by the year 2000. Research published in a report,[1] by the Institute of Social and Economic Research of the University of Alaska, complements these findings, while an assessment by the Federal Power Commission suggests that these estimates may be quite low. At any rate, the project's feasibility was tested not against the composite demand curve but against projected utility requirements. These are estimated to be 4,860 GWH energy and 1,110 MW capacity by the year 1985, and 11,650 GWH energy and 2,660 MW capacity by the year 2000. Based on these lower projections, several alternative plans for development of the Upper Susitna River were found to be economically feasible. The selected plan of development for the Susitna River was also tested against a "low-load" growth demand projection, also provided by APA, which represents a consumption rate influenced by induced conservation measures and little industrial growth. The analysis indicated that the projects would still be economically feasible. In addition to Susitna, a number of other energy sources were evaluated. Oil and natural gas were impractical because of anticipated high cost, shrinking reserves, and their value for purposes other than as fuel. Renewable resources (geothermal energy, solar energy, winds, tides, wood, and solid waste) were undesirable for a number of reasons, i.e., economics, state-of-the-art, environmental problems, or an inability to augment the existing and projected integrated energy system. Nuclear and coal-fired steam plants were found to be economically inferior to Susitna; however, the Corps concluded that, in the absence of hydroelectric power, coal would become the source of energy not only for Fairbanks but for Anchorage as well. This would require the development of the 2.3 billion metric ton Beluga coal fields northwest of Cook Inlet, which would provide energy equivalent to roughly 7 billion barrels of oil. Assuming sufficient thermal coolants are available, the Fairbanks area would continue to utilize and expand mine-mouth generation from the Nenana coal fields, which are estimated to contain at least 7 billion metric tons of coal. Thus coal became the yardstick by which the environmental and economic feasibility of Susitna was measured. By comparing these environmental and economic effects, it was concluded that the Susitna hydroelectric project would be the most advantageous in providing long-range power to the railbelt load centers.

Nevertheless, the Corps did not recommend that the four-dam system be developed. That system would entail dams and power plants at three sites: Devil Canyon, Watana, and Vee (going up river), and a dam for flow augmentation at Denali, farthest upstream. This system would be capable of producing 6,300 GWH in firm annual energy, but it would have an impact on 32,232 hectares of land, including 222 kilometers of river. Instead, the Corps increased the structural height of the Watana Dam and eliminated the Vee and Denali dams upstream. Although roughly 30 meters of power head were relinquished by eliminating these two dams, Watana's large storage capacity offsets this loss. The remaining two-dam system would have a firm annual energy capability of 6,100 GWH, 97 percent of the four-dam system, but would affect only 59 percent as much terrain and river. Many possible dam configurations were studied and it was concluded that the Devil Canyon-Watana scheme was best, both economically and environmentally.

DEVIL CANYON-WATANA COMPLEX

The estimated cost of constructing the two-dam system, based on 1975 prices, is $1,520,000,000. The actual cost will increase as inflation and construction costs rise. However, considering that the construction costs of any alternative power source will increase also, as will the cost of fuel (which is not a factor for hydropower), the Susitna development remains economically feasible.

The upper Susitna basin is a fan-shaped area of 15,047 square kilometers bordered by the Alaska Range to the north, the Talkeetna Mountains to the southeast, and flat, low areas to the southwest. Most of the basin has a well-defined dendritic stream pattern with a main channel flowing from glacial headwaters in the Alaska Range. Below the glaciers, the braided channel traverses a high plateau deposited by alluvial sediment, and then meanders several miles south to its confluence with the Osheta River. The Susitna then takes a sharp turn to the west, and flows through a steeply-cut, degrading channel until it exits into the basin of Devil Canyon. Other main tributaries within the basin are the Maclaren River, which also drains the Alaska Range glaciers, and the Tyone River, which originates in the Lake Louise area. Glacial areas comprise only four percent of the entire basin, but summer glacial melt accounts for a considerable portion of the river's total flow. The highest point within the basin is the 4,212 meter Mount Hayes, while the lowest point is the Susitna water surface as it leaves the basin at a 265 meter elevation. Average annual runoff from the basin is roughly 8.6×10^9 cubic meters, with roughly 95 percent occurring between May and September.

Most of the basin is overlain with moist or alpine tundra, while the area below the Maclaren and adjacent to the Susitna is either upland or lowland spruce-hardwood forest. Wildlife within the basin includes bear, moose, caribou, Dall sheep, mountain goat, wolf, wolverine, waterfowl, birds of prey and other small animals. Migratory fish do not inhabit the upper Susitna basin, because the 18-kilometer stretch of river which passes through Devil Canyon is too strong for them to ascend. Migratory fish do spawn in Portage Creek, which is five kilometers downstream from the Devil Canyon damsite. Principal resident fish include grayling, rainbow trout, lake trout, Dolly Varden, whitefish and turbot.

The present plan for development of the Susitna River entails the construction of dams at Devil Canyon and Watana, and a backbone transmission system to provide energy to Anchorage and Fairbanks. Watana, the first project developed, would be located on the mainstream of the Susitna River halfway between the tributary confluences of Tsusena and Deadman Creeks. Reservoir regulation studies indicate that the

Aerial photo taken by the author of Devil Canyon, looking downstream.

Watana storage capacity would be sufficient to meet the demands of both Watana and Devil Canyon. Consequently, the Devil Canyon project could make maximum use of its available head and would only require the minimal draw down necessary to reregulate the outflow from Watana. The Devil Canyon project would be located in a deep river-cut gorge roughly 52 kilometers downstream from Watana. Energy demand projections indicate that the Devil Canyon project would not be needed until five years after completion of the Watana project.

Construction of Devil Canyon and Watana would require road access to the sites and river diversion during the construction period. To avoid possible detrimental effects of road building should construction not follow Phase I (advanced engineering and design), it was decided to use helicopters and fixed wing aircraft in warm months and cat trains in late winter to reach the site for preconstruction studies. Construction of an access road would be required prior to river diversion. The present plan calls for a 24-foot wide road (7.31 meters) approximately 103 kilometers long beginning at the Parks Highway near Chulitna Station and terminating at the Watana damsite, with side access to Devil Canyon. The road would cross the Susitna River upstream from the Gold Creek railroad bridge, and would parallel the river on the south side. With the exception of the bridge, the road would not be visible from the river.

Foundation preparation for both sites would require stripping the organic overburden and glacial till to expose the bedrock. Seismic studies have revealed approximately 21 meters of channel material at the Watana site, and 11 meters of alluvial material overlaying bedrock in the Devil Canyon channel. Removing the water from the channel and final construction would require the diversion of the Susitna River around the two sites. In both cases, this would be accomplished in a manner similar to that used in construction of the 216-meter-high Hoover Dam. This entails diverting the river around the construction site by way of a tunnel through the canyon walls. The river enters a subterranean channel upstream of the site and returns to the original channel downstream. At Watana, conveyance would be through two 1,220-meter-long, 9.1 meter-diameter horseshoe tunnels excavated into the right abutment. The river would be diverted by two 30-meter-high earth coffer dams which would protect the construction site against flooding. The coffer dams would be placed to allow their incorporation into the main dam embankment. Initial construction of the diversion tunnels would require upstream and downstream sheet-pile coffer dams to isolate the portals. The tunnels would eventually be plugged prior to, and during, the filling of the reservoir; however, the downstream segments of the tunnels would eventually be connected to the low-level and high-level hydraulic outlets. The high-level outlet diversion tunnel would be sufficiently gated to provide minimum releases during reservoir filling prior to dead storage pool elevation.

With the Watana project in operation, river diversion at Devil Canyon would be considerably easier. Total conveyance would include a 7.9 meter-diameter horseshoe tunnel, 350 meters long, through the left abutment. Diversion would entail two cellular coffer dams of a height sufficient to allow a 15.2-meter head on the entrance tunnel invert. After project construction, the tunnel would be gated for early flow control, ultimately plugged, and the coffer dams removed.

EARTHQUAKE HAZARD

Both the Devil Canyon and Watana projects have been designed to withstand the forces of magnitude 8.5 earthquakes. The most probable source of such an earthquake is the Denali fault, located some 64 kilometers to the north. The Susitna fault, which is located just 4.0 kilometers downstream from the Watana site, will be studied in more detail to determine its seismic potential in relation to Watana Dam. Because of the relatively short length of the Susitna fault, it is anticipated that the most severe earthquake that could occur would be on the order of 6.0. Through 1970, 262 earthquakes have been recorded within a 241 kilometer radius of the Devil Canyon site.[2] Of these, 229 had a Richter scale magnitude of less than 5.3, 20 were between 5.3 and 7.0. Eleven were between 7.0 and 7.75, and two were greater than 7.75. Of the two largest earthquakes, one occurred in 1928 about 160 kilometers south of Devil Canyon, and the other was the famous earthquake of 1964 whose epicenter was located approximately 209 kilometers southeast. The most severe earthquake within a 40-kilometer radius of the damsite occurred on the Talkeetna River on July 3, 1929, with a magnitude of 6.25.

FLOODS

The spillways for the two projects would be designed to protect against what is termed a "Probably Maximum Flood" (PMF), the most severe flooding which might occur, for example heavy spring snow melt coupled with maximum precipitation for the area. Providing for a PMF means applying extreme hydrometeorological conditions to an analytical basin model precalibrated by using historic hydrographs. For the present study, hypothetical storm conditions (developed by the Hydrometeorological Branch of the National Weather Service) and an analytical modeling, utilizing the "Streamflow Synthesis and Reservoir Regulation" computer program (developed by the North Pacific Division of the Corps of Engineers), were used. Additional stringent criteria were added, in that both reservoirs would be presumed full and no flow could pass through the turbines. The results of the study indicate a peak Watana outflow of 5,436 cm/sec with a 1.8 meter surcharge over the normal maximum water surface elevation. The peak Devil Canyon outflow was estimated to be 6,286 cm/sec with a 1.0 meter surcharge.

DESIGN FEATURES

The Devil Canyon spillway would consist of a conventional chute located on the left abutment, with a superelevated flip bucket, a structure which would deflect the flow of water into a trajectory above and parallel to the water surface. This design feature would help eliminate a deep river plunge, thus mitigating possible nitrogen supersaturation. The spillway would have an ogee crest elevation of 425 meters and would be controlled by two radial gates, 19.5 meters wide by 18.3 meters high. The Watana gate structures would be similar to Devil Canyon, but the spillway would be considerably different. The Watana spillway would not be connected to the dam. It would be located slightly upstream and would discharge through a saddle in the natural terrain. Discharge would be controlled by three 18.0 meter by 12.8 meter tainter gates. The spillway channel would be roughly 1,000 meters long, widening to 182 meters, and would discharge into Tsusena Creek, approximately 4.1 kilometers upstream from the creek's confluence with the Susitna River. The earth excavated from the Watana spillway would be used in constructing the dam embankment. The channel of the spillway would be entirely lined with concrete to protect against scour.

The heights of the two dams were established from a scoping analysis that compared power benefits with construction costs. It was found that, because the narrow river gorge provides little opportunity for development of storage capacity, dams low-to-medium in height are not economically feasible. If greater heights are built, broader areas of the canyon can be used for storage purposes, resulting in greater firm energy which, in turn, offers greater economic benefits. Conversely, if dam heights are taller, crest lengths become longer in relation to the energy gained, and the benefits realized by raising the dams become offset by disproportionately higher costs.

The scoping analysis indicated optimum economical structural heights of 247 meters for Watana and 194 meters for Devil Canyon. Other features of the two projects which influenced the ultimate choice of the heights of the dams were such traditional components as switchyards, type of dam structures, power plants, spillways, hydraulic features, transmission lines, etc.

The height of the Watana dam would provide a gross maximum power head of 223 meters, and a total reservoir storage content of 1.2 x 10^{10} m^3. The normal maximum water surface elevation of the reservoir would yield a water surface area of approximately 174 km^2, and would stretch over 85 kilometers of river channel. Because the downstream Devil Canyon dam would utilize the regulated releases from the Watana reservoir, the Devil Canyon dam height is dependent only upon its own optimum powerhead. Its reservoir will provide little power benefit. This becomes readily apparent by comparing the size of the Devil Canyon reservoir to that of Watana. Devil Canyon's gross maximum head is 175 meters, resulting in a maximum storage capacity of roughly 1.3 x 10^9 m^3, almost ten times smaller than that of Watana. The maximum surface area of the Devil Canyon project is only 30.3 km^2, stretching over 45 kilometers of river channel.

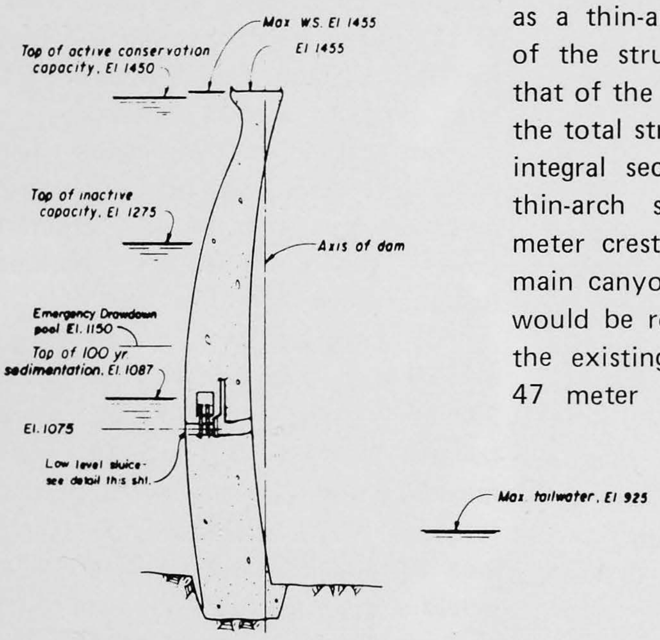
The best type of structure for each dam is primarily a function of site and foundation conditions. Either a concrete gravity or rockfill dam structure would be suited to the massive Watana site, while a concrete thin-arch dam is suitable for the deep, narrow

Devil Canyon site. If a gravity structure were selected for the Watana site, preliminary design work indicates that approximately 5.0 million cubic meters of concrete would be required. Existing cost estimates, however, are based on a rockfill structure consisting of almost 40,328,000 cubic meters of embankment material. The Watana shell, approximately 32,110,000 cubic meters, would be comprised of clean gravel obtained from the terrace along Deadman Creek and from channel excavation. Riprap could be obtained from the spillway excavation, rock drain material from the diversion tunnel and underground features, sand and gravel filters from terrace deposits and gravel bars, and impervious core material from processed glacial till deposits available on the upper levels of the south valley wall. The crest length of the Watana dam would be 1,052 meters at elevation 674 meters, Mean Sea Level. The maximum section, consisting of 2.5 meters to one backslope for the upstream face, 2.0 to one backslope for the downstream face and a 15.2 meter crest width, will yield a toe-to-toe width of 1,093 meters.

Considerably less material would be required for the Devil Canyon project. Although it is commonly referred to as a thin-arch dam, because the height of the structure would be higher than that of the adjacent steep-walled canyon, the total structure would consist of three integral sections. The double curvature thin-arch section would have a 418 meter crest length and would span the main canyon. The height of this section would be roughly 33 meters higher than the existing left abutment, requiring a 47 meter long concrete lateral thrust block. An earthfill structure 61 meters high would be built into the other end of the thrust block and traverse 290 meters of the left abutment where it would eventually tie into higher terrain to the south. The crest elevation of the thin-arch section would be 444 meters M.S.L., and would reach an elevation of 445 meters M.S.L. for the earthfill section. Construction of the thin-arch and thrust-block sections would require approximately 841,000 cubic meters of mass concrete, and 76,500 cubic meters of strucutral concrete. This, in turn, would require approximately 971,500 cubic meters of processed aggregate, most of which would come from a fan at the confluence of Cheechako Creek, located 750 meters upstream from the dam axis.

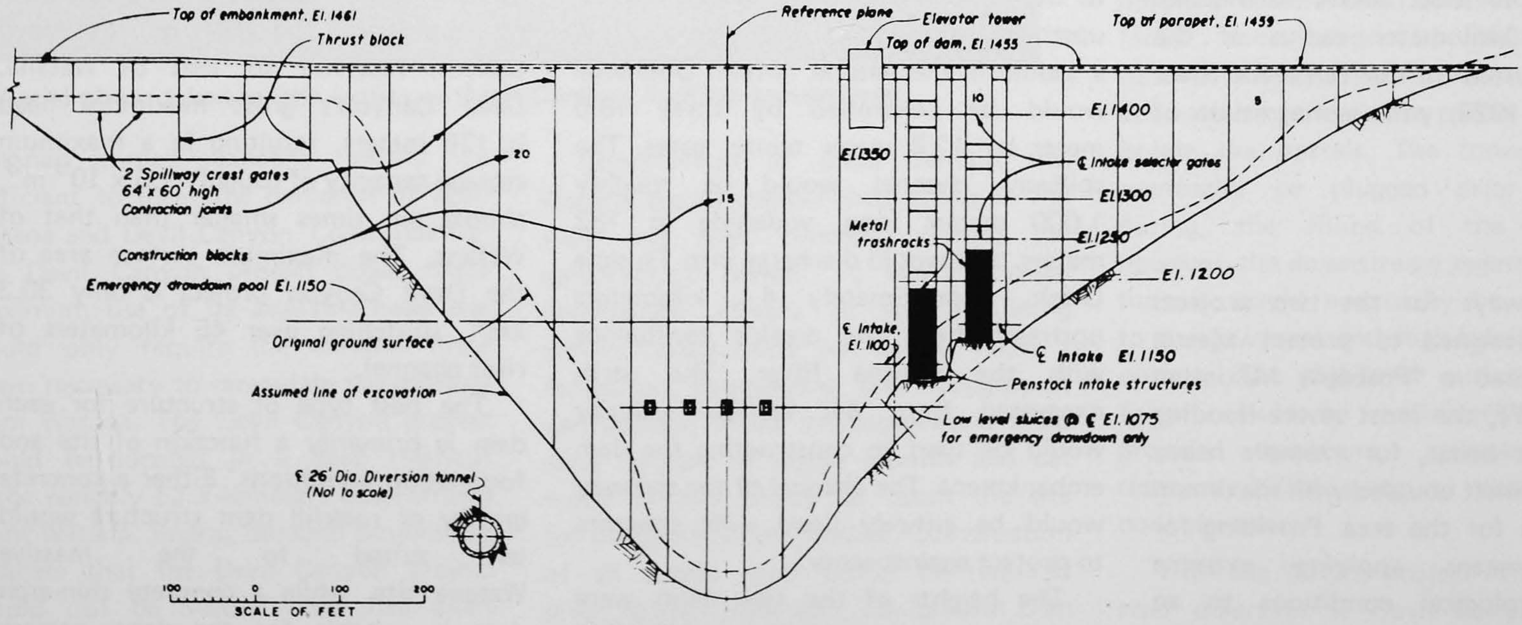
POWER PLANTS

The power plants for the two structures would both be located underground in abutments adjacent to the main dams. The plants would be mammoth, each encompassing an area greater than



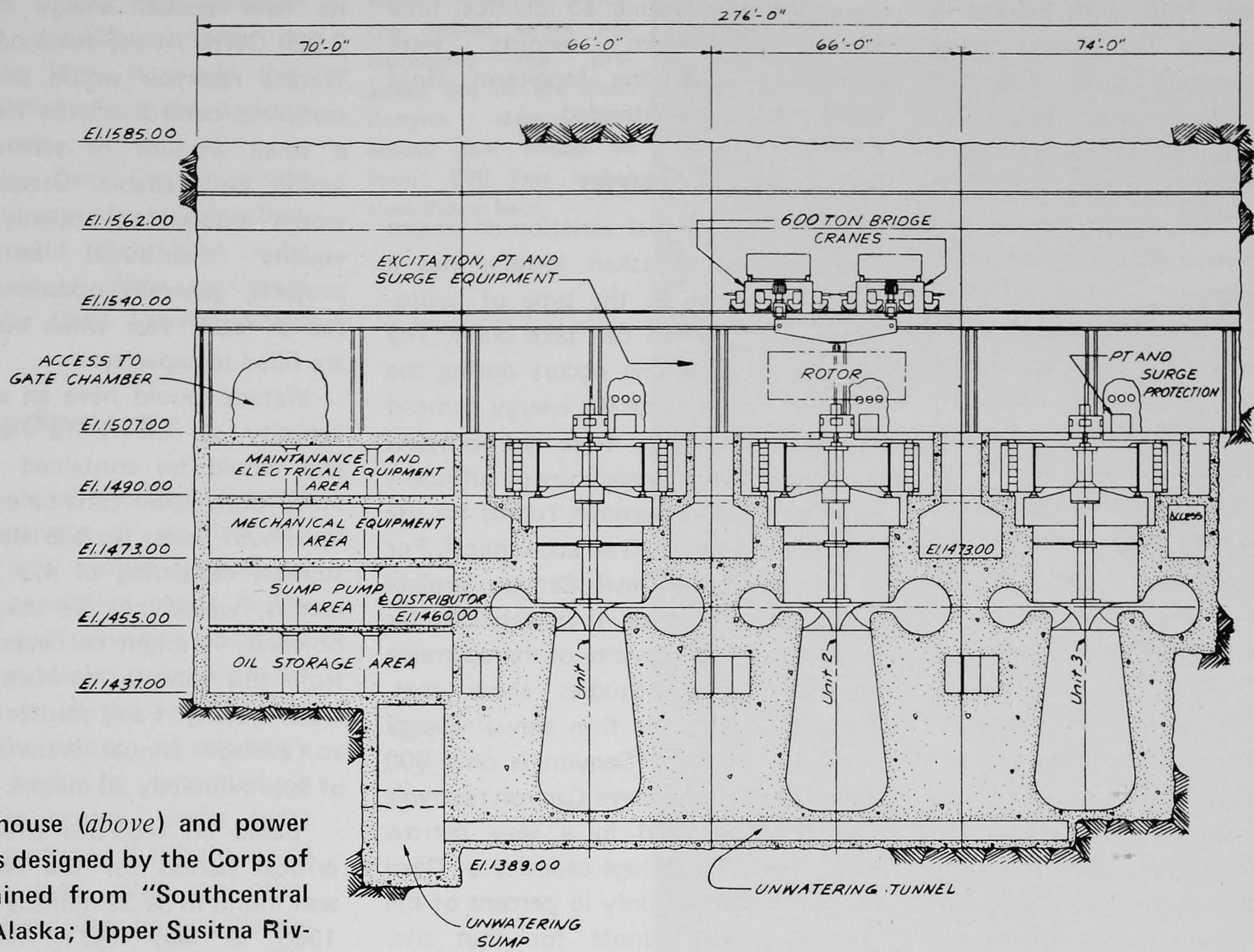
SECTION

The thin arch Devil Canyon dam, section (*left*) and elevation (*below*), designed by the Bureau of Reclamation and modified slightly by the Corps of Engineers (obtained from "Southcentral Railbelt Area, Alaska; Upper Susitna River Basin Interim Feasibility Report").

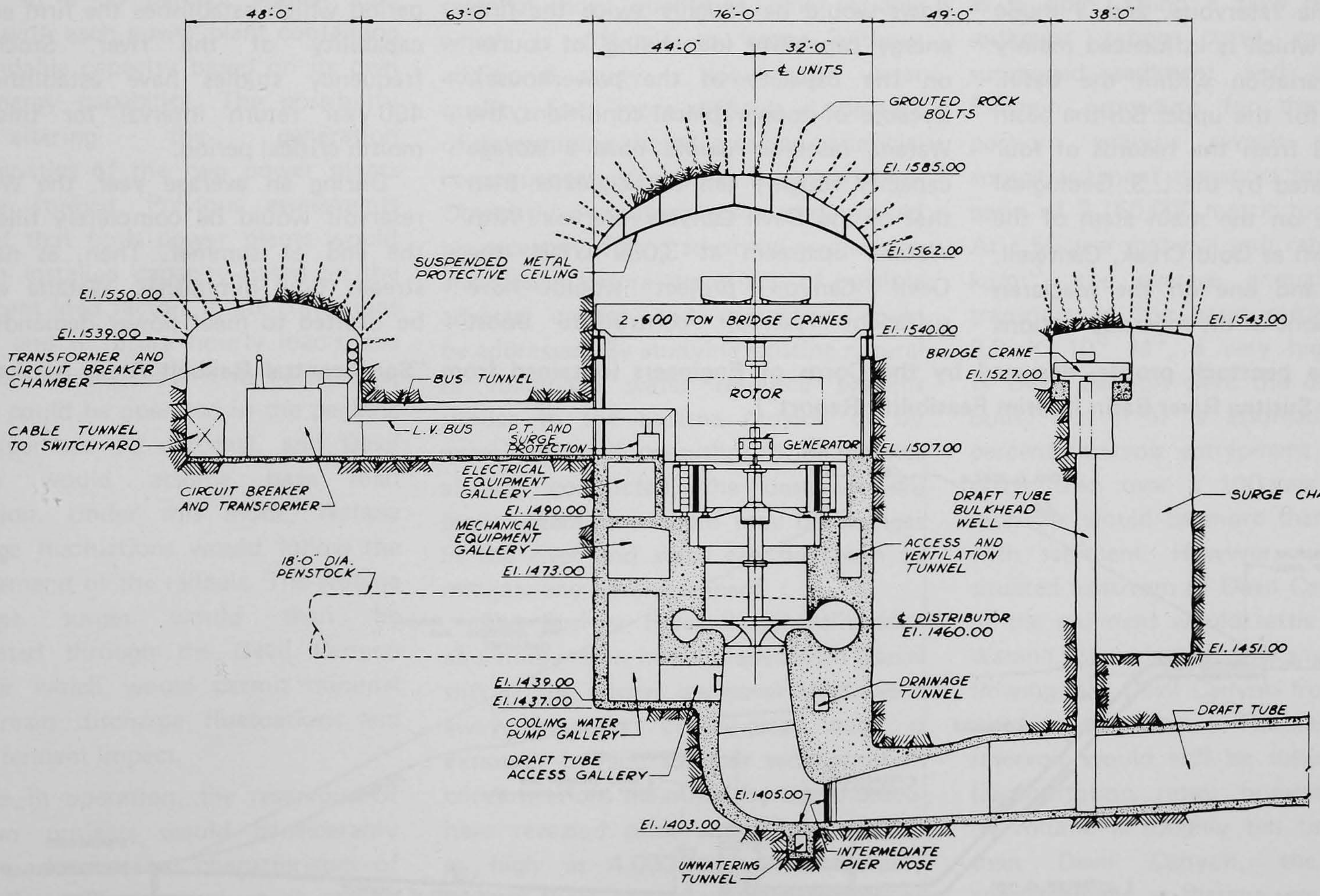


UPSTREAM ELEVATION
DEVELOPED ALONG AXIS OF DAM

Watana power house (*above*) and power plant (*below*) as designed by the Corps of Engineers (obtained from "Southcentral Railbelt Area, Alaska; Upper Susitna River Basin Interim Feasibility Report").



LONGITUDINAL SECTION
THRU ℄ UNITS



TRANSVERSE SECTION
THRU GENERATOR BAY

that of a soccer field, with heights in excess of 61 meters. The Watana power plant would contain three 236 mw Francis turbines, each with a 15 percent overload capacity for a total rating of approximately 814 mw (1,091,000 horsepower). Devil Canyon would contain four Francis turbines each rated at 171 mw for a total overload rating of 784 mw (1,054,000 horsepower).

The Watana power plant would be carved out of the rock of the left abutment, while the Devil Canyon power plant would be nestled in the right abutment. The turbines would receive flow from penstocks which would be connected to multiple level intake structures. The intake structures would allow selective withdrawal from the reservoirs, permitting the projects to maintain downstream water quality.

The power capabilities of the selected plan of development were established from reservoir regulation studies which in general evaluate the capability of the flow of the Susitna to meet a predetermined annual energy load shape and demand. The ability to meet demand is dependent upon the geometric configuration of the reservoirs, and a mode of operation which is influenced mainly by runoff variation within the basin. Stream flow for the upper Susitna basin is determined from the records of four stations operated by the U.S. Geological Survey, three on the main stem of the Susitna (known as Gold Creek, Cantwell, and Denali) and one on the Maclaren River. Since none of the recorded stations were operating during an identical time period, short-term records were corrrelated with the long-term Gold Creek station and extended.

HYDRODEVELOPMENT

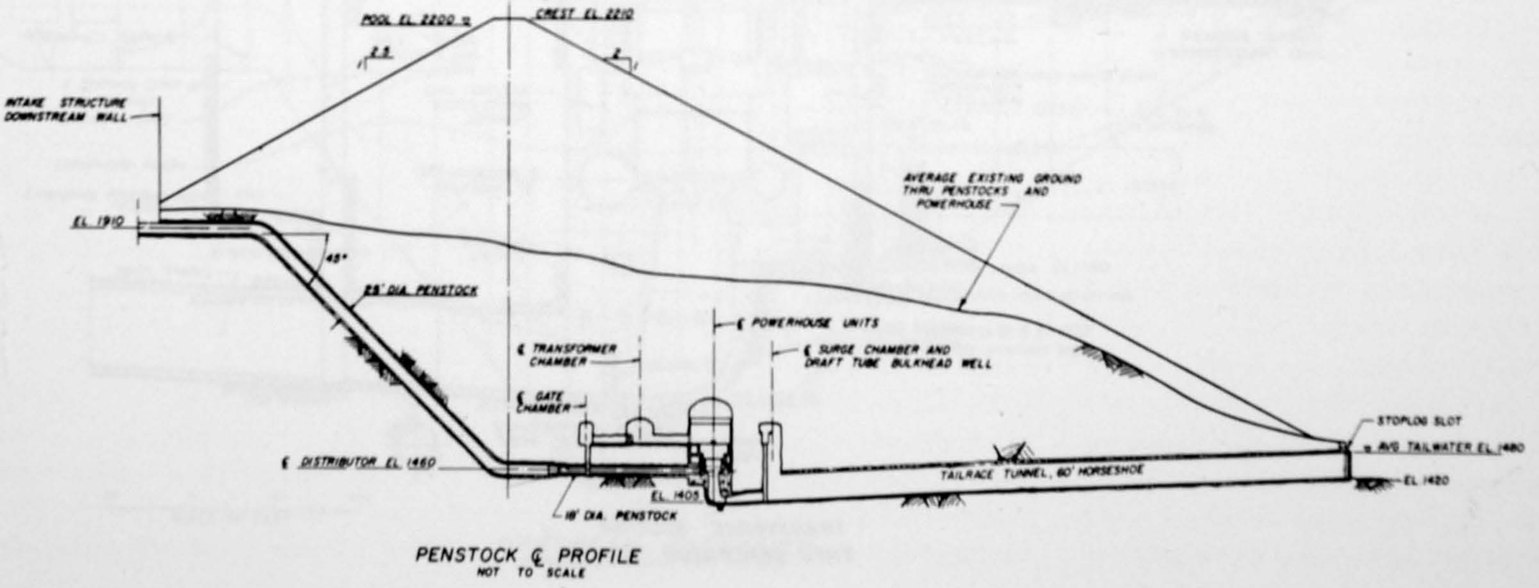
The severe annual variation of stream flow in most Alaskan streams has a profound effect on the type of hydrodevelopment which can take place. The heaviest stream flow occurs during the summer, but the heaviest energy demand is in the winter. Only those hydroprojects which can provide reservoirs of sufficient capacity to store summer runoff for use during the winter will be economical. For this reason, the Devil Canyon project would be impractical if it were not for the large storage capacity of the upstream Watana project. Studies show that, without Watana, the firm annual energy capability of Devil Canyon is only 900 GWH. Because the Devil Canyon reservoir would be confined in a very narrow gorge, the total storage capacity of Devil Canyon would be only 15 percent of the average annual runoff for that site. Thus, the secondary energy available from the virtually uncontrolled summer flows would be roughly twice the firm energy capability (depending, of course, on the capacity of the powerhouse). Because of topographical conditions, the Watana reservoir would have a storage capacity roughly ten times greater than that of the Devil Canyon reservoir. With Watana upstream at 3,080 GWH, the Devil Canyon project would have sufficient reservoir control to boost its firm annual energy capability to 3,020 GWH. At the same time, the larger Watana reservoir would provide almost complete control of the river and only a small amount of secondary energy would be available. Secondary energy would amount to roughly 800 GWH, equally distributed between both projects, generally occurring during the fall of each year when both reservoirs are filled to capacity.

Watana would have an active storage capacity of 7.5 X 10^9 cubic meters, and would be contained within a 78 meter draw-down zone below the normal maximum water surface elevation. Dead storage, consisting of 4.3 X 10^9 cubic meters, would not be used for power; however, it might be necessary to draw from this zone to maintain downstream water quality. Early studies have revealed an average annual Watana draw-down of approximately 30 meters.

Based on recorded stream flow, the critical period for the Watana project was found to be 32 months from October 1968 to May 1971. This represents the most severe drought conditions for the period of record, and hence the period which establishes the firm energy capability of the river. Stochastic frequency studies have established a 400-year return interval for this 32-month critical period.

During an average year, the Watana reservoir would be completely filled by the end of summer. Then, as natural stream flow diminishes, Watana would be drafted to meet power demands and

Watana penstock profile, designed by the Corps of Engineers (obtained from "Southcentral Railbelt Area, Alaska; Upper Susitna River Basin Interim Feasibility Report").



would reach its lowest pool elevation (30 meters of draw-down) prior to spring freshet in May. It would then continue to fill throughout the summer to complete the cycle.

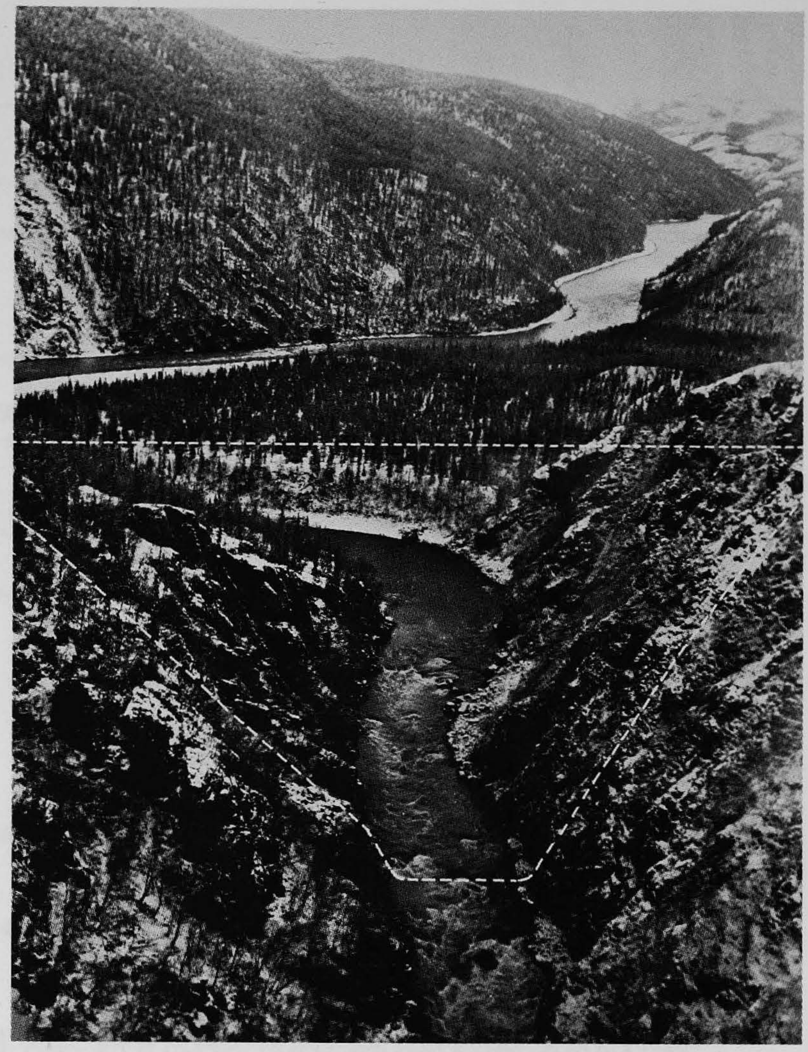
Unlike Watana, Devil Canyon would experience no shortage of reservoir inflow and hence it would rarely have to be drafted. This would allow maximum utilization of the Devil Canyon power head.

OPERATION AND IMPACT

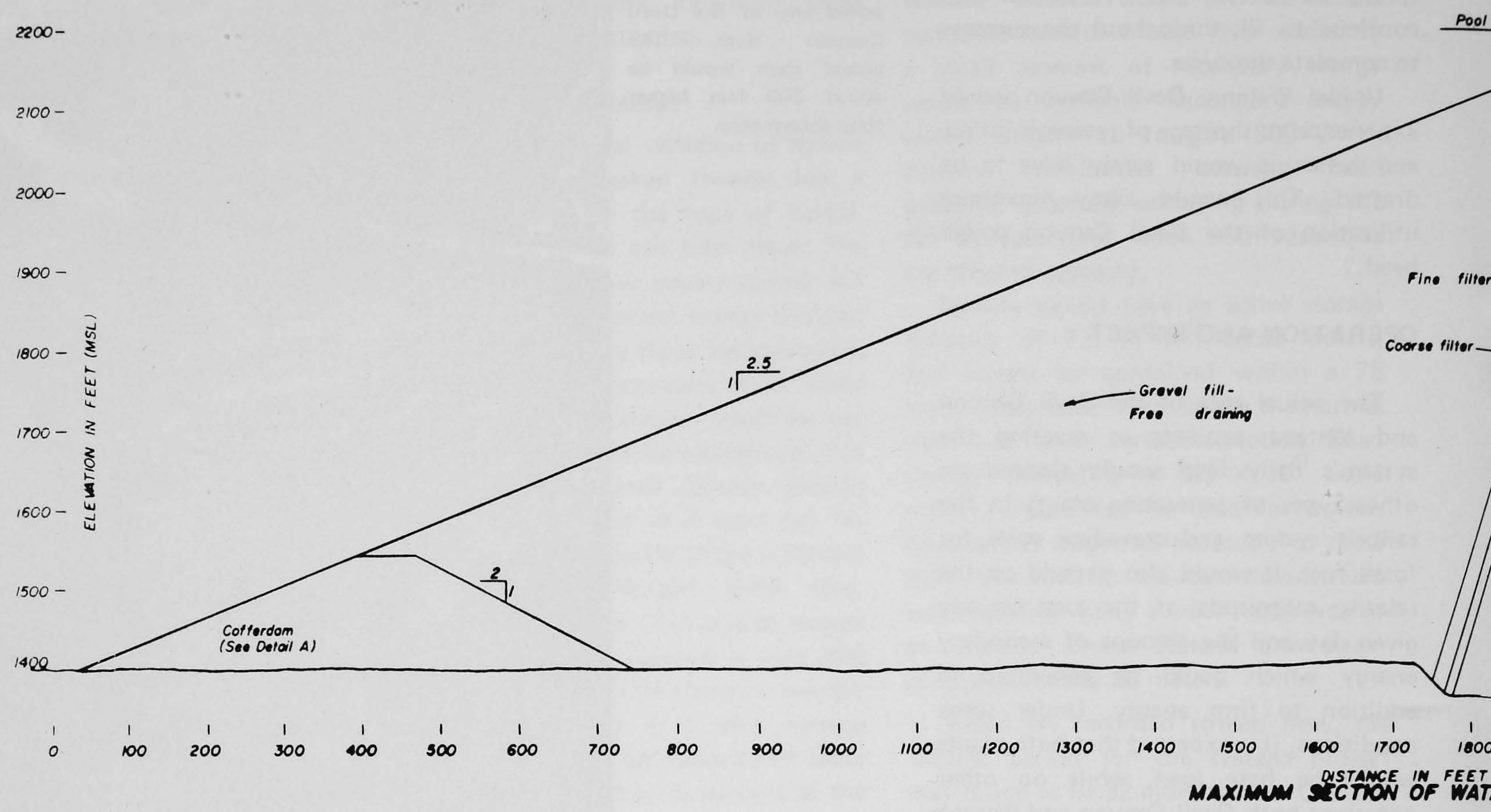
The actual role of the Devil Canyon and Watana projects in meeting the system's daily load would depend on other types of generating plants in the railbelt system and prevailing costs for fossil fuel. It would also depend on the relative magnitude of the load on any given day and the amount of secondary energy which could be generated in addition to firm energy. Under some conditions, it is expected that both plants would be base load, while on other occasions both Devil Canyon and Watana may be relied upon for peaking. The overall complex has been designed to operate at a 50 percent annual load factor, with each power plant containing a dependable capacity based on its own firm energy capability. The possibility of altering the generation characteristics of the two power plants will be studied. Previous assessments assumed that both power plants would have an installed capacity based on the 50 percent load factor. If site conditions permit, and if future hourly load-shape operation studies show it to be feasible, Watana could be operated in the peaking mode (perhaps 30 percent), and Devil Canyon would assume base load generation. Under this mode, Watana discharge fluctuations would follow the daily demand of the railbelt. The Watana discharge surges would then be reregulated through the Devil Canyon reservoir which would permit minimal downstream discharge fluctuations and their attendant impact.

When in operation, the reservoirs of the two projects would considerably alter the downstream characteristics of stream flow. The changes which can be confidently predicted consist of alteration of sediment transport and seasonal flow quantities. The variable which is difficult to assess without additional study is downstream water quality. Even more difficult is the task of determining the adverse and beneficial consequences of altering these variables. Obviously a comprehensive study would be necessary during advanced engineering and design before the effects of possible adverse impact and correction could be addressed. By studying existing natural or manmade water resource systems similar to the Susitna project, or by examination of preauthorization studies already conducted, the designers are made aware that there may be changes in the river and steps can be taken to mitigate any adverse impact.

Right: On this photo, the dashed white line represents the proposed site of the Devil Canyon dam. The actual dam would be about 200 feet higher than shown here.



The Susitna River is generally seen as a milky river, heavily laden with glacial silt. If the winter ice cover is stripped away, however, crystal-clear water is exposed. In fact, summer sedimentation concentrations measured by the U.S.G.S. have revealed peak sediment quantities as high as 4,000 ppm (considerably higher than the summer average of roughly 1,300 ppm), while winter concentrations have been measured as low as 5 ppm. Using a flow duration vs. sediment rating curve method for suspended sediment and a modified Einstein procedure for the bed load portion, analysis reveals an average annual sediment transport for the upper basin of 9,750,000 metric tons per year. At a 50-year material unit rate of 12,482 kg/m^3, the average annual sediment transport at the basin outlet becomes 6.8 X 10^6 M^3, a very high amount. If Devil Canyon were the only project built, and if it is assumed that 100 percent reservoir entrapment would take place, then over a 100-year period its reservoir would be more than half-filled with sediment. However, with Watana situated upstream of Devil Canyon, most of the sediment would settle out in the Watana reservoir with only small amounts flowing into Devil Canyon from the low-yield local terrain. The large Watana reservoir would still be subject to high transportation rates; however, because its volume is roughly ten times greater than Devil Canyon, the sediment encroachment at Watana would only be 5.5 percent over 100 years. With local inflow to the Devil Canyon reservoir,



WATANA MAXIMUM DAM SECTION, AS DESIGNED BY THE CORPS OF ENGINEERS

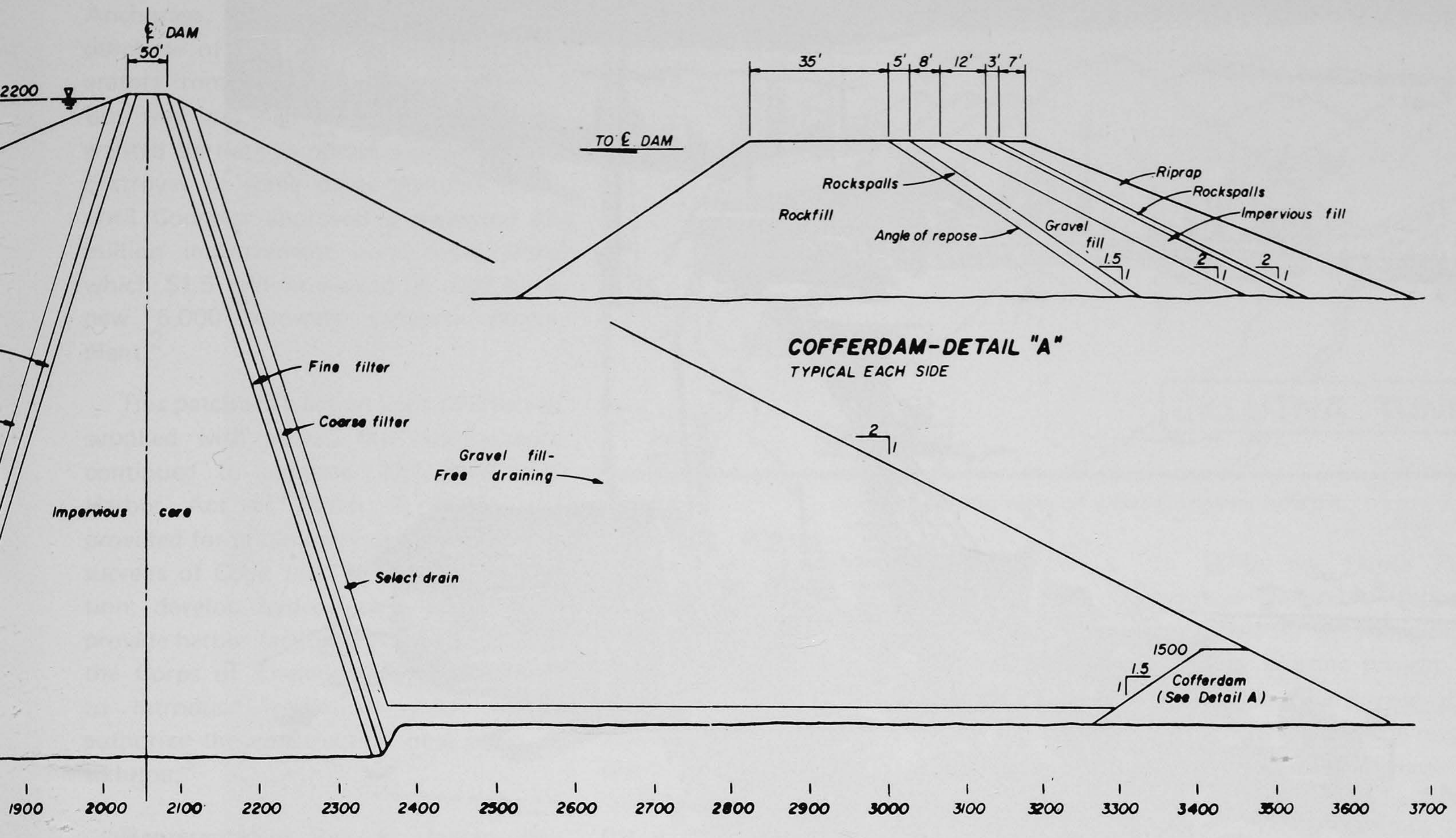
losses at that project would amount to only 6 percent over 100 years. Obviously this is a very simplistic approach, as quantification of sediment transport is considerably more complex. Actual entrapment rates are influenced by particle size, reservoir temperature, density stratification, reservoir conveyence velocities, mixing, intake configurations, and a number of other variables. However, there is sufficient information to determine the general magnitude of sediment transport for the Susitna River and the trap efficiencies of the reservoirs. Indications are that the reservoirs themselves would not be in any danger of significant encroachment for a considerable number of decades. With the reservoirs in place, entrapment rates are estimated to be in the range of 95 percent. Whatever the actual entrapment rate is, some sediment will pass through the reservoirs. Thus it is probable that downstream summer sediment concentrations would be drastically reduced, while winter concentrations would be increased. Mitigation of possible winter increases is possible by discriminate reservoir withdrawal procedures. It is anticipated that density stratification within the reservoir will concentrate the suspended colloid matter in specific portions of the reservoir. By flushing these zones during the summer, and by drawing from zones devoid of sediment during the winter, it may be possible to decrease potential winter impact.

Other impacts associated with the downstream channel geomorphology would be degradation and possible channelization. Previous studies indicate these to be minimal, but verification will be necessary during the next stage of analysis.

There are a number of additional impacts associated with the Susitna proposal which must be assessed before a firm decision regarding construction can be made. A discussion of all impacts is beyond the intent of this article. However, all feasible alternatives for meeting future energy demand within the railbelt, whether strip mining for coal, development of soft technologies, or tidal damming, will have some environmental and social impact. It will be up to the people of Alaska, in concert with national objectives, to determine the role of Susitna energy.

FUNDING

Should Alaskans decide to pursue Susitna energy, funding of the project could be acquired two ways. The 94th Congress made provisions for both a conventional route, which would mean total participation by the Federal Government, and one which would entail a joint venture between State and Federal governments. In the conventional method, Congress would authorize the Corps of Engineers to conduct Phase I advanced engineering and design for development of the river. If determined to be feasible and supported locally, the Corps would then go to Congress for authorization to begin construction. The Federal government would then own the project and its cost would be repaid through revenue from power sales.



A DAM

(OBTAINED FROM "SOUTHCENTRAL RAILBELT AREA, ALASKA; UPPER SUSITNA RIVER BASIN INTERIM FEASIBILITY REPORT").

The other method, leading to state ownership, would use state money to finance federal construction. Here Congress has authorized a holding fund with the Corps of Engineers, consisting of $25 million for "front" money. The Corps could use this original $25 million for Phase I AE&D. If, at the end of the study, the project is determined to be economically unfeasible, then the Federal government would absorb the $25 million cost. On the other hand, if the report concludes that the project is feasible, the State of Alaska would have to repay the holding fund. Congress could then authorize the Corps to construct the project for the State of Alaska with state funds. At the end of construction, Alaska would own the project entirely. Alaska funding would come from the sale of revenue bonds which would be paid back from power revenue returns.

Development of the Susitna River would aid efforts toward U. S. energy independence by conserving annually the equivalent of 113 billion cubic feet of natural gas, or 15.2 million barrels of oil. Unlike most civil works projects, the entire outlay for the construction and operation of the system would be paid back to State or Federal treasuries through revenue returns from the sale of energy to local consumers. The jobs that would be created during the 11-year construction phase would mean opportunities for under- or unemployed workers.

From a regional standpoint, the project would provide an immeasurable stabilizing effect on the energy system of southcentral Alaska. There would be adequate energy available to meet demands; there would be incidental benefits associated with an integrated transmission system. Electrical utility costs would be lower than for other power sources, and rate hikes resulting from fossil fuel cost increases would be in proportion to the limited amount of conventional generation used in the integrated system. Additional benefits could be realized from limited flood control and recreational enhancement.

Alaskans will soon have to decide if they really want to develop the tremendous energy potential of the Upper Susitna River. In an age of ever-shrinking resources, the Susitna Project may be the answer to southcentral Alaska's increasing power needs.

REFERENCES

[1] "Electric Power in Alaska, 1976-1995," Report prepared for the State of Alaska House Finance Committee, 2nd Session, 9th Legislature, by the Institute of Social and Economic Research, University of Alaska, Fairbanks, 1976.

[2] Kachadorian, W. A., "Geology of the Devil Canyon Dam Site," U. S. Geological Survey Open File Report 74-40, 1974.

Eric Yould is Chief Hydrologist for the Alaska District Corps of Engineers. Mr. Yould is in charge of all hydrological studies and the economics associated with them for all projects in Alaska under the Corps jurisdiction.

Work underway on the gate shaft.

HYDROELECTRIC POWER FOR EKLUTNA

by Claus M. Naske

Hydroelectric power is not new in Alaska. In the 1930's, although the state was still thinly populated and little changed in some respects since the days of the gold rush, larger Alaskan settlements nevertheless enjoyed many of the amenities of modern living. They had phone service, water systems and electricity. Most communities generated power from coal or oil, but occasionally small hydroelectric power plants were used.

One such installation was built by private interests in 1929 at the mouth of Eklutna Lake, some 24 miles northeast of Anchorage. Seven-mile-long, one-mile-wide Eklutna Lake, elevation 868 feet, lies in a steep-sided, troughlike valley some 23 miles long, headed by a glacier and a snowfield. The lake overflowed through Eklutna Creek below the rock dam, which had been built to provide a water supply for the small power plant near Eklutna Village, about 8 miles downstream from the dam.

The initial structure was not overly successful because when the water level rose four to five feet above its natural barrier, the slightest leak allowed the water to escape. To remedy the situation, wood pilings were driven across the mouth of the overflow channel, permitting the storage of water to a depth of three to four feet above the natural lake level.

In the fall of 1934 contractors built an earth- and rock-fill structure which incorporated portions of the original dam. It provided a more stable water supply which ensured a more dependable generation of electricity. In 1943 the city of Anchorage purchased the dam from the private owner.[1]

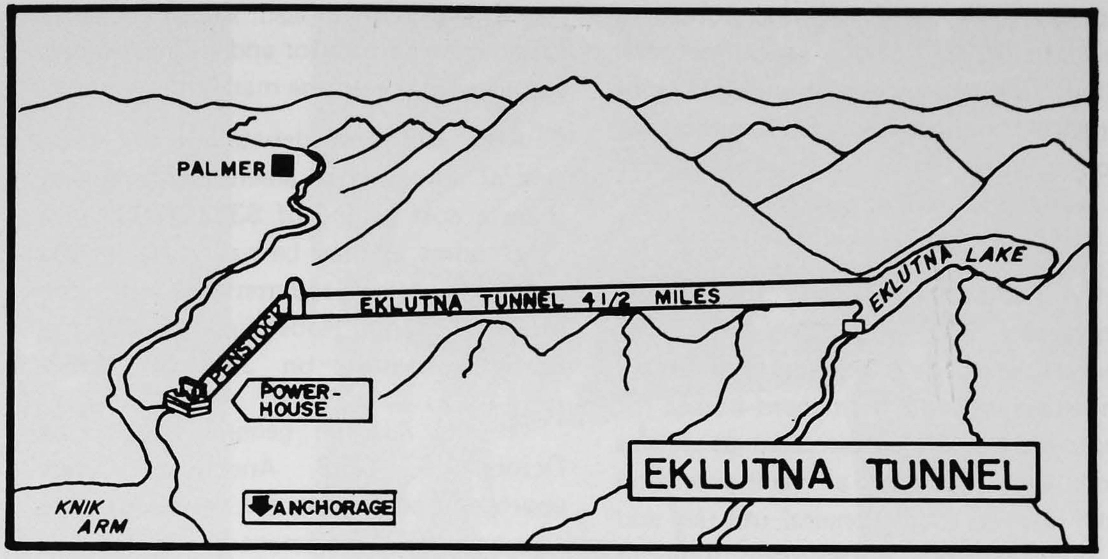
World War II had brought an influx of people to Alaska, particularly to Fairbanks and Anchorage where military construction activities offered employment. Housing, never abundant, was extremely difficult to find, and services could not keep up with increasing demands.

Alaska's man in Washington, territorial delegate E. L. (Bob) Bartlett, received calls for help from many Alaskan towns. To alleviate Ketchikan's power shortage, he was able to obtain a surplus Navy destroyer whose power plant produced some 400 kilowatts per hour. For

Anchorage, the delegate arranged the purchase of 600 and 350 kilowatt generators from the Surplus Property Office. But this was not enough and the city wanted Bartlett to obtain a power barge, destroyer or some other portable plant until Congress approved a requested $7 million improvement bond issue from which $1.5 million was to be used for a new 5,000 kilowatt capacity power plant.[2]

This patchwork action kept Anchorage supplied with power, but requirements continued to increase. The River and Harbor Act of March 2, 1945, had provided for preliminary examination and surveys of Cook Inlet to improve navigation, develop hydroelectric power, and provide harbor facilities. A spokesman for the Corps of Engineers advised Bartlett to introduce legislation which would authorize the construction of a plant at Eklutna.[3]

Representative Ben F. Jensen (R., Iowa), chairman of the House Interior Department Appropriation Subcommittee, interested himself in Alaskan development and was largely responsible for making $150,000 available for an investigation of the territory's power resources. An Alaska Investigations Office was established and under the able leadership of Joseph M. Morgan and his colleagues, an exhaustive investigation of Eklutna and other potential hydroelectric sites was made.



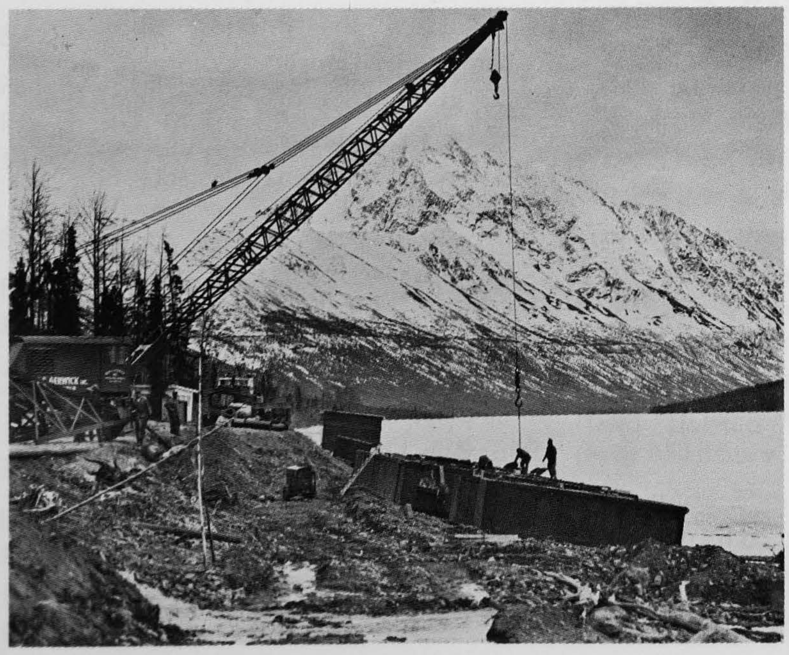
Schematic view of what Congress bought.

The investigation determined that, as of 1949, the utility system serving the Anchorage area and the Matanuska Valley had a production capacity of only 8,625 kilowatts--far short of actual needs. Total Alaskan generating capacity from private plants amounted to 35,931 kilowatts and from public plants to 19,440 kilowatts, for a grand territorial total of 55,371 kilowatts, woefully inadequate for Alaskan needs. Delegate Bartlett asserted in Congress that Federal policy had actively and long supported the development of water resources in the West, while not "a thin dime" had been put into Alaskan water power development. He argued that a "start should be made now" because plentiful power was a prime necessity for "a self-sufficient economy," which, in turn, "was essential for national defense."[4]

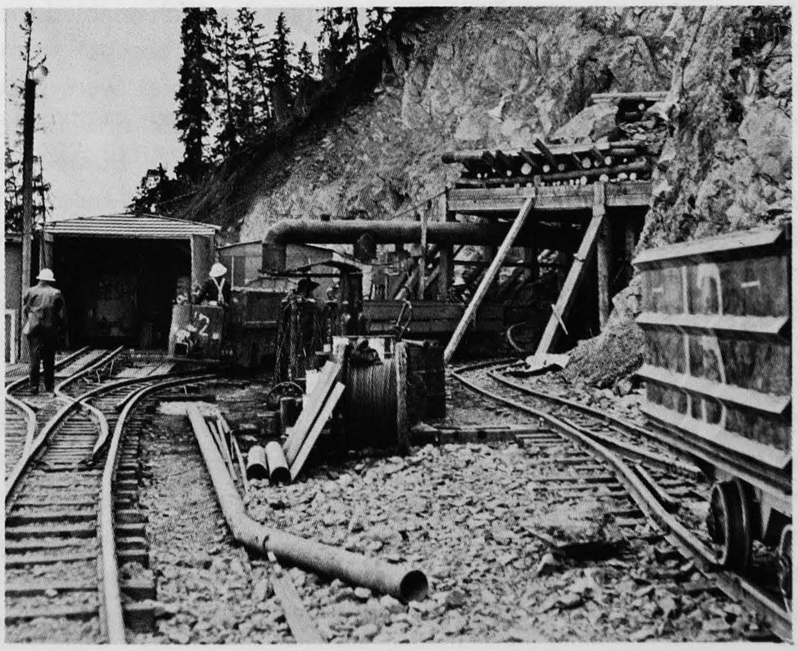
In 1949, the House Public Lands Committee favorably reported a bill which called for the immediate construction of the Eklutna project at a cost of $21,500,000. The Bureau of the Budget gave its approval with the reservation that Federal Reclamation laws were not to be extended to the territory, nor were recreational facilities to be developed along with the project.[5]

The proposed Eklutna facility was to consist of a low dam raising the level of the lake by two feet, a four-and-one-half-mile tunnel leading from the lake through a mountain to the north, a penstock of 1,250 feet and, at the base of the mountain, a power plant of 30,000 kilowatt capacity. Transmission lines would carry the electricity to the Matanuska Valley and to Anchorage.[6] Not until

Ben C. Gerwick, Inc., a subcontractor on the project, uses a crane to assemble barges for dredging Eklutna Lake.



View of tunnel train entering the north portal of the nine-foot diameter tunnel.



September 22, 1950, did the Bureau of Reclamation officially announce that initial plans and specifications were being expedited along with a $1.1 million appropriation to enable construction bids to be received as soon as possible.

By February of 1951, the drilling contractor was employing shifts of workers, seven days a week. In the planning stage were 12 permanent homes for employees at the power plant as well as two 10-car garages, a warehouse and water works, roads, general utilities and a 115,000 volt transmission line to Palmer. Palmer Constructors of Omaha, Nebraska, a three-firm organization including Peter Kiewit Sons, Coker Construction Co. and Morrison-Knudsen Co. had won the bid for building the four-mile long, nine-foot diameter, transmountain water diversion tunnel and other facilities at Eklutna for $17,348, 865. The bid called for completion of the project within 1,050 days.[7] It was soon apparent, however, that the cost of the project had been underestimated. Bartlett was naturally perturbed when several House Committee members advocated abandonment and he pressed for money to complete Eklutna. Certainly abandonment would have been an extremely effective demonstration of Congressional displeasure at the cost overrun, but would mean that the $11, 729,000 already expended would be wasted, as G. W. Lineweaver, Acting Commissioner of the Bureau of Reclamation, pointed out.

On April 2, 1953, after a year's delay and much political maneuvering, the Territories Subcommittee of the House Interior and Insular Affairs Committee debated the Bartlett bill and made a number of recommendations. These were that the cost increase be limited to $30,000,000; that annual operation and maintenance expenditures be restricted to $120,000; that electricity be sold at no less than 11.5 mills; and that the Department of the Interior negotiate with the city of Anchorage for the purchase of existing hydroelectric facilities and water rights at no more than the original costs minus a reasonable depreciation. Until these stipulations were met, and the Department of the Interior had negotiated with Anchorage, the full House Committee on Interior and Insular Affairs would not take up the matter.[8]

After still more debate and the adoption of a number of amendments, among them a cost ceiling of $33,000,000 plus "such sums as may be necessary for the operation and maintenance of the project," the full House finally passed the Bartlett measure on July 30, 1953.

At the Alaskan general election of October 6, 1953, Anchorage voters approved an agreement between the city and the Department of the Interior that stated as soon as power went on line at Eklutna, Anchorage was to transfer the site of its original hydroplant, together with its water rights at Eklutna, to the Department. In return, Anchorage was to receive some 16,000,000 kilowatts of firm power from Eklutna with monthly credits on the city's electric bill to be given until October 12, 1978, the date on which the license from the Federal Power Commission expires.[9] Eklutna power for Anchorage became a reality when the first 15,000 kilowatt unit went on line in January of 1955 and the second in March of the same year. The total project had cost $30,521, 183, approximately $2,500,000 less than the amount Congress finally authorized.

Alaska entered the union in 1959, and by then it had become clear that with the rapid growth of the Anchorage metropolitan area, power demand again far outstripped available generating capacity. Bartlett, now one of the Senators from Alaska, introduced a bill which enabled the Bureau of Reclamation to accept from Anchorage whatever monies were necessary to raise the dam at Eklutna to convert 20,000,000 kwh annual dump power to firm power. At hearings held in May of 1960, the small rural electric cooperative associations in southcentral Alaska opposed the Bartlett measure because it allowed Anchorage to purchase extra power at a discount rate at the expense of other consumers of Eklutna power. The Bartlett bill subsequently died.[10]

On March 27, 1964, at 5:36 p.m., an earthquake, registering 8.5 on the Richter scale, shook southcentral Alaska and devastated several communities. Eklutna suffered much damage to its power plant. As soon as possible after the earthquake, the Bureau of Reclamation performed temporary repairs to restore the power plant and pressure tunnel to normal operation and ensure an adequate supply of water.

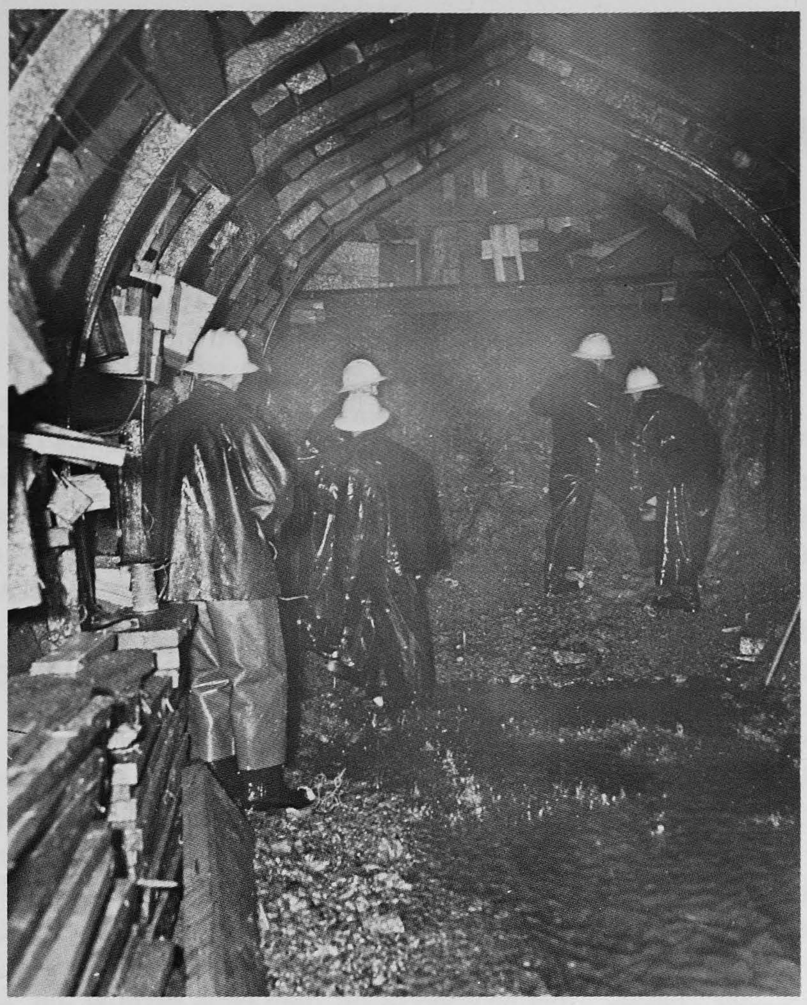
On September 16, 1964, Senator Bartlett submitted a measure on behalf of Senator Gruening and himself which provided that any repair money spent on Eklutna would not be reimbursable from its revenues. The Senator reintroduced the measure in 1965, and the Department of the Interior reported on it favorably in April of 1966. But the Bureau of Reclamation had since been forced to construct a new dam--for $121,000 more than the estimated repair costs to the old one. Bartlett asked that the $121,000 be reimbursable while the estimated repair costs be absorbed by the Federal government. His measure was signed into law on September 26, 1968, saving Eklutna's power customers $2,805,437.

REFERENCES

[1] House of Representatives, 82nd Congress, 1st Session, House Document 197, *Alaska: Reconnaissance Report on the Potential Development of Water Resources in the Territory of Alaska*, Government Printing Office, Washington, D. C., p. 156, 1952. Also extracts from *Rehabilitation of Eklutna Project Following 1964 Earthquake*, U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, June 1967, in E. L. Bartlett's Papers, 90th Congress, Legislative Bill File, Rehabilitation of Eklutna Project, Box 4, 224, 1967-68.

[2] E. L. Bartlett Papers, 81st Congress, Legislative Bill File, Box 2, File H. R. 940, Eklutna Hydro Power, 1949-50; E. L. B. to Bob Lindquist, December 3, 1945; Bob Lindquist to E. L. B., December 5, 1945.

[3] Conrad P. Hardy, Colonel, Corps of Engineers, to Charles A. Wilson,



A final check being made in the wet weather under Goat Mountain before blasting on the north heading of Eklutna tunnel.

A battery-driven locomotive inside the Eklutna tunnel, a 4 1/2-mile long bore driven through the Chugach Mountains.

Anchorage Public Utilities, April 16, 1946, E. L. B. Papers, 81st Congress, Legislative Bill File, Box 2, File H. R. 940, Eklutna Hydro Power, 1949-50.

[4] E. L. B., in support of H. R. 940, Box 2, Eklutna Hydro Power, week of July 11, 1948.

[5] E. L. B. to Robert Atwood, E. L. B. Papers, 81st Congress, Legislative Bill File, Box 2, Eklutna Power Project, June 14, 1949.

[6] E. L. B. in support of H. R. 940, E. L. B. Papers, 81st Congress, Legislative Bill File, Box 2, Eklutna Power Project, July 11, 1949.

[7] Joseph M. Morgan to E. L. B., February 9, 1951; Bureau of Reclamation News Release, E. L. B. Papers, 81st Congress, Legislative Bill File, Box 2, Eklutna Power Project, September 20, 1951.

[8] E. L. B. to George C. Shannon, April 2, 1953, E. L. B. Papers, 83rd Congress, Legislative Bill File, Box 1, Eklutna Power Project, 1953-54.

[9] Bureau of Reclamation News Release, December 2, 1953, E. L. B. Papers, 83rd Congress, Legislative Bill File, Box 1, Eklutna Power Project, 1953-54.

[10] E. L. B. Papers, 86th Congress, Legislative Bill File, Box 9, S. 3222, Eklutna Power Project, 1959-60.

Dr. Claus M. Naske, a frequent contributor to TNE's Historical Engineering section, is on sabbatical leave this year from the University of Alaska's Department of History.

TNE is grateful to Mr. Olav Liland, Alaska Area Manager for Morrison-Knudson Co., Inc., for providing us with pictures of the Eklutna tunnel. Some of them first appeared in the June 1952 issue of the EM-Kayan, the company magazine, as did the original of the tunnel cutaway diagram.

That issue also provides some insight into the problems of providing hydro power to Anchorage at a level different from those discussed in Congress: "...old-time tunnel stiffs will admit the Eklutna bore is a real job. At its deepest point below ground, the tunnel will be 4,500 feet--almost a mile--beneath the snow-capped top of Goat Mountain. On May 3, Palmer Constructors' tunnelers had driven 2,000 feet into the mountain from the north portal...In that first 2,000 feet they had made an average of 25 feet of forward progress daily, bucking badly-fractured rock that required extensive timbering and bracing. Worse yet, however, was the ground water that came gushing in a steady downpour near the heading at a bone-chilling temperature of 36 degrees."

by Robert F. Shaw

THE MOOSE CREEK DAM

Moose Creek Dam is an earthfill structure being built 17 miles east of Fairbanks, Alaska, on the Chena River under the supervision of the U. S. Army Corps of Engineers. The dam is part of the Chena River Lakes Project, a predominately federally funded flood control project, authorized by the Flood Control Act of 13 August 1968. When completed, it will consist of an approximately 30 foot high earthfill embankment extending from the old Moose Creek Dike northeasterly for approximately 7.5 miles to an unnamed ridge north of the Chena River.

The dam will not have a permanent reservoir since it is designed to retain water only when the Chena River flow exceeds its channel capacity. When the Chena River does flood, the dam control works will regulate the river's flow and divert the flood waters by way of a diversion channel into the Tanana River. From there the Tanana River Levee protects the flood plain from both the Chena and Tanana flood waters to the end of the levee west of the International Airport.

PHYSICAL SETTING

The flood plain protected by the dam and levee encompasses the entire city of Fairbanks, the city of North Pole, several unincorporated residential districts, the Fort Wainwright military reservation, the International Airport, and portions of the University of Alaska.

Flooding in these areas can result from an overflow of either the Tanana or Chena Rivers, but the most frequent severe damage is caused by flood waters from the Chena. Flood damages due to seepage occur when the Chena River discharge at Fairbanks is in excess of 10,000 cubic feet per second (cfs) with additional damages experienced at bankfull flows of 12,000 cfs. Major floods occurred in 1948 and 1967, causing $16,500,000 and $97,050,000 in damages respectively (adjusted to 1970 dollars).

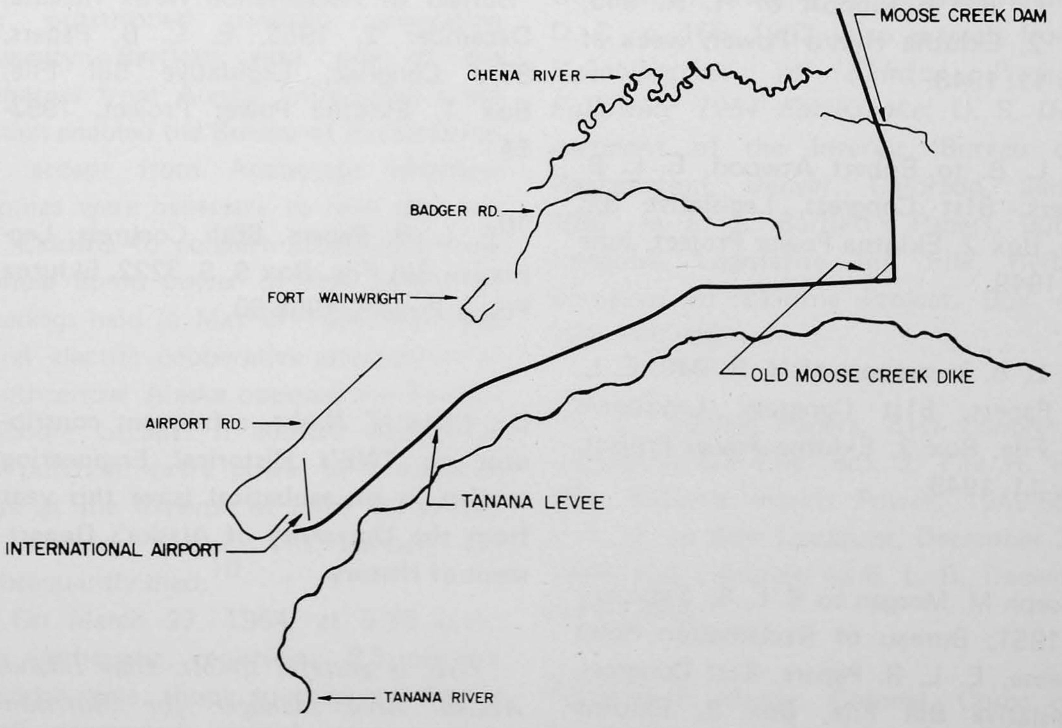
The local annual stream flow pattern consists of high flows during the summer months from May through September and low flows prevailing from September through April. Streams are frozen over during the winter and flow is produced by discharges from ground water storage. As the ground water storage is depleted, flows diminish until minimum flows occur in March or April. Following breakup, flows increase rapidly, and peak flows occur in May or June. Tributaries originating high in the Alaska Range feeding the Tanana River respond more slowly to the annual thaw, and the result of their flows is observed at Fairbanks in July and August.

Maximum precipitation occurs in July and August, and river discharges resulting from these rains may produce floods of relatively short duration.

Major floods result from either severe rainfall or a combination of rainfall and snow melt. Rain floods can have exceptionally high peaks, such as the August 1967 flood, but are of shorter duration than snow melt floods. When rain augments snow melt runoff, the floods have both high peaks and large runoff volumes. The spring floods resulting from melting snow and a warm rain combined with frozen ground conditions give both a high peak and a large volume.

The Standard Project Flood (SPF) was developed for both spring and summer conditions and the summer conditions were used since they produced the most critical conditions. The SPF used for design analysis on the Chena River at the Moose Creek Dam site was of a spring peak flow at 82,000 cfs and summer peak at 93,000 cfs. The Probable Maximum Flood (PMF) at the same location for spring was 164,000 cfs, and for summer was 186,000 cfs. The accompanying tables give further calculations.

The site of the Moose Creek Dam relative to the Fairbanks area.



LOCATION	CAPACITY CFS
Chena River below Moose Creek Dam	7,600
Channel from Moose Creek Dam to Tanana River	190,000
Chena River through Fairbanks	12,000
Tanana River at Fairbanks	115,000

TABLE I. ESTIMATED PEAK DISCHARGE FREQUENCIES IN CFS

Analysis of the above data led to the following design criteria: PMF maximum pool elevation, 525 feet; outlet and spillway capacity, 186,000 cfs; SPF maximum pool elevation, 519.3 ft. The normal elevation of the Chena at the Moose Creek Dam site is 500 feet.

DAM DESIGN

Another consideration which entered into determining the design height of the dam was the construction of the upstream diversion channel floodway between the dam and Moose Creek Bluff. Considerable study had to be made to determine the most economic alignment of the dam because the closer the dam was placed to the Bluff, the less real estate had to be purchased for the floodway, but the higher the cost of the dam because the flood water height was forced up by the constricted floodway and consequently the required dam height and construction costs increased. The present alignment was determined to be the most economical trade off between floodway costs and dam height.

The floodway alignment crosses an existing four-lane divided highway and railway. Both routes are being rebuilt to pass over the dam and cross the floodway on bridges. Bridge approach, pier, and abutment design required another economic trade off to allow maximum unrestricted flow through the floodway for minimum construction costs.

The floodway was designed to hold clearing to a minimum and to present a natural appearance. The cleared area will be a maximum of 1,200 feet wide and will require reclearing every 5 years. This will be the principal flow channel for large floods. It will prevent blockage and backup due to debris lodging in trees and will direct large flood flows and concurrent high water velocities away from the dam. A gravel cutoff dike will intersect the dam to prevent high velocity flow of flood waters along the toe of the dam.

Along the floodway between the Chena River and the bridges, north of the gravel dike, is the low point of the floodway, elevation 487 feet. Since flood waters will be trapped in this area, the Alaska Department of Fish and Game required that the water be drained from this area as rapidly as practical to minimize damage to vegetation and trapped fish. A four-cell (each cell being 5′ x 5′) concrete box culvert has been constructed through the dam at the low point to allow for drainage. The culvert will be gated to prevent flow during a flood.

The design of the dam embankment proper was dependent upon the site conditions. The Chena River occupies a broad, flat, mature valley which is filled with layers of sand and gravel deposited by an aggrading stream. The rock in the bluff to the north is Birch Creek schist, which is highly fractured and folded, exhibiting various degrees of weathering. Foundation materials consist of up to 24 feet of nonplastic inorganic silts and sandy silts overlying relatively clean stratified sands and gravels. The average depth of the silts is 8 to 10 feet and the underlying gravel base is 600 feet thick.

Seasonal frost penetrates depths of 1 to 30 feet and permafrost may exist locally to depths of 100 feet or more. However, no significant areas of permafrost were found along the dam alignment. The ground water averages a depth of 10 feet with seasonal variations of 3 feet. Triaxial loading tests were conducted to determine the mechanical strength of the foundation underlying the dam. The permeability of the gravels was estimated to be 1,000 feet per day, and of the silt blanket to be 1 foot per day.

Based upon these foundation conditions, foundation excavation was required under the dam embankment to ensure removal of all silts and sandy silts to improve the stability of the structure. A gravel berm of varying width was provided at the downstream toe to prevent piping and damage from uplift pressures. A select gravel filter will intercept seepage under and through the dam with lateral drain pipes to collect the seepage waters and carry them under the downstream gravel berm. The collected seepage water will drain into an open channel drainage ditch approxi-

TABLE II. RIVER CHANNEL CAPACITIES

	NON-REGULATED FLOODS		REGULATED FLOODS	
RECURRENCE INTERVAL YEARS	CHENA RIVER FAIRBANKS	TANANA RIVER MOOSE CREEK BLUFF	CHENA RIVER FAIRBANKS	TANANA RIVER MOOSE CREEK BLUFF
5	19,500	92,000	12,000	102,000
10	25,800	106,000	12,000	119,000
25	37,000	129,000	12,000	148,000
50	47,500	157,000	12,000	176,000
100	60,000	194,000	12,000	215,000

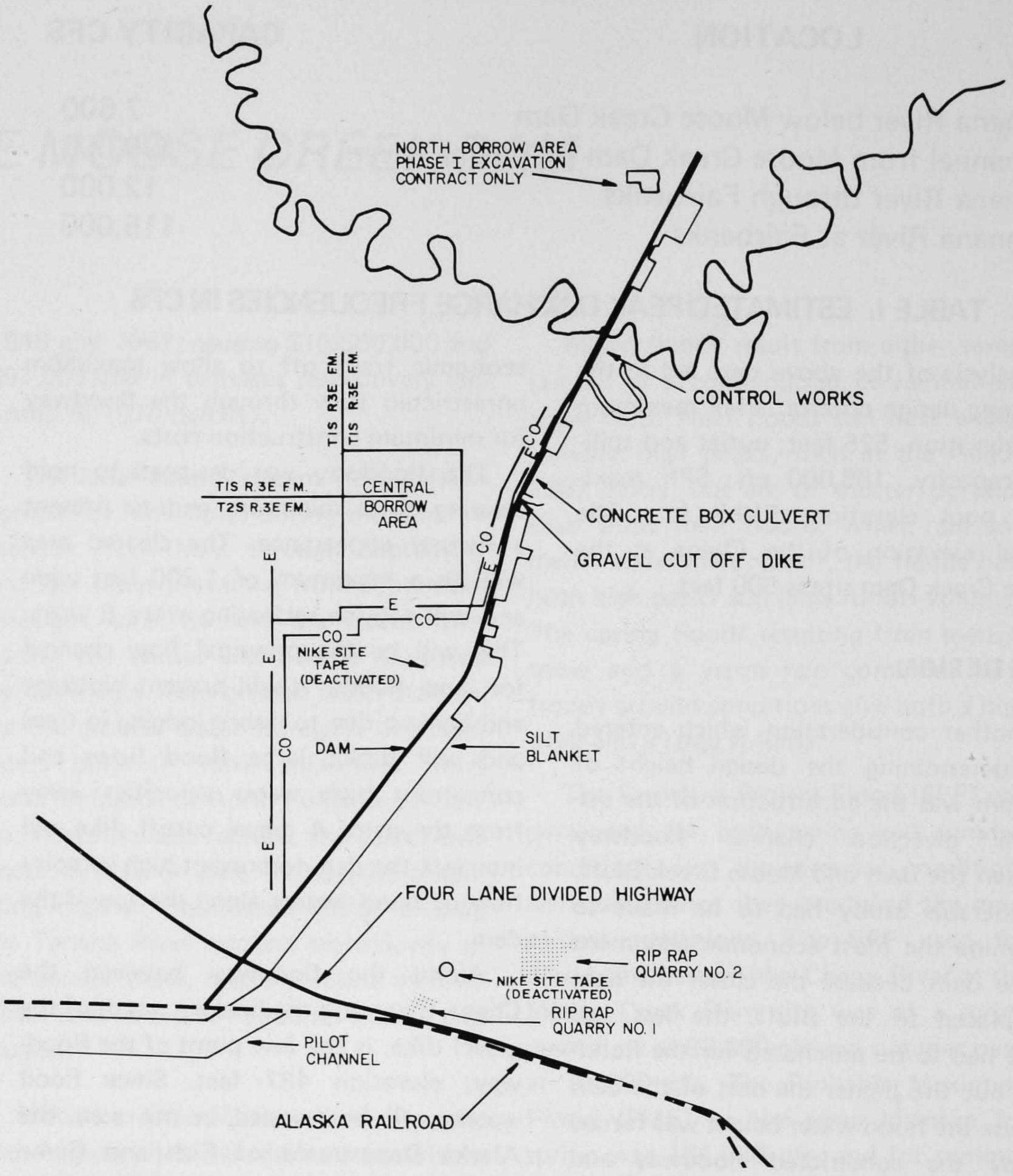
mately 400 feet downstream and parallel to the dam. This ditch is connected to collection channels which will eventually release the seepage waters into the Chena River well downstream of the dam. Upstream of the dam the natural silt cover overlying the gravels will be overlain with additional fine-grained material to ensure the existence of an impervious blanket at least 1,000 feet wide and 5 feet thick for the entire length of the dam.

The embankment was originally conceived as a homogeneous semipervious earthfill. A detailed examination of borrow materials available found sufficient free draining gravels to warrant a change in design. The final design uses the following:

a. *Semipervious gravel* consists of moderately well graded gravel containing 7 percent to 15 percent passing No. 200 sieve and no more than 50 percent passing the No. 4 sieve.

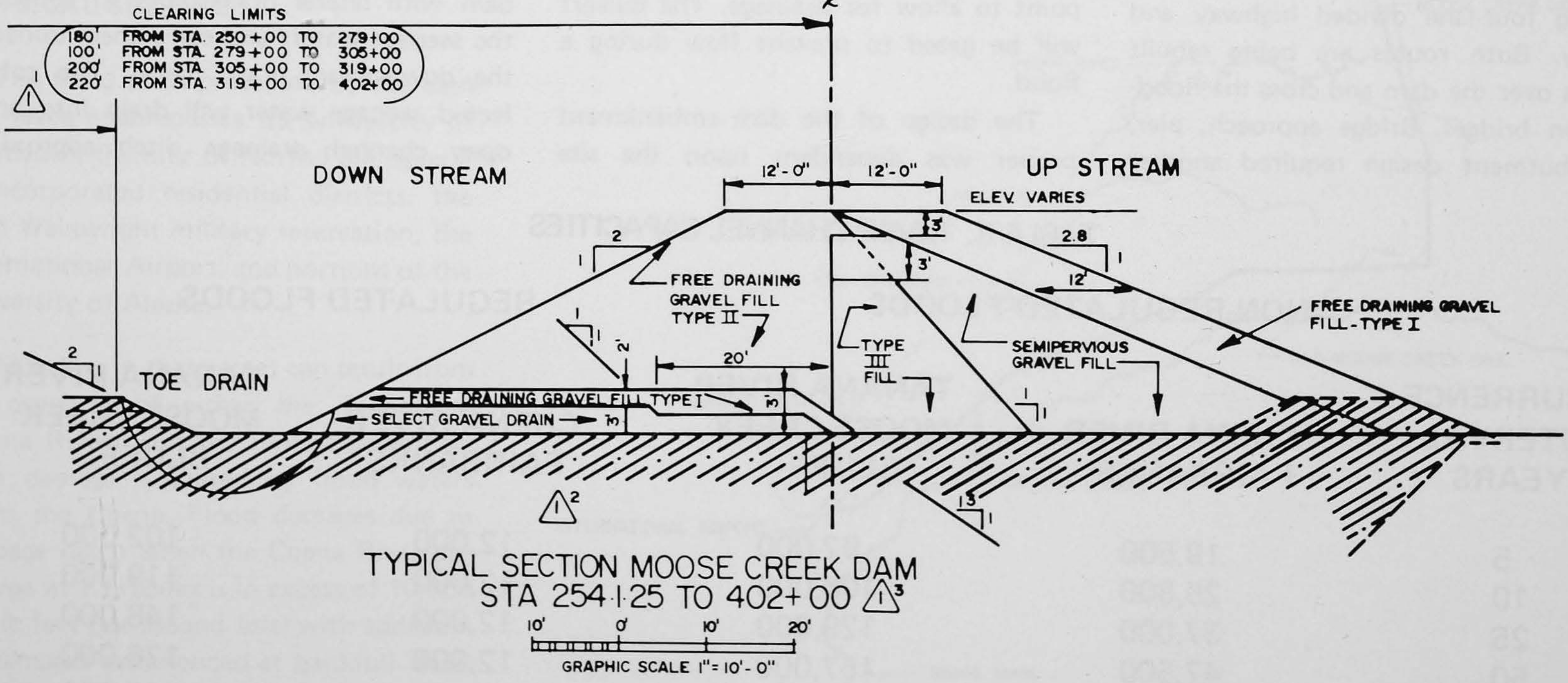
b. *Free draining gravel, Type I,* consists of gravel containing not more than 4 percent passing the No. 200 sieve and not more than 40 percent passing the No. 4 sieve.

c. *Free draining gravel, Type II,* consists of moderately well graded material containing not more than 4 percent by weight passing the No. 200 sieve and not more than 60 percent by weight passing the No. 4 sieve.



Map showing design of the Moose Creek Dam Complex.

A typical section of the Moose Creek Dam showing fill arrangement.



Aerial view looking southeast to the Tanana flats along the Moose Creek dam alignment. Earth coffer dam in foreground surrounds the control works site.

d. *Free draining gravel, Type III,* consists of a mixture of silt, sand and/or gravel containing not more than 15 percent passing the No. 200 sieve.

e. *Select gravel* consists of gravel containing not more than 3 percent passing the No. 200 sieve, not more than 10 percent passing the No. 4 sieve and not more than 85 percent passing the 1 inch screen.

The stratified nature of the sands and gravels in the project area has required some blending and sorting of materials to obtain the required gradations, particularly insofar as the semipervious gravels are concerned.

The control works on the Chena River will be a concrete gravity structure in line with the dam. Four outlets, 20 feet high by 25 feet wide, will be controlled by sluice gates. The size was selected so as to be able to make releases that will not exceed 12,000 cfs in the Chena River at Fairbanks when combined with local drainage from the area downstream of the dam. The outlets are set low in the structure so that ice will not form against the gates. Gate machinery will be located on the top deck and heating units will be provided for the machinery, trunnions, and gate seals. Additional gate mounts will be provided upstream and stoplogs downstream of the sluice gates for emergency, dewatering, and maintenance purposes.

PROGRESS AND COMPLETION

The dam has been under construction since 1973. So far the foundation excavation, the low point drain, and the embankment from the near floodway bridges to the control works have been completed.

During the 1977 construction season the bridge should be completed and the control works essentially completed.

Construction has proceeded with relatively minor problems. The site conditions have presented few unforeseen problems and, very fortunately, no permafrost. Some frozen gravels have been encountered in the borrow pits, but they have had little ice content and were thawed by the time they were placed in the embankment. Some problems were encountered in protecting concrete work from freezing weather, but this was solved by normal cold weather construction methods and supervision.

By planning and proper protection of curing concrete, the construction season should be from April through October with the dam providing flood protection by October, 1979.

Author's Acknowledgements

This article was compiled from information contained in Design Memorandums No. 5 and No. 10, Chena River Lakes Project, U. S. Army Engineer District, Alaska, Corps of Engineers, and office records of the Fairbanks Resident Engineers Office. Assistance was provided by Major Leo M. Laska, Project Engineer, and Mr. Robert E. Davidson, Embankment Engineer.

* * *

Robert F. Shaw is a civilian employee of the Fairbanks Resident Engineers Office, U. S. Army Corps of Engineers. He is a graduate of the United States Military Academy and expects to complete work for a Master's degree in Engineering Management at the University of Alaska in May 1977.

by Joseph W. Meeker

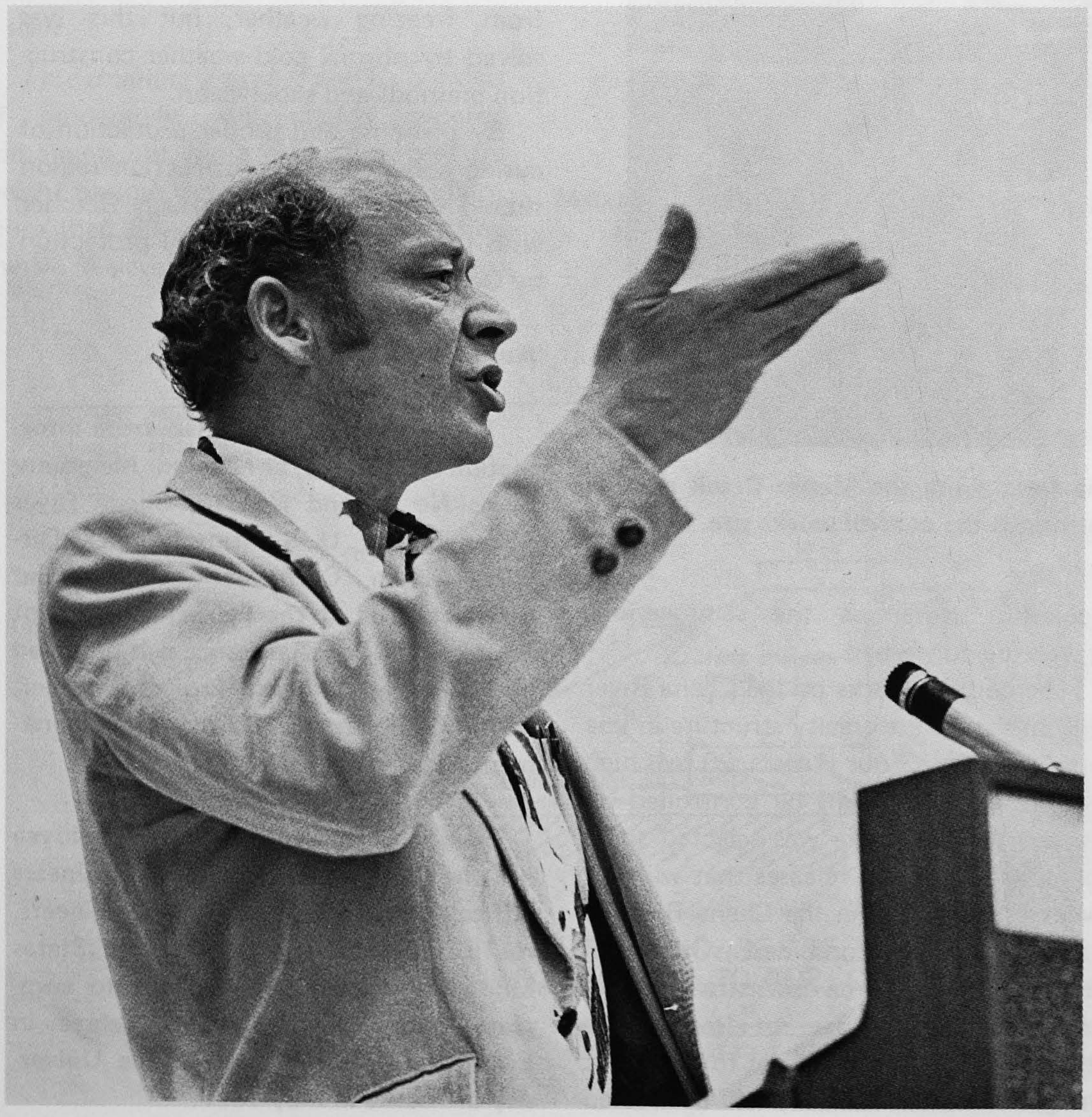
NORTHERN CHANGE IN PERSPECTIVE

If This Is North, Which Way Is Tomorrow?

On November 18-19, 1976, the Arctic Institute of North America, in cooperation with the Alaska Humanities Forum, sponsored a Conference on Northern Change–The Canadian Experience/Implications for Alaska, in Anchorage, Alaska. At the conclusion of this conference, Mr. Joseph Meeker, Interdisciplinary Professor, Athabasca University, Edmonton, Canada offered a summation and a prospective. After reading Mr. Meeker's provocative remarks, we felt that they would be of interest to readers of The Northern Engineer and asked permission to publish them. Mr. Meeker's thoughts will obviously appear spoken rather than written, but we feel important considerations are discussed here for anyone having the orderly development and well-being of the North and its peoples as their concerns. We encourage response from our readers. We are grateful to Mr. Meeker for allowing us to publish his talk and to Ms. Claudette Reed, Coordinator of the Conference, for her interest and encouragement.

Dr. Joseph Meeker

Photograph by Paul Helmar



Perhaps we need to summarize not only this meeting, but also the larger record of resource development and extraction in the North and in our larger cultural tradition. We cannot hope to achieve the four-million-year perspective that has been recommended here, but we can at least look a bit further beyond our noses than we have done so far in this meeting.

HISTORICAL RESOURCE DEVELOPMENT

There are few fairly consistent principles that are evident when you look at large-scale resource extraction and developments of various kinds in our cultural history. For one thing there aren't many cultural centers in our civilization, or in its past, which were also and at the same time, sources of wealth and energy. The general pattern is that the source of the wealth and energy does not itself benefit from it and does not use its own energy or resources to provide creative or lasting gifts to mankind as a whole.

One distant example that is, I think, fairly typical of that tradition comes from the third millenium B. C. in Mesopotamia. One of the conference participants wondered if the Mesopotamians did impact studies before they went ahead with things; I can affirm to him that they probably didn't. The ancient *Epic of Gilgamesh* describes what they did instead. One of Gilgamesh's problems was that he wanted to leave an enduring record to prove that he had been on the earth for a time and to keep his identity alive. He had to build a monument of some kind, so he decided to build a city, and for this he needed wood. He lived in Uruk, a place where wood was scarce at that time, and so he went elsewhere to get it. He went to Lebanon. And he's the guy who cut all those cedars of Lebanon, and hauled them to Uruk to build his great city. There aren't many cedars left in Lebanon today, and Lebanon wasn't the source of great epics or other works of art--Uruk was.

That's roughly the way it usually works. Greek civilization was supported by trade and exploitation of other Mediterranean cultures and areas. Then there's the whole sad story of what happened to the gold civilizations of more recent history in the West—the Aztecs and the other South American gold civilizations who did not themselves benefit from those resources, though others in Europe did. Egypt mined Nubia, Spain exploited her South American colonies, New York and San Francisco and Los Angeles profited from California's gold mines, and, of course, from Alaskan gold as well.

And then, more recently, there's oil, and we have to consider Oklahoma, and maybe Texas. Some say that Texas is a place that has both resources and culture, but those outside of Texas sometimes dispute that. The Middle East is grappling with oil problems now, as are nations on the North Sea, and, of course, we in the Arctic. These places are being "developed" for the advantage of somebody else, somewhere else. The places that produce wealth are seldom used to produce important things for mankind; rather they support other centers where art and thought flourish, while the sources themselves—the places that produce that wealth—are used up and destroyed in the process of production.

That implicit threat has been in the minds of most of us throughout this meeting, and it's time we made it a little bit more explicit. We're afraid that the Arctic, with which we're all connected in some way, for which we have some special attachment, might go the way of those other resource sources...down the drain.

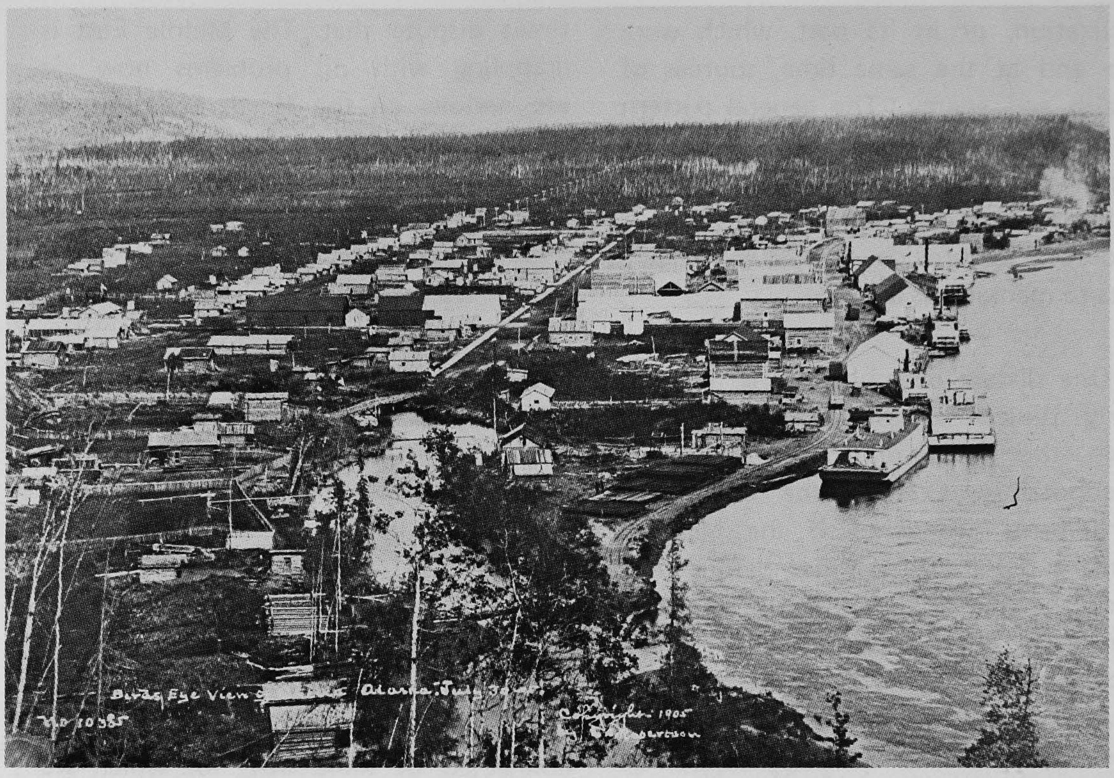
Another characteristic of resource development that is consistent over a long period of time is that it always seems to acquire a pseudo-religious character. Like all other wealth resources—gold, diamonds, and other goodies which have inspired people in the past—oil, too has a religious-type following. Or, perhaps more accurately, the machine technology that oil supports seems to generate religious commitments. Those who believe in it as a way of life share certain presuppositions and beliefs. The missionaries in this religion are usually engineers and businessmen. And they are supported, as other missionaries have been in the past, by governments which endorse their causes. They share a common belief in the myth of power; they believe in the inevitability of technological process.

One wonders what would happen, or what might have happened, if eighteenth-century missionaries had held a conference something like ours to assess the impact of mining the souls (and incidentally the furs) of the Arctic. I suppose they would have emphasized too, that they were governed by a divinely-sanctioned inevitability in their efforts. And it's most likely that they, like we, would have overlooked some of the important effects of their actions, simply because they were unseeable through the assumptions they were bringing to the task. Their spiritual impact study would probably have ignored the impacts that mattered most.

Well, what are the impacts that matter most? Some of the impacts of resource development are historically clear. There are characteristics that have now become fairly constant, that occur in the places where oil and gas have been extracted in large quantities. These characteristics, too, have been implicit throughout much of this conference. That is, they are implicit as problems that we all are trying to think of ways to avoid if we possibly can. They became explicit at a couple of points in the conference, for instance, in Charles Hobart's[1] paper in which he summed up many of the cultural and social effects of oil extraction and other exploitation projects. Charles borrowed the words of Ruth Benedict to summarize such impacts: "Our cup (the cup from which we drink our life) is broken."

Obviously, there must be some serious environmental damage in places where large-scale extractions have taken place. Some of it will be permanent and irreversible. There are sure to be major social disruptions for the resident populations. Their lives will suddenly be governed by external, uncaring forces which dictate the manner in which they will live, sometimes with token participation on their part. Many of the resident's rights are likely to be either ignored or denied. And perhaps worst of all, people who live amidst resource extraction share a common feeling that all power lies elsewhere. They feel impotent compared to those who make the big decisions that affect their lives: governments, corporations and others who live far away.

Other characteristics of places where resources come from are corruption and moral decay which always seem to accompany excess money and a large transient or irresponsible population. Anyone who has visited Fairbanks recently knows what I mean, but the same is true of most other northern communities that are associated with such developments. Many communities must also face some irreversible changes in community values and social values. Whether they're really irreversible or not remains to be seen, but as often as not in the past they have proved to be so. At this meeting, for instance, we've heard of the problems of native peoples who must accept some foreign way of life. Alaska's oil extraction has led directly to the adoption of American corporate structures for governing the Alaskan native community. It may also lead, we have heard, to the end of hunting life and its replacement by a wage-earning laboring economy.



"These places are being "developed" for the advantage of somebody else, somewhere else..." Chena, Alaska, in 1905 was a bustling river town that owed its existence to gold. Eventually the gold gave out, the river changed course slightly and today nothing whatever remains of a fair-sized townsite that flourished and died with an ephemeral industry. (Photograph Courtesy of the Wilson Erskine Collection, University of Alaska Archives, Fairbanks)

PROGRESS AND PEOPLE

Another big question that has been in our consciousness, if not in our words, over the past couple of days is whether oil and gas development is or is not a reasonable basis upon which to build a northern future. We heard that identified by Peter Usher[2] earlier in our discussions as a basic premise of Canadian government policy. Peter's comment was affirmed by Eric Gourdeau,[3] and it is perhaps implicit in the Alaskan policy as well, though we have not discussed that. But when we asked whether oil and gas is a firm basis for the future of the North, we must also ask if they are important to the long-term future anywhere, north or south. The whole history of oil's importance will run its course in decades, as we have heard from several speakers. Oil's total chapter in the whole of human history will amount to little more than one century. In that time perspective, the question acquires a new dimension: What are we getting—what is civilization getting—out of these few decades during which oil is prominent in our minds, and what are we giving up in exchange?

If the possible values of oil do not provide a good basis for the future of the North, or the future of anywhere, what then are the values that matter? Perhaps that's the most distressing thing about our conference to me. We've had very little discussion of what values are most important in the North, or of what might be done to maintain those values that are threatened by northern change. Of course, we did hear Keith Penner[4] affirm that "people are the first priority" in Canadian development policy, but he didn't explain which needs should come first or how to resolve conflicting demands among people, even though we have seen that the people of the North, especially the native communities, have different values and different priorities from people in the southern centers where that oil is going to be burned. Jim Riddick[5] added another statement of value: that land itself is a social value; but that probably means about the same thing as Keith Penner's statement, that people are the first priority. It assumes that land exists primarily for human benefit, and that human wishes govern all decisions concerning it. As I heard that, I was reminded of a contrary statement from another ancient culture, China. Chuang-Tzu, Taoist writer of the third century B.C., observed what was happening around him and came to the conclusion that "he who helps mankind must necessarily destroy the world." Maybe the point is that human and environmental values can't be separated, the way we have tended to separate them in our discussions during this meeting, because the humans after all remain animals living in their environments and they are dependent upon the same conditions as all other wildlife. The integrity of the whole has to be assured somehow, but we have given that problem very little attention during this meeting.

We have talked about some of the differences between what's happening in Alaska and in Canada. Both Canada and Alaska, of course, are subject to the same large, overall conditions which accompany resource extraction elsewhere. The difference between the two countries seems to be largely differences in method, and one suspects they may be relatively minor. There is more public participation in Alaska than there is in Canada, for instance. There are questions of state versus federal decisions, and which level of government has priority over the other. There are questions of more versus less profit, and Tom Kelly[6] reminded us that Canadians have found a way to profit much more than Alaskans from their oil development. These are relatively minor differences that in the long run may not matter much at all, one suspects.

The large consequences of Northern oil extraction have not been revealed by any of the differences we have uncovered between the Canadian approach and the Alaskan approach. It seems likely that Canada and Alaska will probably endure much the same conditions over the next few years or decades, with only minor differences. We're in the same boat, we face the same problems and we don't have radically different ways of coping.

TECHNOLOGY AND HUMAN VALUES

Let me come back then, for a minute, to the other kinds of values and resources that are available. Walter Parker[7] identified some important Northern values in his opening remarks, but we have not mentioned them since.

Walt reminded us of what most of us know very well, that the North really stands for freedom of the spirit. There is a sense of freedom here, and a sense of depth and significance that is appreciated by many people who have had long experience in the North. In other words, the North has emotional and spiritual resources which may be more important than oil. Some of those are accessible through tourism and leisure activities. Gerry Lee[8] reminded us how important it is to maintain natural settings in the North which people may use to satisfy inner needs. Self-discovery is important and the North is a great place to pursue it, according to people who live here in a significant relationship with the Arctic environment. It may be that the North's most significant resource is emotional and spiritual; special and deep experiences are available here that simply are not available elsewhere. They include the discovery of one's limits by testing them against an environment that is considerably stronger and more powerful than oneself, living in the presence of risks and of danger, and living in a scale that shows clearly where one is in relation to a large and relatively indifferent world.

IDENTITY CRISIS

Besides oil, there is another problem that Canadians and Alaskans share, and that they perhaps need to co-operate on. You've probably heard about the fabled Canadian identity problem. Canadians, it is often said, do not know who they are. The same is often said about Alaskans. Both Canada and Alaska have an identity problem because both are places where life is too often lived according to borrowed cultural values and in response to external forces. In both Canada and Alaska there has always been the sense that the real power is somewhere else—in Washington D.C., in London, in Houston. Wherever it is, power always seems out of the hands of the people who live in Canada or in Alaska. That is less true of the people who are native to these places, of course. The North is their identity, the setting for their indigenous culture, and the source of a strong and rich personal life. The problem for the transplanted white culture in the North is that borrowed values—the values of Mediterranean and European culture—simply don't fit the circumstances here, and consistently fail to meet peoples' everyday needs, internal or external.

Whether in Canada or in Alaska, identity problems exist for people who have not come to terms with the land they live on. Identity problems occur in climate-controlled bubbles at Prudhoe Bay, in the Polaris Building of Fairbanks, or in a split-level on Turnagain Arm. They are burdensome to Calgarians who live in an insulated manner in Tuktoyatuk, or for D.E.W. Line attendants on ice islands. For people who are technologically shielded from the conditions of the North, identity is a problem. No such uncertainty about identity is common among native people of the North, or among whites who live here intimately with the land. The Canadian identity is strong in the Canadian bush, just as the Alaskan identity is strong in the Alaskan bush. Character and self-knowledge arise from discovering one's limits in touch with the land, and from changing oneself in order to suit the place, not from changing the place, or insulating oneself from its conditions.

I'm suggesting that Northness is a resource, and one that may contribute toward solving the Canadian and Alaskan indentity problems. Oil, at the moment, is a diversion from that important task. Oil is a southern affair, not a northern affair. It is another southern affair that will hurt and will leave some scars, but it can't last too long.

The Canadian literary critic, Northrop Frye, made a wise observation about identity problems when he noted that the real question is not "who am I?," but "where is here?". Identity follows naturally from knowing and being a part of the place where one lives. For people who live in the Arctic, the answer to the question "where is here?", is the North. When Canadians and Alaskans start living more appropriately to the North, it may be that their identity problem if not their oil problem, will be near its solution.

REFERENCES

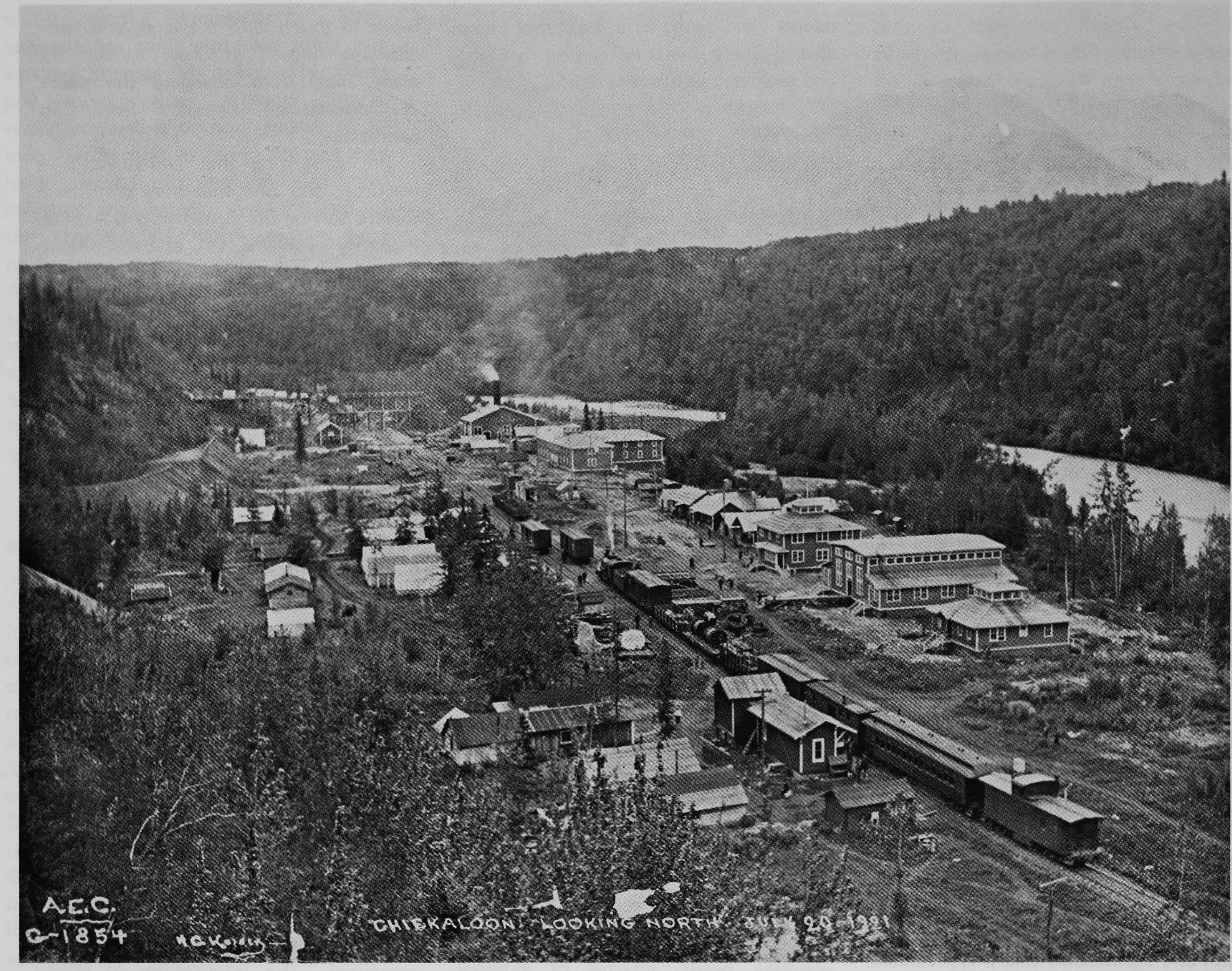
[1] Charles Hobart, Department of Sociology, University of Alberta, Canada, presented "The Implications of Policy for Political/Social Institutions."

[2] Peter Usher, formerly of the Committee on Original People's Entitlement, Canada, presented "The Implications of Policy for the land and the People."

[3] Eric Gourdeau, Consultant, Lecturer, Laval University, Quebec, Canada, was a member of the panel on "Equity in the Land: Who has What Right of Use/Ownership?"

[4] Keith Penner, Parliamentary Secretary, Department of Indian and Northern Affairs, Canada presented "The Goals of Canadian Resources Development and the Evolution of Policy."

[5] James Riddick, Manager Environmental Program, Polar Gas Project,



"The source of wealth and energy does not necessarily benefit from it..." In 1921, when this picture was taken, Chickaloon, Alaska, one mile northwest of Mile 78, Glenn Highway, was a thriving community. The town, built and owned by the Federal Government, was located in the Chickaloon coal region and was established to provide coal for a two-ocean navy. Halfway through a million dollar project to build a coal washing station, the Navy converted to cheaper California oil. When an exploratory well drilled at Chickaloon yielded nothing, the town was abandoned. The National Register of Historic Places Inventory reads "Today much of the town is covered by a new-growth forest. ...a few decayed foundations remain. Numerous structures...have been burned or torn down. ...little evidence is left of the busy industrial community." The condition checked for the site is "ruins". (Photograph Courtesy of the Charles Bunnell Collection, University of Alaska Archives, Fairbanks.)

Canada, presented "Land Use Planning and Management."

[6] Thomas E. Kelly, Consultant, Earth Sciences, Anchorage, Alaska, was a member of the Panel on "What are the Implications in the Canadian Experience for Alaska?".

[7] Walter Parker, Conference Chairman, made the opening remarks.

[8] Gerry Lee, Land Use Studies Branch, Environment Canada, was a member of the Panel on "Equity in the Land: Who Has What Rights on Use/Ownership?".

Proceedings of the Conference on Northern Change have been published and are available from the Arctic Institute of North America, 1343 G. St., Anchorage, Ak 99501.

Joseph Meeker has a long and close relationship with the north. He has served as a ranger in Mt. McKinley National Park and as head of the English department at the University of Alaska, and is currently with Athabasca University in Edmonton, Alberta. His book, *The Comedy of Survival*, was nominated for a Pulitzer prize.

by Larry Gedney

SEISMIC HAZARDS OF RESERVOIR LOADING

Fill a lake, start an earthquake—J. P. Rothe, 1968

On June 21, 1967, Fairbanks, Alaska, experienced a series of sharp earthquakes, some of which exceeded magnitude 6 on the Richter scale. In the weeks that followed, many aftershocks were felt and thousands more were detected instrumentally. As is usual, the aftershock sequence decayed with time producing fewer earthquakes of decreasing magnitude—until another notable event occurred—the "thousand year" flood of August, 1967. When the water crested at 12 feet over flood stage, there was a resurgence of seismic activity. Although local seismic recording gear was destroyed by the flood, field stations recorded several severe shocks in the Fairbanks area. As the waters receded, so did the level of seismic activity.

THE FLOOD-EARTHQUAKE SEQUENCE

This flood-earthquake sequence appears to have been an example of load-induced seismicity. As the Tanana River lowlands turned into one vast lake, the crustal loading imposed by millions of tons of water reactivated the fault responsible for the original earthquakes.

This is not a unique occurrence, nor is it even unusual. There have been instances all over the world of earthquakes accompanying the impoundment of water in reservoirs. It is not necessary that the reservoir lie on, or near, a fault although this is often the case because rivers tend to follow the weakened and often depressed terrain of a fault zone. Ordinarily it would not be expected that a mere ten or twelve feet of water would exert a load heavy enough to induce movement on a fault located at a depth of several miles. In the case of the Fairbanks earthquakes, however, the load was directly distributed over a fault zone which had not "healed" from previous earthquakes and was still undergoing readjustment. In similar cases around the world, earthquakes did not generally begin until water impoundment levels reached several hundred feet.

Boulder City, Nevada, the site of Hoover Dam, had very few earthquakes—until 1936. The dam was completed in 1935 and when the water level reached 300 feet in September of 1936, about 100 tremors were felt. As Lake Mead continued to fill, the number of perceptible earthquakes continued to increase until they reached a maximum in May 1939, when the lake reached its intended level of 475 feet. Since then, the level of seismicity has fluctuated in direct response to water level. None of the earthquakes have been particularly damaging. The largest event recorded did not exceed magnitude 5. Geologists attribute the tremors to the reactivation of faults bordering the dam basin which had been dormant since the Pleistocene era.

Another good example in the U. S. is that of the Grand Coulee Dam in Washington state. A stable area prior to the completion of the dam in 1942, it is now characterized by frequent small earthquakes.

Other examples abound. In 1962, the Kariba Dam in Zambia, located in a previously quiescent area, was the site of several magnitude 6 earthquakes. In 1966, the Kremasta Dam in Greece produced a destructive magnitude 6.3 earthquake which was preceded by an exponentially increasing sequence of fore-shocks as the reservoir filled. Earthquake swarms occurred near Monteynard, France, in 1962 coinciding with the filling of a reservoir there. Similar seismic activity has been recorded at dams near Mangla, Pakistan; l'Oued Fodda, Algeria; Catalogne, Spain; Contra, Switzerland; Marathon, Greece; and Grandval, France, to name a few.

There has been surprisingly little damage caused by load-induced earthquakes. No dam has given way because of quakes, although the dirt-fill Boca Dam in California nearly failed in 1966. In a few instances, however, significant damage and loss of life occurred either directly or indirectly from earthquakes resulting from reservoir loading. From 1960 to 1963, while the reservoir behind the new Vajont Dam in Italy was being filled, some 250 tremors were felt as the water rose. The reservoir and dam are located in a deep, steep-walled canyon. Over a period of time, surveyors had noted a gradual downslope creep of the weak strata composing one of the canyon walls above the reservoir. One day, when the reservoir was completely full, a huge slab of mountainside broke off and plunged into the lake, creating an immense wave which rushed over the top of the dam into the valley below. Hundreds of people drowned and property damage was in the millions of dollars. It can be argued that the earthquakes induced by reservoir loading were not the sole agent responsible for the landslide (there had been a great deal of rain) but it is almost certain that they were a contributing factor.

The Koyna Dam in India, about 80 miles southeast of Bombay, was the site of another disaster in 1967. Detectable earthquakes began in 1962 when the reservoir was about a third full. In June, 1965, a strong earthquake was instrumentally located directly beneath the dam. Having noted that, in some instances, earthquake activity associated with reservoir filling built to a crescendo and then tapered off over the years, authorities optimistically predicted that the same would hold for the Konya Dam and the worst was over. Unfortunately, this was not the case. On December 10, 1967, an earthquake of magnitude 6.4 occurred, killing some 200 people in the town of Koynanagar, 60 miles from the dam, and producing extensive damage over a large part of India.

A point that bears repeating is that, in the cases cited above, no dam was constructed in an area with an earthquake history.

DAMS IN SEISMIC AREAS

What would happen if a dam were to be constructed in a seismically active area? It may be that we will have an answer to that question in a few years if a proposed major hydroelectric project planned by the Corps of Engineers for the Susitna River in south-central Alaska is completed. The contemplated site is highly-seismically active. More importantly, a recently-recognized active fault, called the Susitna fault, crosses the river between the two proposed dams. No less than five moderate earthquakes (and many smaller ones) have occurred along this fault in the past six years. The larger earthquakes were of about magnitude 5. The Susitna fault and locations of the proposed dams are shown in the accompanying LANDSAT mosaic. As can be seen, the Susitna River actually follows the course of the fault for a short distance near the lower right center of the picture.

The Corps of Engineers recognizes the problem and is conducting an extensive study of the project from engineering, geological, and seismological viewpoints. In the past it was common practice to perform careful geologic mapping and surveying studies in the area of a proposed dam. It is now clear that these studies should be extended to cover the area of the artificial lake as well. If the area is carefully monitored seismically before, during, and after the impoundment of water, the Susitna project should provide an ideal laboratory for establishing the mechanics of self-induced seismicity, about which so little is known at present.

SUMMARY

As with natural earthquakes, the cause of those produced by reservoir loading is evidently the release of energy stored in a limited volume of rock along lines of weakness. While the origin of the energy released in natural earthquakes is not always clear, it is apparent that the mass of stored water causes those earthquakes which occur in and around artificial lakes, possibly triggering the release of strain energy which was present in the rock prior to impoundment.

Geologic setting is all-important to the earthquake-producing potential of an artificial reservoir. While the tremors produced can occur in either previously fractured or fresh rock, under some conditions they may not occur at all. An example of this is the dam at Serre-Poncon in the French Alps. Here the reservoir lies on flexible terrain of black soil which apparently does not allow stresses to accumulate. No earthquakes accompanied or followed filling of the dam.

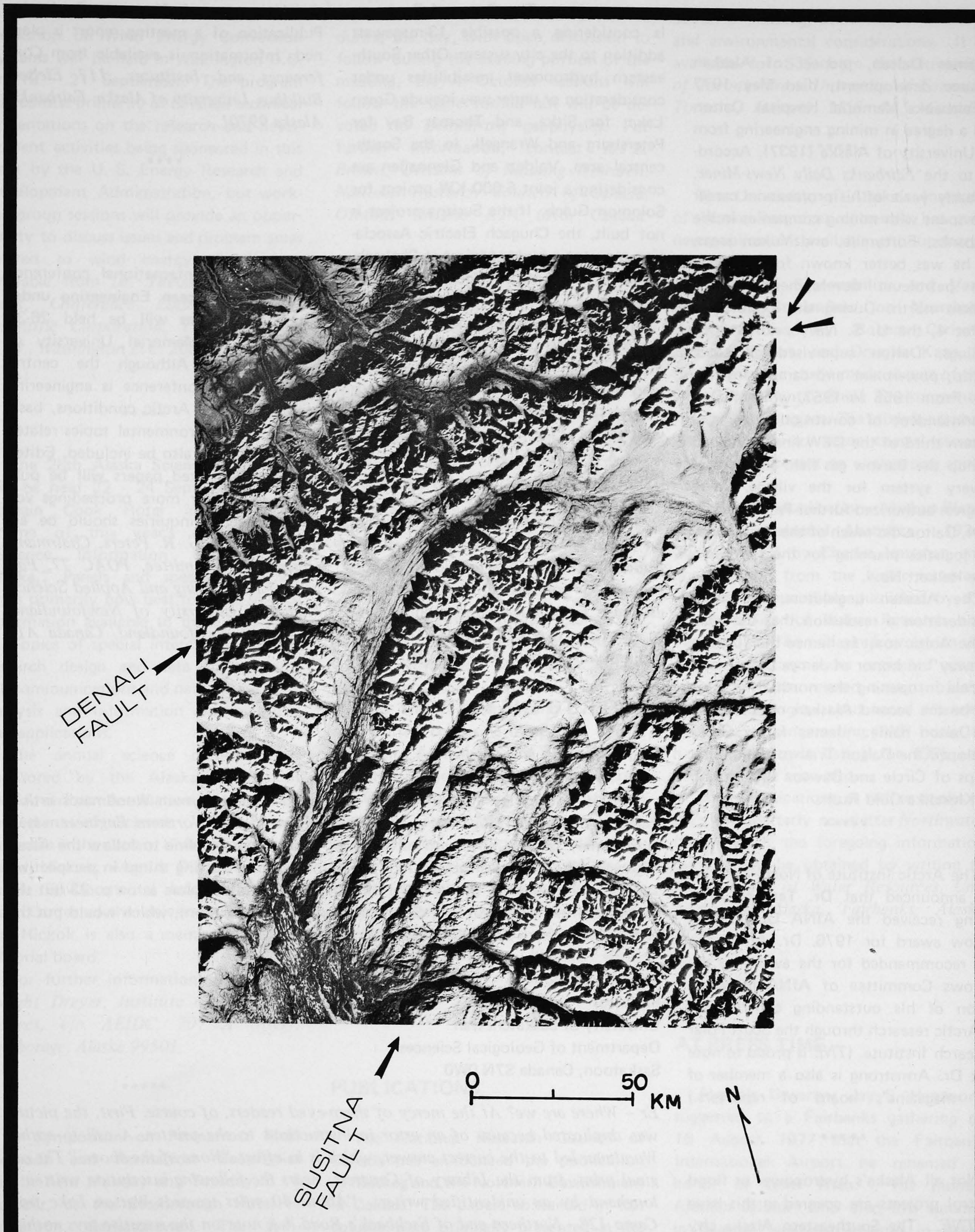
To quote Rothe again, "It is by now clear that one can cite specific cases where tremors, some of which are severe enough to produce extensive damage, are caused by the construction of dams. When he builds these, Man plays the role of the Sorcerer's Apprentice: in trying to control the energy of rivers, he brings about stresses whose energy can be suddenly and disastrously released."

Larry D. Gedney is an Associate Professor of Geophysics with the Geophysical Institute of the University of Alaska, Fairbanks.

The quotations that appear in this article are taken from J. P. Rothe's, "Fill a Lake, Start an Earthquake," New Scientist, 39, 75-78, 1968.

Facing Page →→→

LANDSAT satellite imagery mosaic centered at about 63^{O}N, 149^{O}W. The area shown includes the Alaska Range, with the Denali fault indicated at north and the Susitna fault running from top right to bottom center. The transportation corridor between Fairbanks and Anchorage is in the left half of the photograph. The Susitna River crosses the right two-thirds of the scene just below the center of the picture. The locations of the two proposed Susitna River dams are indicated by white crescents.


DENALI FAULT
SUSITNA FAULT
0
50
KM
N

NOTED:

James Dalton, pioneer of Alaskan resource development, died May 1977 in Fairbanks Memorial Hospital. Dalton held a degree in mining engineering from the University of Alaska (1937). According to the *Fairbanks Daily News-Miner*, the early years of his professional career were spent with mining companies in the Fairbanks, Fortymile, and Yukon areas, but he was better known for his work with petroleum development in the Alaskan north. During the exploration of Pet 4, the U. S. Navy's north slope holdings, Dalton supervised all road, airstrip, powerplant and camp construction. From 1955 to 1957, while he was superintendent of construction for the western third of the DEW line, he helped develop the Barrow gas field and the gas delivery system for the village. After Congress authorized further Pet 4 work in 1974, Dalton did much of the engineering and logistics planning for the first well, Cape Halkett No. I.

The Alaskan Legislature has under consideration a resolution that the road to the Arctic coast be named the "Dalton Highway" in honor of James Dalton and his role in opening the north. If it is, it will be the second Alaskan road bearing the Dalton name: James' father, Jack, developed the Dalton Trail to the mining camps of Circle and Dawson City during the Klondike Gold Rush.

*****

The Arctic Institute of North America has announced that **Dr. Terence Armstrong** received the AINA Outstanding Fellow award for 1976. Dr. Armstrong was recommended for the award by the Fellows Committee of AINA in recognition of his outstanding contribution to Arctic research through the Scott Polar Research Institute. (*TNE* is proud to note that Dr. Armstrong is also a member of this magazine's board of reporters.)

*****

Not all Alaska's hydropower or flood control projects are covered in this issue of *TNE*. The Southeastern Alaska city of Ketchikan has one of the least expensive power rates in the state; the city's electricity comes from three older hydropower projects. The Corps of Engineers is considering a possible 13-megawatt addition to the city system. Other Southeastern hydropower possibilities under consideration or under way include Green Lake, for Sitka, and Thomas Bay for Petersburg and Wrangell. In the Southcentral area, Valdez and Glennallen are considering a joint 6,000 KW project for Solomon Gulch. If the Susitna project is not built, the Chugach Electric Association may try a hydro project at Chakachamna, a lake across Cook Inlet from Kenai.

Readers interested in knowing more about the current politics and possibilities of dam building in Alaska might want to read the June 1977 issue of *Alaska Industry* magazine, from which the above items were taken.

MEETINGS

The stated purpose of the **Symposium on North American Forest Lands at Latitudes North of 60°** is to explore opportunities for managing high latitude forest lands to produce wood products and to meet the needs of people. The Symposium will be held 19-22 September at the University of Alaska in Fairbanks. Publication of a meeting report is planned. Information is available from *Conferences and Institutes, 117 Eielson Building, University of Alaska, Fairbanks, Alaska 99701.*

****

The fourth international conference on **Port and Ocean Engineering under Arctic Conditions** will be held 26-30 September at Memorial University of Newfoundland. Although the central theme of the conference is engineering problems under Arctic conditions, basic science and environmental topics related to this area will also be included. Edited versions of printed papers will be published in one or more proceedings volumes. Specific inquiries should be addressed to *Dr. G. R. Peters, Chairman - Organizing Committee, POAC 77, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. Johns, Newfoundland, Canada A1C 5S7.*

LETTER TO THE EDITOR

Dear Editor:

This is just to let you know that I enjoyed reading Lyman Woodman's article *Building the Alaska Highway* in the recent issue of *The Northern Engineer.* It is most timely indeed, now with all the talk about a gas pipeline to follow the Alcan Highway. An historical article like this helps much in putting things in perspective.

I have one question though. The picture on p. 13 is the same as on p. 23 but the captions differ. Where are we? South of Watson Lake (Yukon), which would put the picture in northern British Columbia, or in Alaska?

W. O. Kupsch
Professor
University of Saskatchewan
Department of Geological Sciences
Saskatoon, Canada S7N 0W0

Er – Where are we? At the mercy of sharp-eyed readers, of course. First, the picture was duplicated because of an error in instructions to the printer. A call to author Woodman led to the correct answer, which is in effect "None of the above." The original print, from the Library of Congress, bears the following inscription written in longhand by an unidentified writer: "About 40 miles towards Watson Lake from Camp 128 - Northern end of Eschback's Road." A note on the negative says nothing about location. Thanks to reader Kupsch for pointing out the confusion, and to author Woodman for removing it. Now - does anyone know who Eschback was? TNE and Lyman Woodman would both like to know.

The third biennial conference and workshop on **Wind Energy Conversion Systems** will be held in Washington D.C. on 19 - 21 September. The program will consist primarily of detailed technical presentations on the research and development activities being sponsored in this field by the U. S. Energy Research and Development Administration, but working group sessions will provide an opportunity to discuss issues and problem areas related to wind energy. Details are available from *Dr. Theodore R. Kornreich, Conference Coordinator, JBF Scientific Corporation, 1701 K Street N. W., Washington D.C. 20006.*

*****

The 28th **Alaska Science Conference** will be held 22 - 24 September at the Captain Cook Hotel in Anchorage. Theme of this year's conference is "Science Information Exchange in Alaska." Panels and speakers will address primarily how best to make science information available to those who need it. Topics of special interest will include research design and data management, telecommunications and networking, data analysis and information dissemination, and applications.

The annual science conference is sponsored by the Alaska division of the American Association for the Advancement of Science. This year's chairman is the current division president, David Hickok, who is Director of the Arctic Environmental Information and Data Center of the University of Alaska. Mr. Hickok is also a member of *TNE*'s editorial board.

For further information, write *Linda Dwight Dreyer, Institute of Water Resources, c/o AEIDC, 707 A Street, Anchorage, Alaska 99501.*

*****

A **Symposium on Permafrost Field Methods and Permafrost Geophysics** will be held Monday and Tuesday, 3 - 4 October, at the Bessborough Hotel in Saskatoon, Saskatchewan. The symposium will form part of the annual meeting of the Canadian Geotechnical Society. On 3 October, invited papers on field methods will be presented during the day, with open discussion to follow during the evening portion of the meeting; the 4 October sessions will follow the same format but will be devoted to permafrost geophysics. For further information, contact *R.J.E. Brown, Division of Building Research, National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada.*

*****

On 3 and 4 November, the first **Conference of l'Association Quebecoise de Teledetection** will be held at the Ecole Polytechnique in Montreal. Subject of this conference will be integration of remote sensing with natural resource management in Quebec. Direct inquiries to *Robert Denis, President du comite du congres, l'Association quebecoise de teledetection, C.P. 10047, Sainte-Foy, Quebec G1V 4C6, Canada.*

*****

Western Washington State College will play host to two related meetings on 2 - 5 November. The **Pacific Coasts Symposium** will deal with shoreline changes and problems along the coasts of countries bordering the Pacific Ocean. The **Third Annual Meeting of the Coastal Society** has the theme of "Energy Across the Coastal Zone." Sessions will deal with applicable state and federal policies, industrial and environmental considerations, and alternatives to moving energy sources through the coastal zone. Information on either or both meetings may be obtained from *M. L. Schwartz, Department of Geology, Western Washington State College, Bellingham, Washington 98225.*

PUBLICATIONS

The National Research Council of Canada has announced the publication of **Muskeg and the Northern Environment in Canada**. The papers contained in this volume were originally presented at the 15th Muskeg Conference (1973).

The book takes an interdisciplinary approach to the description and classification of muskeg, utilization of muskeg, and environmental considerations. It is available for $35 from the *University of Toronto Press, University of Toronto, Toronto, Ontario M5S 1A5 Canada.*

*****

The University of Alaska's Institute of Water Resources currently has two new publications available without charge on request.

Effects of Seasonability and Variability of Streamflow on Nearshore Coastal Areas, by Robert Carlson, Richard Seifert, and Douglas Kane, is the report of a study made as part of the Outer Continental Shelf Environmental Assessment Program. The study's primary objective was to assess coastal stream parameters relevant to engineering applications.

The other publication, **Alaskan Water Resources, Selected Abstracts - 1974,** was compiled by Charles Hartman and Sheila Finch from the water resources abstracts compendium published by the U. S. Office of Water Research and Technology. The bulletin from which the Alaskan abstracts were extracted covers reports in water-related aspects of the physical, biological, and social sciences, the law, and engineering. IWR hopes to have the abstract listing for 1975 and 1976 available soon also.

These publications, as well as copies of the IWR quarterly newsletter *Northwater* (from which the foregoing information came), may be obtained by writing to the *Institute of Water Resources, University of Alaska, Fairbanks, Alaska 99701.*

AT PRESS TIME

Alaska's Governor Jay S. Hammond suggested to a Fairbanks gathering on 16 August 1977 that the Fairbanks International Airport be renamed in honor of **Noel Wien.** The pioneer Alaskan aviator, who died this summer in Seattle, was instrumental in developing commercial airline service in the north.

According to the governor, final

decision on the airport naming will rest with the Fairbanks community.

*****

One more word on the **Susitna hydropower project**: the latest newsletter from the office of Alaska Senator Mike Gravel reports that the U. S. Senate in June appropriated $5.4 million for the project. Additionally the Office of Management and Budget approved the transfer of $100,000 from the state to the Army Corps of Engineers to prepare a Plan of Study outlining the Phase I work.

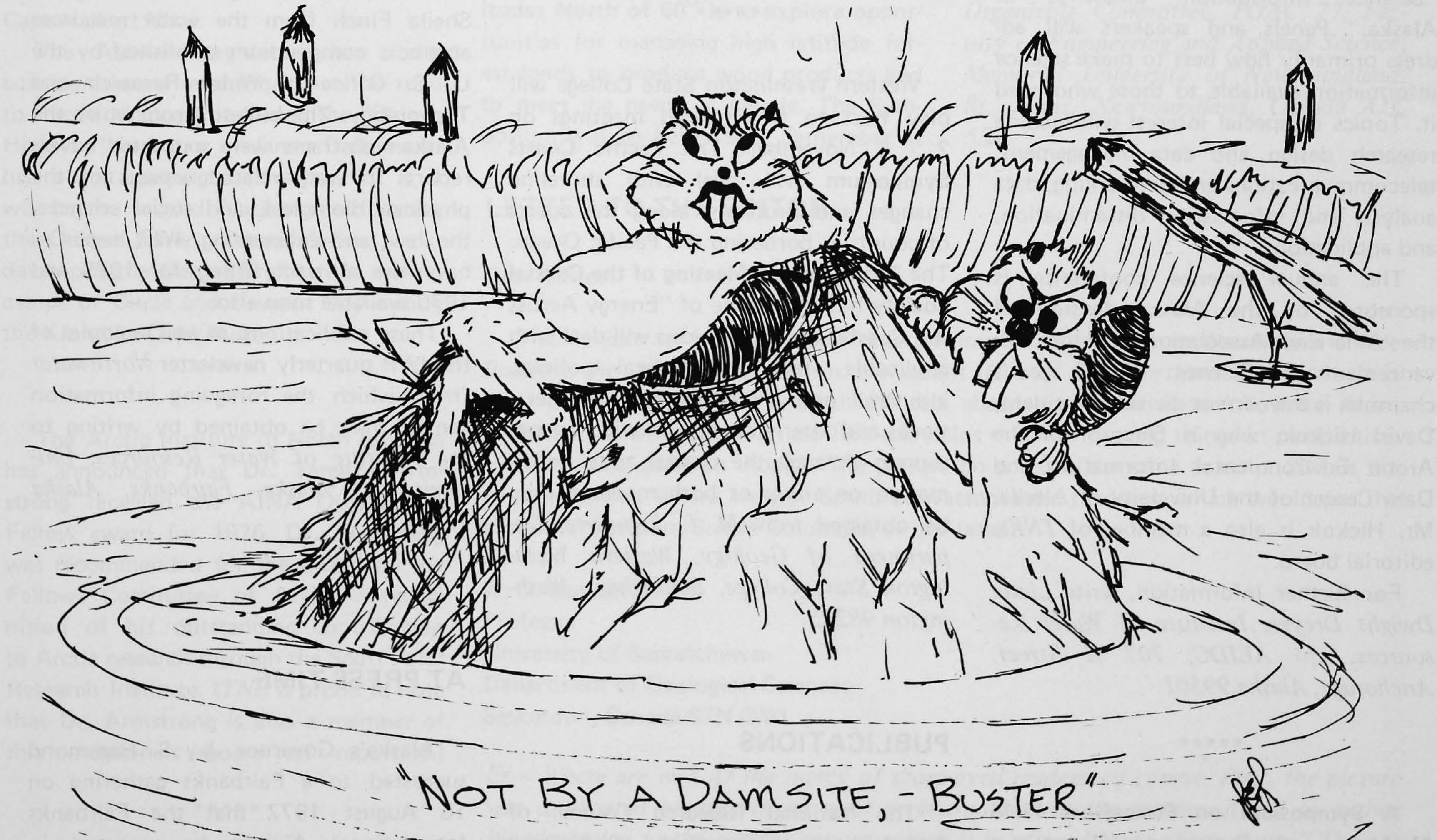
The Watana and Devil Canyon dams will be financed and owned by the state of Alaska if the Phase I environmental, engineering, and economic work leads to the conclusion that the project should be built. This is in effect the second funding option noted in Eric Yould's article in this issue. The $5.4 million federal appropriation is the first of some $15 million that will go to guarantee the state's Phase I bonds.

If the Phase I work does lead to a decision to proceed with constructing the project, the state would sell additional bonds to finance construction, currently estimated to cost $1.5 billion. According to Gravel, the dams could be completed by 1990.

A complete status report is available from Senator Gravel's office at *3121 Dirksen Building, U. S. Senate, Washington D.C. 20510.*

*****

A request for help from our **Canadian subscribers**: Many of you (bless you) have been with *TNE* a long time--longer than the Canadian postal code system has been in effect. An editorial scan of the new mailing label printing showed that the computer is unaware of several hundred subscriber postal codes. That can lead to delayed deliveries (as well as annoyed mail clerks). So please take the time to check the back cover of this issue, and let us know if we need to bring your address up to date.



THE **NORTHERN ENGINEER**

GEOPHYSICAL INSTITUTE
of the
UNIVERSITY OF ALASKA
Fairbanks, Alaska
99701

BULK RATE
U.S. POSTAGE
PAID
Permit No. 2
Fairbanks, Alaska

Address Correction Requested

NE
02870

NEWS SERVICE
108 BU 00101