A CASE STUDY: LOWER CHURCHILL RIVER

WATER LEVEL ENHANCEMENT WEIR PROJECT

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The Lower Churchill River Water Level Enhancement Weir Project was a collaborative study in which Manitoba Hydro and the Town of Churchill evaluated ways of improving water levels on the lower Churchill River near Churchill. As a result of screening evaluations, engineering and environmental studies, and community consultation, a decision was reached by both parties to design and construct a rockfill weir which would create an upstream reservoir that could be utilized for fishing and boating activities. The weir design took into consideration such factors as recreational potential, aquatic habitat, ability to pass river flow under open water, winter ice and spring breakup conditions, allowance for fish passage, environmental effects, cost, and public input. This paper focuses on some of the design features of the project and the design process that was used in defining a low cost engineering project that could operate within a harsh subarctic climate.

1. Introduction

Since the late seventies, water from the Churchill River upstream of Southern Indian Lake has been diverted into the Nelson River by means of the Rat and Burntwood Rivers for the purposes of hydropower development in Manitoba (see Figure 1). This project became known as the Churchill River Diversion (CRD) and has resulted in many physical and environmental changes to the open water and winter ice regimes of the lower Churchill River which extends some 400 km from Southern Indian Lake to the mouth of the Churchill River at Hudson Bay. This case study focuses on the lower Churchill River Water Level Enhancement Weir Project (The "Project") in the most downstream 10 km reach, from Morrier - Thibaudeau Islands to Mosquito Point.

Since the operation of the CRD, average annual flow of the Churchill River at Churchill has been reduced from about 1300m^3/s to 300m^3/s thus significantly changing the lower river reach from a very wide medium depth river to a narrow shallow river which meanders within the confines of the original riverbed along the deepest part of the river thalweg. Spring flooding which occurred frequently at the mouth of the Churchill River before the CRD, now occurs sporadically with the reduced river discharges in the lower reach.

As one could image, this modified water regime has caused considerable mitigative problems and environmental concerns for the Town of Churchill. In 1993, Manitoba Hydro and the Town of Churchill undertook a collaborative study to enhance the water regime of the Churchill River near Churchill. As a result of this collaborative study, an overall settlement package was negotiated on the premise that a rockfill weir would be constructed in the river near Mosquito Point. The rockfill weir would rewater that natural pre-diversion shoreline, raising water levels in the immediate reservoir by 2 m and ponding water levels upstream for a distance of approximately 10 km with the intent of enhancing recreational boating and fishing. The project would also ensure or guarantee a safe water supply for the Town of Churchill which gets its potable water from the river at the CR30 pumphouse which is located approximately 6 km upstream of the weir. Also included in the agreement was a commitment by Manitoba Hydro to improve aquatic and fish habitat through the development of a fish habitat enhancement area in Goose Creek and through the construction of two fish passage facilities or fishways in the weir section.

This paper focuses on the design and construction of the low head rockfill weir and the main fishway, in which Manitoba Hydro was faced with a number of challenges given that the Churchill River near this location has been prone to severe ice jam flooding in the past, and, thus, could cause significant problems to the Project and the potable water supply system for the Town of Churchill. Construction of the project began in May of 1998 and was completed for the most part in December of the same year. A discussion of the Goose Creek Enhancement Works and Fishway with respect to their interaction with river ice processes and the environment is presented in a separate paper at this Conference.

2. Project Description

The main component of the project is a rockfill river which crosses the Churchill River just upstream of the tidal zone influence of Hudson Bay at Mosquito Point. (See Figure 1). The weir under normal operation is expected to raise water levels 2 m in the vicinity of the weir and extend the reservoir approximately 10 km upstream.

The design of the weir incorporates an overflow section and a dyke section as shown in Figure 2. The overflow section has an overall length of about 2300 m in which a 400 m segment has a flat profile slope that is predominantly in the west bank outside the natural riverbed zone and normally operates when either an open water flood with a return period of 20 years or more occurs or a spring ice jam event occurs at the structure on a more frequent basis. For open water floods with a return period of less than 20 years, the flow is contained within the natural riverbed of the Churchill River. The remaining overflow section (1900 m in length) forms a shallow V-notch profile shape with profile slopes ranging from 1 in 650 on the east side to 1 in 1100 on the west side. The deepest part of the V-notch (crest elevation $4.0^m/4.25^m$) is positioned at or near the deepest part of the natural riverbed section at the axis location. Integrated into the overflow section at its lowest invert elevation is a 300 m fishway which has been designed to accommodate fish passage under most open water flow conditions.

On either side of the overflow section are dykes which tie into high ground on the west side and to an existing axis road on the east side. Within the East dyke, two specific features have been incorporated into the design. One is the Goose Creek fishway which facilitates fish passage to the lower Goose Creek fish habitat enhancement and the other is a flood relief section which may be breached under extreme ice jam staging at the Churchill weir.

A typical cross-section of the overflow section is shown in Figure 2. The section generally incorporates a broad crest which varies in elevation along the axis of the weir, together with a downstream backslope which ranges from a slope of 1:30 in the deepest portion of the V-notch within the fishway to a slope of 1:10 on the outside edges of the overflow section. The overflow section consists of random rockfill with a layer of sand on the upstream face of weir in order to minimize leakage. The random rockfill is generally quarry run rock material which is well graded from 1.07m to spall size and contained less than 10% by weight of particles smaller than 4.76 mm (No 4) sieve.

The main fishway in the deepest part of the V-notch generally follows the same cross-sectional shape as shown in Figure 2 with the exception of a very rough course rockfill surface which is placed on the backslope to simulate a "boulder garden effect" which approximates natural pools and riffles to allow fish migration upstream. On the crest of the fishway, large boulders (1.0 - 1.5^m diameter) were strategically placed to provide resting areas for the migrating fish.

3. Historic Ice Breakup Conditions

Historically spring breakup on the lower Churchill River near Churchill has been a relatively orderly event with a "thermal" breakup occurring and the ice cover remaining in place and slowly disintegrating by internal melt and erosion. However, in some years such as in 1983 and 1986, the breakup was started by a rapid snow melt and thermal weakening of the ice cover which resulted in extensive ice runs in the upper reach of the lower Churchill River. In these years, an ice jam formed just upstream of Mosquito Point and caused significant flooding of the area with staging reaching elevation 7.9^m in 1986 at the CR 30 pumping station for the town water supply system. Fortunately the ring dyke surrounding the pumphouse was not overtopped and serious damage to the town water supply system was avoided. Flooding did however, overtop the access road to the pumphouse, and caused breaching of the road at several locations.

These particular two ice jam events which occurred after the CRD created some concern for Manitoba Hydro engineers in designing the Churchill weir and in discussion with other ice experts[1,2] across Canada, it was surmised that a weir built downstream of the CR30 pumphouse could increase the frequency and persistence of breakup jamming with possible adverse impacts on the water intake, the pumphouse, and the access road. The weir in ponding a reservoir upstream would create ideal conditions for the formation of a relatively thick, wide, strong ice cover which would be the last to thermally deteriorate, whereby, any run of incoming ice from the upstream reach would be arrested at the pond creating an ice jam which may remain in place for a longer time than would be possible without the weir. Therefore, any structures upstream of the toe of this jam such as the access road or the pumphouse could be inundated under similar conditions with the recurrence of the 1986 spring event. Furthermore the toe of the jam could eventually move downstream in the immediate vicinity of the weir and cause a "dambreak" surge which could damage the rockfill weir.

Because of the potential impact a weir could have on the potable water supply system, ice studies to address this problem as well as the surge problem at the weir were undertaken in designing the Churchill weir.

4. Prediction of Maximum Ice Jam Staging Under Post Churchill Weir Conditions

Engineering studies to predict the potential impact that the weir could have on the Churchill pumphouse were undertaken by Acres Wardrop[3] who were involved in the initial planning and design phases of the project. In predicting the potential ice jam effects upstream of the weir, Acres utilized their computer model of river ice processes, ICESIM, in their engineering analysis. ICESIM had been used in the analysis of spring ice jams and other similar projects in Canada as well as numerous other applications in studies involving ice cover formation in winter conditions. Their experience in these projects (Athabasca River near Fort McMurray, Saskatchewan River at the Nipawin Hydroelectric Project, and the St. Johns River near Sproules Island) demonstrated that the technology developed within ICESIM provided a good degree of credibility and could be used with confidence in addressing potential ice jamming on the Churchill River.

Because of the low frequency of observed jams that have occurred since the CRD, verification of the model for the Churchill River was limited to the simulation of the 1986 ice jam event. Normally, in the verification process, the empirical parameters within the ICESIM model are adjusted to represent observed conditions in the prototype being simulated. These adjusted parameters can then be applied to study future modified conditions. In the case of the Churchill River, there was no extensive database which could be used for detailed calibration, and consequently, values of the main parameters were selected on the basis of experience in other rivers. The parameters used by the ICESIM model to simulate the 1986 jam are summarized in Table 1.

TABLE 1

SELECTED PARAMETERS FOR 1986 ICE JAM SIMULATION

PARAMETER DESCRIPTION	ADOPTED VALUE
n-value of ice under-surface	0.06 for 5 m thickness
n-value of river bed	0.04 to 0.05
Cohesive strength of ice jam	0
Pariset & Hausser μ value	1.5
Critical velocity for deposition of ice flows under ice cover	1.5 m/s
Critical velocity of erosion of ice flows under ice cover	3.5 m/s
Critical Froude No. For submergence of incoming ice at the leading edge of the ice cover	0.12
Minimum ice thickness at leading edge	0.9 m

Based upon a best estimate of river flow of 2100 m^3/s (return period greater than 500 years) and an observed jam which extended 8.2 km upstream from the downstream point of lodgement near Mosquito Point, the observed stage of 7.9^m at the CR30 pumphouse was simulated by the calibrated model for the 1986 ice jam profile (refer to Figure 3). Based upon this simulation, it was estimated that the 1986 jam event contained 23×10^6 m^3 of ice (gross volume including voids).

With the calibrated model, Acres Wardrop was able to evaluate the 1986 ice jam conditions at a number of locations within the reservoir formed by the weir, over a number of flow conditions ranging from an estimated 1 in 100 years spring flood flow (1500m^3/s) to the 1 in 500 year '86 flood event. For each case, a volume of ice of $23 \times 10^6 m^3$ was used so as to represent a repetition of ice influx of the 1986 event. Based upon this analysis, an envelope of ice jam profiles was developed for the different flow conditions, of which only one flow condition for the 1986 flood event is shown in Figure 4. The envelope of profiles indicated that the ring dyke (crest elevation 9.14^m) would be safe under a recurrence of the 1986 flood. Further analysis did indicate that for the ring dyke to be overtopped, the river flow would have to be some 50% more than in 1986, or alternatively, the ice influx would have to be over three times the volume that was estimated in the simulated 1986 jam event.

In summary, it was concluded that the construction of the weir at Mosquito Point would not likely cause ice jams which would result in overtopping the ring dyke protection for the pumphouse. However, overtopping of portions of the access road is possible for floods with a return period greater than 1 in 100 years.

5. <u>Ice Blockage At The Rockfill Weir</u>

In the previous section, it was recognized by Manitoba Hydro and Acres Wardrop, that an ice jam could advance downstream in the immediate vicinity of the rockfill weir, causing an ice blockage which could release abruptly at the weir as a surge of water and ice. This hydraulic condition could therefore erode and scour the weir with severe damage to the rockfill surface, and the integrity of the structure. It was therefore important to assess the amount of staging that could occur under this potential situation, so that the appropriate sizing of rockfill and design of backslope for the overflow section could be made in keeping the rockfill weir stable under spring flood conditions.

In assessing the potential for this ice blockage problem, Manitoba Hydro and Acres Wardrop[4] went through a series of studies which ultimately ended in the final V-notch weir profile described in the project description for this paper. This weir alternative was evaluated on the basis of a number of observations and assumptions which were applied to the open water discharge rating curve for the rockfill weir (see Figure 5). These observations and assumptions included:

1) Because the weir was a low head structure with little to no risk with respect to loss of life in terms of dam safety, a 1 in 100 year hydrologic spring flood was assumed in the ice blockage scenario. This design frequency was consistent with other projects Manitoba has constructed in the past, namely, the Cross Lake Weir on the Nelson River and the Manasan groin structure on the Burntwood River.

2) Field observations have indicated that a large percentage of the river freezes to the river bed as bottomfast ice during the winter season. Because of the CRD and low winter runoff into the project area, about 25% of the river freezes to the bottom in shallow shore zone areas. During the spring season, most of this bottomfast ice continues to adhere to the bed surface, and open water flow occurs over top of the ice. Consequently, it was assumed that under a worst case scenario, at least 25% of the weir section would continue to operate under open water flow conditions during a blockage event at the weir. This area would be confined to the outer edges of the weir where the shallow shore zone areas would be most prevalent.

3) With the lowest invert of the V-notch profile located in the deepest part of the natural river cross section, it would be reasonable to assume that most of the incoming ice will concentrate in this conveyance area which makes up the remaining 75% of the overflow section (See Figure 6). During this plugging condition, it was assumed that the open water discharge capacity in this blockage area would be reduced, and arbitrary flow reduction factors of 20, 75, and 90% were applied to the open water discharge rating for this portion of the overflow section. In the final analysis, the most pessimistic 90% flow reduction factor was utilized in the blockage area for the worst case scenario.

In applying these assumptions to the open water discharge rating curve, it was estimated that in the unlikely event that a 1 in 100 year ice jam event were to progress downstream to the rockfill weir, the spring stage could rise to about elevation 6.5^{m}.

Following the final design of the rockfill weir on the basis of the 6.5^{m} spring design flood elevation at the weir, an independent review of the weir design was undertaken by several ice experts from La Salle Consulting Group Inc. and Acres Engineering (Niagara Falls). In their review[5,6], it was concluded that the rockfill weir should perform adequately under normal winter and break-up conditions. However, in the event of a worst case scenario, in which an ice jam can move downstream to the weir axis, there still existed a possibility that the main overflow section could be temporarily blocked by the encroaching ice melee and increase the risk for flooding in the upstream reservoir area. In order to minimize flooding as much as practicable, it was recommended that Manitoba Hydro provide additional flood relief with a possible overflow arrangement in the east dyke. Final design changes to the weir were therefore incorporated such that a 300 m section of the east dyke could be easily breached under extreme flood conditions thus lowering the amount of spring ice staging. Hydraulic studies indicated that the initiated breach in the flood relief section would lower the spring break-up stage by as much as 0.25^{m} to elevation 6.25^{m}.

6. Design Features of Rockfill Weir and Main Fishway

As pointed out earlier in the project description, the backslope of the V-notch weir and fishway have been designed with very flat slopes ranging from 1:30 in the deepest part of the weir where surging flow velocity and erosion could be the highest, to a slightly steeper slope of 1:10 where velocity head will be lower on the outside edges of the weir. The design of these overflow section was supported by extensive scale model testing by Manitoba Hydro staff at the University of Manitoba Hydraulic Research Test Facility (HRTF), to ensure appropriate hydraulic performance of the weir under a design spring breakup stage of 6.25^{m}. The model studies did not however address the potential problem of ice passage of large pieces of ice which could bulldoze the rock surface of the weir and fishway increasing the risk of maintenance on a regular basis.

Rock plucking on the surface of the rockfill weir was also an engineering concern which was investigated by Manitoba Hydro. With the potential for shallow aufeis formation on the surface of the rockfill weir, it is possible for rock to be picked up by the floating ice and carried downstream, thus degrading the design shape of the weir over a number of years of service for the structure.

Because it was not completely clear how the rockfill weir and main fishway would perform it was recognized that maintenance of the weir would be required on a regular basis, and would require readily available material sources. Consequently, rockfill material was stockpiled on both shores of the weir so that it could be accessed easily for future maintenance of the weir.

The main fishway within the weir profile (refer to Figure 7) also incorporates a number of unique rockfill features designed specifically for the passage of the fish with the intention of achieving suitable velocity profiles for which the fish can move upstream. The main fishway provides for burst swimming (a water velocity of 2 m/s against which a fish can swim for 10 seconds or less) and for sustained swimming (or resting velocities of 0.5 m/s for target cisco or juvenile whitefish and 0.13 m/s for northern pike). As well, a minimum water depth of 0.2 m was considered adequate to pass the above species and size of targeted fish.

Under extreme low flow conditions, fish are able to move upstream through a 10^m slot in the middle of the fishway. The slotted area has been depressed by 0.25^m below the remainder of design profile to provide a minimum water depth of 0.25^m under low tailwater conditions. Within the slot, irregularly shaped large quarry rock has been embedded into the surface to simulate a hydraulic pool and riffle environment.

Under average tailwater conditions, upstream fish movement is improved by a much larger 300 m boulder garden area which extends over the remaining backslope area of the main fishway. The boulder garden is formed by large irregular shaped rockfill which provides an extremely rough bed surface and simulates a pool/riffle habitat similar to the 10^m slotted area. Along the crest, larger armor rock has been placed in 10^m sections, to facilitate movement of fish from the boulder garden area to the reservoir.

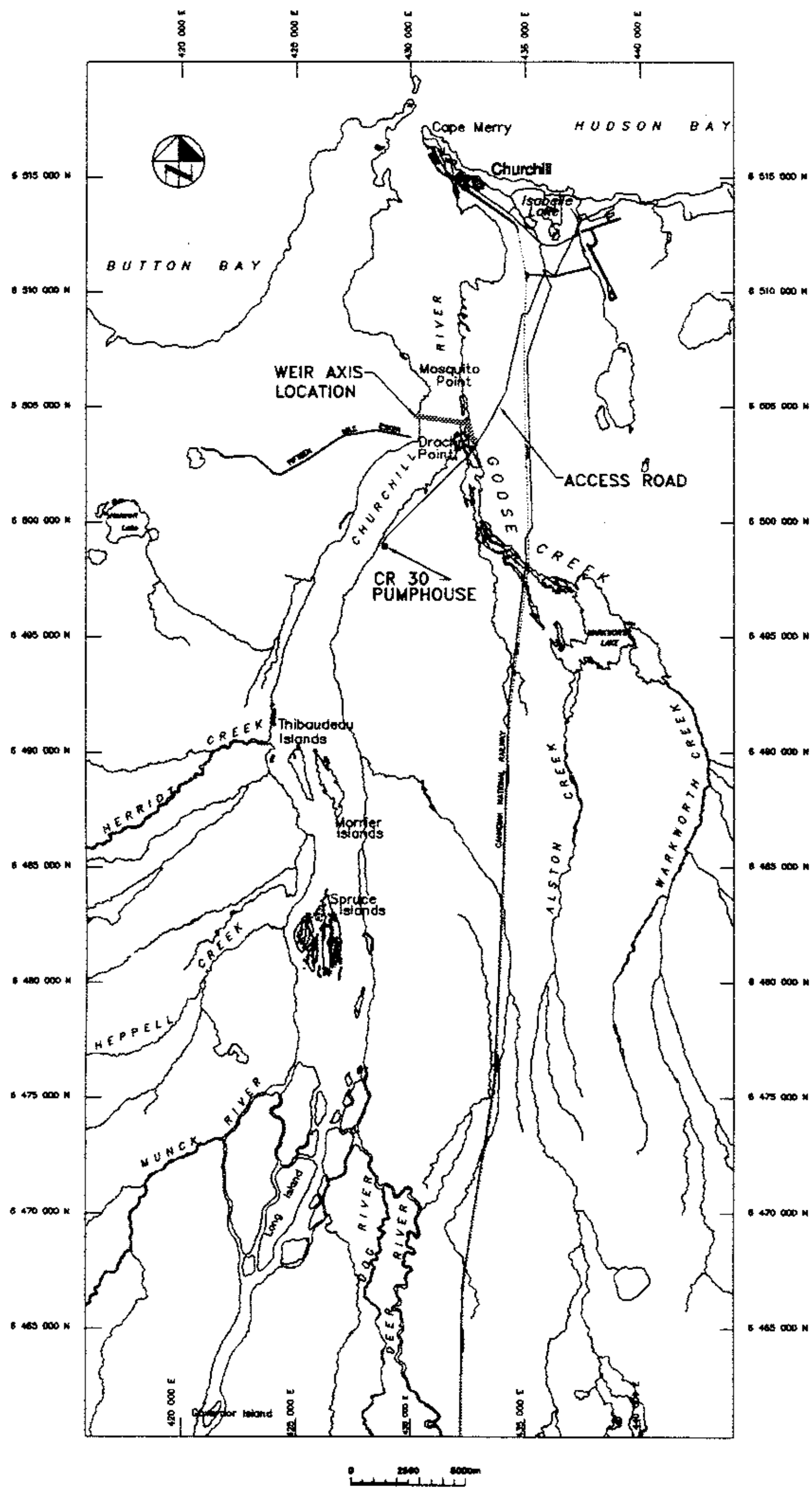
Under high flow conditions, a unique zig zag alignment of large armor rock along both outer edges of the fishway creates resting pools within the configuration of the rock placement for fish to move upstream under high velocity conditions during larger flood events.

7. Summary

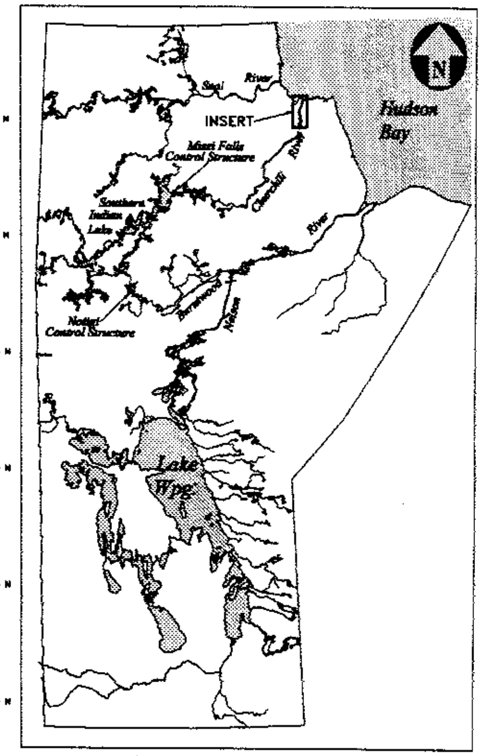
In the design of the rockfill weir and main fishway, Manitoba Hydro has designed sensible, practical, and economical structures for the purposes of maintaining an upstream recreational reservoir which will accommodate fish passage. The improved open water conditions of the rewatered reservoir area will return this area to its natural environment with the structures also blending in well within the existing environmental setting. The ice management characteristics built into the project should perform well under most conditions, however, under potentially extreme breakup conditions, maintenance of the structures will inevitably be required. Because of the simplicity in the rockfill weir design, maintenance will, however, be easy to carry out and can be done with accessible construction materials, equipment, and work forces from the Town of Churchill.

References

1. Beltaos, S., June 1994. *Review of Ice Breakup in Lower Churchill River*
2. Acres Wardrop, June 1994. *Review of Ice Effects on Possible Remedial Measures In Lower Churchill River*
3. Acres Wardrop, August 1995. *Lower Churchill River Studies of Effects Of A Weir At Mosquito Point on Spring Ice Jams*
4. Acres Engineering (Manitoba), March 1996. Design Memorandum on *Churchill River Water Level Mitigation Study*
5. F.E. Parkinson, August 1997. *Project Review, Lower Churchill River - Water Level Enhancement*
6. T. Lavender, August 1998. *Ice Mechanics Review, Lower Churchill River Water Level Enhancement Project*

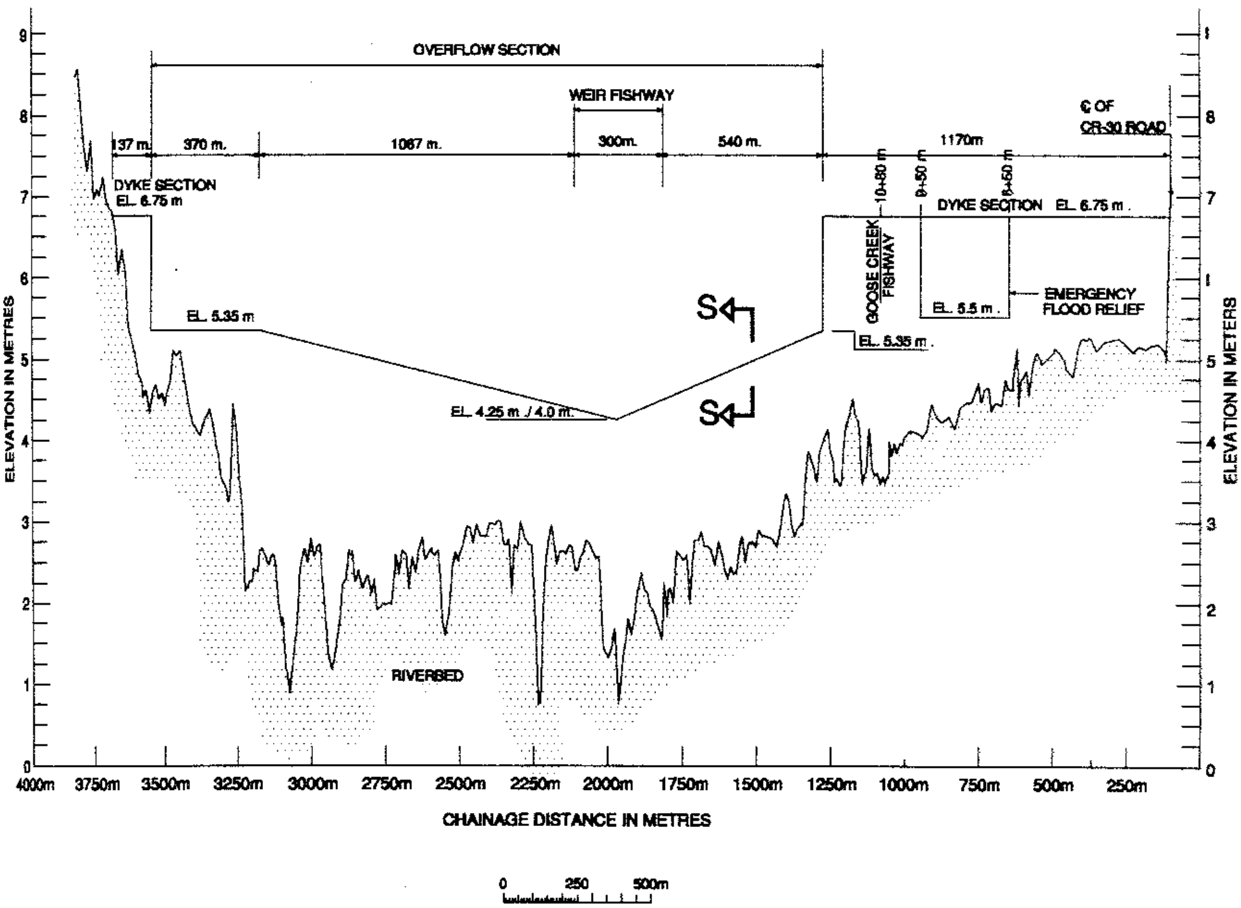


VICINITY MAP

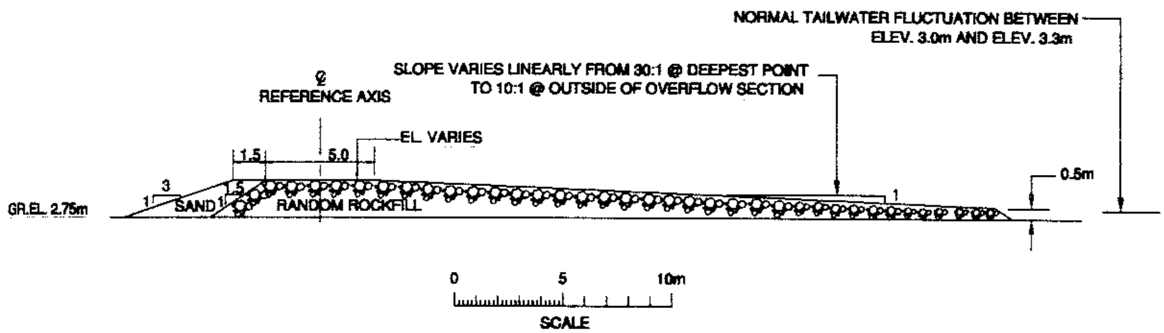


KEYMAP

Figure 1 LOCATION PLAN



CHURCHILL WEIR PROFILE



TYPICAL CROSS SECTION OF DYKE OVERFLOW

Figure 2 CHURCHILL WEIR

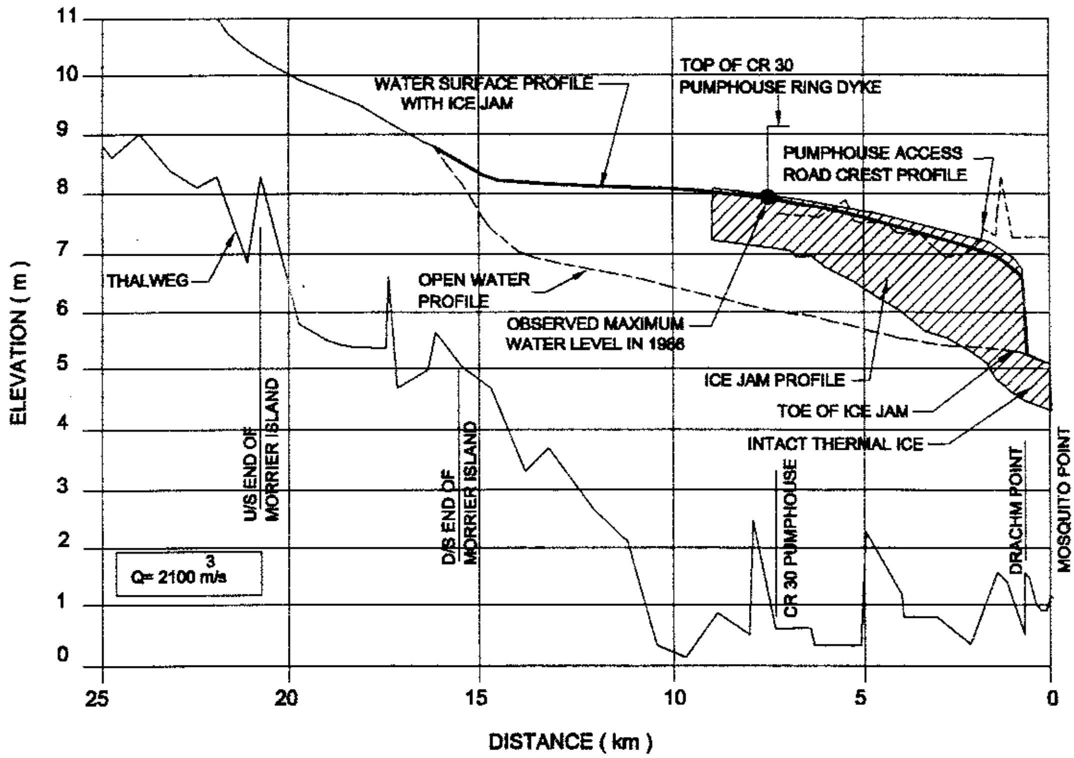


Figure 3 CALIBRATED 1986 SPRING ICE JAM

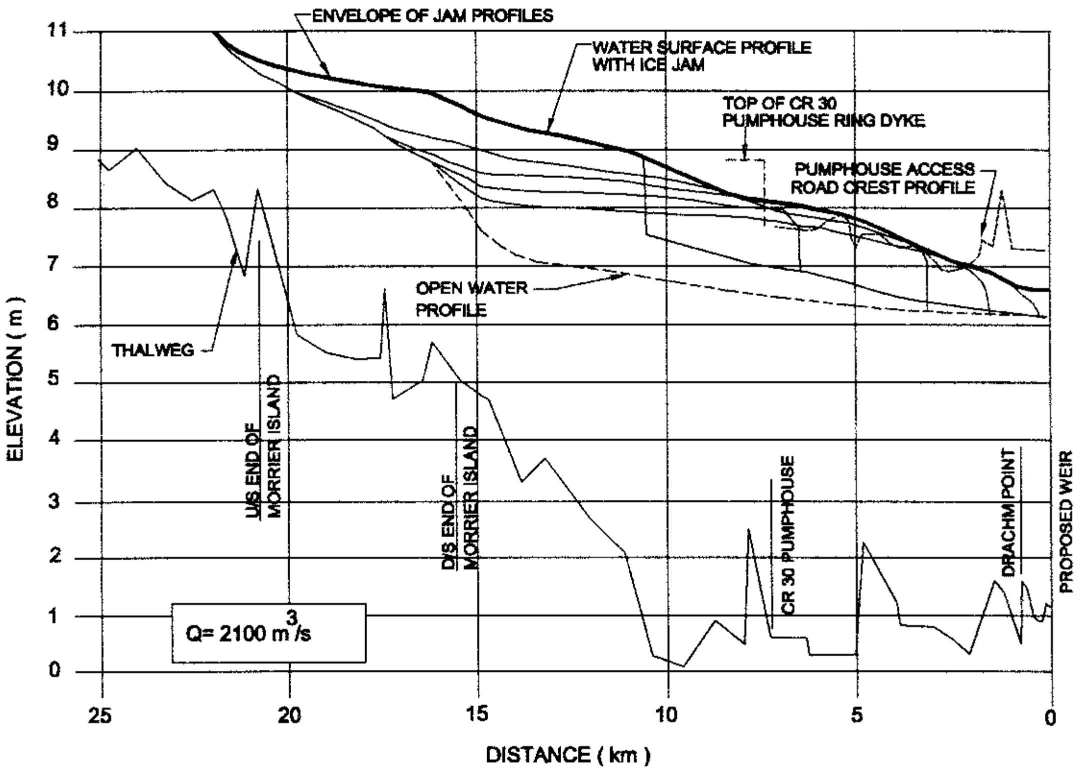
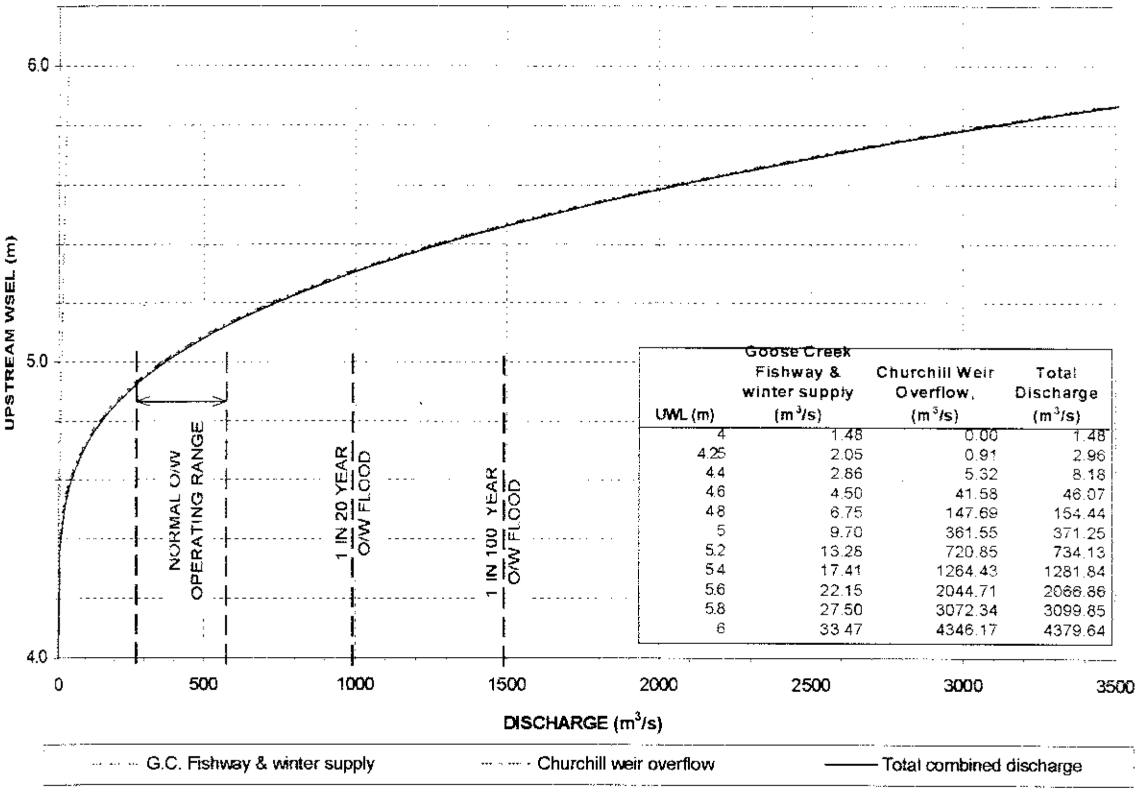


Figure 4 ENVELOPE OF 1986 JAM EVENTS WITH WEIR IN PLACE



UWL (m)	Goose Creek Fishway & winter supply (m^3/s)	Churchill Weir Overflow, (m^3/s)	Total Discharge (m^3/s)
4	1.48	0.00	1.48
4.25	2.05	0.91	2.96
4.4	2.66	5.32	8.18
4.6	4.50	41.58	46.07
4.8	6.75	147.69	154.44
5	9.70	361.55	371.25
5.2	13.26	720.85	734.13
5.4	17.41	1264.43	1281.84
5.6	22.15	2044.71	2066.86
5.8	27.50	3072.34	3099.85
6	33.47	4346.17	4379.64

Figure 5 CHURCHILL WEIR AND GOOSE CREEK FISHWAY OPEN WATER RATING CURVE

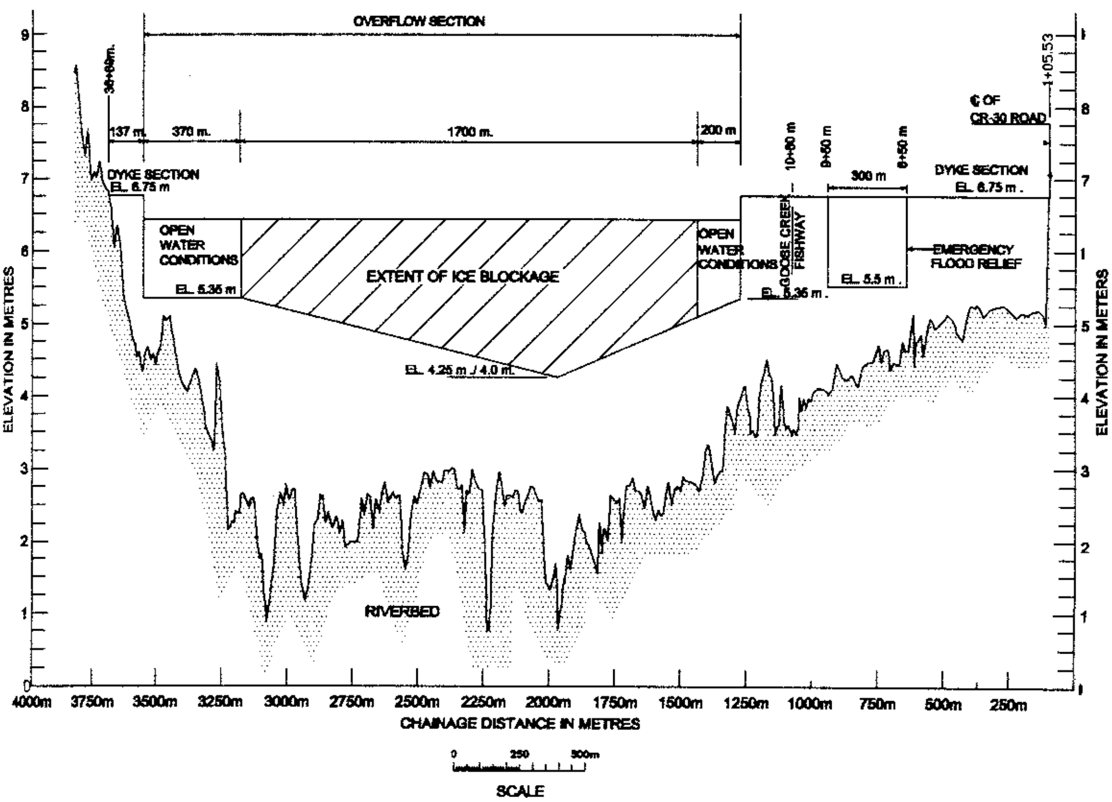


Figure 6 POTENTIAL ICE BLOCKAGE AT WEIR

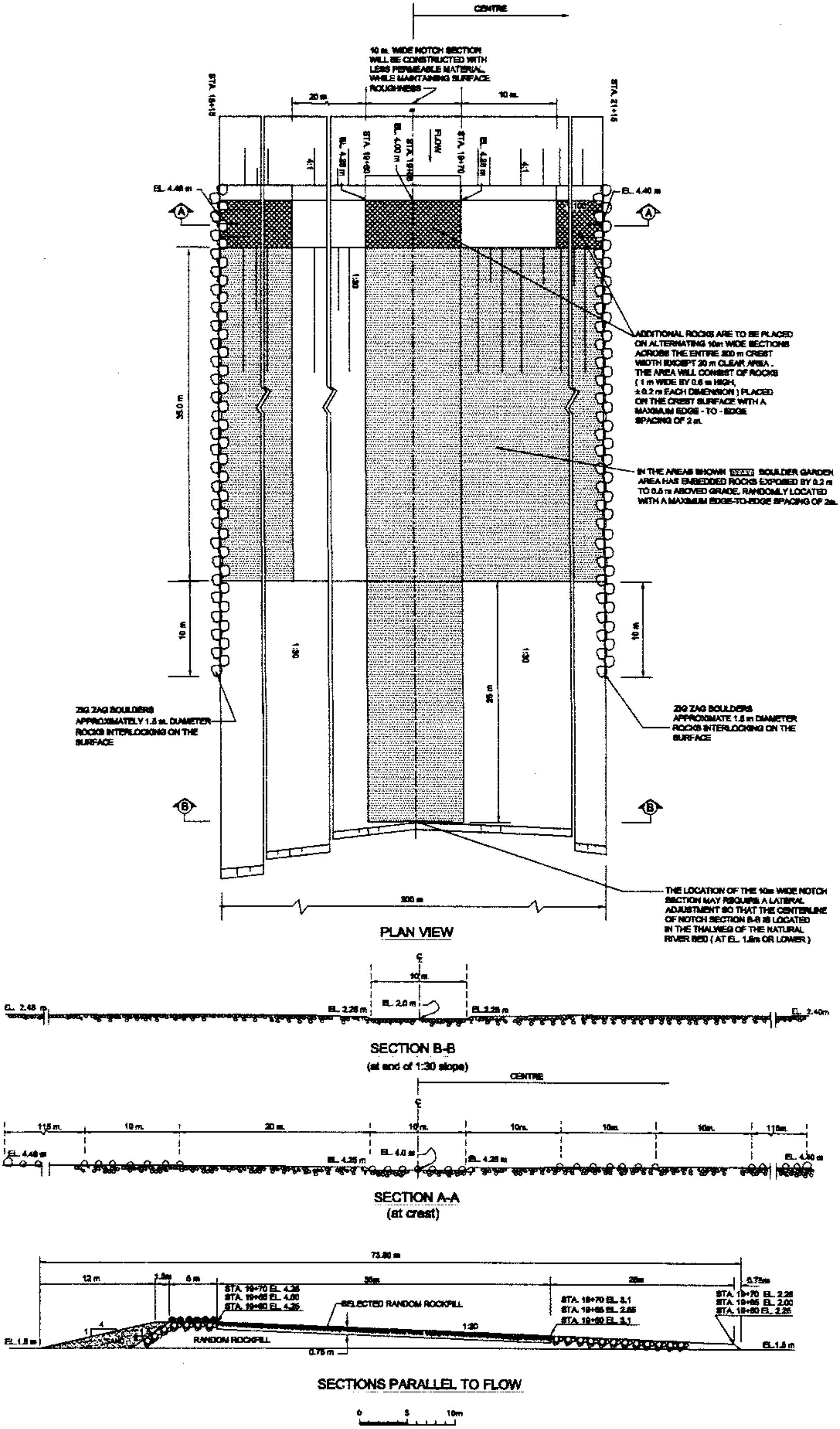


Figure 7 CHURCHILL WEIR FISHWAY