SIGMA ENGINEERING LTD

E6348

Technical Memorandum for Alaska Hydro Corporation **10 November 2016**

More Creek Hydroelectric Project – Forrest Kerr Diversion

Background

Alaska Hydro Corp. (AHC) is proposing to develop the More Creek hydroelectric project, located approximately 10 km northwest from Bob Quinn Lake in the Northwest region of British Columbia. A Prefeasibility Study for the project was completed in June 2015.

A low ridge approximately 2.5km wide divides the Forrest Kerr Creek watershed and the South Arm of More Creek. Diverting Forrest Kerr Creek into the More Creek watershed by building a channel across this ridge would increase the energy production for the More Creek Hydro Project. Water that initially is lost to the existing Forrest Kerr plant is returned via More Creek and Iskut River back to the plant.

The More Creek project was examined by BC Hydro in the 1980s. BC Hydro conducted a feasibility study of the project, including the Forrest Kerr Diversion. The cost estimate conducted by Sigma is based on the layout and concept presented in the BC Hydro study.

This memorandum considers the diversion of Forrest Kerr Creek into the More Creek watershed and provides an estimate of the increased average annual generation at More Creek as well as conceptual level cost estimates of the diversion.

Generation Estimate - Assumptions and Methodology

The proposed diversion site is approximately 25 km upstream from the confluence of Forrest Kerr Creek with Iskut River. The water available at the diversion is based on flow data from the Water Survey Canada (WSC) streamflow gauge ‘08CG006 – Forrest Kerr Creek above 460m contour’. The gauge is located about 5 km downstream of the proposed diversion site; it was active from 1972 to 1994 and has 20 complete years of daily flow data available. The drainage area of WSC 08CG006 is 311 km². The drainage area at the proposed diversion site is 275.3 km². Flows from WSC-08CG006 were prorated to the diversion site based on drainage areas.

The above calculated daily flows from Forrest Kerr Creek were added to the daily More Creek flows that were previously (June 2015) used to provide generation estimates at the More Creek plant. This study used 18 common years of flow data at WSC gauges 08CG005 and 08CG006.

A spreadsheet model is used to calculate the monthly and annual generation at the site. The model uses 18 complete years of daily flows as the basis of the calculations.

The basic assumptions, unchanged from the 2015 Prefeasibility Study, used in the model are as follows:

Design flow	*80*	*m³/s*
Dam crest elevation	*498*	*m*
Minimum lake level	*468*	*m*
Mean tailwater level	*380*	*m*
Gross head	*118*	*m*
Instream flow release	*2.476*	*m³/s (5% of mean annual flow)*
Minimum turbine flow	*20*	*m³/s*
Generating equipment efficiency	*86.45%*	
Friction head loss	*6%*	

A lake storage curve, which was developed from available 1:20,000 mapping, is used.

The model used monthly targets for the design flow to simulate the operation of the plant and maximize the average annual generation and revenue. Our preliminary analysis determined monthly targets for the design flow that resulted in the maximum generation at the plant.

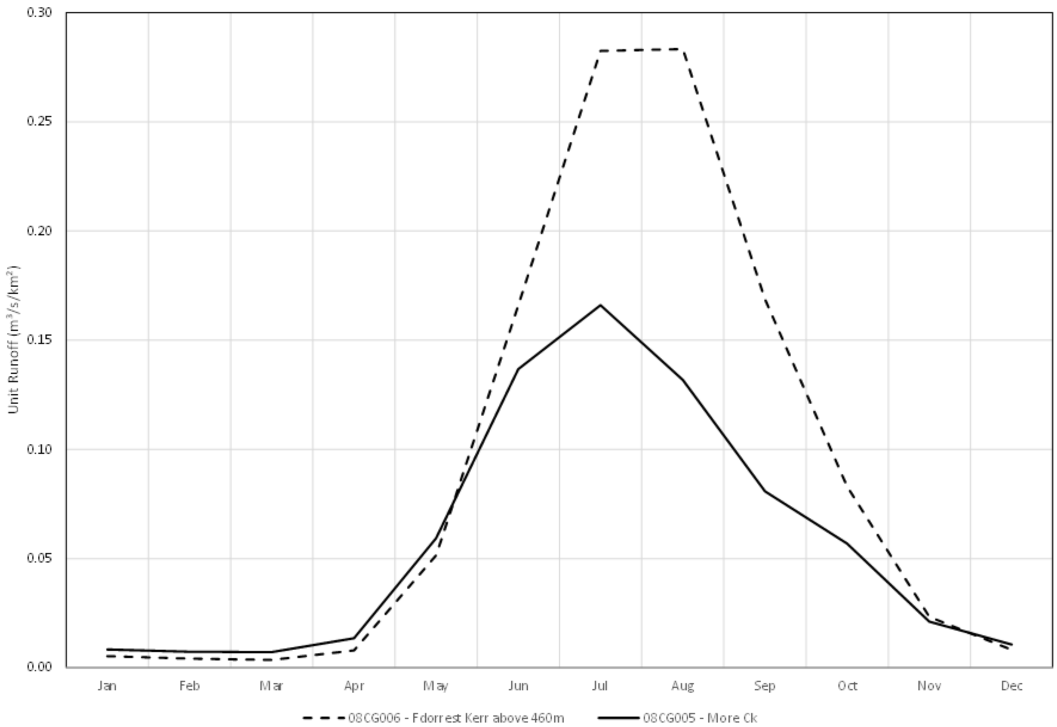
The operation of the More Creek plant is described in more detail in the 2015 Prefeasibility Study.

At the Forrest Kerr Diversion, for the purpose of this analysis, it is assumed that:

- An instream flow release of 3.77 m³/s (15% of the estimated 25.13 m³/s mean annual flow at the point of diversion).
- All flow in excess of 3.77 m³/s is diverted to More Creek.

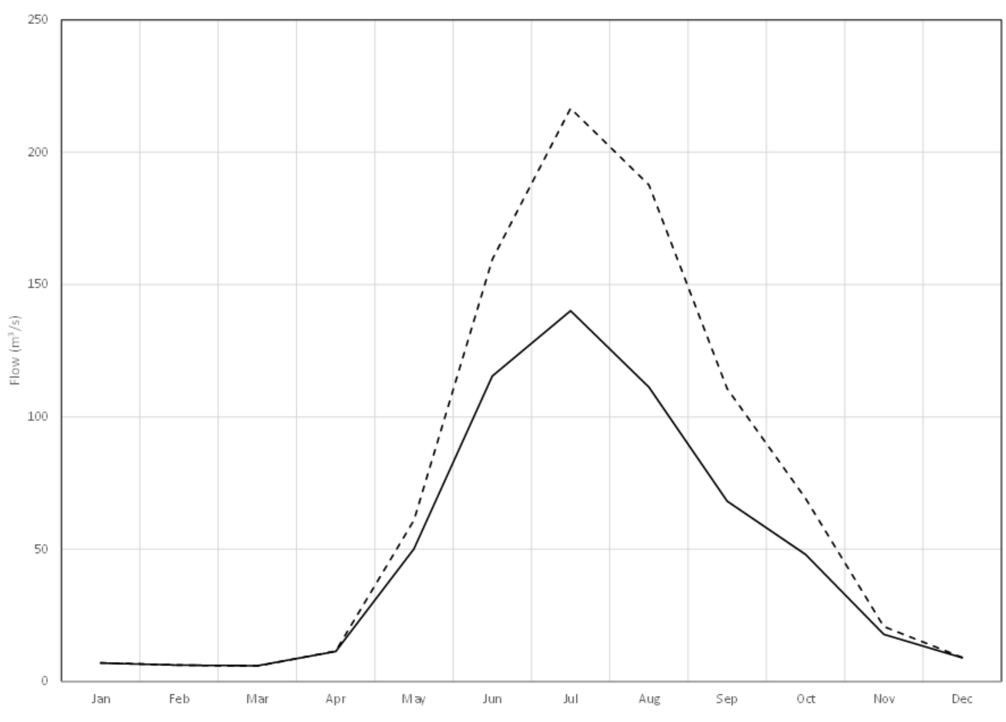
The monthly unit runoff at the two WSC gauges is shown on Figure 1 below:

Figure 1. Unit Runoff



The average monthly flows at the project intake with and without the Forrest Kerr diversion are shown on Figure 2 below:

Figure 2. More Creek Average Monthly Flows



- **Annual Generation Estimate**

The resulting monthly and annual generation estimates with and without the Forrest Kerr diversion are shown in Tables 2 and 3, respectively, below:

Table 1. Generation estimates **with** Forrest Kerr Diversion (GWh)

	1974	1975	1977	1978	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Average
Jan	52.7	48.8	8.1	31.1	47.2	48.2	47.0	45.4	23.8	20.9	28.2	47.6	46.2	45.3	45.8	41.6	46.3	32.7	39.3
Feb	46.4	34.1	2.7	1.3	20.8	31.0	16.6	4.0	1.3	1.3	0.0	22.3	10.9	5.4	8.1	1.3	13.7	2.7	12.4
Mar	46.8	1.3	2.7	0.0	1.3	2.7	1.3	1.3	1.3	1.3	2.7	1.3	1.3	1.3	1.3	1.3	5.4	1.3	4.2
Apr	16.5	1.3	5.4	4.0	4.0	2.7	1.3	5.4	4.0	1.3	4.0	4.0	5.4	5.4	5.4	5.4	6.7	8.1	5.0
May	17.5	20.2	25.6	20.2	31.1	31.3	10.7	29.7	27.0	17.6	18.8	21.5	35.1	25.7	31.2	36.6	25.7	35.5	25.6
Jun	35.6	41.7	43.1	42.2	45.5	44.1	43.4	45.1	40.7	42.5	42.3	41.3	41.8	44.9	44.9	43.8	45.4	49.9	43.2
Jul	45.3	52.0	50.5	50.8	54.0	51.8	53.1	53.1	48.6	50.7	51.1	49.9	50.1	53.3	53.4	52.7	55.3	55.5	51.7
Aug	50.0	55.8	55.4	55.7	56.0	56.0	56.0	56.0	54.3	55.7	55.9	55.0	55.0	56.0	56.0	55.9	56.0	56.0	55.4
Sep	52.2	53.7	54.1	54.0	54.2	54.2	54.2	54.0	53.9	54.2	54.1	54.2	54.1	54.2	54.2	54.2	53.9	54.1	54.0
Oct	55.7	53.6	54.8	55.4	55.9	55.4	55.7	54.4	54.4	55.0	55.9	55.5	55.3	55.6	55.2	55.8	54.8	55.7	55.2
Nov	53.4	48.9	50.9	52.9	52.9	52.5	52.0	50.4	50.1	50.8	53.1	51.9	51.8	51.8	51.3	52.2	50.7	53.3	51.7
Dec	52.7	45.8	48.6	51.7	52.1	51.5	50.4	47.9	47.5	48.4	52.0	50.8	50.2	50.4	49.5	50.8	48.7	52.5	50.1
Annual	524.6	457.2	401.9	419.5	475.0	481.5	441.8	446.6	407.1	399.7	418.1	455.5	457.4	449.3	456.2	451.7	462.6	457.2	447.9

Table 2. Generation estimates **without** Forrest Kerr Diversion (GWh)

	1974	1975	1977	1978	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Average
Jan	52.7	25.1	2.7	20.9	20.8	48.3	46.2	37.1	10.9	2.7	8.1	35.5	28.1	25.2	45.7	45.1	46.0	23.7	29.2
Feb	46.4	1.3	2.7	1.3	2.7	31.1	9.6	0.0	1.3	0.0	0.0	1.3	1.3	2.7	6.8	4.0	10.9	2.7	7.0
Mar	41.3	2.3	2.3	1.2	1.2	2.3	1.2	1.2	1.2	2.3	3.5	1.2	1.2	1.2	2.3	1.2	5.9	1.2	4.1
Apr	20.9	1.3	4.7	2.7	4.0	3.4	1.3	4.7	2.7	0.7	2.7	4.0	4.7	4.0	5.4	4.7	7.4	6.7	4.8
May	13.6	15.9	21.3	15.9	21.5	20.8	9.8	21.3	20.7	13.0	14.4	15.2	22.4	19.7	20.7	22.4	18.3	23.6	18.4
Jun	18.2	18.7	18.9	19.0	20.2	19.7	19.1	19.7	18.9	19.1	19.0	18.6	19.4	19.5	19.8	19.7	19.9	21.3	19.4
Jul	25.9	29.0	28.1	28.0	30.0	28.7	29.1	29.1	27.7	28.7	28.7	28.1	28.5	29.1	29.3	29.5	30.8	30.5	28.8
Aug	36.6	40.8	40.8	40.0	41.8	40.9	41.2	40.5	39.8	40.8	40.9	39.9	40.3	41.2	41.5	41.3	42.0	42.0	40.7
Sep	48.7	52.2	53.6	51.9	53.8	54.0	53.7	53.0	51.8	52.7	52.5	51.7	52.9	54.1	54.2	54.0	53.4	53.8	52.9
Oct	45.1	45.2	47.1	46.1	48.8	48.2	47.8	46.3	45.2	46.5	46.9	46.7	46.9	48.4	48.3	48.4	47.0	47.7	47.0
Nov	43.3	41.0	43.7	43.5	46.2	45.4	44.7	42.8	41.1	42.7	44.6	43.5	43.7	45.2	45.1	45.4	43.6	45.7	43.9
Dec	47.6	32.7	47.5	47.3	52.2	50.9	49.2	46.2	34.2	45.9	49.0	48.0	47.8	50.4	50.1	50.6	47.7	51.1	47.1
Annual	440.3	305.6	313.4	317.8	343.1	393.8	352.9	342.0	295.5	295.1	310.3	333.7	337.1	340.7	369.1	366.5	372.8	350.0	343.3

The additional average annual generation from the diversion of Forrest Kerr is estimated at about 104.6 GWh.

If an electricity price of $100/MWh is assumed the same throughout the year, then the average annual incremental revenue as a result of the diversion would be $10.46 million.

Applying the current BC Hydro monthly delivery adjustment factors, the average annual revenue of the project, including Forrest Kerr diversion, would be about $60.3 million.

Note that if the electricity price variance through the year is different from that of the current SOP, the monthly target for the design flow may differ from the ones shown above. Also, the impact of any monthly variation of electricity prices may vary depending on price variance and plant operation.

Conceptual level construction cost estimate - Methodology

- **Background**

  Alaska Hydro is proposing to construct a hydro project on More Creek. A low ridge approximately 2.5km wide divides the Forrest Kerr Creek watershed and the South Arm of More Creek. Diverting Forrest Kerr Creek into the More Creek watershed by building a channel across this ridge would increase the energy production for the More Creek Hydro Project.

  The More Creek project was examined by BC Hydro the 1980s. BC Hydro conducted a feasibility study of the project, including the Forrest Kerr Diversion. The cost estimate conducted by Sigma is based on the layout and concept presented in the BC Hydro study.

- **Layout**

  The diversion layout is presented in BC Hydro plate 3-4 and Figure 5.7.2. The diversion would be accomplished by damming Forrest Kerr Creek and directing the entire creek flow into a channel partially excavated across the ridge separating the two watersheds. A release back to the creek of 3.77 m^3/s (15% of mean annual flow) is provided.

  <u>Diversion Dam</u>

  The diversion dam would be an earthfill structure 37m high and 200m long with an impermeable core. A 220m long diversion tunnel (5.5m diameter) would be required to divert Forrest Kerr Creek around the dam site during construction. This diversion tunnel would be gated, and filled with a concrete plug after the completion of the dam. A small lake would develop after the completion of the dam.

  <u>Diversion Channel</u>

  A lake would be formed by the earthfill dam after its completion. A diversion channel would be excavated to divert flow across the ridge separating the two watersheds. The 500m long seven meter wide channel would be excavated approximately halfway across the ridge. From the downstream end of the channel, water would flow over natural ground towards the South Arm of More Creek (creating an eroded channel through the ridge in the process). Some of the channel excavation could be used to construct the dam.

  <u>Access Road</u>

  Access to the site would require construction of a 19km long road from an existing Galore Creek road in the More Creek watershed. The road requires two large bridges. Portions of the Galore Creek road may need to be rerouted to avoid inundation from the More Creek reservoir.

- **Conceptual level construction cost estimate**

  The cost of the diversion is estimated to be about $35,000,000 including contingency. A breakdown of the costs is presented below.

Table 3. Conceptual level construction cost estimate

ACTIVITY	Qty	Unit	Unit Cost	Total	SubTotal	Contingency %	Contingency $	Total
A Access Roads								
Access Road to Power House	19.0	km	165,000	3,135,000				
Bridges	2	LS	1,200,000	2,400,000	**5,535,000**	**20%**	**1,107,000**	**6,642,000**
B Diversion Structure								
Clearing, Grubbing, Stripping	2.50	ha	100,000	250,000				
Earth Dam Fill	265,000	m^3	40	10,600,000				
Diversion Tunnel	220	m	15,000	3,300,000				
Tunnel Gate	1	LS	450,000	450,000				
Tunnel Plug	1	LS	350,000	350,000				
Cofferdam	1	LS	250,000	250,000	**15,200,000**	**30%**	**4,560,000**	**19,760,000**
C Diversion Channel								
Channel Excavation	100,000	m^3	25	2,500,000	**2,500,000**	**20%**	**500,000**	**3,000,000**
D Work Camp								
Camp	5,500	man-days	200	1,100,000	**1,100,000**	**5%**	**55,000**	**1,155,000**
TOTAL CONSTRUCTION COSTS							**6,222,000**	**30,557,000**
E Insurance and Bonding								
Insurance on Project (1% of construction costs)	1	ls	243,350	243,350				
Bonding (1% of construction costs)	1	ls	243,350	243,350	**486,700**	**25%**	**121,675**	**608,375**
F Interest During Construction								
Interest During Construction (4% of const. cost)	1	ls	973,400	973,400	**973,400**	**10%**	**97,340**	**1,070,740**
G Project Management								
Project Management (2% of construction costs)	1	ls	486,700	486,700	**486,700**	**10%**	**48,670**	**535,370**
H Engineering								
Consulting (5% of construction costs)	1	ls	1,216,750	1,216,750	**1,216,750**	**10%**	**121,675**	**1,338,425**
I Permitting and Environmental								
Permitting and Studies (1% of construction costs)	1	ls	243,350	243,350				
Compensation (1% of construction costs)	1	ls	243,350	243,350	**486,700**	**10%**	**48,670**	**535,370**
TOTAL INDIRECT COSTS							**438,030**	**4,088,280**
TOTAL COST								**34,645,280**

- **Environmental and Regulatory Issues**

  The BC Hydro layout of the diversion was developed in the 1980s when environmental regulations were less complex and standards lower. This design may present issues with permitting the project in today's regulatory environment.

  <u>Diversion and Green Power</u>

  Most regulations limit the use of the diversion in power generation. Although the diversion may be economic and may have few environmental impacts (based on the alpine environment), the diversion may be precluded from consideration as a green power project. More Creek itself is potentially precluded from being considered a green power project due to the presence of the dam and reservoir. However, the More Creek project (including the Forrest Kerr Diversion) may be considered as green if the overall impact is considered low. The project should be considered clean due to CO_2 offsets.

  <u>Instream Flow Release</u>

  The BC Hydro project concept does not have an instream flow release at the earthfill dam. 100% of the Forrest Kerr Creek flow is diverted. Forrest Kerr Creek would be dry immediately downstream of the dam. The present analysis assumes instream flow release of 3.77 m^3/s (15% of mean annual flow).

Diversion Flow over Natural Ground

The BC Hydro concept has a portion of the diversion flowing over the native natural ground of the ridge. A channel would be eroded down by the flow until coarse materials (boulders) are encountered or the channel slope is reduced. This would incise a channel through the ridge. This erosion would cause sedimentation issues downstream, potentially affecting fish populations.

Bed Load Transport

The new lake created by the diversion would trap sediment, and therefore water flowing from Forrest Kerr Creek into More Creek would lack coarse sediment material (gravel, cobbles). The increased flow in More Creek may cause erosion of the More Creek creek-bed. Typically eroded creek bed material would be replaced by material moving downstream from higher parts of the watershed, however there would be a lack of bed load as the cleaner creek water would carry less coarse material. Less sediment would be input into the system than removed. This would cause More Creek to be incised lower until equilibrium is reached. The effect is negligible in rocky channels.

Impact on downstream facilities

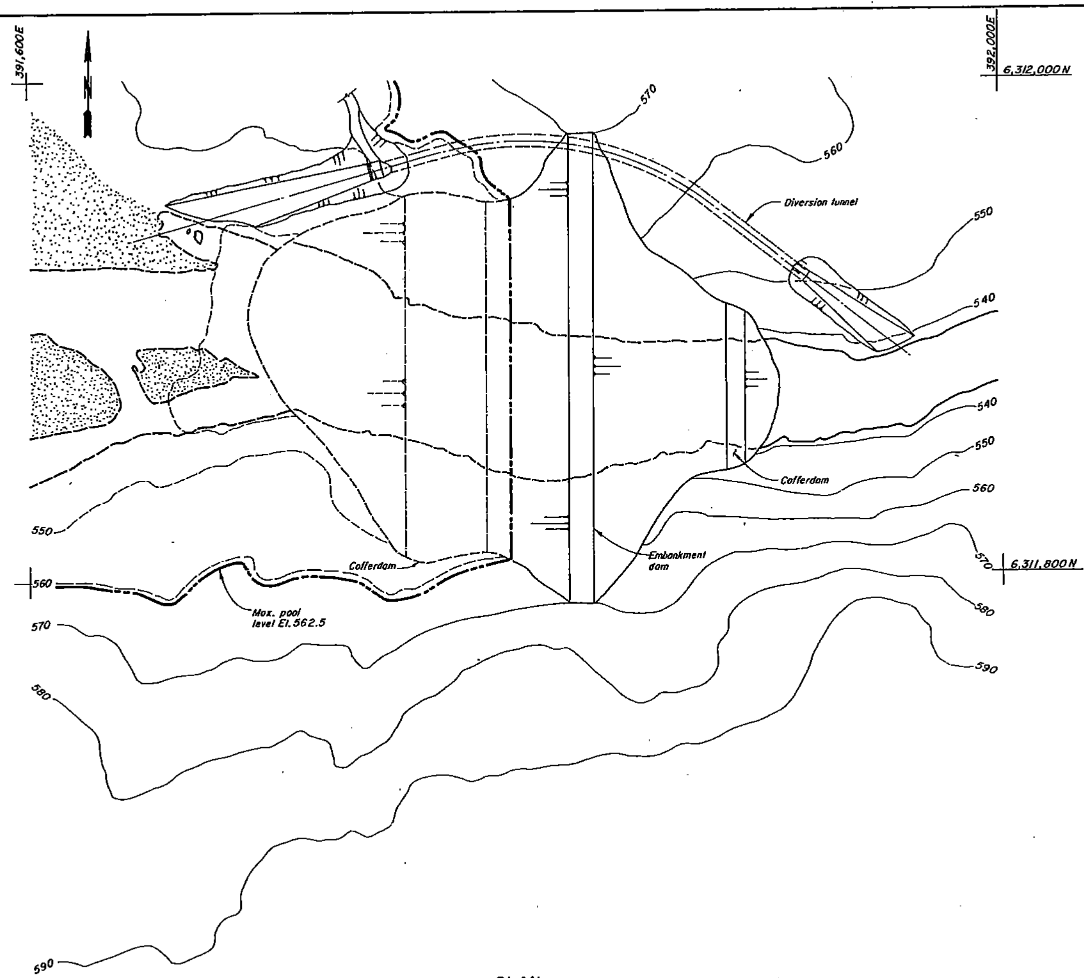
The impact of the More Creek project on the existing downstream Forrest Kerr project, should be further assessed, although overall there appear to be benefits to them given:

(a) The likely reduction of the sediment load at Forrest Kerr project
(b) The decrease in freshet flows and the increase in winter flows
(c) The energy output at Forrest Kerr project should increase

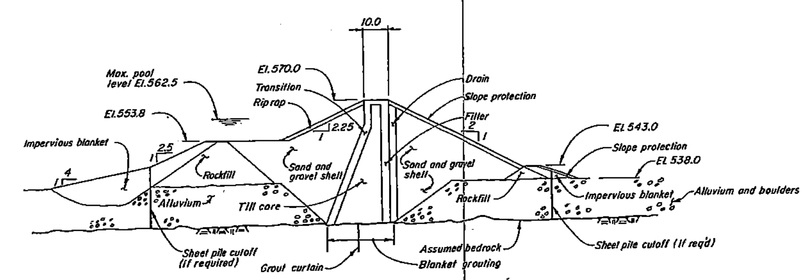
It is anticipated that construction will be staged from the More Creek camp site to minimize diversion footprint.

Attached are text and figures from BC Hydro's "*Stikine Iskut Development, Iskut Canyon and More Creek Projects – Preliminary Design Study Phase 1 Interim Report*" (1984) and an earlier 1980 report (title unknown) regarding potential hydro projects in the area.

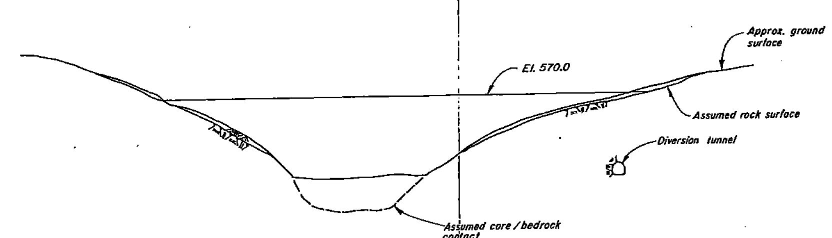
Prepared by Sigma Engineering Ltd



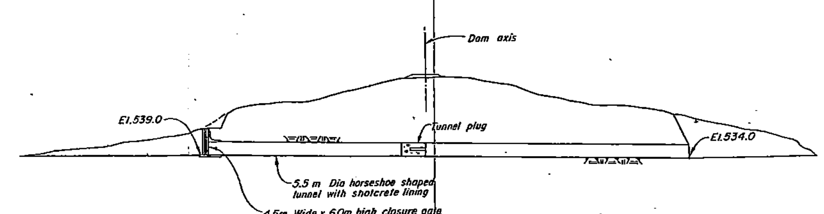
PLAN



SECTION THROUGH EARTHFILL DAM



DOWNSTREAM ELEVATION



SECTION THROUGH DIVERSION TUNNEL

Scale: 20 0 20 40 60 80 Metres

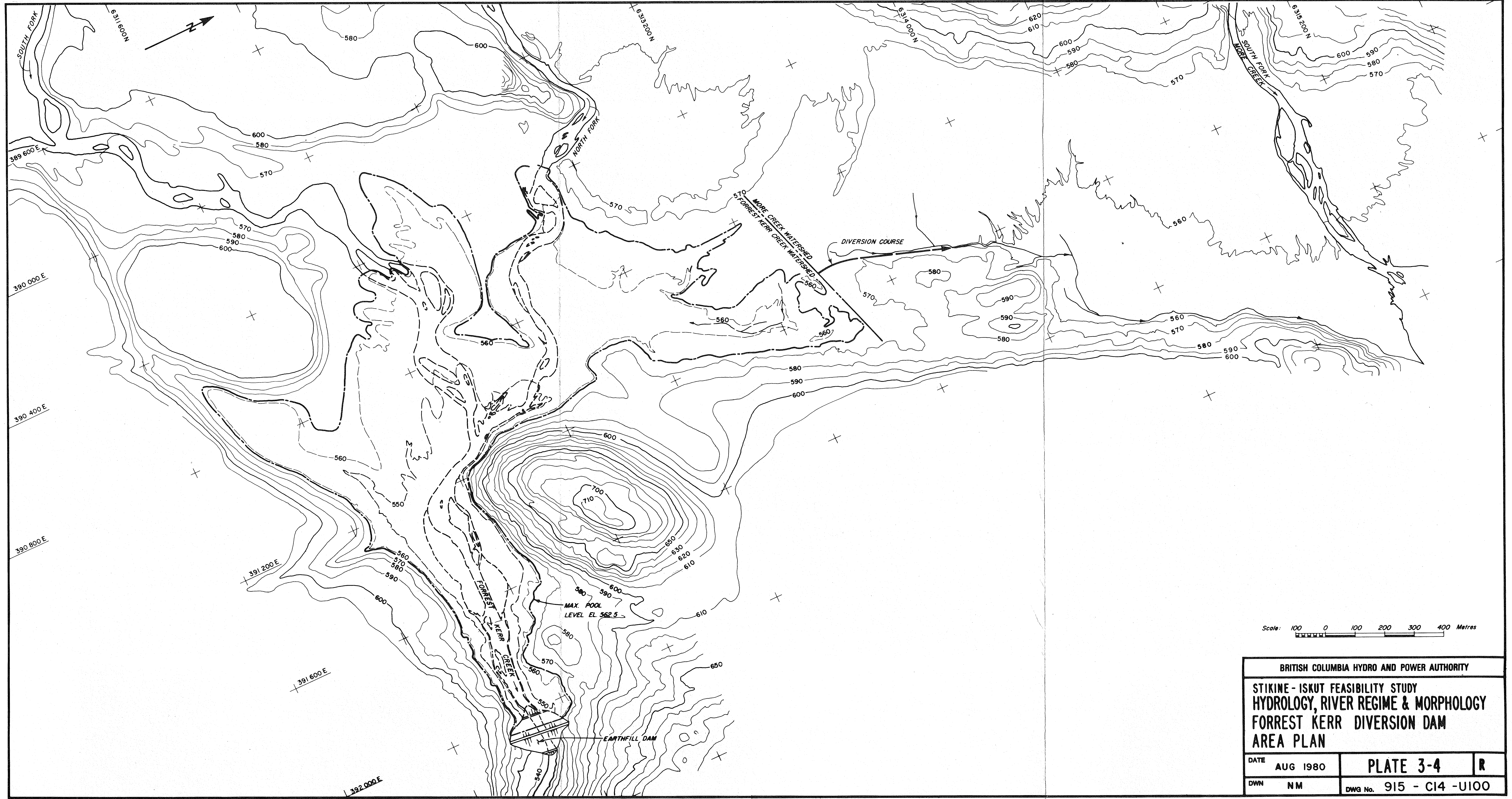
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

STIKINE - ISKUT DEVELOPMENT - MORE CREEK PROJECT

FORREST KERR CREEK DIVERSION DAM
PLAN, ELEVATION & SECTIONS

DATE AUG 1984	FIG. 5.7 - 2
DWN CY	DWG No. 913-C14-U357


BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
STIKINE - ISKUT FEASIBILITY STUDY
HYDROLOGY, RIVER REGIME & MORPHOLOGY
FORREST KERR DIVERSION DAM
AREA PLAN
DATE AUG 1980
PLATE 3-4
R
DWN NM
DWG No. 915 - C14 - U100
Scale: 100 0 100 200 300 400 Metres
SOUTH FORK
NORTH FORK
SOUTH FORK MORE CREEK
MORE CREEK WATERSHED
FORREST KERR CREEK WATERSHED
DIVERSION COURSE
FORREST KERR CREEK
MAX. POOL LEVEL EL. 562.5
EARTHFILL DAM
6311 600 N
6313 200 N
6314 000 N
6315 200 N
389 600 E
390 000 E
390 400 E
390 800 E
391 200 E
391 600 E
392 000 E

3.4 MORE CREEK PROJECT - (Cont'd)

(d) Power Facilities

The power intake comprises a 60 m high concrete gate shaft housing, a hydraulically-operated fixed wheel service gate. The penstock would be approximately 380 m in length and 5 m in diameter. It would lead to an underground powerhouse located in the north side of the canyon containing one Francis turbine. The turbine flow would be discharged back to the river via a tailrace tunnel.

(e) Reservoir Operation

Operation of the Iskut projects was studied with the use of the SHRUMO computer program using a 35-year sequence of historical and correlated streamflow data for the period July 1940 to June 1975. The program estimated outflows, spills and reservoir levels on a monthly basis and indicated that for a maximum reservoir level of El. 528 a drawdown of 40 m would result in a flow utilization for power generation of virtually 100 percent with a capacity factor of 65 percent.

Daily simulations of the More Creek project were made using the monthly outflows as determined by the SHRUMO program. These simulations indicate that the reservoir tended to be almost full (El. 528) around September to October and nearly empty (El. 488) in spring (April and May). The relatively large reservoir and regular runoff pattern would allow for very high flow utilization and even in wet years such as 1974, only minor spills might be needed.

3.5 FORREST KERR DIVERSION

(a) General

Plate 2-1 shows the location of the Forrest Kerr Diversion site and Plate 3-2 is an area map of the three projects proposed for the Iskut basin. The purpose of this project is to

3.5 FORREST KERR DIVERSION - (Cont'd)

divert the upper end of Forrest Kerr Creek into the More Creek reservoir. A 37 m high 200 m long earthfill dam would create a small reservoir from which water would be diverted through a channel excavated into a low divide to the south fork of More Creek and from there into the More Creek reservoir. The mean annual diversion flow is expected to be about 20.7 m^3/s which is an increase to the More Creek flows of about 43 percent. A detailed plan of this project site appears as Plate 3-4.

3.6 ISKUT CANYON

(a) General

Plate 3-2 shows the proposed layout of the three projects on the Iskut River and the approximate extent of the Iskut Canyon reservoir at full supply level (El. 347).

Table 3-1 presents the principal project data for the proposed projects. As shown in Table 3-1, the significant features of the Iskut Canyon project are as follows:

A concrete arch dam would be built across a narrow, deep gorge. On both sides of the canyon, the arch dam would be connected to concrete gravity dams which would be connected to earthfill wing dams. The reservoir created would have a total storage of 3.8 bcm (which represents 49 percent of the average annual runoff volume of 7.9 bcm). The live storage volume would be 0.8 bcm or approximately 10 percent of the average annual runoff volume.

(b) Spill Facilities

The spillway discharge facilities would consist of:

5.6 SEDIMENTATION ASPECTS OF THE FORREST KERR CREEK DIVERSION

(a) Introduction

Forrest Kerr Creek would be diverted towards the south branch of More Creek by means of a low dam situated approximately 3 km downstream of the two snouts of Forrest Kerr glacier (Plate 3-4). The dam, with a crest at El. 570.0 would impound the flow of Forrest Kerr Creek and divert it through a partly excavated channel across the divide towards More Creek at approximately El. 562.0. No spillway or other outlet works are proposed for the diversion dam so that the diversion flows would be entirely unregulated.

(b) Potential Evolution of the Diversion

A general, qualitative description of the morphological developments that would be likely to take place along the diversion route is given here with more detailed discussion of the various phases in subsequent sections.

During an initial period following diversion, both branches of Forrest Kerr Creek would be flowing into the diversion pool and would be depositing their bed-load and the coarser fractions of their suspended-load there. The essentially sediment-free diversion flow would, depending on slope and grain size along the diversion route, erode a more or less incised diversion channel to More Creek. From the confluence with More Creek down to the new reservoir, the diversion would greatly increase natural flows in a highly-braided gravel-bed channel, without a corresponding increase in sediment load. This would be likely to lead to some morphological changes.

As the western end of the diversion pool filled with sediment, first the north fork, and eventually both forks of Forrest Kerr Creek would begin to transport coarse sediment into the diversion channel. This would lead to gradual aggradation and to the eventual formation of braided gravel bed channels from the two snouts of Forrest Kerr glacier to the More Creek reservoir. The eastern part of the diversion pool would probably maintain a connection to Forrest Kerr Creek, but it would no longer receive much sediment and might therefore persist for hundreds of years. As the area of the divide would aggrade due to the heavy gravel load of Forrest Kerr Creek, the water level in the remains of the diversion pool would also increase. As there would be little need or incentive for the operating staff of the project to inspect and monitor the diversion dam area, it might be advisable to build the diversion dam to a height that would assure continued diversion even after a new, stable Forrest Kerr Creek has developed across the divide area.

(c) Initial Phase

During the initial phase, the coarser part of the Forrest Kerr Creek sediment load would be deposited in the diversion pool and the diversion channel to the south fork of More Creek would adopt the properties of a lake outlet channel.

The dimensions of natural lake outlet channels have been investigated by Kellerhals (1967). His relation between slope S, 2-year flood discharge, Q, and bed material size, D_{90} is:

$$S = 0.12\, Q^{-0.4}\, D_{90}^{\,0.92} \text{ (in Imperial units)}$$

It is based on a purely empirical channel width relation, a tractive force criterion for a stable channel armour and a resistance law similar to the Manning formula. With the slope of the diversion route of 0.0265 (Plate 5-9) and the 2-year maximum diversion flow of 201 m^3/s, one obtains an armour size of 227 mm. Whether sufficient material of this size to armour an incised channel is available along the diversion route is doubtful, but the following points also need to be considered.

1. The above equation is based on observations made along natural lake outlet channels which may have been in operation for hundreds or thousands of years and are therefore very stable (may have coarser armour than required for stable operation over a period of a few decades).

2. A gravel sample taken close to the point where the More Creek south fork emerges from its canyon has a D_{90} of 245 mm, although two samples taken somewhat further downstream have D_{90} values of 105 mm and 78 mm only.

3. Materials along the diversion route have not been sampled but the relatively flat slope suggests that the predominant fluvial deposits, at least, might be medium to fine gravel. This has been confirmed by field inspection. However, the diversion route crosses several small terminal moraines and there might be extensive till deposits containing cobbles and boulders at shallow depths below the fluvial deposits. The depth of overburden is unknown.

It appears from the above that there might be some initial degradation along the diversion route to More Creek. The prevailing slope of 0.00265 does, however, not exceed a clearly stable slope by much, so that the initial degradation would likely be minor and mainly restricted to the formation of a stream channel.

At the confluence with the south fork of More Creek, the slope of the diversion route increases abruptly by more than a factor of 3 to 0.00957, while the diversion flows would increase natural flows by a similar factor of somewhat over 3. For a lake outlet type channel to be stable at that discharge and on such a slope it would need to be armoured with 1000 mm material (D_{90})

which is unlikely to be available there, even at considerable depth.

Plate 5-10 can be used to see whether the steep, braided pattern of More Creek might persist even after diversions. The diversion would move the point representing the More Creek (south fork) from the centre of the scatter band of Plate 5-10 towards its upper edge without any significant increase in sediment supply from upstream. Therefore it is most unlikely that a braided channel would persist on the south fork of More Creek after regulation.

The probable sequence of events would be as follows:

During the first freshet season after diversion there would be considerable erosion and deposition along the diversion route to More Creek, resulting in the formation of an incised stream channel which might contain boulder rapids and other irregularities wherever it spills across terminal moraines or bedrock sills. In the vicinity of the confluence with More Creek there would be considerable degradation, changing the present braided channel to an entrenched single channel. Degradation would progress both upstream and downstream from the confluence area and this would provide the sediment supply needed to maintain the braided pattern further downstream along More Creek.

How far this degradation can progress would be uncertain, as it depends primarily on the type of materials that the degrading channel would encounter. After a few years the degradation would probably reach the divide and begin to reduce the water level in the diversion pool. No serious consequences would appear to be associated with these changes. Parts of the present channel zone of More Creek would become permanently dry and would slowly become vegetated.

(d) Duration of the Initial Phase

The initial phase would end when significant amounts of coarse sediment begin to move across the divide and into the diversion channel. Exactly how much of the diversion pool volume would need to be filled with sediment for this to take place is difficult to estimate, but it is estimated to be less than one third of the volume, or $4 \times 10^6 m^3$.

Coarse sediment transport in Forrest Kerr Creek is unknown but the bed-load of the north fork of More Creek has been computed as approximately 200 000 t/yr, with an additional 200 000 t/yr of sand transported in suspension. Flows in Forrest Kerr Creek are comparable so that one can assume that the coarse sediment load might also be comparable. This indicates that the initial period might last approximately 10 years.

(e) The Long-term Equilibrium Phase

Towards the end of the initial period, sand would begin to move across the divide in a newly developed river channel on the delta deposited in the diversion pool by the two branches of Forrest Kerr Creek. This new river reach would be characterized by rapidly decreasing slope and decreasing grain size in the downstream direction. A major portion of the new channel would be characterized by a sand bed and almost negligible slope. Many comparable lake basins, filled recently by active gravel rivers exist in the Canadian Cordillera. The Vermilion Lakes area on the Bow River near Banff (Alberta) is one well known example.

The upstream gravel bed reach of Forrest Kerr Creek would gradually progress across the infilled diversion pool basin. Eventually gravel would begin to be carried across the divide, into the entrenched diversion channel formed during the initial phase, and the channel would begin to aggrade again. Based on the above bed-load estimates, it would take 20 to 50 years for this to occur.

Over the very long-term, one can expect the formation of a typical, highly braided proglacial channel from the snout of Forrest Kerr glacier to the More Creek reservoir. In the existing valley of Forrest Kerr Creek, such channel reaches have slopes of approximately 0.01, which should be close to the final slope backwards (upstream) from the south fork of More Creek (Plate 3-4). This would indicate a final water surface elevation of around 585.0 near the confluence of the two forks of Forrest Kerr Creek. The gravel volumes needed to fill the diversion pool to this level are, however, so large that it would be at least 100 years before presently proposed diversion dam crest at El. 570.0 would become inadequate.

5.7 RESERVOIR LIFE ESTIMATIONS

The Iskut River, Stikine River and More Creek all carry large amounts of suspended and bed-load material. The reservoirs formed for the projects would cause a large percentage of the suspended load and all of the bed-load to be trapped. The build-up of this material would eventually fill up the reservoir. To estimate the useful life of the reservoirs a number of assumptions must be made, the two major ones are listed below:

(a) Trap Efficiency

It is reasonable to assume that 100 percent of the bed-load would be trapped. Of the suspended load the sand and silt would be captured, while much of the clay material would remain in suspension and pass through the outlet facilities. For the present however, the conservative assumption was made that 100 percent of the material would be trapped.

For the single concrete-lined tailrace tunnel serving both turbines, the maximum combined turbine discharge and minimum half gate opening discharge for one turbine would be 128 m^3/s and 27.5 m^3/s, respectively. The corresponding flow velocities in the tailrace tunnel would be 3.1 m/s and 0.8 m/s.

Operation of the powerplant could be restricted by high tailwater levels during the passage of extreme floods. No studies have been carried out to determine the frequency of such occurrences.

5.7 FORREST KERR CREEK DIVERSION

5.7.1 PROJECT AREA DESCRIPTION

Forrest Kerr Creek has its headwaters in the Coast Mountain ice field. Its primary source is two glaciers about 3 km south of the More Creek valley. The area which divides the two watersheds comprises an alluvial terrace approximately 1 km wide and 1.5 km long having several transverse ridges of terminal moraine.

The Forrest Kerr Creek diversion damsite (Fig. 5.7-1) is located 0.8 km downstream from the confluence of the north and south forks of this creek and approximately 1.7 km from the divide separating the Forrest Kerr Creek and the More Creek drainages. At the damsite the riverbed is about 50 m wide and consists of alluvium of unknown depth. For preliminary layout an alluvial depth of 15 m has been assumed. Close to river level the right abutment slope is about 45° from the horizontal flattening to about 25° near the proposed crest level. The left abutment has slopes varying from 30° near river level to 15° near crest level. Both sides of the valley are covered by dense bush.

5.7.2 GEOTECHNICAL INVESTIGATIONS

Very limited geotechnical investigations for the Forrest Kerr Diversion scheme were carried out in 1979 for the Feasibility Investigations as described in Report No. H 1228.[13] These investigations have been supplemented only by aerial reconnaissance and by air photo work in subsequent years. The 1979 investigations consisted of geologic mapping at the damsite and a construction materials investigation in the vicinity of the damsite. No subsurface investigations were undertaken at that time.

At the damsite, bedrock consists of meta-sediments argillite and bedded limestone (with some silicification to "quartzite" reported) and a granitic intrusion. All of these units appear to be sound and of good foundation quality. In particular, no solution features have been noted in the limestones. Detailed geologic and topographic mapping as well as a foundation drilling program would be required for preliminary design of the dam.

The 1979 construction materials investigation consisted of reconnaissance work, one auger drill hole in till, and two hand dug test pits in sand and gravel. No difficulty is anticipated in meeting the materials requirements of the diversion dam from local sources; however, more exploration work would be required as the level of design advances.

5.7.3 HYDROLOGIC STUDIES

Forrest Kerr Creek is a major tributary of the Iskut River between More Creek and the Iskut Canyon dam. A portion of the lower Forrest Kerr Creek would be flooded by the Iskut Canyon reservoir. Approximately half of the Forrest Kerr drainage area would be controlled by the proposed diversion dam, with all flows from this area being diverted into the More Creek reservoir.

The estimated mean annual flow diverted to More Creek would be 21 m³/s. This runoff derives from rain, snowmelt and glacier melt. Approximately two-thirds of the drainage above the diversion is covered by glaciers and the contribution of glacier melt is significant (21 percent).

Annual flood peaks can occur from July through October. The highest potential for peak runoff occurs in the fall. Summer and winter flood frequencies are plotted on Fig. 4.3-1.

The Forrest Kerr Creek carries a large amount of sediment, and it is estimated that the pond upstream of the diversion dam would theoretically fill with sediment in about 34 years. All sediment entering the diversion pond after some initial period, earlier than the theoretical 34-year filling time, would pass to the More Creek reservoir.

5.7.4 DIVERSION DAM ARRANGEMENT

(a) General

Consideration of possible arrangements for the Forrest Kerr diversion dam would be inseparable from the construction program timing and construction methods. It is recognised that the site is at a relatively high altitude and that persistence of cold temperatures would adversely limit the season for earthfill placement. Placement of the embankment material could be accomplished in less than one season while possibly avoiding river discharge peaks. If this could be done the requirement for construction diversion would be greatly reduced. It is concluded that for the Preliminary Design Phase I the layout should be based on a conservative diversion arrangement. Examination of climatic data indicated the earliest starting time to be about mid May with completion of fill placement expected in August. The summer daily flows for the 1972-82 period rarely exceed 200 m³/s, and this was selected as the required diversion flow. The approximate return frequency for a 200 m^3/s flow would be about 1 in 10 years. The practicality and costs of early placement of embankment fill, and of the risk in adopting a reduced diversion capacity should be investigated in future studies. The possible reduction in diversion capacity might be sufficient to enable a culvert to be substituted for the diversion tunnel.

On the basis of the limited geological and mapping data several alternative dam axes were considered. The proposed location (Fig. 5.7-1) would require a smaller fill volume than others studied, and also lends itself to a convenient alignment for diversion by tunnel, or by culvert if considered suitable in future studies.

There would be no provision for water releases past the diversion dam, with all flows diverted across the divide to the More Creek reservoir.

(b) Dam

The embankment dam (Fig. 5.7-2) would be constructed with a central impervious core placed on sound bedrock and gravel shells at slopes of 2.25H:1.0V and 2.0H:1.0V upstream and downstream, respectively. The maximum height would be about 50 m and crest length would be about 190 m. Blanket grouting would be provided directly under the core, in addition to a grout curtain. Cofferdams for construction diversion would be integrated with the main embankment.

(c) Diversion

The 195 m long diversion tunnel would have a 5.5 m diameter horseshoe shape and a shotcrete lining. Diversion closure would be made by utilizing a 4.5 m wide by 6.5 m high closure gate and the tunnel would be permanently plugged following dam completion.

The upstream cofferdam, about 14 m high, would be constructed of dumped rockfill with a dumped impervious blanket. The seepage beneath the cofferdams would be controlled by wells for pumping or a positive cutoff such as sheet piles. A small downstream cofferdam would be required.

(d) Permanent Access

No permanent access is planned to the diversion dam, except for water transport on the More Creek reservoir and about 7 km of low grade road over the divide to the damsite.

5.8 CONSTRUCTION ASPECTS

5.8.1 CONSTRUCTION SCHEDULE

The More Creek Project construction schedule for the Featured Project Arrangement comprising a concrete arch dam and underground powerhouse is shown on Fig. 5.8-1. Assuming that the first contract is awarded on 1 January of Year 1, the in-service dates would be as follows:

Units 1 and 2	1 October	Year 6

Reservoir filling would commence on 1 November Year 5 and with average run-off conditions the reservoir would be sufficiently filled by mid July Year 6, allowing an adequate period for testing and commissioning of the units.

Fig. 5.8-1 shows a construction period from award of first contract to first in-service date of 5 3/4 years, which is 1 year longer than