Study of Flood Proofing Barriers in Lower Mainland Fish Bearing Streams

May 1999

Department of Fisheries and Oceans
Habitat and Enhancement Branch
Pacific Region

Prepared by:

Alan R. Thomson and Associates
1124 Hoover Street, Nelson, BC.
Tel: 250-352-0016
msc@telus.net

and

Confluence Environmental Consulting
Whistler, BC.

Executive Summary

Pumping stations on the lower Fraser River are well known to impart significant mortalities on migrating salmonids, specifically smolts and kelts, that are out migrating from lower Fraser River natal streams to the estuary during the Fraser River freshet. Although several studies have determined that pumping stations kill out-migrating fish, little is known about pumping stations' ability to limit in-migrants from accessing natal and non-natal stream habitat during winter months. In this report, fish migration issues are scoped for ten pumping stations and associated flood boxes on the lower Fraser River from Hope to Richmond. The majority of pumping stations likely constitute a barrier to in-migrating juvenile salmonids, and kill out-migrating fry, smolts and kelts that exit their natal stream after the Fraser River freshet arrives. Each of the ten pumping stations is described, analyzed and discussed with the intent of developing recommendations for operational and capital changes and for further study. Research on the pumping stations / fish migration conflict by water resources and biology professionals from Canada and the United States is also presented. Options to address the conflict are discussed and include changing the type of pump, installing pump bypass systems, changing operational procedures at each facility, conducting fish salvage operations, allowing marginally productive land to flood, and installing higher volume flood boxes with lighter flap gates.

Table of Contents

List of Figures

List of Tables

List of Photos

List of Appendices

Acknowledgements

This study could not have been possible without the kind assistance of many individuals. The authors wish to thank:

Canadian sources		American sources	
Tom Bird	Katzie First Nations	Ken Bates	Washington State Dept. of Fish & Wildlife
Eric Bonham	MELP	Jim Buell	J.Buell and Associates (Portland, OR)
Lynne Campo	DOE	Mike Chamblin	Washington State Dept. of Fish & Wildlife
Maurice Coulter-Boisvert	DFO	John Clarke	Delaware State Dept. of Fish & Wildlife, Fisheries Section.
Greg Cross	Pitt Meadows	Rod DenHerder	U.S. Dept. of Agriculture - Natural Resources Conservation Service (Renton, WA)
Leslie Douglas	Township of Langley	John Easterbrooks	Washington State Dept. of Fish & Wildlife
Jim Elliot	DFO	Warren Frizell	Water Resources Research Laboratory, Bureau of Reclamation
Matt Foy	DFO	Jeff McGowan	Washington State Dept. of Fish & Wildlife(LaConnor, WA)
Stephen Frick	MELP	Al Mirati	Oregon State Dept. of Fish & Wildlife(Portland, OR)
Greg Giles	District of Mission	Mark Schuler	Natural Resources Conservation Service (Spokane, WA)
Bill Hamilton	District of Mission	Ed Zapel	Northwest Hydraulic Consultants (Tukwila, WA).
John Heinonen	DFO		
Al Jonsson	DFO		
Kon Johansen	DFO		
Sylvia Letay	MELP		
Sandy McCormick	Pemberton Dyking District		
Rob McCullough	District of Mission		
Darryl McDonald	DAID		
Dave Nansen	DFO		
Keith Paisley	District of Kent		
Krista Payette	MELP		
Jerry Pitney	Village of Harrison Hotsprings		
Clive Roberts	Township of Langley		
Marvin Rosenau	MELP		
Fred Wodtke	MELP		
Frank Wright	City of Abbotsford		
Pamela Zevit	MELP		

1.0 Introduction

It is well recognized that significant amounts of fish habitat have been alienated in the lower mainland due to the ongoing flood proofing initiative of the last century. Areas that were once used by anadromous fish for rearing are now largely isolated from the Fraser River, its tributaries and many other smaller watersheds. Fish access to several important rivers and wetland areas is now impeded or controlled by dykes, pump houses, hydraulically operated flood boxes, and manual flow control structures. Although many of these structures have been designed and are operated to allow for fish migration, there is a growing belief that fish passage through and past these structures is far more impeded than previously believed.

This study examines two classes of flood control structures: pump stations and flood boxes.

Pump stations are located throughout the lower mainland and are primarily used to pump water from low lying ditches and water courses that surround farmlands and communities to receiving waters, usually the Fraser, Serpentine and Nicomekl Rivers or one of their tributaries. Pumps range in size from those privately owned and operated and found in many agricultural drainage ditches, to large multi-pump facility operated by municipalities or districts. Some of the larger pumping stations are known to kill juvenile fish or to impede migration, whereas fish mortalities are not known but highly suspected at many smaller pumping stations.

Flood boxes play an equally important flood proofing role in many lower mainland rivers. However, unlike the large pumping stations, they are not well studied. MELP officials estimate that up to 500 flood boxes exist in the lower mainland, 200 in the Surrey Dyking district alone. Flood boxes allow upland areas to drain into the dyked receiving waters, but prevent rising waters in the dyked water body to flood areas outside of the dyke. Although flood boxes are designed to safely pass fish, and many do, there is mounting evidence that some don't. The widely held assumption that flood boxes safely pass fish has never been thoroughly tested in the lower mainland. In addition, many of the low gradient streams that are governed by flood boxes contain valuable coho habitat that is in many cases underutilized. This problem may be partially due to fish passage problems that involve flood boxes.

This report explores the above issues as they pertain to ten pumping stations on tributaries of the lower Fraser River between Hope and Richmond. Each of the pumping stations is described, analyzed and recommendations are made as to what actions can be taken to minimize the conflict between fish and flood proofing needs in the future. Data gaps are also identified and where appropriate recommendations are made to gather additional information such that resource managers may better determine the impact that facilities have on fish resources. The report also details current and ongoing applicable research by prominent water resources experts and professional biologists, both in

Canada and in the United States, and makes recommendations of how current research may apply to some fish migration problems experienced in the lower mainland.

1.1 Report Structure

The report is divided into four main sections. Section 1 introduces the report and report structure. Section 2 gives a detailed background to the issues and outlines past and current ongoing research efforts to address the fish / flood proofing conflict. Section 3 examines ten watersheds in the lower Fraser River that are partially regulated by pumping stations and the impact these stations may be having on the local fish resource. Section 3 also examines all the pumping stations and flood boxes within the District of Mission and discusses the impacts on the local fish resources and possible mitigation procedures. Finally, Section 4 discusses several mitigative solutions to the general fish / flood proofing conflict that will both aid agencies and local governments to address the conflict and point to areas of additional research.

2.0 Research of Fish Passage and Mortality associated with Pumping Stations and Flood Boxes

2.1 Salmonid Use of the Lower Fraser River System

The lower Fraser River and delta is a vast floodplain ecosystem comprising tidal and freshwater sloughs, many streams and side channels, and forest wetlands. In addition to other marine and freshwater fish species found in these watercourses, there are eight species of anadromous fish that are native to the Fraser River system and two more that were introduced[1]. Certain species such as chinook salmon (*Onchorhynchus tshawytscha*) can migrate several hundred kilometers upstream to preferred spawning and rearing habitat, while other salmonids including coho salmon (*O. kisutch*), chum salmon (*O. keta*) anadromous cutthroat trout (*O. clarki clarki*), and steelhead trout (*O. mykiss*) prefer lower Fraser River sections. Although the expansion of urban, agricultural, and industrial development has significantly reduced the habitat once available to these fish, many stocks continue to spawn and rear in the numerous small tributaries to the Fraser River.

The life cycle phase of the salmonid species found in Lower Mainland streams that is relevant to this report is the migration phase. As will be discussed in detail throughout this report, flood proofing facilities impede and disrupt salmonid migratory patterns. As salmonids move within and outside flood proofed streams, they must successfully negotiate either a pump or a flood box to reach their destination, either in an up or downstream direction. Some species have to negotiate passage several times during their life span. A brief overview of the migratory needs of several salmonid species is presented below.

2.1.1 Coho Salmon

Coho salmon usually rear in small freshwater streams for one or two years and then migrate downstream to the marine habitats from late April to June. During their rearing stage coho will migrate up and down the stream corridor seeking the best habitat for the season. Typically in urban streams coho migrate from areas where poor water quality and high temperatures inhibit their growth to more suitable areas, such as deeper pools with adequate overhead cover. In the fall, coho juveniles will move back into quieter waters to avoid high flows, suspended sediments, and cold water temperatures. Coho smolts typically measure 100 mm fork length upon leaving rearing waters.

Table 1: Life histories of salmonids specific to streams in the Lower Fraser River.[2]

Species	Spawning period	Downstream migration
Coho salmon	Nov. –Feb.[3]	April-June peak mid May
Chum salmon	Nov.- Dec.	April-June peak mid May
Chinook salmon	Aug.- Oct.	Feb. - June[4]
Anadromous cutthroat trout	Feb.- April	April-June peak mid May
Steelhead trout	Jan. – June	April - June

2.1.2 Chum Salmon

Unlike coho salmon, chum salmon have a very short resident time in freshwater, and begin their migration soon after emergence from the gravel in the early spring. They usually migrate downstream at a slightly earlier or the same time as the coho smolts. Unlike coho smolts, chum smolts are small (less than 55 mm) upon leaving their natal stream.

2.1.3 Chinook Salmon

Chinook salmon spawn in the larger rivers of the lower Fraser River system, such as the Pitt or the Harrison, typically between August and October. Upon emergence in the early spring, chinook juveniles either migrate directly to the ocean, rear for 90-120 days in freshwater and then migrate, or rear for an additional year in freshwater. In one study that was conducted during downstream migration period from February to June 1989, Murray *et al.* (1989) found juvenile chinook rearing in small non-natal streams in the lower Fraser, including the Brunette River and Nathan Creek. No evidence was found that chinook had spawned in these streams where juveniles were found rearing. At all sites, chinook juveniles were found from zero to 6.5 km upstream, mostly in tributaries that did not have obstructions or passage barriers, such as water falls, culverts, flood control structures. By June, chinook juveniles had left the tributary rearing streams and presumably migrated to marine environments. Murray et al. (1989) studied three of the streams included in this report that are hydraulically controlled by pumping stations and flood boxes. Notably, none of the streams contained chinook juveniles. This issue will be discussed throughout the report.

2.1.4 Anadromous or Sea-Run Cutthroat Trout

Anadromous or sea-run cutthroat trout, like coho salmon, prefer to spawn and rear in small streams. Alevins typically emerge in the early summer and rear in their natal stream for 2-3 years. Parr of 1+ age migrate frequently throughout their natal streams seeking the best habitat for the given season[5]. Downstream migration of parr to the estuary or into the mainstem usually begins in mid-winter and peaks in the late spring. Many of these fish will spend the summer in the estuary and mainstem and then migrate back to the small tributaries before the autumn rains. This activity may last from one to four years before the parr smolt and leave for the marine environment in the spring. Smolted cutthroat spend several months in a marine environment before returning to spawn in their natal streams in the fall. The following spring the kelts may migrate to marine environments again. Oregon data suggests that the out-migration of kelts precedes that of the smolts, and occurs in early April[6].

2.1.5 Steelhead Trout

Adult steelhead trout can enter their natal stream or river year round but usually return as either awinter run (November to May) or a summer run (May to October). Emergence from the gravel takes place from June to August. Juveniles usually remain in freshwater environments for between 2 and 4 years, them smolt during April to June. Adults may spawn more than once and can live to be 8 years old.

2.1.6 Escapement information

Escapement information is available for only four of the ten watersheds examined in this report. The data found in Table 2 was generated from published stream reports, and indicates an overview of the relative productivity of the watersheds for which data exists. This data can be used to help determine which pumping stations should receive priority attention for any mitigation works or additional research effort.

The data reveals several facts: that Matsqui Slough watershed is the largest producer of coho within the period examined; the Hatzic Slough watershed overwhelmingly produces the most chum, primarily because of the ground water channel on Chilqua Slough and coho production is generally much higher than chum production. Most of the other watersheds examined for which no escapement data exists would likely have small chum and coho runs.

Interpretation and management decisions using these escapement figures must be made with caution. It is not clear in many cases how the data was collected, and whether the enumeration methodology was consistent over the years. In some systems, the counts likely under-represent the true numbers. For example, in Mountain Slough, coho and chum were first enumerated in 1978, although there is no apparent explanation for their sudden appearance. It is likely that they have inhabited the watershed before 1978, yet the escapement figures do not indicate this. Enumeration details for the four watersheds examined in this report for which escapement data is available are found in Appendix 1.

Table 2: Escapement records and statistics for various watersheds from 1949-1985.

	Matsqui Slough - Clayburn Creek, Abbotsford	**Mountain Slough, District of Kent**	**Miami Creek, Harrison Hot Springs**	**Hatzic Watershed**
	Coho	Coho	Coho	Coho
Total over period	6220	230	825	5830
Mean	177.7	46.0	31.7	149.5
Standard Deviation	155.2	87.1	56.4	130.8
Range -Low	0	0	0	0
-High	650	200	200	525
	Chum	Chum		Chum
Total over period	300	50		55,892
Mean	25.0	10.0		1,433.1
Standard Deviation	0.0	13.7		2,252.1
Range -Low	25	0		100
-High	25	25		11,130

Sources: statistics derived from raw escapement data in FHIPP Steam Summary Catalogues for the Lower Fraser River.

2.2 Flood Protection in the Lower Fraser Valley

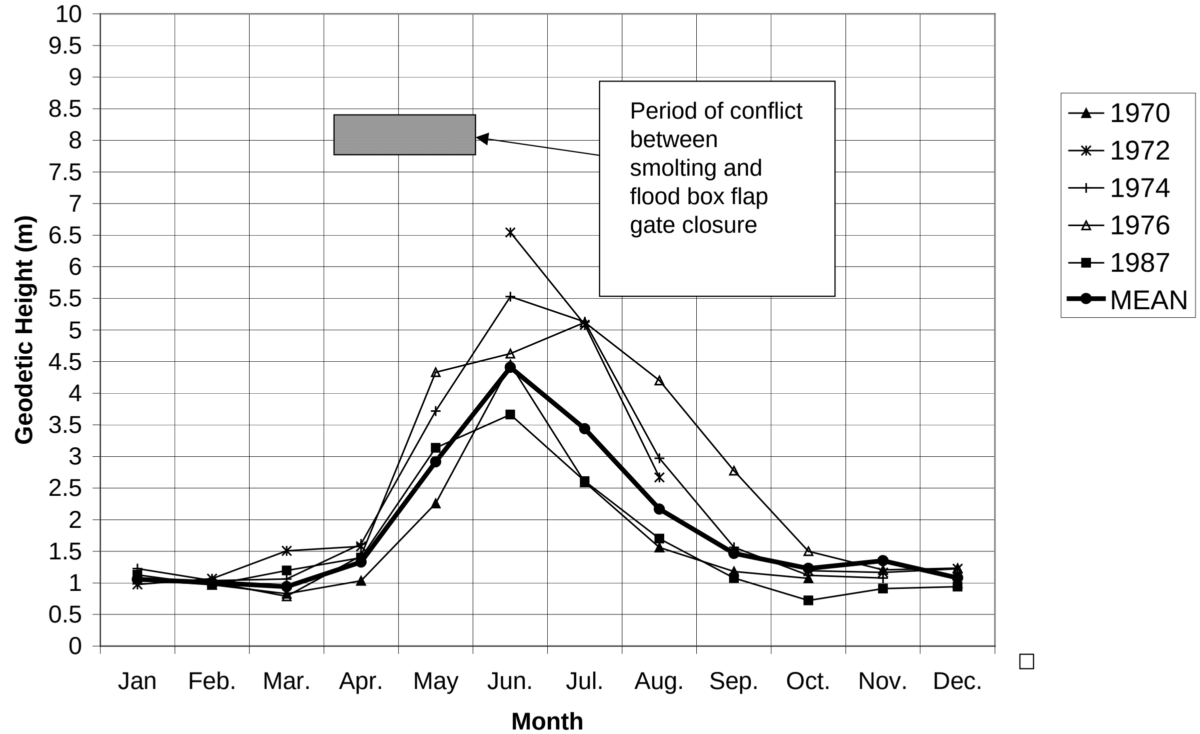
2.2.1 The Drainage and Flood Control System

A system of structures including dykes, pumping stations, and flood boxes constructed along the lower Fraser River controls drainage and minimizes flooding of low lying land in the valley bottom (see Figures 1A – 1C). While the valley bottom represents a floodplain ecosystem that was naturally subjected to inundation by high stage flows before major flood protection works were constructed on the Fraser and its tributary streams, flood protection initiatives aim to maintain a drainage system that will allow continued use of the rich floodplain land area for agriculture and rural habitation. About 70,000 hectares of valley bottom land is under cultivation on over 5,000 farms in the Lower Fraser Valley, which combined generate over half of the province's farm production revenues[7]. More than half of the B.C. population lives in the Lower Mainland and an unknown number are protected from annual Fraser River flooding by the dyking system.

Dykes are elevated earthen berms constructed along rivers, streams and excavated channels or canals. Dykes are designed to contain high stage flows and protect areas lying outside of the dyked areas from flooding. Flood boxes are the culverts that extend through the dyke to allow gravity discharge of internal drainage into the mainstem when water levels are lower outside the dyke than inside. The key component of a flood box is a flap gate fitted onto the discharge end of the culvert, which only allows one-way flow (See Photo 14 for example). When high flows or rising tides on the mainstem close the flap gate and thereby prevents gravity discharge of the internal drainage water, pumping is required for continued drainage to the mainstem. Flood boxes located near the mouths of tributaries and sloughs along the lower Fraser River are often closed for long periods during late spring and early summer when the mainstem freshet occurs. As a result, the flap gate closure period and the migration period always overlap. The duration of overlap is largely dependent upon when the freshet arrives and when the salmonids start smolting (See Figure 2). In some years when the freshet arrives late, it is likely that the majority of smolts leave their natal stream unimpeded through the flood boxes. In other years when the freshet arrives early, the pumps likely entrain the majority of smolts (see Figure 3).

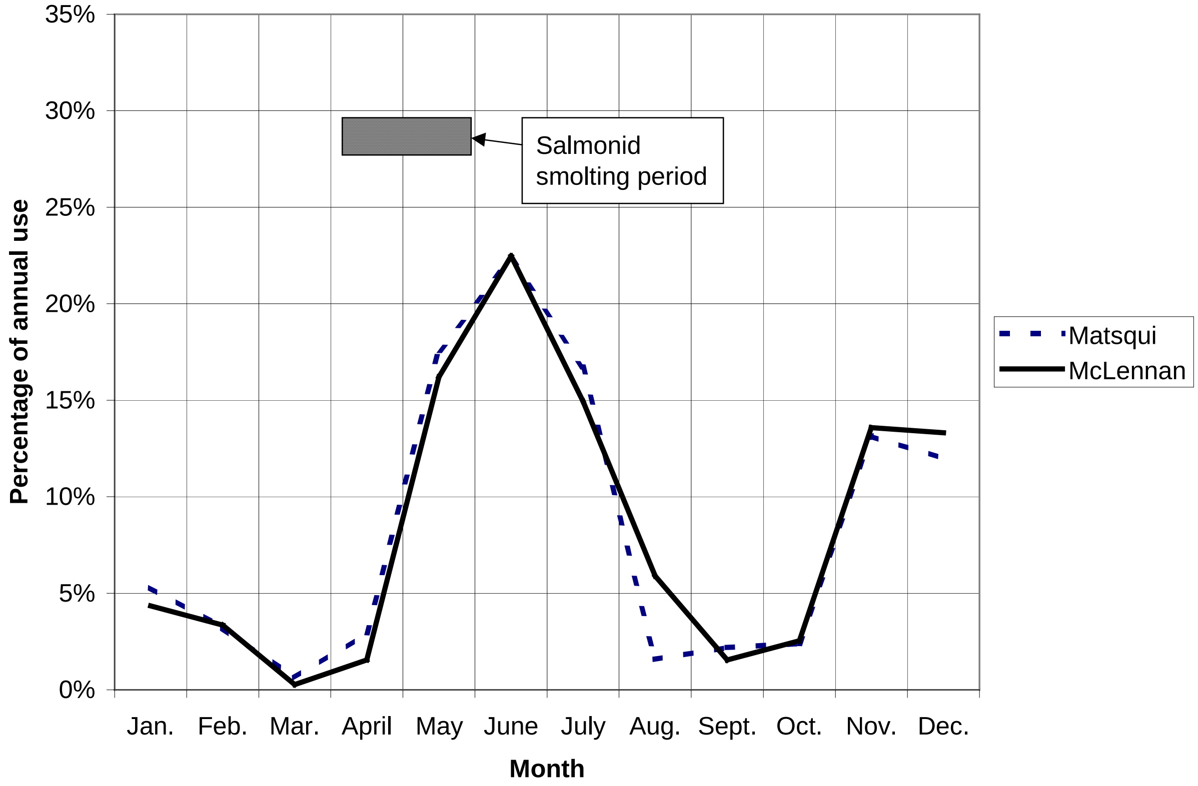
Figure 1a-1c: Lower Fraser River Pumping Stations and Dykes, Richmond to Hope, B.C.

Figure 2: Monthly water levels of the Fraser R. at Mission for selected years between 1969 – 1992.



Note: Years represented in the figure are included to indicate extreme values (both high and low discharge years) and the mean discharge over the time period. Source for hydrometric data: Environment Canada

Figure 3: Average monthly pump station operating hours expressed as percentage of total annual hours for Matsqui Slough and McLennan Creek stations from 1974- 1987.



Source: UMA, 1988.

2.2.2 Abbreviated History of Flood Protection

Flood protection works have been undertaken in the Lower Mainland for over 130 years, starting in 1864 with private landowner initiatives in the Richmond area and gradually expanding into the joint federal/provincial Fraser River Flood Control Program of the 1990's [8]. Determination and defeat, judging by the history of the Mission area marked early flood proofing initiatives along the lower Fraser. Kinneard *et al*. (1981) describe how the elevated Canadian Pacific Railway grade completed in 1885 along the north side of the Fraser River served for decades as a flood protection dyke in the vicinity of the Hatzic Prairie. At about the same time as the 1894 flood washed out portions of that railway grade, an administrative body was established and then reorganized several years later as the Dewdney Dyking District. A small pump and flood box was installed in the railway grade around the turn of the century. By the 1940's, flood protection works under the same section of railway grade consisted of a four-unit pumping station capable of pumping up to 80,000 gallons per minute and a much larger, concrete flood box with oak gates. The 1948 floods washed out this flood control structure. Following this event, the railway grade was no longer used as a primary dyke was, and the present day dyke (7.4 miles long, 30 feet high) was constructed with new pumps and flood boxes installed to drain the Hatzic Prairie.

A comprehensive flood control program had been initiated at this time throughout the lower Fraser Valley. Across the Fraser River from Mission and downstream, agricultural land on the Salmon River floodplain had been completely inundated by the 1948 flood as well. The Salmon River pump station, dyke, and flood box structures were constructed in 1949. Also on the south side of the Fraser River, opposite and slightly upstream of Mission, approximately 9,000 ha of floodplain (more accurately, lake bottom) had been developed for agriculture following the 1920 construction of flood protection works on the Sumas River[9]. A system of dykes was first constructed along the lower Vedder River (Vedder Canal), Sumas River, and Fraser River to protect this area known as the Sumas Prairie from flooding. By 1923 the Sumas Pump Station was in operation, pumping drainage collected in the Sumas Canal and tributary ditches to the mainstem. This pumping station was operated for 60 years before being replaced by the present Barrowtown Station.

Present day District Dyking Authorities established throughout the Lower Mainland administer the construction and maintenance of modern flood protection works under the *BC Dyke Maintenance Act*. Current design flood figures used to plan flood protection works in the Lower Fraser Valley are based on the 1894 freshet flood levels of the Fraser River (considered to be the approximate equivalent of the 1:200 year design flood) and high water marks identified during the wide scale flooding in 1948[10].

Figures 1A – 1C indicate the location and extent of the current flood protection structures on the lower Fraser River from Hope to Richmond.

2.3 Pumping Stations

2.3.1 Pump Station Configuration

Pumping stations vary considerably in their size, pumping capacity, and design features, but a typical configuration involves a concrete intake structure, a trash rack on the pump intake to prevent debris from entering the pump, a system of lead and lag pumps if more than one pump exists, discharge pipes, and a spillway leading to the outlet (See Photo section for numerous examples). Pumping stations are often integrated with flood box structures, such that drainage water through the dyke may be either free-flowing (gravity discharge) or is pumped into the receiving water when the flood box is closed. Some pumping stations (e.g. French Creek, Washington State) have no flood boxes and rely exclusively on pumps for discharge to the mainstem[11].

Pump operation is usually automated and is governed by the water level in the forebay area of the pumping station. When the pump is turned on, water is lifted by the pump several metres above the intake elevation, and then discharged by pipes to the outlet structure on the downstream side of the dyke. If the pipe outfall is located below the flood water elevation in the receiving waters, the pipe outfall is fitted with a flap gate to prevent reverse flow when the pump is not operating. The pumped water is discharged into a concrete spillway. The roughness of the spillway and riprap is designed to dissipate energy associated with the discharge.

2.3.2 Pump Types

Pump characteristics refer to the pump capacity, the total head developed by the pump, the power required to drive it, and the resulting efficiency[12]. The type of pump chosen for flood protection works must have characteristics that are suited to the application, namely high capacity and efficiency, and low total head. There are three general types of pumps used for flood control purposes:

1. Propeller pumps (a.k.a. axial flow pumps) force liquids in an axial direction only, or in other words they force liquids at right angles to the impeller blades;

2. Centrifugal pumps (a.k.a. radial flow, or mixed radial/axial flow pumps) either force liquids at right angles to the impeller axis, or they give the liquids both radial and axial velocity. Propeller-type pumps have been the most widely used in flood protection works to date because of their efficiency in such operating conditions; and,

3. Archimedes screw-type pumps are non-pressurized pumps that lift water using a tube wrapped around a long, rotating cylinder in the form of a corkscrew.

2.3.3 Efficiency and Fish Passage Capability of Different Pump Types

2.3.3.1 Propeller Pumps

Propeller pumps have had a long history of use for drainage and flood protection systems in the lower Fraser River. At the Salmon River pumping station built in 1949, for example, three self-contained propeller pumps had a combined capacity of almost 4 cubic metres per second (cms) or 58,525 U.S. gallons per minute (gpm) at 4.3 m total dynamic head[13]. These pumps, however, were not known as being "fish friendly". Russell (1980, 1981) conducted fish mortality experiments at the Salmon River pumping station which revealed pump-related coho smolt mortality rates of 31.3% and 25.8% in successive years (see Table 3).

Propeller pumps are also in use at the Matsqui Slough pump house. Coho smolt mortality tests conducted on Pump No. 4 indicated an average mortality rate of 70.2% after a 72 hour observation period. While the study noted that stress and injury associated with recovery of the test fish may have inflated the total mortality rate, nonetheless an average of 47.3% of the test fish were recovered dead immediately after passing through the pump, the majority of them dismembered[14]. These figures were very similar to the results of tests conducted two years earlier at Matsqui Pump No. 2. Lougheed and Pike (1984, reported in Sookachoff 1986) determined immediate mortality rates of 33.3% and 67.3% mortality after a 72 hour observation period.

Both the Salmon River and Matsqui Slough stations since these tests were conducted have been upgraded to include new pumps which are designed to be fish friendly. For a complete discussion of the success of the new fish friendly pump arrangement at the Matsqui pumping station, refer to Sections 3.2.3 and 4.2.

Table 3: Summary of fish passage study results through lower Fraser River pumping stations

Pumping Station Location	Pump Type	Individual Pump Capacity	Pump Speed (rpm)	Immediate Fish Mortality (%)	Total Fish Mortality (delay time)	Source
Salmon River	Vertical impeller	1.1 m^3/sec (16,300 USGPM)	575	30.2 (av.)*1	31.3 % (48 hrs)	Russell 1980
Salmon River	Vertical impeller	N/A	N/A	23.0*2	25.8 % (48 hrs)	Russell 1981
McLennan Creek	Vertical impeller	N/A	N/A	31.5 (av.) *3	53.5 % (48 hrs)	Russell 1981
Matsqui Slough	Vertical impeller	2 m^3/sec (31,000 USGPM)	580	47.3 (av.) *4	70.2 % (72 hrs)	Sookachoff 1986
Matsqui Slough	Vertical impeller	N/A	N/A	33.3*5	67.3 % (72 hrs)	Lougheed and Pike 1984 (reported in Sookachoff 1986)
Erickson Creek	Archimedes Screw	2 m^3/sec	N/A	0*6	0	ECL Envirowest 1992

*1. Total of 135 coho salmon smolts (unspecified length)
2. Total of 1500 coho salmon smolts (63 mm average fork length)
3. Total of 117 coho salmon smolts (unspecified length)
4. Total of 219 coho salmon smolts (127 mm average length)
5. Details not available at time of study
6. Test included 80 coho salmon smolts (approx. average 100 mm fork length) and 91 cutthroat trout (200+ mm). No injured or dead fish recovered; 74% of coho and 89% of cutthroat were recaptured following test, and remainder were thought to have escaped net capture.

Fish mortality associated with roto-dynamic pumps is strongly correlated with the "probability of strike" by the impeller blades[15]. Factors influencing the probability of strike include distance between impeller blades, clearance between blades and pump housing, size of fish passing through the pump, and pump speed. A fish that is passing through a pump that is rotating at 9 to 10 rotations per second (600 rpm) has a significant chance of coming into contact with the pump impeller. Most pumps examined in this study rotated at speeds in the range of 495 – 875 rpm. Pumps used in the District of Mission rotate at 1200 rpm, by far the highest speed of any pump station examined during this study.

2.3.3.2 Centrifugal Pumps

Four centrifugal pumps with a mixed-flow design were installed at Barrowtown Pump Station in 1984, replacing the set of vertical pumps that had been used for the previous 60 years and were suspected of causing significant fish mortality [16,17]. This pumping station is now capable of pumping 10 cms (almost 150,000 USGPM) at 12 m total dynamic head. The new concrete pumps were designed to operate at two speeds (117 rpm and 175 rpm), with fish mortality thought to be minimized at the lower speed. While larger pumps operating at relatively low speeds are understood to be more "fish-friendly" than smaller, high-speed pumps[18], these centrifugal pumps still have significant pressure differentials that may lead to fish injury or disorientation. Significant pressure drops within the pump chamber can cause fish internal organs to rapidly expand and cause immediate death. Disorientation of fish that survive passage through a pump make a fish more susceptible to predation at the outfall area until reoriented. An additional problem of fish passage through centrifugal and most other pump types is that the fish may display avoidance behavior at the pump intake due to the unfamiliar hydraulic conditions. They then are sucked in backwards and as a result are more likely to sustain injuries[19].

A different centrifugal pump design being experimented in California recently has generated renewed interest in the field of fish passage engineering. A screw/centrifugal pump, alternatively described as an internal helical pump, manufactured by WEMCO/Hidrostal has been operated since 1995 at the Red Bluff Research Pumping Plant located near Sacramento, CA. The pumping plant is operated by the U.S. Bureau of Reclamation for the express purpose of evaluating different types of pumps for their ability to pass fish, in part to fulfill a commitment to improve the passage of adult and juvenile chinook salmon through irrigation diversions along the Sacramento River. The pump is a variable speed unit (300-450 rpm) designed to pass up to 3 cms (100 cfs) at a total dynamic head of 6.75 m. The Red Bluff pump runs at 400 rpm and delivers about 2.5 cms (85 cfs). This large pump was manufactured under special order, as its 1200 mm inlet is roughly twice the size of an "off the shelf" WEMCO pump, and it features a single-vane, helical screw-type impeller with a rotating conical shroud designed to prevent injury to fish on entrance to the pump[20]. Preliminary evaluations of fish passage indicate that the screw/centrifugal pump is capable of passing smolts ranging in size from 42 mm to 128 mm fork length with a 3% mortality rate or better[21].

A much smaller centrifugal pump is used primarily in the food processing industry, but has application in passing fish around flood control structures. The recessed-impeller type pump is most often used at fish hatcheries to collect and transport fish. Information supplied by Cornell Pump Co. indicates that their fish handling pump features a patented offset volute design (the volute being the pump casing) that minimizes injury. The design flow stream and pump casing are engineered such that fish are less likely to come into contact with either the cut water edge or the sides of the volute. Unfortunately, these pumps can deliver a maximum of less than 0.3 cms (approximately 4000 gpm). As reported by Envirocon (1986), a multi-pump installation would be required to achieve the flow capacity required at most flood protection works, and gains in fish passage success would have to be evaluated against both extra costs and a significant reduction in efficiency. Alternatively, as suggested below in the discussion of pump bypass options, the fish pump can be incorporated into a system of larger pumps fitted with diversion screens and serve to pump mainly fish before they reach more damaging high capacity pumps, rather than pump the entire drainage flow containing the fish. This type of system is currently employed at the Matsqui Slough and McLennan Creek pumping stations (refer to Section 3 for additional discussion of these pumping stations)

2.3.3.3 Screw Pumps

There are several designs of Archimedes screw-type pumps currently in use. They appear to be the most "fish-friendly" pumps due to their low operating speeds, wide spacing in the screw flight, and the absence of pressure differentials and extreme turbulence. Small diameter, single screw pump installations have been used specifically to transport fish, while much larger screw pumps and multi-pump installations efficiently and safely lift both large volumes of water and entrained fish. The largest Archimedes screw pump installation noted in the course of investigation was built by Machinefabriek Spaans of Hoofdorp, Holland and installed in Cologne, Germany. A total of nine screws inclined side by side are reported to have a combined discharge of 20 cms (20,000 litres/second).

Two Archimedes screw pumps were installed at the Red Bluff Research Pumping Plant in addition to the screw/centrifugal pump described above. These particular Archimedes screw-type pumps are of the rotating cylinder design, in which helical flights are welded to the inside of the cylinder body, and the entire unit is inclined at an angle of 38 degrees and then rotated by motor drive. Each 3.3 m diameter, 3-flight pump is supported both radially by a system of rollers, and at the top of the cylinder by a roller bearing[22]. Each pump is capable of delivering approximately 3 cms (100 cfs) at 26.5 rpm, with the same vertical lift as the screw/centrifugal pump. A variable speed drive allows speeds down to 1 rpm. Preliminary evaluations of fish passage indicate that the rotating cylinder Archimedes screw pump is capable of passing smolts ranging in size from 42 mm to 128 mm fork length with less than a 1% mortality rate[23].

Two 2.4 m diameter Archimedes screw pumps were installed at the Erickson Creek Pump Station constructed in 1991 in Surrey, B.C. They represent the first installation in British Columbia of screw-type pumps. These pumps are of the more conventional Archimedes screw design, with flights attached to the screw impeller. Each pump is capable of delivering 2 cms at the rated operating head when Erickson Creek is at a low stage flow and the Nikomekl River receiving waters are high. An evaluation of their effectiveness in passing fish indicates that both coho smolts (approximately 100 mm fork length) and much larger cutthroat trout (200 mm fork length and larger) were passed without one observed mortality or injury at the time of passage.

2.3.4 Other Considerations of Fish Passage Through Pumping Stations

Given that fish mortality associated with pumps is in part a function of the size of fish passing through the pumping system, it can be reasonably expected that larger smolts and kelts are more susceptible to pump injury. Consequently, out-migrating smolts that successfully pass through pumping stations are more likely to be of a smaller size class. Envirocon (1986) points out that in the case of cutthroat trout smolts, which are documented to have higher ocean survival rates in the larger size classes, the smaller fish which survived pumping are “unlikely to make strong contributions to adult returns”. Further, repeat spawners are also susceptible to pump mortality due to their large size and the timing of their downstream migration (possibly coinciding with pump operation) after spawning[24]. This issue has also been noted at the Hatzic pumping station for cutthroat kelts (refer to Section 3.2.1. for additional discussion).

While it is recognized that fish injury and mortality in pumping stations is most likely to result from direct contact with the pump impeller, other features of the pump and the pumping station flow stream may contribute to the injuries. Possibilities include fish injury at pump intakes, diversion screens, discharge flumes and energy dissipation structures, as well as mortality due to increased predation either at the outlet or during periods when water is impounded at the inlet. A review of the literature indicates that this issue is not well documented for small pumping stations and is implicitly considered to be relatively insignificant compared to pump-related mortality. However, the exhaustive studies ongoing at Red Bluff Research Pumping Plant address “fish-friendliness” throughout the entire flow stream of the pumping operation. For example, several modifications were made along the flow streams of each of the pumps “to facilitate safe fish passage”, including the installation of baffles “to control sweeping and approach velocities on wedge wire screens in the plant in order to prevent injury to passing fish” [25]. The study design also involves the use of both treatment and control samples of fish introduced to and collected from the pumping station flow stream at various points, in an effort to assign passage-related fish injury and mortality to specific segments of the system. The results of standardized biological evaluation studies conducted in 1997 and 1998 are not yet available.

2.4 Flood Boxes

2.4.1 Function

A flood box is the culvert or set of culverts that provide hydraulic connectivity through dykes that separate internal drainage areas and the receiving waters. The size of the flood box is dependent upon the expected flood water discharge rate and capacity requirements. A typical flood box measures 1.2 m by 1.2 m and can be up to 50 m in length. A flap gate mounted at the discharge end of the culvert allows the gravity discharge of flow in a downstream direction only, thereby acting as a check valve by preventing back flow from the mainstem when the mainstem water level exceeds that behind the dyke. The flap gate is mounted either with a horizontal hinge (i.e. it is “top-hinged”) or, more recently, with a vertical hinge (“side-hinged”). See Photos 12 and 14 for examples of both flap gate configurations. Positive head differential against the upstream face of a flap gate will open it to release drainage, and the pull of gravity will serve to close the horizontally hinged gate in the absence of significant head differential. Conversely, positive head differential on the downstream face of either a horizontally or vertically hinged gate will close it. When high flows on the mainstem close the flap gate, the water behind the dyke must be either temporarily stored or else pumped over the dyke to the mainstem receiving waters. Flood boxes may be located anywhere that small watercourses intersect a dyke, or they may be installed in tandem with a pumping facility at the outlets of larger tributary streams.

2.4.2 Flood Boxes as Fish Barriers

Flood boxes are located at the outlets of numerous Fraser River tributary streams that provide spawning and rearing habitat for anadromous fish. They represent an obvious barrier to fish migration when the flap gates are closed, forcing smolts to either migrate downstream by way of pumping stations or otherwise rear or hold in the impounded water until such time that the flap gates open. Closed flap gates also would prevent the upstream migration of spawners, although anecdotal information suggests that flap gates are rarely completely closed during the fall in-migration due to the low water levels in the Fraser River. Some flood boxes likely represent a fish barrier even when the flap gates are open, to the extent that in-migrating fish of different sizes or swimming abilities have difficulty passing into or through the flood box. Extensive research has been conducted on adult and juvenile swimming speeds (see Table 4). It is probable that velocities within flood boxes during winter and spring months could exceed 0.5 m/s that would prevent juvenile coho, for example, access into a tributary from the Fraser River mainstem. Other possible obstructions to passage would include flood box outlets perched above the mainstem water surface and restrictive gap width when the flap gate is only partially open due to limited head differential.

Table 4: Sustained and prolonged speed for coho salmon and cutthroat trout.

Species and life stage	Sustained speed (m/s)	Prolonged speed (m/s)
Coho		
Adults	0.0 - 2.7	2.7 - 3.2
Juveniles (120 mm)		0.4 - 0.6
Juveniles (90 mm)		0.3 - 0.5
Juveniles (50 mm)		0.2 - 0.4
Cutthroat		
Adults	0.0 – 0.9	0.9 – 1.8
Juveniles (125 mm)	0.0 – 0.38	0.38 – 0.75
Juveniles (50 mm)	0.0 – 0.15	0.15 – 0.3

Source: Chilibeck, B. 1992.

Finally, any of the above-noted obstructions to fish passage would effect not only the smolts and spawners normally associated with these tributaries, but also effect other species such as chinook juveniles salmon seeking nutrient rich non natal streams to rear in before migrating to the estuary.

A thorough review of the literature and discussions with both fish biologists and engineers who are involved in fish passage-related work indicates that the main concerns are with certain types of flap gates operating under certain flow conditions. As summarized by Eliason (1986): “These structures have historically blocked fish migration into potentially productive fish habitats since most of the gates do not open sufficiently under a low head differential and create a velocity barrier to upstream migrants under a high head differential.” While no empirical data describing these effects is known to have been reported to date, at least one biologist has personally observed dead in-migrating coho salmon below flap gates (gates described as “heavy” and “small”) located at the Nooksack River and Cougar Creek[26]. Other officials in both Oregon and Washington reported that flap gates (and in particular, horizontally hinged gates made of cast iron) represent a significant fish passage barrier[27,28]. Further, with respect to different age classes of anadromous fish, flap gates are thought to be barriers to both juvenile and adult salmonid passage[29].

2.4.3 Fish Injury And Mortality

There are only a few references in the literature to fish injury or mortality specifically associated with flap gates or flood box structures. During a study of pump-related fish mortality at the Salmon River pumping station, Russell (1980) conducted one test of fish passage through a flap gate and associated concrete outlet structure. Of the 35 coho salmon smolts introduced into the pump discharge flow, 34 were recovered by seine net below the flood box and the remaining smolt was unaccounted for. Russell repeated this test procedure in a subsequent pump mortality study on McLennan Creek where, of 31 coho salmon smolts introduced into the pump discharge flow, all were recovered but 7 died within a 48-hour observation period. This 22% mortality rate was attributed to “injuries the smolts sustained after they glanced off a flap gate and concrete beam and were forced against a rip-rap apron” [30].

The degree to which fish mortality associated with increased predation that might be attributed to flood boxes is currently unknown. It is plausible that smolts are more vulnerable to predation, either upstream of closed flap gates or immediately downstream of pumping facilities or flood boxes, especially given their possible disorientation or injury after negotiating such structures.

Finally, fish mortality has been linked with gated impoundments of estuarine systems as a result of altered tidal exchange. Reported experience on the Delaware River confirms fish kills (of both resident fish and important migratory populations of juvenile sea-run trout, striped bass, and white perch) associated with estuary flap gates that have turned former saltwater marshes into essentially freshwater impoundments[31]. It is speculated that changes in dissolved oxygen levels, changes in water temperatures, and changes in the mix of saltwater with freshwater in gated estuaries may have a significant adverse effect on juvenile salmonids in particular, as they require time to adjust to the marine environment during that phase of their life cycle[32,33].

2.5 Summary of the Research of Fish Passage and Mortality associated with Pumping Stations and Flood Boxes.

It is clear from understanding the smolting periods of the salmonids found in lower mainland streams, the hydrology of the Fraser River and the operation of flood proofing structures at the mouths of many lower mainland streams that a conflict exists between fish migration needs and the needs of communities to protect flood prone lands. All salmonids found in lower mainland streams smolt between April and June. The arrival of the Fraser River freshet at this time results in flood box flap gates closing and the start of the pumping season. Salmonids that smolt after the flood box flap gates have closed either must delay smolting a year by residing in their natal stream or else leave the stream via the pumps.

The research is fairly conclusive that fish that migrate either through pumps during the smolting season or at other times of the year may sustain injury or death. Various fish mortality studies conducted at lower mainland pumping stations within the last two decades found that between 30% and 70% of fish that were passed through various pump configurations were killed. Flood boxes fitted with heavy top mounted flap gates also are believed to block up-streaming migrants under both low and high flow conditions that occur throughout any given year.

The following section examines eight pump stations on the lower Fraser River and considers the effect that each has on migrating salmonids given the information presented above.

3.0 Selected Pumping Stations on the Lower Fraser River

3.1 Introduction

In order to determine the applicability of the information presented in Section 2, ten lower mainland pumping stations were examined to determine whether a fish migration / pumping facility conflict exists. The stations that are examined are located in the following watersheds:

- Hatzic Watershed;
- Katzie Slough;
- Matsqui Slough;
- McLennan Creek;
- Miami Creek;
- McLean Creek;
- Mountain Slough; and,
- Nathan Slough.

The second part of this section involves examining all of the pumping stations and flood boxes in the District of Mission. Eventually every pumping station and flood box that may impact upon fish in all lower mainland jurisdictions will be examined using a format similar to that which follows. The stations that are examined within the District of Mission include:

- Chester Creek; and,
- Lane Creek.

All ten watersheds examined in this section has a pumping station at the confluence of the watershed and the Fraser or Pitt River. Each pumping station consists of one or a series of pumps and flood boxes. Each watershed is introduced, and all fish resources and watershed quality are described. The pumping station physical and operational characteristics are also outlined, and the fish / facility conflict discussed and analyzed. In all eight cases, there are several issues that require additional analysis before substantive conclusions can be made of the degree of conflict and what the best migitative solutions are that will address the conflict. These issues analyzed, discussed and summarized at the conclusion of each sub section. All the information presented in this section is also summarized in Tables 19a & 19b.

3.1.1 Hatzic Watershed

3.1.1.1 Introduction

The Hatzic Slough pumping station is located at the outlet of a 9,000 hectare drainage that includes Hatzic Slough and Lake, Lagace, Scorey, Belcharton and Draper Creeks (see Figures 1A – 1C). The station is located on the north side of the Fraser River approximately 10 km west of downtown Mission. The general area is known as "Hatzic Prairie" and the middle and lower sections of the watershed are low elevation flood plain, while the upper watershed is remote and mountainous. The area has suffered many serious floods in the last century and is now surrounded by a series of dykes and flood control structures.

3.1.1.2 Fish Resources and Watershed Quality

The Hatzic watershed contains a wide variety of resident and anadromous fish, including coho, chum and cutthroat trout. It is suspected that the vast majority of cutthroat trout in the system are anadromous[34]. Coarse resident fish are found primarily in the Slough and Hatzic Lake, while the salmonids reside or utilize the upper sections of the watershed. Hatzic Slough is used primarily as a migration route for coho, chum and cutthroat trout as spawning habitat is considered marginal[35]. Very little is known about salmonid utilization of Hatzic Lake, although juvenile coho, cutthroat and rainbow trout have been sampled in the lake during the summer. Chum salmon are suspected of spawning at some creek outlets[36]. The vast majority of spawning and rearing occurs in the upper watershed, in Lagace, Scorey, Belcharton and Draper Creeks, and in the upper sections of Chilqua Slough. A ground water channel was built in the headwaters of the Chilqua Slough in 1984, and accounts for the dramatic increase in chum salmon returns since that time. Two sturgeon of approximately 2 m in length were also caught in the lake in June of 1981[37].

The Hatzic Prairie watershed is dominated by agricultural land in the low lying areas and logging operations in the upper forested areas. Sedimentation and debris torrents, due to either natural or logging-related activities, have caused significant damage to many of the small tributaries used for coho and chum spawning and rearing. Sedimentation and sediment dredging have damaged or eliminated many spawning grounds. In the lower watershed, agricultural activities withdraw water for irrigation purposes and have removed riparian vegetation in some areas. Water quality has not been documented thoroughly enough to determine trends. However, if agricultural practices in the Prairie area resemble those in most other areas of the lower Fraser River, then water quality is likely degraded due to pesticide and herbicide applications, livestock management and riparian vegetation removal. FPAP lists all of the lower gradient valley bottom streams as "Endangered", while the upper watershed and higher gradient streams are considered "Threatened"[38].

3.1.1.3 Pump Station

The Hatzic pump station, located in the Dewdney Area Improvement District at the confluence of Hatzic Slough and the Fraser River, was installed in 1949 (see Photos 1 and 2). With only a few minor changes and ongoing maintenance, the original pumps remain in place and are recognized as being undersized for the watershed area being served[39]. Four concrete flood boxes were also built in 1949 adjacent to the pump house and have a total area of 14.4 square metres, are approximately 52 m long and are mounted with top-hinged cast iron flap gates[40]. The pumping station consists of a concrete base with a wooden superstructure that houses two identical pumps of the following characteristics:

Table 5: Characteristics of the Hatzic Slough Pumping Station pumps.

Pump No.	Make	Type	Total Station Capacity (USGPM)	Impeller speed (rpm)	Power (HP)
1,2	Paramount 1.22 m dia.	Propeller axial flow drainage pump	96,000	495	350

Major flood events in Hatzic Prairie usually occur between November and February, and June and July of any given year. Such floods usually occur during the freshet when the flood boxes are closed due to high Fraser River water levels and when regional storms drop significant amounts of precipitation in the watershed. The flooding in the fall and winter months is due in part to undersized flood box discharge capacity. Numerous studies have documented the flooding process and the ensuing problems (Wigmore, 1983; Ministry of Agriculture, 1980). In 1992 Dewdney Area Improvement District contracted Associated Engineering (1992) to analyze the flooding issue and make recommendations to alleviate flooding problems. The study's recommendations concerning the pump house and flood box configuration that are relevant to this report are as follows:

- increase pumping capacity from 48,000 USGPM to 114,000 USGPM, a 138 % increase;
- install a fish-friendly submersible vacuum pump complete with inclined and hinged screen in front of the lead pump, similar to the arrangement at the Matsqui Slough pumping station;
- provide only coarse trash rack screens on the remaining pump intakes and flood boxes;
- increase flood box area from 14.4 square metres to 28.8 square metres, a 100% increase;
- install side mounted flap gates on the discharge ends of the flood boxes.

However, since the completion of the study, none of the above infrastructure recommendations have been installed or built[41].

As with all other pumping stations, the spring pumping season is largely dependent upon the arrival of the Fraser River freshet in the spring of each year. The pumps generally begin to pump water from the Slough into the Fraser River when the Fraser River reaches 2.62 m (GSC). The pumping season can commence as early as March (in 1994) and end as late as late August (in 1998). The pumping schedule since 1991 is shown in Table 6. When the freshet arrives, the flap gates shut and remain closed until the Fraser River recedes to below 2.82 m, generally in late August. During this time, the pumps are on for an average of 10 hours per day[42].

Table 6: Pump start and stop dates for the Hatzic Pumping station between 1991-1998.

Year	Date that pumping starts and gravity discharge ends	Date pumping ends and gravity discharge starts
1991	May 6	August 6
1992	May 1	August 26
1993	May 1	August 23
1994	March 28	August 2
1995	April 27	July 17
1996	April 27	August 2
1997	April 25	August 17
1998	April 28	August 29

Source: McDonald, D. Per. comm.

The Department of Fisheries' involvement with the operation of the pumping station has been minimal. Associated Engineering (1992) reported that Fisheries, in commenting on the proposed pumping station and in particular on the screening of pump intakes, "demanded approach velocities that can be as low as 0.15 m. /sec, resulting in very large screen structures", and that Fisheries suggested they might "levy a tax on the operating municipality based on the fish loss due to pumping stations and its economic impact in the fishing industry." Local DFO staff have had no dealings of note with the station or operators in the last 5 years[43]. However, DFO now requires that future pumps installed at this facility must be fish-friendly[44].

3.1.1.4 Discussion of Pump Operation and Fish Migration

Fish mortality tests were first conducted on the Hatzic pump station in 1949 shortly after the pumps were installed (Anon., 1949). In this study dead Kamloops trout were placed in the forebay area. It was found that the degree of carcass mutilation due to contact with the propeller blades was directly related to size. Fish over 120 mm had a greater than 55% chance of being mutilated and Kamloops trout of the same size as coho smolts had a 33 % probability of being mutilated.

Since these tests were performed in 1949, the pumps have not been reconfigured and likely still cause significant mortality to all migrating salmonid species. George (1983) commented that "the pump, when in operation, poses a serious threat to out-migrating salmonids (smolts and kelts). Fish greater than 170 mm are killed attempting to pass through the pump and consequently most anadromous species are depressed." George (1983) also noted that repeat spawning cutthroat were almost absent from Hatzic Lake. Only a small percentage of female cutthroat spawners are sexually mature on their initial spawning migration. Successful female spawners would have to pass through the pumps or the flood box twice (in the downstream direction) before returning to spawn. Since the older female spawners are larger than 170 mm, it is plausible that the anadromous cutthroat population is depressed. George (1983) concluded that the absence of older more sexually mature cutthroat in the Hatzic system might prevent the system from becoming fully seeded.

It is clear from all the studies completed on the Hatzic drainage that the pump station and flood boxes are due for replacement or at the very least a major overhaul. The pump is old and inefficient, and the flood boxes are undersized. No current plans to replace the station are known of and replacement or at least an upgrade may not happen in the near future. Although Associated Engineering (1992) study found the pumps to be operating outside of the recommended service range, they also noted that "there is no reason to believe [the pumps would] not continue to do so." The cost for installing a new fish-friendly pumping station complete with new flood boxes was estimated at $2.7 million in 1992 dollars. As upgrading the station is likely well beyond the financial resources of the local dyking district, external funding sources and initiative will likely be required for the flooding issue (and the fish/pump conflict) to be addressed properly. Of all the pump /fish migration conflicts examined in this report, the one that exists at the Hatzic pumping station is likely of the most concern. In order to address this problem, it is recommended that the level of overall interest by all governmental and non governmental groups that have an interest in the upgrading or modifying of the station be determined. If there is no likelihood of the station being upgraded for flood relief reasons in the near future, a plan should be developed by DFO and others interested in fish passage issues to address the fish mortality problem. Reasonable options of installing fish bypass systems without upgrading the rest of the station may exist yet require further analysis to be identified and developed.

3.1.2 Katzie Slough

3.1.2.1 Introduction

Katzie Slough is located in Pitt Meadows and drains a large flat lowland on the northwest side of the confluence of the Pitt and Fraser Rivers (see Figures 1A – 1C). The entire drainage is located on the Fraser River delta and as such, is located behind dykes on both the Fraser and Pitt River. Before the dykes were built around Pitt Meadows, Katzie Slough flowed south into the Fraser River near Port Hammond and the Katzie Indian Reserve. Land developments inside the watershed include urban subdivisions in the upper areas, large agricultural areas (blueberry, livestock and tree farming), a golf course and the CP Intermodal yard.

3.1.2.2 Fish Resources and Watershed Quality

Katzie Slough contains mostly coarse fish and cutthroat trout[45]. One 1983 DFO report also lists coho salmon as inhabiting the Slough, although this is the only coho reference found in all databases[46]. Recent spot sampling in the Slough by environmental consultants only found resident coarse fish during late summer periods in isolated pools[47]. However, the Katzie band caught one chinook juvenile in an 18 hour set Gee trap

70 m upstream of the pumping station in April 1997[48]. In addition, a cursory biophysical survey completed in September 1978 found healthy cutthroat populations and good habitat[49]. Since that time, significant land development has taken place and the water quality has likely degraded. It is likely that if salmonids did inhabit the Slough during the summer months they would be in locations where cool groundwater upwelling occurred. Salmonids may inhabit the Slough during the winter and leave the system in search of higher quality habitat in the spring as water quality degrades. Although a recent biophysical assessment has not been completed on the Slough, it is suspected that salmonid habitat is marginal due to sluggish flows, poor water exchange, marginal riparian areas and most importantly, poor water quality especially during summer months. It is therefore likely that salmonids that did utilize the Slough for over winter rearing would be natal to other streams and would in-migrate to Katzie Slough sometime in the fall.

Water quality in Katzie Slough is suspected to be marginal during the summer periods for salmonids due to the reasons mentioned above. No water quality data are available that indicates monthly water quality parameters. FRAP considers the watershed as "Endangered." The majority of the watershed is dominated by agricultural activities, and water quality is likely highly impacted by agricultural runoff and water withdrawals for irrigation.

3.1.2.3 Pump Station

The pumping station is located approximately 30 m upstream of the confluence of the Slough with the Pitt River (see Photos 3 and 4). The existing pumping station, known as the Kennedy Pumping Station, was constructed in 1983 under the auspices of the Canada – British Columbia Fraser River Flood Control 1968 Agreement. It replaced a smaller pump house and flood box structure. The present pumping station consists of four flood boxes with side mounted flood gates and four pumps with the following characteristics:

Table 7: Characteristics of the Katzie Slough pumping station pumps.

Pump No.	**Make**	**Type**	**Total Station Capacity (USGPM)**	**Impeller speed (rpm)**	**Power (HP)**
1 - 4	ABS Pumpen	VUP-704 submersible propeller axial flow	95,000	590	112

The pumps' operation is automatically controlled and switched by the water level in the Slough. The pumps turn on and off in a pre-determined sequence at pre-determined water levels. Typically the pumps run during the Pitt River freshet from May to August. Pump cycling is largely dependent upon the water level of the Pitt River, the amount of precipitation in the Katzie Slough watershed, and the amount of upwelling groundwater. There were no special fish passage provisions required by DFO when the Kennedy station was installed in 1983. Since installation, DFO has not had any significant involvement with the station.

3.1.2.4 Discussion of Pump Operation and Fish Migration

Dykes and the pumping station have governed the hydrology of Katzie Slough watershed for several decades. In addition, water quality in the Slough has likely degraded in the last few decades. As such, it is not surprising that salmonids are not known to inhabit the Slough, although sampling during the winter months is required to confirm this belief. It is likely that the Slough's water quality is acceptable during the winter months for in-migrants seeking non-natal stream refuge from the Pitt River mainstem. It is not clear whether the current flood boxes act as in-migration barriers during fall and winter months. To determine the impact of the flood boxes, further research needs to be done on the local watershed and Pitt River hydrology, water levels, water velocities and operational characteristics of the flood boxes, and pump cycling. It is suspected that juvenile coho or other species seeking refuge or non-natal water rearing opportunities could access the Slough during winter months when the flood box gates are open and the water velocities inside the flood boxes are low. How often this situation occurs however, is not known and should be examined more closely. The fact that only a single chinook was sampled in the Slough in the spring points to possible in-migration access problems though the flood boxes, as smolting chinook are known to hold in side channels during their migration to marine environments. Salmonids that did manage to access and over-winter in the Slough and smolted late in the spring would necessarily pass through the pumps and sustain injuries. Early out-migrants would likely pass through the flood box before the Fraser and Pitt River freshet arrives in May.

Without the benefit of a detailed bioinventory, it is suspected that Katzie Slough primarily functions or has the potential to function as an over-wintering non-natal stream for salmonids. This assumption should be checked however by conducting a detailed bioinventory and water quality sampling program to determine salmonid over-winter rearing use, potential spawning sites (likely in groundwater upwelling areas), and factors limiting salmonid utilization of the Slough. If the surveys conducted in the late winter find adequate rearing water quality but no salmonids, then the flood box would be suspected of being an in-migration barrier. If it is determined that salmonids do over-winter in the Slough in significant numbers, then the pump station's operating characteristics should be examined more closely to determine whether a fish/pump conflict exists. If a conflict does exist, operational or physical change options may exist to increase safe smolt out-migration during the freshet.

3.1.3 Matsqui Slough and Tributaries

3.1.3.1 Introduction

Matsqui Slough is located on the Matsqui Prairie in the City of Abbotsford at the northern end of Gladwin Road and drains directly into the Fraser River (see Figures 1A – 1C). The slough's confluence with the Fraser River is directly south of the City of Mission on the south bank of the Fraser River. The Slough and tributaries drain approximately 7,770 hectares of mostly agricultural land, with the most significant tributaries being Page, Willbrand and Clayburn Creeks. Drainage for agricultural purposes is difficult in the southern most section of the watershed due to both depressed areas and the high middle section. Hence, flooding is common in the southern section. The Matsqui Slough pump station (also known as the Gladwin station) through which all the flood waters drain is located immediately upstream of the confluence of the Slough and the Fraser River. The District of Abbotsford is wholly responsible for the pumping station's maintenance and operation.

3.1.3.2 Fish Resources and Watershed Quality

Of the salmonids, coho, chum, chinook and pink salmon, cutthroat trout and steelhead trout are known to inhabit Matsqui Slough and its tributaries[50,51]. The better fish spawning habitat exists in the tributaries and not in the Slough itself. Clayburn Creek is the most productive, with spawning in the middle reaches upstream from the confluence with Stoney Creek. Summer rearing of the entire system is marginal, however, due to poor water quality and extreme low flows during summer months. In the Slough itself, low dissolved oxygen levels can form a barrier to in-migrating salmon adults bound for spawning grounds further up the watershed[52]. Historically, coho have been recorded in Clayburn Creek since 1950. Chum and pink salmon were also consistently recorded between 1950 and 1969, but within the last 30 years only chum have been noted only twice by fisheries officers. Steelhead have consistently been recorded in Clayburn Creek since 1972. Refer to Table 2 for a summary of escapement statistics or Appendix 1 for complete escapement details.

Matsqui Slough and tributaries pass through a mixture of cultivated lands and mixed urban/rural development. As a result of agricultural practices, drainage projects, residential and commercial developments, both water quality and quantity have degraded to the point where salmonids populations are "Endangered"[53]. Water quality tests in the Slough and in Page Creek indicate low dissolved oxygen and high nutrient concentrations, most likely caused from algal die-off and agricultural animal manure inputs[54]. In addition, withdrawals for irrigation purposes exceed the naturalized summer seven-day low mean flow. To address the demand for irrigation water, the District of Abbotsford installed a bi-directional pump in the early 1990s at the pumping station to pump water from the Fraser River into the Slough during the late summer when natural flows are minimal and irrigation withdrawals are high[55]. This operational mode is discussed in more detail below.

Clayburn Creek, the system's most productive tributary, is also considered "Endangered" by FRAP for many of the same reasons as Matsqui Slough, including concentrated urban development in close proximity to the stream. Water quality is better than that in the Slough, especially in upland areas where riparian vegetation has been preserved and agricultural and urban development is minimized. However in the lower sections of Clayburn Creek, water quality issues remain a concern, especially total ammonia concentrations and temperature levels. Many lower sections of the creek that pass through agricultural areas are dyked and have no riparian vegetation, and water withdrawals for irrigation far exceed the seven-day mean low flow[56].

3.1.3.3 Pump Station

The current Matsqui pumping station was built in 1973 and has been modified several times since then (see Photos 5 and 6). The current station houses the following pumps:

Table 8: Characteristics of the Matsqui Slough Pumping Station pumps.

Pump No.	Make	Type	Capacity (USGPM)	Impeller speed (rpm)	Power (HP)
1 & 2	Peerless	Propeller axial flow	30,000	710	200
3	Paramount	Propeller axial flow	32,000	680	200
4	ABS Submersible	Propeller axial flow	31,000	594	170
5	Flygt Submersible VUP 705	Propeller axial flow	35,000	590	275
6	Flygt Submersible PL 7060	Propeller axial flow	15,850	875	120
7	Aqualife Model 1080-P	Hydraulic drive	1,109	unknown	unknown
Total station capacity (approx.)			145,000		

The station also has four concrete square flood boxes with side mounted flap gates on the outfalls. One of the flood boxes has an electrically operated sluice gate on the box's entrance. This feature is discussed in detail below.

The operation of the station's pumps is, relative to other pumping stations, complex because the City of Abbotsford has several operational objectives for the station. The station has to satisfy basic flooding issues during winter storms and the Fraser River freshet, allow fish to pass safely, and maintain adequate water levels during the late summer and fall for irrigation purposes. The station operates in four modes: summer, irrigation, drainage, and winter.

- Summer mode: This mode is set to begin March 1 and lasts until sometime between August 1-30. Pumps No. 5 and No. 7 (the fish-friendly pump) are the lead pumps and can usually handle all the pumping needs for this period.

- Irrigation mode: In years when the Slough water level is low during late summer and early fall (due to low Fraser River levels), stop logs are placed in front of the flood boxes to maintain high water levels in the Slough (see Photo 7). Bi-directional pump No. 6 is reversed and pumps water from the Fraser River into the Slough when required. Irrigation mode lasts from sometime between August 1-30 until mid September.

- Winter and drainage mode: From mid-September to April 30th, the pumps are set to turn off and on in an ordered sequence according to set water levels in the Slough. As water levels pass the first set point, one pump turns on. If the water level continues to rise, a second pump turns on. If the water level remains constant, the first pump will remain on until the water level drops to a preset water level. The pumping set points and pumping sequences are computer controlled but can be remotely overridden by station operators from the City's office.

Of particular interest for this study are the "summer" and "irrigation" modes.

During the summer mode, Pump No. 5 is the lead pump during the summer freshet. In 1992, the District installed Pump No. 7, a fish-friendly submersible vacuum pump complete with hinged screen in front of Pump No. 5. When the water level in the forebay exceeds a pre-determined level, Pump No. 5 starts. After a 30 second delay, Pump No. 7 starts and continues to pump until Pump No. 5 shuts down. The fish-friendly pump is mounted on a sloping screen in front of the lead pump. The screen mesh openings are small enough to prevent smolt sized salmonids from passing through the screen. The fish are forced down the sloping screen to the bottom, where the fish pump intake is located. The fish are sucked into the vacuum pump and passed around the pumping station in a pipe and deposited via a concrete flume into the Fraser River. The other five pumps will start automatically in sequence if the lead pump is unable to maintain or reduce the water level in the forebay area. Pump No. 5 is the only screened pump for the smolting period, and is typically on 6-8 hours per day during the freshet. During other pumping modes the screen is in the up position and the fish pump inoperable. Smolts would certainly be drawn into Pumps No. 1-4 if all or any combination were running during any operational mode.

In irrigation mode, water levels are maintained in the Slough by inserting stop logs in front of the flood boxes. In the event of a significant regional summer storm, one of the flood gates has an electrically operated slice gate that can be easily opened to allow flood waters to exit through one of the flood boxes in case the pumps are unable to handle the sudden increase in water volume. Lastly, Pump No. 6 is bi-directional and pumps water from the Fraser River into the Slough when Slough water levels drop below a certain level. In this manner during low precipitation periods, farmers can irrigate their fields using water from the Slough without fear of depleting the water resource.

DFO's last significant involvement with the pumping stations was in 1990 when the fish pump and screen were installed[57].

3.1.3.4 Discussion of Pump Operation and Fish Migration

Although a significant amount of time and energy has been expended over the fish/pump conflict at the Matsqui Slough pumping station, a fish / pump conflict still exists. One of the concerns with the current pumping arrangement is that only one of the pumps is screened and combined with a fish-friendly pump. Smolts or any other migrating fish can easily be sucked into the remaining five pumps when they are operational. A review of the operations manual for the pumping station indicates that the "summer [operational] mode" is set for the months April –June. During this time, Pump No. 5 is the lead pump with the fish pump in operation. An analysis of the operational data supplied by the City of Abbotsford for the 1998 operating season indicate that during May, the peak migration smolting period, non fish-friendly pumps were in operation 33 % of the total pumping time (for additional detail concerning pumping hours for each pump during 1998, refer to Appendix 2, otherwise refer to Table 9).

Table 9: Pumping hours for fish-friendly and non fish-friendly pumps for Matsqui Slough pumping station for 1998.

Month	**Hours of operation**		**Percentage of time pumps 1-4,6 in operation (non fish-friendly).**
	Pumps 1-4, 6	Pumps 5 and 7	
April	0.24*	0.08*	75 %
May	107.33	220.85	33 %
June	0	362.82	0 %

* hours are likely related to pump and motor maintenance.

It is difficult to determine the degree of impact the operation of the non fish-friendly pumps has on fish populations. Certainly some smolts would be entrained in Pumps Nos. 1-4 and 6 during all operational modes, including summer mode. Determining an entrainment figure and resulting impact is difficult when more pumps than Pump No. 5 are running and is dependent upon understanding:

- which section of the channel (thalweg or banks) in the forebay area is more attractive to migrating fish. If fish congregate along the right bank when migrating then the impact may be lessened since the fish-friendly pump is located along the right bank. If the smolts (and other migrating juveniles) prefer the center of the stream where the current is faster and the non fish-friendly pumps are located, then the impact could be quite significant. If the smolts prefer the left bank, the impact could be very high as they would have to swim across the entire forebay area towards the right bank to escape entrainment in the non fish-friendly pumps;

- when the smolts arrive at the pumping station and what triggers them to leave the system. If high flows in the creek trigger migration, then it is likely that entrainment in non fish-friendly pumps is high, since more of the pumps are operational at the same time during flood events. A detailed analysis of daily pumping logs would be required to determine the severity of this issue. Such an analysis is highly recommended;
- whether other fish (notably coho fry) are migrating downstream to habitat downstream of the pumping station. If juveniles are migrating, then the timing or migration time triggers should be determined and contrasted with the pump operation.

These issues require further analysis before the severity of impacts of the non-fish friendly pumps running during migration period can be determined.

The use of stop logs to raise the water levels in the Slough during late summer low flows is another issue of concern (see Photo 7). The use of stop logs essentially prohibits fish, in this case juvenile coho or resident trout, from leaving the system during August and part of September. Notably, this is the period when water quality is the poorest, as water temperatures are typically elevated and dissolved oxygen levels suppressed. Under these circumstances, juveniles migrate and seek out reaches with better water quality. Placement of the stop logs at the pumping station effectively traps juveniles in the creek and in habitats that are sub-optimal, and in some areas lethal. In the case where pumping is required during the irrigation mode (during a short intense rain storm), the lead pump remains Pump No. 5. that is coupled with the fish-friendly pump. This issue requires further analysis, possibly even some sampling at the pumping station mouth when the pumps are running during the late summer to determine whether juveniles are attempting to migrate past the station. If juveniles are attempting to leave the system, this points to a need to address either allowing safe passage at irrigation times through the flood boxes (i.e. remove the stop logs and reconfigure irrigation procedures) or address the water quality (and likely quantity) during summer months by augmenting areas with groundwater, enhancing known summer rearing areas to increase holding densities, or other options.

3.1.4 McLennan Creek / Gifford Slough

3.1.4.1 Introduction

McLennan Creek is located in Abbotsford and drains approximately 4,360 hectares of primarily agricultural land. The mouth of the creek is approximately 76.5 kilometres from the mouth of the Fraser River (see Figures 1A – 1C). The present pumping station, named the McLennan Creek or the “Glenmore” pumping station, was built in 1973 and is located 100 m upstream from the confluence with the Fraser River on Gifford Slough. McLennan Creek comprises most of the drainage area, and contains the more valuable fish habitat than found in Gifford Slough. The City of Abbotsford is wholly responsible for the pumping station's maintenance and operation.

3.1.4.2 Fish Resources and Watershed Quality

McLennan Creek and Gifford Slough support several salmonid populations, namely coho, chum, anadromous and resident cutthroat, steelhead and rainbow trout[58]. No escapement number records are available for either the creek or the Slough. In addition, few biological studies exist on this system, presumably for the reason that the Matsqui Slough-Clayburn Creek watershed is 1.5 km to the west and has almost identical morphology, land use and drainage problems, and has been studied extensively. One could assume that the salmonid species present and densities would be similar.

Water quality indicators in Gifford Slough and McLennan Creek are similar to those in the Clayburn Creek-Matsqui Slough watershed. Gifford Slough and McLennan Creek suffer from low dissolved oxygen concentrations, high fecal coliform counts due to improper manure handling and high temperatures during summer months[59]. However, other indicators, such as urban development and water withdrawals for irrigation reveal relatively better water quality conditions than in Clayburn Creek and Matsqui Slough. However, both systems suffer from narrow or non-existent riparian areas, and intensive agriculture activities that result in poor water quality. FRAP biologists have rated the watershed as "Endangered".

3.1.4.3 Pump Station

The present McLennan pump station (see Photos 8 and 9) was installed in 1973 and houses the following four pumps:

Table 10: Characteristics of the McLennan Creek Pumping Station pumps.

Pump No.	**Make**	**Type**	**Capacity (USGPM)**	**Impeller speed (rpm)**	**Power (HP)**
1 & 2	Peerless	Propeller axial flow	28,200 each	710	200
3	Flygt Submersible PL 7060	Propeller axial flow	28,055	590	295
4	Aqualife Model 1080-P	Hydraulic drive	1109	N/A	unknown
Total pumping capacity (approx.)			85,500		

The pumping operation at the McLennan Creek pumping station is similar to the Matsqui pumping station operation except that there is no bi-directional pump that draws water from the Fraser River during dry spells. The Flygt submersible pump coupled with the Aqualife fish pump and screen and is the lead pump during the "summer" mode when smolts are leaving the system.

The station also has two square concrete flood boxes with side mounted gates on the outfall. During the summer irrigation season in years that the river water level is low, stop logs are placed in front of both flood boxes to raise and maintain the water level in the Creek. The stop logs are usually inserted during August and are not typically removed until mid-September.

DFO has had no involvement with the station since the installation of the fish pump.

3.1.4.4 Discussion of Pump Operation and Fish Migration

Except for the issues that deal specifically with the bi-directional pump at the Matsqui Slough pumping station, the fish passage issues at the McLennan Creek station are similar to those at the Matsqui Slough pumping station. Due to time constraints, the pumping cycling data from the McLennan Creek station were not analyzed. It is recommended that this be done in order to understand further the impact the station has on migrating salmonids. Such an analysis would likely reveal that the fish-friendly pumping arrangement is not as functional as currently believed, for the same reasons as discussed in the Matsqui Slough pumping station section (For a complete discussion of the fish-friendly pump, see Sections 2, 3.1.3 & 4.2).

The flood boxes at the McLennan Creek station may pose a barrier to in-migrating juvenile salmonids seeking upstream natal or non-natal habitat. Water velocities observed (although not measured) during a February storm in the flood box appeared to exceed the sustained speed for coho juveniles of 0.3 – 0.5 metres per second (See Table 4). This matter requires additional observation and study to determine whether in fact it is of concern for this station.

The use of stop logs to raise the water levels in the Slough during late summer low flows is another issue of concern. The use of stop logs essentially prohibits fish, in this case juvenile coho or resident trout, from leaving the system during August and part of September. Notably, this is the period when water quality is the poorest, as water temperatures are typically elevated and dissolved oxygen levels suppressed. Under these circumstances, juveniles migrate and seek out reaches with better water quality. Placement of the stop logs at the pumping station effectively traps juveniles in the creek and in habitats that are sub-optimal, and in some areas lethal. In the case where pumping is required during the irrigation mode (during a short intense rain storm), the lead pump remains Pump No. 2 that is coupled with the fish-friendly pump.

This issue requires further analysis, possibly even some sampling at the pumping station mouth when the pumps are running during the late summer to determine whether juveniles are attempting to migrate past the station. If juveniles are attempting to leave the system, this points to a need to address either allowing safe passage at irrigation times through the flood boxes (i.e. remove the stop logs and reconfigure irrigation procedures) or address the water quality (and likely quantity) during summer months by augmenting areas with groundwater, enhancing known summer rearing areas to increase holding densities, or other options.

3.1.5 Miami Creek

3.1.5.1 Introduction

Miami Creek is located in the Harrision-Lilloet habitat management area, and drains into Harrison Lake immediately west of the Village of Harrison Hot Springs (see Figures 1A – 1C). An old pump housed in a building that resembles a windmill pumps water from Miami Creek into Harrison Lake when Harrison Lake is in flood, usually from May to August. The water level in the lake, and the dates the flood box gates close are dependent upon the rate and extent of snowpack melting and rainfall. The Village of Harrison Hot Springs administers and maintains the pumping station.

3.1.5.2 Fish Resources and Watershed Quality

Miami Creek is reported to support both coho salmon and cutthroat trout. Escapement records reveal that spawning coho were last recorded in 1969; however, the installation of the new flood box in 1993 enabled spawning fish to gain access Miami Creek for the first time in many years[60]. The public works staff for the Village of Harrison Hot Springs also recall recently seeing spawners (species unknown) in the headwaters of the watershed. Spawners have also been noted excavating redds in the culvert that passes under Highway No. 9[61]. There are no records of the timing of spawning salmon in-migration or smolt out-migration for the watershed.

The Village of Harrison Hot Springs is interested in conducting a much needed biophysical study of the watershed to determine presence and abundance of biological aquatic resources[62]. Currently it is difficult to determine abundance and utilization trends of aquatic resources in the watershed simply because there are little baseline data available. It is recommended that in addition to conducting a standard biophysical inventory that the Village also enumerate spawning numbers, spawning locations, and emergent fry and smolting periods with detailed descriptions as to environmental factors that influence such periods.

Before the dyke was placed to protect the area now occupied by the Village, the entire alluvial fan south of the Lake likely flooded each spring with the rising Harrison Lake water levels. Miami Creek was likely then a low gradient highly productive rearing area for several salmonid species. However, with the building of the dyke and subsequent rural and agricultural development Miami Creek more resembles a “swamp”[63]. The middle and lower sections resemble many other Fraser Valley low gradient creeks that pass through agricultural land. Riparian areas are largely void of vegetation in the lower and mid sections, and agriculture runoff has resulted in excessive nutrient loading and algal blooms[64]. Several upper sections are channelized and follow road and property alignments[65]. Water withdrawals for irrigation purposes are considered moderate compared with other watersheds in the Fraser Valley. The naturalized summer 7-day low flow is 11% of the mean annual flow[66]. FRAP considers the watershed as "Endangered".

3.1.5.3 Pump station

The Miami Creek pumping station was installed in 1948 with a used pump and motor acquired from the Mission area[67] (see Photos 10-12). The same pump and motor are still in use. Due to its age, little is known about the pump and there is local concern that the pump is unreliable because of its age. A coarse screen in front of the pump intake partially prevents debris from entering the sump area.

Table 11: Characteristics of the Miami Creek pumping station pump[68].

Pump No.	Make	Type	Capacity (USGPM)	Impeller speed (rpm)	Power (HP)
1	Unknown	Propeller axial flow	26,000 – 36,000	Unknown	75

Two new flood boxes and pump house foundation were constructed in 1993 under the auspices of the Fraser River Flood Control 1968 Agreement. Part of the dyke in the immediate area was also rehabilitated. The new flood boxes have two opposing side mounted flap gates that are set at approximately 4 degrees off vertical. The new flood boxes lower the creek water level by about 1 metre more than the old flood box did. Water flows freely out through the flood boxes at all times except during spring freshet when the flap gates are closed[69].

The automatically operated pump is governed by the water level in Miami Creek in the sump area. During the spring and summer, Harrison Lake rises due to snow pack melt and precipitation in the Harrison and Lilloet River watersheds. The floodgates typically close in May and remain closed until August. The pumping station operates as needed to keep water levels in Miami Creek at preset levels. From discussions with Village staff, the pump only runs during the summer after a significant regional storm. During dry summers, such as in 1996 and 1998, the pump doesn't run at all[70]. Unfortunately most of the pump annual records are not detailed enough to easily allow determination of pumping start/stop times and dates. The Harrison Lake water levels recede in time for the fall rains, and the current flood box capacity adequately handles fall and winter runoff.

Apart from the motor being rewound once in recent years, the pumping station has received little attention. When the new flood boxes were installed in 1993, a concrete sump was poured to support 2 new pumps to be installed at a later unspecified date. The engineering drawings indicate that the new sump was designed to encase two traditional vertical propeller style pumps. The sump may be too small to house fish friendly screw pumps that will likely be required by DFO when the existing pumping station is eventually replaced[71].

DFO's last major involvement with the pump station was in the early 1990's when the new flood boxes were built. Currently DFO and MELP sit on a Miami Creek committee that periodically examines fish related issues in the watershed.

3.1.5.4 Discussion of Pump Operation and Fish Migration

Miami Creek pumping station has long been suspected as killing or injuring fish, particularly migrating smolts. Given the record of other similar pumping stations in the lower Fraser River, this suspicion is not unreasonable. However, there are little data and no anecdotal evidence available to support this opinion.

Whether the smolts leave Miami Creek through the flood box before the Harrison Lake water level rises, or are entrained in the pumps is largely dependent upon the rate of snow melt in the Harrison and Lilloet River watersheds and the rainfall in the Miami Creek watershed. During an average year the coho and chum smolt migration will likely peak in mid May, approximately the same time the Harrison Lake water levels begin to rise. In years that experience a wet spring and summer, and given the general coho and chum smolt migration timing and the flood gate closure period, some later migrating smolts are likely entrained and killed by the pump. However, in low precipitation years when the pump doesn't run, the late leaving smolts are trapped in the Creek and will either likely perish due to unfavorable water quality, or spend another year rearing hoping to smolt the following year. Hence the likelihood of salmonids becoming entrained in the pump is largely dependent upon the amount of precipitation and runoff in the Miami Creek watershed, and the amount of water withdrawals for irrigation purposes. The lack of salmonids is likely due to the fact that in some years the smolts can't get out of Miami Creek at all, because of gate closures during the smolting period. It is interesting to note that the local MELP habitat protection officer has never observed fish mortality at the station nor received public complaints concerning fish mortality at the pumping station[72].

Given the above information coupled with the lack of biological knowledge and pump cycling information, it initially appears that the pump is not the most significant factor that limits salmonid migration. The limited data points to the dyke and the altered hydrology of the Creek as the limiting factors. However, it is difficult to assess the real impact of the pump station, flood box operation and the dyke in general on the salmonid population without additional biophysical data (as recommended above) and analysis of the pump cycling records. Further study to shed light on these data gaps is highly recommended.

3.1.6 McLean Creek

3.1.6.1 Introduction

McLean Creek drains a small watershed (area estimated at 960 hectares) into the Pitt River immediately north of the City of Coquitlam / City of Port Coquitlam border. The station is within the North Deboville Dyking District which is administered by MELP

Region 2. McLean Creek is sometimes referred to as Alarm Creek or North Deboville Creek. Little is known about the biology, hydrology or the physiography of this small watershed.

3.1.6.2 Fish Resources and Watershed Quality

Very little is known of the fish resources in McLean Creek. Officially the creek only contains cutthroat trout[73]. However the Katzie band sampled for salmonids in April 1997 and found 6 chinook ranging from 40-70 mm fork length and two small cutthroat trout upstream of the pumping station[74]. The watershed is reported as having excellent rearing habitat[75], although the fact that coho were not sampled may be due to several issues: spawning habitat is negligible, the watershed suffers from lethal water quality conditions when salmonid are unable to out-migrate, the pumping station has eliminated any species natal to the creek due to poor access in both directions, or a combination of all three factors.

3.1.6.3 Pump Station

The pump station, known as the "North Deboville Pump Station" pumps water from the creek into the Pitt River during the freshet when the Pitt and Fraser Rivers are at high stage (see Photos 13 and 14). The pump station, originally built in 1938 at the present location, has the following characteristics:

Table 12: Characteristics of the McLean Creek pumping station pump.

Pump No.	**Make**	**Type**	**Capacity (USGPM)**	**Impeller speed (rpm)**	**Power (HP)**
1	Paramount	36 inch propeller axial flow	20,000	Unknown	60

The original pump and motor still exist, although both were rebuilt in 1992 when the pump house superstructure was replaced[76]. Pump records were not available for analysis during this study. The records are kept in the pump house and only reveal the number of hours on the pump, with no date association.

The existing flood boxes were installed in 1984 and have greatly increased the gravity drainage capacity relative to the older flood boxes. As a result, the pumps are only used occasionally during high water levels in the Pitt River, although during a local heavy rainstorm the pumps can run up to 23 hours per day[77]. The flood box flap gates are round, top-mounted and made of cast iron.

DFO has had no recent involvement with this pumping station.

3.1.6.4 Discussion of Pump Operation and Fish Migration

It is likely that since the watershed size is relatively small, and would receive little water from snowmelt, the amount of water requiring to be pumped during the spring and summer freshet would be minimal. It is suspected that the pump only operates after summer rain storms when the flood boxes are closed due to the high Pitt River water level. However, seepage and upwelling may occur in the watershed, and thus would necessitate additional pumping.

Since little readily available data exists that indicated when the pump is on during the spring and summer months, it is difficult to assess the impact the pump has on the salmonid population. However, there is no doubt that the flood boxes exclude salmonids attempting to in-migrate McLean Creek from other watersheds during the freshet, and perhaps even adults seeking spawning areas in the fall. A velocity barrier inside the flood box likely discourages fry from entering the creek during periods when the Creek and River water levels are equal, or during times when water is being discharged out the flood boxes. During the fall when water flows through the flood boxes is small, adult salmon seeking spawning sites may be unable to negotiate the small opening between the gate and the pipe (see Sections 2.4 and 4.2.3 for a complete discussion of this problem).

It appears that without the aid of biological, hydrological or pump cycling data that the flood box gates are likely the most significant limiting factor to salmonid migration in both directions. It is recommended that additional information be gathered on salmonid utilization of the watershed, the local hydrology (specifically water levels) and pump cycling information. Although the flap gates on the flood boxes were recently installed, it is highly recommended that they be scrutinized to determine whether they pose a migration barrier as assumed. If the assumption is proven valid, the purchase and installation of side mounted gates (with provisions to keep Pitt River debris from jamming the gates open during freshet) should be considered.

3.1.7 Mountain Slough

3.1.7.1 Introduction

Mountain Slough, part of the District of Kent, drains a small watershed of approximately 3,100 hectares into the Fraser River 7 km due west of Aggasiz (see Figures 1A – 1C). A dyke and pump station at the confluence of the Fraser River and the Slough protects the area. Land development is predominantly agricultural in the low lands while in the mountainous upper watershed logging takes place.

3.1.7.2 Fish Resources and Watershed Quality

Coho and chum salmon and cutthroat and rainbow trout are the only salmonid resources that are found in Mountain Slough. Coho and rainbow trout have been sampled in the upper reaches of McCallum Ditch, a tributary to Mountain Slough, in the vicinity of the Mountain Institute in Agassiz[78]. Coho are known to use the upper sections of the watershed, while chum utilize the lower kilometre of the Slough[79]. Little else is known about the biological resources or water quality in the watershed. Due to the significant amount of agriculture in the watershed and the low base flows, the water quality likely is very poor in the summer months, and contains high nutrients concentrations which can cause eutrophication and chronic weed growth.

3.1.7.3 Pump station

The Hammersley pumping station pumps water from the sections of Mountain Slough that are located behind the dyke into the Fraser River. The station is of unknown vintage but the oldest pump was installed in 1956 (see Photos 15 and 16). The pump house contains two pumps of the following characteristics:

Table 13: Characteristics of the Mountain Slough pumping station pumps.

Pump No.	**Make**	**Type**	**Capacity (USGPM)**	**Impeller speed (rpm)**	**Power (HP)**
1	Peerless	Propeller axial flow	23,500	595	125
2	Fairbanks-Morse	Propeller axial flow	11,500	870	50

Two older style flood boxes that were likely installed in the 1950's pass gravity flow water during the fall, winter and spring periods around the pumping station. Unlike most other flood boxes, these gates are manually operated top mounted sluice gates, and when closed, remain closed until manually opened. They will not open with the fluctuations of the water level in the Fraser River, as flood boxes mounted with hinged flap gates will.

The pump station's operation is straightforward. When the Fraser River freshet arrives and the Fraser River water levels rise, the flood gates are manually closed. Water levels in the Slough rise and when a certain elevation is reached, Pump No. 2 is activated. Pump No. 1 will only start if Pump No. 2 is unable to maintain or draw down the water level in the Slough. The pumps typically will start running from March 10th to April 15th, and stop in the period of August 1st to September 15th. The pumps are considered undersized although the District of Kent rarely hires temporary pumps to draw down high water levels in the Slough[80].

DFO has had no involvement with the pumping station for many years[81].

3.1.7.4 Discussion of Pump Operation and Fish Migration

Relatively little is known about the potential conflict between migrating fish and the pumping station and flood box. Indeed, little is known about the fish and habitat values in the Slough itself. However, based upon discussions with DFO staff, District of Kent staff, and from anecdotal reports, the pumping station is believed to kill or maim migrating fish, specifically smolting coho and chum. A fisheries officer in 1978 described the station as "…having a severe detrimental effect on migrating fry and smolts."[82] Based upon fish mortality tests conducted in the lower mainland over the last 20 years, mortality rates of 25 - 70 % are likely (see Table 3). Unfortunately the pumps' cycling data are not in a usable format for the purposes of this report. However, water level data may exist that would shed light on the operating characteristics of the pumps. It is recommended that this and other data be collected and analyzed, or other methods be utilized to determine the operating characteristics of the pumps.

The arrival of the Fraser River freshet dictates the date the sluice gates on the flood boxes are closed and the pumps activated. Unlike hinged flap gates at most other pumping stations that open and close with changing Fraser River water levels, the sluice gates require an operator to raise or lower them. The result is that if the Fraser River water level drops for a short time after the gates have been closed, access in either direction through the flood boxes is not possible. Additional fish passage through the flood box would be possible with a side mounted flap gate mounted on the end of the flood box, although this may only increase the number of fish passage days slightly.

The flood boxes may constitute a fish in-migration barrier. Initial observations of the flood box reveal that a velocity barrier might exist for juveniles attempting to access the upper watershed areas during times when the sluice gates are open. This may be due to undersized flood boxes, resulting in a high hydraulic gradient and high water velocity inside the flood boxes. Additionally, a significant head loss at the flood box entrance results in a water elevation drop of up to 0.5 m. during higher discharges[83]. The result is that juvenile access to habitats upstream of the flood box may be restricted to times of low to extreme low flow. This item requires additional analysis and field assessment during the winter, spring and fall months when many species of salmonid juveniles in the Fraser River are seeking refuge in natal and non-natal sloughs and side channels. Further analysis of this issue is highly recommended.

Another issue of concern involves the occasional running of the pumps when the flood boxes are fully open and water is being discharged to the Fraser River. This is done to increase draw down rates in response to requests from the agricultural community to drain the Slough faster. The result is that fish may be drawn into the pumps which are situated upstream of the flood boxes. It should be noted that the discharge capacity of the pumps is a minute fraction of the discharge capacity of flood boxes, even given the assumption that the flood boxes are undersized. Turning the pumps on to draw down the water levels likely makes little difference to the draw down time and results in higher electrical and pump maintenance costs. The solution to this issue involves discussions between representatives of the agricultural community and the District, and developing an understanding the costs and benefits of running the pumps for this purpose.

While it is acknowledged (although not proven) that the pumps kill fish, simple and easily implemented solutions to address this problem are not apparent. However, a small measure to improve the situation involves reversing the pumping sequence such that lower speed Pump No. 1 is the lead pump. Fish mortality may be reduced slightly in this manner. How this change would impact on the overall operation, costs and maintenance of the pumping station is unclear and requires consultation with the District. There are also a number of options for dealing with the larger fish mortality issue that are discussed in Section 4.

3.1.8 Nathan Slough

3.1.8.1 Introduction

Nathan Slough is a relatively small and poorly understood drainage of approximately 1440 hectares that drains directly into the Fraser River on the municipal boundary between the Township of Langley and District of Abbotsford (see Figures 1A – 1C). The area is known as “Glen Valley” and has its own dyking district of the same name. Nathan Slough is not to be confused with Nathan Creek which is a much larger creek that drains mostly Abbotsford and flows into the Fraser River approximately 2 km. to the west of Nathan Slough. It appears from a review of airphotos that Nathan Slough and Creek were once connected, and that the lower sections of Nathan Creek were created to divert upland water from passing through Glen Valley. The lower 3.5 km section of Nathan Creek is both dyked and channelized.

3.1.8.2 Fish Resources and Watershed Quality

Little fish or other biological data exists for Nathan Slough. The FISS database indicates that cutthroat trout inhabit the Slough, although it is not clear if they exist upstream or downstream of the pumping station. A Langley Environmental Partners Society (LEPS) crew recently sampled for fish upstream of the pump station and found four coho juveniles in January 1999[84]. There is no habitat information currently for the system. However, from initial cursory field observations and air photo analysis, Nathan Slough appears to have poor winter rearing habitat, and little or no spawning habitat upstream of the pump station and marginal riparian or instream cover below an impassable culvert at 88th Avenue.

Nathan Slough drains a mixed-use agricultural area. Hog and livestock operations, as well as cranberry and other crops are managed in the Glen Valley[85]. The water quality is very poor during the fall and spring months, with very high ammonia concentrations, high fecal coliform counts and low dissolved oxygen levels. Benson Canal, a former creek that has been converted into a drainage ditch, has virtually no riparian zone left intact, and is likely a source for agricultural runoff that drains directly into Nathan Slough[86]. Summer coho rearing habitat would likely be marginal for these reasons. FRAP considers Nathan Slough as “Endangered”.

3.1.8.3 Pump station

Nathan Slough is regulated by a pumping station approximately 700 m upstream of the confluence with the Fraser River (see Photos 17 and 18). The station comprises of two separate pump houses. Representatives of the Glen Valley Dyking District could not confirm any details about the pumping station[87]. However, it is known that one station was built or refurbished in 1950, and the other built at an unknown but suspected later date. The pumping stations are believed to have the following characteristics:

Table 14: Characteristics of the Nathan Slough Pumping Station pumps.

Pump No.	Make	Type	Pump Capacity (USGPM)	Impeller speed (rpm)	Power (HP)
1	Paramount.	Propeller axial flow drainage pump	Unknown	Unknown	100
2	Flygt submersible	Propeller axial flow drainage pump; model 7060	15,000*	Unknown	120
3	Flygt submersible	Propeller axial flow drainage pump; model 7080	25,000*	Unknown	150 or 175

* Note: capacity estimated from pump performance curves

In addition, two flood boxes pass gravity flow water under the 1950 pumping station. The steel or aluminum flap gates are the typical side mounted and slightly off-vertical configuration of an estimated area of 4.5 square metres. Both gates appeared to open easily with marginal head.

DFO has had no involvement with the pumping station within the last 5 years[88].

3.1.8.4 Discussion of Pump Operation and Fish Migration

As the Dyking District representatives were unable to furnish any operational data concerning the station, it is difficult to make specific comments concerning the impact of the station on the salmonid resource. Coho and chinook likely utilize the Slough below the pump station for rearing in the winter months. Murray *et al* (1989) found high chinook smolt densities in Nathan Creek, two kilometres to the west during May. The flood boxes appear adequately sized and are not suspected as constituting a velocity barrier during fall and winter flows, and as such, both species would be suspected of inhabiting the Slough upstream of the station. However, the flood box should be observed and water velocities noted during these times to confirm this assumption. If salmonids are utilizing sections above the station, then it is likely that the station kills out migrating salmonids that delay their migration until after the Fraser R. freshet arrives. A full biophysical inventory should be completed on the system during summer and winter months to determine natal and non-natal rearing of the system. Operational data may be available from other sources and should be analyzed to determine operating times and characteristics.

Lastly, the culvert at 88th Avenue, approximately 300 m in length, likely constitutes a fish migration barrier[89]. If this assumption is correct, then the accessible habitat upstream of the pump station is greatly reduced. Any plan to modify the pump station for fish passage should consider removal or modification of the culvert to open up the upper Slough sections to fish.

3.1.9 Chester Creek Pumping Station

3.1.9.1 Introduction

Chester Creek pumping station is located on the western edges of the District of Mission and drains a small area of 660 hectares that is dominated by agricultural activities in the low lands and is forested in the uplands (see Figures 1A – 1C).

3.1.9.2 Fish Resources and Watershed Quality

Chester Creek contains coho and chum salmon, as well as cutthroat trout and possibly steelhead trout[90]. Coho have been observed throughout the creek, whereas the upper limit of chum distribution is Silverdale Ave[91].

To address the high mortality rate that the pumping station inflicts upon the salmonid population, the District of Mission has retained the services of Scott Resource Services since 1994 to conduct fish salvages at the pump station when the pumps are on during the smolting period. The consultant salvages salmonids using seine nets placed in front of the pump station. As a result, several thousand smolts and juveniles are safely transported around the pumping station. In 1997 and 1998, the Fraser River freshet arrived early necessitating the need for salvage (see Table 15).

Table 15: Salmonids captured and transported safely around the Silverdale Pump Station, 1997-98.

Year	Species	No. captured	When captured	Peak migration
1997	Coho salmon	3,999	Mid-late May	Mid May
	Chum salmon	0		
	Cutthroat trout*	562	Mid-late May	Mid May
1998	Coho salmon	1938	Mid May-early June	Mid-late May
	Chum salmon	108	Mid May-early June	Mid-late May
	Cutthroat trout*	708	Mid May-early June	Mid-late May

*Assumed majority sampled were anadromous.
Source: Walter, A.R. *et al*. 1998, 1998a

In 1997, 3,999 coho smolt and fry, and 562 cutthroat trout were captured. The consultant was able to estimate the peak migration time during the sampling period based upon CPUE calculations but he noted that the actual number of fish salvaged did not indicate the total of out-migrants nor the actual migration peak. Occasionally the Fraser River receded enough for the flap gates to open and allow fish unobstructed passage around the pumping station. In addition, the majority of the smolts had likely left Chester Creek before the flood box gates shut due to rising Fraser River water levels. In 1998, the salvage operations captured 1938 coho fry and smolts, 108 chum smolts, one sockeye smolt and one rainbow trout. Portions of the chum sampled were likely from the 20,000 released from the Stave River Salmonid Enhancement Society out planting program. Between 1994 and 1996, however, the vast majority of smolts left the creek via the flood boxes before the Fraser River freshet arrived at the end of May[92]. The consultant also noted that a significant percentage of the coho salvaged appeared to be fry, indicating that the fry are moving downstream during the late spring.

Little information exists about watershed quality and factors that may affect salmonid productivity. FRAP rates the watershed as "Endangered" due to riparian vegetation loss, channelization, and water quantity problems[93].

3.1.9.3 Pump Station

The Silverdale Pumping station is located approximately 6.5 km. west of central Mission along Highway No. 7. It consists of a pump house with 2 identical pumps and one flood box (see Photos 19 and 20). A coarse trash rack protects the intake area from floating debris. The pump house was expanded in 1983-84 to include an additional pump that effectively doubled the pumping capacity of the station.

Table 16: Characteristics of the Silverdale Pumping Station pumps.

Pump No.	**Make**	**Type**	**Pump Capacity (USGPM)**	**Impeller speed (rpm)**	**Power (HP)**
1 & 2	Unknown	Propeller axial flow drainage pump	7,500 each	1200	50
		Total station pumping capacity	15,000		

The pumps' operation is controlled by the elevation of water on the upstream side of the pump house (i.e. the water level in Chester Creek). Each pump is set as either lead or lag. As water rises behind the dyke, the lead pump starts and continues to pump until the water level drops to the "off" water level. If the water continues to rise, the lag pump will automatically start at a predetermined water level. With both pumps on, the water level should recede until the set point where both pumps stop. The pump timing logs were unavailable for analysis.

The flood box at the Silverdale pumping station consists of one concrete box 1.8 m by 1.8 m by 13 m in length on a 0.4% slope. A top-mounted double hinged flap gate installed in 1997 is mounted on the outfall. The flap gate requires approximately 0.15 m of head to open at least 0.3 m[94].

DFO has had no involvement with this pumping station other than to approve fish salvages that have taken place in the last two years[95].

3.1.9.4 Discussion of Pump Operation and Fish Migration

As with most pumping stations on the lower Fraser River, the most significant pumping schedule on Chester Creek corresponds with the coho and chum smolting period. It is an undisputed fact that the pump station imparts significant mortalities on smolting chum and coho. The high impeller speed (almost twice that of many other lower Fraser R. pumps studied) greatly increases the probability of contact between the fish and the propeller blades, resulting in mortality. The District of Mission engineering and operational staff have taken it upon themselves to address the pump related fish mortality issue by hiring an environmental consultant to conduct a fish salvage for the latter part of the smolting period, usually about four weeks in May and June. From all indications, the District is committed to continuing this practice until alternative solutions of ensuring smolts pass safely by the pumping station is found. They have invested several thousand dollars upgrading the area in front of the pump house to make seining more efficient and less costly. Although no study has been conducted to determine the cost/benefit of alternative solutions, the District is of the opinion that an alternative such as a new fish friendly pump would more costly in the long term. However, the District is willing to experiment with changing the pumping schedule or other parameters if it can be proven to be both beneficial to fish and the District. One such experiment may be in forcing the fish to stay in the Creek by temporarily screening the pumps until the Fraser recedes and flap gates open (or until an agreed upon “late date” with the DFO) thereby allowing safe unimpeded passage to the Fraser R. The impact on the salmonids due to a several week smolting delay is unclear, and requires analysis and discussion. One study by Walter *et al.* (1998a) recommends the installation of a fish friendly screw pump while recognizing the prohibitive cost involved.

The data collected and analyzed in Walter *et al.* (1998a) reveal that most coho and cutthroat smolts (and presumably kelts) enter the Fraser River through the flood box before the freshet forces the flap gate shut. Since the migration period had been closely monitored beginning in 1994, fish salvage operations have only take place twice in the last 5 years. In addition, Walter (1998a) notes that in both cases where salvage operations took place, a significant percentage of smolts had likely left Chester Creek before the flap gate shuts. This belief is borne out by the fact that in the spring of 1997 the Stave Valley Salmonid Enhancement Society released 20,000 chum into the creek. The consultant only salvaged 108 of them from mid May to early June, and thus it is assumed that the vast majority exited the creek through the flood box before mid May. Hence it appears that over the last 5 years the vast majority of coho and chum smolts have left the system safely and unimpeded. It is only the smolts that attempt to leave the system late in the smolting period in the minority of years that require assistance in the form of a salvage to reach the Fraser River safely.

The sampling data also reveal that substantial number of coho juveniles are attempting to leave Chester Creek during the spring, presumably to rear in the lower sections of the Slough or to seek out other rearing streams that offer higher quality habitat. The implications of this are two fold: that the pump is killing juveniles as well as smolts that are not salvaged, and that coho juveniles (0+) must make their way back up through the flood box into the headwaters in the fall before the onset of winter flood events in the mainstem Fraser. For the late date out-migrators, this means having to pass through the pump station twice before reaching the ocean as a smolt if the salvage operation fails to capture them. This finding is more relevant to all the other flood-proofed streams with drainage pumps on the lower Fraser than to Chester Creek. The non-smolting juveniles in Chester Creek have the benefit of a fish salvage to ensure their safe passage to downstream rearing habitats. Juveniles in virtually all other streams do not. This finding broadens the issue to be resolved from smolt entrainment in pumps to smolt and juvenile entrainment in pumps.

The District of Mission currently spends on average $7,000 annually during salvage years. If the last five years is any indication of the fiscal amount and District staff resources required to ensure that fish are afforded safe passage past the Silverdale pumping station, then other fish passage options such as installing a fish friendly screw or vacuum pump initially appear without the aid of a cost-benefit study economically unattractive. However, an analysis of the relative costs and benefits of the current practices versus other fish passage options should be completed and is highly recommended. This analysis could also be expanded to include other systems that are known to kill migrating fish.

Lastly, the flood box flap gate may pose a barrier to upstream migration of juveniles during the winter or spring months. Although the gate swings easily, a velocity barrier may exist during higher flows. The gate operation should be observed under different flow conditions and seasons when juveniles and possibly chinook smolts are attempting to migrate into Chester Creek.

3.1.10 Lane Creek Pumping Station

3.1.10.1 Introduction

Lane Creek is a relatively small watershed of approximately 400 hectares that drains a highly urbanized area of Mission. The Creek drains directly into Mandale Slough on the north bank of the Fraser River (see Figures 1a - 1c).

3.1.10.2 Fish Resources and Watershed Quality

Mandale Slough contains chinook, chum, coho and sockeye salmon, and cutthroat trout[96]. Lane Creek, which drains into the top of Mandale Slough, contains coho and chum salmon, and rainbow and cutthroat trout[97]. The species present (see Table 17) is based upon one fish salvage report (Walter *et al.* 1998a) and may not be indicative of all species present. Other standard sources detailing fish species present in water bodies contain no biological information on Lane Creek.

As with the Silverdale pumping station, the District of Mission hires an environmental consultant to conduct fish salvage operations if smolts are still upstream of the pumping station at the start of the Fraser River freshet. Based upon salvage data, the species present have the following migration characteristics:

Table 17: Salmonids captured and transported safely around the Lane Creek Pump Station, 1997-98.

Year	**Species**	**No. captured**	**When captured**	**Peak migration for capture period****
1997	Coho salmon	2,906	Late May-late June	Early-mid June
	Chum salmon	0		
	Cutthroat trout*	0		
1998	Coho salmon	913	Mid May-mid June	Mid May
	Chum salmon	7	Mid May-mid June	Not determined
	Cutthroat trout*	4	Mid May-mid June	Not determined

* Assumed majority sampled were anadromous.

Although the data reveal when the peak migration times occurred during the sampling period, it is highly likely that many smolts and kelts migrated before sampling commenced. Thus the peak migration time is likely in the early to middle period of May for all species.

Lane Creek watershed has been largely culverted and as such contains little rearing or spawning habitat. The District of Mission installed 30 m of spawning gravel in 1995 near Durieu Street which accounts for most of the spawning habitat in the entire system. However, fish presence sampling at this site in the fall of 1997 found that only cutthroat trout were utilizing the spawning area as rearing area.

Since Lane Creek drains a highly urbanized watershed, water quality is likely a problem. Unfortunately water quality data are unavailable for this watershed. However, it may suffer from the same afflictions that plague other streams that drain urbanized areas: low base flows, high and perhaps lethal-to-fish summer water temperatures, low dissolved oxygen and above normal water pollution concentrations (i.e. hydrocarbons, suspended sediments, nutrients, and detergents etc.[98]). FRAP rates the watershed as “Endangered”.

3.1.10.3 Pump Station

The pump station on Lane Creek is located approximately 300 m. west of the Mission Bridge on the north side of the Fraser River (see Photos 21 - 23). The facility was constructed in 1979-80 and contains two pumps of the following specifications:

Table 18: Characteristics of the Lane Creek Pumping Station pumps.

Pump No.	**Make**	**Type**	**Pump Capacity (USGPM)**	**Impeller speed (rpm)**	**Power (HP)**
1 & 2	Unknown.	Propeller axial flow	7,500	1200	50
Total pumping station capacity			15,000		

A coarse wooden screen that surrounds the pump house building protects the pumps' intakes. Water enters the pump gallery pond from two culverts that pass under the southbound road to the Mission Bridge. The water is then discharged through two flexible pipes into Mandale Slough. Fish mortalities had been noted before 1998 at the outfall when the water was discharged onto an angular rock apron[99]. The District of Mission rectified this problem by using a "Big O" pipe to redirect the discharge water into the Slough.

The flood box pre-dates the construction of the pumping station. Judging from the poor condition of the top hinge-mounted wooden flap gate, the flood box may be 40+ years old and is acknowledged as being undersized. The flap gate requires approximately 0.3 m. of head to open slightly[100] and appears quite heavy and is likely a barrier under most flow conditions for in-migrating juveniles and adults. The pumps often run during the winter months even when water is draining through the flood box. The District plans to replace the flap gate and increase the capacity of the flood box within the next two years.

DFO has had no involvement with the pumping station in recent years other than to permit fish salvages.

3.1.10.4 Discussion of Pump Operation and Fish Migration

The fish sampling done by Scott Resource Services seems to confirm the theory that the flood box is a barrier to juvenile movement from the Slough into the creek. Fish presence sampling in September in the creek only found cutthroat trout and only seven coho between 70 and 96 mm in fork length. This information coupled with the large numbers of 0+ juveniles sampled in the spring indicates that either coho yearlings do not over-winter in the creek for unknown reasons, or else they have not returned from downstream migration completed the previous spring. Both juvenile and adult coho would typically move into the Lane Creek upon arrival of the fall rains would likely face a velocity barrier in flood box during this increased runoff period. The few coho that were sampled in the fall either were able to return up through the flood box or never left Lane Creek initially. If the District decides to delay the modification of the flood box, it is recommended that sampling both upstream and downstream of the station be done later in this fall season (November or December) to determine firstly whether juveniles are attempting to access the Creek and secondly, their ability and success rate at negotiating the flood box.

The migratory pattern observed in Lane and Chester Creeks illustrates what problems migrating fish face in creeks that are governed by flood proofing facilities. In these two creeks (and presumably many other lower Fraser R. streams), coho may pass through or around the pumping station and flood boxes (upstream and downstream) a minimum three times before reaching the Fraser River and proceeding to the estuaries at the mouth of the Fraser River, and then once again upon returning to spawn. Coho which smolt at year 2+ must pass through or around the pumping station and flood box a minimum 5 times before heading to sea. If one assumes a 50 % average mortality rate over the age classes, the probability of a late migrating 2+ coho smolt successfully passing downstream through the pumps 3 times is about 12.5%[101].

As Lane and Chester Creek pumping stations operate in virtually the same manner and share the same problems with respect to fish passage, refer to the "Analysis" section under the Chester Creek heading and to Section 4 for discussion of the various mitigative options. The issues at Lane Creek of most immediate concern are the flood box and the flap gate. Since the District is planning on replacing them in the near future, the outstanding concern is the pump house. As described in the Chester Creek section and Section 4, a further study on alternatives other than replacing the pump with a fish friendly pump or other pumping arrangement should be pursued.

3.1.11 The Remaining Pumping Stations in the District of Mission

Two other pumping stations of note exist within the District of Mission. They are located:

- at the west end of Cooper Avenue, approximately 400 m. due south of the Silverdale pumping station. This station is known as "Pump station No.3". The small pumping station drains farmland during periods of excessive rainfall, and pumps water directly into the Fraser River. Since there are no fish habitat values in the land being drained and fish access is not possible, Station No. 3 does not warrant further discussion;
- south of the CPR tracks and immediately south of Windebank Creek. This pumping station is known as the "Fiberglass pump station" and drains an industrial area during periods of excessive rainfall. As with Pumping Station No. 3, since there are no fish habitat values in the land being drained and fish access is not possible, the Fiberglass pump station does not warrant further discussion.

3.1.12 Flood Boxes within Mission

There are four flood boxes that drain directly into the Fraser River from the District of Mission. They are:

- At the south end of Commercial Street;
- 200 m. east of Bank Street;
- 400 m. east of Bank Street;
- 100 m. west of Bank Street.

All of these flood boxes drain road and storm runoff from areas that are neither considered fish habitat nor fish accessible, and thus do not warrant further discussion.

3.1.13 Internal Drainage Flood Boxes in Mission

There is one flap-gated culvert in Mission that drains fish habitat and whose function is not related to a pumping station. Horne Creek discharges into Windebank Creek just below Highway No. 7 through a culvert with a top mounted cast iron flap gate on the discharge end. The upper reaches of Horne Creek contain resident (cutthroat) fish[102]. However, Horne Creek flows through approximately a mile of storm drain between the upper inhabited reaches and Windebank Creek. As it is unlikely that salmonids would attempt to access Horne Creek through the flood box and flap gate, this flood box will not be considered further.

3.2 Conclusions and Summary of Recommendations for Section 3

The overwhelming conclusion that can be reached from Section 3 is that our understanding of the impacts that the ten selected flood proofing structures have on migrating fish is limited. Some systems have been moderately studied, yet some questions remain; other systems are relatively obscure and unknown and require further examination. At most pumping stations examined additional analysis is required before any significant action can be taken. Some of the additional analyses required is straightforward and simply requires examination of existing data. Other analyses require generating additional biological and hydrological data. It is clear from the research that the traditional high speed axial propeller pumps cause mortalities ranging from 30-70% on fish that are entrained in the pumps. It is not clear what percentage of the smolting population, on average over the years, migrates through the flood boxes and bypasses the pumps altogether. It is also clear that the flood proofing structures have disrupted the natural hydrological cycle of the low land areas and thus the ability of juveniles to access these areas during the Fraser River freshet. It is not clear under what flow conditions juveniles are unable to access these upland areas due to either gate closures, restrictions or velocity barriers. These and other questions require further thought and analysis.

Several themes common to most of the pumping stations examined during this study are presented below:

- All pumping stations examined operate in the same manner. The arrival of the Fraser River freshet in the spring forces all flap gates shut. Water levels behind the dyke rise and the drainage pumps automatically commence pumping water over the dyke into the Fraser River until gravity discharge begins in the late summer. All pumps examined are the axial propeller type and rotate in the range of 495-875 rpm (District of Mission pumps being the exception. They rotate at 1200 rpm).

- Pump stations and flood box operation effects several different life phases, not solely smolting salmonids as widely believed. Juvenile salmonids that over winter in freshwater habitats (steelhead, coho, rainbow, cutthroat) may seek habitats downstream of the pumping station, and attempt to out migrate during periods when pumps are active and the flap gates closed. Thus the pumping station likely imparts significant mortality on fresh water rearing juveniles. In addition, flood boxes may pose as a barrier to in-migration in the fall, either by remaining shut during low flow periods, or by the resulting velocity barriers during high runoff events. Flood boxes in this manner likely impact both adults returning to spawn and juveniles seeking smaller natal or non natal headwater habitats.

- Pumping stations have a significant impact on both steelhead and anadromous cutthroat populations. Fish mortality rates are strongly correlated with size. Out migrating kelts that must pass through a pump impeller have a greater chance of sustaining an injury than juveniles due to their size. This is of particular concern in the Hatzic watershed and the Matsqui Slough watershed (both watersheds have known steelhead and/or anadromous cutthroat populations). The problem is likely acute in some other watersheds; however, there is little data to verify this concern.

- Some "fish friendly" pumping configurations may not be as "fish friendly" as previously thought (Matsqui Slough and McLennan Creek pump stations). Other pumping stations thought to impart significant mortality rates on fish populations may be more benign than previously thought (Miami Creek). It is difficult to assess the degree of the fish / pump conflict without additional analysis.

- A flood box flap gate that is side mounted and made of light weight material poses less of a barrier to in-migrating fish than a top mounted cast iron flap gate.

- DFO has had no recent involvement in all ten pumping stations examined other than to comment on pumping station modifications.

However, many of the conclusions and recommendations made in Section 3 are specific to each pumping station and flood box configuration. The following is a summary of the action items for each of the ten stations reported on. Tables 19a and 19b are a summary of the all the pertinent information found in Section 3.

Table 19a: Summary of all watershed and pump station data and mitigative options for Chester Creek, Hatzic watershed, Katzie Slough, Lane Creek and Matsqui Slough pumping stations.

See file entitled “Pump Stn Database” for Tables 19a & 19b

Table 19b: Summary of all watershed and pump station data and mitigative options for McLennan, Miami and McLean Creeks, Mountain and Nathan Sloughs.

See file entitled “Pump Stn Database” for Tables 19a & 19b.

3.2.1 Hatzic Station

- Of all the pump /fish migration conflicts that exist in the lower mainland, the one that exists at the Hatzic pumping station is likely the most pressing of all. In order to address this problem, it is recommended that the level of overall interest by all governmental and non governmental groups that have an interest in the upgrading or modifying of the station be determined. If there is no likelihood of the station being upgraded for flood relief reasons in the near future, a plan should be developed by DFO and others interested in fish passage issues to address the fish mortality problem. Reasonable options of installing fish bypass systems without upgrading the rest of the station may exist and yet require further analysis to be identified and developed.

3.2.2 Katzie Slough Station

- A detailed biophysical should be conducted to determine both spawning potential and winter rearing potential for all salmonid species. Surveys should be conducted in the late summer and spring months. If the surveys conducted in the late winter find adequate rearing water quality but no salmonids, then the flood box would be suspected as being an in-migration barrier. If it is determined that salmonids do over-winter in the Slough in significant numbers, then the pump station’s operating characteristics should be examined more closely to determine whether a fish / pump conflict exists. If a conflict does exist, operational or physical change options may exist to increase safe smolt out-migration during the freshet.

- As it is not clear whether the flood boxes act as in in-migration barrier during the fall and winter months, further research needs to be done on the local watershed and Pitt River hydrology, water levels, flood box water velocities and operational characteristics. Pump cycling information should also be collected and analyzed.

3.2.3 Matsqui Slough Station

- It is difficult to determine the degree of impact operation of the non-fish friendly pumps have. Certainly some smolts would be entrained in Pumps Nos. 1-4 & 6. Determining an entrainment figure and resulting impact is difficult when more pumps than Pump No. 5 is running and is dependent upon understanding:

  1. which section of the channel (thalweg or banks) in the forebay area is more attractive to migrating fish. If fish congregate along the right bank when migrating then the impact may be lessened since the fish friendly pump is located along the right bank. If the smolts (and other migrating juveniles) prefer the centre of the stream where the current is faster and the non-fish friendly pumps are located, then the impact could be quite significant. If the smolts prefer the left bank, the impact could be very high as they would have

to swim across the entire forebay area towards the right bank to escape entrainment in the non-fish friendly pumps;

2. when the smolts arrive at the pumping station and what triggers them to leave the system. If high flows in the creek trigger migration, then it is likely that entrainment in non-fish friendly pumps is high, since more of the pumps are operational at the same time during flood events. A detailed analysis of daily pumping logs would be required to determine the severity of this issue. Such an analysis is highly recommended;

3. whether other fish (notably coho fry) are migrating downstream to habitat downstream of the pumping station. If juveniles are migrating, then the timing or migration time triggers should be determined and contrasted with the pump operation.

These issues require further analysis before the severity of the non-fish friendly pumps running during migration period can be determined.

- The use of stop logs to raise the water levels in the Slough during late summer low flows is another issue of concern. This issue requires further analysis, possibly even some sampling at the pumping station mouth when all pumps are running during the late summer to determine whether juveniles are attempting to migrate past the station. If juveniles are attempting to leave the system, this points to a need to address either allowing safe passage at irrigation times through the flood boxes (i.e. remove the stop logs and reconfigure irrigation procedures) or address the water quality (and likely quantity) during summer months by augmenting areas with groundwater, enhancing known summer rearing areas to increase holding densities, or other options.

3.2.4 McLennan Creek Station

- It is recommended that pumping cycling data be analyzed in order to further understand the impact the station has on migrating salmonids. Such an analysis would likely reveal that the fish friendly pumping arrangement is not as functional as currently believed, for the same reasons as with the Matsqui Slough pumping station (For a complete discussion of the fish friendly pump, see Sections 2 and 4).

- The issue of the flood boxes may pose a pose a barrier to in-migrating juvenile salmonids seeking upstream natal habitats, or seeking out a non-natal rearing stream requires additional observation and study to determine whether in fact it is of concern for this station.

- As with the Matsqui Slough station, the issue of salmonid migration being restricted by placement of stop logs during the late summer months requires additional thought and discussion.

3.2.5 Miami Creek Station

- The fact that little is and the lack of biological knowledge of the watershed, and pump cycling information, it is difficult to assess the impact of the pump station and flood box operation on the salmonid population. It is recommended that a complete bioinventory of the watershed that includes collection of migration timing data be conducted. In addition, the pumping records require further analysis to determine whether the severity of the impact on salmonid populations. Further study to shed light on these data gaps is highly recommended.

3.2.6 McLean Creek Station

- It appears that without the aid of biological, hydrological or pump cycling data that the flood box gates are likely the most significant limiting factor to salmonid migration in both directions. It is recommended that additional information be gathered on salmonid utilization of the watershed, the local hydrology (specifically water levels) and pump cycling information. Although the flap gates on the flood boxes were recently installed, it is highly recommended that they be scrutinized to determine whether they pose a migration barrier as assumed. If the assumption is proven valid, the purchase and installation of side mounted gates (with provisions to keep Pitt River debris from jamming the gates open during freshet) should be considered.

3.2.7 Mountain Slough Station

- It is recommended that the flood box be examined in more detail to determine whether it is an in-migration barrier to juvenile fish.

- The issue of running the pumps during times when the flood box is opened requires examination and discussion with the District and the agricultural community.

- Unfortunately the pumps' cycling data are not in a format that is usable for the purposes of this report. However, water level data may exist that would shed light on the operating characteristics of the pumps. It is recommended that this and other data be collected and analyzed, or other methods be utilized to determine the operating characteristics of the pumps.

- While it is acknowledged (although not proven) that the pumps kill fish, simple and easily implemented solutions to address this problem are not apparent. However, a small measure to improve the situation involves reversing the pumping sequence such that lower speed Pump No. 1 is the lead pump. Fish mortality may be reduced slightly in this manner. How this change would impact on the overall operation, costs and maintenance of the pumping station is unclear and requires consultation with the District.

3.2.8 Nathan Slough Station

- A full biophysical inventory should be completed on the system during summer and winter months to determine natal and non-natal rearing of the system. Pump station operational data may be available from other sources and should be analyzed to determine operating times and characteristics.

3.2.9 Chester Creek Station

- An analysis of the relative costs and benefits of the current fish salvage practice versus other fish passage options should be conducted.

- The flood box flap gate may pose a barrier to upstream migration of juveniles during the winter or spring months. Although the gate swings easily, a velocity barrier may exist during higher flows. The gate operation should be observed under different flow conditions when juveniles and chinook smolts are attempting to access the Creek.

3.2.10 Lane Creek Station

- Since the District is planning on replacing the flood boxes in the near future, the only concern is the pump house. If however the District decides to delay the modification of the flood box, it is recommended that sampling both upstream and downstream of the station be done later in this fall season (November or December) to determine firstly whether juveniles are attempting to access the Creek and secondly, their ability and success rate at negotiating the flood box.

- As described in the Chester Creek section and Section 4, a further study on alternatives other than replacing the pump with a fish friendly pump or other pumping arrangement should be pursued.

4.0 General Opportunities For Mitigation of Fish / Pumping Station Conflict

4.1 Introduction

Based upon current literature and experience with pumping facilities on the lower Fraser and throughout the Pacific Northwest, it is clear that fish injury and mortality occurs to varying degrees at flood protection structures. Resource managers, facility operators, environmental consultants and drainage engineers have over the years attempted to address the fish / pump station conflict. A much smaller group has addressed the fish passage problems associated with flood boxes. Some of the findings and current techniques to improve fish passage through both pumping stations and flood boxes are discussed below.

4.2 Improved Fish Passage Through Pumping Stations

4.2.1 Retrofit Pumping Stations with "Fish-friendly" pumps

Limited testing of the high speed, axial flow propeller-type pumps used at several facilities along the Fraser River indicates mortality rates of between 25% and 70% for entrained coho salmon smolts. In contrast, large screw pumps whose capacity is comparable to more conventional axial flow or centrifugal pumps inflict injury on less than 2% of the entrained fish. Variations on the centrifugal pump also hold promise of reducing fish mortality. Retrofitting of existing stations may be possible by replacing conventional propeller pumps with different designs that can meet both drainage pumping and fish passage requirements. Given that intake structure dimensions and configuration are substantially different for a vertically mounted impeller versus an inclined screw pump, it may be significantly more cost effective to build new facilities (e.g. the Archimedes screw pump installed at Erickson Creek in Surrey) rather than retrofit existing ones.

On a cautionary note, discussions with engineers who have been testing the large Archimedes screw pumps and the screw/centrifugal pump at Red Bluff Research Pumping Station reveal that these special order pumps are expensive and require extensive engineering adaptation and maintenance. The cost of buying the screw pumps and building the superstructure exceeds the financial resources of most jurisdictions bordering the lower Fraser River. In addition, fish mortality experiments planned at Red Bluff Research Pumping Station for the period 1995 to present have been periodically hampered by mechanical failures of both pump types that have resulted in significant maintenance problems and expenses[103]. Anecdotal accounts suggest that the Hidrostal screw/centrifugal pump is especially problematic as a result of its asymmetry; the pump is hard to keep balanced, drive shafts tend to break, and excessive turbulence develops in the impeller housing[104].

The design of new or retrofitted facilities featuring such "fish-friendly" pumps should carefully consider other components of the pumping facility and its flow stream to identify and minimize potential sources of passage-related fish injury.

4.2.2 Pump Bypass Options

In light of the fact that pump retrofitting is expensive, attempts have been made to improve fish passage at existing facilities through various means of fish bypass around the pumps. Options include the installation of bypass structures, manual fish salvage and transport, and changes to flood protection procedures to minimize the temporal overlap of fish migration and pump operation.

4.2.2.1 Bypass Structures

Bypass structures typically involve the use of a diversion screen to keep out-migrating fish from entering pump intakes, diverting them instead to an alternative bypass route. In this manner fish are entrained in a secondary flow stream while the primary discharge is lifted over the dyke by way of conventional drainage pumps. Diversion screens, it should be noted, must be appropriately designed, installed, and maintained to successfully prevent fish from being entrained in pump intake flows or becoming impinged on the screen[105]. Experimental investigations conducted by ECL Envirowest (1991) recommended that for fish bypass structures to be effective, their maintenance should include an underwater inspection of diversion screens prior to the annual freshet to ensure that fish are unable to be inadvertently bypass the screen through holes or gaps between the screen and the sump walls.

Louvers are less widely used in flood control facilities than diversion screens but serve the same purpose by different means. Louvers are vertical slats set perpendicular to the intake current and arranged in a diagonal fence in the path of downstream migrating fish, such that the fish are diverted to the bypass route[106]. While capital and operating costs are thought to be lower for louvers than for diversion screens, in part due to the relative ease with which they can be cleaned of fine debris, they may be less efficient because of the requirement for constant flow at the intake to make the louver system work.

Finally, alternative technologies for fish diversion into bypass structures include both deterrent and attractant guidance systems including sound projectors, electric pulses, and strobe lights. Studies conducted by BC Hydro as reported by IRC (1996) concluded that further research into these technologies was required due to their limited guidance effect on coho smolts.

Small fish pumps installed in tandem with a conventional drainage pump should be considered when safe fish passage is required. An inclined screen fitted upstream of the main pump in the sump area deflects fish to the bottom of the sump as is the case at the Matsqui Slough and McLennan pumping stations. The intake to the fish pump is located at the bottom of the screen. Fish are entrained into the fish pump and safely discharged to the receiving waters. As described above in the discussion of pump types, fish pumps are typically recessed impeller-type centrifugal pumps of the kind used in the food processing industry. A standard Aqualife fish pump with a capacity of 0.08 cms (75 L/sec) and diversion screen were installed at the Matsqui Slough and McLennan Pumping Stations in 1990 to provide safe fish passage around the facility. An assessment was made by ECL Envirowest (1991) of the efficiency with which the fish pump successfully passed hatchery coho smolts. After the tests were completed, it was determined that only 27% of the hatchery fish placed in front of the pump were accounted for and were confirmed as passing through the fish pump. While the study recommended further assessment using an improved experimental design, it concluded that the overall mortality rate due to the fish pump and holding pens was 6.6%"[107] It is important to emphasize that Envirowest was only able to confirm that the fish that passed through the friendly pump suffered much lower mortalities than those that would have passed through the propeller pump. *What the study could not conclude was that the fish friendly pump prevented fish from becoming entrained in the main pump.* The fact that 73% of the fish placed in the forebay were unaccounted for after the tests were completed suggests that the test results are inconclusive. One of two explanations exist: the fish either escaped from the holding pen in front of the pump intake, or that they somehow bypassed the fish pump and screen altogether, and became entrained in the main pump situated behind the fish pump. The experiment did not test for the latter possibility, and thus it remains unclear as to the fate of the majority of smolts. Hence, since the fish bypass system employed at Matsqui Slough and McLennan Pumping Stations effectively remains untested, it is recommended that the original test be repeated immediately with tighter experimental controls and better methodology.

As an alternative to the use of centrifugal or volute fish pumps, small Archimedes screw pumps that pass fish around the large propeller pumps have been used with excellent results. Week *et al*. (no date) studied the passage of juvenile steelhead, chinook, and coho salmon through a modified prototype Archimedes screw pump. The study is informative not only for its test results, but also for the information it compiles describing alternative pump sizes and their relative characteristics (i.e. speed, discharge, and head) which would be useful in preliminary investigations into applying the technology at different pumping stations. The screw pump evaluated in this study was 75 cm in diameter, 300 cm long, with three internal helical flights welded to the pump cylinder. The design was modified so that the leading edge of the flights tapered into the bottom end of the cylinder to reduce chop at the entrance to the pump, thereby minimizing the potential for injury to fish and also providing an appropriate hydraulic environment for fish uptake. The pump was operated alternately at speeds of 24 rpm and 13.75 rpm. Fish used in the study were of various species and sizes, including steelhead (ranging in size class from 1000 fish/lb. to 7.5 fish/lb.), chinook salmon (ranging in size class from 1000 fish/lb. to 134 fish/lb.), and coho salmon (12.1 fish/lb.). At the start of testing, a gap observed between the bottom of the screw and the faceplate produced 8 mortalities in the smaller size classes of fish. Following modification to eliminate the gap, more than 1000 test fish were introduced to this system and none were killed during passage through the screw pump. There were no delayed mortalities following a 9-14 day observation period.

In addition to the volute and screw-type fish pumps described above, an "air lift" has been used as an alternative fish bypass system for downstream migrating salmonids. The Black River Pumping Station located at the confluence of Black River and Green River in the Renton Valley, WA, is designed to pass migrating coho and other fish in the river system. Coho smolts are diverted from the main pump intakes through the use of diversion screens and drawn into the bypass pipes measuring 45 cm in diameter and 21 m in length. Vertical lift of fish is achieved through the use of a 100 h.p. rotary compressor that jets compressed air into the bottom of the water column, creating bubbles that provide the lift. Both the bypass pipe and fish ladder (for upstream migration) installed at the facility have automatic closure gates to prevent back flooding when the Green River rises. No evidence of fish mortality has been observed. Gate closure is not considered to represent a problem during the usual November fish in-migration as the gates are reportedly closed for up to only a few days at a time, and this normally occurs during peak flows in December[108].

4.2.2.2 Trap And Transport

Russell (1980, 1981) recommended a trapping and transport program as one means of addressing the problem of fish mortality. A system of either fish fences, floating traps, beach seines, minnow traps or combination of the above was proposed for the lower Salmon River during the period of smolt migration, with the salvaged fish transported around the pumping station and flood box for release downstream. Russell (1982) specifically recommended against the use of beach seine nets for fish salvage following fry salvage trials at various pumping stations, "due to the restricted volume of water seined per set, the design of pump forebay (most bays had numerous fish refuge areas where seines could not reach them) and the presence of rip-rap bank stabilizing in seine dry-up sites". Additionally, beach seining was suspected of flushing fish upstream into holding areas with vegetative cover, thus undermining salvage attempts. In-stream fences and live-traps custom-designed to the dimensions of individual pump forebay were recommended as the most reliable fish capture methods, with the use of live boxes (to be emptied daily) for collection[109]. Some injury and/or mortality would be expected to occur as a result of fish handling. The District of Mission and the Township of Langley currently employ the "trap and transport" method at Chester and Lane Creeks, and Salmon R. pumping stations respectively.

4.2.2.3 Modified Operating Schedule

Russell (1980, 1981) recommended that the operating schedule for the Salmon River pumping station be modified to accommodate fish migration, by way of both delaying the spring start-up of the pumps and opening the flood box gates intermittently during low tide. Envirocon (1986) further explored this proposal for delayed start-up of pumping operations on the Salmon River, indicating the possibility of raising the pump-activation water level datum (i.e. the sub-flood water level at which the gates are closed and the pumps started) without actually inundating agricultural land. Based on a comparison of available fisheries enumeration data and adaptations to the pumping station activation schedule, Envirocon (1986) demonstrated that in certain years (depending on the onset intensity of the freshet) a delay in pump activation of up to 3 or 4 weeks was conceivable, and this delayed pumping during peak migration would significantly decrease mortality.

On the one hand, this proposed means of improved fish passage would be the easiest of all bypass options to implement, given that no additional installations or expenditures are required. However, the potential costs associated with this option include increased exposure to the risk of flooding, or at the very least there would be poorer drainage and resulting reduced agricultural productivity. Given that the schedule for flood box closure and pump operation is determined by way of monitoring rising water levels and predicting in advance their effect on the flood protection area, it is unclear how much flexibility there is for discretionary changes to operating procedures. During this study, those responsible for drainage were asked if there was flexibility in changing the set points on the pumps. All responded that there was no or very little additional flexibility in the pumps' operation. Increasing the set points at which the pumps turn on would result in increased flooding and lost agricultural productivity.

4.2.3 Improved Fish Passage Through Flood Boxes

According to one estimate there are "perhaps thousands of flap gates installed in North America"[110], and there appears to be wide acceptance of the belief that most of these gates represent a partial barrier to fish passage. Some of the flap gates examined in this study were top mounted and fabricated of heavy cast iron. Improved fish passage through some of these structures appears to be a simple matter of modifying the gate such that it is mounted near vertical ("side-mounted") and made of lighter weight material (see Photo 12). The off-vertical suspension is aimed at maintaining some effective force of gravity, but not so much that the gate remains shut under a low head differential. Similarly, a gate made of aluminum, fiberglass, or plastic is thought to be more likely displaced by outflow and to remain open under conditions of hydraulic equilibrium (e.g. at slack tide on tidal systems). Eliason (1986) recommended that vertical slide gates and multiple gate structures be modified to include at least one side-mounted flap gate to ensure fish passage. However, this idea requires further study given the concern that a series of flood boxes with only one fitted with a light-weight gate may result in a velocity barrier to in migrating juveniles at critical access times.

In discussing options for improving fish passage through flap gates, Bates (1992) endorses the "method used in Canada" of modifying top-mounted gates so that they swing from the side instead. He notes that the gate hinge hardware must be modified to be able to support the weight of the gate, and recommends that for optimum performance the gate should be rotated less than 90 degrees so that it is suspended slightly off-vertical.

Bates (1992) supports his additional recommendation that flap gates be made of lighter weight materials with data in the form of hydraulic characteristics curves for flap gates made of cast iron vs. aluminum. Derived from a static hydraulic model, the curves depict the relationship of gate opening (gap in feet) to flow (cfs) for the differently weighted flap gates. Submergence of the gate and pressure head is also accounted for in the theoretical model, but velocity head is not. For any given downstream water level (submergence) and head differential, the aluminum gate is open more than twice as wide as the iron gate, while under no conditions is the iron gate open wide enough to comply with U.S. fish passage standards. Bates also points out that the lighter gate has a significantly greater flow capacity under all conditions, with the result being that gravity-feed drainage will occur more rapidly. Only one gate in a flood box system of parallel culverts should be made of lighter weight material, so that there is no "competition" for flow. The use of light-weight flap gates though can cause operational problems. Aluminum flap gates installed at the Salmon River pump station occasionally become warped and out of alignment, presumably due to debris becoming stuck in the gate as it closes on a rising Fraser River water level[111]. However, the Surrey Dyking District is experimenting with a PVC flap gate with fiberglass stiffeners and neoprene seals in the Nicomekl River watershed with apparent success. The gate was installed in August 1997 on an ABS pipe and initial findings are that the gate requires less maintenance, passes more water and is two-thirds the cost of a traditional corrugated pipe with a cast iron flap gate. However, the District is hesitant to install lightweight gates on pipes 600 mm or larger due to the increased likelihood of large debris passing through the flood box and damaging the gate[112]. From these few findings, it appears that the choice of flap gate material should take into account the likelihood of damage from debris from both upstream and downstream sources. In addition, provisions should be made to ensure that large debris not come in contact with the flap gates.

Finally, Bates (1992) describes the use of mechanical or electrically powered "gate operators" designed to prevent flap gate closure until rising water levels activate a floating switch mechanism that trips a latch. Such automatic floating gates apparently now are being produced under the name of Watermans Self Regulating Tide (SRT) Gates and are being installed in Washington State for testing in 1999. At the Yorkson and Salmon River pump stations, the Township of Langley chains up one of flood box gates from mid summer to January to allow for in-migrants to access the lower reaches of the watershed. The gate is closed if water levels threaten to flood low lying land. The Township is examining the idea of installing an automatically controlled sluice gate to replace the chain-up method due to the agricultural community's concern over the lack of water level control[113].

Throughout the states of Washington and Oregon, reportedly there has been a growing awareness of flap gates as barriers to fish migration[114]. Flood boxes are being retrofitted with lighter weight flap gates, and the trend in replacing top-mounted flap gates with side-mounted gates (a trend which apparently started at the initiation of DFO Pacific Region) is well established there. Habitat biologists in Whatcom County, WA, recently have been encouraging area farmers to leave manually operable flap gates open during the period of salmonid migration[115]. And in the Yakima basin, many flap gates installed by the US Army Corps of Engineers have been entirely removed because fish passage was deemed to be more important than back watering in the river system[116].

Anecdotal information suggests in the Pacific Northwest there is a growing belief that reclamation of estuarine wetlands and aquatic habitat is more important than the continued integrity of drainage control systems; especially so in situations where low economic returns from marginal farm land protected by dykes, plus the cost of dyke maintenance, is weighed against the costs associated with the loss or deterioration of high quality fish habitat. It is important to note that this idea is highly contentious and may involve significant changes to traditional land use practices. However, in some circumstances it may prove the best alternative when compared to other options for addressing fish / pump facility conflicts. At the very least this concept should be subjected to a rigorous cost / benefit analysis to determine the best use of the land in question. There may be higher value in allowing low elevation areas that can be proven as marginally productive to be returned to active flood plain during the spring freshet. The cost / benefit analysis may indicate that it is cheaper to compensate land owners for temporary loss, conversion or sale of land rather than to install flood proofing facilities that cost millions of dollars to build, maintain and operate, but still cause fish migration and habitat degradation problems. When many of the flood proofing facilities were installed decades ago, environmental issues were not included in the cost / benefit analysis. Now that environmental issues are better understood, and somewhat quantifiable, the true costs of flood proofing facilities have risen and the benefits have dropped. Additional research and discussion of this idea is recommended to determine its applicability to flood proofing facilities on the lower Fraser River.

4.3 Summary Of General Recommendations For Further Study

Several of the ideas that were introduced in the above sections and require additional analysis and discussion are summarized below.

- A more in-depth literature review of the migration patterns of the different salmonids may shed light on the impact that particular stations have on fish migration and abundance. Although this study touched on the main migration trends, there is much fish migratory pattern and preference- related literature that could not be reviewed given time constraints. Such a review may shed light more definitively some of the concerns or unknowns posed in this report.

- Additional fish mortality testing of the fish friendly pump arrangement of the type found at the Matsqui Slough and McLennan pumping stations should be conducted as soon as possible, ideally before or during the smolting period in the spring. There is concern that this particular fish bypass arrangement may not be as effective as previously thought. The environmental consultant who conducted the initial tests (ECL, 1991) made some recommendations that should be considered for future fish mortality testing. Tighter controls and a better testing methodology are required if the test is to be conclusive.

- Some intriguing alternatives to using expensive screw pumps to transport fish safely around dykes were mentioned in this report. Due to the overview nature and timeframe of this report, extensive research into some of the more promising technologies was not possible. The option of using compressed air to lift water (and juvenile fish) over obstacles is particularly appealing. It is recommended that additional research be conducted as to the details of such technology and of the applicability to flood proofing related fish passage barriers that exist in the lower Fraser River.

- There are wide-ranging opinions on the type of flap gates can meet the both drainage and fish passage needs. Lighter gates hold promise but there are circumstances under which they can cause maintenance problems. Heavier gates that appear in most cases more resilient and robust can cause fish migration problems. Most of the sources that commented on the benefits of the lighter gates were not those who have to maintain them. A comprehensive polling of drainage engineers and supervisors and field personnel would likely lead to a better understanding of the circumstances under which lighter gates could work, and how to modify existing gates to achieve both fish passage and drainage needs.

- Some of the alternatives to pumping stations and flood control that are being pursued in the U.S. should be considered for the lower Fraser River. There may be opportunities to convert marginally productive low lands protected by dykes and pumping facilities to flood areas during or part of the freshet period. A cost benefit study could indicate whether the costs of flood proofing facility maintenance / installation / upgrade plus environmental costs outweigh the benefits of no or reduced facility maintenance / installation / upgrade with increased fish habitat productivity and reduced mortality. Such an analysis of the issues involved is highly recommended.

- Only ten of the approximately 40 pumping stations in the lower mainland were examined in this report. It is very likely that the remaining stations impart mortalities on fish populations at a similar rate as do the stations examined in this report. Some stations not identified in this report may require only minor modification in order to become fish friendly. In addition, modification of a flood box to allow returning adults to access spawning grounds or juveniles access to prime rearing areas costs relatively little and is easily implemented when compared to other habitat management programs that are designed to increase instream habitats at considerable cost and administrative time. It is recommended that this initiative of examining pumping stations and flood boxes in the lower mainland continue such that the magnitude of the problem can be identified and the worst offending pumping stations and flood boxes can be modified.

Bibliography

Anonymous. 1949. Hatzic pump experiments. Can. Dept. Fish., Fish Culture Branch. Unpubl. Memo. Report.

Associated Engineering. 1992. Hatzic Prairie drainage study volumes one and two – Preliminary report. Prepared for the Dewdney-Alouette Regional District.

Bates, Ken. 1992. Fishway Design Guidelines for Pacific Salmon. Washington State Department of Fish & Wildlife.

BC Ministry of Agriculture, Fisheries and Food. 1996. BC MAFF "Regional Profiles" from website (www.agf.gov.bc.ca/educate/profile/regions.html). November 1996.

deLeeuw, A.D. and K.M. Stuart. 1981. Small stream enhancement possibilities for sea run cutthroat trout in the Lower Mainland and Sechelt Peninsula (4 volumes). Unpublished Manuscript. Fish Habitat Improvement Section, Fish and Wildlife Branch, Victoria, B.C.

Department of Fisheries and Oceans. 1983. The lower mainland non-salmonid harvesting guidelines.

Department of Fisheries and Oceans. 1989. Fish habitat Inventory and Information System. Stream summary catalogue, subdistrict #29B, Surrey.

Department of Fisheries and Oceans. 1989a. Fish habitat Inventory and Information System. Stream summary catalogue, subdistrict #29D, Mission.

District of Abbotsford. 1993. A Guide to the Barrowtown Pump Station and Sumas Prairie Floodplain. Description of Operational Characteristics of the Barrowtown Pump Station, Dam and Flood box.

District of Abbotsford. No date (circa 1987-1995). Barrowtown Pump Station, Abbotsford, British Columbia, Canada. Description, construction history, and operating specifications of the Sumas/Barrowtown Pump Station.

ECL Envirowest Consultants Limited. 1991. An Assessment of a Fish Screen and Fish Pump Installed at the Matsqui Slough Pump Station, Matsqui, BC. Report prepared for Department of Fisheries & Oceans, Habitat Management Unit, New Westminster.

ECL Envirowest Consultants Limited. 1992. An Assessment of Fish Survival at the Erickson Creek Pump Station, Surrey, BC. Report prepared for Ministry of Environment, Lands and Parks, Fish & Wildlife Branch, Surrey, BC.

ECL Envirowest Consultants Ltd. 1992. In*: Hatzic Prairie drainage study volumes one and two –Preliminary report* by Associated Engineering, 1992.

ECL Envirowest Consultants Ltd. 1998. District of Kent 1998 watercourse maintenance habitat mitigation plan. Prepared for the District of Kent.

Eliason, Richard. 1986. "Side Hinged Flap Gates: An Alternative to Salmonid Migration Barriers in Flood Drainage". Information release from Department of Fisheries & Oceans, Nanaimo. (BCMELP Fisheries Lib.Pub. 3622).

Enkon Environmental. 1996. Letter to the Ministry of Environment Lands and Parks. Maintenance of roadside ditches in Richmond, Langley, Coquitlam, Maple Ridge and Pitt Meadows. Internal Fisheries Publication No. 3468.

Enkon Environmental. 1997. Letter to the Ministry of Environment Lands and Parks. Environmental Monitoring at the CP Rail Intemodal Yard, Pitt Meadows. Internal Fisheries Publication No. 3572.

Envirocon Pacific Limited. 1986. Assessment of the Salmon River pump house. Prepared for the Ministry of Environment Lands and Parks, Surrey, BC. Reference No.:1993/WP 2864.

Envirocon Pacific Limited. 1986. Assessment of the Salmon River Pump house. Report prepared for Ministry of Environment, Surrey, BC. (BCMELP Fisheries Lib.Pub. LM 132).

Environment Canada. 1998. Fraser River Action Plan Final Report. (Five booklets contained in portfolio report). Vancouver, BC: Environment Canada.

Fraser, F.J., P.J. Starr and A.Y. Fedorenko. 1982. A review of the chinook and coho salmon of the Fraser River. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1126.

Frizell, K.W. and S.P. Atkinson. 1996. Engineering Shakedown and Evaluations at Red Bluff Research Pumping Plant, 1995. Report prepared for RBRPP Evaluation Team.

George, G.A. 1983. A biophysical assessment of Hatzic Lake tributaries with reference to fisheries enhancement opportunities. Prepared for Ministry of Environment, Fisheries Branch.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Ore. State Game. Comm., Fish. Res. Rep. 6: 61 p.

Hancock, M.J. and D.E. Marshall. 1985. Catalogue of salmon streams and spawning escapements of statistical area 29 Chilliwack-Hope. Can. Data Rep. Fish and Aquat. Sci. 521: xiv +132p.

Hancock, M.J. and D.E. Marshall. 1985. Catalogue of salmon streams and spawning escapements of statistical area 29 Chilliwack-Hope. Can. Data Rep. Fish and Aquat. Sci. 521: xiv +132p.

Hancock, M.J. and D.E. Marshall. 1985. Catalogue of Salmon Streams and Spawning Escapements of Statistical Area 29, Mission-Harrison. Department of Fisheries & Oceans, Salmonid Enhancement Program. Canadian Data Report of Fisheries & Aquatic Sciences No. 518. (BCMELP Fisheries Lib.Pub. 1052).

Harper, Lynn. 1979. Freshwater commercial coarse fisheries assessment project. Prepared for the Ministry of Environment, Fisheries Branch.

IRC Integrated Resource Consultants Inc. 1996. Salmon River Pump Station Fish Diversion Options. Report prepared for Stanley Associates Engineering Ltd., Surrey, BC.

Johnson, P.L. and D.K. Edwards. 1993. The Planning and Design of a Prototype Pumping Plant Using Archimedes Screw Pumps. Paper (PAP-639) presented at the USCID/Bureau of Reclamation 1993 Seminar, Sacramento, CA.

Johnston, J.M. 1981. Life histories of anadromous cutthroat with emphasis on migratory behaviour, p.123-127. In E.L. Brannon and E.O. Salo [ed.] Salmon and trout migratory behaviour symposium. Univ. Wash., Seattle.

Kinneard, R. et al. 1981. Dewdney Area Improvement District: A Look at the History and Problems. Report prepared by Dewdney Area Improvement District Board of Trustees.

Klohn Leonoff Consulting Engineers. 1983. Fraser River flood control program – Dewdney area improvement district dyke rehabilitation program. Stage 1 report. Prepared for the Ministry of Environment Water Management Branch.

Klohn Leonoff Consulting Engineers. 1989. Miami Creek Study. Prepared for The Corporation of the Village of Harrison Hot Springs.

Marshall, D.E., R.F.Brown. M.M. Musgrave and D.G. Demontier. 1979. Preliminary catalogue of salmon streams and spawning escapements of Statistical Area 29 (New Westminster). Fish and Mar. Serv. Report. 115.

McJunkin, F.E. and P.A. Vesilind. 1968. "Practical Hydraulics for the Public Works Engineer". Reprinted from Public Works Magazine, Ridgewood, NJ.

McNabb, C.D., C.R. Liston, and S.M. Borthwick. 1998. In-Plant Biological Evaluation of the Red Bluff Research Pumping Plant on the Sacramento River in Northern California: 1995 and 1996. Summary report, Red Bluff Research Pumping Plant Report Series, Vol.3, prepared for U.S. Bureau of Reclamation – Red Bluff Fish Passage Program.

Ministry of Agriculture. 1980. Hatzic Prairie land use and drainage study. Province of British Columbia

Ministry of Environment. 1985. Fraser delta strategic environmental management plan. Province of British Columbia.

Murray, C.B. and M.L. Rosenau. 1989. Rearing of juvenile chinook salmon in nonnatal tributaries of the lower Fraser River, British Columbia. In : Transaction of the American Fisheries Society. 118:284-289.

Nener, J.C. 1997. Watershed Stewardship: A Guide for Agriculture. Ottawa, ON: Queen's Printer. Co-published by the Government of British Columbia.

Nener, J.C. and B.G. Wernick. 1997. Fraser River basin strategic water quality plan: Lower Fraser River; Fraser Delta, Pitt-Stave, Chilliwack and Harrison-Lilloet Habitat Management Areas. Fraser River Action Plan, Habitat and Enhancement Branch, Department of Fisheries and Oceans, Canada.

Pollard, D.A. and J.C. Hannan. 1994. "The Ecological Effects of Structural Flood Mitigation Works on Fish Habitats and Fish Communities in the Lower Clarence River System of South-Eastern Australia" in Estuaries Vol.17 No.2 (pp.427-461). Estuarine Research Federation.

Precision Identification Biological Consultants. 1998. Wild, threatened, endangered and lost streams of the lower Fraser Valley summary report. Prepared for Fraser River Action Plan, Habitat and Enhancement Branch, Fisheries and Oceans Canada.

Rood, K.M. and R.E. Hamilton. 1995. Hydrology and water use for salmon streams in the Harrison Habitat Management Area, British Columbia. Can. Manuscr. Rep. Fish Aquat. Sci. 2293. 184 pp.

Russell, R. 1980. “Pump mortality Tests in the Salmon River (Fort Langley, B.C.)”. Memorandum dated January 14, 1980 from Water Use Unit of Habitat Protection Department to R. Robertson. (HPD File 5903-85-S38).

Russell, R. 1981. “Pump mortality studies in the Salmon River (Fort Langley) and McLennan Creek (Matsqui), 1980”. Memorandum dated January 8, 1981 from Water Use Unit of Habitat Protection Department to R. Bell-Irving and R.A. Robertson. (HPD File 5903-85-S38).

Russell, R. 1982. “Pump mortality studies on tributaries of the Lower Fraser River – Results of HMD’s 1981 Fry Salvage Program”. Memorandum dated March 2, 1982 from Water Use Unit of Habitat Management Department to R. Bell-Irving, W.J. Schouwenberg, and R. Harrison. (HMD File 5900-85-S516).

Shubert, N.D. 1982. A bio-physical survey of thirty lower Fraser valley streams. Can. MS Rep. Fish. Aquat. Sci. 1644: 130 p.

Sookachoff, Paul. 1986. Matsqui Slough Pump house Mortality Test – Pump No.4. Report prepared for Municipality of Matsqui.

Swales, S. 1980. “Environmental Effects of River Channel Works Used in Land Drainage Improvement” in Journal of Environmental Management Vol.14 (pp.103-126).

UMA Engineering Ltd. 1988. Matsqui prairie drainage and irrigation project; ARDSA Project No. 22007. Prepared for the Province of British Columbia, Ministry of Agriculture and Fisheries, ARDA branch.

Walter, A.R. and K.J. Scott. 1998. Mitigation procedures to prevent pump mortalities related fish mortalities at Chester and Lane Creeks, Mission, B.C., in 1998. Prepared for the District of Mission.

Walter, A.R. and K.J. Scott. 1998a. Mitigation procedures to prevent pump mortalities related fish mortalities at Chester and Lane Creeks, Mission, B.C., in 1997. Prepared for the District of Mission.

Washington Department of Fish & Wildlife. 1998. Screening Requirements for Water Diversions. Design criteria from WDFW web site (www.wa.gov/wdfw/hab/engineer/fishscrn.htm).

Watt, W.E. (Ed.). 1989. “Urban Design Floods” (Ch. 9) in Hydrology in Canada: A Guide to Planning and Design. Ottawa, ON: National Research Council Canada.

Week, L.E., V.C. Bird, and R.E. Geary. 1989. Effects of Passing Juvenile Steelhead, Chinook Salmon, and Coho Salmon Through an Archimedes’ Screw Pump.

Study conducted by the California Department of Fish & Game and Pacific Gas & Electric Company for PG&E.

Whyte, I.W., S. Babakaiff, M.A. Adams, and P.A. Giroux. 1997. "Restoring Fish Access and Rehabilitation of Spawning Sites" in Fish Habitat Rehabilitation Procedures (Edited by P.A. Slaney and D. Zaldokas). Watershed Restoration Technical Circular No.9, Watershed Restoration Program series. Vancouver, BC: Ministry of Environment, Lands and Parks.

Whyte, I.W., S. Babakaiff, M.A. Adams, and P.A. Giroux. 1997. "Restoring Fish Access and Rehabilitation of Spawning Sites" in Fish Habitat Rehabilitation Procedures (Edited by P.A. Slaney and D. Zaldokas). Watershed Restoration Technical Circular No.9, Watershed Restoration Program series. Vancouver, BC: Ministry of Environment, Lands and Parks.

Wignore, J. 1983. A review of the outlet conditions at Hatzic Lake. Ministry of Environment.

Woods, P.J. 1996. "Management of Flood Protection Systems in British Columbia" in Watercourses: Getting on Stream with Current Thinking. Canadian Water Resources Association Conference Proceedings, Vancouver, BC October 22-25, 1996.

Personal Communications

Who	Position	Affiliation
Al Mirati	Fish Passage Coordinator,	Oregon State Dept. of Fish & Wildlife (Portland, OR)
Bill Hamilton	Supt. of Roads & Drainage	District of Mission
Clive Roberts	Drainage Department	Township of Langley
Darryl McDonald	Pump station manager	DAID
Dave Nansen	Habitat Protection Biologist	DFO
Ed Zapel	Professional Engineer	Northwest Hydraulic Consultants (Tukwila, WA).
Frank Wright	Superintendent of Drainage, Dyking and Irrigation	City of Abbotsford
Fred Wodtke	Senior Dyke Inspection Technician	MELP
Greg Cross	Drainage Supervisor	Pitt Meadows
Greg Giles	Supt. of Utilities	District of Mission
Jeff McGowan	Habitat Biologist,	Washington State Dept. of Fish & Wildlife (LaConnor, WA)
Jerry Pitney	Public Works Foreman	Village of Harrison Hotsprings
Jim Buell	Fish Biologist,	J.Buell and Ass. (Portland, OR)
Jim Elliot	Biologist	DFO
John Clarke	Fisheries Biologist, Delaware	State Dept. of Fish & Wildlife, Fisheries Section.
John Easterbrooks	Fish Screening Program Manager/Biologist,	Washington State Dept. of Fish & Wildlife (Yakima, WA)
Keith Paisley	Professional Engineer	District of Kent
Ken Bates	Chief Environmental Engineer,	Washington State Dept. of Fish & Wildlife (Olympia, WA)
Kon Johansen	Technical Officer	DFO
Krista Payette	Stewardship Advisor	MELP
Leslie Douglas	Environmental Coordinator	Township of Langley
Leslie Douglas	Environmental Coordinator	Township of Langley

Personal Communications continued…

Who	**Position**	**Affiliation**
Mark Schuler	Fisheries Biologist	U.S. Dept. of Agriculture - Natural Resources Conservation Service (Spokane, WA)
Marvin Rosenau	Biologist	MELP
Maurice Coulter-Boisvert	Community Advisor	DFO
Mike Chamblin	Puget Sound Technical Assistance Biologist	Washington State Dept. of Fish & Wildlife
Rob McCullough	Environmental Technician	District of Mission
Rod DenHerder	Project Engineer, U.S. Dept. of Agriculture -	Natural Resources Conservation Service (Renton, WA)
Sandy McCormick	Operations Manager,	Pemberton Dyking District (Pemberton, BC)
Sandy McCormick	Operations Manager	Pemberton Dyking District
Sylvia Letay	Habitat Protection Technician	MELP
Tom Bird	Biologist	Katzie First Nations
Warren Frizell	Research Hydraulic Engineer,	Water Resources Research Laboratory, Bureau of Reclamation (Denver, CO)

Appendix 1: Escapement Information for Matsqui Slough, Mountain Slough, Miami Creek and the Hatzic watershed. Source: Hancock *et al*. 1985.

	Matsqui Slough Claybурn Creek				Mountain Slough		Miami Ck	Hatzic Lake Drainage		
Year	Co	Cm	Pk	St	Co	Cm	Co	Co	Cm	Pk
1947								50	650	25
1948								0	650	0
1949								500	525	0
1950	65	25						50	575	0
1951	138							150	1050	0
1952	200	25						500	850	0
1953	75		25				200	125	900	0
1954	75							275	300	0
1955	75	25	25					100	500	0
1956	75						75	50	400	0
1957	75	25	25				75	225	900	0
1958	75	25					25	125	500	0
1959	75	25	25					100	175	0
1960	75	25					0	100	275	0
1961	75	25	25				25	100	250	0
1962	75	25					200	75	250	0
1963	200	25	25				75	50	175	0
1964	200	25					75	175	250	0
1965	200		25				25	75	355	0
1966	75						25	50	775	0
1967	105						0	50	100	0
1968	232						0	100	1150	0
1969	200		75				25	100	800	0
1970	200			0			0	125	600	0
1971	200						0	175	825	0
1972	500			50			0	100	600	0
1973	650							100	600	0
1974	600			20				75	825	0
1975	200			20			0	525	1025	0
1976	25			25			0	75	450	0
1977	350			25			0	100	2700	0
1978	260	25			200	25	0	50	1050	0
1979	0				0	0	0	100	700	0
1980	26			0	30	25	0	250	2700	0
1981	100						0	85	4017	0
1982	400			27	0	0	0	270	2220	0
1983	150			15	0	0	0	45	7145	0
1984	194			19				370	11130	0
1985								260	6950	5
	Matsqui Slough Claybурn Creek				Mountain Slough		Miami Ck	Hatzic Lake Drainage		
	Co	Cm	Pk	St	Co	Cm	Co	Co	Cm	Pk
Total	6220	300	250	201	230	50	825	5830	55892	30
Mean	177.7	25.0	31.3	20.1	46.0	10.0	31.7	149.5	1433.1	0.8
SD	155.2	0.0	17.7	14.2	87.1	13.7	56.4	130.8	2252.1	4.1
Range - low	0	25	25	0	0	0	0	0	100	0
Range- high	650	25	75	50	200	25	200	525	11130	25

Appendix 2: Pump log data for Matsqui Slough pumping station for 1998.

Month	**Pumping hours for each pump**						**Pump Mode**	**Total hours for fish friendly and non-fish friendly pumps.**		**% non fish friendly pumps on**
	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5	Pump 6[4]	Mode	Pumps 1-4,6	Pump 5	
	NFF	NFF	NFF	NFF	FF	NFF		NFF	FF	
Jan	119.4	148.1	106.1	124	35.1	9.85	Winter	507.45	35.1	94%
Feb	0.4	0.4	0.2	0	0	0	Winter	1	0	100%
Mar	0	0	0	0	0	0	Winter	0	0	0%
Apr[5]	**0.1**	**0**	**0.1**	**0**	**0.08**	**0.04**	**Summer**	**0.24**	**0.08**	**75%**
May	**35.1**	**30.7**	**0**	**5.1**	**220.77**	**36.59**	**Summer**	**107.49**	**220.77**	**33%**
Jun	**0**	**0**	**0**	**0**	**262.82**	**0**	**Summer**	**0**	**262.82**	**0%**
Jul[2]	10	23.4	-1 [3]	0	35.57	0	Irrigation	32.4	35.57	48%
Aug	10.3	7.2	0	0	227.2	38.36	Irrigation	17.5	227.2	7%
Sep	0	0	0	2.7	11.15	0	Irrigation	2.7	11.15	19%
Oct	0.1	0	0	0.1	0.14	0	Winter	0.2	0.14	59%
Nov	41.5	67.4	120	102.3	74.9	16.48	Winter	347.68	74.9	82%
Dec	11.6	69.5	80.1	63.1	32.63	0.07	Winter	224.37	32.63	87%
Sum	228.5	346.7	305.5	297.3	900.36	101.39				

Notes:

1. NFF: Not fish friendly; FF: Fish friendly.
2. Irrigation stop logs installed.
3. Value for Pump 3, July: this negative value is due to an error in the original pump log data. However, the error is minor and is of no consequence.
4. Pump 6 is the reversible pump and pumps water from the Fraser into the Slough during "Irrigation" mode. Sum value includes pumping water from the Fraser into Slough.
5. Values for April are likely associated with pump and motor maintenance.

Source: City of Abbotford pumping records for Matsqui pump station 1998.

Photo 1: Hatzic Slough station: pump intakes (L), flood box (R).

Photo 2: Hatzic Slough station: flood box (L) and pump (R) discharge.

Photo 3: Katzie Slough station: pump intakes (R), flood box entrance (L).

Photo 4: Katzie Slough station: pump and flood box outfall.

Photo 5: Matsqui Slough station: fish pump and screen located in right forebay.

Photo 6: Matsqui Slough station: flood box outfall (R), pump outfall (L).

Photo 7: Matsqui Slough station: entrance to flood boxes. Note hydraulic gate and slots for stop logs.

Photo 8: McLennan Creek station: fish pump and screen in left forebay.

Photo 9: McLennan Creek station: pump (left) and flood box (right) outfalls.

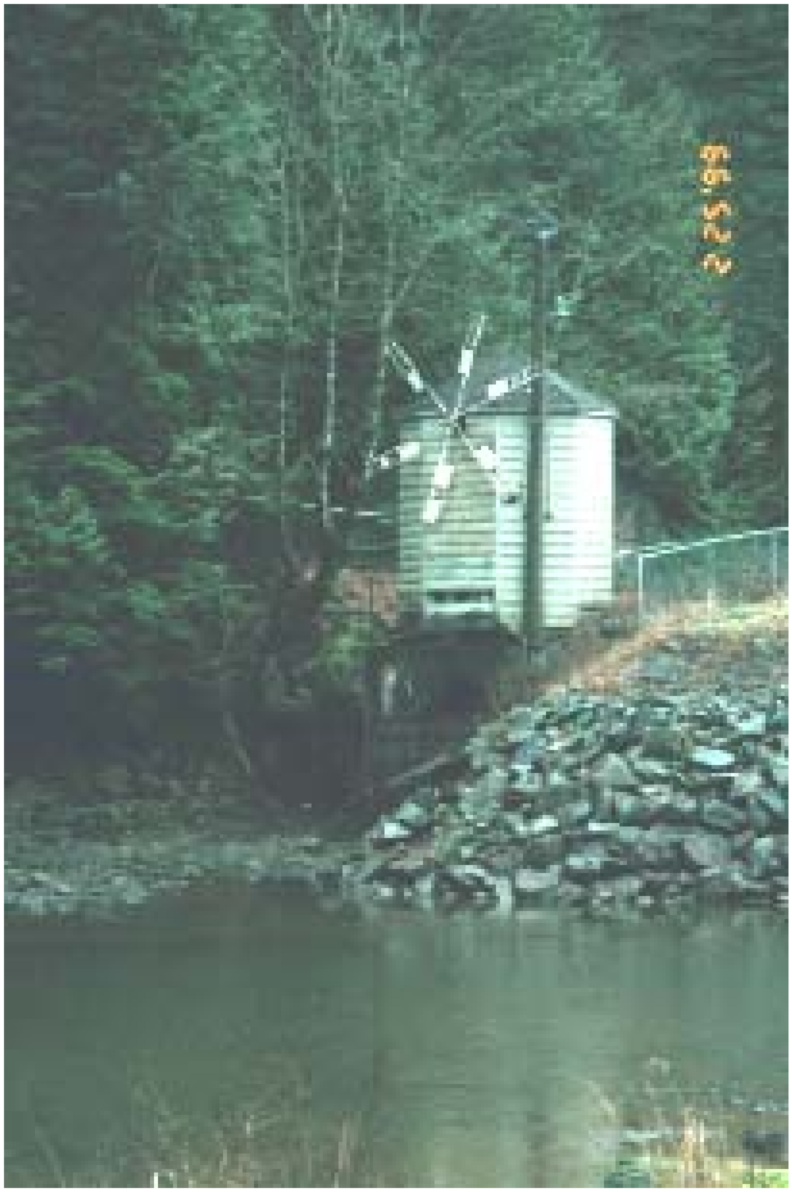


Photo 10: Miami Creek pumping station: old flood boxes under station. Also note the aged screen in front of the sump.

Photo 11: Miami Creek station: flood box entrance (R), future pump house sump (L)

Photo 12: Miami Creek station: flood box outfall. Note that gates are wide open with little flow.

Photo 13: McLean Creek station: flood box entrance (L), pump house (R).

Photo 14: McLean Creek station: cast iron top-mounted flap gate on flood box outfall.

Photo 15: Hammersley pump station on Mountain Slough

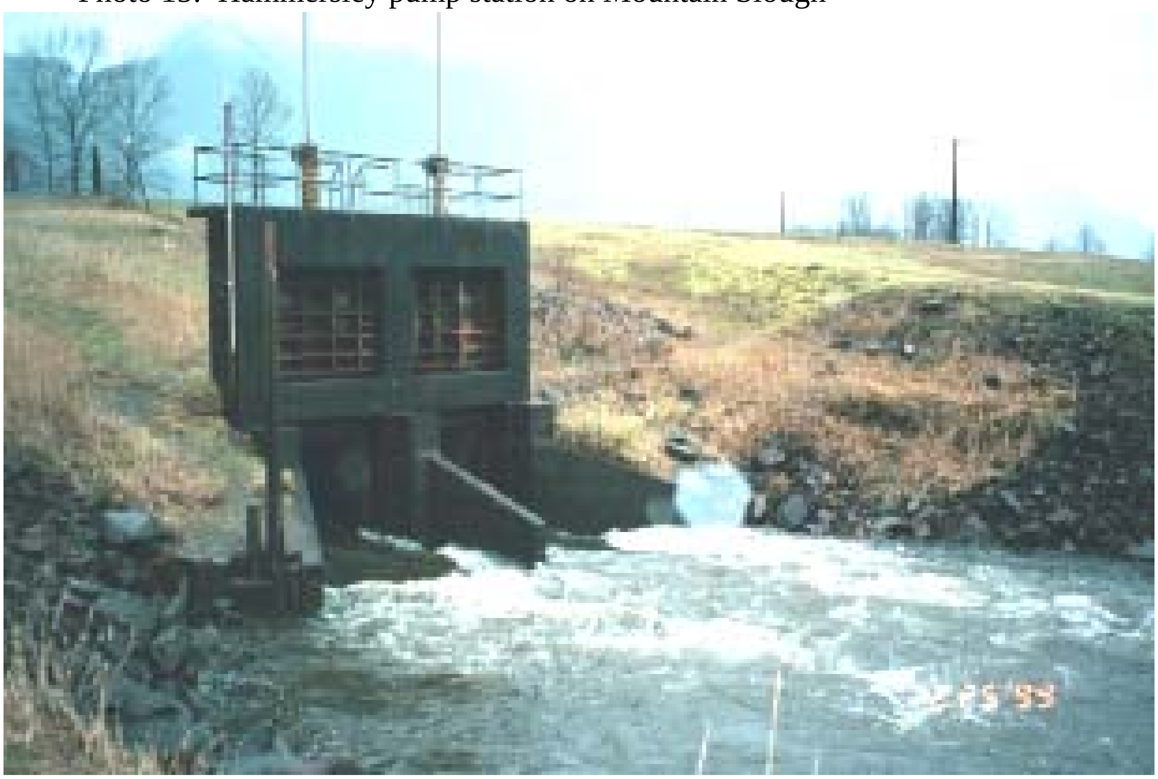


Photo 16: Hammersley pump station: flood box outfall. Note hydraulic jump – possible barrier.

Photo 17: Nathan Slough station: older station (R), new station (L) with submersible pumps.

Photo 18: Nathan Slough station: flood box and pump outfalls.

Photo 19: Silverdale station (Chester Creek): walkway to facilitate fish salvage during freshet.

Photo 20: Silverdale station (Chester Creek): new top mounted steel flap gate on flood box outfall.

Photo 21: Lane Creek station: Lane creek enters through culvert in center of pic.

Photo 22: Lane Creek station: culverts lead to pump station behind embankment.

Photo 23: Lane Creek station: pump (L) and flood box (R) outfalls.

Endnotes

---

[1] Environment Canada 1998.
[2] Shubert, N.D. 1982.
[3] Shubert, 1982.
[4] Rosenau, M. Per. comm.
[5] Johnston, J.M. 1981.
[6] Giger, 1972.
[7] BC MAFF 1996.
[8] Woods 1996.
[9] District of Abbotsford 1993.
[10] Woods 1996.
[11] M. Shuler.. Pers.comm.
[12] McJunkin and Vesilind 1968.
[13] Envirocon 1986.
[14] Sookachoff 1986.
[15] J. Buell. Pers. comm.
[16] District of Abbotsford 1993.
[17] M.Schuler. Pers.comm.
[18] J.Buell. Pers.comm.
[19] J.Easterbrooks. Pers.comm.
[20] Frizell and Atkinson 1996.
[21] McNabb *et al.* 1998.
[22] Johnson and Edwards 1993.
[23] McNabb *et al.* 1998.
[24] Envirocon 1986.
[25] McNabb et al. 1998.
[26] J.McGowan Pers. comm.
[27] A.Mirati. Pers.comm.
[28] K.Bates. Pers.comm.
[29] E. Zapel. Pers.comm.
[30] Russell 1981.
[31] J. Clarke. Pers.comm.
[32] Bates 1992.
[33] E.Zapel. Pers.comm.
[34] George, G.A. 1983.
[35] Harper, Lynn. 1979.
[36] Envirowest, 1992.
[37] George, G.A. 1983.
[38] DFO, 1997.
[39] Klohn Leonoff Consulting Engineers, 1983
[40] Klohn Leonoff Consulting Engineers, 1983.
[41] Darryl McDonald. Per. comm.
[42] Associated Engineering. 1992.
[43] Jim Elliot. Per. comm.
[44] Kon Johansen. Per. comm.
[45] FISS database.
[46] DFO, 1983.
[47] Enkon Environmental. 1996 & 1997.
[48] T. Bird. Per. comm.
[49] Harper, Lynn. 1979.
[50] MOE, 1985
[51] DFO, 1989
[52] Nener *et al*, 1997.
[53] Precision Identification Biological Consultants. 1998.
[54] Nener *et al*, 1997.

[55] F. Wright. per. comm.
[56] Nener *et al*, 1997.
[57] Kon Johansen. Per. comm.
[58] FISS database.
[59] Nener *et al*, 1997.
[60] Rood *et al.* 1995.
[61] G. Pitney. Per. comm.
[62] Mark Brennan. Per. comm.
[63] Hancock *et al.*1985.
[64] Nener *et al*, 1997.
[65] Klohn Leonoff, 1989.
[66] Nener *et al*, 1997.
[67] J. Pitney. Per. Comm.
[68] Klohn Leonoff. 1989.
[69] S. Letay. Per. Comm.
[70] A. Primeau,. Per. Comm.
[71] K .Johansen,. Per. comm.
[72] S. Letay,. Per. comm.
[73] FISS database.
[74] T. Bird. Per. comm.
[75] K. Johanson, per. comm.
[76] MELP Files.
[77] Fred Wodtke. Per. comm
[78] ECL Envirowest Consultants Ltd., 1998.
[79] Hancock *et al.*1985.
[80] Keith Paisley. Per. comm.
[81] J Elliot and K. Johansen. Per. comm.
[82] Hancock *et al.*1985.
[83] K. Paisley. Per. comm.
[84] L. Parker. Per. comm.
[85] Douglas, Leslie. Per. Comm
[86] Nener *et al.* 1997.
[87] B. Bowman. and J. Dewhit. Per. comm.
[88] K. Johansen. Per. comm.
[89] L. Parker. Per. comm.
[90] Watler *et al.*1998.
[91] FISS database.
[92] Walter A.R. *et al.*, 1998a.
[93] Precision Identification Biological Consultants. 1998.
[94] G. Giles,. Per. comm.
[95] J. Elliot. Per. comm
[96] FISS database.
[97] Walter *et al.* 1998.
[98] Nener *et al.* 1997.
[99] Walter *et al.* 1998.
[100] G. Giles,. Per. comm.
[101] 0.5 *0.5 *0.5 =0.125
[102] G. Giles,. Per. comm.
[103] W. Frizell. Pers.comm.
[104] J. Buell. Pers.comm
[105] WDFW 1999.
[106] IRC 1996.
[107] ECL 1991.
[108] H. Allmendinger. Pers.comm.
[109] Russell 1982.
[110] Eliason 1986.
[111] C. Roberts. Per. Comm.
[112] R. Bishop. Per. comm.
[113] C. Roberts. Per. Comm.

[114] K. Bates, J. McGowan. Pers.comm..
[115] J. McGowan. Pers.comm.
[116] J. Easterbrooks. Pers.comm.