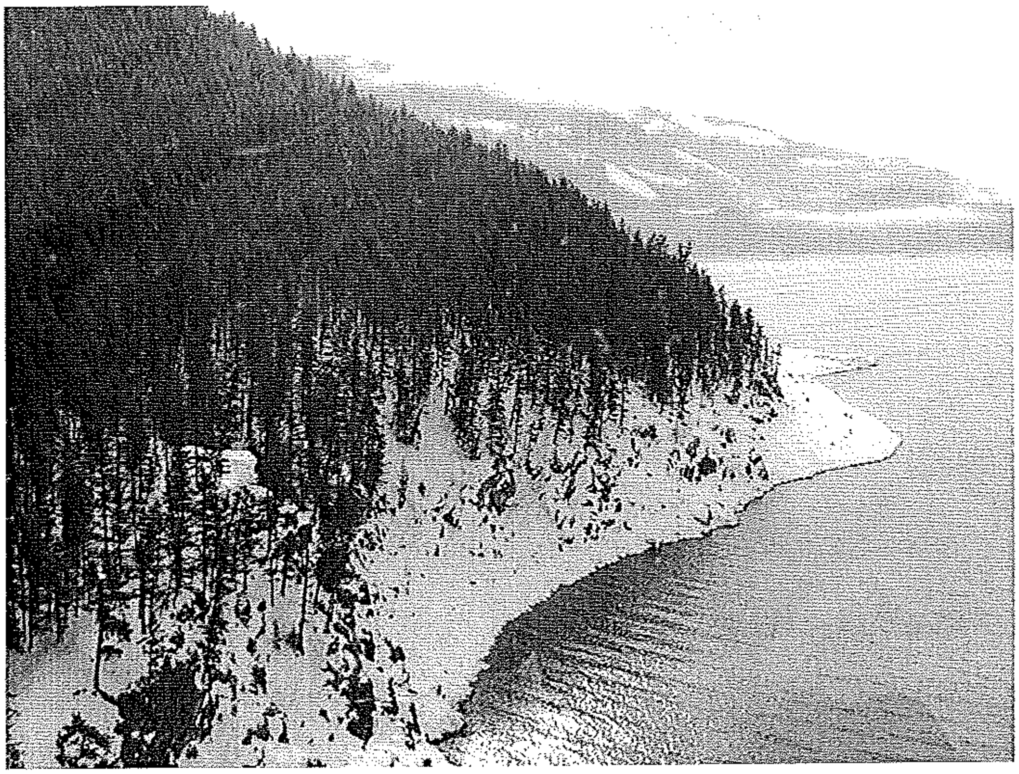
Ministry of Transportation

BRITISH COLUMBIA

Upper Arrow Lakes Fixed Crossing Feasibility Study

FINAL REPORT



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Project 82002-003

NDLEA™

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Executive Summary

This report provides a preliminary evaluation of the feasibility of a new fixed crossing to replace the existing Arrow Lakes ferries that operate between Galena and Shelter Bay. While the report is focused on the engineering feasibility of potential fixed crossing options, other issues that will affect the feasibility of the crossing have also been identified. The study is a technical and engineering feasibility assessment. It does not represent a business case nor does it attempt to establish the economic viability of the project.

The study area is focused in the vicinity of the Shelter Bay and Galena Bay, but it is not limited to the existing ferry crossing location. A feasibility study of three potential crossing locations and the highway connections required for each was completed in March 2004 by Buckland and Taylor.

In 2002, the total traffic crossing the Galena-Shleter Bay Ferry was approximately 173,000 vehicles, or an average of 374 vehicles/day, made up of approximately 10% trucks, 14% recreational vehicles and the remainder, passenger vehicles.

Population growth in the region has generally been flat. Most of the communities along Highway 23 between Revelstoke and Nelson have experienced population losses in recent years. The region is heavily reliant on the forest industry, which has not performed well recently. Population growth for the Arrow Lakes Local Health Area is expected to be less than 1% per annum over the next 25 years. Therefore, while a fixed crossing would affect some new traffic, major growth is not anticipated.

Three potential crossing options were considered:

- Albert Point - Suspension Bridge
- Storm Point - Suspension Bridge
- Storm Point - Bridge/Causeway

Due to the distance between piers, a conventional bridge is not feasible for the Albert Point or the Storm Point crossing alignments. A floating bridge similar to the Okanagan Lake Bridge near Kelowna was not considered, as it was deemed to be not suitable for the Upper Arrow Lake because of the large fluctuations in water levels. The change in water levels due to the dam is approximately ten times that for Lake Okanagan. For the Storm Point Bridge/Causeway crossing, the shallower water depth makes a causeway / bridge combination feasible.

The total costs of the suspension bridges and approaches are in the order of $500 M to $550 M, while the estimated cost for the causeway/bridge option is in the range of $175 M to $200 M. These costs do not include environmental assessment or mitigation costs. Given the nature of the project, the cost of an environmental assessment is expected to be in the order of hundreds of thousands of dollars.

Given the scale of this project, there are several environmental factors that may be influenced, changed or significantly impacted by construction and subsequent operation of any of the proposed options. In particular, the causeway is most likely to generate the greatest environmental issues as it creates a physical change in the conditions of the reservoir, affecting aquatic resources and in the potential effects on critical wildlife habitat.

The Ministry of Transportation will need to consult with affected First Nations and ensure accommodation of their interests in the development of this project. The magnitude of the project would indicate a high level of consultation would be required. Early dialogue with First Nations and in particular the development of a corridor/site specific traditional use study will help to mitigate potential impacts.

The project is expected to trigger both the British Columbia Environmental Assessment process and the Canadian Environmental Assessment process, likely at the Comprehensive Study level. Such a process would extend over one to two years and would likely be conducted as a joint review between federal and provincial agencies.

Based on this preliminary assessment, it appears that the three fixed crossing options considered are feasible in the vicinity of the existing Upper Arrow Lakes ferry crossing. All are very expensive, although a bridge/causeway option is considerably less expensive than the suspension bridge options. Because of the water depths at the narrowest potential crossing points, suspension bridges would be required with main spans in the order of 2.0 to 2.2 km, making such a bridge among the longest in the world once constructed.

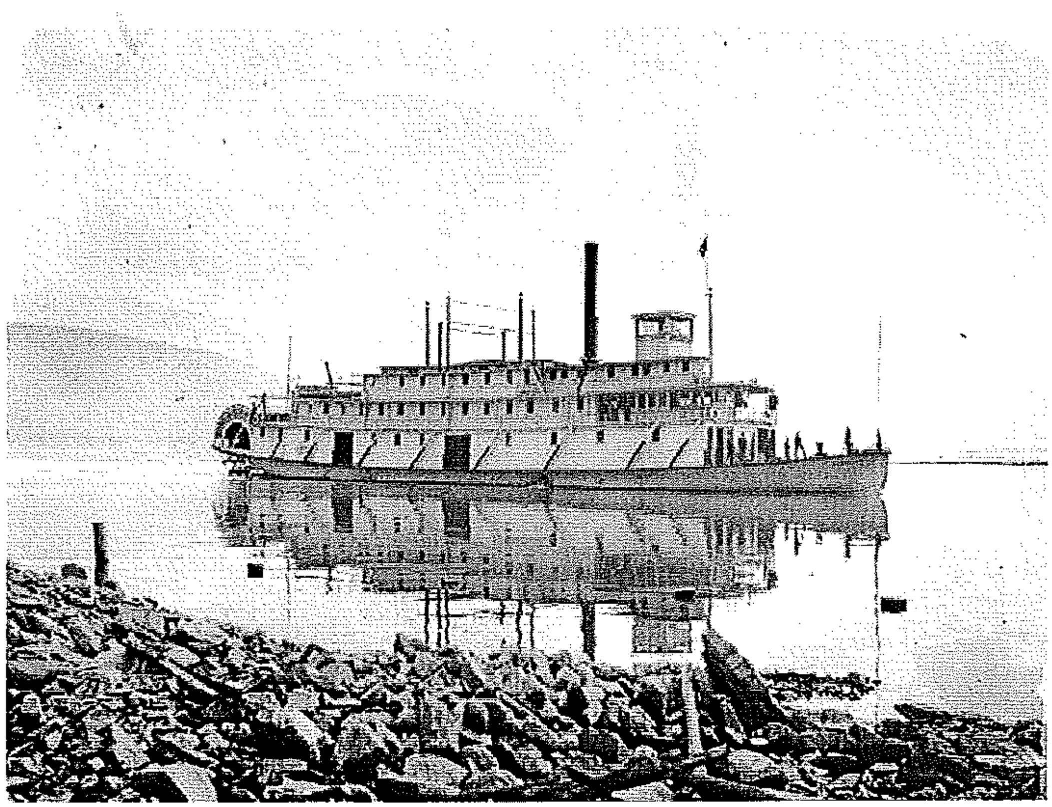
The bridge/causeway option is considerably less expensive. There several uncertainties that still exist and will need to be further investigated, not the least of which are geotechnical conditions, environmental concerns, reservoir hydraulics, and First Nations consultation.

1 Introduction

This report provides a preliminary evaluation of the feasibility of a new fixed crossing to replace the existing Arrow Lakes ferries that operate between Galena and Shelter Bay. While the report is focused on the engineering feasibility of potential fixed crossing options, other issues that will affect the feasibility of the crossing have also been identified.

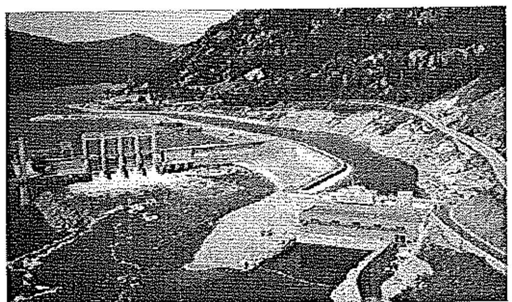
1.1 Background

Ferry service has existed on the Arrow Lakes since the late 1800s, initially provided by steam stern wheelers. These stern wheelers were first operated by the Columbia and Kootenay Steam Navigation Company Ltd. and its successor, the Canadian Pacific Railway as the north-south link between the CPR main line in Revelstoke and the railway lines in the south Kootenays. Through the 1950s and early 1960s, CPR initiated abandonment of its Arrow Lakes service. By 1964, the Province constructed a road from Naksup to Galena Bay and initiated a ferry service between Galena Bay and Arrowhead, completing the north-south transportation link that was broken with the termination of ferry services along the lake.



SS *Kootenay*, c. 1900, **Photo: B.C. Archives Call Number: G-07122**

In 1968, the Hugh Keenleyside Dam was opened, resulting in the flooding of the Columbia River and raising the level of the Arrow Lakes. The ferry service was moved from Arrowhead to its current northern terminus at Shelter Bay. The Hugh Keenleyside dam is an earth fill and concrete structure that controls drainage to an area of 3,650,000 ha in the Upper Arrow Lake Reservoir for a distance of 232 km. The dam is 53 m high with a crest length of 853 m of which 366 m is concrete dam and the rest earth filled dam. Release is controlled by four sluiceways and eight low level ports. A 1280 m concrete channel diverts water 400 m downstream to the Arrow Lakes Generating Station. The dam causes the water level of the lake to fluctuate significantly, with levels changing by up to 30 cm in a 24 hour period. Over the course of a year, there may be a 20 metre difference between high water level and low water level.



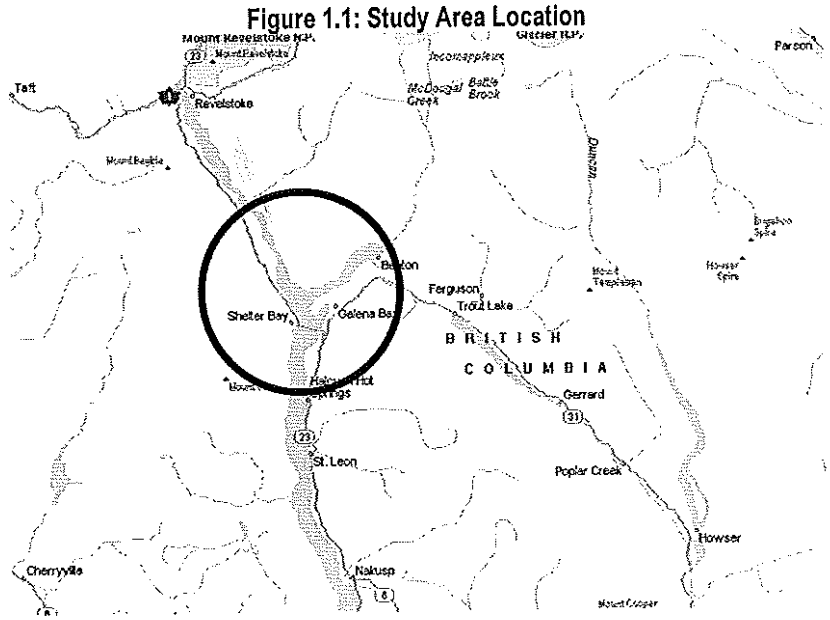
Arrow Lakes Generating Station

1.2 Project Location

The study area is focused in the vicinity of the Shelter Bay and Galena Bay, but it is not limited to the existing ferry crossing location. A feasibility study of three potential crossing locations and the highway connections required for each was completed in March 2004 by Buckland and Taylor. The full report is attached as Appendix A.

Figure 1.1 shows the general study area.

Figure 1.1: Study Area Location



1.3 Study Objectives

As noted above, this study represents a preliminary assessment of the feasibility of constructing a fixed crossing of Upper Arrow Lake to replace the existing ferry service. The objectives of this report are:

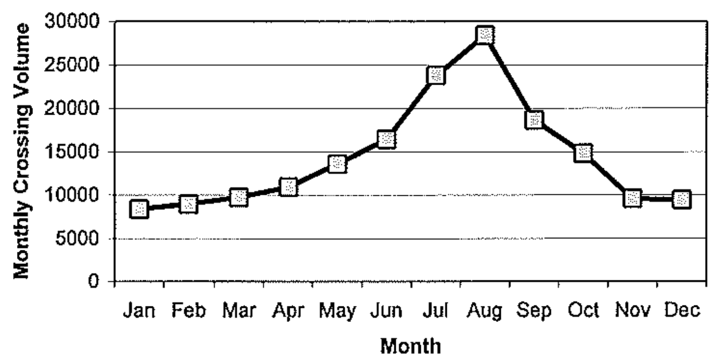
- to identify potential crossing options;
- to provide an order of magnitude cost estimate based on existing information;
- to recommend a preferred crossing type and location if one exists; and
- to identify further work required.

The study is a technical and engineering feasibility assessment. It does not represent a business case nor does it attempt to establish the economic viability of the project.

2 Existing Conditions

The Upper Arrow Lakes area is sparsely populated with no significant new economic activity expected that would generate increased growth, although a fixed crossing has the potential to generate some demand for development along the lake. The current conditions in the area are summarized in this section.

Figure 2.1:
Monthly Crossing Volume, Galena Bay-Shelter Bay, 2002

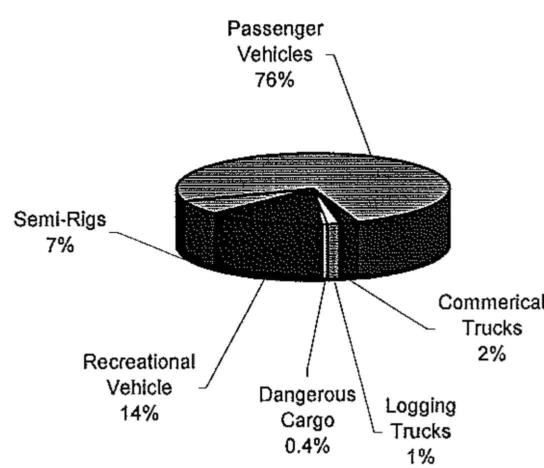


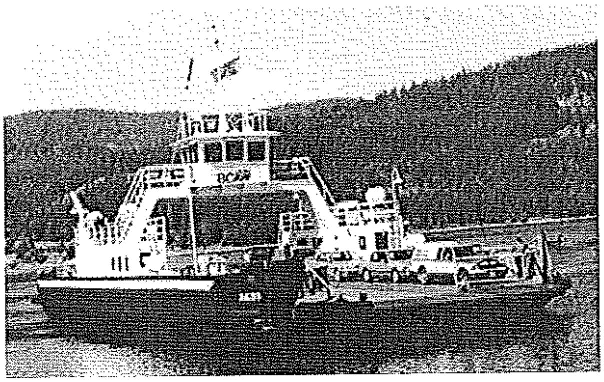
2.1 Traffic Demand

Figure 2.1 shows the monthly distribution of traffic using the Galena-Shelter Bay ferry crossing. Volumes increase sharply in the summer months, reflecting a high volume of tourist traffic. In 2002, the total crossing volume was approximately 173,000 vehicles, or an average of 374 vehicles/day.

The vehicle types using the ferry crossing are shown in Figure 2.2. As the figure shows, trucks make up approximately 10% of the traffic, which is typical of most provincial highways. The proportion of recreational vehicles however is very high at 14% of the annual traffic. In August of 2002, RVs represented almost one-quarter of the total traffic stream, again demonstrating the high tourist use of the ferry and of Highway 23.

Figure 2.2:
Vehicle Classification, Galena-Shelter Bay, 2002





2.2 Ferry Operation

The current ferry service is operated by the Ministry of Transportation. The route is served by DEV "Galena" and MV "Shelter Bay", both free running ferries of 1960s vintage. The distance across the lake is 5.2 km with a crossing time of approximately 30 minutes. Service is generally hourly from 6:00 am to 11:00 pm, with additional sailings during periods of high demand.

2.3 Regional Economy

Population growth in the region has generally been flat. Most of the communities along Highway 23 between Revelstoke and Nelson have experienced population losses in recent years. The region is heavily reliant on the forest industry, which has not performed well recently. Population growth for the Arrow Lakes Local Health Area is expected to be less than 1% per annum over the next 25 years.

2.4 Environmental Conditions

No environmental study related to the crossing has been completed. The general environmental conditions are described as follows:

- Climate: The area of the proposed alignment is within the Interior Cedar–Hemlock (ICH) biogeoclimatic zone. Sites vary from dry warm to wet cool. The dominant tree cover is cedar and hemlock with minor amounts of white pine and Douglas fir. Mature stands have a herb and moss dominated understorey. For the most part, the area is characterized by warm wet summers and cool winters with moderate to deep snowpacks. Some sites may experience hot moist summers and mild winters with light snowfall particularly on exposed faces.
- Geology: On the western shore of Arrow Lake in the vicinity of Shelter Bay, a series of normal faults parallel the shore line. Glacial silts and till overlay bedrock geology. Bedrock consists of mixed metamorphosed and sedimentary rocks intruded by plutonic rock consisting of monzonite, granodiorite and diorite suites. Soil development consists of morainal, colluvial and glacio fluvial soils with loamy, sandy, and silty textures.
- Wildlife: Wildlife habitat in the area is classified as Eastside Interior Mixed Conifer forest consisting of Douglas Fir, Ponderosa Pine forests with pockets of Western Red Cedar or Western Hemlock forest. The habitat is generally located between the elevations of 305 m and 2135 m. The

area under consideration is home to moose (as noted from the helicopter), grizzly bear, and wide ranging carnivors. Critical ungulate range exists near the ferry terminal at Shelter Bay.

- Vegetation: Understory consists of short deciduous shrubs and herbaceous broadleaf plants
- Fish: Rainbow trout, bull trout, kokanee, white sturgeon and other regionally significant species exist in Upper Arrow Lake.
- Wetlands: Biodiversity and connectivity are major concerns for development particularly in the wetland areas which were staging areas for migratory birds. Wetlands exist to the northwest of Shelter Bay.

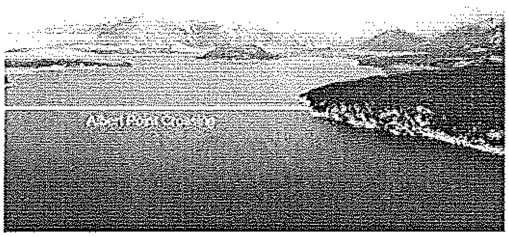
3 Potential Options

The assessment of potential options was based upon the results of a site visit, depth charts from the Canadian Hydrographic Service, topographical maps, and aerial photographs. At this point, only limited geotechnical information has been considered. Bridge design criteria were based upon those used for the Needles-Fauquier bridge project, and included, a navigational envelope with a minimum clearance of 18.5 m between high water level and the underside of the middle 60 m of the bridge, with a minimum clear span 130 m. This envelope will accommodate the tug boats and log booms that use the lake.

3.1 Alignments

Three potential crossing alignments have been considered. The Albert Point Crossing and the Storm Point Crossing were based upon previous studies for potential cable ferry locations, and were selected primarily for their relatively short crossing distances and also to minimize any new road construction requirements. The Storm Point Bridge/Causeway Crossing was selected because of the relatively shallow lake depth. The key features of each crossing alignment are summarized as follows:

Albert Point - Suspension Bridge
Crossing Distance - 2.4 km



New Highway Requirements

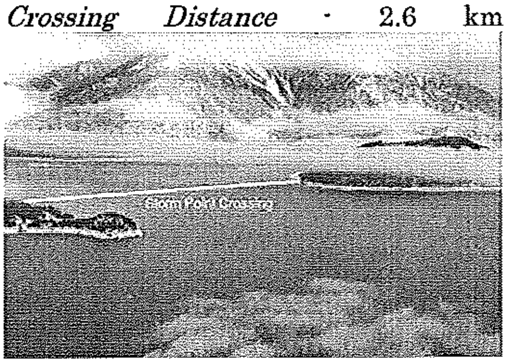
North Approach – 8.2 km

South Approach – 4.0 km

Water Depth

- Generally greater than 200m
- Max. Depth 230 m
- Depth reaches 50 m within 100 m of shoreline

Storm Point - Suspension Bridge
Crossing Distance - 2.6 km



New Highway Requirements

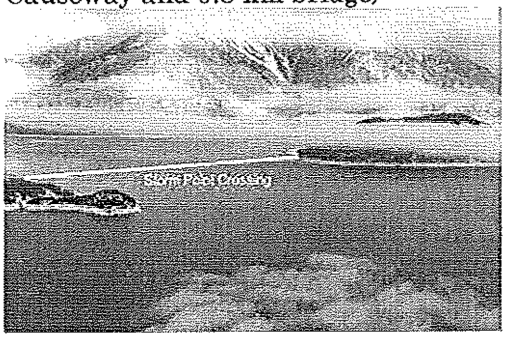
North Approach – 1.1 km

South Approach – 10.3 km, plus upgrading of 8.8 km of Highway 31

Water Depth

- Generally greater than 100m
- Depth is generally less than 50 deep, 500 m from the west shoreline and 100 m on the east

Storm Point - Bridge/Causeway
Crossing Distance – 5.2 km (4.4 km Causeway and 0.8 km bridge)



New Highway Requirements

North Approach – 1.4 km

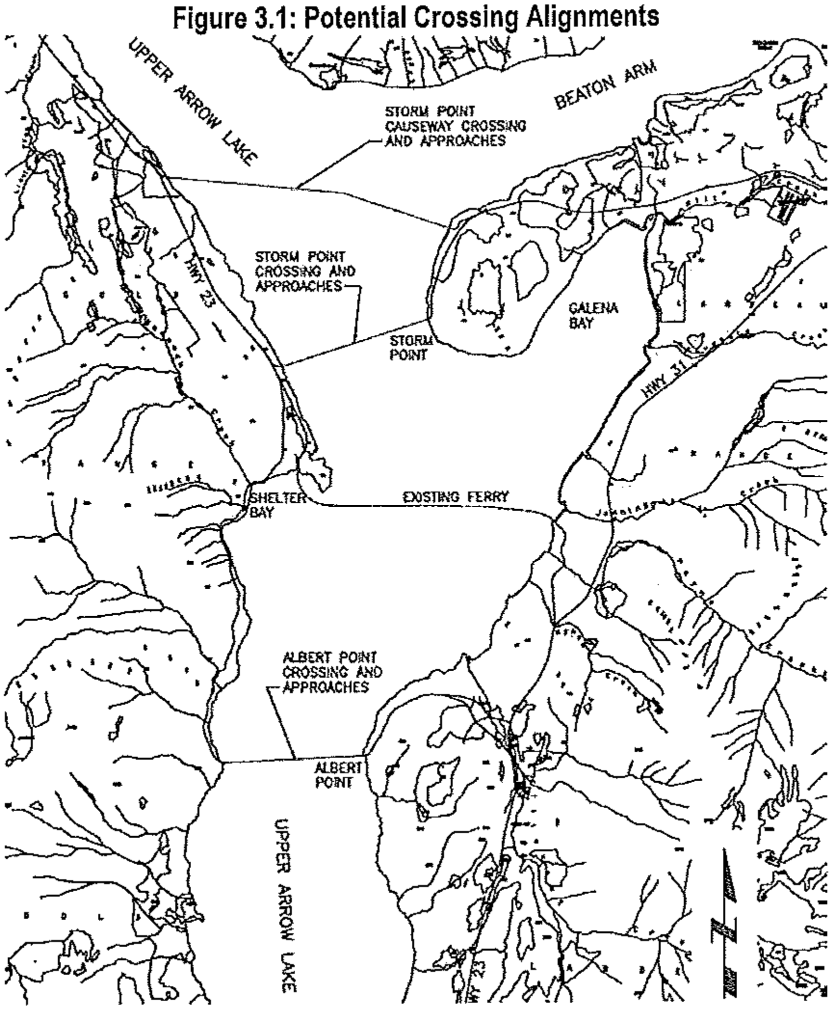
South Approach – 8.3 km, plus upgrading of 8.8 km of Highway 31

Water Depth

- 12 to 17 m on west half
- 17 to 22 m on east half

The alignments are shown in Figure 3.1

Figure 3.1: Potential Crossing Alignments



3.2 Structures

Due to the distance between piers, a conventional bridge is not feasible for the Albert Point or the Storm Point crossing alignments. A floating bridge similar to the Okanagan Lake Bridge near Kelowna was not considered, as it was deemed to be not suitable for the Upper Arrow Lake because of the large fluctuations in water levels. The change in water levels due to the dam is approximately ten times that for Lake Okanagan. Anchorages for a floating span would be very complicated in order to accommodate such an extreme vertical movement. Transition spans, which would ramp from the fixed approaches to the floating spans would need to be quite long to accommodate the required road grades. These long ramps would be difficult to construct and maintain.

The only feasible bridge structure at these locations would be a suspension bridge, with a main span over 2 km long. Similar types of bridge have been built in Norway over deep fjords, however the bridges in Norway have main spans much shorter. Indeed, 2 km is longer than the longest existing suspension bridge span, the 1,991 m long main span of the Akashi Kaikyo Bridge in Japan. Design is currently under way of longer crossings, such as the 3.2 km Strait of Messina Bridge between Italy and Sicily. A bridge of this length is technically possible, but challenging and very costly.

For the Storm Point Bridge/Causeway crossing, the shallower water depth makes a causeway bridge combination feasible.

3.2.1 Suspension Bridges

The main piers would be pylons, supported on steel pipe piles driven into the lake bed by equipment on barges. Precast concrete shells would be floated out to the base of the pylons, and then filled with concrete to sink them onto the pipe piles. Once out of the water, the pylons would be constructed using slipforms or jumpforms.

Although only minimal and general geotechnical information on the site was available for the preparation of this report, it is known that BC river valleys that were formed by glaciers during the Ice Age typically exhibit competent rock along the sides. The visual inspection of the proposed alignments indicated rocky outcrops along the east side of the lake at all three proposed alignments. It is therefore anticipated that the valley will provide favourable conditions for anchorages of the bridge cables. The anchorages would be large concrete structures founded in the sides of the valley, so as to resist the tension applied by the cables.

The main suspension cables and the hangers would be erected on the pylons and anchored into the sides of the valley. Due to the relatively narrow width of the bridge, cables could either be prefabricated or spun in place. The bridge deck would be transported to the site on barge to the underside of the bridge, and the pieces individually hoisted and connected to the hangers. Lateral cables would be required to provide the relatively narrow bridge with increased lateral restraint, thereby avoiding instability in major winds.

The approach spans would likely be constructed using conventional bridge techniques.

3.2.2 Bridge/Causeway

The causeway would consist of a 13 to 23 m deep rock-filled structure, which would allow for the roadway to be 1.0 m above the high water level of the lake. Previous studies indicated that wind could generate waves of up to 1.8 m. A roadway level of 1.0 m above the high water level was deemed sufficient in this case because of the low probability of high winds being coincident with the high water level in the reservoir, and because of the ability to close the highway if necessary. The side slopes of the causeway would be 1.0 m vertical to 2.0 m horizontal, with embankment protection to prevent wash-out.

The causeway could be constructed from the east and west ends towards the middle of the lake, and the bridge section constructed independently of the causeway, or afterwards to use the causeway for access. The bridge would be founded on steel pipe piles, driven by barge-mounted equipment. Reinforced concrete pile caps would be cast on top of the pipe piles, supporting a conventional superstructure consisting of a concrete deck on steel plate girders. The environmental issues associated with the bridge/causeway option may be significant. While not assessed within the feasibility study, a low level bridge along the same alignment may be an alternative worthy of consideration.

Since the geotechnical information available for this site is minimal, it is assumed that if the causeway is constructed from blasted rock and allowed to sit for at least one year before paving, the lake bed is considered suitable to support the weight of the causeway and the amount of post construction settlement will be negligible.

3.3 Option Comparison

The option comparison considered the relative costs and performance as well as environmental and other risk considerations.

3.3.1 Cost

The main spans of the suspension bridge options are larger than any constructed to date, therefore it is difficult to draw upon experience of past projects to accurately estimate the cost. Existing suspension bridges with similar main span lengths are all outside of Canada, so exchange rates, material costs, labour supply, and design philosophy all become important factors. The estimates provided below are thus preliminary.

The estimated costs are presented in Table 3.1.

Table 3.1: Conceptual Cost Estimates

Option	Bridge/Causeway	Approach Roadway	Total
Albert Point Crossing (Suspension Bridge)	$504 M	$46 M	$550 M
Storm Point Crossing (Suspension Bridge)	$485 M	$36 M	$521 M
Storm Point Bridge/ Causeway Crossing	$152 M	$33 M	$185 M

These costs do not include environmental assessment or mitigation costs. Given the nature of the project, the cost of the assessment is expected to be in the order of hundreds of thousands of dollars. While the environmental mitigation cannot be determined until after the assessment is completed, it is possible the mitigation and monitoring costs could be in the order of several million dollars, and it is likely that the environmental mitigation for the bridge/causeway will be more extensive than for the suspension bridges.

3.3.2 Performance

While this assessment does not include an evaluation of the economic performance of the options, it is possible to provide some rough indicators of the benefits of each option. A comparison of the travel time differences between the ferry and each crossing are presented in Table 3.2. An average travel speed on each route of 80 km/h and an average ferry wait plus crossing time of 40 minutes are assumed. The value of travel time savings are based on the crossing volumes in 2002 and an average travel time value of $11/hour for passenger vehicles and RVs, and $23/hour for commercial vehicles.

Table 3.2: Travel Time Savings

Option	Additional Vehicle Travel Distance (km)	Travel Time Saving (min)	2002 Travel Time Saving Value
Albert Point Crossing (Suspension Bridge)	5.0 km	35.0 min	$1.24 M
Storm Point Crossing (Suspension Bridge)	15.5 km	28.4 min	$1.01 M
Storm Point Causeway Crossing (Bridge/Causeway)	11.5 km	31.4 min	$1.11 M

The construction of any of these options would likely attract additional traffic, thus increasing the value of annual travel time saving. The current travel distance between Calgary and Nelson, via Golden and Cranbrook is approximately 635 km, with a travel time in the order of 7.7 hours. The route via Revelstoke is approximately 660 km and 8.3 hours, which includes a ferry wait time plus crossing time of 40 minutes. The construction of any of these options would make the travel times comparable via either route.

It is unlikely that there would be significant safety benefits related to any of the crossing options. While there would be savings related to the ferry operation and maintenance costs, there would be costs associated with additional roadway maintenance and with the bridge operation and maintenance. At this time, no detailed assessment of the life-cycle costs has been completed.

3.3.3 Environmental Considerations

Given the scale of this project, there are several environmental factors that may be influenced, changed or significantly impacted by construction and subsequent operation of any of the proposed options. In particular, the causeway is most likely to generate the greatest environmental issues as it creates a physical change in the conditions of the reservoir, affecting aquatic resources and in the potential effects on critical wildlife habitat. Physical change to the structure of the reservoir may affect reservoir dynamics and present its own set of challenges. A multi-disciplinary approach to assessing the effects of development and operation of any crossing will be required to minimize the environmental effects.

3.3.4 Risk

The feasibility assessment of the options is based on reasonable assumptions about the geotechnical conditions of the site, but a geotechnical investigation will be required at an early stage to confirm that the ground will be suitable. It was assumed that rock for the causeway may be found locally. If that is not the case, then the causeway will be significantly more expensive. Large fluctuations in lake levels may cause difficulty in construction. Co-ordination of construction with BC Hydro will be essential and construction of any of these crossings will be a multi-year endeavour, so weather may have a significant effect. The suspension bridges are almost entirely out of the water, and thus would not greatly disturb fish. However, the causeway construction may have significant environmental consequences. Since the causeway constricts the cross-section area of the lake, hydraulic effects must be considered. Local First Nations should be consulted early in the project to address any concerns they may have.

Public safety concerns need to be considered as an operational environmental risk in each of the options. High winds on a long open lake can provide a series of weather conditions that affect the operation and safety of the highway. In particular icing may be a concern during the winter, or wave action during periods of high water in the summer months.

4 Outstanding Issues

As indicated throughout this report, this level of feasibility assessment is preliminary and requires substantially more investigation before proceeding with more detailed planning and design. The need for a geotechnical evaluation has been noted. There will also be a need for environmental and First Nations work early in the process. This section outlines some of these issues.

4.1 First Nations

The Ministry of Transportation will need to consult with affected First Nations and ensure accommodation of their interests in the development of this project. The magnitude of the project would indicate a high level of consultation would be required to create an appropriate risk assessment necessary for an accommodation agreement. Consultation processes would be required with three Nations:

- Secwepemc
- Okanagan
- Ktunax-Kinbasket.

This may mean meeting with individual bands that have territorial interest in the area and site specific information. Early dialogue with First Nations and in particular the development of a corridor/site specific traditional use study will help to mitigate potential impacts. Archaeological assessments will also need to be conducted where surface altering activities may occur. Albert Point and Storm Point options have a high likelihood of affecting archaeological and culturally significant sites.

4.2 Environmental Assessment

Each of the three proposed options involve constructing structures in the Upper Arrow Lake reservoir and as such would require authorizations of Fisheries and Oceans Canada under subsection 35(2) of the *Fisheries Act*. The project would also trigger section 5(1) of the *Navigable Waters Protection Act*. In turn, the approval of a federal authority would trigger a *Canadian Environmental Assessment Act* screening study by virtue of section 43 of the Inclusion List Regulation and possibly sections 46.1 and 47 of the Inclusion List Regulation in the case of the causeway option.

Upper Arrow Lakes is known to be white sturgeon habitat, which is an endangered species, thus potentially triggering a comprehensive assessment. Fisheries and Oceans Canada has indicated that since habitat in this drainage is being already managed for effects of BC Hydro's operation, a cumulative effects assessment would likely also be required.

In addition to the federal process, the project would trigger the *BC Environment Assessment Act* on the basis of a variety of Provincial Acts such as the *Water Act* or

Wildlife Act where both the provincial and federal processes are triggered, the processes often run concurrently under a joint review process.

Under the *Canadian Environmental Assessment Act* (CEAA), a comprehensive study will be required for a project of this magnitude, and the project would likely be jointly reviewed under the BCEAA as well. While the suspension bridge options have a lesser chance of environmental impact, they have significant technical challenges and very high cost. Some of the key environmental studies that will be required as part of a comprehensive study include:

- Approaches to the causeway may disrupt current wildlife migration corridors. Wildlife experts will need to examine the biogeophysical connectivity and identify critical wildlife habitat in the immediate vicinity of the corridor.
- An earth/rock filled causeway can be expected to alter the sediment levels in the lake during the construction phase. The fill source is anticipated to come from either dredged reservoir materials or from locally suitable materials. Dredging would provide a geochemically compatible source material with the reservoir and minimized metallic contamination of the water but would cause sediment to be released through the dredging process. Addition of locally suitable materials would require assessment for any metallic components which may affect fish species.
- Reservoir dynamics will change with the addition of the causeway. Water flow, reservoir levels and debris build-up may be significantly altered by the causeway, and the resulting restricted opening may result in increased flow rates and erosion effects.
- The proposed site is located in a geologically active area, particularly in the vicinity of Shelter Bay. Geothermal resources are present in the area and are indicative of deep set fault patterns. Currently, the area does not appear to be tectonically active.
- The area is designated as Columbia River Basin Wildlife Habitat – Eastern Interior Mixed Forest. A wide range of wildlife can be expected. Currently the area is remote and relatively inaccessible. The causeway or bridge options will significantly improve access resulting in increased pressure on wildlife. An access plan should be developed with public consultation.
- Recreation/visual quality objectives consultation with the tourism industry and in particular local establishments should occur to minimize impacts.
- Public consultation and with other land users to determine cumulative effects. Initially a round table meeting should be held with Government entities to scope out potentially affected groups. Possible participants include:
    - Guiding/backcountry
    - Tourism
    - Industrial/forestry
    - BC Hydro
    - Ministry of Sustainable Resource Management, Ministry of Forests

An assessment of this magnitude would require in the order of one to two years to complete to allow for year-round data collection to establish baseline conditions.

5 Conclusions

Based on this preliminary assessment, it appears that the three fixed crossing options considered are feasible in the vicinity of the existing Upper Arrow Lakes ferry crossing. All are very expensive, although a bridge/causeway option is considerably less expensive than the suspension bridge options. Because of the water depths at the narrowest potential crossing points, suspension bridges would be required with main spans in the order of 2.0 to 2.2 km, making such a bridge among the longest in the world once constructed.

The bridge/causeway option is considerably less expensive. There several uncertainties that still exist and will need to be further investigated, not the least of which are geotechnical conditions, environmental concerns, reservoir hydraulics, and First Nations consultation.

BRITISH COLUMBIA

Appendix A

Arrow Lake Bridge – Feasibility Study
Bridge Causeway Engineering Advice
Final Report

Buckland and Taylor

83002-003

BUCKLAND & TAYLOR LTD.
Bridge Engineering

Ministry of Transportation

Arrow Lakes Bridge - Feasibility Study

Bridge/Causeway Engineering Advice

Final Report

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Executive Summary

Buckland & Taylor Ltd. was retained by British Columbia Ministry of Transportation to perform bridge engineering services and provide bridge concept advice for the Arrow Lakes Bridge Feasibility Study. The study, which is being undertaken by the Ministry, involves conducting a high level feasibility study to examine possible bridge/causeway crossing options for Highway 23 over Upper Arrow Lake near the location of the existing Upper Arrow Lake Ferry (Galena Bay to Shelter Bay) crossing.

This Bridge Concept Advice Report presents the results of an investigation into the feasibility and estimated cost of constructing a bridge/causeway at three possible crossing locations and will be incorporated into the Ministry's Arrow Lakes Bridge Feasibility Study. The report includes discussion about constructability issues and construction risks associated with the three crossings.

It is deemed to be feasible to construct a fixed link for Highway 23 across Upper Arrow Lake at all three crossings considered in this report. The recommended concepts comprise suspension bridges of world record proportions at Storm Point and Albert Point, and a combined bridge and causeway at Storm Point Causeway crossing. The estimated costs for construction of the crossings, including planning level contingency and an allowance for engineering and associated costs, range from $152 million to $504 million, excluding the cost of new and upgraded approach highways, intersections and other roadway work. Despite being the longest crossing, the combined bridge and causeway at Storm Point Causeway crossing is the preferred concept, based on cost.

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1 Introduction

Buckland & Taylor Ltd. was retained on February 12, 2004 by British Columbia Ministry of Transportation (the Ministry) to perform bridge engineering services and provide bridge concept advice for the Arrow Lakes Bridge Feasibility Study. The study involves conducting a high level feasibility study to examine possible bridge/causeway crossing options for Highway 23 over Upper Arrow Lake near the location of the existing Upper Arrow Lake Ferry (Galena Bay to Shelter Bay) crossing. The general site location is shown in detail and in relation to the Province of British Columbia in Figure 1.

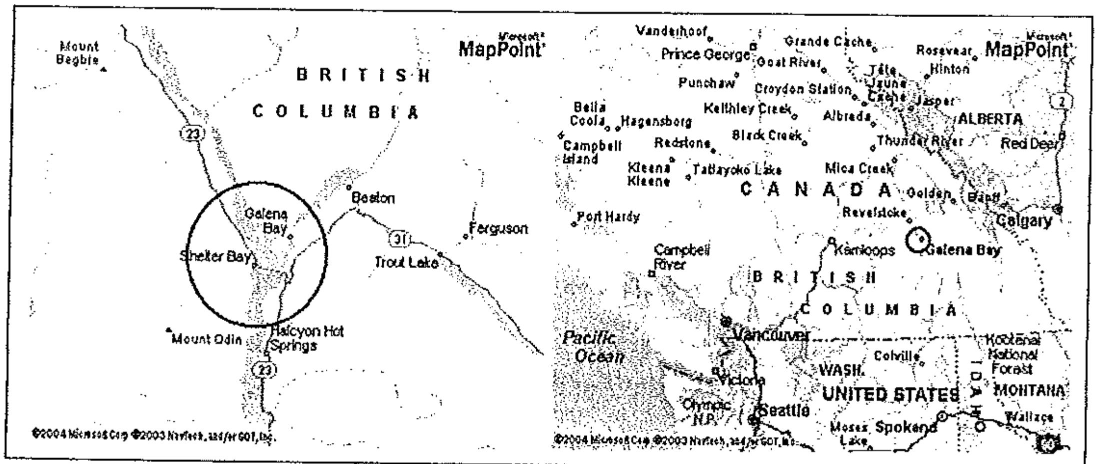


Figure 1: **General Site Location**

The Ministry is undertaking the Arrow Lakes Bridge Feasibility Study, utilizing both in-house and consultant staff, to determine whether there is a feasible alternative to the continuation of the ferry service at the Upper Arrow Lake.

Currently, the Ministry is collecting information and reviewing and updating conceptual highway route options and requires advice related to three bridge/ causeway options in order to develop effective solutions. The Ministry requires advice regarding the following:

- What are the viable bridge/causeway options for the three proposed crossings?
- What are the estimated construction costs for the bridge/causeway options?
- What construction methods would likely be required for the bridge options?
- What are the potential risks associated with the identified bridge options?

- What changes to the highway alignments should be considered in order to make the bridge/causeway construction more cost effective?
- What is the most viable location for the crossing based on the identified options?

This Bridge Concept Advice Report presents the results of our investigation of the three possible crossing locations and will be incorporated into the Arrow Lakes Bridge Feasibility Study, which is being prepared by the Ministry.

1.1 Project Scope

The project scope, outlined hereunder, is extracted from the terms of reference prepared for the feasibility study, that formed the basis of the agreement between the Ministry and Buckland & Taylor Ltd.

i. Conduct a visual inspection of the site.

ii. Review available project information.

iii. Liaise and exchange information with Ministry staff.

iv. Identify, investigate and make recommendations for conceptual bridge/ causeway options for three proposed crossing locations.

v. Complete planning level (ball park) cost estimates for the identified bridge/ causeway options.

vi. Prepare a Bridge Concept Advice Report that includes:

- planning level cost estimates and concept sketches for the recommended bridge/causeway options.
- a brief commentary on any bridge constructibility issues associated with each option.
- identification and management of construction risks associated with each option.
- recommendations with regard to the preferred crossing location.

The Ministry will provide the input for highway engineering, geotechnical engineering, environmental engineering and field survey (if required), concurrently with the bridge engineering.

1.2 Site Visit

A site visit including staff of the Ministry and Buckland & Taylor Ltd., was conducted on the morning of February 16, 2004. The site visit comprised the following activities:

- Introduction of team members.
- Site aerial (helicopter) reconnaissance by various team members to visually survey identified and potential crossing locations, during which the locations were extensively photographed.
- The two proposed cable ferry crossing sites, Storm Point and Albert Point, were visually surveyed for potential for a bridge crossing.
- A third potential bridge/causeway crossing location was identified and visually surveyed. This crossing was located north of the proposed Storm Point cable ferry crossing on a similar alignment to that proposed by the Arrow Lakes Transportation Infrastructure Association.
- Existing project information was exchanged and reviewed. Additional information required to complete the assignment, was identified.

Site Meeting Minutes prepared by the Ministry are included in Appendix A of this report.

1.3 Information Received

The following information was received from the Ministry:

- Terms of Reference including Bridge Design Criteria.
- Conceptual Estimate (cable ferry options) – Upper Arrow Lake Ferry, Storm Point Route, Albert Point Route; by Ernest Wolski dated May 14, 2001. Included within the cable ferry estimate package is (i) the approximate horizontal alignment for the two crossings; (ii) an 11x17 photocopy from Chart #3057, Burton to Arrowhead, Canadian Hydrographic Service, giving lake depth information at the site (the full chart was later received from the Ministry as well as field sheet data for the chart, in digital format); and (iii) ALTIA Connecting with the rest of British Columbia – Proposal Information Brochure; Arrow Lakes Transportation Infrastructure Association.
- 1:50,000 topographical maps: (i) BEATON 82 K/12 Edition 2 and (ii) CAMBOURNE 82 K/13 Edition 2, both "current as of 1977".
- 1: 20,000 topographical map – GALENA BAY – and digital file of the same.

- Several aerial photos of the Shelter Bay area.
- Traffic count data: TMPs 34-014N & S, 38-003N & S.

In addition, the Ministry asked Buckland & Taylor Ltd. to use relevant bridge design criteria from another concurrent project (Conceptual design and cost estimate for crossing of Lower Arrow Lake at the Needles-Fauquier location), to supplement missing data from the supplied Bridge Design Criteria (e.g. navigational envelope, ice impact load).

1.4 Additional Information Required

At the site visit, the Ministry team agreed that only minimal information was available for this site. In addition to the information supplied at the start of the assignment, the following was requested from the Ministry in order to complete the study:

- Geotechnical conditions at the site.
- More detailed contour mapping and/or depth sounding data for the bottom of the lake at the proposed crossing locations.
- Clarification of the location of the third proposed crossing alignment, identified during the site visit.
- Investigation of environmental issues relating to the three proposed crossing locations.
- Investigation of First Nations issues and concerns relating to the three proposed crossing locations.

The Ministry subsequently provided detailed lake depth data, some geotechnical information and fixed the third crossing alignment in response to this request.

1.5 Upper Arrow Lake Surface Levels

Upper Arrow Lake forms part of the Arrow Lakes Reservoir, a 230 km long reservoir which impounds the original Arrow Lakes and Columbia River behind the Hugh Keenleyside Dam, situated 12 km upstream from Castlegar. This dam was the second of three Columbia River Treaty dams to be built by BC Hydro and was completed in 1968. The treaty allowed construction of dams to regulate the flow of the Columbia River and end the annual threat of flood damage in BC, Washington and Oregon, among other benefits.

The result of reservoir operations downstream is that Arrow Lake water levels are constantly changing and can fluctuate by up to 30 cm in a 24-hour period (ref. BC Hydro) and by approximately 20 m annually. A summary table of Arrow Reservoir Levels (1969-2003 at Fauquier, Nakusp) included in the cable ferry cost estimate package confirms the high fluctuation, giving maximum/minimum levels of approximately 441.0/420.0 m, a fluctuation of 21.0 m over the record period. These levels are assumed to be reduced to geodetic datum (GD).

The above high fluctuation in water levels effectively prohibits the selection of a floating bridge of similar form to the Okanagan Lake Bridge to span Arrow Lake, for the following reasons:

- transition spans at each end of the bridge would be excessively long, having to span approximately 167 m (based on an elevation change of +/-10 m from mean elevation and a maximum road gradient of 6%).
- submerged anchorages along the floating bridge would be very complicated, having to be designed to restrain the bridge laterally but not vertically.

In accordance with the navigational envelope requirements given in the Needles-Fauquier Bridge Criteria, this study assumes a clearance of 18.5 m over the middle 60 m width of the envelope above elevation 441.0 m, for all fixed crossing structures. This fixes the minimum navigational clearance elevation at 459.5 m. For all three alignment options, the most favorable vertical profile is the lowest possible while respecting the navigational clearance requirement.

1.6 Geotechnical Information

The following comments, observations and description of the general geotechnical conditions in the project area, were supplied by the Ministry.

Prior to the flooding of the Arrow Lakes by the Hugh Keenlyside Dam in the late 1960's / early 1970's, the valley where the project area is located had an existing lake. The high water level for the lake was approximately 430 m elevation and the average annual variation of the lake level was around 10 m. Since the reservoir was put into operation, the typical high water elevation is around 440 m, which means the lake level has been raised by 10 - 12 m.

The original lake was formed around the last glaciation period, similar to nearby Okanagan Lake. Recent subsurface investigations at Okanagan Lake for the new floating bridge project has revealed that thick, very soft silts and clays are present along the lake bottom. Since the deposition mechanisms are similar at Okanagan and the Arrow Lakes, it can be assumed that any terrain below elevation 430 m will have thick layers of soft silts and clays, especially in areas that are identified as relatively flat. It should also be noted that the original glacial lake that formed as the glaciers were receding had a higher lake elevation then the pre-reservoir Arrow Lake elevation of the 1960's. Therefore, there is also a high probability that soft silts and clays exist above the 430 m elevation and even above the present reservoir high water elevation. These silts and clays are likely to be buried under colluvial and alluvial material that was deposited as the glaciers receded, making them difficult to identify from surface visual observations. However, some silt and clay deposits have been exposed during wave erosion and beach regression in areas south of Nakusp.

Since the reservoir has been in operation, numerous slope stability problems have occurred, mostly along Highway 6 between Nakusp and Fauquier. It appears that the primary cause of the failures is the rise and fall of the reservoir level. When the reservoir level is increased, the pore pressure within the soils increases to the point that the shear strength of the soils effectively drops to zero. Below the old lake level of 430 m elevation most slopes have stabilized to angles that are appropriate for the pore pressure fluctuation. Many slopes above the 430 m elevation however are at an angle that is too steep to be stable when the pore pressure increases, resulting in movement of the slopes. The same problem occurs when the reservoir is drawn down suddenly.

Bedrock in the project area generally consists of slates, gneisses and recent granite intrusions. Overall, the rock is considered to be relatively intact and sound. Very little rockfall or rock slides have been recorded in the recent past.

2 Bridge Span Requirements

The three proposed bridge crossing alignments are shown in Figure 2 along with the approximate alignment extensions at each crossing approach. The third crossing, identified during the site visit, is labelled Storm Point Causeway crossing.

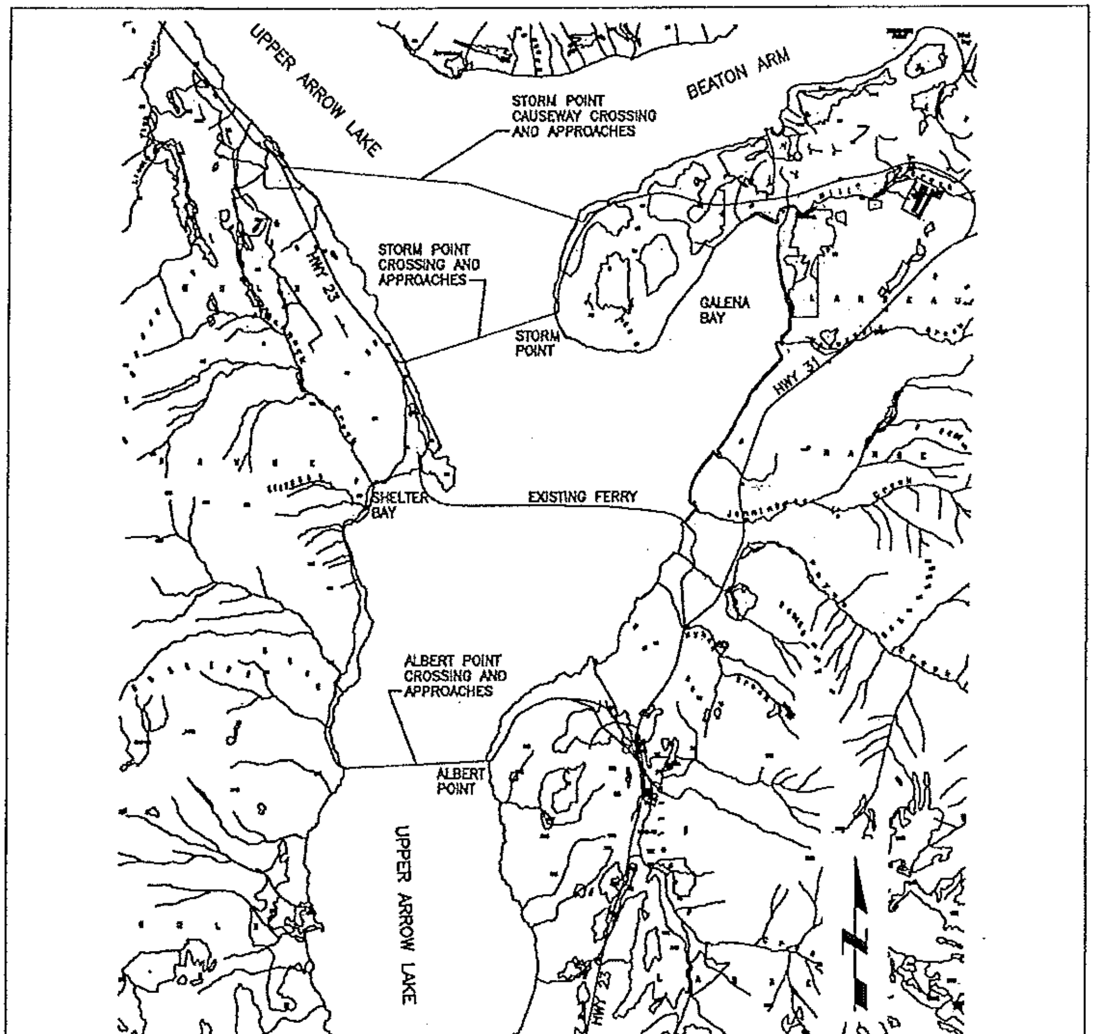


Figure 2: Proposed Bridge/Causeway Crossing Alignments

Previous selection of the Albert Point and Storm Point bridge crossing locations was based on cable ferry criteria – i.e. the shortest, straight/visible route across the lake with minimum new highway construction at the approaches to connect the ferry ramps to Highway 23. As such, these two crossings are not necessarily suitable for locating a bridge/causeway, but they have been retained in the scope of work at the request of the Ministry.

The Storm Point Causeway crossing is situated north of the proposed Storm Point bridge crossing and was selected to satisfy bridge/causeway construction criteria.

As described in Section 1.5, deck elevation is required to be above 459.5 m within the navigational channel for all three crossing locations to satisfy navigational requirements.

Section 1.6 describes the general geotechnical conditions in the project area, however it is presently unknown whether favorable founding conditions for bridge/causeway construction, will be found at the specific crossing locations. Historically, river valleys in BC that were formed through past glacial activity typically exhibit competent rock along the sides, and since steep rocky outcrops were observed along the eastern shore of the lake in the vicinity of all three crossing locations, we anticipate favorable founding conditions along the shores of the lake. An example of the surface rock observed at the site is shown in Figure 3.

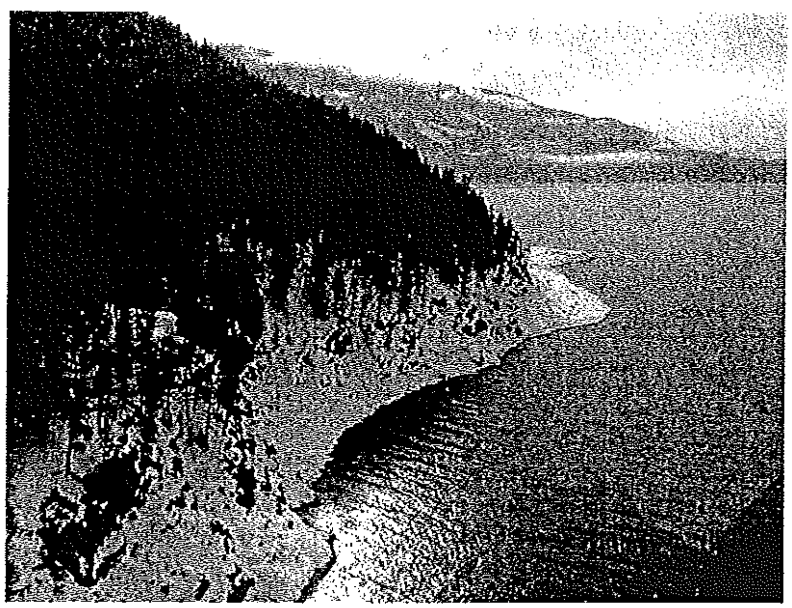


Figure 3: Surface Rock Visible on Eastern Shore of the Lake

For the purposes of this study, it is assumed that good quality bedrock exists within reasonable depth for piled foundations at all proposed bridge locations and that the lake bed materials are suitable for supporting a causeway.

Notwithstanding the recommendations of this report, a thorough geotechnical investigation will have to be undertaken to confirm these assumptions, if the bridge/causeway concept is carried beyond this initial study phase.

2.1 Albert Point Crossing

Albert Point crossing is located just over 4 km south of the existing Ferry route and is oriented in an east-west direction across the lake. The approximate crossing alignment is shown in Figure 4.

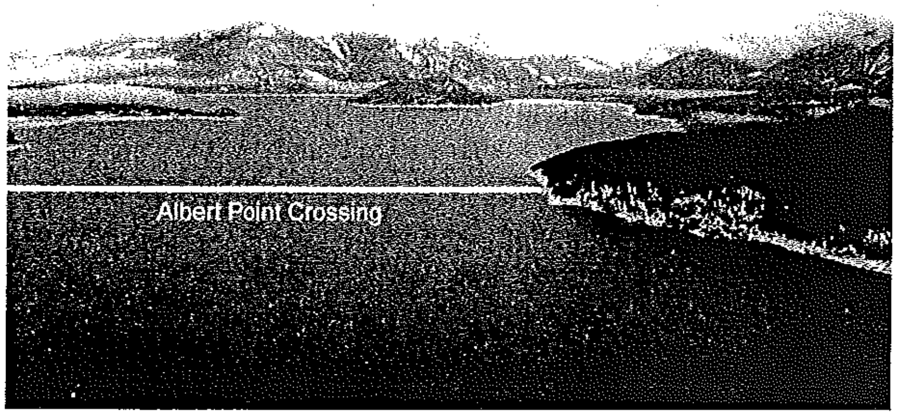


Figure 4: Proposed Albert Point Crossing

Highway 23 is located some considerable distance from this crossing, requiring lengthy approaches on each side. The west approach comprises approximately 8.2 km of new/upgraded highway to connect to Highway 23, mostly following the route of existing forestry roads. The east approach comprises approximately 4.0 km of new/upgraded highway and includes some existing forestry road.

The lake is approximately 2.4 km wide at this location. From Chart #3057 of the Canadian Hydrographic Service, the lake is more than 200 m deep over most of this width reaching a maximum depth of approximately 230 m below HWL. Depth is gained rapidly from either shore, exceeding 50 m within about 100 m of the shoreline.

For reasons given in Section 1.5, selection of a floating bridge to span this deep and wide crossing is impractical due to high fluctuations in water level. In addition, because the lake is so consistently deep, construction of intermediate bridge supports in the lake cannot be practically considered – foundations would typically not be constructed in water exceeding about 60-70 m in depth.

Assuming suitable founding material exists at the site, the only feasible bridge type for this crossing location is a suspension bridge of world record proportions, with a main span of about 2200 m, just over 200 m longer than the longest suspended span presently in service. The two pylons are located at maximum economic depth within the shallower water at the edges of the lake in order to shorten the required main span length to a minimum. Locating them within the lake requires that they be designed to withstand ice and vessel impact forces, favoring shorter submerged foundations. Alternatively, independent dolphins could be constructed to protect the pylons.

The following Table 1 gives a summary of the longest suspension bridges in service in the world to offer a perspective of the scale and magnitude of the proposed bridge. Longer suspension bridges with main spans of up to 3200 m are currently being designed – e.g. across the Strait of Messina connecting Italy to Sicily. Many examples of shorter 2-lane suspension bridges crossing very deep water can be found in the Norwegian fjords.

Table 1: Suspension Bridge Inventory

Bridge	Year	Span (meters)	Country	Pylon Material	Girder Material
Akashi Kaikyo	1998	1991 m*	Japan	Steel	Steel
Great East Belt	1997	1624 m	Denmark	Concrete	Steel
Humber	1981	1410 m	England	Concrete	Steel
Jiangyin	1999	1385 m	China	(un-confirmed)	Steel
Tsing Ma	1998	1377 m	Hong Kong	Steel	Steel
Verrazano Narrows	1964	1298 m	USA	Steel	Steel
Golden Gate	1937	1280 m	USA	Steel	Steel
Hoga Kusten	1998	1210 m	Sweden	Concrete	Steel
Mackinac Straits	1957	1158 m	USA	Steel	Steel
Minami Bisan-Seto	1988	1100 m	Japan	Steel	Steel

*Due to a shift of 1 metre in the position of a pylon following the Kobe earthquake, the actual as-constructed span of 1991 metres exceeds the design span of 1990 metres.

A conceptual bridge plan, elevation and details are shown on Drawing nos. 1685-001, 002 of Appendix B. The bridge does not require significant side spans since the approaches are almost oriented at 90 degrees to the bridge alignment. It is proposed to construct side spans using traditional shorter span bridge forms, which will be beneficial to the design of the pylons and in reducing cable and hanger costs in the main bridge. An added benefit is that the side spans do not have to follow the straight alignment of the main bridge and can be curved to suit road geometry from just past the pylons. It should be possible to anchor the main cables into competent rock sockets at each end of the bridge without requiring costly massive concrete anchorages.

The narrow width of girder required for this 2-lane bridge requires special consideration. The girder will be very light compared to a typical long span suspension bridge resulting in beneficial savings in suspension cable, hanger and pylon costs. However, because of the length of the bridge, the girder will be laterally flexible and unstable when subjected to wind forces if no additional restraint is provided. For this reason, additional wind cables are provided on either side of the bridge at girder level to resist these lateral forces and simplify deck design. Wind cables are unusual for road crossings since bridge width is usually sufficient to resist lateral effects and spans are shorter, but they are more common in long and narrow pipe and pedestrian crossings.

The curved vertical profile of the bridge has its high point at midspan, satisfying navigational clearance requirements. The ends of the bridge are provided with 3 m freeboard above HWL to permit long-term bridge inspection and maintenance. The ends of the bridge are kept as low as possible to generally tie into the approaches prepared for the cable ferry cost estimate. Nevertheless, the approach road geometry will probably require local revision to suit the proposed bridge.

2.2 Storm Point Crossing

Storm Point crossing is located about 2.5 km north of the existing Ferry route and is oriented in a WSW direction across the lake from Storm Point on the eastern bank. The approximate crossing alignment is shown in Figure 5.

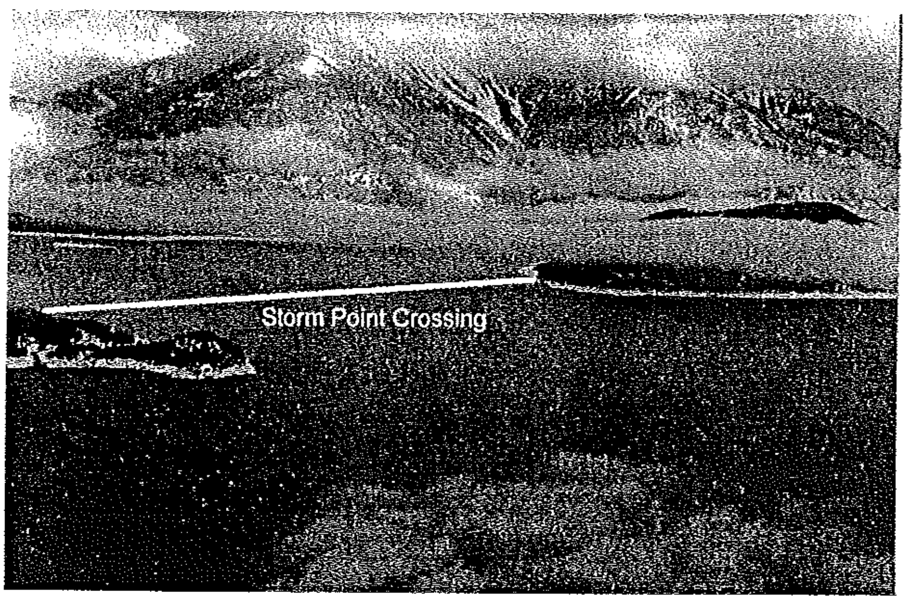


Figure 5: Proposed Storm Point Crossing

Highway 23 is near to the crossing at the west end, being about 130 m from shore and at approximate elevation 465 m at the nearest point (i.e. 24-45 m above the lake). The cable ferry cost estimate proposed 1.1 km of new highway on the west approach to connect the proposed cable ferry ramp to Highway 23, allowing for sufficient vehicle rest area and gradient change. The east approach comprises approximately 10.3 km of new highway from Storm Point through Hill Creek to Highway 31 and approximately 8.8 km of upgrade for Highway 31 to the present intersection with Highway 23.

The lake is approximately 2.6 km wide at this location. From Chart #3057, the lake is shallower than at the Albert Point crossing, but is still relatively deep, at about 100 m below HWL over 60% of the width (1500 m). The lake is shallower than 50 m for a distance of about 500 m and 100 m from shore on the western and eastern sides respectively.

For similar reasons to the Albert Point crossing, the only feasible bridge type for this crossing location is a suspension bridge with a main span of about 2000 m. The two pylons are located at maximum economic depth within the shallower water at the edges of the lake in order to shorten the required main span length to a minimum. A conceptual bridge plan, elevation and details are shown on Drawing nos. 1685-003, 004 of Appendix B.

Most of the features of the proposed Albert Point crossing suspension bridge apply equally to the bridge at this crossing. The vertical profile of the bridge is raised at the west end to tie into the existing Highway 23 alignment at approximate elevation 466.0 m thereby eliminating the proposed cable ferry approach. The east end of the bridge is provided with 3 m freeboard above HWL to permit long term bridge inspection and maintenance and to generally tie into the approach prepared for the cable ferry cost estimate. If this option is developed, the approach geometry will probably require local revision by the highway designers to suit the proposed bridge. The navigational channel is located west of midspan to suit the bridge profile.

2.3 Storm Point Causeway Crossing

Storm Point Causeway crossing is located about 2.5 km north of Storm Point and just over 5 km north of the existing Ferry route. The crossing is oriented in a WNW direction across the lake from the eastern bank. The approximate crossing location is shown in Figure 6.

Highway 23 is near to the crossing at the west end, being about 150 m from shore and at approximate elevation 500 m (i.e. 59-79 m above the lake) at the nearest point. Assuming a constant elevation for the top of the causeway of 442.0 m (i.e. HWL + 1m freeboard), a west approach of about 1.4 km will be needed to join the causeway to Highway 23. The length of approach road could be reduced by raising the west end of the causeway for some distance into the

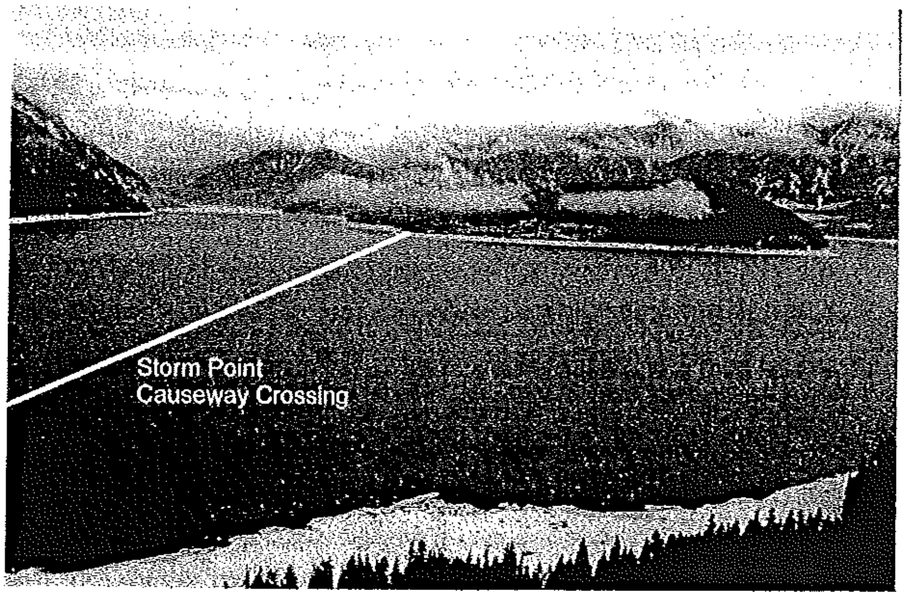


Figure 6: Proposed Storm Point Causeway Crossing

lake, if economically justified in comparison to the cost of approach road. The east approach is similar to that proposed for Storm Point crossing, but shorter by about 2 km because of the more northerly location of the crossing.

The crossing traverses about 5 km of water, making it significantly longer than the other two alignments. The slightly curved alignment has been optimally chosen to maximize shallow water while maintaining a reasonably direct route across the lake. From Chart #3057 the lake is approximately 12.0 – 17.0 m deep relative to HWL over the western half of the crossing and 17.0 - 22.0 m deep relative to HWL over the eastern half of the crossing. At the site visit, the shallow water of this crossing was generally identified during the aerial survey by lighter water color and localized darker (deeper) channels. An example of the shallow water and channels is shown in Figure 7.

The proposed Storm Point Causeway crossing comprises a rock filled causeway over most of its length with an 810 m long bridge centered near the midpoint of the crossing to span over the navigation channel. A conceptual plan, elevation and details are shown on Drawing nos. 1685-005, 006 of Appendix B. The height of causeway varies as a function of lake depth and is approximately 13 m to 18 m over the western half of the crossing and 18 m to 23 m over the eastern half, to maintain a freeboard of 1 m above HWL. Some wind and wave analysis was completed by Thurber Engineering in the mid 1970's. Results of this analysis indicated that wind induced wave action could potentially reach maximum wave

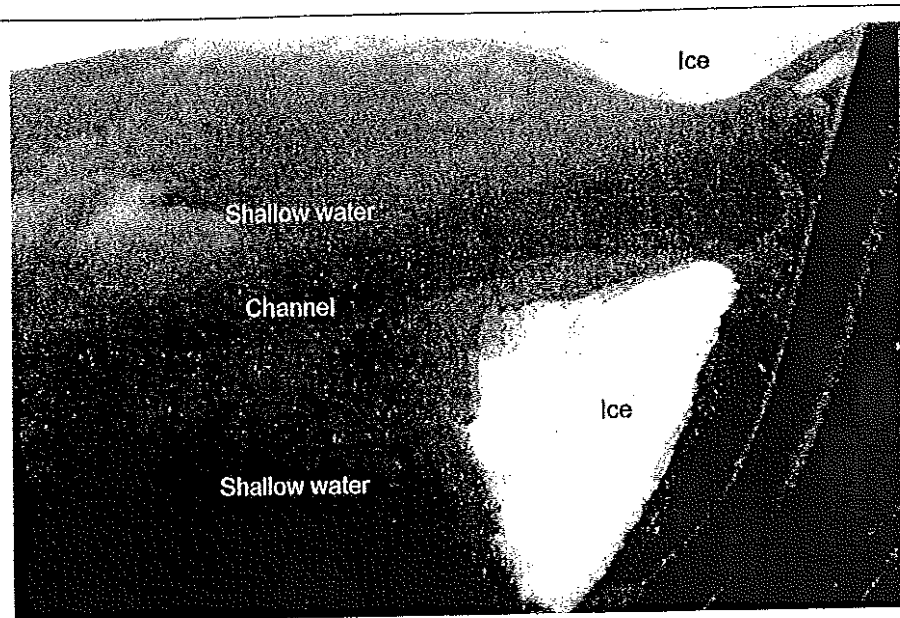


Figure 7: Shallow Water and Channel at Causeway Crossing Location

heights of 1.8 m with winds of up to 60 km/hr. A freeboard of 1m above HWL has been chosen for this study while recognizing the low potential risk of overtopping and consequential closure of the causeway in extreme weather conditions coincident with HWL. Side slopes of 1:2 are assumed for the causeway, based on recommendations from the Ministry's geotechnical engineer. The bridge comprises a multi-span variable depth continuous girder supported on reinforced concrete substructure and piled foundations. The superstructure comprises twin steel plate girders supporting a composite concrete deck. The bridge is long enough to raise the alignment profile by approximately 23 m over the navigation channel, with 6% maximum approach gradients on each side. This bridge solution is known to be cost-effective and easily constructed, based on recent design/build experience at Jemseg River Bridge in New Brunswick.

If the bridge/causeway concept is carried beyond this initial study phase, possible cost saving options should be given serious consideration. These could include lengthening the causeway and shortening the bridge to suit a smaller and consequently lower navigation channel, and investigating the most cost-effective type of causeway construction. In addition, if causeway construction is deemed to be environmentally unacceptable or if expensive pre-treatment of the lake bed is required to support the causeway, then further consideration should be given to a low-level bridge solution as an alternative to the causeway.

3 Erection Methods

3.1 Albert Point Crossing and Storm Point Crossing

The concept for constructing/erecting a suspension bridge at one of these two crossings generally comprises the following:

- Installation of steel pipe piles socketed into rock as foundations for the pylons, using barge mounted equipment.
- Pilecap construction for the pylons by fabricating precast concrete shells, floating them into position and supporting them on spud piles while concreting the interior. The precast shells are a favorable method of avoiding environmental contamination during pilecap concreting and could be positioned before piling to serve as templates for installing the permanent piles.
- Construction of the concrete pylons using slipforming or jumpforming (climbing form) techniques, and pylon crossbeams.
- Construction of suitable anchorages to transfer the suspension cable and wind cable forces to the rock.
- Erection of prefabricated suspension cables and hangers. The bridge is considered "small" enough in terms of suspended weight not to warrant aerial spinning of the suspension cables although this may be the preferred option to eliminate transporting prefabricated cables to site. Parallel strand suspension cables with open construction could be considered to simplify the erection process.
- Erection of deck components by floating them into position and hoisting from a barge; deck components to be pre-fabricated off-site, shipped to site by rail/road and transferred to the barge at the existing ferry ramps.
- Installation of wind cables (during deck erection) and remaining bridge components.
- Completion of side spans using conventional bridge construction techniques.

Concrete pylons are proposed on the assumption that a site batching facility will be established for casting the pilecaps and other concrete components (e.g. side spans). The pylons could equally be constructed from steel.

The erection methods described above have all been historically well tried and proven and should be readily accomplished by a suitable long span bridge contractor.

3.2 Storm Point Causeway Crossing

The concept for constructing/erecting a bridge/causeway at this crossing generally comprises the following:

- Construction of the causeway from each end of the crossing. Construction could possibly be simplified and the founding conditions improved if this activity is timed to coincide with the "dry" window when the lake level is at its lowest and much of the lake bed along the causeway alignment is reputed to be exposed. Alternatively, this construction could take place during the "wet" window.
- Installation of steel pipe piles as foundations for the bridge substructure, using barge mounted equipment or land-based equipment, depending on lake level.
- Pilecap and substructure construction for the bridge. Depending on lake level, pilecaps could be constructed in the dry or within cofferdams or by using a similar technique to that proposed for the suspension bridges.
- Erection of the bridge deck girders and bracing, concrete deck slabs and remaining bridge components by conventional bridge construction techniques using floating equipment.
- Local completion of the causeway at the bridge abutments.

Bridge construction could take place independently of causeway construction but it may be beneficial to have the causeway mostly in place first to provide better access to the bridge site.

4 Constructibility Issues

Factors affecting constructibility include the following:

- Access. The site is generally perceived to benefit from ready access for materials and equipment via rail and road (e.g. Hwy 23 from Revelstoke) and by barge (e.g. from Nakusp in the south). However, local access to the ends of the crossings and construction of anchorages for the suspension bridge cables could be difficult in the rugged terrain, particularly on the eastern shore. Some relief could be obtained by delaying construction of the crossings until the approach roads have been established, thereby improving local site access. Construction of the Storm Point Causeway bridge should also follow behind causeway construction for improved access to the bridge site.

- Materials and equipment. It is anticipated that these will largely be obtained through Revelstoke and that Hwy 23 can be used for delivery without undue disruption to the public. It is also assumed that suitable material for causeway construction can be cost-effectively sourced within reasonable proximity of the site. An alternative possible source of materials and equipment is further south on the lake at Nakusp. Construction of the suspension bridge crossings will require suitable barges and barge mounted equipment that will probably have to be acquired from elsewhere for the contract. The Storm Point Causeway bridge could require a variety of equipment types to suit construction timing in relation to lake surface levels.

- Geotechnical considerations. The proposed suspension bridge concept relies on satisfactory rock existing more or less at the required founding depth and cable anchor locations. Furthermore, rock consistency should be suitable for socketing of the piles and cable anchors. Following detailed geotechnical investigation, suspension bridge geometry or location may have to be adjusted, to suit. The Storm Point Causeway bridge is founded on piles that could be end-bearing or friction type to suit founding conditions in the middle of the lake. The lake bed may require local densification in preparation for causeway construction to minimize future settlements.

- High fluctuation in lake surface level. Foundation construction within the lake and at the shoreline will be affected by large fluctuations in lake surface level. Relevant construction activities should be timed to coincide with the low-water "window", if at all possible.

- Weather and the prevailing elements. Construction of a crossing of this magnitude is likely to span a number of years and could be affected by cold weather, snow and ice developing on the lake, etc.

5 Construction Risks

The following describes some of the main risks to bridge/causeway construction at these three locations and proposals for their management:

- Geotechnical. At present there is insufficient test data available to confirm the viability of constructing a bridge at Storm Point or Albert Point and a bridge/causeway at Storm Point Causeway crossing. In addition, causeway viability is dependent on suitable fill material being found in reasonable proximity to the site and alluvial deposits on the lake bed being able to support the causeway without excessive settlement potential. An appropriate level of geotechnical investigation must be carried out from an early planning stage through final design to mitigate this risk.

- Fluctuating lake levels. It is understood that lake level predictions can be made with reasonable confidence based on historical data, but there will be no way to control lake levels during construction. Nevertheless, every effort should be made to plan appropriate construction activities in conjunction with BC Hydro in order to benefit from the seasonal changes in lake level and reduce the risk of unanticipated changes in water level.

- Environmental. Appropriate environmental planning and due-diligence throughout all stages of the planning process will mitigate this risk. A long span suspension bridge has the advantage of being "environmentally friendly" since construction is mainly above water. By its very nature, the Storm Point Causeway crossing does not have such an advantage and may cause greater concern to environmentalists. Wherever possible, construction techniques such as that described for the pylon pilecaps, should be employed to reduce the environmental risk.

- Hydraulic impact. The hydraulic impact of constructing a causeway across the lake at Storm Point Causeway crossing will have to be carefully investigated, as well as the potential for consequential scour at the bridge opening.

- First Nation Issues. Early consultation and dialogue with First Nations will provide a better understanding of the magnitude of this risk.

In addition, there may be some construction risk from the weather and prevailing elements, which could be minimized by appropriate scheduling and planning.

6 Costs and Quantities

Section 2.1 contains a summary of the ten longest suspension bridges in the world, as measured by main span length. The data base that can be drawn upon for establishing costs for the construction of a major suspension bridge at Albert Point and Storm Point is obviously quite limited as all of the listed bridges have shorter spans than the bridges envisaged in this study. Another consideration in cost estimating is the applicability of known historical costs to the Canadian and British Columbia economy owing to such factors as currency exchanges, differences in labor rates, differences in material costs, variations in labor productivity and practices and differences in design requirements and philosophies in particular countries. Consequently, the estimated costs for the proposed suspension bridges at Albert Point and Storm Point shown in this report cannot be considered to have a high degree of certainty. The only certainty is that the bridges will be very expensive.

Cost estimating of approach spans at Storm Point and Albert Point is done rudimentarily on a square meter of bridge deck basis since the construction of such bridges is quite common and an extensive data base exists to allow reasonable confidence in the accuracy of the results. An additional consideration in using this estimating method is that the approaches form a small percentage of the overall cost of bridge construction at these two crossings.

Cost estimating of the Storm Point Causeway crossing is based on measured quantities of major construction items.

6.1 Estimated Cost Summary

Appendix C contains a summary of planning level estimated costs for bridge/ causeway construction at the three proposed crossing locations. The summary clearly indicates that a combined bridge and causeway located at Storm Point Causeway crossing is far less costly than a bridge crossing at Albert Point or Storm Point.

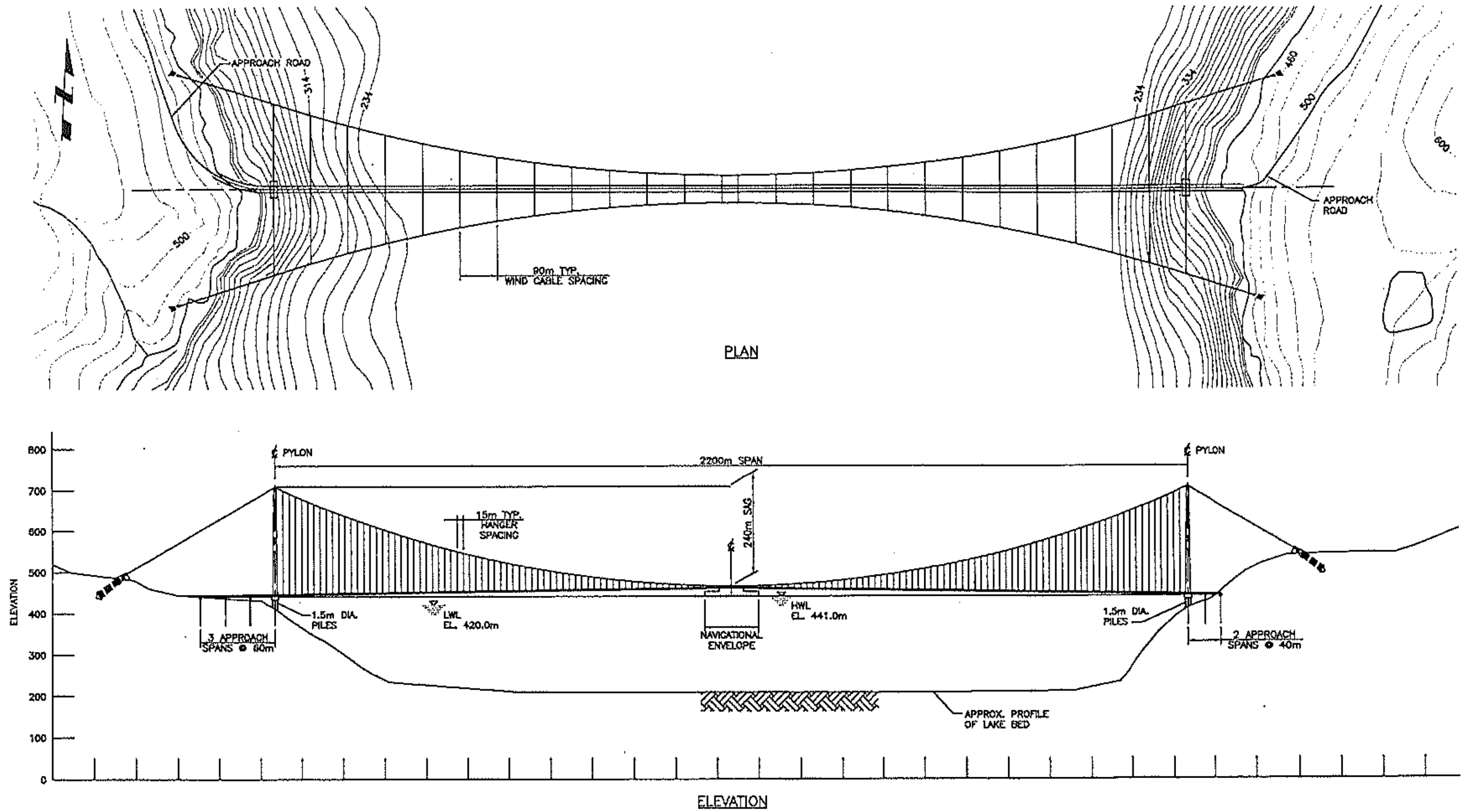
The summarized costs include separate subtotals for the construction capital costs of the bridges and causeway. A planning level contingency allowance of 25% has been applied to construction costs to allow for unknowns. Engineering, project management, administration and quality assurance costs, including those of the Ministry, are added separately as an additional 20% contingency. Engineering costs are likely to include wind tunnel (aerodynamic) investigations for the suspension bridge options, detailed geotechnical studies, development of design criteria documents, preliminary designs and the like.

7 Recommendations

It is feasible for Highway 23 to cross Upper Arrow Lake at all three proposed bridge/causeway locations that form the basis of this study, near the existing Upper Arrow Lake Ferry (Galena Bay to Shelter Bay) crossing. Of the three options, a clear preference has emerged for a combined bridge and causeway located at Storm Point Causeway crossing, based on cost, even though this is the longest crossing. The other two crossings require suspension bridges of world record proportions to span the very deep waters of the lake.

Due to lack of additional information, this study has not included the influence of additional factors on the crossings, such as geotechnical, environmental and First Nations issues, but it is highly unlikely that the very high cost differential between the preferred option and its competitors will be significantly influenced by including these factors.

A budget of $152 million in Canadian dollars is suggested for the bridge/causeway component of this crossing. The amount includes a planning level contingency and an allowance for engineering, project management, administration and quality assurance costs, but excludes the cost of new and upgraded approach highways, intersections and other roadway work, which must be added to this budget.



ORIGINAL SCALE IN mm FOR REDUCED PLANS

REV	DESCRIPTION	DR.	APP.	DATE
A	ISSUED FOR FEASIBILITY STUDY	KKC	ILW	04-03-24

Province of British Columbia
MINISTRY OF TRANSPORTATION

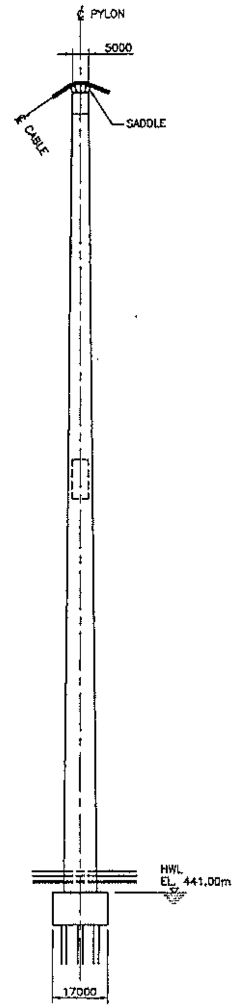
PROJECT: ARROW LAKES BRIDGE – FEASIBILTY STUDY

TITLE: ALBERT POINT CROSSING
BRIDGE LAYOUT

BUCKLAND & TAYLOR LTD.
Bridge Engineering

DESIGN	ILW	CHECKED	DOM
DRAWN	KKC	APPROVED	PRT
SCALE	1:5000	DATE	2004 MAR 09
DRAWING No.	1685-001	REV.	A

File: 1685-001.dwg Date/Time: March 09, 2004 11:45 a.m. Scale: 1=5 pc29 Xrefs:



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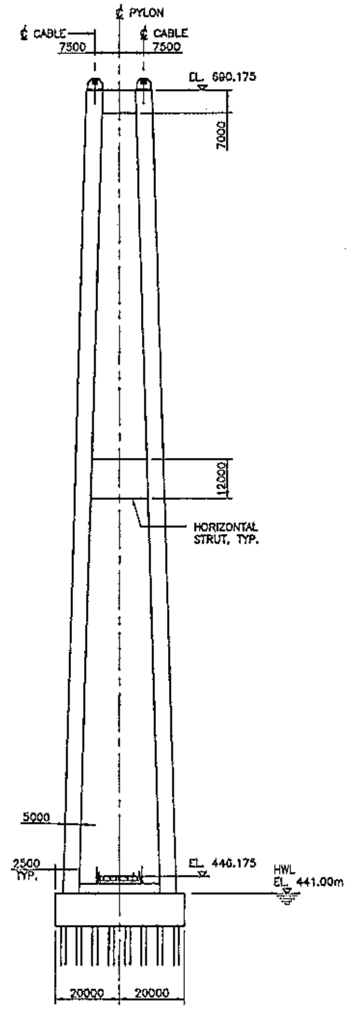
(TRANSVERSE)
1:750 000



ELEVATION
(LONGITUDINAL)
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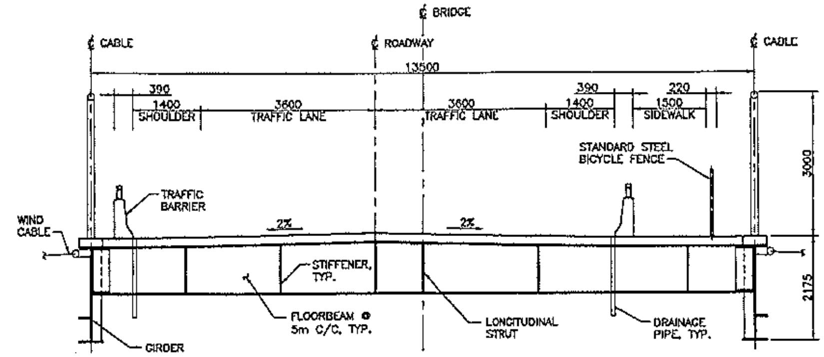

TYPICAL BRIDGE DECK SECTION
1:50 000

A	ISSUED FOR FEASIBILITY STUDY	KKC	ILW	04-03-24

Province of British Columbia
MINISTRY OF TRANSPORTATION

ARROW LAKES BRIDGE – FEASIBILTY STUDY

ALBERT POINT CROSSING DETAILS

BUCKLAND & TAYLOR LTD.
Bridge Engineering

DESIGN	ILW	CHECKED	DOM
DRAWN	KKC	APPROVED	PRT
SCALE	AS SHOWN	DATE	2004 MAR 09
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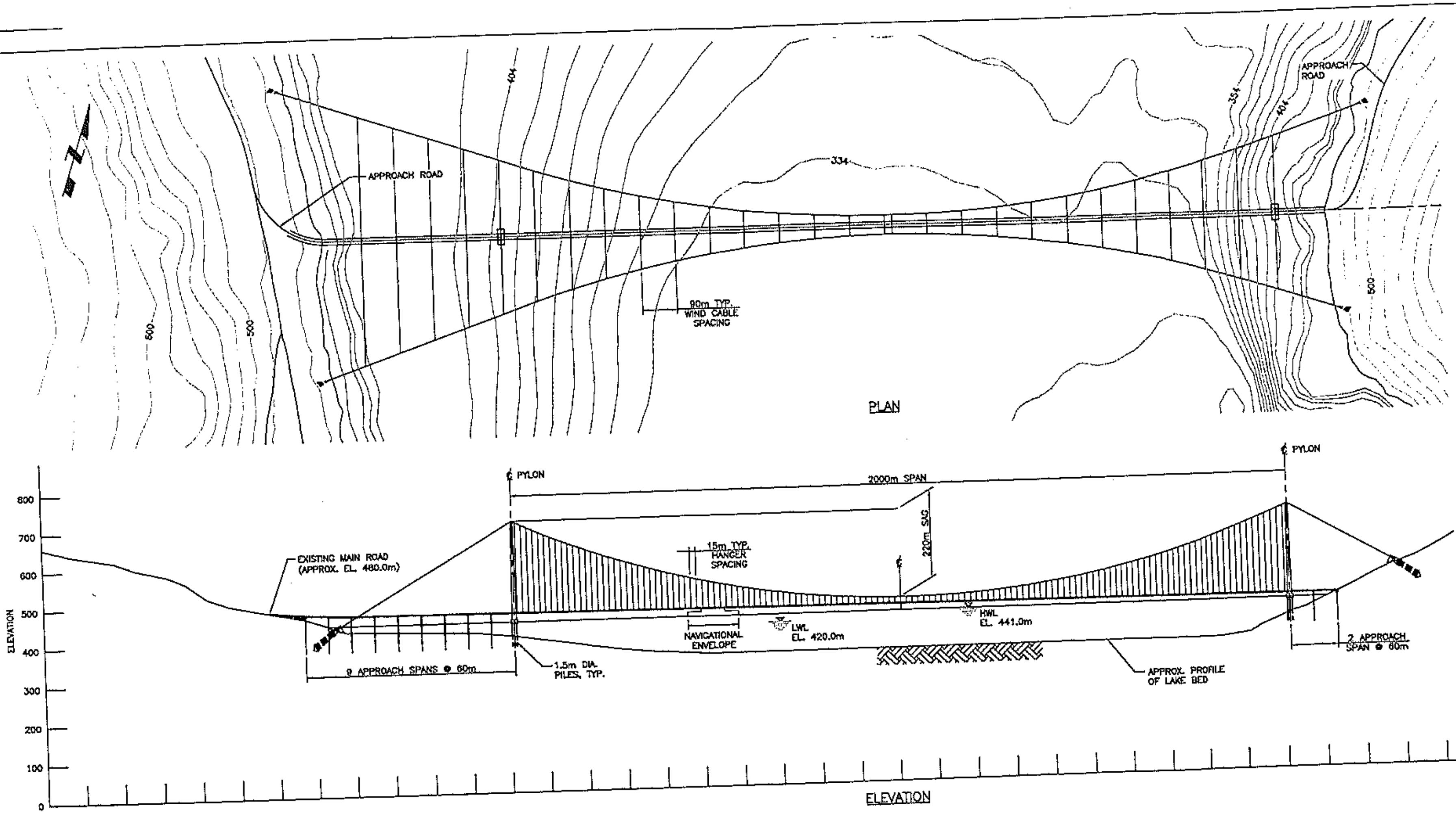

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ORIGINAL SCALE IN mm FOR REDUCED PLANS

REV	DESCRIPTION	DR.	APP.	DATE
A	ISSUED FOR FEASIBILITY STUDY	KKC	ILW	04-03-24

Province of British Columbia
MINISTRY OF TRANSPORTATION

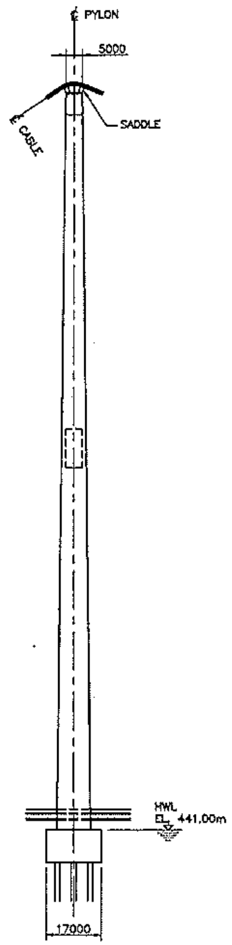
ARROW LAKES BRIDGE – FEASIBILTY STUDY

STORM POINT CROSSING
BRIDGE LAYOUT

BUCKLAND & TAYLOR LTD.
Bridge Engineering

DESIGN ILW	CHECKED DDM
DRAWN KKC	APPROVED PRT
SCALE 1:5000	DATE 2004 MAR 09
DRAWING No. 1685–003	REV. A

File: 1685-003.dwg Date/Time: March 09, 2004 8:51 a.m. Scale: 1=5 pc29 Xrefs:



ELEVATION
(TRANSVERSE)
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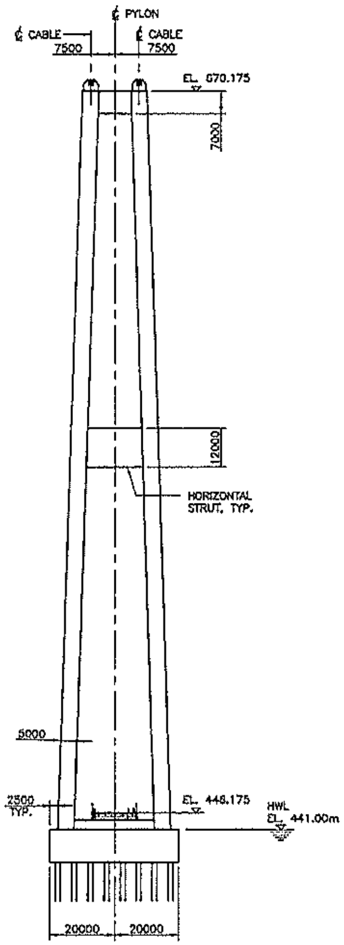

ELEVATION
(LONGITUDINAL)
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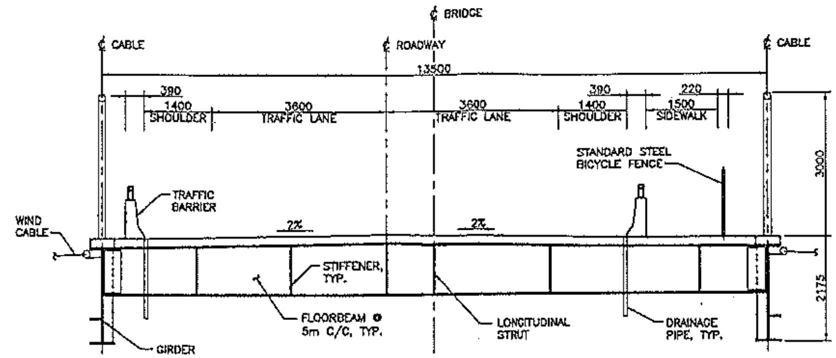

TYPICAL BRIDGE DECK SECTION
1:50 000

A	ISSUED FOR FEASIBILITY STUDY	KKC	ILW	04-03-24	

Province of British Columbia
MINISTRY OF TRANSPORTATION

ARROW LAKES BRIDGE – FEASIBILTY STUDY

STORM POINT CROSSING DETAILS

BUCKLAND & TAYLOR LTD.
Bridge Engineering

DESIGN	ILW	CHECKED	DDM
DRAWN	KKC	APPROVED	PRT
SCALE	AS SHOWN	DATE	2004 MAR 09
DRAWING No.	1685-004	REV.	A

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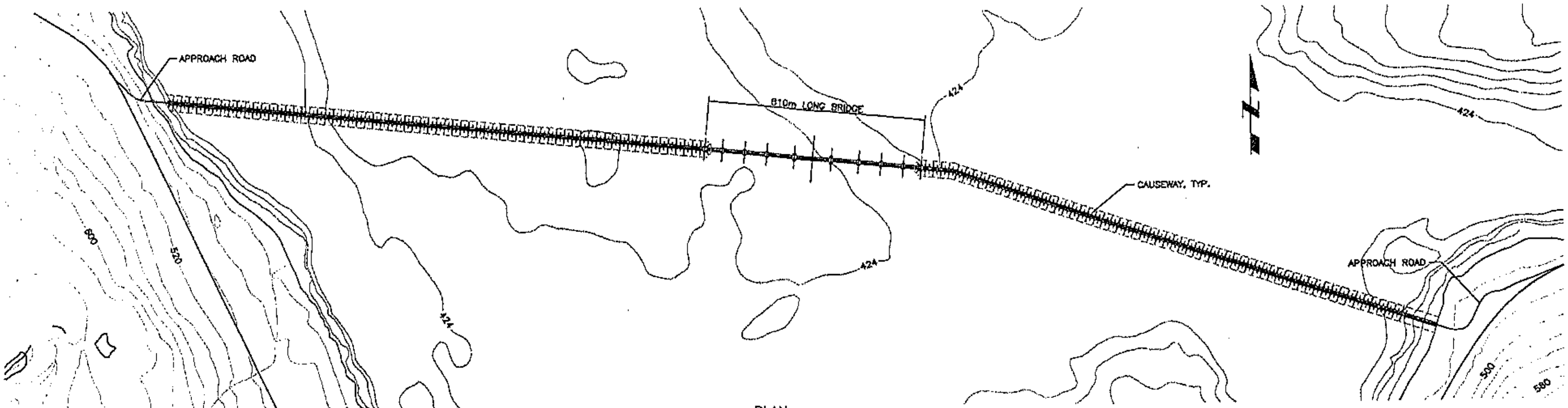
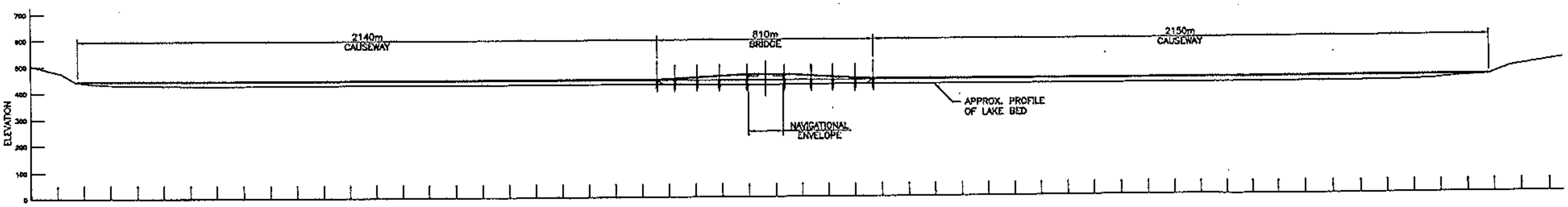


PLAN



DEVELOPED ELEVATION

Province of British Columbia
MINISTRY OF TRANSPORTATION

ARROW LAKES BRIDGE – FEASIBILTY STUDY

STORM POINT CAUSEWAY CROSSING
BRIDGE AND CAUSEWAY LAYOUT

BUCKLAND & TAYLOR LTD.
Bridge Engineering

DESIGN	ILW	CHECKED	DOM	
DRAWN	LTG	APPROVED	PRT	
SCALE	1:75000	DATE	2004 MAR 09	
DRAWING No.	1685–005			REV. A

REV	DESCRIPTION	DR.	APP.	DATE
A	ISSUED FOR FEASIBILITY STUDY	KKC	ILW	04–03–24

0 50
ORIGINAL SCALE IN mm FOR REDUCED PLANS

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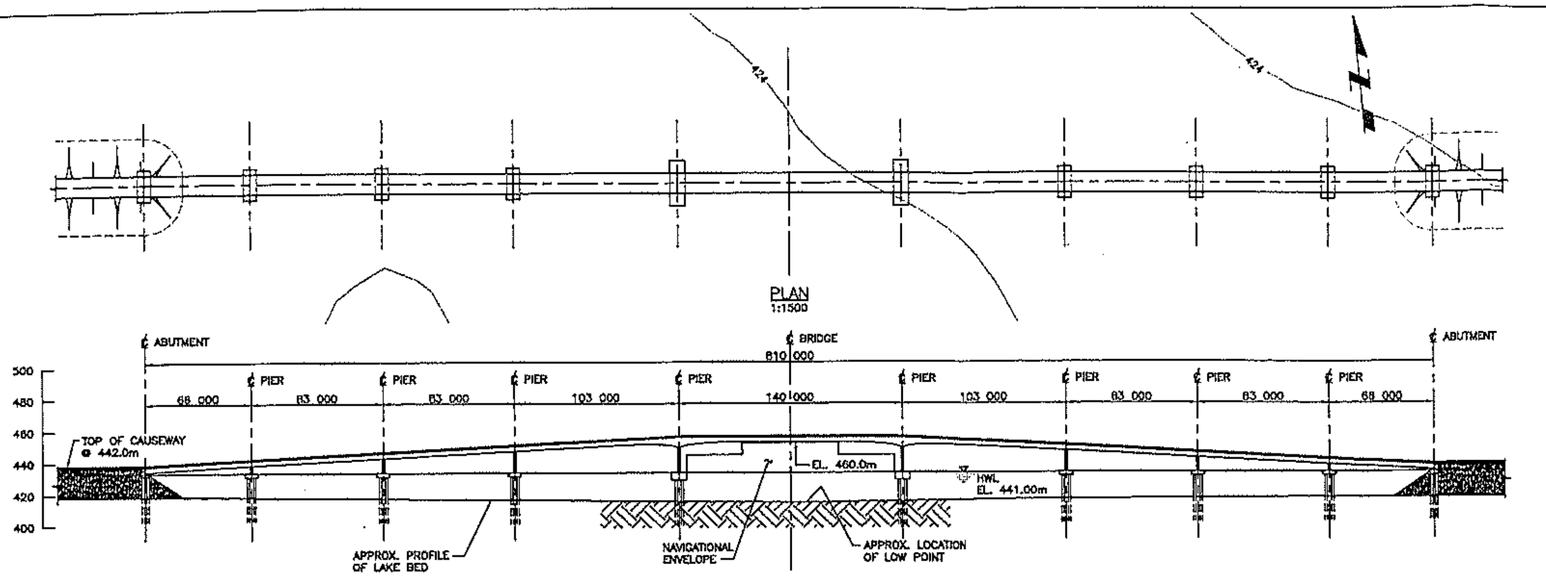
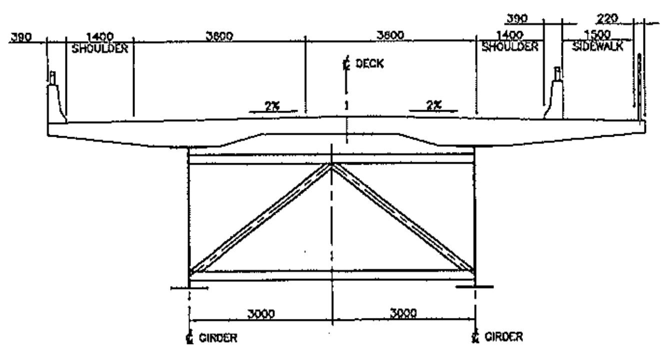
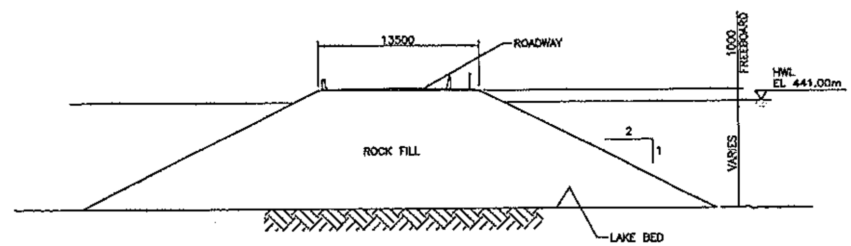


PLAN
1:1500

ELEVATION
1:1500



TYPICAL BRIDGE DECK SECTION
1:50



TYPICAL CAUSEWAY SECTION
1:200

REV	DESCRIPTION	DR.	APP.	DATE
A	ISSUED FOR FEASIBILITY STUDY	KKC	ILW	04-03-24

ORIGINAL SCALE IN mm FOR REDUCED PLANS

Province of British Columbia
MINISTRY OF TRANSPORTATION

ARROW LAKES BRIDGE – FEASIBILTY STUDY

STORM POINT CAUSEWAY CROSSING
BRIDGE AND CAUSEWAY DETAILS

BUCKLAND & TAYLOR LTD.
Bridge Engineering

DESIGN	ILW	CHECKED	DDM
DRAWN	KKC/LTO	APPROVED	PRT
SCALE	AS SHOWN	DATE	2004 MAR 09
DRAWING No.	1585-006	REV.	A

File: 1585-006.dwg Date/Time: March 22, 2004 10:01 a.m. Scale: 1=0 ps29 Xrefs:

ARROW LAKES BRIDGE - FEASIBILITY STUDY
BRIDGE/CAUSEWAY ENGINEERING ADVICE

BUCKLAND & TAYLOR LTD.
Bridge Engineering

Planning Level Summary of Estimated Costs (March 2004)

ALIGNMENT			Albert Point Crossing		Storm Point Crossing		Storm Point Causeway Crossing	
ITEM	UNIT	Rate	Quantity	Cost (*)	Quantity	Cost (*)	Quantity	Cost (*)
CAUSEWAY								
Rock Fill	cu.m	$20					3600000	$72.0
Roadway surface	lin.m	$250					4350	$1.1
SUB-TOTAL 1								$73.1
Length of Causeway (lin.m)							4350	
Cost/lin.m							$16,802	
BRIDGE								
Piles	lin.m	$1,200					3040	$3.6
Abutments	cu.m	$1,500					600	$0.9
Piers	cu.m	$1,500					4000	$6.0
Deck concrete	cu.m	$1,500					3900	$5.9
Deck steel	t	$5,000					2400	$12.0
SUB-TOTAL 2								$28.4
Area of deck (sq.m)							10328	
Cost/sq.m of deck							$2,750	
SUSPENSION BRIDGE								
Piles	lin.m	$1,200	3300	$4.0	3300	$4.0		
Anchorages	cu.m	$2,500	9000	$22.5	8500	$21.3		
Pylons	cu.m	$1,600	52500	$84.0	50000	$80.0		
Deck concrete	cu.m	$1,500	6800	$10.2	6200	$9.3		
Deck steel	t	$5,500	6300	$34.7	5700	$31.4		
Cable & Bridge Rope	t	$7,500	23000	$172.5	21000	$157.5		
SUB-TOTAL 3				$327.8		$303.4		
Area of deck - excluding approach spans (sq.m)			28050		25500			
Cost/sq.m of deck			$11,687		$11,896			
SUSPENSION BRIDGE APPROACH SPANS								
West Approach span	sq.m	$2,400	2295	$5.5	6885	$16.5		
East Approach span	sq.m	$2,400	1020	$2.4	1530	$3.7		
SUB-TOTAL 4				$8.0		$20.2		
TOTAL 1+2+3+4				$335.8		$323.6		$101.5
Planning Level Contingency (25%)				$83.9		$80.9		$25.4
SUB-TOTAL				$419.7		$404.4		$126.9
Engineering etc. (20%)				$83.9		$80.9		$25.4
TOTAL				$503.6		$485.3		$152.2

Note: (*) Costs are expressed in millions of dollars.