Key Issues:
3- Fish Migration and River Navigation

Climate Zone:
Cf: Temperate

Subjects:
- Fish Bypass Screen for Hydropower Plant

Effects:
- Improved downstream passage of salmon smelts

Project Name: Puntledge Powerplant Fish Bypass Screen
Country: Vancouver Island, British Columbia, Canada (North America) (N49°41’, W123°58’)

Implementing Party & Period
- Project: BC Hydro 1993-1995
- Good Practice: BC Hydro 1993-1995

Key Words:
Fish Bypass Screen, Downstream Fish Migration; Fish Passage

Abstract:
A penstock screen design, patented by George Eicher, was used at Puntledge power intake. The screen removes juvenile anadromous fish from power flows and returns them to the river. Turbine mortality has been eliminated. Mortality through the bypass is less than 1%.

1. Outline of the Project

In 1913, Canadian Collieries Ltd. completed the construction of a hydroelectric facility on the Puntledge River to supply power to local coalmines. The facility consisted of an impoundment dam on Comox Lake, a low diversion dam and intake structure 4 km downstream of Comox Dam, and a flume and penstock system, which conveyed water to a powerhouse a further 7 km downstream. In 1953, the British Columbia Power Commission initiated a project to expand the facility and final construction was completed in 1956. The new facility included a 5.1 km long penstock from the diversion dam to a 24 MW powerhouse located on the right bank of the Puntledge River. BC Hydro acquired the facility in 1962 (Fig. 1).

The original impoundment and subsequent redevelopment had a significant impact on salmon stocks. Provision for upstream passage was made at each dam, but downstream passage resulted in high juvenile mortality through the turbines. This had to be resolved. An initial study considered the use of louvres, drum screens and vertical screens but concluded that a penstock screen, of the type patented by George Eicher, would provide the most economical solution at the Puntledge Diversion Dam. The alternative of not generating during the migration had an estimated present value approximately six times the cost of screening. Final design commenced in 1993.

Drawing records from the 1950's show several alternative layouts for fish screens. In anticipation of fish screen construction the power intake section of the dam was constructed with four intakes, although only two were used for power generation. They converge immediately downstream of the dam into a single 3.66 m diameter woodstave penstock. The other two intakes were capped on the downstream side of the dam.

Water velocity in the woodstave penstock is 2.64 m/s. The grade of the penstock for the first 1200 m is sufficient only to compensate for hydraulic losses in the pipe and maintain the hydraulic gradient 9.49 m above the crown of the pipe.

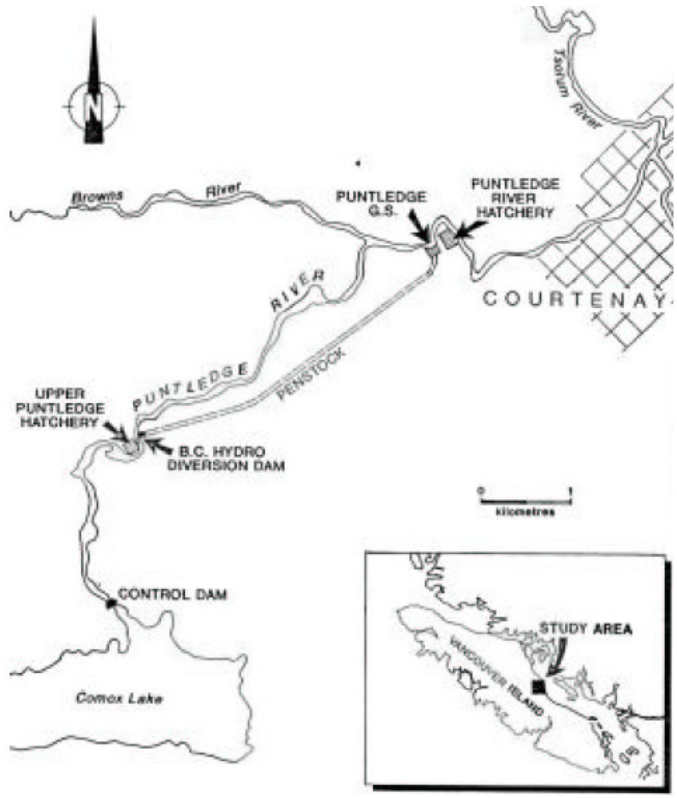

Figure 1 Location of Puntledge River Study Area

A critical factor in the choice of screen location was the length of time the generating plant would be out of service for the screen installation. It was concluded that a screen should be installed on each of the capped intakes. The two pipes converge immediately downstream of the screens into a 3.66 m diameter pipe. The work required during the plant outage included the connection of the new steel penstock to the existing woodstave pipe, capping the 3.66 m diameter stub and moving the intake gates.

2. Features of the Project Area

The Puntledge River drainage originates in the Forbidden Plateau range of the Vancouver Island Mountains, and has a total drainage area of 450 km2. Second and third order streams flow into Comox Lake, and in turn the lake feeds the lower Puntledge River from an outlet at its northern end.

Major tributaries of Comox Lake include the upper Puntledge River and Cruikshank Creek, while smaller tributaries include Toma, Perseverance and Cumberland creeks. In total, the lake's tributaries provide about 49 km of low gradient, accessible fish habitat, and account for nearly 70% of the potential spawning habitat in the drainage.

The lower Puntledge River is 17.5 km long, and flows in a general northeasterly direction into Comox Bay on the Strait of Georgia. In the lower river, Browns River, Morrison Creek and the Tsolum River are the three major tributaries.

3. Major Impacts

Historically, the Puntledge River supported significant salmon and steelhead trout populations and the river system was considered to be one of the more important salmon production areas on the east coast of Vancouver Island. Construction of the impoundment dam on Comox Lake in 1913 affected production of coho salmon, summer chinook salmon and steelhead trout which spawned in tributaries to Comox Lake. The expansion project increased the diversion flow from 8.5 m^3/s. There followed in immediate and drastic decline of chinook salmon stocks. Provision for adult upstream passage was made at both dams but the downstream passage of juvenile fish through the turbine at the Puntledge Generating Station resulted in an estimated 60% mortality.

The resulting decline in chinook (fall and summer runs) and coho stocks due to hydroelectric development from 1949 to 1973 on the Puntledge River are shown in Table 1.

Table 1 Decline in Chinook and Coho from 1949 to 1973

Five Year Period	Summer Run Chinook (X)	Fall Run Chinook (X)	Coho(X)
1949 - 1953	2,636	2,760	2,840
1954 - 1958	1,530	3,960	2,400
1959 - 1963	820	1,430	3,650
1964 - 1968	423	495	3,600
1969 - 1973	380	252	2,140

Several mitigation programs were undertaken with varying degrees of success but the one major impact that remained was the turbine mortality. In 1988 BC Hydro decided to resolve the issue of downstream passage.

4. Mitigation Measures

Previous attempts to divert juveniles away from the penstock intake had been either unsuccessful, or only a short-term solution. In 1992, three screening alternatives were considered: fixed vertical screens, rotating drum screens, and an Eicher screen. Layouts and cost estimates of each of the screens showed the Eicher screen to be the least expensive option at about $4 million. The vertical screen was estimated to cost in excess of $8 million, while the drum screen ran into physical site constraints resulting in a higher cost than that of the vertical screen. Therefore, the Eicher screen was selected for final design.

The Eicher screen is a fairly new concept in screening, with only two precedents in existence (the Sullivan plant at Willamette Falls near Portland, Oregon in 1982, and the Elwha project near Port Angeles, Washington in 1989). It consists of a wedge-wire screen installed in a steel penstock at a shallow angle to the flow, and passes fish through a bypass pipe branching from the top of the penstock. The design is unique in two ways: in that it uses much higher approach velocities at the screen than other conventional screens, and the travel time along the screen is very short (Fig. 2).

Consideration was given to installing a single screen in the existing 3.66 m diameter penstock. In order to meet the approach velocity criteria, the diameter would have to have been increased to 4.37 m, which would have been significantly larger than the 2.74 m diameter prototype at Elwha. The low gradient of the penstock downstream of the dam did not allow for such an expansion of the penstock for a

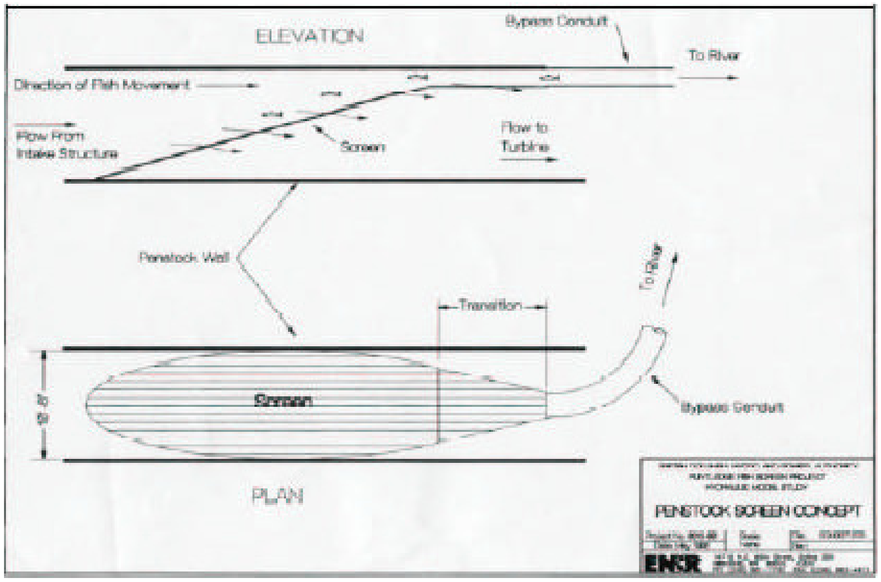

Figure 2

considerable distance and there was concern that the screen may not function as well on fish that would have to travel a considerable distance in a totally dark pipe. As the Elwha screen was very close to the intake, it was decided that the location at Puntledge should be as close to the intake as possible, using two 3.2 m diameter penstocks.

At the start of final design it was judged that, in order to obtain a uniform velocity distribution across the screen, there should be no horizontal bends upstream of the screen and the screen should be located a minimum of 10 diameters downstream of the intake structure. These criteria would not allow the screens to fit within the existing penstock trench and would have required a relocation of the training wall which separates the penstock trench from the river. A location 3 diameters downstream of the intakes would allow construction to be contained within the existing penstock trench.

In order to solve this and other problems a 1:10.96 scale hydraulic model of the forebay, intake structure, penstocks, screens and bypasses was constructed. Prototype material was used for the wedgewire screen. The supporting structure for the screen was scaled geometrically. The model was designed to be operated using Froude scaled velocities as well as full scale velocities. The flow patters in the forebay, intakes and penstocks up to the screen location were studied while operating the model according to Froude similitude laws. Through-screen velocity measurements and head loss measurements were collected while operating the model at full scale approach velocities. Tests were conducted to ensure that the flow patters immediately upstream of the screen in the full scale velocity tests were similar to those in the Froude scale test.

The hydraulic model indicated that the improvements gained by the downstream location of the screen were small when compared to the additional construction cost. The screen location 3 diameters downstream of the intakes was therefore chosen.

The second task for the hydraulic model study was to determine the benefits of varying the porosity of the screen. There were indications from the work at Elwha that gradually reducing the porosity of the screen as the bypass entrance was approached may help achieve the 3:1 sweeping to normal velocity criteria. Although some small benefits were demonstrated they were not considered sufficient enough to offset the more complicated fabrication and additional headloss. A standard Johnson stainless steel wedgewire screen with a uniform porosity of 58% was chosen.

The limited available head of 0.49 m posed a problem for maintaining pressures above atmospheric in the bypass pipes. The bypass entrance, therefore, was set within the crown of the penstock and the penstock was tapered until the rectangular bypass pipe had fully exited the crown of the penstock. The invert of the penstock was kept constant throughout this transition. Each bypass discharges $0.71 m^3/s$. The screens are cleaned by rotating them about a horizontal trunnion at their mid point. The backflushing action on the wedgewire provides an effective method of cleaning. Rotation is accomplished by two hydraulic cylinders attached to the screen frame each side of the bypass entrance. An adjustable timer controls screen rotation.

The project included the design and installation of an evaluation facility which can be connected to the bypass pipe from either screen. The facility consists of an energy dissipation tank, wolf traps, collection tanks, an evaluation tank, holding tanks, a downwell and an outfall pipe. Bypass flow enters at the bottom of the energy dissipation tank, where the velocity is reduced with turbulent diffusion in the tank. Flow is controlled with a stoplog weir at the downstream end of this tank. Sampling of 15% of the flow is also performed at the weir, with three wolf traps diverting fish into three collection tanks.

Each collection tank can be drained into an evaluation tank, which, in turn, can divert the fish into one of four holding tanks. Fish that are not sampled flow over the control weir, into the downwell, and are released back into the river through the outfall pipe. Wolf traps can be located at any point on the weir, have an adjustable slope and can be baffled to control flow at the downstream end of the trap.

In order to accommodate the upwelling method of energy dissipation, the minimum radius of curvature on the connection of the bypass pipe to the evaluation facility was reduced to 3 diameters. Although this increases the risk of a pipe blockage by debris, the evaluation facility will only be operational long enough to demonstrate the performance of the screens and the risk was considered acceptable.

The overall schematic is shown in Fig. 3.

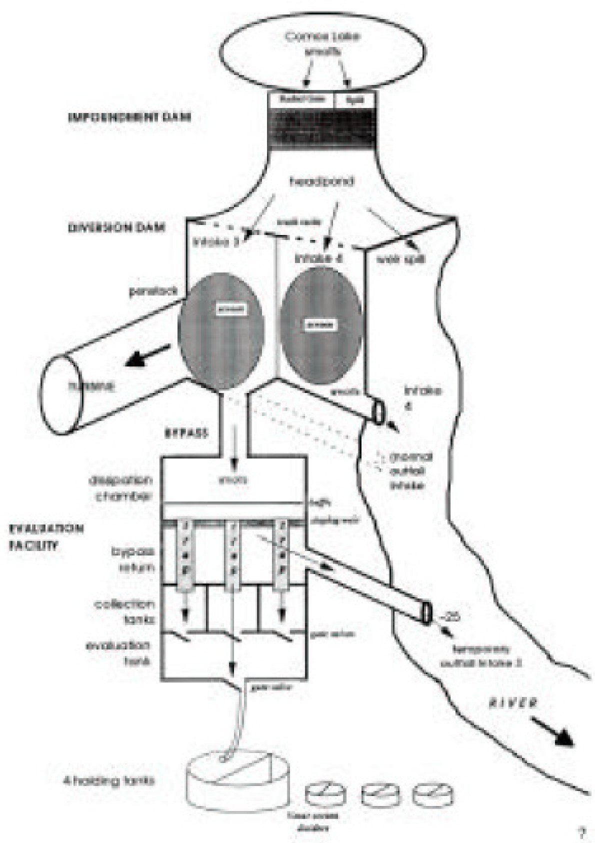

Figure 3 Pathways and Obstructions for Smolts Leaving Comox Lake

5. Results of the Mitigation Measures

Two extensive studies were done to test the effectiveness of Eicher Fish Screens at the Puntledge River Hydro Intake Facility (Bengeyfield, 1994 & 1995). The first study was conducted in 1993, between May 24th and July 30th, and focused on the Eicher screen in the southern penstock (No. 3 Intake) while the northern penstock (No. 4 Intake) returned its bypass flow directly to the river. The second study was conducted the following year from April 20th to December 12th. The same basic methodology was applied as in the first study, but the fish passing screen 1 in the northern penstock were released directly back into the river by switching the bypass pipes to allow for evaluation of fish passing screen 2 in the southern penstock (see Fig. 3).

To allow for observation of the fish passage, plexiglas ports were installed in the penstock wall along the side and top of each screen. The fish travelled through the pipes and were diverted by the Eicher screens to the bypass pipe. The fish then entered a dissipation chamber where velocity was decreased the discharge was spilled over a stoplog weir. The wolf traps, made of stainless steel and measuring 2 m by .15 m, were mounted along the crest of the weir, and collected fish which were then held in one of four fiberglass collection tanks for 96 hours.

For both studies, “direct mortality” is defined as the number of recently dead fish that were recovered primarily in the collection tanks of the evaluation facility. “Latent mortality” is fish that die within 96 hours after collection (Bengeyfield, 1994). The two types of fish studied were wild and hatchery juvenile salmon. Hatchery fish ere defined as fish released directly into the river from the hatchery.

When evaluating the Eicher screen in the southern penstock, two primary and two secondary objectives were researched. The primary objectives were to determine the rate of direct mortality to wild and hatchery juvenile salmon moving past the screen, and to determine the rate of latent mortality to wild and hatchery populations. The secondary objectives were to determine the sub samples of wild population in order to characterize the degree of scale loss associated with passage along the screen, and also to determine the timing and estimate the numbers of wild juvenile salmon in the 993 run (Bengeyfield, 1994). Fish were classified as descaled if more than 16% scale loss was on one side, or if more than 40% scale loss in each of two zones was on the same side.

Run size estimates for smolts was calculated using the proportional recover rate, and trap efficiency rate methods. Mortality as a result of the backwash cycle was also observed.

Test fish were used in the 1993 study, and were released at two different locations. The first group was released behind the trash rack at Intake 3. This group was used to determine the injuries encountered by fish passing across the screen and through the evaluation facility. The second group was released in the dissipation chamber which tested for injuries through the evaluation system alone. For results of the first study see Table 2.

Table 2 Comparison of mortalities, scale loss and run size estimate for the test period of May 24th to July 30th, 1993 (Bengeyfield, 1994)

	Direct Mortality	Latent Mortality	Backwash Cycle Mortality	Total Mortality	Scale Loss Average (%)	Run Size Estimates
Coho Juvenile Salmon	0.05	0.13	0.73	0.91	4.6	102,700 - 119,000
Chinook Juvenile Salmon	0.14	0.58	0.73	1.45	6.1	15,200 - 17,600

The evaluation procedures of fish at Intake 4 paralleled Intake 3, but only wild migrant populations of coho and chinook were used to evaluate screen 2 (Bengeyfield, 1995). No hatchery fish were used for this group because hatchery fish had an increased rate of problematic health conditions. For results of the second study see Table 3.

Table 3 Comparison of total mortalities, scale loss and run size estimate for the test period of April 20th to December 12th, 1994 (Bengeyfield, 1995)

	Direct Mortality	Latent Mortality	Backwash Cycle Mortality	Total Mortality	Scale Loss Average (%)	Run Size Estimates
Coho Juvenile Salmon	0.06	0.05	0.73	0.84	6.10	88,698 - 71,892
Chinook Juvenile Salmon	0.00	0.19	0.73	0.92	5.60	11,987 - 9,716

A variety of recommendations were made for the application of the Eicher screen in the second study. They included decreasing fish impingement on screens by cleaning the trash rack at the intake system more often, cleaning the plexiglas when the penstock is under annual maintenance, and raising the jump screen on the collection tank to prevent large steelhead and age 1+ chinook smolts from escaping (Bengeyfield, 1995).

If the Eicher screens had been functional during the period between 1990 to 1991, when the coho smolt out migration was estimated to be from 108,600 fish to 149,000 fish, turbine mortality would have ranged from 1,358 to 1,862 smolts per season as a result of the backwash cycle (Bengeyfield, 1995). The bypass results for the four methods tested from 1989 to 1993 are shown in Table 4.

Table 4 Rates of penstock bypass for smolts using four different methods during the period from 1989 to 1993 (Smith, 1993)

YEAR	METHOD	BYPASS RATE	(N)
1989	Behavioral Device	8.6%	114 000
1990	Electrical Field	11.1%	149 000
1992-93	Barrier Net	>99%	240 739
1993	Eicher Screen	99.8%	59 300

6. Reasons for Success

The following may be cited as reasons for success.

1) Establishing the Design Criteria

One of the most challenging aspects of the project was establishing the design criteria. BC Hydro held a workshop which was attended by representatives of the fisheries agencies and by some of those involved in the design and evaluation of the Elwha facility. Based largely on the consensus of opinion at the workshop design criteria were chosen for the following components:

- Design fish
- Approach flow to screen
- Screen physics
- Bypass parameters
- Outfall characteristics
- Penstock grade
- Evaluation facility

2) Planning the Implementation of Project

The construction schedule was set by the requirement to have the screens operational for the 1993 migration. The schedule was very tight and required several contracts to be issued as components of the design were completed.

The screen sections were fully assembled and tested in the shop before shipping to site. There was limited space on site for the operation of a large crane and careful sequencing of delivery was required. The plant outage required for connecting the screen s to the existing woodstave penstock was 2½ weeks, during which the annual maintenance was performed at the generating plant. Any extension of the outage would have resulted in $15,000 per day of lost revenue.

3) Hydraulic Model Studies

In order to design the screen to meet all of the above criteria, a hydraulic model study was undertaken by ENSR Consulting & Engineering, located in Redmond, Washington. The objectives of the model study were to:

- Optimize the overall layout, location and design details of the installation with respect to its hydraulic performance
- Confirm that the hydraulic performance of the final design satisfies the criteria established for the project, and
- Estimate the headloss created by the screen

A 1:10.96 scale physical hydraulic model was constructed. The model included the forebay, intake structure, conical expansion fittings, and penstocks. The model was designed to be operated using Froude scaled velocities as well as full scale velocities. The flow patterns in the forebay, intakes, and penstocks up to the screen location were studied while operating the model according to Froude similitude laws. The through-screen velocity measurements and headloss measurements were taken while operating the model at full scale approach velocities. Tests were conducted to ensure that the flow patterns immediately upstream of the screen in the full scale velocity tests were similar to those in the Froude scale tests.

7. Outside Comments

BC Hydro has been recognized as an industry leader by receiving several awards for the Puntledge Project. The awards include:

1) Association of Professional Engineers and Geoscientists 1995 Environmental Award Competition Design, Construction and Monitoring Phase, presented for design and construction of Eicher penstock fish screens
2) Electric Power Research Institute (EPRI) contribution to the Electrical Industry and Customer in the development of new technology
3) Electrical Power Research Institute (EPRI) 1994 Generation and Storage Product Champion, presented to Mr. H.A. Smith at BC Hydro

8. Further Information

8.1 References

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8.2 Inquiries

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