SUSITNA HYDROELECTRIC PROJECT

TUNNEL ALTERNATIVE REPORT

TASK 6 : DESIGN DEVELOPMENT

JULY 1981

Prepared by:

ACRES

ALASKA POWER AUTHORITY

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SUSITNA HYDROELECTRIC PROJECT

TASK 6 - DESIGN DEVELOPMENT

SUBTASK 6.02 - CLOSEOUT REPORT
INVESTIGATE TUNNEL ALTERNATIVE

JUNE 1981

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1 - INTRODUCTION

1.1 - Overview

Subtask 6.02 of Task 6 Design Development studies for the Susitna Hydroelectric Project is entitled "Investigate Tunnel Alternative". The scope of this subtask as originally defined in the Acres American Inc. POS dated February 1980, was expanded in the revisions to the POS issued in September 1980. The objective of the Subtask 6.02 study is to undertake a preliminary assessment of the feasibility of using a major tunnel to develop hydroelectric power on the Susitna River between the proposed Watana and Devil Canyon dam sites (see Figure 1.1).

The scope of work involves essentially a desk study utilizing available data. The limited specific geologic or geotechnical information available along the tunnel route will allow no more than a conceptual assessment of the feasibility of excavation of tunnels in the geologic structures adjacent to the Susitna River in the region considered. Thus the assessment of the structural design requirements and the determination of feasible size and cost of such tunnels has necessarily been based on Acres engineering judgement and experience at this time. It is considered unlikely that goetechnical conditions would be so poor that tunnels could not be excavated by some means in the region under consideration. Nevertheless it is important to note that the worse the conditions, the higher the cost will be. Estimates based substantially on judgement and experience, however good, will be subject to the uncertainties of the basic assumptions used.

To establish the technical and economic feasibility of a tunnel alternative, a substantial amount of field geotechnical investigation, design, and construction cost estimating and scheduling work would be required. Notwithstanding the foregoing constraints, the study has been directed towards assessing whether or not there are sufficient grounds to consider the tunnel option in more detail as a potentially economic, technically feasible and environmentally sound alternative to the Devil Canyon development. This report presents the results and conclusions of this study.

1.2 - Devil Canyon Dam and Tunnel Schemes

The Watana-Devil Canyon dam scheme is comprised of two major dams, Watana and Devil Canyon (Figure 1.1). As currently envisaged, Watana is a 840-foot high gravel and rockfill structure with a crest elevation at 2225 feet and an 800 MW underground powerhouse. The full pool surface area of Watana reservoir is 43,000 acres and full pool storage volume is 10 million acre-feet. The large storage volume allows regulation of river flows on both a seasonal and yearly basis. The Devil Canyon dam is a 625-foot high concrete arch structure with a crest elevation of 1464 feet and a 400 MW underground powerhouse. The Devil Canyon dam has a full pool storage volume of 1 million acre-feet and the reservoir surface area is 7600 acres.

A large power tunnel could be utilized to develop the head below Watana instead of the Devil Canyon dam. Conceptually, this Devil Canyon tunnel scheme could be used to develop either the total head of both dams or just that portion developed by the Devil Canyon dam. This could be achieved by locating the intake works either in the Watana reservoir or at some point downstream from the Watana dam. Based on initial conceptual design considerations, a typical tunnel scheme would comprise the following major components:

- Power tunnel intake works.

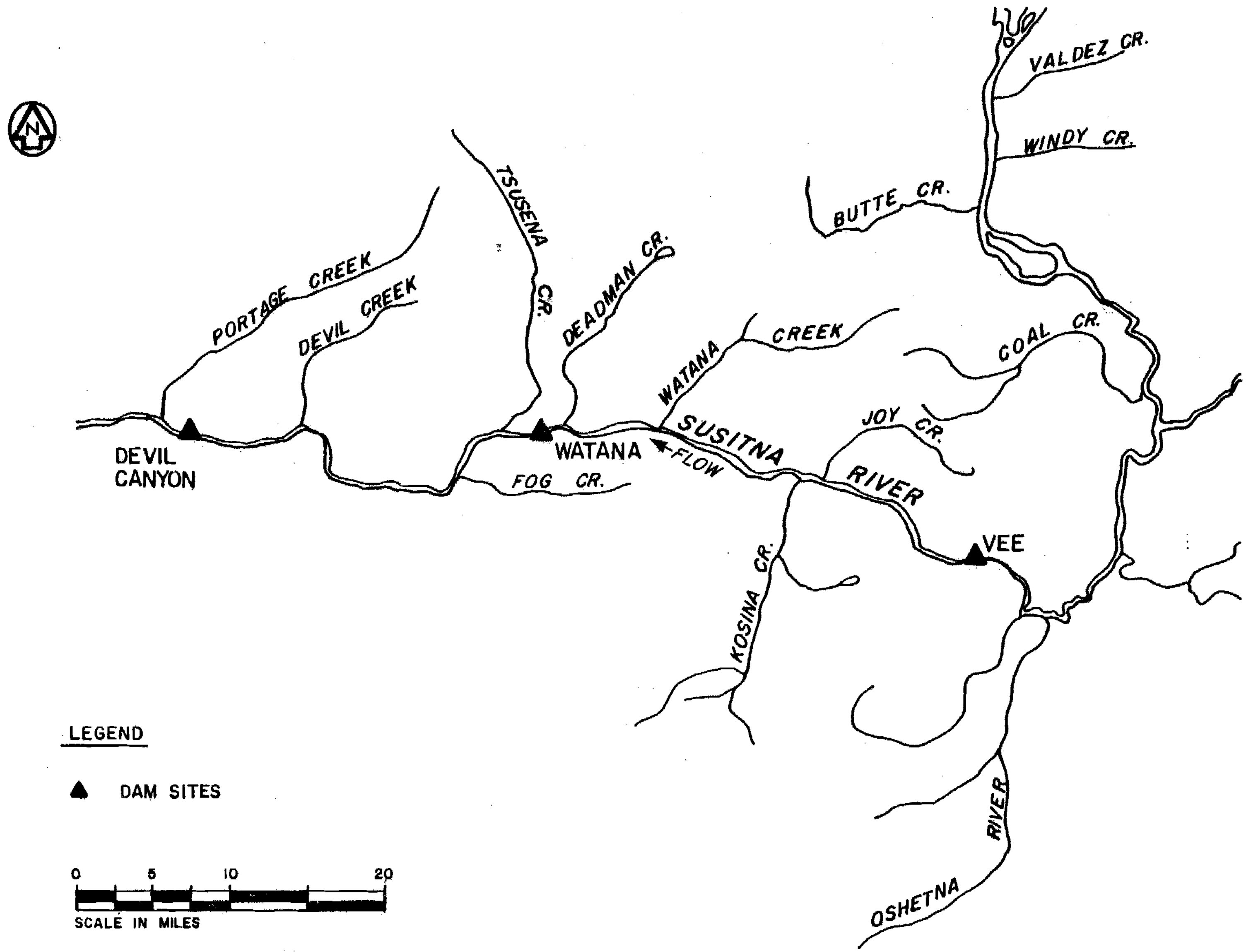
- A re-regulation dam if the intake works are located downstream from Watana, with a small hydroelectric development to utilize the available head and flow.

- One or two power tunnels of up to forty feet in diameter and up to thirty miles in length.

- An underground powerhouse with a capacity of up to 1200 MW located in the vicinity of the Devil Canyon dam site.

1.3 - Report Contents

Section 2 of this report is a summary of the work undertaken and conclusions and recommendations. Section 3 is an outline of the scope of work. The four basic conceptual tunnel schemes considered are described in Section 4 and the screening process used to select the preferred scheme is outlined in Section 6. An overview of the site geology and geotechnical design considerations are dealt with in Section 5. The preferred tunnel scheme is described and analyzed in more detail in Section 7 and compared to the Watana-Devil Canyon dam scheme in Section 8. Conclusions and Recommendations are presented in Section 9.



TUNNEL ALTERNATIVE VICINITY MAP

FIGURE 1.1

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2 - SUMMARY

2.1 - Scope of Work

The scope of work for Subtask 6.02 consisted of a preliminary assessment of the feasibility of using a major tunnel to develop hydroelectric power on the Susitna River between the proposed Watana and Devil Canyon dam sites (See Figure 1.1). Utilizing available geologic and geotechnical data along the proposed tunnel route, four basic conceptual tunnel schemes were proposed as alternatives for developing the head between the Watana and Devil Canyon sties. Each of the four tunnel schemes was investigated further with regard to cost, energy yields, and environmental impact and, based on this information, one scheme was selected for additional study. The selected tunnel scheme was compared with the Devil Canyon dam alternative by considering technical, economic, environmental, and construction schedule factors, and a number of conclusions and recommendations were developed.

2.2 - Conceptual Tunnel Schemes

Four basic tunnel schemes were selected for study. They involved utilizing either the full head represented by both the Watana and Devil Canyon dams, or just the head represented by the Devil Canyon dam and two basic operating modes (peaking and base load power generation). The installed capacities for the schemes were all based on a total Susitna Basin development plant factor of between 50 and 55 percent. The schemes are:

- Scheme 1: This scheme involves the development of head between the Devil Canyon dam site and Watana, and incorporates peaking operation of the tunnel powerhouse.

- Scheme 2: Similar to Scheme 1, except that the full head (including that available at the Watana dam) is utilized.

- Scheme 3: This scheme involves the development of head between the Devil Canyon dam site and Watana, and incorporates base load operaton of the tunnel powerhouse.

- Scheme 4: Similar to Scheme 3, except that the full head (including that available at the Watana dam) is utilized.

These schemes involve tunnel lengths of up to 30 miles and diameters up to 40 feet. A review of world wide experience indicates that, although there is little precedent for power tunnels of this size and length, similarly sized tunnels have been built for other purposes. The proposed tunnel schemes are therefore within the current state-of-the-art.

2.3 - Tunnel Design and Construction Considerations

Geotechnical design (and hence the cost and construction schedule) for a tunnel is heavily dependent upon evaluation of the geology along the potential routes. Major tunneling problems are usually created by fault and shear zones, joint sets, lithologic contacts, water and gas. These factors, along with seismic considerations, rock quality, and construction methods must be explored in more detail before any final decision can be rendered concerning the relative merits of a tunnel scheme versus the two dam scheme.

The tunnel schemes are located in a complex geologic region incorporating Argillite-Graywacke, Biotite-Granodiorite and Schist-Migmatite-Granite lithologic units. Although there is very limited geologic or geotechnical information along the proposed tunnel routes, the results of exploratory drilling at the Devil Canyon and Watana dam sites are available. These data indicate that one can expect the rock quality to generally vary from good to excellent, but zones of fair to poor rock could also be encountered. These conditions can generally be termed as favorable for tunnel construction.

Due to the lack of specific geologic knowledge, conservative and relatively flexible methods of tunnel construction and tunnel support have been assumed for purposes of estimating capital costs in this study. These assumptions include a modified horseshoe shape cross section and drill and blast construction methods. One third of the tunnel length is assumed to require structural concrete lining and rockbolt support, one third shotcrete lining and rockbolt support, and the remaining one third is assumed to require no lining (but occasional rockbolts for support) and a concrete-lined invert.

2.4 - Screening of Conceptual Tunnel Schemes

A screening analysis was performed to compare the four conceptual tunnel schemes and to determine the best tunnel scheme for further study. Costs, power and energy, geology, and environmental aspects were used as screening criteria.

Due to a lack of detailed geologic information, total project cost estimates are tentative at this time; however, total project costs are relevant for a valid economic comparison between conceptual tunnel schemes. Scheme 3 has the lowest comparative cost, followed by Schemes 4, 1, and 2, respectively (See Table 6.2).

Energy values for the tunnel schemes were determined from an annual flow duration curve developed from the simulated monthly outflow from the Watana reservoir (35). This curve was adjusted to allow for a 1000 cfs minimum discharge in the river, and allowance was made for tunnel friction and minor losses. As shown in Table 6.2, Scheme 3 yields the largest increase in energy production with 2180 Gwh of added annual energy. Scheme 1 would provide for a 2050 Gwh increase, Scheme 2 a 1900 Gwh increase, and Scheme 4 a 890 Gwh increase.

From a geotechnical perspective, the northern and the alternative direct alignments for Schemes 1, 2, and 4 are similar (See Plate 1); therefore, they were compared as a group while Scheme 3 was considered separately. Using the information presently available, Scheme 3 appears to be preferable geotechnically. However, further explorations are required to confirm this point.

A preliminary assessment of the environmental aspects associated with the four tunnel schemes was carried out for comparison and screening of the tunnel schemes only, and impacts common to all schemes were not addressed. Based on the available data, Scheme 3 would incur the least overall environmental impact.

2.5 - Preferred Tunnel Scheme

Scheme 3 was chosen for further study. The aim of the more detailed study was to further refine engineering concepts, improve the accuracy of the cost estimate, and evaluate the power and energy potential in more detail.

Scheme 3 is composed of a re-regulation dam, power tunnel, and powerhouse at Devil Canyon. The re-regulation dam is located approximately 16 miles downstream from the Watana site. Site selection was based on regional geologic mapping, and air photo and topographic interpretations. The 245 foot high dam is assumed to be a rockfill dam with an impervious core. A spillway is located on the north abutment, and a relatively small 30 MW powerhouse is located on the south side of the river.

Power tunnel intakes are lcoated on the south side of the river approximately 2000 feet upstream from the re-regulation dam. The optimum power tunnel diameter is 30 feet for each of the two tunnels.

The underground Devil Canyon powerhouse has an installed capacity of 300 MW, with an assumed four generating units. Overland acces to the powerhouse access adit area runs parallel to Cheechako Creek. A surge tank for each power tunnel is located just upstream of the powerhouse. Small cellular cofferdams are required along the south bank of the Susitna to allow construction of the tailrace. As part of this scheme, the installed capacity at the Watana dam is increased by 50 MW to reduce the overall system plant factor once the base load tunnel generating plant comes on line.

2.6 - Comparison with Devil Canyon Dam Scheme

The comparison of the tunnel scheme with the Devil Canyon dam scheme indicates that the dam would yield approximately 36 percent more energy at a 49 to 54 percent lower energy cost. Environmentally, the tunnel scheme has advantages; however, these do not appear to outweigh the economic benefits of the dam scheme. From a construction schedule point of view there is little difference between the schemes.

2.7 - Conclusions and Recommendations

A base load tunnel scheme incorporating a re-regulation dam downstream from Watana dam and developing the potential head of the Devil Canyon Dam is the most economic tunnel scheme. There is no evidence that this scheme is not technically feasible. However, a substantial amount of field data would be required to firmly establish feasibility.

A comparison of the tunnel scheme with the Devil Canyon Dam scheme indicates that the tunnel scheme yields less (26 percent) and more costly (93 to 120 percent) energy. The tunnel scheme exhibits less environmental impact than the dam, but this reduced impact is insufficient to outweigh economic advantages of the dam scheme.

In order to confirm the economic comparisons with the dam scheme, the preferred tunnel scheme should be incorporated with the Susitna Basin development selection studies. These will involve a system wide generation planning model, which will allow a more realistic assessment of the economics of the tunnel scheme to be carried out.

Based on the data evaluated, it is recommended that additional field or office studies of the tunnel scheme not be undertaken at this stage.

3 - SCOPE OF WORK

3.1 - Study Objective

The objectives of this study are to investigate the feasibility of replacing the currently proposed Devil Canyon dam project with a tunnel-supplied power plant fed from the Watana dam site.

3.2 - Approach

To satisfy the study objectives, the work was organized and carried out in the following manner:

- Four basic conceptual tunnel schemes were developed to investigate alternatives for utilizing the available head between the Watana and Devil Canyon dam sites.

- The available information on tunnels of similar size previously constructed elsewhere in the world was reviewed and summarized.

- A general evaluation of the topography, geology, and seismicity of the area was undertaken on the basis of the available information.

- Preliminary assessments were made of geotechnical and structural design assumptions and criteria for use in evaluation and comparison of alternatives.

- A preliminary assessment of costs, energy yields, and environmental impact associated with the conceptual tunnel schemes was undertaken.

- Based on the information developed above, a single scheme was selected as a tentative optimum for further study. This, more detailed study, included:

  - Development of preliminary engineering layouts.

  - More detailed assessment of capital costs and development of construction schedules.

  - Monthly simulation of power and energy yields utilizing a computer model.

  - Preliminary environmental impact assessment.

- The selected tunnel scheme was compared with the Devil Canyon dam alternative on the basis of technical, economic, environmental and construction schedule considerations.

- The study was completed with the development of conclusions on the viability of the tunnel scheme and recommendations for further consideration of the scheme as an alternative for inclusion in Susitna Basin development planning studies.

4 - CONCEPTUAL TUNNEL SCHEMES

4.1 - Economics of Tunnel Schemes Within the Susitna Basin

In order to put the Devil Canyon tunnel scheme into perspective, a brief study was undertaken to assess the relative economics of tunnel schemes located in various portions of the basin. An essential part of a tunnel scheme is an upstream reservoir for seasonal and yearly flow regulation. Initially, the Watana and Vee dam sites (see Figure 1.1) were selected as potential upstream reservoir sites at which tunnel intakes would be located. An appropriate index for initial comparison of alternatives was derived on the basis of the estimated energy yield in kWh per cubic yard of tunnel excavation for each alternative. The basic assumptions used in this analysis are shown in Table 4.1. The energy yield was evaluated using the average annual discharge less 500 cfs compensating flow, and the net head allowing for friction losses. Studies indicated that minimum cost of energy occurred at maximum flow velocities ranging from about 5.9 to about 9.9 feet per second at rated tunnel discharges, as shown in Table 7.2. For preliminary study purposes a constant annual average velocity of 6 feet per second was adopted. Estimates of kWh/yd^3 for the alternatives considered are illustrated in Figure 4.1, from which it is evident that the first 12 miles of a tunnel starting at Watana has lower economic potential than the lower portion from Devil Creek downstream to Portage Creek.

The curves also indicated that the economic potential of a tunnel scheme downstream from the Vee dam site is much lower than that between Devil and Portage Creeks.

The third curve on Figure 4.1 indicates the economic potential of a tunnel starting from a re-regulation dam located downstream from Watana and just upstream from Devil Creek. As outlined in the following section, this re-regulation dam was ultimately chosen as the site for the intake in one of the tunnel schemes.

4.2 - Conceptual Devil Canyon Tunnel Schemes

All tunnel schemes considered assume that Watana (maximum water surface elevation 2200 feet) with an installed capacity of 800MW is the project's first stage of development and that a minimum of 1000 cfs compensation flow is required in the Susitna River downstream from Watana at all times.

Four basic tunnel schemes were selected for study. These involve utilizing either the full head represented by both the Watana and Devil Canyon dams or just the head represented by the Devil Canyon dam and two basic operating modes, i.e. peaking and base load power generation. The installed capacities for the schemes are all based on a total Susitna Basin development plant factor of between 50 and 55 percent. These schemes are depicted in Figure 4.2 and are as follows:

(a) Scheme 1

This scheme involves the development of head between the Devil Canyon dam site and Watana and incorporates peaking operation of the tunnel powerhouse.

(b) Scheme 2

As for Scheme 1 except that the full head, including that available at the Watana dam, is utilized.

(c) Scheme 3

This scheme involves the development of head between the Devil Canyon dam site and Watana and incorporates base load operation.

(d) Scheme 4

As for Scheme 3 except that full head, including that available at Watana dam, is utilized.

Schemes 1 and 3 require a secondary dam downstream of Watana to re-regulate Watana releases and to control the water level at the tunnel intakes.

For Scheme 1 this re-regulation dam requires relatively little storage as the two powerhouses operate essentially in series, i.e. they both peak simultaneously. This can be provided by a small re-regulation dam located some 2 miles downstream from Watana.

Re-regulation storage requirements for Scheme 3 are much greater. To allow peaking operations from the Watana reservoir and base load operation of the tunnels requires a substantially larger volume. A brief economic study revealed that this could best be provided by a re-regulation dam located some 15.8 miles downstream from Watana. This site appears to be suitable for dam construction and is located immediately upstream from the reach from Devil Canyon to Portage Creek with higher economic tunnel potential, as discussed in Section 4.1. The savings in tunnel cost at this site more than compensate for the increased height of the re-regulation dam located this far downstream from Watana.

A more detailed discussion of the tunnel schemes is presented in the following sections. Table 4.2 summarizes pertinent information on each of the schemes which are illustrated on Plate 1.

4.3 - Scheme 1 (Devil Canyon Head, Peaking Operation)

Scheme 1 consists of the Watana dam with an 800 MW powerhouse and a re-regulation dam approximately 75 feet in height located two miles downstream. The tunnel intake works are located just upstream from the re-regulation dam and a 550 MW powerhouse is located in the vicinity of Devil Canyon. Tunnel length is about 27 miles. A minimum compensation flow of 1000 cfs is provided between Watana and Devil Canyon. The re-regulation dam's storage capacity is that required for the powerhouses to operate in series. For preliminary study purposes it has been assumed that sufficient storage to absorb approximately one hour of peak power discharge from Watana will be necessary. This requires 1,600 acre-feet of storage. Peaking operations will create daily water level fluctuations downstream from the Devil Canyon powerhouse, which will probably require regulation.

4.4 - Scheme 2 (Full Head, Peaking Operation)

Scheme 2 consists of the Watana dam and power tunnel intake works located upstream of the dam. Two tunnels, 29 miles long will discharge at a 1150 MW powerhouse at Devil Canyon. Upon completion of the tunnel stage of the overall project, the Watana powerhouse capacity will be reduced from 800 MW to 70 MW, just sufficient to release the required minimum compensation flow. Base load and peak power demands will be generated at the Devil Canyon powerhouse. Water level fluctuations downstream of Devil Canyon are similar to those of Scheme 1.

4.5 - Scheme 3 (Devil Canyon Head, Base Load Operation)

Scheme 3 consists of the Watana dam with an 850 MW powerhouse and a re-regulation dam approximately 245 feet in height located 15.8 miles downstream from Watana. The tunnel intake works are upstream of the re-regulation dam with a 300 MW powerhouse in the vicinity of Devil Canyon. The re-regulation dam has a storage capacity of approximately 350,000 acre-feet. A maximum water level fluctuation of four feet is sufficient to store the daily peak discharge from Watana and release a constant discharge into the power tunnels. Watana's 800 MW powerhouse will be operated as a peaking hydro facility discharging into the re-regulation reservoir. Devil Canyon's 300 MW powerhouse will be operated as a base load facility, and thus, no significant daily water level fluctuation will occur downstream.

A relatively small powerhouse with a capacity of 30 MW will be constructed at the re-regulation dam. A minimum flow of 1000 cfs will be passed through the re-regulation dam powerhouse to supply the required downstream compensation flow.

4.6 - Scheme 4 (Full Head, Base Load Operation)

The general layout of Scheme 4 is similar to Scheme 2 with the following operational changes. The Watana powerhouse will remain at 800 MW and meet peaking requirements. During off peak periods a constant base load of 35 MW will be generated at Watana while satisfying compensation flow requirements between Watana and Devil Canyon. The Devil Canyon 365 MW powerhouse and tunnel will be operated as a base load facility. The full head potential for the entire flow is not developed in Scheme 4, and thus annual energy production is less than the other schemes. Daily water level fluctuations downstream of Devil Canyon are similar to Schemes 1 and 2, and large water level fluctuations between Watana and Devil Canyon will occur.

4.7 - Historical Precedence

In order to obtain a perspective of the tunnel scheme in terms of world wide historical experience, a brief review of other tunnel schemes was undertaken. The results of this review are summarized in this section.

Table 4.3 compares on a greately abbreviated basis, the Susitna tunnel alternative with several other projects.

It is clearly evident that the proposed tunnel concept at Susitna is unique. However, it is important to note that tunnels of similar size, length, purpose, and located in similar geology have been successfully completed. The Susitna tunnel alternative is definitely within the state of the art. Larger and longer tunnels have been driven in more complex geologic settings.

TABLE 4.1: ASSUMPTIONS FOR TUNNEL SITE COMPARISON INDEX

(1) The tunnel powerhouse operates as a base load facility.

(2) Straight line tunnel alignments between the dam site and the tunnel tail race.

(3) Tunnel discharge is the average annual discharge less 500 cfs compensation flow.

(4) Tunnel diameter is sized for an annual average flow velocity of six feet per second and one power tunnel.

(5) Annual energy is based on annual average head discharge and head loss.

(6) Average head loss is based on a flow velocity of six feet per second and a manning n of 0.026.

TABLE 4.2: INFORMATION ON THE DEVIL CANYON DAM AND TUNNEL SCHEMES

	Devil Canyon Dam	Tunnel Scheme 1	Tunnel Scheme 2	Tunnel Scheme 3	Tunnel Scheme 4
Reservoir Area (Acres)	7,500	320	0	3,900	0
River Miles Flooded	31.6	2.0	0	15.8	0
Tunnel Length (Miles)	0	27	29	13.5	29
Tunnel Volume (Yd^3)	0	11,976,000	12,863,000	3,732,000	5,131,000
Compensating Flow Release from Watana (cfs)	0	1,000	1,000	500[1]	1,000
Downstream[2] Reservoir Volume (Acre-feet)	1,100,000	9,500	--	350,000	--
Downstream Dam Height (feet)[3]	625	75	--	245	--
Typical Daily Range of Discharge From Devil Canyon Powerhouse (cfs)	5,750 to 8,400	4,000 to 14,000	4,000 to 14,000	8,300 to 8,900	3,900 to 4,200
Approximate Maximum Daily Fluctuations in Downstream Reservoir (feet)	2	15	--	4	--

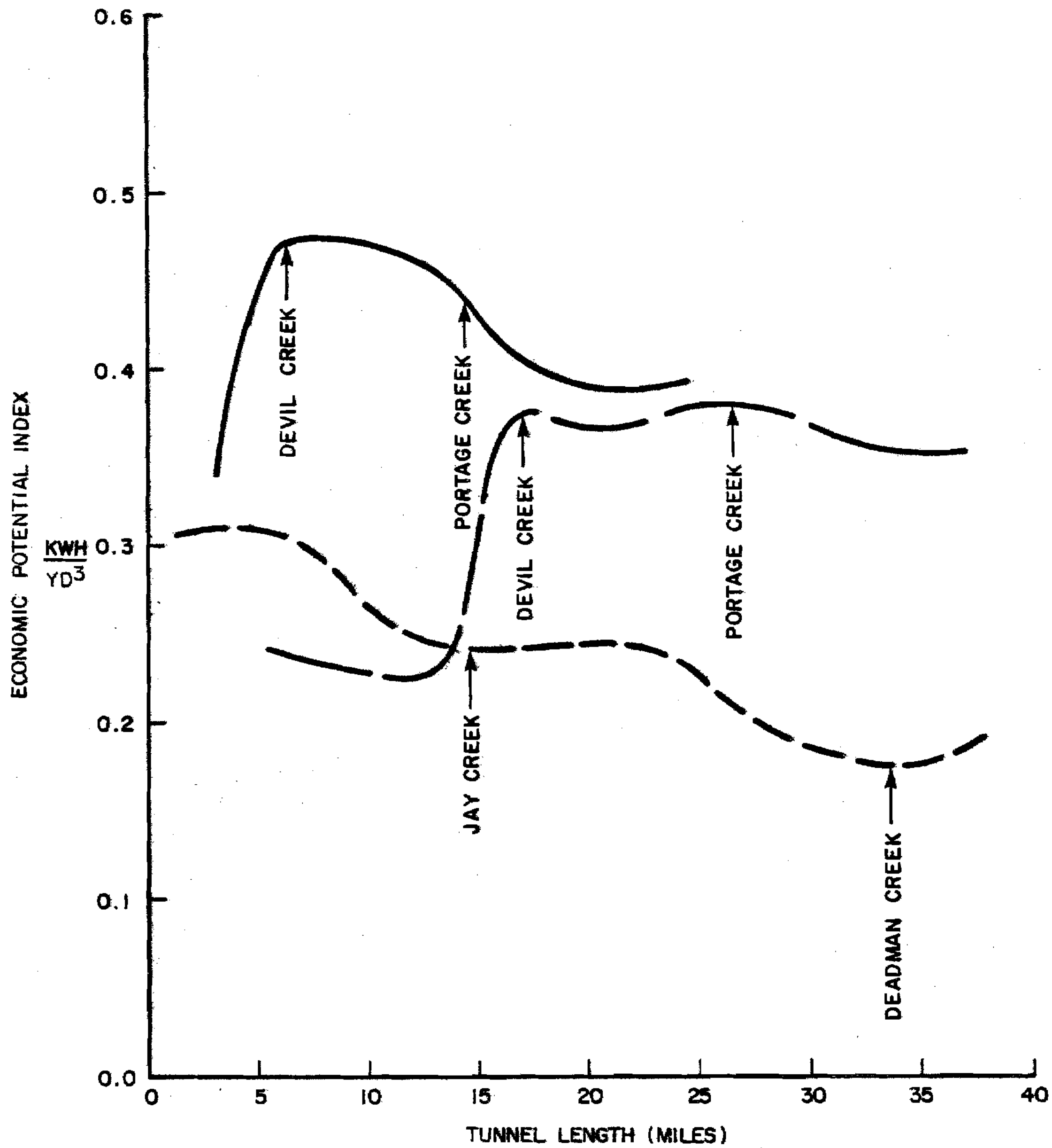
1 1,000 cfs compensating flow release from the re-regulation dam.
2 Downstream from Watana.
3 Estimated, above existing rock elevation.

TABLE 4.3: HISTORICAL TUNNELING PRECEDENCE

Project Name	Location	Type	Length (miles)	Shape	Diameter	Rock	Excavation Method[1]	Maximum Depth	Static Head	Lining
TARP	Chicago	Sewer	Approx. 140	Circular	18 ft-35 ft	Dolomite	TBM	Approx. 300 ft	---	Partially concrete lined
Kemano	British Columbia	Power	10.1	Modified Horseshoe	25 ft	Igneous and metamorphics	D&B	2200 ft	2585 ft	Approx. 1/3 unlined, 1/3 concrete lined and 1/3 lined with rock bolts and shotcrete
Snettisham	Alaska	Power	1.9	Modified Horseshoe	13.5 ft	Quartz-dorite, Gneiss, Biotite, Schist	D&B	1200 ft	Approx. 900 ft	87 percent unlined, supported with rock bolts, 13 percent supported with rock bolts and concrete
Bersimis 1	Quebec	Power	7.6	Modified Horseshoe	31.0 ft	Gneisic and Granitic	D&B	800 ft	875 ft	Concrete lined, entire length
Bersimis 2	Quebec	Power	0.5	Circular	38 ft	Gneisic and Granitic	D&B	N	387 ft	Concrete lined
Chute-des-Passes	Quebec	Power	5.8	Modified Horseshoe	34.3 ft	Gneisic and Granitic	D&B	N	640 ft	Concrete lined
Chute-des-Passes	Quebec	Tail	1.7	Modified Horseshoe	48 ft	Gneisic and Granitic	D&B	250 ft	N	Unlined
Paijanne	Sweden	Water Supply	72	Horseshoe	26.4 ft	Granite. Gneiss	D&B	N	N	Unlined
Oahe	South Dakota	Power (2 tunnels)	2.6 2.8	Circular Circular	24 ft 24 ft	Clay-Shale Clay-Shale	TBM TBM	N	210 ft, 272 ft	Concrete lined
Eklutna	Alaska	Power	4.5	Circular	9 ft	Argillite, Graywacke	N	N	74 ft	Concrete lined
Bath Co.	Virginia	Power	Approx. 4	Horseshoe	32 ft	Shale, Sandstone	D&B	N	N	Concrete lined
Susitna (Tentative)	Alaska	Power	13.5 or 29	Modified Horseshoe	25 ft-40 ft	Argillite, Graywacke, Granite, Granodiorite	D&B	Approx. 2000 ft	600 ft to 1300 ft	Suggest same as Kemano for study purposes

1 ABBREVIATIONS:

TBM - Tunnel Boring Machine
D&B - Drill and Blast
N - Not Known



LEGEND

TUNNEL INTAKE WORKS AT:

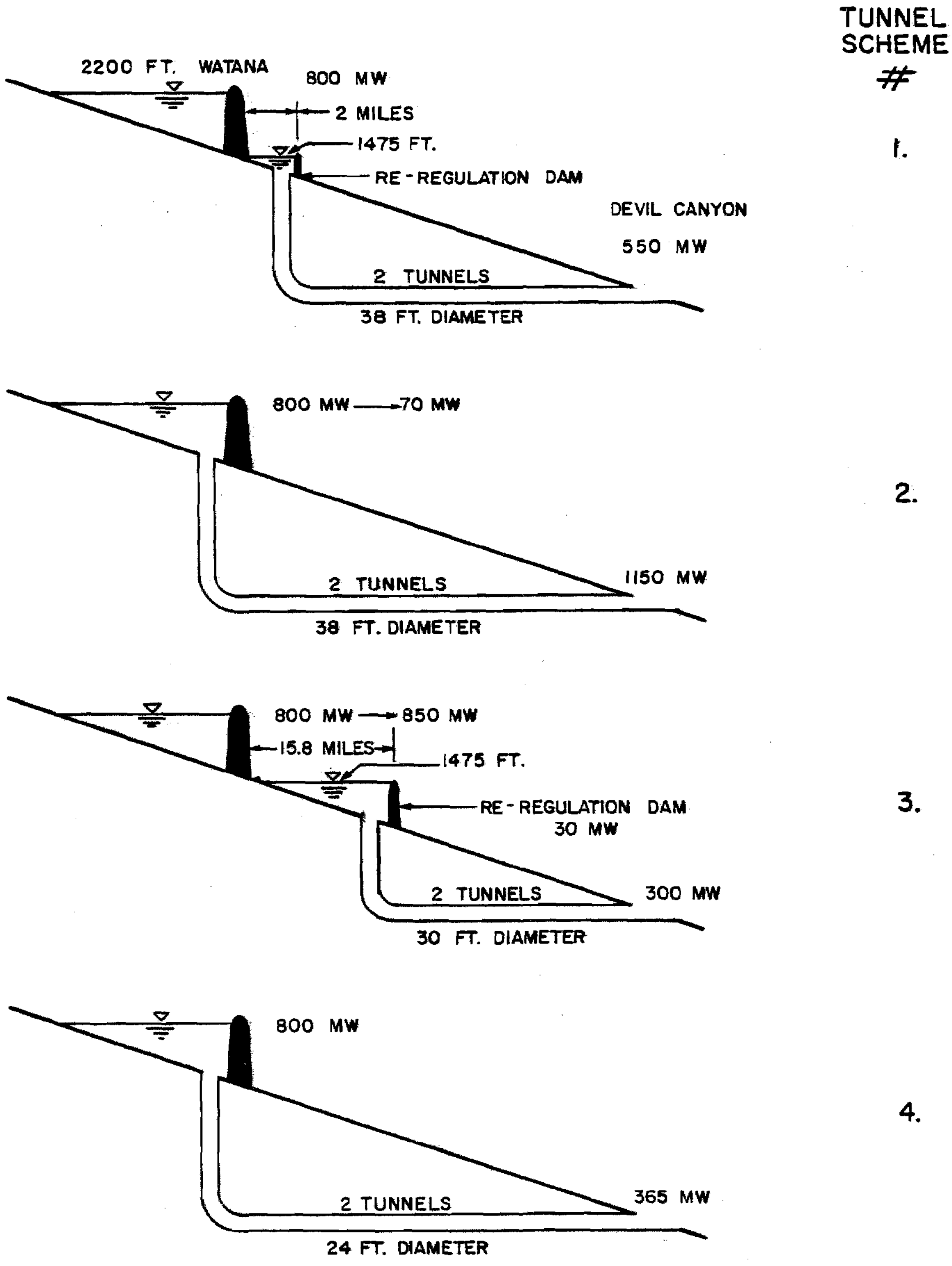
——— RE-REGULATION DAM SITE LOCATED JUST UPSTREAM FROM DEVIL CREEK

— — — WATANA DAM SITE

— — — VEE DAM SITE

ECONOMIC POTENTIAL OF TUNNEL SCHEMES

FIGURE 4.1



SCHEMATIC REPRESENTATION
OF CONCEPTUAL TUNNEL SCHEMES

FIGURE 4.2

5 - TUNNEL DESIGN AND CONSTRUCTION CONSIDERATIONS

5.1 - Geologic Setting

Determining the geology along the tunnel alignment is critical in predicting tunneling conditions, methods, and costs. The information acquired to date includes several regional geology reports, site specific geology for the Devil Canyon and Watana dam sites, and the findings of the Woodward-Clyde Consultants' (WCC) 1980 Seismicity Study (43).

The Susitna project is located in a tectonically active and geologically complex region. Subduction of the Pacific plate under the North American plate (Figure 5.1) has resulted in forces which have folded, faulted, thrusted, sheared, differentially uplifted, metamorphosed and intruded the area. The most common geologic structures encountered include folds, faults, shear zones, joints, flow foliation, stocks, dikes, and plutons.

(a) Lithology

As shown on Figure 5.2, three main lithologic units are crossed by the tunnel alignments: Argillite-Graywacke; Biotite-Granodiorite; and Schist, Migmatite, and Granite.

The Argillite-Graywacke Unit (Kag) has undergone complex folding with a well developed axial plane cleavage and numerous quartz stringers. The argillite is dark gray to black and in some areas has metamorphosed to a slate or fine-grained phyllite. Tests performed by the USBR for samples taken at the Devil Canyon site indicate its unconfined compressive strength ranges from 12,900 to 16,850 psi, Young's modulus averages 9×10^6 psi, and Poissons' ratio averages 0.17.

The Graywacke is dark to medium-gray, fine to medium grained, and is intercalated with the argillite in graded beds ranging in thickness up to 16 feet. It comprises between 30 percent and 40 percent of the Argillite-Graywacke Unit. Tests performed by the USBR indicate its unconfined compressive strength ranges between 28,540 and 36,570 psi, Young's modulus averages 9.8×10^6 psi and Poissons' ratio ranges between 0.15 and 0.25.

The Biotite-Granodiorite Unit (Tbgd) is described as light to medium-gray, medium to coarse grained intrusive rock with a granitic texture. Biotite is the chief mafic mineral, but hornblende is occasionally present. Although no test data is available, the average static properties for this type of rock are generally believed to be an unconfined compressive strength between 20,000 and 30,000 psi, Young's modulus about 8×10^6 and a Poissons' ratio of 0.2.

The Schist, Migmatite and Granite Unit (Tsmg) can be described as undifferentiated terrain of relatively high grade pelitic schist, migmatite and small granitic plutons occurring in approximately equal proportions with gradational contacts.

Again, no static properties are known for this unit, but the granite and migmatite properties are probably similar to the granodiorite. The schistose rock properties will vary with the direction they are loaded and will probably demonstrate a wide range of values. It is important to determine the properties of this unit and the percentage of tunnel through it. A poor quality schistose rock may present major problems to tunneling operations.

A complete description of these units is included as Appendix A (40).

(b) Structure

As mentioned earlier, the geologic structure in this region is complex. The major structural trends are NE-SW and NW-SE and major faults trend NE-SW. Results of outcrop mapping between Devil Canyon and Watana are shown in Table 5.1.

(c) Topography

The topography is generally rugged along the tunnel alignments, and the geologic structure exerts some topographic control. Elevations vary between 1300 and 3500 feet. Topographic lows, such as the locations of streams and creeks, are areas of concern. They may represent zones of poorer rock quality and may require that tunnels be structurally lined to meet stability and cover requirements.

(d) Lineaments

As part of the WCC study, several lineaments were mapped which cross the tunnel routes. These are shown on Figures 5.3 to 5.6. These lineaments are considered significant for further investigations due to their characteristics and possible problems in tunneling through them. Other lineaments may exist along the tunnel routes which were not identified due to their distances from the dam sites. A more detailed investigation is required if the tunnel alternative studies are continued as a preferred scheme.

5.2 - Geotechnical Design Aspects

Potential geotechnical problems and their impact on the tunnel schemes are reviewed in this section.

Geotechnical design and hence the cost and construction schedule for a tunnel is heavily dependent on evaluation of the geology along the potential routes. The major tunneling problems are created by fault and shear zones, joint sets, lithologic contacts, water and gas. It is normally not economically feasible to undertake a comprehensive exploration program for the entire route. Therefore, reconnaissance, mapping, and exploratory work must be directed towards locating all potential problem areas and these must be evaluated in detail.

Fault and shear zones may create severe problems. Special tunneling techniques and heavy supports may be required and decreased production rates during construction can be expected in these areas. If the lineaments identified by WCC prove to be fault and/or shear zones, the tunnel alignments will probably have to be adjusted to avoid or minimize the impact of these features. The shortest route across these zones is preferred.

Topographic lows such as Devil Creek, Tsusena Creek and other creeks and streams may indicate weak zones. Drilling and seismic refraction survey techniques will be required to determine the properties of the lineaments and topographic lows.

A limited amount of outcrop geologic mapping has been used to align the routes at this time. Tunnel alignments have been oriented to cross the joints to decrease support requirements and to help control overbreak.

Lithologic contacts may also present several problems. If the contact is sharp and fresh, no structural problem may exist, but production rates may change and tunneling methods will have to be adjusted for the new rock. Problems will also be encountered if the contact is sheared or brecciated. Special designs are required if these contacts contain unconsolidated material and these contacts may also be a source of water which can create serious difficulties. Many joints in the Watana and Devil Canyon drill cores are tight and healed. Downhole permeabilities vary but average less than 10^{-5} cm/sec below the weathered zone. If this remains true along the tunnel alignments, water should not be a problem.

Gas can create both health and safety problems, i.e. asphyxiation and/or explosion. Gas is not usually a problem in the lithologies present and good ventilation will probably eliminate any potential problems.

5.3 - Seismic Considerations

There are several ways an earthquake may adversely effect a tunnel. Three common sources of damage are displacement, shaking, and ground failure.

Displacement is usually associated with serious damage and is considered the most severe problem. Small movements along discontinuities are generally not critical and only minor damage may result. However, displacements of several feet can lead to serious damage.

Shaking may cause cracking, rockfalls, or possibly collapse. Dynamic stress concentrations occur which increase static loadings and may result in damage.

Ground failure includes liquefaction and landsliding. These types of failures may not damage the tunnel itself, but may seriously damage portal areas, and thus, effect the tunnel use.

Dowding and Rozen (11) studied the effects of seismic loading on tunnels. Based on 71 tunnels throughout Japan, Alaska, and California, they developed a correlation between peak motion, particle velocity and observed damage. Table 5.2 summarizes their findings.

They concluded that earthquakes expected to cause heavy damage to surface structures cause only minor damage to tunnels. Peak motions for earthquakes usually occur in the 0.4 to 10 Hz range. These low frequencies are several orders of magnitude lower than the natural frequencies of tunnels and not likely to create differential acceleration and damage to tunnels. Lined and grouted tunnels are less subject to damage than unlined ones. Under similar seismic loadings an unlined tunnel may experience rockfalls while a lined and grouted tunnel may experience only minor cracking.

Seismic design considerations for tunnels usually include:

- Avoiding faults which may experience large displacements during an earthquake.

- Supporting, lining, and grouting areas of poor rock quality.

- Adequately designing portals for seismic loadings.

The preliminary indications from the WCC studies indicate that the Benioff Zone may produce the controlling or design earthquake in the vicinity of the Watana and Devil Canyon dam sites. The design earthquake would, thus, be as high as 8.5 magnitude event (Richter Scale) and produce mean peak horizontal accelerations in the order of of 0.4 g. Therefore, minor rockfalls and some cracking of concrete may occur but no major tunnel stability problems are anticipated.

5.4 - Design Considerations

The following preliminary design considerations were adopted for purposes of estimating costs of the conceptual tunnel schemes outlined in Section 4.

(a) Tunnel Size

The power tunnels were sized to maximize the net benefit. This required cross-sectional areas of between 700 and 2000 ft^2. The geologic information to date indicates that tunnels in the 700 to 1000 ft^2 range could be constructed without major problems. Although it may be difficult to economically construct very large tunnels through poor rock, no adjustments to the economically sized tunnels was made during this study as the amount of geologic information available was not sufficient for this adjustment.

(b) Tunnel Shape

Tunnel shape is generally a function of hydraulics, stability and ease of construction. In good quality, high strength rock, stability is not a problem and the other factors govern the shape. As rock quality and strength decrease or the rock is overstressed, shapes tend to be more circular.

For purposes of this study, a modified horseshoe shape was tentatively selected based on the assumptions that:

- The majority of the tunnel is in good to excellent rock requiring little support.

- It is the easiest shape to drill and blast.

(c) Tunnel Alignment

The objective of aligning the tunnels is to have the shortest tunnel through the best rock. Avoiding zones of poor quality and topographic lows, crossing adverse geologic structures (not paralleling them), attaining the minimum cover over the tunnel, and keeping the stresses compressive around the tunnel are major considerations.

(d) Tunnel Grade

Tunnel grade or depth is selected so as to locate the tunnel in a competent strata and meet cover requirements. These cover requirements vary greatly and Table 5.3 summarizes the cover used in several projects. It indicates that values of between 15 percent and 50 percent of the total hydraulic design head have been used.

For purposes of these studies, rock cover equal to the static head was used. When the rock cover is less than this, a lining is assumed necessary.

It has been assumed that slopes within the tunnels will be inclined slightly (approximately 0.5 percent) to ease construction and haulage. Access adits are located so as to minimize their lengths. Maximum grades are 3 percent for rail haulage system and 10 percent for trucks.

(e) Tunnel Lining and Support

Drilling at Watana and Devil Canyon indicate that the rock is tight and impermeable at depth. For purposes of this study it has been assumed that one third of the tunnel length will require structural concrete lining with a combination of steel sets and rockbolting, one third shotcrete lining and rockbolting, and the remaining one third will require no lining or support, except for the concrete-lined invert.

5.5 - Construction Methods

Initially, three tunneling methods were considered for this study:

- Drill and Blast

- Tunnel Boring Machine (TBM)

- Road Header

Based on available knowledge, drill and blast appears to be the most viable for Susitna and the tunnel estimates are currently based on this method. Each method, however, has advantages and disadvantages and is discussed briefly below.

(a) Drill and Blast

Drill and blast is the oldest form of rock tunneling. Each cycle involves:

- Drilling

- Loading

- Shooting

- Ventilating

- Supporting

- Mucking.

The two most common approaches involve heading and bench or full face excavation. Heading and bench removes a small top heading at a higher unit cost, then removes the bench at a lower unit cost. The full face excavation method excavates the entire face at once. In large tunnels, heading and bench may be more economical than full face excavation. Both methods would be suitable for the proposed Susitna tunnel scheme.

There are several advantages to drilling and blasting:

- It is flexible and will accommodate most rock types, tunnel shapes, grades, and can be adapted to rapidly changing geologic conditions.

- The initial cost is generally lower.

- Lead and mobilization times are usually shorter.

- There are many experienced contractors.

Some of the disadvantages include:

- Running costs are higher.

- Ground disturbance is high and overbreak may be considerable.

- More extensive support and/or lining may be required.

- Production, on the average, is lower than for mechanical excavators.

Considering the complex geology and the present lack of geologic information along the tunnel routes, this method was selected. It is sufficiently flexible to deal with any problems that may arise and yields a relatively conservative construction cost estimate.

(b) Tunnel Boring Maching (TMB)

Machine tunneling has advanced greatly in the last 20 years. TBMs are being designed to handle a variety of geologic conditions and by the time the Devil Canyon tunnels are required machine tunneling may be an attractive option. Presently, this system seems too inflexible for the geologic conditions anticipated.

The TBMs have several advantages:

- Low rock disturbance.

- Lower support requirements.

- Lower running cost.

- A lining may not be required.

- Higher production rates if the rock quality is good and the geology is uniform.

Some major disadvantages are:

- They are inflexible, that is, grades and operating radii are limited and only a circular shape is possible for large tunnels.

- High initial cost. These machines are uneconomical for tunnels less than several miles in length.

- Longer lead time, probably one year.

- Longer setup time, probably six weeks.

- Problems tunneling through poor quality rock. TBMs work very well under the conditions they were designed for, but do not adapt well to geologic changes.

(c) Road Headers

A road header is an offshoot from the mining industry and involves a mechanical tunneling system. It has the advantages of being more flexible than a TBM, but presently cannot cut hard rocks efficiently. If these machines had the capability of cutting hard rocks at reasonable production rates, they would merit serious consideration.

(d) Mucking

Mucking is the term used to describe removal of the excavated material from the tunnel. Selecting a mucking system depends on tunnel grade, length, and equipment the contractor has available. Within the tunnel, two haulage systems are commonly used, rail and truck.

Rail systems are favored for long tunnels since they can usually haul large quantities economically. Their maximum grade is 3 percent, but they may be winched on steeper grades. Trucks are favored in tunnels less than about 4000 feet. Their maximum grade is 10 percent.

Considering the volume of material and haul distance to the access way, a rail system has been assumed for the Susitna tunnel schemes.

TABLE 5.1: GEOLOGIC STRUCTURE OF REGION BETWEEN THE DEVIL CANYON AND WATANA DAM SITES

A. GENERAL AREA

Feature	Orientation		Spacing
	Average	Range	
Major Joint Set	335°, 82° SW	320°-355°, 63°-90° SW	6 in to 2 ft
Major Joint Set	325°, 77° NE	300°-355°, 62°-90° NE	6 in to 3 ft
Major Joint Set	48°, 79° SE	40°- 60°, 65°-90° SE	6 in to 1.5 ft

B. ARGILLITE-GRAYWACKE AND UNIT IN THE IMMEDIATE VICINITY OF THE DEVIL CANYON DAM SITE (Based on Geologic Mapping)

Feature	Orientation
Bedding	53°- 70°, 50°-80° SE
Major Joint Set	320°-350°, 82° NE (average)
Major Joint Set	70°-105°, 15°S (average)
Minor Joint Set	70°-105°, 65° NW (average)

TABLE 5.2: EFFECTS OF SEISMIC LOADING ON TUNNELS (11)

Horizontal Acceleration(g) (ft/sec^2)	Velocity (In/sec)	Damage
< 0.19	< 8	None
0.19 - 0.25	8.16	Few instances of minor cracking, some rock falls in unlined tunnels
0.25 - 0.52	16-32	One partial collapse in a masonry lined tunnel associated with a landslide

TABLE 5.3: TUNNEL COVER EXPERIENCE

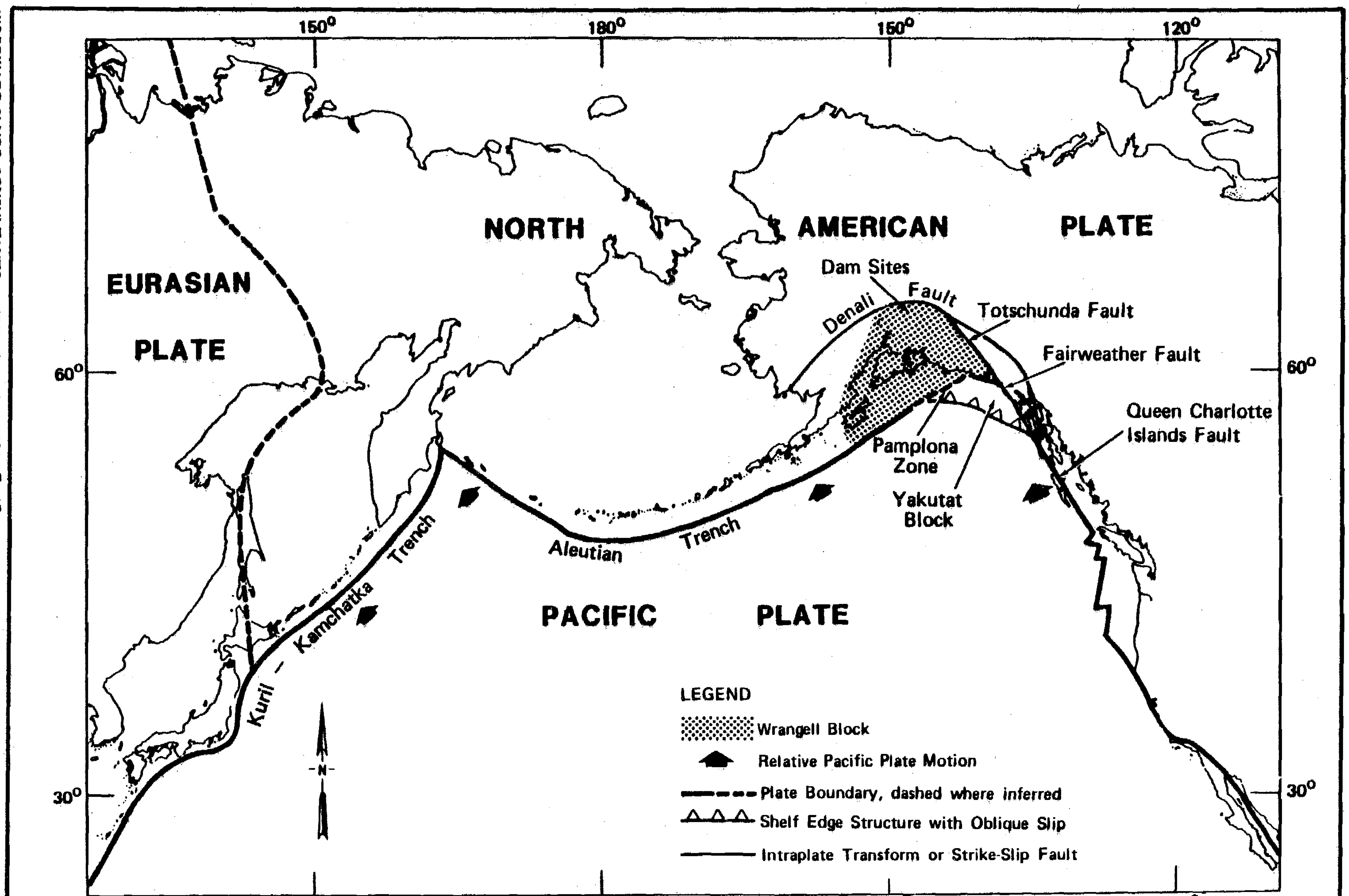
Project	Ratio of Rock Cover to Hydraulic Head*
Abjors	0.4
Bersimis 2	0.5
Gondo	0.2
Handek I	0.16
Handek II	0.18
Innertkirchen	0.14
Kemano	0.4
Montpezat	0.26
South Holston	0.5
Bersimis 1	0.5
Calancasa	0.33
Chute des Passes	0.5
Spray	0.24

*Hydraulic head includes both static and dynamic head.

TABLE 5.4: REGIONAL GEOLOGY MAP UNITS

Cenozoic	Qs	Undifferentiated Surficial Deposits
	Tsu	Undifferentiated Sedimentary Rocks
	Tv	Undifferentiated Volcanic Rocks
	Tbgd/Thgd	Biotite & Biotite-Hornblende Granodiorite
	Tsmg/Tkgr	Granites and Schists
Mesozoic	Kag	Argillite and Graywacke
	Jtr/Jgd/Jgdm	Quarts Diorites & Granodiorites
	Jam	Amphibolites
	TRv	Basaltic Metavolcanic Rocks
	TRvs	Metabasalt and Slate
Paleozoic	Psv/Pls	Basaltic to Andesitic Metavolcanogenic Rocks with Interbedded Limestone

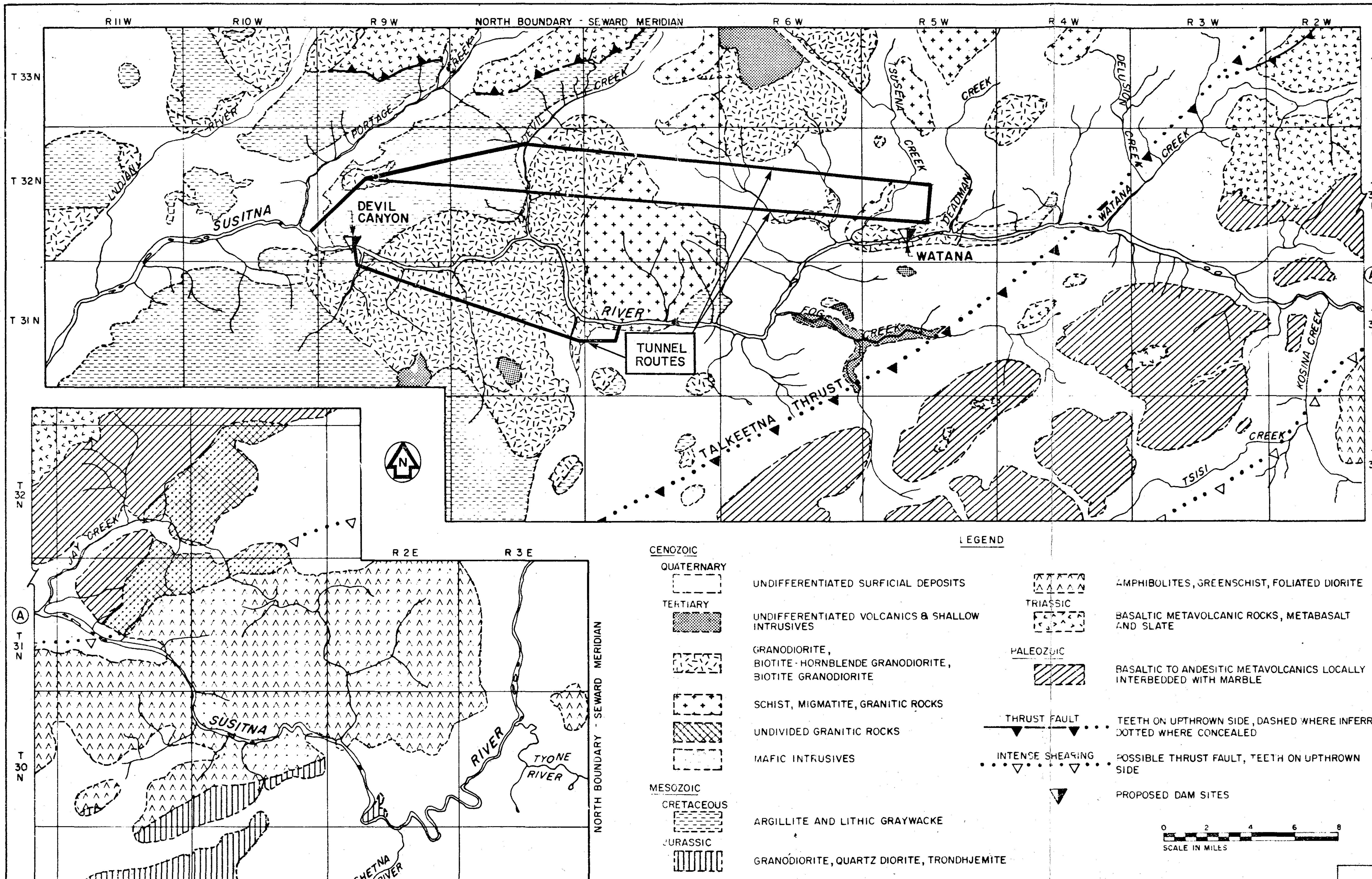
Modified after Csejtey and others, 1978.



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

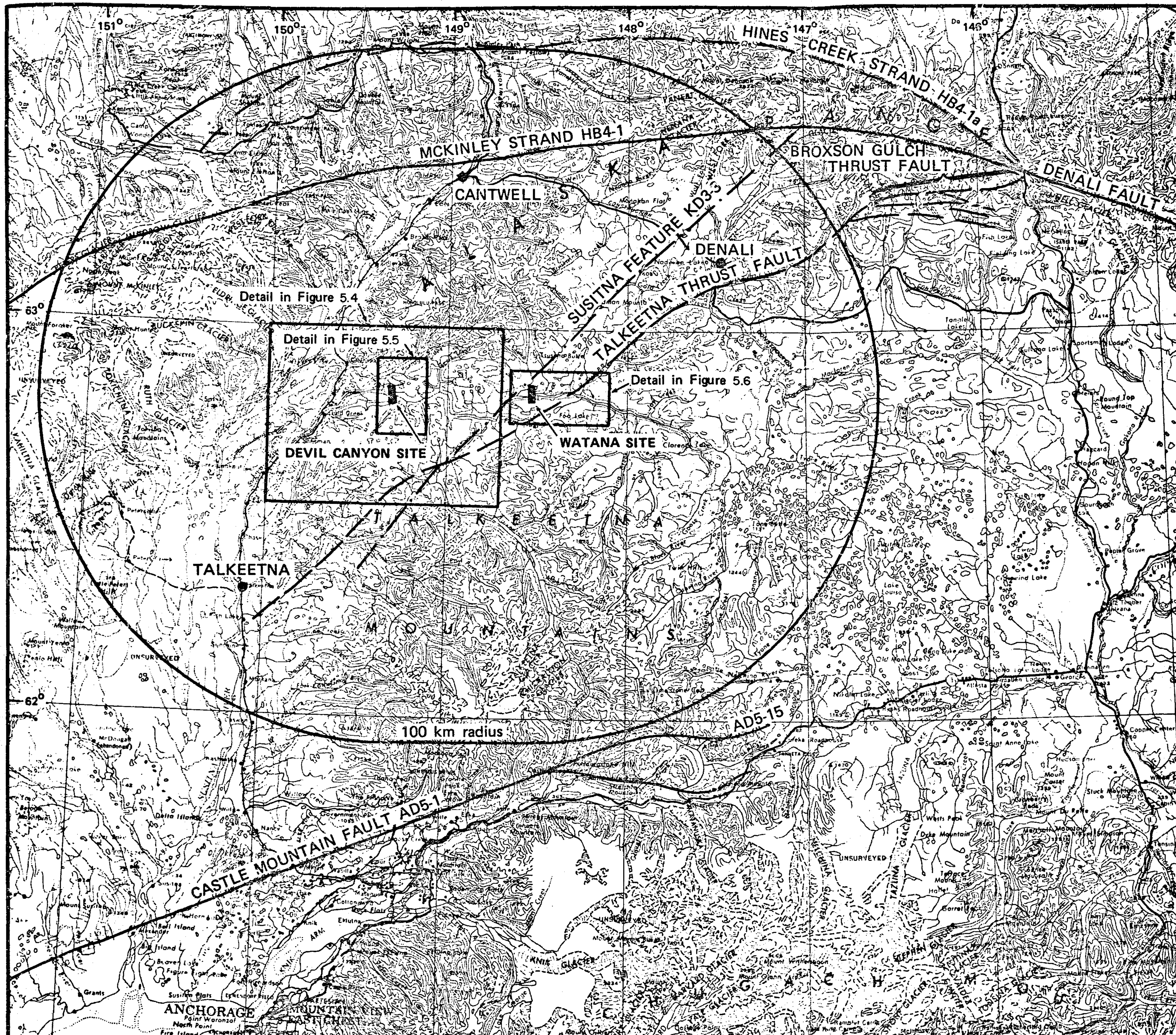
PLATE TECTONIC MAP

FIGURE 5.1



REGIONAL GEOLOGY WITH TUNNEL ROUTES

FIGURE 5.2



LEGEND

BOUNDARY FAULTS

Faults with recent displacement

SIGNIFICANT FEATURES

Indeterminate A feature

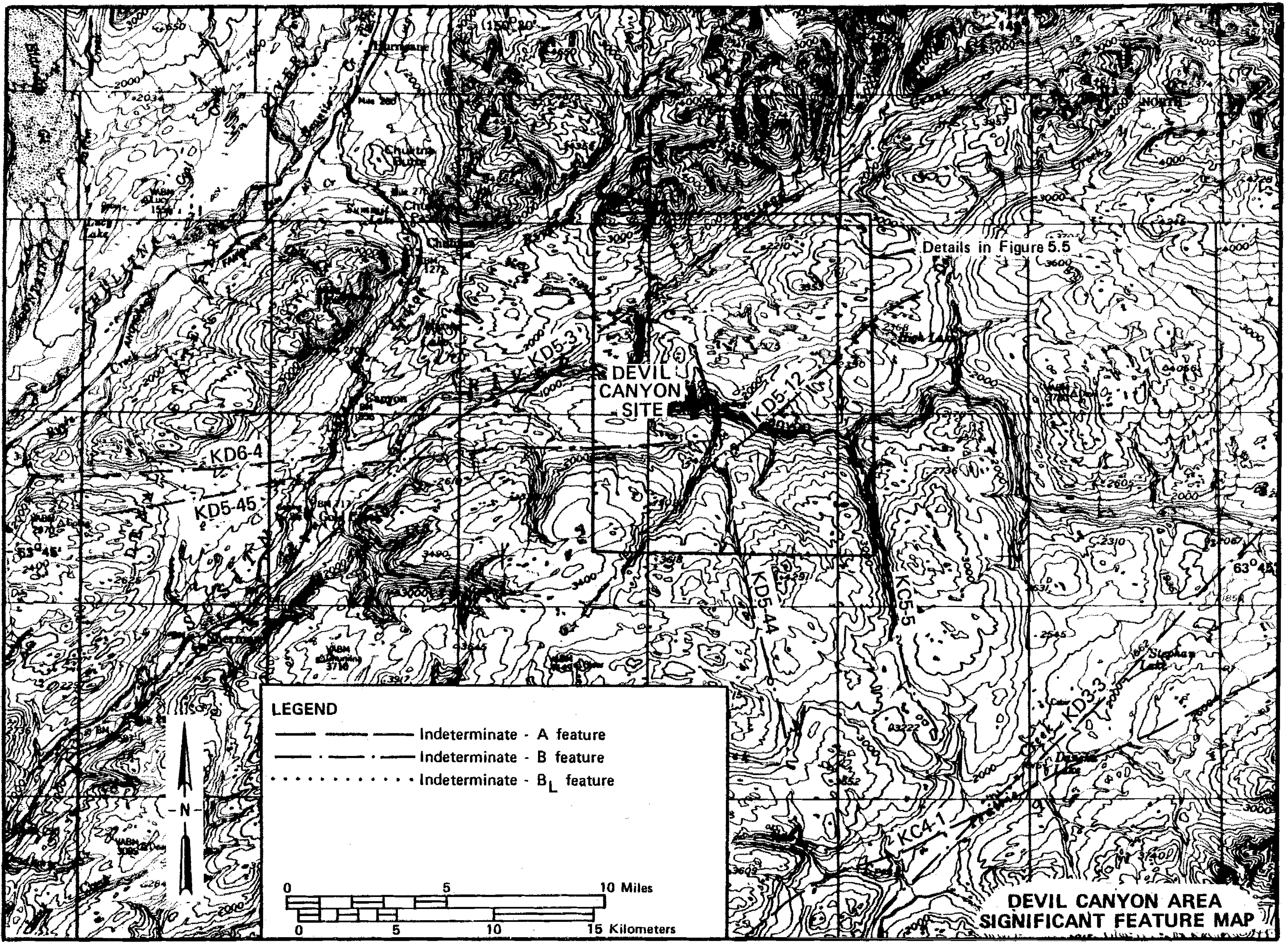
Indeterminate B feature

N

BOUNDARY FAULT AND SIGNIFICANT FEATURE MAP FOR THE SITE REGION

0 10 20 30 40 50 Miles

0 10 20 30 40 50 Kilometers



Details in Figure 5.5
DEVIL CANYON SITE
KD5-3
KD5-12
KD6-4
KD5-45
KD5-44
KC5-5
KD3-3
KC4-1
63°45'
LEGEND
Indeterminate - A feature
Indeterminate - B feature
Indeterminate - B_L feature
N
0 5 10 Miles
0 5 10 15 Kilometers
DEVIL CANYON AREA
SIGNIFICANT FEATURE MAP

FIGURE 5.4

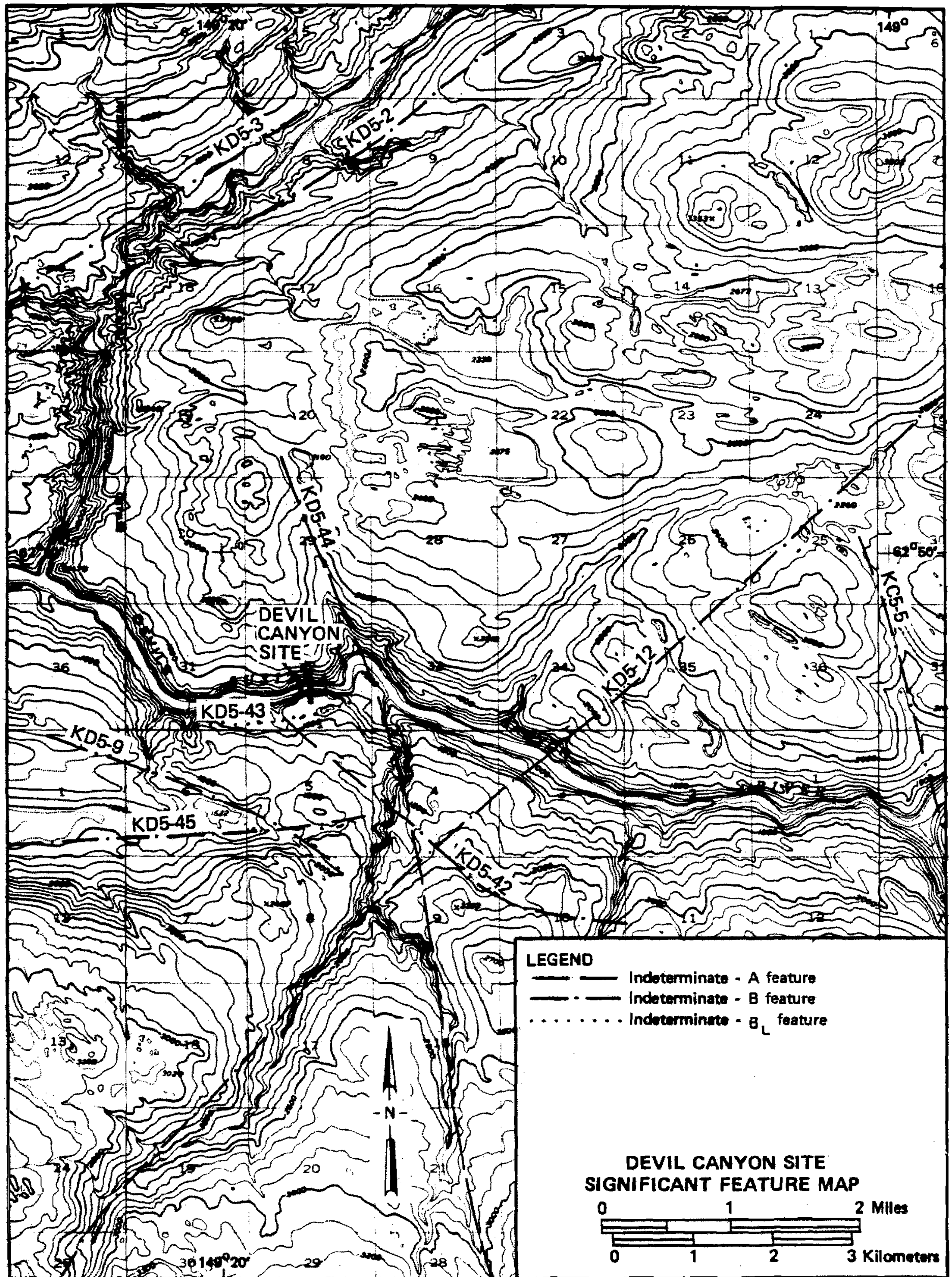

KD5-3
KD5-2
KD5-44
DEVIL
CANYON
SITE
KD5-43
KD5-9
KD5-45
KD5-42
KD5-12
KC5-5
149°20'
149°
62°50'
LEGEND
Indeterminate - A feature
Indeterminate - B feature
Indeterminate - B_L feature
N
DEVIL CANYON SITE
SIGNIFICANT FEATURE MAP
0 1 2 Miles
0 1 2 3 Kilometers

FIGURE 5.5

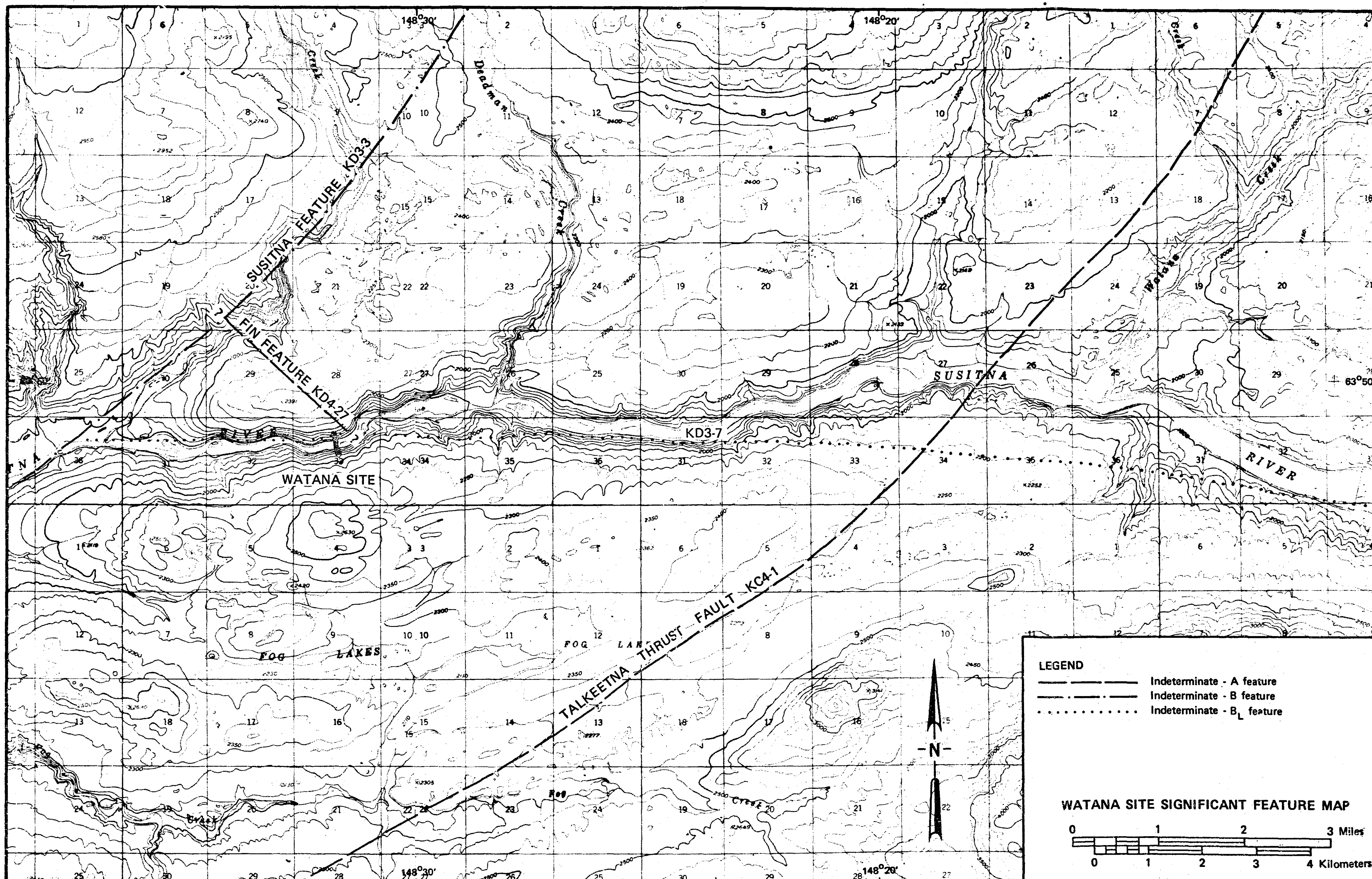


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FIGURE 5.6

6 - SCREENING OF CONCEPTUAL TUNNEL SCHEMES

6.1 - Introduction

The screening analysis was performed to compare the four conceptual tunnel schemes and determine the best tunnel scheme for further study. Costs, power and energy, geology, and environmental aspects are used as screening criteria.

6.2 - Tunnel Scheme Costs

All costs are based on 1980 dollars. Unit prices were applied to estimated quantities for the various components in each tunnel scheme. The total project cost for each tunnel scheme includes the total construction cost plus a 20 percent contingency and a 12 percent allowance for engineering and administration.

Wherever possible unit prices were developed and/or compared with cost information on recent projects in Alaska. Unit prices developed from projects outside of Alaska were adjusted to Alaska using the Handy Whitman price indices. In general, costs are based on the same unit prices as those used for the Susitna Basin dam alternatives outlined in the Subtask 6.05 report on "Development Selection".

Tunnel costs are based on the conservative assumption that excavation will be done by conventional drill and blast operations. Knowing very little about the rock mass quality along the route, support requirements are difficult to predict. Therefore, the lining and support assumptions were based largely on experience at the Kemano Project which is similar in concept, and the results of drilling at Devil Canyon and Watana, as outlined on Table 6.1.

As mentioned previously, due to the lack of geologic information and the fact that the tunnel is a major cost item, total project cost estimates must be regarded as tentative at this time. In any event, total project costs are relevant for a valid economic comparison between conceptual tunnel schemes. Tunnel scheme total project costs are given in Table 6.2 for each of the four tunnel schemes.

6.3 - Power and Energy

Energy values for the tunnel schemes were determined from an annual flow duration curve developed from the simulated monthly outflow from the Watana reservoir (35). This curve was adjusted to allow for a 1000 cfs minimum discharge in the river. Allowance was made for tunnel friction and entrance losses. Installed capacities were calculated to yield an overall plant factor of between 50 and 55 percent for the total Watana dam-tunnel system. For the tunnel generating portions of the total development plant factors of about 50 percent were used for peaking tunnels and about 80 percent for base load tunnels.

The resultant installed capacities and average annual energy yields are shown in Table 6.2. Figure 6.1 illustrates in the form of simplified power duration curves the operating modes of the various powerhouses in the tunnel schemes.

Of primary importance in the assessment of the tunnel schemes' potential is the increase in energy production over the single Watana development. As shown on Table 6.2, Scheme 3 yields the largest increase in energy production with 2180 Gwh of added average annual energy. Schemes 1 and 2 would provide for an increase in average annual energy of 2050 Gwh and 1900 Gwh, respectively. Scheme 4 would have the smallest increase of only 890 Gwh.

6.4 - Environmental Considerations

A preliminary assessment of the environmental aspects associated with the four tunnel schemes has been made (33). This preliminary assessment was done for comparison and screening of the tunnel schemes only, and impacts common to all schemes were not addressed. The results of this assessment are as follows:

(a) Scheme 1

The environmental impacts associated with this tunnel scheme are likely to be greater than those of at least one of the other tunnel schemes evaluated (i.e. Scheme 3). The main criterion for this assessment is the adverse effects, particularly on fisheries and recreation of the variable downstream flows (4000-14000 cfs daily) created by the Devil Canyon powerhouse peaking operation. Other negative impacts would result from construction of both the re-regulation dam and a relatively long tunnel. Tunnel impacts are similar to those of Schemes 2 and 4 and include disturbance of Susitna tributaries as a result of tunnel access and the potential problems associated with disposal of a relatively large volume of tunnel muck.

(b) Scheme 2

As for Scheme 1, this scheme involves adverse environmental impacts associated with variable downstream flows caused by peaking operation at the Devil Canyon powerhouse (4000-14000 cfs). Without the re-regulation dam, however, less land would be inundated and the impacts associated with construction of this relatively small dam would be avoided. As for Scheme 1, the long tunnel proposed will also have negative consequences, including disturbance of tributaries for tunnel access and the potential problems connected with tunnel muck disposal.

(c) Scheme 3

The overall environmental impact of this scheme is considered less than that related to each of the two previous schemes, and also less than that related to the fourth scheme. The relatively constant discharge (about 8300-8900 cfs) from the Devil Canyon powerhouse is desirable for maintaining downstream fish habitat and recreational potential. A general reduction in river flows through Devil Canyon in this alternative may allow anadromous fish access to a previously inaccessible 15 mile stretch of the Susitna River, and an opportunity for enhancement of the fisheries resource.

With a compensation flow sufficient to allow minimum discharge of 1000 cfs through Devil Canyon, the riverine character of the reach should be maintained.

As with all of the tunnel schemes, the wildlife habitat in the stretch of river bypassed by the tunnel might improve temporarily because of an increase in riparian zone vegetation. With Scheme 3, however, this stretch of river is shorter than with the other tunnel schemes so a smaller area would benefit. The wildlife habitat downstream of Devil Canyon powerhouse may well benefit from the flow from the hydroelectric project regardless of the scheme chosen. With the constant flows allowed in Scheme 3, the improvements to that habitat may be somewhat greater than with the variable flows resulting from peaking in the other tunnel schemes.

One environmental disadvantage of this scheme compared to the others is the larger area to be inundated by the re-regulation reservoir. This area includes known archeological sites in addition to wildlife habitat. Nevertheless, this disadvantage is offset by the more positive environmental factors associated with constant discharge from the Devil Canyon powerhouse.

(d) Scheme 4

Scheme 4 involves peaking operation at Watana with baseload operation in the tunnel. Since the net daily fluctuations in flow below Devil Canyon would be considerable (4000-13000 cfs), Scheme 4 is judged to be less desirable than Scheme 3 from an environmental standpoint. Although Scheme 4 would avoid the impacts associated with the lower dam and its impoundment (as planned under Scheme 3), the adverse impacts that would result from fluctuating downstream flows are considered to be an overriding factor.

Another, although less significant, disadvantage of Scheme 4 compared to Scheme 3 is the longer tunnel length planned for the former, and perhaps the proposed location of the tunnel on the north side of the river.

6.5 - Geotechnical Considerations

From a geotechnical perspective, the northern and the alternative direct alignments for Schemes 1, 2 and 4 are similar (see Plate 1). Therefore, they will be discussed together while Scheme 3 will be discussed separately. Table 6.3 shows estimates of tunnel length proportions within the various lithologic units.

The results of drilling at Devil Canyon and Watana show that rock quality improves with depth. Therefore, the rock at tunnel grade for all three alignments should be good since the minimum rock cover is several hundreds of feet. The geology along the northern and direct routes seems more complex. These routes cross at least four lithologic contacts, three different rock units, two major lineaments, and several minor ones. One lineament is the Susitna Feature. Although it is not currently considered likely, if this feature were found to be a fault zone, it could create a very difficult tunneling environment. The topographic low at Devil Creek may also be a problem zone. Tunneling through the schistose portions of the schist, migmatite and granite unit may also be difficult.

Scheme 3 has several advantages. It is about half as long, crosses only one known lithologic contact, is 90 percent in the Biotite-Granodiorite unit, and crosses one known major lineament and several minor ones. Being 90 percent in one unit, machine tunneling may be possible.

Various lineaments cross the alignments. None have been classified as active faults and most were in the doubtful category as being faults (43). None of these features appear to present extreme tunneling problems, but all will require exploration to determine their characteristics. If they are faults, strengthened linings will have to be designed and tunneling techniques may have to be modified.

All tunnel alignments were laid out so that they crossed the known joint sets. The northern alignment (for Schemes 1, 2 and 4) was suggested because as it increases available cover. The tunnel length crossing topographic lows at Tsusena and Devil Creeks is minimized, but is about two miles longer than the direct route. The direct route has been proposed because it is the shortest. However, the tunnel lengths crossing the topographic lows at Devil and Tsusena Creeks are longer and the cost of lining these areas may make this alignment less attractive. Also, if these lows are zones of poor rock quality, tunneling through them may be more costly than minimizing these lengths by avoiding them.

Scheme 3 was aligned to maintain the minimum cover over the entire route. The tunnel was diverted around topographic lows. Future alignment adjustments may decrease the tunnel length, but not significantly.

Presently, the Scheme 3 alignment appears to be preferable from a geotechnical viewpoint. However, explorations are required on all three alignments to firm up this judgement.

6.6 - Preferred Tunnel Scheme

It is evident from the above discussion that of the four conceptual tunnel schemes, Scheme 3 is preferred. The economic aspects, environmental aspects, and geological conditions of Scheme 3 are considered superior to the other tunnel schemes at this time. Scheme 3 produces additional energy at by far the lowest cost as is shown in Table 6.2. Scheme 3 was, therefore, selected for further, more detailed study.

TABLE 6.1: ASSUMED TUNNEL SUPPORT

Rock Quality (RQD)	Percent of Tunnel	Support and Lining
> 90	34	None to occasional rockbolts
50-90	33	Rockbolts, shotcrete, welded wire fabric
25-50	25	Rockbolts, shotcrete, welded wire fabric, concrete
< 25	8	Steel sets, shotcrete, concrete

TABLE 6.2: DEVIL CANYON TUNNEL SCHEMES
COSTS, POWER OUTPUT AND AVERAGE ANNUAL ENERGY

	Installed Capacity (MW) Watana	Installed Capacity (MW) Devil Canyon	Increase[1] in Installed Capacity (MW)	Devil Canyon Average Annual Energy (Gwh)	Increase[1] in Average Annual Energy (Gwh)	Tunnel Scheme Total Project Costs ($ x 10^3)	Cost[3] of Additional Energy[1] (mills/kWh)
STAGE 1:							
Watana Dam	800	---	---	---	---	---	---
STAGE 2:							
Tunnel:							
- Scheme 1	800	550	550	2,050	2,050	1,979,000	42.6
- Scheme 2	70	1,150	420	4,750	1,900	2,317,000	52.9
- Scheme 3[2]	850	330	380	2,240	2,180	1,221,000	24.9
- Scheme 4	800	365	365	2,490	890	1,494,000	73.6

1 Increase over single Watana, 800 MW development, 3250 Gwh/yr

2 Includes power and energy produced at re-regulation dam

3 Energy cost is based on an economic analysis (i.e. using 3 percent interest rate) as discussed in Section 7.6.

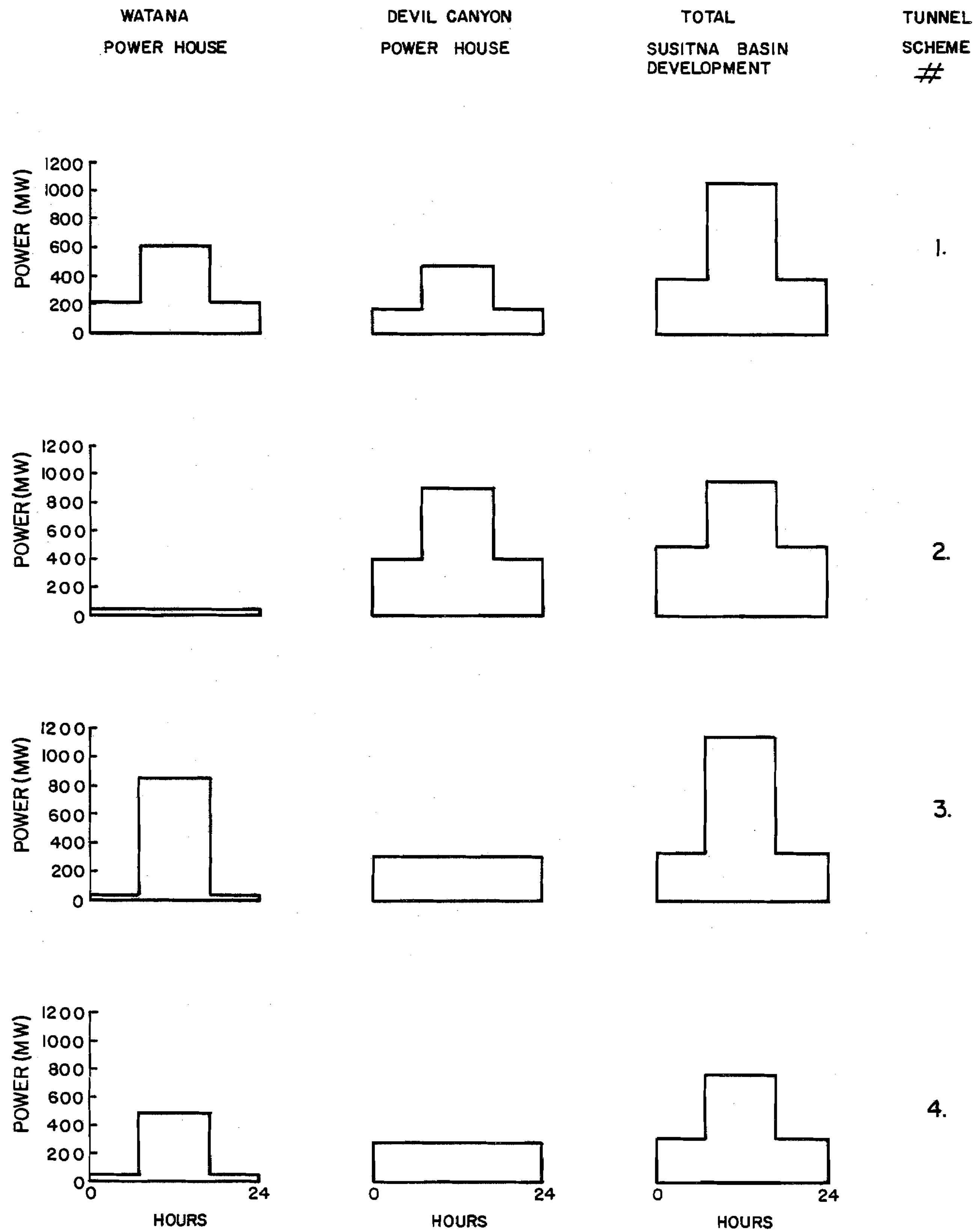
TABLE 6.3: LITHOLOGY OF TUNNEL ROUTES

Scheme(s)	Alignment	Percent Tunnel Route in Each Lithologic Unit**			
		Lithology			
		Kag	Tbgd	Tsmg	Qs*
1,2,4	Northern	31	11	10	48
1,2,4	Direct	13	29	31	27
3		10	90	0	0

NOTES:

* The rock units below the Quaternary soils along the alignments are most likely Tsmg and Tbgd.

** These percentages are based on surficial rock unit distributions. The actual length of tunnel in each unit is unknown.



TYPICAL DAILY POWER PRODUCTION FOR MARCH

FIGURE 6.1

ACRES

7 - PREFERRED TUNNEL SCHEME

7.1 - Introduction

As outlined in Section 6, tunnel Scheme 3 was selected for more detailed study. The aim of the more detailed study is to further refine the engineering concepts, to improve the accuracy of the cost estimate, and to evaluate the power and energy potential in more detail. This information is used for comparison of the tunnel scheme with the Devil Canyon dam scheme in Section 8.

7.2 - Design and Operational Assumptions

(a) Design Assumptions

The design assumptions used in the more detailed study are essentially as previously outlined in Section 5.4 and the construction technique as in Section 5.5.

The proposed alignment crosses the known joint sets to minimize support and overbreak problems. Adequate cover is maintained along the entire route and the minimum tunnel depth of 250 feet is believed to be conservative. The lining requirements for the tunnel are as outlined in Section 5.4.

Table 7.1 summarizes the rock quality observed in the drill holes at the Watana and Devil Canyon dam sites. If these rock qualities remain true along the Scheme 3 alignment, up to 50 percent to 80 percent of the tunnel could be unlined and lightly supported, 20 percent to 40 percent may require rock bolts and shotcrete, and 10 percent to 20 percent may require rock bolts, shotcrete and a cast in place concrete lining. In view of these results, the lining and support requirements suggested in Table 6.1 are conservative and were retained.

As before, the tunnel size was selected on the basis of an economic analysis. The optimal tunnel size was determined such that the sum of the amortized tunnel cost and the value of energy lost due to friction is minimized. The value of energy was based on a thermal coal-fired plant in the year 2000. Table 7.2 summarizes the results of the analyses and also indicates that tunnel sizes would not be significantly different for lower energy values or if the cost of energy produced by the tunnel had been minimized.

The single tunnel diameter was taken to be 40 feet, which is relatively large. In view of the sparsity of geotechnical data, two smaller, parallel tunnels of similar total capacity were conservatively selected for study purposes. Such a concept also has security advantages, the optimum sizes of these tunnels being 30 foot diameter.

For this study it has been assumed that the powerhouse is located at the downstream end of the tunnel. This does not necessarily imply that a powerhouse located at the upstream end would not be studied, with the tunnels being used for tailrace discharges. Further study would be required to determine the optimum location.

(b) Operational Aspects

Minimum discharge of not less than 500 cfs from Watana and 1000 cfs from the re-regulation dam were specified. No daily maximum limit on the discharge from Watana was specified because of the downstream re-regulation dam. Constant daily discharges from the re-regulation dam and the Devil Canyon powerhouse were specified.

The Devil Canyon powerhouse is assumed to be operated as a base load power facility. No daily discharge fluctuations are allowed at the Devil Canyon powerhouse and daily peaking power demands are supplied by the Watana powerhouse. Daily peak discharges from Watana are regulated at the re-regulation dam with a maximum fluctuation in the re-regulation reservoir of less than four feet. A relatively small powerhouse at the re-regulation dam operates as a base load power facility and supplies the required downstream compensation flow.

7.3 - Project Description

Scheme 3 is composed of a re-regulation dam, power tunnel, and powerhouse at Devil Canyon. Plates 2 and 3 illustrate the details.

The re-regulation dam is located approximately 15.8 miles downstream from the Watana dam site. Site selection was based on regional geologic mapping and airphoto and topographic interpretations. The 245 foot high dam is assumed to be a rock fill dam with an impervious core. A spillway is located on the north abutment, and a relatively small powerhouse with a capacity of 30 MW on the south side of the river. The maximum normal operating reservoir level is 1475 feet.

Power tunnel intakes are located on the south side of the river approximately 2000 feet upstream from the re-regulation dam. The optimal power tunnel diameter is 30 feet for each of the two power tunnels.

The underground Devil Canyon powerhouse has an installed capacity of 300 MW, with an assumed four generating units. Overland access to the powerhouse access adit area runs parallel to Cheechako Creek. A surge tank for each power tunnel is located just upstream of the powerhouse. Small cellular cofferdams are required along the south bank of the Susitna to allow construction of the tailrace.

As part of this tunnel scheme, the installed capacity at the Watana dam is increased by a small amount to reduce the overall system plant factor once the base load tunnel generating plant comes on line. A provision for an additional 50 MW has been made in this study.

7.4 - Cost Estimate and Construction Schedule

(a) Cost Estimate

The cost estimating methodology described in Section 6.2 was employed to develop cost estimates for the preferred scheme. However, as more detailed engineering layout drawings were available, it was possible to undertake a more detailed cost estimate than for the study described in Section 6.

Total project costs were re-estimated for both the two 30 foot diameter and the one 40 foot diameter schemes. These costs amounted to $1.50 billion and $1.34 billion, respectively. It should be noted that they are somewhat higher than the estimates associated with the conceptual tunnel schemes due to the higher level of detail involved. Summary cost estimates for the two schemes are shown in Tables 7.3 and 7.4.

(b) Construction Schedule

As shown in Figure 7.1, five years will be needed to complete construction of the Scheme 3 facilities. For the purposes of this study, the schedule is based on an assumption that access will be available from a previously constructed road from the Parks Highway to the Watana site. Underground work is assumed to be possible throughout the entire year, and rock placement only throughout the six months of summer. The exact timing and sequencing of the various "noncritical" activities will be dependent upon resource and seasonal limitations and other factors.

Initial work will be to construct several access roads of up to six miles in length to connect the Watana-Parks Highway to the re-regulation dam, Devil Canyon and intermediate access sites. It is expected that the construction of the Devil Canyon powerhouse can start shortly thereafter with the power on line date approximately 52 months after work commences.

Access to the main power tunnels will be through inclined access tunnels at two intermediate points. Additional tunneling will occur at both the power intake portal and at the main powerhouse. This will enable the tunnels to be driven from as many as six faces, resulting in an estimated maximum tunnel length of approximately five miles.

The complete re-regulation dam will take approximately three and one half years to construct with an estimated placement rate of approximately 640,000 cubic yards/month during the two year placement period.

As shown in Figure 7.1, the power on line date is approximately the same for both the re-regulation dam and the Devil Canyon powerhouses.

7.5 - Power and Energy

Power and energy have been evaluated by a demand driven computer simulation model. The model is based on monthly average demands and 30 years of historical monthly inflows. Scheme 3 incorporated with the Watana dam has been simulated to accurately represent operation of the entire development. Powerhouses were sized to achieve an overall capacity factor of 53 percent which is within the desired plant factor range of the Watana-Devil Canyon dam scheme.

Power and energy production from a Susitna basin development composed of Watana and Tunnel Scheme 3 is summarized in Table 7.5.

7.6 - Environmental Impact Assessment

A more detailed assessment of the environmental aspects associated with Scheme 3 has been made (33). A comparative environmental analysis on the location of the Devil Canyon powerhouse was also performed to determine the preferred powerhouse location.

(a) Location of Devil Canyon Powerhouse

Alternative locations for the Devil Canyon powerhouse have been proposed. Two alternative locations have been determined by the ease of access to the tailrace and powerhouse access area. The two sites are an upstream location about 0.3 miles above the Devil Canyon dam site and a downstream location about 1.5 miles below Portage Creek. The major environmental consideration is that a powerhouse upstream of Devil Canyon would preserve much of the aesthetic value of the canyon. In addition, the shorter tunnel would confine construction activities to a smaller area and may result in slightly less ground disturbance, particularly if there are fewer access points as well as a smaller muck disposal problem. It is for these reasons that this powerhouse location is preferred.

A downstream powerhouse location, on the other hand, might create a mitigation opportunity by opening up a longer stretch of river that perhaps could be managed to create salmon spawning habitat due to the lower flows through the rapids. However, there is currently no data to confirm this and at this stage the downstream powerhouse location is considered less flexible.

(b) Environmental Impacts

The major adverse environmental impacts associated with the tunnel scheme are the inundation of 3900 acres by the re-regulation reservoir, disruption during construction, disposal of tunnel muck, and bypassing the major portion of river flows through the tunnel. The area to be inundated by the re-regulation reservoir includes known archeological sites in addition to wildlife habitat.

The major beneficial environmental impact is the ability to regulate peak discharges from the Watana Dam. The re-regulation dam would store the daily peak discharges from Watana and release a constant downstream flow. The re-regulation dam would eliminate the effects of Watana peaking operations on the Susitna River. This would allow Watana to produce the maximum amount of peak energy possible with no adverse impacts downstream.

The compensation flow in the bypassed section of the Susitna River is totally controllable and could be varied seasonally. The controlability of the compensation flow could be an asset to the fisheries and wildlife in the stretch of the river bypassed by the tunnel.

(c) Disposal of Tunnel Muck

It is important to note that cost estimates for tunnel schemes are currently based on minimal requirements for transportation and disposal of excavated materials by whatever means are finally selected. If a costly disposal method is selected, total project costs could increase as much as 1 percent. The total volume of excavated material from the two 30 foot diameter tunnels amounts to 3.7 million cubic yards. Allowing for a bulking factor of 1.5 this would amount to approximately 5.6 million cubic yards of muck.

There are a number of options which may to be considered for environmentally acceptable disposal of the rock removed in excavating the tunnel. All of these will probably involve a small additional transportation and/or disposal cost, and include: stockpiling the material for use in access road repair, construction of the re-regulation dam (total volume = 7.7 million cubic yards), or stabilization of the reservoir shoreline; disposal in Watana reservoir; dike construction; disposal in a borrow pit created in dam constructions; sculpture, cover, and seed the pile; and disposal in a ravine or other convenient location. It is unlikely that the most environmentally acceptable option will also be the most economical. Because many unknown factors now exist, a firm recommendation cannot be made without further evaluation. It is quite likely, however, that a combination of disposal methods will be the best solution.

Stockpiling at least some of the material for access road repairs is believed to be environmentally acceptable provided a suitable location is selected for the stockpile. The material could possibly be utilized for construction of any of the access road spurs or temporary roads that are not already completed at the time the tunnel is excavated.

Another acceptable solution might be to stockpile the material for use in construction of the re-regulation dam. This rock could also be a potential source of material for stabilization of reservoir shorelines if required. As with the previous option, an environmentally acceptable stockpile location would be required. Material disposal in Watana Reservoir might also be environmentally acceptable. A small amount of tunnel muck could possibly also be used for stream habitat development. With any of these options, the possible toxicity of minerals exposed to the water should be first determined by assay, if there is any reason to suspect the occurrence of such materials and minerals.

Two environmental problems might be solved by disposing of the material in a borrow pit created in dam construction.

To sculpture, cover, and seed the material is worthy of further consideration, and would require proper planning. For example, borrow areas used in dam construction could, perhaps, be restored to original contour by this method. The source of soil for cover is a major consideration as earth should only be taken from an area slated for future disturbance or inundation.

The most economical solution might be to fill a ravine with the material or to dispose of it in another convenient location. Unless the chosen disposal site will eventually be inundated, however, such an arrangement is environmentally unacceptable, especially since better options are obviously available.

TABLE 7.1: DRILLING RESULTS AT WATANA AND DEVIL CANYON DAM SITES

Drill Hole	Depth (ft)	Percent of Core		
		RQD>80	50<RQD<80	RQD<50
BH-4	486	76	16	8
BH-2	653	89	8	3
BH-1	738.4	87	9	4
BH-2	391	46	28	26
BH-6	732.4	78	19	3
BH-8	736.7	70	21	9

TABLE 7.2 - OPTIMIZATION OF TUNNEL DIAMETER

Diameter (ft)	Installed Capacity: Watana (MW)	Installed Capacity: Devil Canyon (MW)	Installed Capacity: Re-regulation Dam (MW)	Maximum Head Loss (ft)	Maximum Velocity(1) (fps)	Tunnel Alternative Annual Net Benefit(2) ($ x 10^6)	Tunnel Alternative Annual Net Benefit(3) ($ x 10^6)	Cost of Energy Produced (mills/kwh)
Two Tunnels								
20	850	115	100	97.5	5.6	1.0	(17.3)	45.2
25	850	220	50	88.0	6.8	29.9	(1.5)*	30.8*
30	850	300	30	45.6	5.9	34.7*	(1.7)	30.8*
35	800	400	30	30.5	5.6	29.4	(9.0)	34.0
One Tunnel								
30	875	190	50	86.0	8.1	31.9	3.1	28.2
35	880	310	30	94.0	9.9	44.7*	9.3*	25.5*
40	800	300	30	33.4	6.5	44.7*	7.1	26.8
45	900	375	30	19.9	6.3	42.9	3.4	28.5
50	900	380	30	9.8	5.0	35.8	(3.9)	31.7

Notes:

(1) Velocity in unlined tunnel section.

(2) Based on an energy value of 47 mills/kwh, (i.e. the thermal system cost in the year 2000). This value used in this study.

(3) Based on an energy value of 30 mills/kwh, (the average Watana-Devil Canyon Dam hydrosystem cost in the year 2000).

( )Denotes a loss in annual net benefit.

* Optimum tunnel diameter.

TABLE 7.3: COST ESTIMATE FOR DEVIL CANYON TUNNEL SCHEME
(TWO 30-FOOT DIAMETER TUNNELS)

1980 PRICE LEVELS

Item	Cost ($1,000)
Land and Damages	$ 10,200
Reservoir Clearing	3,300
Re-Regulation Dam	101,900
Spillway	41,700
Diversion Works	34,800
Intake Works - Main	26,000
Power Tunnels	556,600
Powerhouse - Main	80,300
Tailrace - Main	13,000
Switchyard	3,500
Transmission Lines	15,000
Roads and Bridges	42,000
Recreational Facilities	1,000
Building and Grounds	4,000
Permanent Operating Equipment	3,000
Secondary Power Station	21,400
Subtotal	$ 957,700
Camp Facilities and Support	130,700
Mobilization	47,000
TOTAL CONSTRUCTION COST	$1,136,300
Engineering, Construction, Management and Owner's Costs	136,400
Contingencies	227,300
TOTAL PROJECT COST	$1,500,000

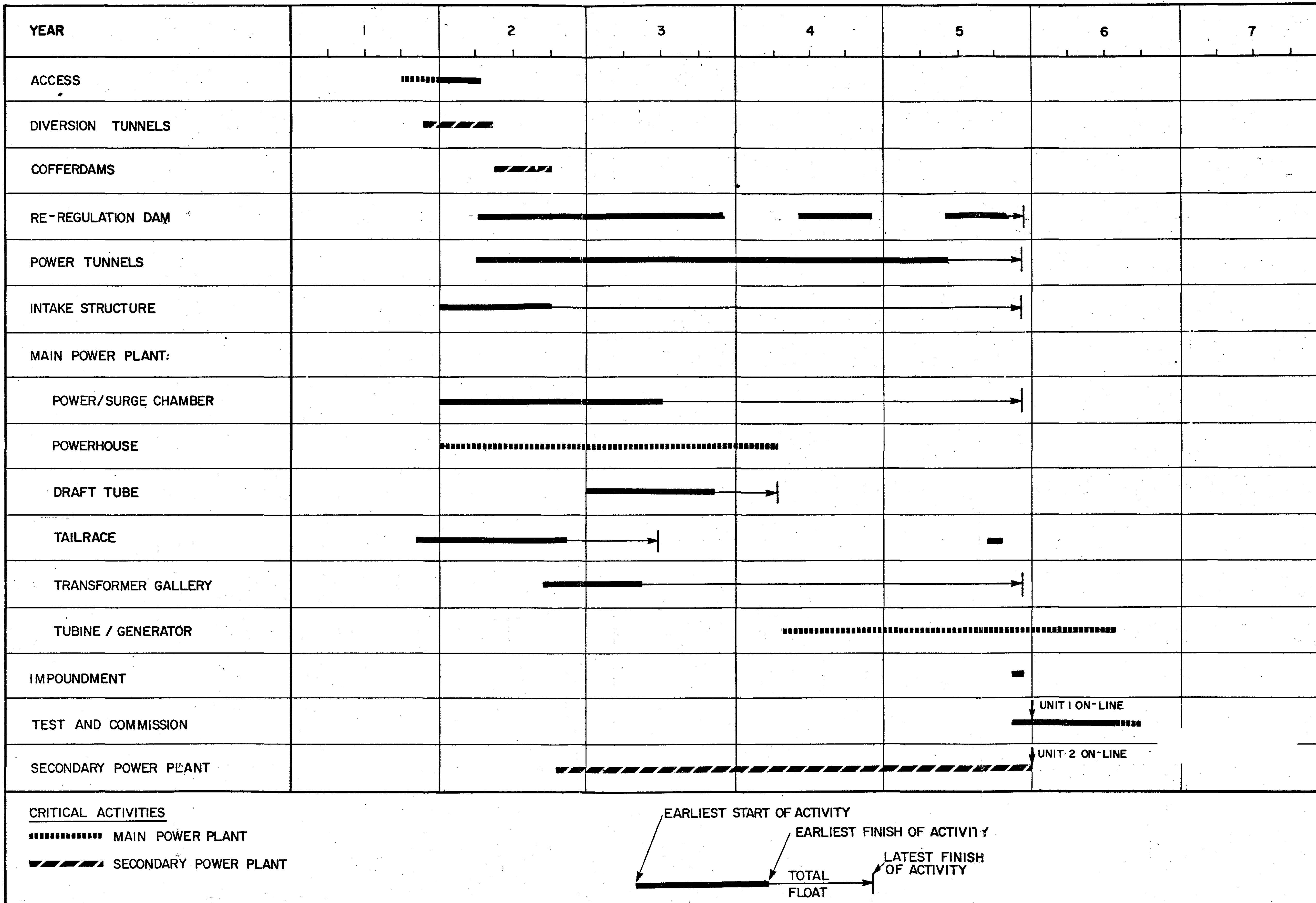
TABLE 7.4: COST ESTIMATE FOR DEVIL CANYON TUNNEL SCHEME (ONE 40-FOOT DIAMETER TUNNEL)

1980 PRICE LEVELS

Item	Cost ($1,000)
Land and Damages	$ 10,200
Reservoir Clearing	3,300
Re-regulation Dam	101,900
Spillway	41,700
Diversion Works	34,800
Intake Works - Main	26,000
Power Tunnel	453,100
Powerhouse - Main	80,300
Tailrace - Main	13,000
Switchyard	3,500
Transmission Lines	15,000
Roads and Bridges	42,200
Recreational Facilities	1,000
Building and Grounds	4,000
Permanent Operating Equipment	3,000
Secondary Power Station	21,400
Subtotal	$ 854,400
Camp Facilities and Support	117,000
Mobilization	42,700
TOTAL CONSTRUCTION COST	$1,014,100
Engineering, Construction, Management and Owner's Cost	121,700
Contingencies	202,800
TOTAL PROJECT COST	$1,338,600

TABLE 7.5: POWER AND ENERGY PRODUCTION FROM TUNNEL SCHEME

Description	1-40 Ft Diameter Tunnels	2-30 Ft Diameter Tunnels
Installed Capacity:		
Watana Dam	850 MW	850 MW
Devil Canyon	300 MW	300 MW
Re-regulation Dam	30 MW	30 MW
TOTAL	1,180 MW	1,180 MW
Average Annual Energy:		
Watana Dam	3,194 Gwh	3,192 Gwh
Devil Canyon	2,064 Gwh	2,053 Gwh
Re-regulation Dam	195 Gwh	188 Gwh
TOTAL	5,453 Gwh	5,433 Gwh
Annual Firm Energy:		
Watana Dam	2,810 Gwh	2,833 Gwh
Devil Canyon	1,927 Gwh	1,925 Gwh
Re-regulation Dam	127 Gwh	127 Gwh
TOTAL	4,864 Gwh	4,885 Gwh



CONSTRUCTION SCHEDULE PREFERRED TUNNEL SCHEME 3

FIGURE 7.1

ACRES

8 - COMPARISON WITH DEVIL CANYON DAM SCHEME

This section outlines a brief comparison of the preferred tunnel scheme with the Devil Canyon dam scheme. The schemes are compared from economic, environmental, and scheduling points of view.

8.1 - Economic Comparison

Table 8.1 summarizes the results of the comparative economics of the two versions of the tunnel scheme involving either one or two tunnels and the Devil Canyon dam scheme. The economic parameters used are as follows:

- Interest rate = 3%.
- Escalation rate = 0%.
- Economic life = 50 years.
- Annual cost factor = (3.00 interest
  +0.89 - sinking fund
  +0.10 - insurance)

  = 3.99
- Operation and maintenance = \$11/kW/year.
- Allowance for funds during construction was based on an assumed S-shaped distribution of cash flow throughout the construction period.

The average annual energy yields in Table 8.1 represent the net increases over the first stage Watana dam in each case. It will be noted that the one and two tunnel schemes can deliver energy at a cost of \$29 or \$33 per 1000 kWh, respectively. The equivalent cost associated with the Devil Canyon dam is \$15 per 1000 kWh. The tunnel scheme represents a 93 or 120 percent increase in cost. It should also be noted that the tunnel schemes annually yield between 770 and 790 Gwh less energy than the Devil Canyon dam scheme. This represents about 26 percent.

A further factor that should be taken into consideration in the economic comparison of the tunnel and dam schemes is the lower reliability associated with the capital cost estimate of the tunnel scheme. Because of the uncertainty associated with the geologic conditions as well as the probable availability of more sophisticated tunnel construction methods in the next decade, it is conceivable that the tunnel costs estimates could vary widely. For purposes of this study, sensitivities have been checked by assuming that tunnel costs could be doubled or halved. Allowing for this potential range in tunnel construction costs and still incorporating a 20 percent general contingency the economic analyses shown in Table 8.1 were repeated and the results are summarized on Table 8.2.

Table 8.2 clearly indicates that even allowing for the uncertainty associated with the costs of the tunnel scheme, the Devil Canyon dam scheme is still economically superior.

8.2 - Environmental Comparison

At present, many gaps exist in the available environmental data. Additional information, combined with environmental field investigations would permit a much more detailed comparison of these two development alternatives. Nevertheless, from what is presently understood about Scheme 3, it is believed that it is environmentally superior to the Watana-Devil Canyon dam scheme. By virtue of size alone, construction of the smaller re-regulation dam (245 ft) would have less environmental impact than the Devil Canyon dam. The river miles flooded and the reservoir area created by the Scheme 3 re-regulation dam would be about half those of the Devil Canyon dam, thereby reducing negative consequences such as loss of wildlife habitat and possible archeological sites. In addition, the adverse effects upon the aesthetic value of Devil Canyon would be substantially lessened with Scheme 3, particularly with the powerhouse location upstream of the Devil Canyon dam site. Furthermore, Scheme 3 may possibly present a rare mitigation opportunity by creating new salmon spawning habitat that could be actively managed. With the increase in riparian zone vegetation allowed by Scheme 3 the wildlife habitat in the stretch of river bypassed by the tunnel might be temporarily improved. It is believed that the impacts associated with tunnel access and disposal of tunnel muck would be offset by the plan's advantages.

8.3 - Comparison of Construction Schedules

As shown in Figure 8.1, the construction duration of the tunnel scheme is approximately one year shorter than the dam scheme. Construction startup to power on line for the dam scheme is approximately 66 months while the tunnel scheme is 52 months. The dam scheme's critical path is controlled by dam construction and the tunnel scheme is controlled by powerhouse construction. There is about a 6 month float period in the construction associated with the tunnel and this could accommodate some of the potential construction delays which are more likely with the tunnel than the dam scheme given the limited geologic information.

The construction schedule for the tunnel alternative is based on the assumption that an access road from the Parks Highway to Watana is available. Should this not be the case, access by a new route from Watana, presumably via the Denali Highway, will be required. The same is clearly true for construction of the Devil Canyon. However, additional costs will arise due to a considerably longer haul distance for equipment and materials from Anchorage and/or Fairbanks.

8.4 - Summary

The comparison of the tunnel schemes with the Devil Canyon dam scheme indicate that the dam would yield approximately 36 percent more energy at a 49 to 54 percent lower energy cost. From an environmental viewpoint, the tunnel scheme has advantages, however, these do not appear to outweight the economic benefits of the dam schemes. From a construction schedule point of view there is little difference between the schemes.

It should be borne in mind that the reduced environmental impact outlined in Section 8.2 would have to be traded off against the higher cost and lower energy production of the tunnel scheme. This can be quantified in two ways as outlined below.

(a) Environmental-Capital Cost Tradeoff

The total increase in capital cost between the Devil Canyon Dam Scheme and the more expensive tunnel scheme amounts to \$500 to \$700 million. These figures are derived by assuming a base fixed cost of 30 percent and prorating the remaining 70 percent of the Devil Canyon dam costs downwards by the ratio of the average annual energy yield of the tunnel schemes to that of the dam scheme. (This hypothetically results in a Devil Canyon Dam capable of producing energy equal to the tunnel scheme for a capital cost of \$0.80 billion.) The environmental benefits to be gained in terms of about 16 miles of Susitna River and Devil Canyon which would not be inundated, would not appear to be justified by this additional cost.

(b) Environmental-Energy Tradeoff

The tunnel schemes yield approximately 770 Gwh less energy on an annual basis than does the dam scheme. In the long term this implied that an additional generating facility would have to be provided to generate this energy when required and this would create an additional source of environmental impact and cost which has not been factored into the comparison at this time.

TABLE 8.1: SUMMARY OF ECONOMIC EVALUATIONS (Million Dollars)

	Scheme 3 2-30 Foot Tunnels	Scheme 3 1-40 Foot Tunnel	Devil Canyon Dam
Total Investment Cost:			
Total Project Cost	$ 1,500	$ 1,339	$ 903
Construction Period (years)	5	5	6
Allowance for Funds During Construction (i = 3%, e = 0%)*	121	108	81
	$ 1,621	$ 1,447	$ 984
Annual Cost:			
Amortized Cost (i = 3%, 50-year economic life)	$ 65	$ 58	$ 39
Operation and Maintenance Cost (@ $11/kV)	6	6	6
	$ 71	$ 64	$ 45
Cost Per kWh:			
Increase in Average Annual Energy (Gwh)**	2,183	2,203	2,997
Cost of Additional Energy ($/1000 kWh)	32.5	29.1	15.0
Relative Cost of Power (Devil Canyon Dam = 100%)	217	194	100

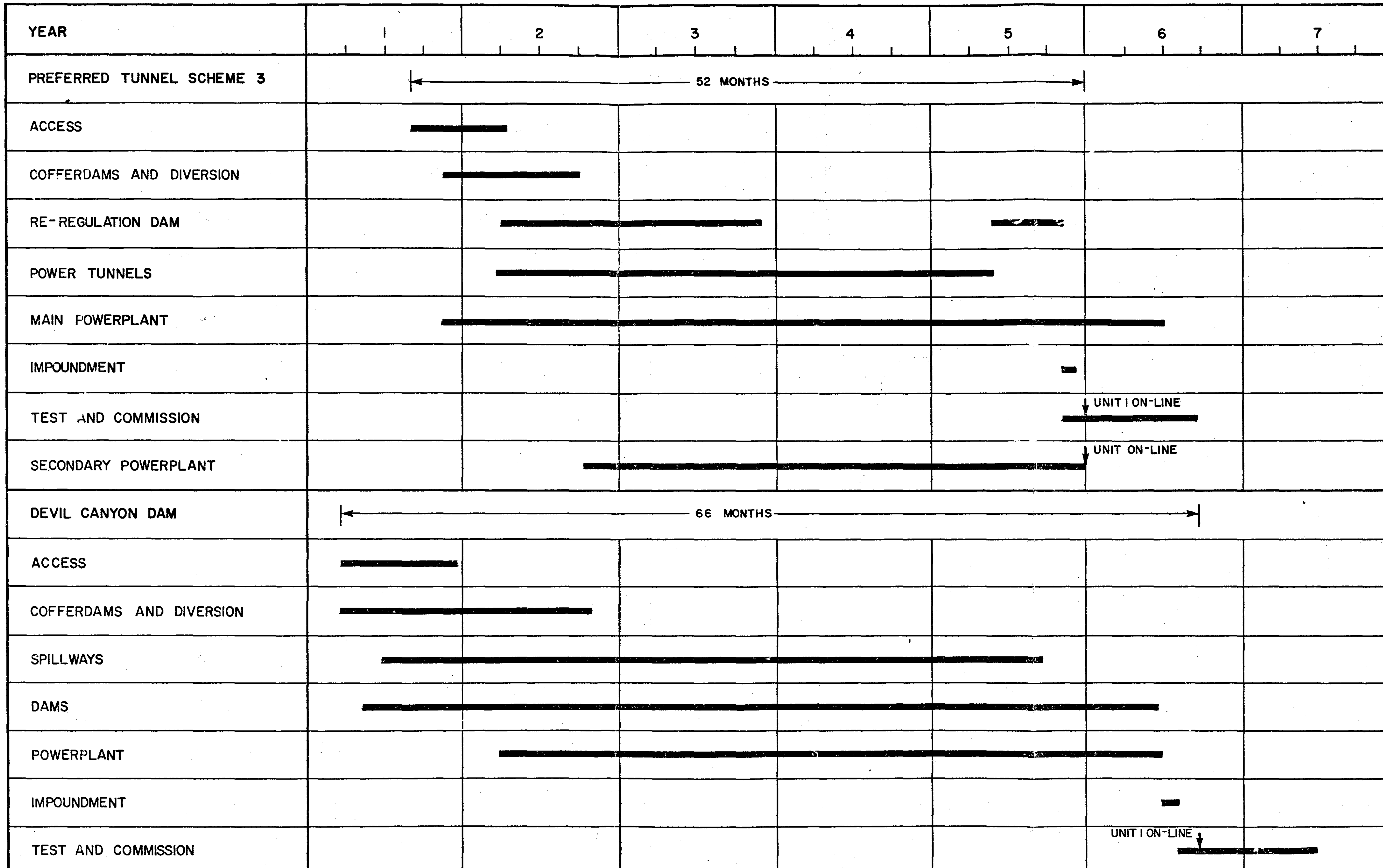
* i = interest rate, e = escalation rate

** Increase over single Watana dam, 800 MW developed with an average annual production of 3250 Gwh

TABLE 8.2: SUMMARY OF ECONOMIC SENSITIVITY EVALUATIONS (Million Dollars)

	Scheme 3 2-30 Foot Tunnels	Scheme 3 1-40 Foot Tunnel
Total Investment Cost Including AFDC		
- maximum*	$ 2,563	$ 2,213
- minimum**	$ 1,150	$ 1,063
Cost per kWh ($ per 1000 kWh)		
- maximum	48.7	41.9
- minimum	22.9	21.1
Relative Cost of Power (Devil Canyon Dam = 100%)		
- maximum	341	293
- minimum	160	148

*Based on doubled tunnel costs.
**Based on halving tunnel costs.



CONSTRUCTION SCHEDULE COMPARISON

FIGURE 8.1

9 - CONCLUSIONS AND RECOMMENDATIONS

9.1 - Conclusions

The conclusions of this study are:

- A base load tunnel scheme incorporating a re-regulation dam downstream from the Watana dam site and developing the head that could be developed by the Devil Canyon dam is the most economic type of tunnel scheme.

- There is no evidence that the tunnel scheme is not technically feasible. However, a substantial amount of additional field data would be required to firmly establish feasibility.

- The estimated capital cost (excluding AFDC) for the selected tunnel schemes varies from $1.34 to $1.50 billion depending on whether one or two tunnels are required. The range of capital costs associated with a tunnel scheme could be as high as $2.37 billion or as low as $0.98 billion, i.e. from $1.06 to $2.37 billion or from $0.98 to $2.05 billion for the two and one tunnel schemes, respectively.

- The total average energy yield from the tunnel scheme is approximately 2200 Gwh over and above that obtained from the Watana dam.

- A comparison of the tunnel scheme with the Devil Canyon dam scheme indicates that it yields less (26 percent) and more costly (93 percent to 120 percent) energy. The potential environmental impact associated with the tunnel scheme is less than that of the dam scheme, but it is believed that this reduced impact is not sufficient to outweigh the economic advantages enjoyed by the dam scheme.

9.2 - Recommendations

The recommendations resulting from this study are:

- In order to confirm the economic comparisons with the dam scheme the preferred tunnel scheme should be incorporated in the Susitna Basin development selection studies. These studies incorporate a systemwide generation planning model which will allow a more realistic assessment of the economics of the tunnel scheme to be made.

- Additional field or office studies of the tunnel scheme should not be undertaken at this stage.

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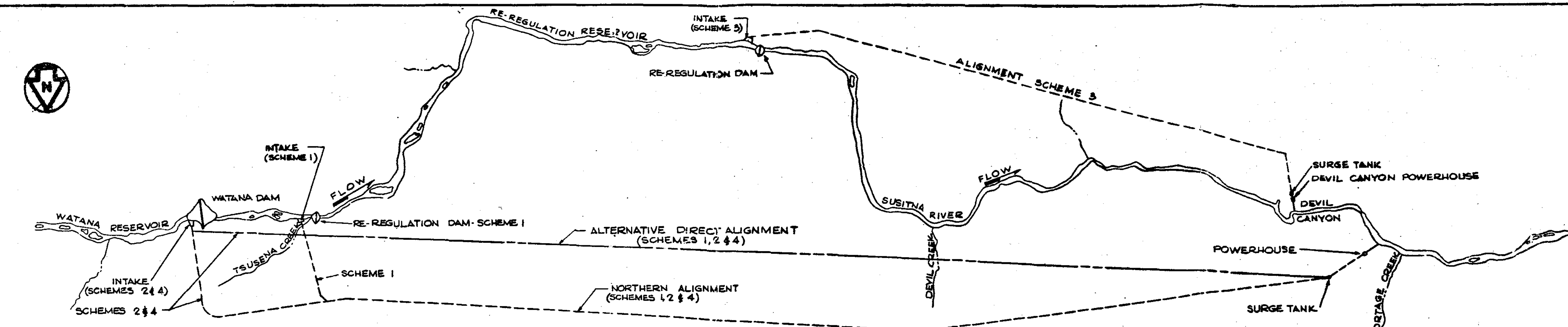

TUNNEL PLAN

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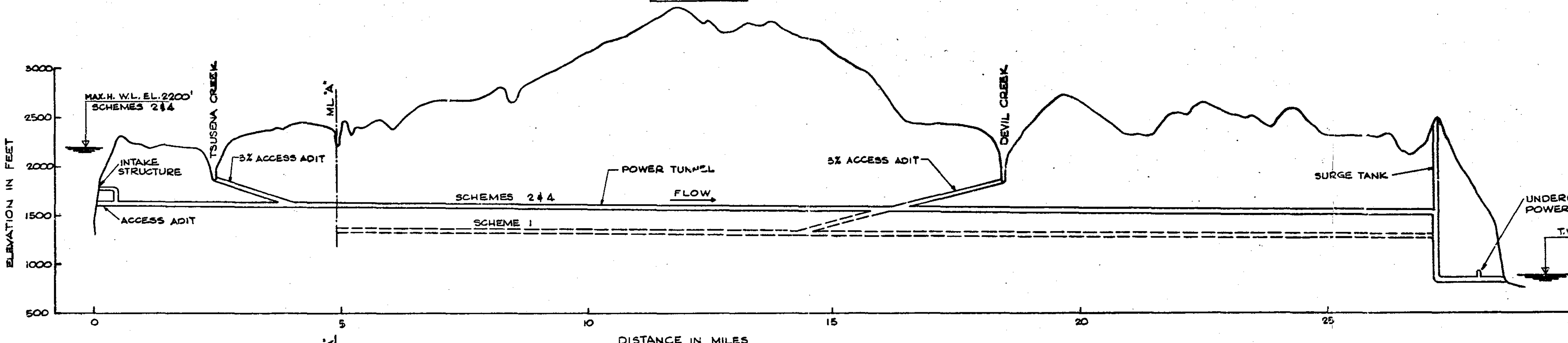
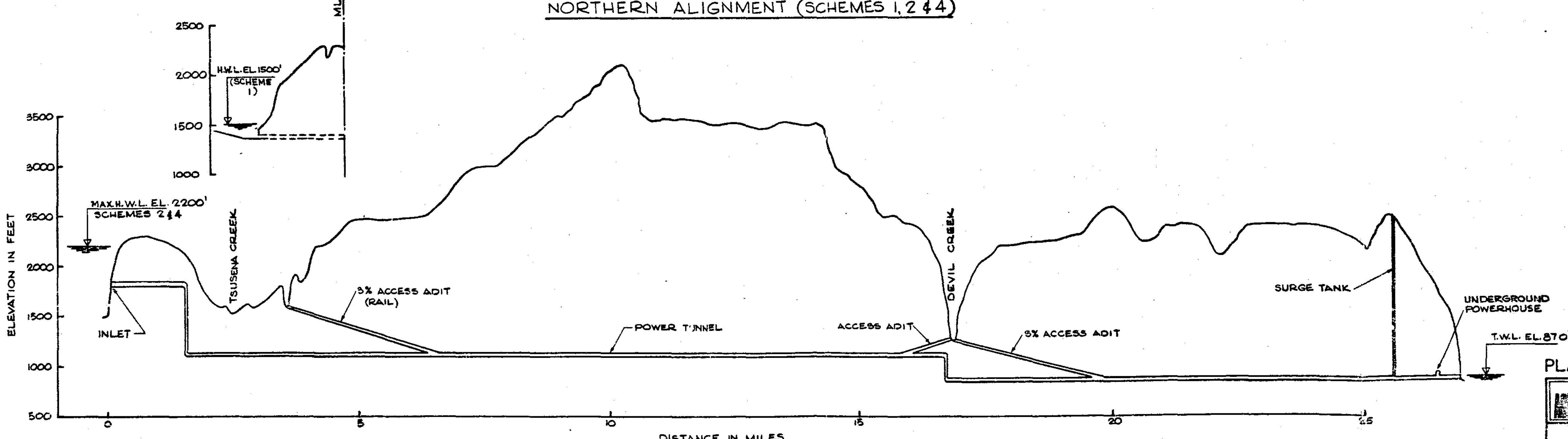


NORTHERN ALIGNMENT (SCHEMES 1, 2 & 4)



DIRECT ALIGNMENT (SCHEMES 1, 2 & 4)

NOTES:

1) TUNNEL ALIGNMENT FOR SCHEME 3 IS SHOWN ON DRAWING Nº 5700-CG-112

2) ALL PLANS AND PROFILES FOR CONCEPTUAL STUDY PURPOSES ONLY.

PLATE 1

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

CONCEPTUAL TUNNEL SCHEMES PLAN & SECTIONS

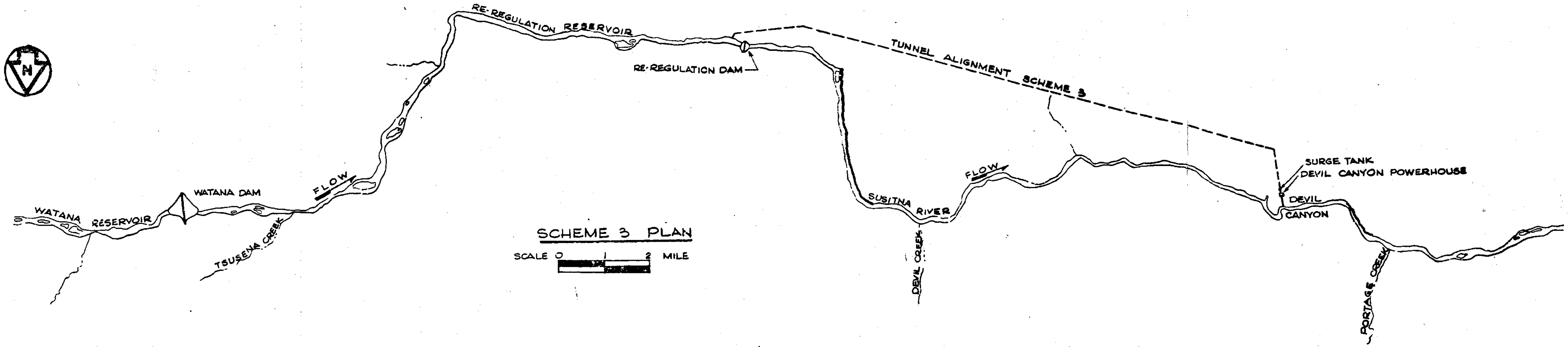
DATE	NO.	REVISIONS	CH.	APP.	APP.

ACRES AMERICAN INCORPORATED

DATE MAY, 1981

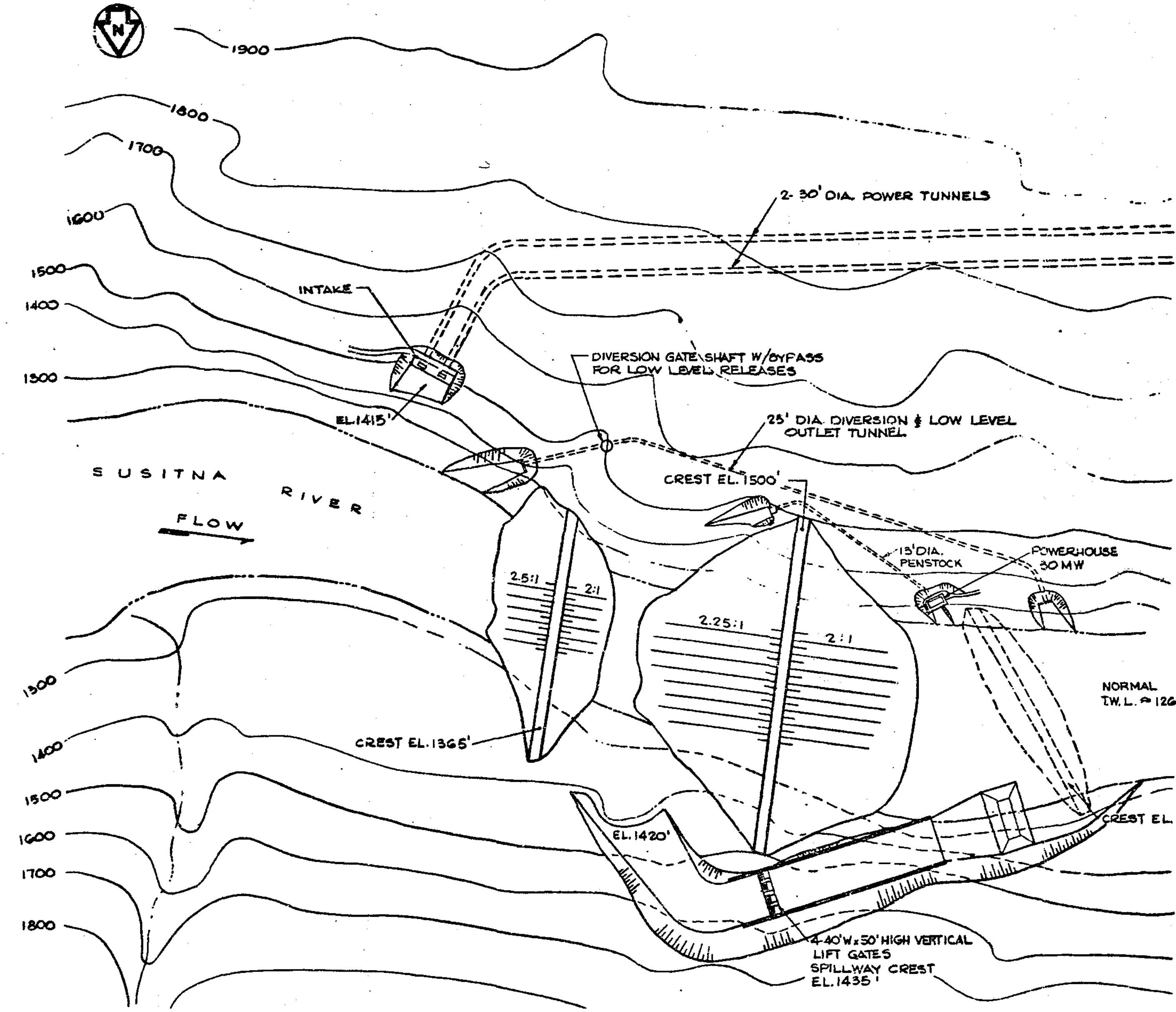
SCALE AS SHOWN

DRAWING NO. SK-5700-CG-111



SCHEME 3 PLAN

SCALE 0 1 2 MILE

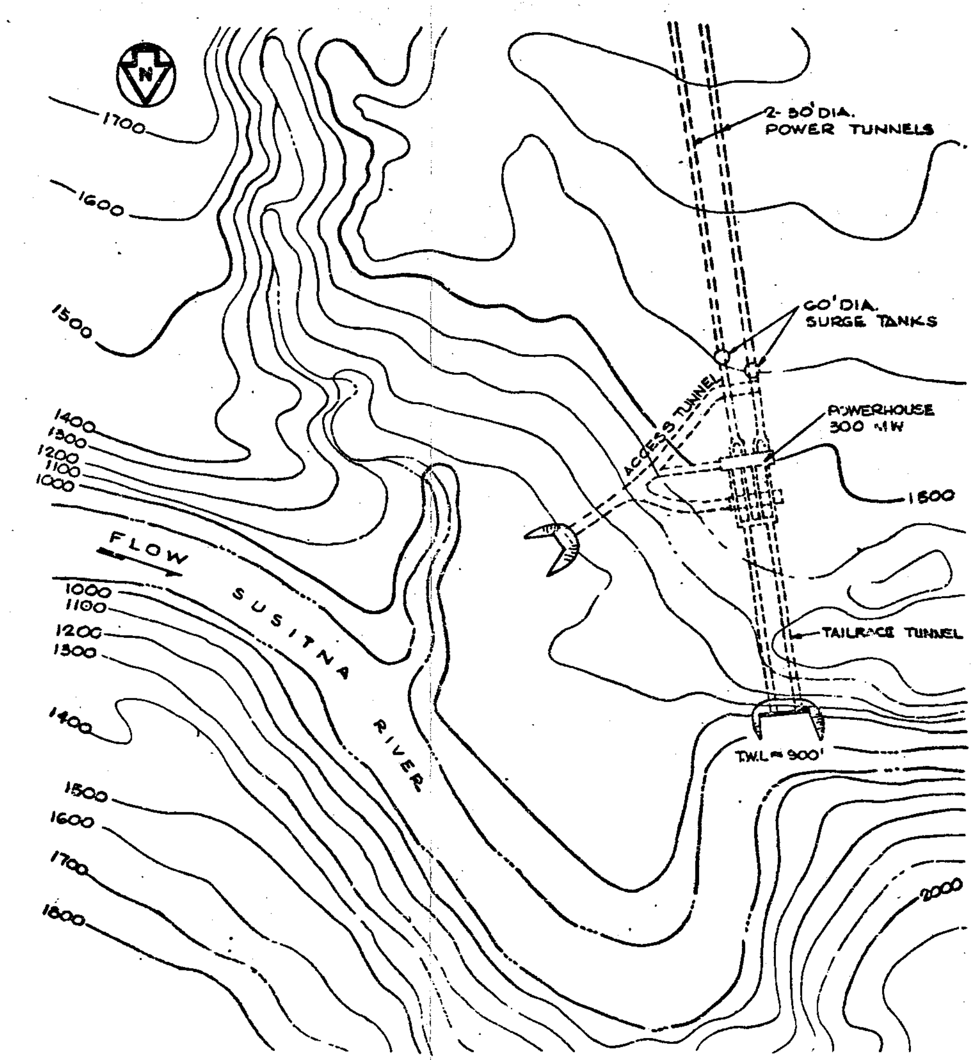


GENERAL ARRANGEMENT
RE-REGULATION DAM

SCALE 0 300 600 FEET

NOTE:

ALL PLANS AND LAYOUTS FOR CONCEPTUAL STUDY PURPOSES ONLY.



GENERAL ARRANGEMENT
DEVIL CANYON POWERHOUSE

SCALE 0 400 800 FEET

PLATE 2

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

PREFERRED TUNNEL
SCHEME 3
PLAN VIEWS

DATE	NO.	REVISIONS	CH.	APP.	APP.

ACRES AMERICAN INCORPORATED

DATE MAY, 1981

SCALE AS SHOWN

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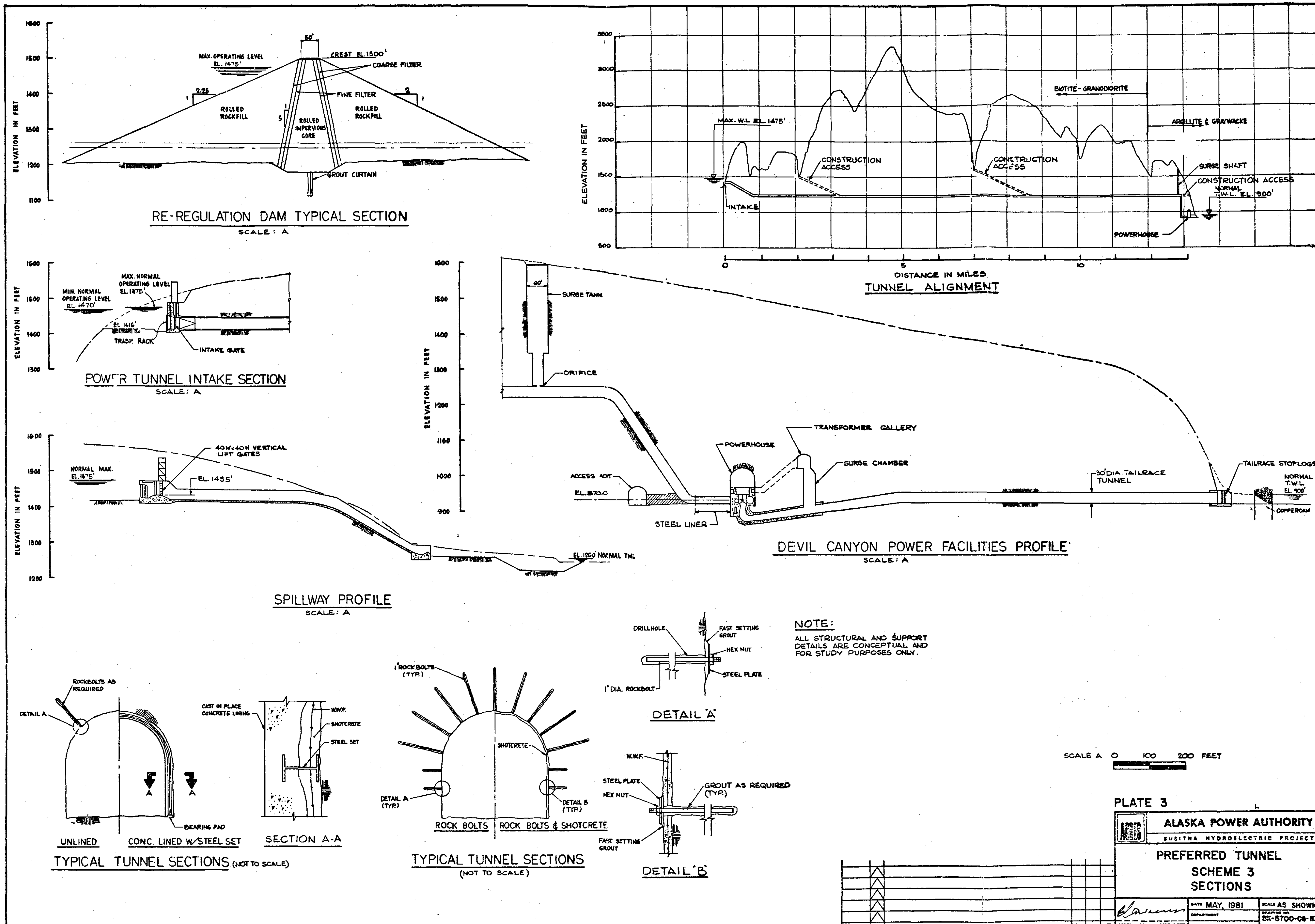

RE-REGULATION DAM TYPICAL SECTION
SCALE: A
ELEVATION IN FEET
MAX. OPERATING LEVEL EL. 1475'
CREST EL. 1500'
COARSE FILTER
FINE FILTER
ROLLED ROCKFILL
ROLLED IMPERVIOUS CORE
GROUT CURTAIN
TUNNEL ALIGNMENT
DISTANCE IN MILES
MAX. W.L. EL. 1475'
INTAKE
CONSTRUCTION ACCESS
BIOTITE - GRANODIORITE
ARGILLITE & GRAYWACKE
SURGE SHAFT
NORMAL T.W.L. EL. 900'
POWERHOUSE
POWER TUNNEL INTAKE SECTION
SCALE: A
MAX. NORMAL OPERATING LEVEL EL. 1475'
MIN. NORMAL OPERATING LEVEL EL. 1470'
EL. 1415'
TRASH RACK
INTAKE GATE
SPILLWAY PROFILE
SCALE: A
NORMAL MAX. EL. 1475'
40W x 40H VERTICAL LIFT GATES
EL. 1455'
EL. 1260' NORMAL TWL
DEVIL CANYON POWER FACILITIES PROFILE
SCALE: A
SURGE TANK
ORIFICE
TRANSFORMER GALLERY
POWERHOUSE
SURGE CHAMBER
ACCESS ADIT
EL. 870.0
STEEL LINER
30' DIA. TAILRACE TUNNEL
TAILRACE STOPLOGS
NORMAL T.W.L. EL. 900'
COFFERDAM
NOTE:
ALL STRUCTURAL AND SUPPORT DETAILS ARE CONCEPTUAL AND FOR STUDY PURPOSES ONLY.
DRILLHOLE
FAST SETTING GROUT
HEX NUT
STEEL PLATE
1" DIA. ROCKBOLT
DETAIL 'A'
W.W.F.
GROUT AS REQUIRED (TYP.)
DETAIL 'B'
ROCKBOLTS AS REQUIRED
DETAIL A
BEARING PAD
UNLINED
CONC. LINED W/STEEL SET
TYPICAL TUNNEL SECTIONS (NOT TO SCALE)
CAST IN PLACE CONCRETE LINING
SHOTCRETE
STEEL SET
SECTION A-A
1" ROCKBOLTS (TYP.)
DETAIL A (TYP.)
DETAIL B (TYP.)
ROCK BOLTS
ROCK BOLTS & SHOTCRETE
TYPICAL TUNNEL SECTIONS
(NOT TO SCALE)
SCALE A 0 100 200 FEET
PLATE 3
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
PREFERRED TUNNEL SCHEME 3 SECTIONS
DATE MAY, 1981
SCALE AS SHOWN
ACRES AMERICAN INCORPORATED
SK-5700-C6-113
DATE
NO.
REVISIONS

APPENDIX A

ROCK UNIT DESCRIPTIONS (40)

ROCK UNIT DESCRIPTIONS (40)

Tbgd BIOTITE GRANODIORITE (Paleocene, in part may be Eocene) -- Biotite granodiorite and adamellite in approximately equal proportions. Biotite is the chief mafic mineral, hornblende is occasionally present. Color is light to medium gray, grain size is from medium to coarse, texture is granitic to seriate. Very faint flow structures have developed only locally. These rocks occur in shallow, forcibly emplaced epizonal plutons in the northwestern Talkeetna Mountains. Aplitic and pegmatitic dikes are common in all the plutons. Just north of the map area, these plutonic rocks grade into felsic volcanic rocks. Potassium-argon age determinations (see Table 1) indicate that the biotite granodiorite and adamellite of the present unit are essentially of the same age as the biotite-hornblende granodiorite (unit Thgd). Thus, the rocks of these two units, in view of their spatial proximity, probably are the products of differentiation of the same parent magma, either in situ or at some deeper levels in the Earth's crust. The biotite granodiorite intrusives are also considered to be the plutonic equivalents of some of the felsic volcanic rocks in the lower portion of the unit Tv.

Tsmg SCHIST, MIGMATITE, AND GRANITE (Paleocene intrusive and metamorphic ages) -- Undifferentiated terrane of andalusite and (or) sillimanite-bearing pelitic schist, lit-par-lit type migmatite, and small granitic bodies with moderately to well-developed flow foliation. These rocks occur in approximately equal proportions, and the contacts between them are generally gradational, as is the contact between the schist and its unmetamorphosed pelitic rock equivalents (unit Kag) outside the present map unit.

The pelitic schist is medium to dark gray, medium grained, has well-developed but wavy foliation, and contains lit-par-lit type granitic injections in greatly varying amounts. Rock forming mateials of the schist include biotite (pleochroism Nz = dark reddish brown, Nx = pale brown), quartz, plagioclase, minor K-feldspar, muscovite, garnet, and sillimanite which locally coexists with andalusite.

The lit-par-lit type granitic injections within the schist are medium gray, medium grained, and consist of feldspar, quartz, and biotite.

The rocks of the small, granitic bodies range in composition from biotite adamellite to biotite-hornblende granodiorite. They are medium gray and medium grained, generally have granitic textures, and, in addition to the flow foliation, locally display flow banding of felsic and mafic minerals. These granitic bodies appear to be the source of the lit-par-lit intrusions.

Tsmg (Cont'd)

The proximity of the schist to the small granitic bodies, the occurrence of the lit-par-lit injections, and the presence of andalusite in the schist indicate that the schist is the result of contact metamorphism. Perhaps this metamorphism took place in the roof zone of a large pluton, the cupolas of which may be the small granitic bodies.

Kag

ARGILLITE AND LITHIC GRAYWACKE (Lower Cretaceous) -- These rocks occur in a monotonous, intensely deformed flyschlike turbidity sequence, probably several thousand meters thick, in the northwest part of the mapped area, north of the Talkeetna thrust fault. The whole sequence has been compressed into tight and isoclinal folds and probably has been complexly faulted as well. The rocks are highly indurated, and many are sheared and pervasively cleaved as a result of low-grade dynamometamorphism, the intensity of which is only locally as high as the lowermost portion of the greenschist metamorphic facies of Turner (1968). Most of the cleavage is probably axial plane cleavage. Neither the base nor the top of the sequence is exposed and, because of the intense deformation, even its minimal thickness is only an estimate.

The argillite is dark gray or black. Commonly it contains small grains of detrital mica as much as 1 mm in diameter. Because of the dynamometamorphism, in large areas the argillite is actually a slate or fine-grained phyllite. This sections show that some the argillites are derived from very fine grained siltstone and that they contain considerable carbonaceous material.

The typical lithic graywacke is dark to medium gray, fine to medium grained, and occurs intercalated with the argillite in graded beds ranging in thickness from laminae to about 1.5 m. The individual graywacke beds are not uniformly distributed throughout the whole sequence, of which they comrpise about 30 to 40 percent by volume, but tend to be clustered in zones 1 to 5 m thick. Thin sections of graywacke samples show them to be composed of angular of subrounded detrital grains of lithic fragments, quartz, moderately fresh plagioclase, and some, generally altered, mica in a very fine grained matrix; euhedral opaque grains, probably authigenic pyrite, are present in most thin sections. The lithic fragments consist in various proportions of little altered, fine-grained to aphanitic volcanic rocks of mafic to intermediate composition; fine-grained, weakly foliated low-grade metamorphic rocks; chert; and some fine-grained unmetamorphosed sedimentary rocks possibly of intraformational origin. No carbonate grains were seen. The matrix constitutes about 20 to 30 percent of the rock by volume, generally contains some secondary sericite and chlorite, and, in the more metamorphosed rocks, biotite and possibly some amphibole.

Kag (Cont'd)	Analyses of paleocurrent features, such as small-scale cross-stratification, found in several exposures near the western edge of the mapped area, suggest that depositional currents came from the east or northeast (A.T. Ovenshine, oral commun., 1974).

Because fossils are extremely sparse, the exact age of the argillite and lithic graywacke sequence is imperfectly known. A poor specimen of Inoceramus sp. of Cretaceous age was found just west of the map area between the Chulitna and Susitna Rivers, and a block of Buchia-bearing limestone of Valanginian age was found in float near Caribou Pass in the Healy quadrangle north of the mapped area (D.L. Jones, oral commun., 1978).