TRANS-CALEDON TUNNEL AUTHORITY

BERG RIVER VOËLVLEI AUGMENTATION SCHEME (BRVAS)

CONTRACT №: 21-041

COMBINED FISHWAY-CANOE CHUTE DESIGN FOR THE BRVAS

FOR

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BRVAS WEIR FISHWAY MONITORING PROGRAMME

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1 BACKGROUND AND TERMS OF REFERENCE

The Berg River-Voëlvlei Augmentation Scheme (BRVAS) includes the construction a ca. 6.4 m high weir (above the current alluvial bed) and abstraction on works the Berg River, approximately 2.7 km downstream of the Zonquasdrift Flow Gauging Station. The scheme will transfer up to 23 million m^3/annum of water from the river into Voëlvlei Dam, located some 5 km south-east of the weir site. As the proposed instream weir would form a formidable barrier to upstream fish movement at most river flows, the Environmental Authorisation (EA), dated 20/06/2017, granted by the National Department of Environmental Affairs (DEA) recommended that an investigation be undertaken of the need to incorporate a fishway into the weir and, if found necessary, to recommend suitable design parameters.

1.1 Migratory Fish Species and Need for Fishway

The most important indigenous migratory fish in the Berg River that could potentially be negatively impacted by the BRVAS Weir is the potamodromous Berg-Breede River Whitefish (Pseudobarbus capensis, previously named Barbus andrewi) that historically inhabited the affected reach of the Berg River. The other indigenous species potentially present in the river are thought to only migrate short distances within reaches and an instream barrier would thus have limited impact on their life-cycles.

The IUCN Red Listed (endangered) Whitefish undertakes long-distance upstream spawning migrations in spring or early summer during elevated river flows and, if present, would be negatively impacted by instream barriers in the Berg River. Ripe fish (25 – 60 cm in length) migrate upstream during the breeding season and congregate at the head of large, stony pools, at the base of rapids or in deep (1 to 1.5 m) riffles where the eggs are laid in clean gravel (Skelton 2001, Impson et al. 2017).

Whitefish populations in the Berg River have declined drastically in recent years and it is speculated that this species may even have gone extinct in this river system (Impson et al. 2017). Although CapeNature developed a Whitefish reintroduction plan in 2016 to re-establish this species in the Berg River, this has not yet been implemented due to recent financial and staff cut-backs (pers. comm. July 2021, Dr Martine Jordaan, Ecologist, CapeNature). However, in terms of long-term environmental planning, it appears warranted to anticipate the success of a Whitefish reintroduction plan in the future.

A recent investigation by Bok (2021) found that the only existing barriers to fish migration in the effected reach of the Berg River at elevated flows are the Misverstand Dam Wall, located approximately 53 km downstream, and the Paarl Abstraction Works Weir, located some 76.4 km upstream of the BRVAS Weir site. The approximately 129 km of river channel between these two barriers therefore forms continuous aquatic habitat for Whitefish.

Additional motivation for incorporating a fishway at the BRVAS Weir despite the apparent present absence of Whitefish in the Berg River, is because any attempt to retrofit a fishway onto the weir after construction would not only be technically challenging but also vastly more expensive than incorporating the structure into the original weir design. Due to the above findings and in anticipation of the success of a Whitefish reintroduction plan in the future, it is considered important to incorporate a fishway at the BRVAS Weir for adult Whitefish.

1.2 Hydraulic Modelling Studies at Stellenbosch University

The Hydraulics Laboratory in the Department of Civil Engineering at Stellenbosch University has been commissioned by the Trans Caledon Tunnel Authority (TCTA) to undertake comprehensive hydraulic model studies of the proposed BRVAS Weir and associated infrastructure in their hydraulics laboratory under the auspices of Professor Gerrit Basson.

As the BRVAS Weir is required to include a canoe chute to accommodate canoeists participating in the highly popular annual Berg River Canoe Marathon, the concept of investigating the feasibility of incorporating a fishway into the canoe chute appeared warranted. This option was discussed and agreed to by Prof. Basson in May 2021, before the hydraulics studies involving the canoe chute had begun. To the author's knowledge there are no existing combined fishway-canoe chutes in South Africa which could be used to provide design guidance (Bok et al. 2007).

Due to the present absence of Whitefish in the Berg River at the BRVAS Weir site, post-construction monitoring of the efficiency of the combined fishway-canoe chute to facilitate Whitefish passage over the weir will not be possible in the short-term. However, hydraulic model testing of the fishway-canoe chute at Stellenbosch University should provide the opportunity to ensure the hydraulic conditions (water flow depths and current velocities) are suitable for the upstream migration of adult Whitefish.

The proposed hydraulic modelling studies at Stellenbosch University therefore presented a unique opportunity to develop and test the viability of the proposed fishway-canoe chute for the BRVAS Weir.

2 CONSTRAINTS ON FISHWAY DESIGN

2.1 Definition of a Fishway

A fishway can be broadly described as any natural or artificial device that enables fish to overcome obstructions in streams in their migratory or other movements. Clay (1995) defines a fishway as "essentially a water passage around or through an obstruction, so designed to dissipate the energy in the water in such a manner as to enable fish to ascend without undue stress".

The successful design of a fishway therefore depends largely on providing the hydraulic and physical characteristics (i.e. water depths, current velocities, turbulence levels) which suit the target species for which it is intended.

2.2 Fish Swimming Ability

One of the most important constraints influencing fishway design is the swimming ability of the migratory fish in terms of speed and endurance. Swimming speeds of fish are commonly classified into three categories (Beach 1984), namely:

a) “sustained” – the speed which can be maintained for 200 minutes and longer,
b) “prolonged” –the speed which can be maintained for between 15 seconds to 200 minutes, and which results in fatigue if continued, and
c) “burst” – the speed which is the maximum a fish can maintain for up to 15 seconds.

2.3 Design Constraints at the BRVAS Weir Site

2.3.1 Existing BRVAS Weir Canoe Chute Dimensions

The proposed BRVAS Weir has a height of approximately 7 m from the weir crest at the canoe chute to the bedrock of the tailwater pool. The Campsdrift Weir Canoe Chute on the Dusi River in KwaZulu-Natal was used as the basis for the BRVAS canoe chute design. The general slope of the canoe chute was stipulated to be 1:5 in order to minimize costs, thus giving a chute channel length to just above bedrock in the tailwater pool of approximately 35 m. This is slightly steeper than the maximum slope of approximately 1:7 that is recommended for baffle fishways for large migratory salmonids by Larinier (2002a).

Fishways typically incorporate a range of in-channel structures such as small weirs or walls with vertical slots across the fishway channel in order to dissipate the energy of the water, increase depths and reduce current velocities. In contrast, canoe chutes require unobstructed water flow from the weir crest down the chute to the tailwater pool to ensure safe canoe passage, resulting in elevated current velocities, especially if the slope is steep. The proposed combination of the fishway and canoe chute into a single structure at the BRVAS Weir therefore placed additional design constraints, particularly in terms of ensuring suitable hydraulics (e.g. current velocities and flow depths) for upstream fish passage.

2.3.2 Swimming Ability of Target Species

Both prolonged and burst swimming speeds of the target fish species are normally of relevance when considering an appropriate fishway design. However, due to the high flow velocities anticipated in the proposed BRVAS fishway-canoe chute, it is anticipated that migrating Whitefish will mainly use their burst speed swimming ability when negotiating the proposed fishway.

Research in experimental flumes has shown that the burst swimming speed (i.e. maximum speed maintained for a few seconds) is given as varying between 5 to 15 times the body length in m/s, depending on fish species and size Clay (1995). Thus larger fish can attain much higher swimming speeds than smaller fish. Although there are no empirical data available to the author, adult Whitefish are estimated to have a maximum burst speed of at least 2.5 m/s (i.e. approximately 10 x body length). This estimate may be conservative, as maximum swimming speeds under favourable temperature conditions are given by Larinier (2002b) as about 6 m/s for adult salmon and between 3 m/s to 4 m/s for adult trout.

Burst speeds employ the white or anaerobic muscle of the fish. These muscles contract rapidly in the absence of oxygen and become exhausted when all the glycogen stores are converted into lactic acid. Fish using burst speed for migration therefore require a recovery period in slow-flowing, well-oxygenated water before further use of their white muscle. It was thus considered critical to incorporate resting zones at appropriate intervals along the fishway-canoe chute channel to allow migrating fish to rest and recover. Resting pools were therefore incorporated into the structure at approximately 10 m intervals. This is in line with recommendations for baffle fishways designed for sea trout and salmon, where resting pools are installed every 1.8 to 2.5 m of drop, with a distance between resting pools of 10 m to 12 m (Larinier 2002a).

2.3.3 River Hydrology and Migratory Period

The water level upstream of the weir will determine the discharge through the fishway-canoe chute and changes in this water level due to seasonal rains is therefore an important design parameter. It is important to ensure that the hydraulic conditions (current velocities and water depths) within the fishway-canoe chute are suitable for fish migration at the river discharges expected during the anticipated peak migratory period of the Whitefish. Existing knowledge indicates that Whitefish migrations mainly take place during medium to high river flows in spring (September to November) and are probably triggered by minor floods or freshets. It is thus important than the proposed fishway-canoe chute operates effectively at the river flows anticipated during this period.

It is commonly found that the water level in the tail-water pool downstream of the barrier increases faster than the upstream level. This rapidly rising water level may therefore submerge the downstream section of the proposed fishway-canoe chute during high flows. During major floods elevated tailwater levels could even submerge the weir crest and allow upstream fish migration. The weir drown-out characteristics therefore determines the maximum flow at which the canoe-chute-fishway should operate effectively.

The expected flows in the Berg River at the BRVAS Weir site and the hydraulic parameters within the fishway-canoe chute during this migratory period in spring are discussed in Section 4 below.

2.3.4 Fish Swimming Behaviour

The hydraulic conditions within the fishway should also cater for the migratory behaviour and swimming preferences of the migrants. Studies indicate that migrating fish often prefer to migrate upstream on the edge of the main river flow against the river bank or near the stream bottom to utilize slower flowing water in the boundary layers in an attempt to avoid strong instream currents (Bok et al. 2007). This swimming behaviour was taken into account when considering the design parameters of the fishway-canoe chute.

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3 CONCEPTUAL DESIGN OF THE BRVAS WEIR FISHWAY-CANOE CHUTE

The various constraints influencing fishway design at the BRVAS Weir, including the requirement for canoe safe passage as discussed earlier in Section 2, were taken into account during the preliminary design of the combined fishway-canoe chute. Inputs from canoeists regarding important safety features to be incorporated into the fishway-canoe chute design were solicited by the hydraulic model team at Stellenbosch University.

3.1 Energy Dissipating Structures

In order to reduce current velocities along the floor of the chute, chevron shaped floor baffles or weirs of 200 mm in height are placed on the floor at regular intervals along the full length, but at a height considered not to interfere with canoe passage. These so-called “Larinier super active baffles” are designed to create secondary helical currents which dissipate energy and create a boundary layer of slower moving water near the bottom of the chute, allowing fish to move upstream (Larinier 2002a).

The fishway-canoe chute also incorporates side baffles to deflect water towards the centre of the chute and to create eddies and slower flowing water at the sides. In addition, the floor immediately downstream of these baffles has been lowered in order to increase water depths to create more favourable hydraulic conditions for the migrating fish. In order to ensure safe canoe passage, the side baffles are curved with a 1m radius, starting parallel to the flow direction and curving upstream away from the centre of the chute to ensure that a canoe striking the sides is deflected towards the centre of the chute.

3.2 Swimming Behaviour

It is anticipated that Whitefish will swim up along the bottom at the sides of the fishway-canoe chute in order to avoid the higher current velocities found towards the middle of the chute. Due to the high current velocities anticipated in the chute, the migrating fish will be required to use their burst speed swimming ability for up to about 10 seconds before seeking slow-flowing water for rest and recovery. Resting zones are provided by low turbulent, slow-flowing water behind the side baffles and within the resting pools jutting out from both sides of the chute. The resting pools are placed at 10 m horizontal and 2 m vertical intervals, as recommended by Larinier (2002a) for baffle fishways designed for strong-swimming fish such as trout and salmon.

The proposed combined fishway-canoe chute design was tested in a flume at a scale of 1:15 before being constructed in the three-dimensional 1:40 scale physical model in the Hydraulics Laboratory. All design drawings provided have been produced by the Stellenbosch University Hydraulics Laboratory team.

4 COMBINED FISHWAY-CANOE CHUTE DESIGN

The final design for the proposed fishway-canoe chute at the BRVAS Weir is the result of numerous earlier proposals that were refined after hydraulic model tests were undertaken and inputs received from all parties involved. The final design is therefore a compromise between incorporating energy dissipating structures to reduce current velocities and create water depth to allow upstream fish movement, while providing safe downstream passage for canoes. Design details (including photographs) of the final updated fishway-canoe chute model tested (which were kindly provided by Professor Basson's team at the Stellenbosch University Hydraulics Laboratory) are given in Figures 1 and 2 below.

The proposed combined fishway-canoe chute has the following characteristics:

a) The chute will be constructed on the right bank side of the 17 m long low notch portion on the edge of the 40 m right bank notch of the BRVAS Weir;

b) The low notch crump weir crest is at 51.6 masl, while the right bank notch is a 51.9 masl;

c) Both notches have a Crump crest design for flow measurement by the Department of Water and Sanitation (DWS);

d) The crest level at the fishway-canoe chute is 0.3 m lower than the low notch of the weir to ensure that low flows pass through first before spilling over the low notch;

e) The fishway-canoe chute starts 0.5 m downstream and 0.1 m lower than the crest level so as not to influence the gauging properties of the BRVAS Weir;

f) The upstream end of the chute at the weir crest is 3.0 wide, while downstream of the crest the total width of the fishway-canoe chute is 4.0 m, including the side baffles;

g) The weir wall is approximately 7.3 m high (above bedrock). However, at a "medium low" river discharge of 5 m^3/s the weir crest at the chute is only 3.3 m above the tailwater pool level;

h) The general longitudinal slope of the fishway-canoe chute is 1:5 (V:H);

i) The total length of the fishway-canoe chute is 35.75 m in order to ensure safe passage for canoeists through the unstable jump at the downstream end of the chute at low river discharges when tailwater pool levels are low;

j) Side baffles angled downstream are placed every 1.0 m along both sides of the chute, starting at the downstream end of each step and protrude 0.5 m from the side walls;

k) These side baffles are curved in plan view, with a 1 m radius starting parallel with the flow direction at the edge of a step and curving outward to form a baffle in order to deflect any canoe strikes towards the centre of the chute;

l) There are openings of 0.3 m between the baffles and the pools downstream of the baffles are 0.9 m long at the side walls, creating resting zones of quiet water for fish migrating upstream, while ensuring canoes cannot get stuck against the baffles in the event of a canoe strike;

m) Steps of 0.2 m high in the chute floor are located in line with the edge of the baffles (i.e. every 1.0 m) and there are no sloping sections on the chute floor;

n) Chevron shaped weirs 0.2 m high are located on the floor of the chute to dissipate energy and create sufficient depth for migrating fish but are low enough to allow unobstructed canoe passage down the centre of the chute;

o) Resting pools of 1.0 m wide and 2 .0 m long jut out from the sides of the chute every 10 m along the chute, i.e. every 2.0 m drop.

p) The minimum operation level of the BRVAS abstraction works will be at a head of 0.3 m upstream of the fishway-canoe chute, at the minimum stipulated environmental water requirement (EWR) of 1 m^3/s.

Following safety concerns expressed by canoeists, additional modifications to the chevron weirs were made, namely (i) the upstream edges are rounded (0.1 m radius) to prevent injury to the legs of canoeist that capsize when negotiating the chute, and (ii) the narrow spaces within the chevron weirs and the upstream steps near the middle of the chute up to 0.3 m from the upstream step are filled in with concrete to prevent the possible wedging of feet in these small openings on the chute floor. These features are shown in Figure 2b.

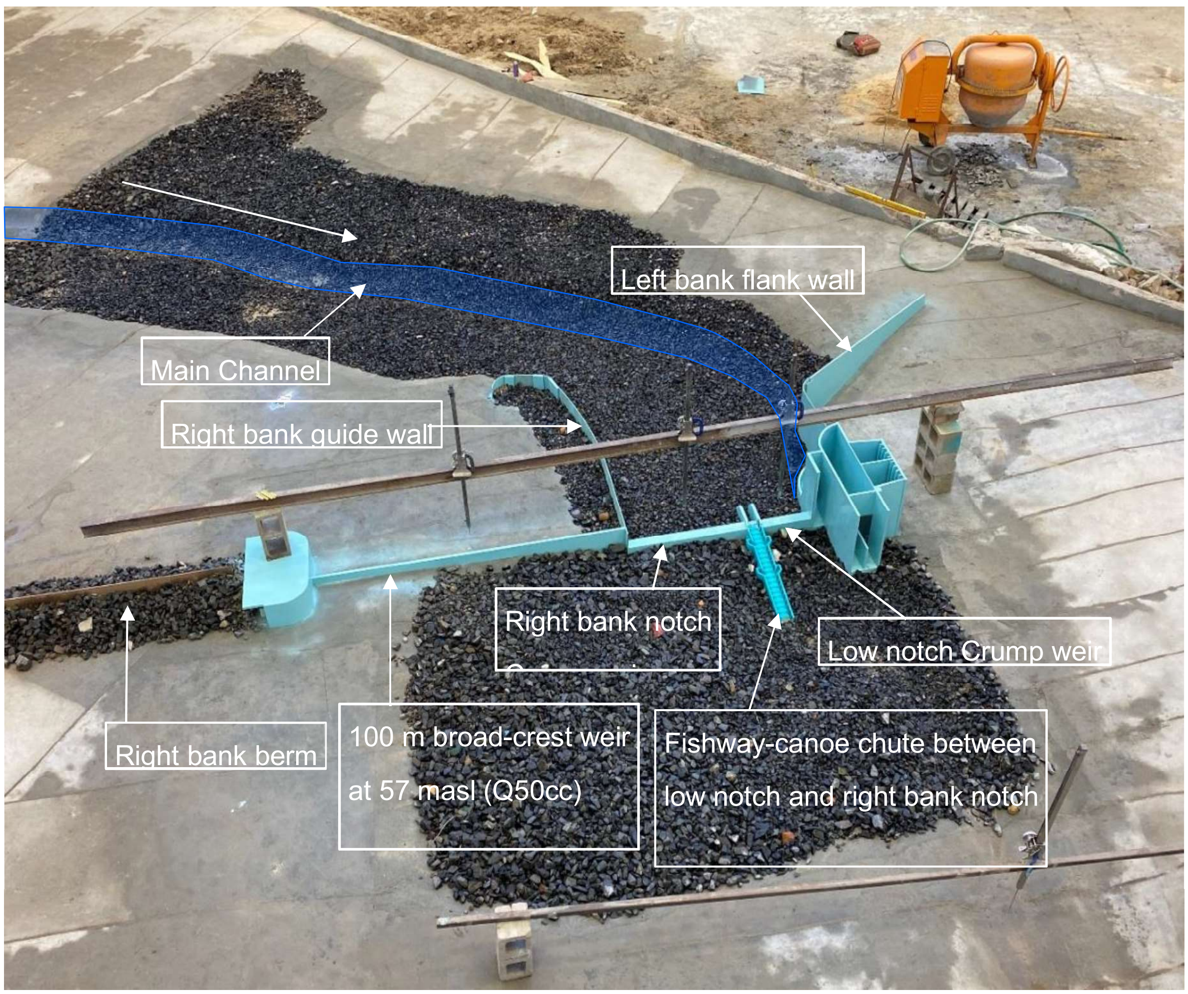

Figure 1: General layout of the BRVAS Weir in the Berg River showing the fishway-canoe chute located on the right side of the 17 m low notch section of the weir crest

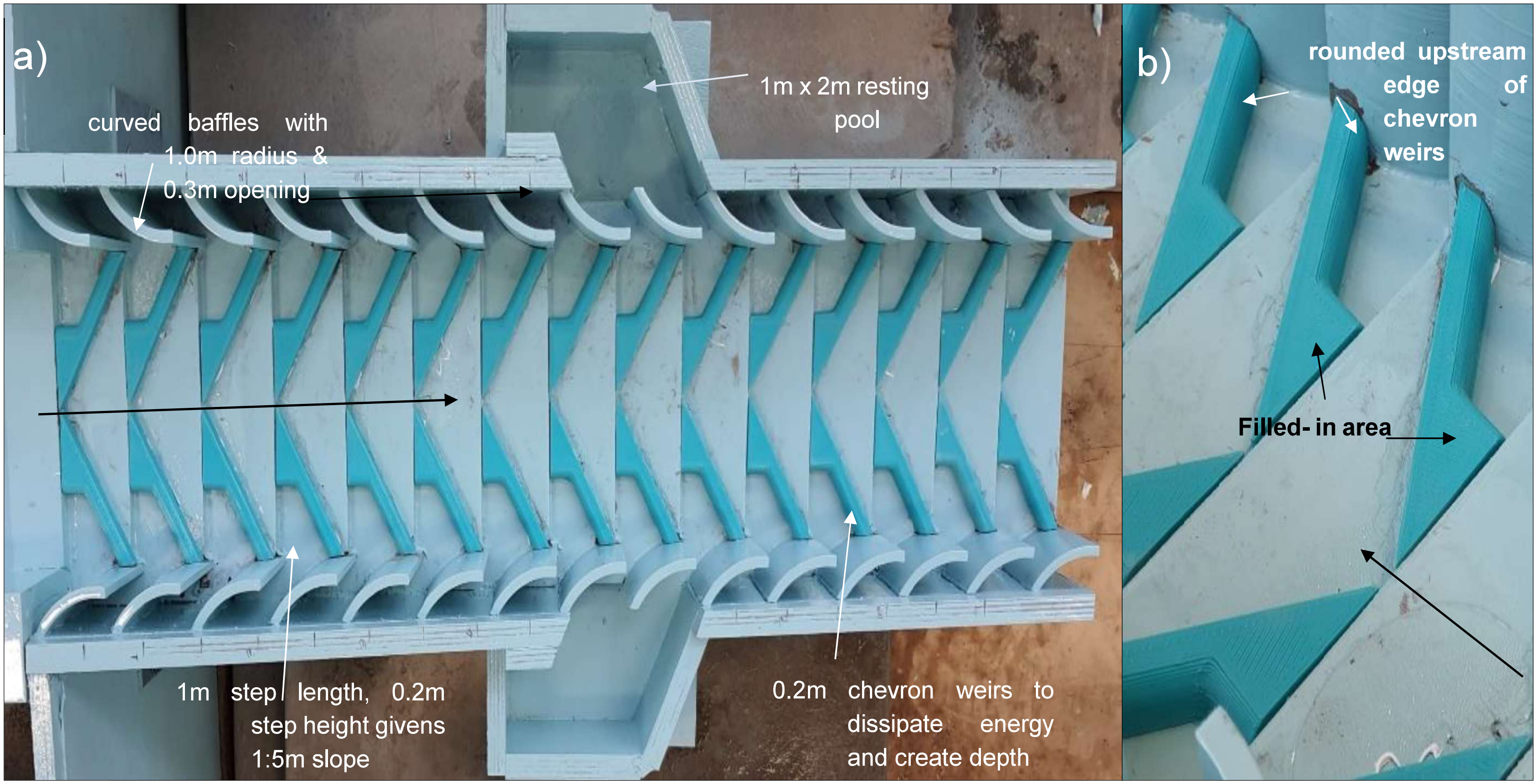

Figure 2: a) 1:15 scale model of the final fishway-canoe chute design constructed in the hydraulics laboratory, b) close-up view of the filled area and upstream rounded edges (0.1 m radius) of the chevron weirs.

5 MODEL STUDIES OF HYDRAULIC CHARACTERISTICS OF THE FISHWAY-CANOE CHUTE (1:15 MODEL)

5.1 Background

A series of hydraulic model studies of the various designs of the proposed BRVAS Weir fishway-canoe chute at a scale of 1:15 were conducted at the Hydraulics Laboratory at Stellenbosch University by Professor Basson's team in July, August, and September 2021. The design of the various prototypes were progressively modified in order to address the safety concerns of canoeists, as well as to accommodate the upstream swimming requirements of the target fish species, namely adult Whitefish.

The earlier canoe chute fishway models used in the hydraulic tests described below had 0.5 m wide side baffles placed at 1.75 m intervals at 45° to the side wall, but the ends of the baffles were not curved downstream as in the most recent design described in Section 4 (see Figure 2a and 2b). The curved side baffles with a 1 m radius and a 0.3 m opening between baffles, as well as the rounded upstream edges of the chevron baffles and filled in sections downstream of the chute steps, are features which were incorporated into the design of the final model to ensure safe canoe passage following concerns expressed by canoeists.

Details of the model designs and results obtained from hydraulic model studies conducted during the development of the various fishway-canoe chute designs are given in the internal reports submitted in July, August, and September by the Stellenbosch University Hydraulics Laboratory to AEJV and TCTA. Only details of the hydraulic model test results obtained from of the final modified fishway-canoe chute design, as described in Section 4, are given in this report. These results are presented here with kind permission from Professor Basson.

5.2 Hydrology of the Berg River at the BVRAS Weir

Table 1: Water levels at the fishway-canoe chute weir crest at various river discharges and the % time exceedance during winter, spring and summer.

ha fishway (m)	Q river (m^3/s)	Q chute- (m^3/s)	% exceedance in winter, spring & summer								
			June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
0.3	1.0	1.0	99%	99%	100%	100%	98%	75%	55%	50%	55%
0.4	2.6	1.5	94%	97%	%100	97%	80%	40%	20%	13%	10%
0.5	5.1	2.1	80%	92%	96%	93%	55%	15%	7%	3%	2%
0.6	8.3	2.8	65%	80%	86%	75%	30%	9%	2%	2%	1%
0.8	23.3	4.3	30%	50%	40%	30%	7%	2%	1%	1%	0%
1.0	45.8	5.9	2%	3%	3%	2%	1%	0%	0%	1%	0%
1.2	73.5	7.8	1%	2%	3%	1%	0%	0%	0%	0%	0%
1.5	123	10.9	1%	1%	1%	1%	0%	0%	0%	0%	0%

As indicated in Table 1, a river discharge of ca. 23 m^3/s (or at a fishway-canoe chute weir crest head of ha = 0.8 m) is exceeded 30% of the time in September and 9% of the time in October. This river flow is postulated to approximate the preferred river discharge when adult whitefish would undertake upstream migrations. Existing knowledge indicates that spawning migrations are undertaken in late spring, when water temperatures rise above 200 C (Impson, et al. 2017). Further field data are required to confirm the above and to determine more accurately when these water temperatures are reached in the Berg River in the study area during spring.

The hydraulic characteristics (current velocities and water depths) in the canoe-chute-fishway at water levels above the weir crest (ha) of approximately 0.5 m to 1.0 m, equivalent to river discharges of 5.1 m^3/s to 45 m^3/s at the BRVAS Weir, are therefore considered of particular importance for fish migration.

5.3 Hydraulic Model Study Results

The location of each measurement that was taken during the model studies over a range of river flows are given in Figure 3. Water depths were also recorded in the upper resting pool over the tested range of river discharges.

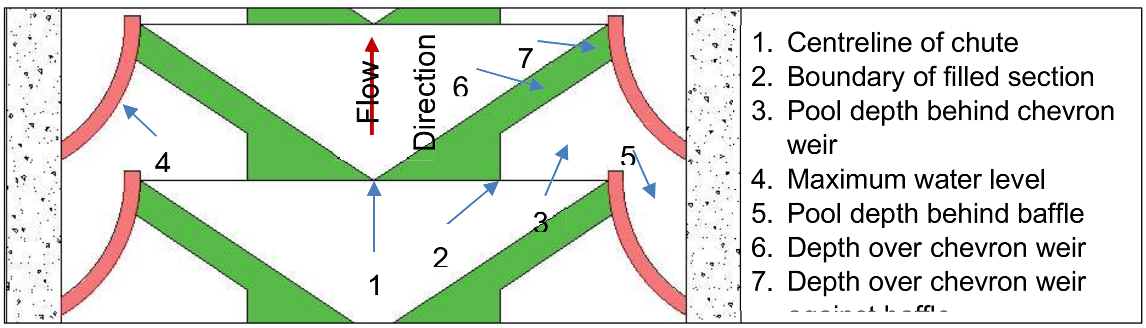

Figure 3: Measurement locations in physical model tests.

5.3.1 Water Depths in Fishway-canoe chute

Table 2: Water levels at the fishway-canoe chute weir crest at various river discharges and the % time exceedance during winter, spring and summer.

Water level (m) above weir crest and river discharge (m^3/s) in brackets	ha = 0.5 (5.1 m^3/s))	Ha = 0.8 (23.3 m^3/s)	ha = 1.2 (73.5 m^3/s)
Water depths in centre of chute (m) – location 1	0.20 – 0.40	0.30 – 0.50	0.50 – 0.70
Water depths at chevron weir (m) – location 6	0.12 – 0.20	0.22 – 0.38	0.38 – 0.61
Water depth inside side baffles (m) location 5	0.42 – 0.51	0.58 – 0.68	0.76 – 0.88
Water depths in resting pool (m)	0.51	0.68	0.86

As seen in Table 2, during the model tests at a water height above the weir crest (ha) of 0.5 m (or Q river = 5.1 m^3/s), the observed flow depths along the fishway-canoe chute, both in the centre of the chute and in line with the edge of the side baffles, varied from about 0.2 m to 0.4 m. At a river discharge (Q river) of 73.5 m^3/s or ha = 1.2 m, the flow depth varied between about 0.5 m to 0.7 m in the centre of the chute up to the hydraulic jump located only some 11 m downstream from the weir crest due to elevated tailwater pool levels.

Flow depths within the side baffles were found to be considerably greater compared to the centre of the chute (Table 2). At a river discharge of 5.1 m^3/s or a water level above the weir crest (or ha) of 0.5 m, the minimum depth within the side baffles is > 0.4 m. At flows of 23.3 m^3/s (ha = 0.8 m) this depth within the baffles increases to between 0.58 m to 0.68 m. During high floods (Q = 73.5 m^3/s) the depths inside the side baffles is over 0.76 m. In addition, the observed turbulence levels inside the baffles were relatively low. These water depths and low turbulence inside the baffles should provide conditions suitable for fish passage.

5.3.2 Resting Pools

In the large resting pools, the water depth at river discharge of 5.1 m^3/s (ha =0.5 m) was measured at 0.54 m and at a river discharge of 23.3 m^3/s (ha = 0.8 m) the water depth in the resting pool was 0.68 m.

During model tests at a river discharge of 73.5 m^3/s (H = 1.2 m), high turbulence and currents not suitable for resting fish were observed in the resting pool which had 2 openings at baffles 9 and 10 (see Figure 4a). With only one opening, however, the flow in the resting pool was much less turbulent (Figure 4b) and this modification will be made to the final design.

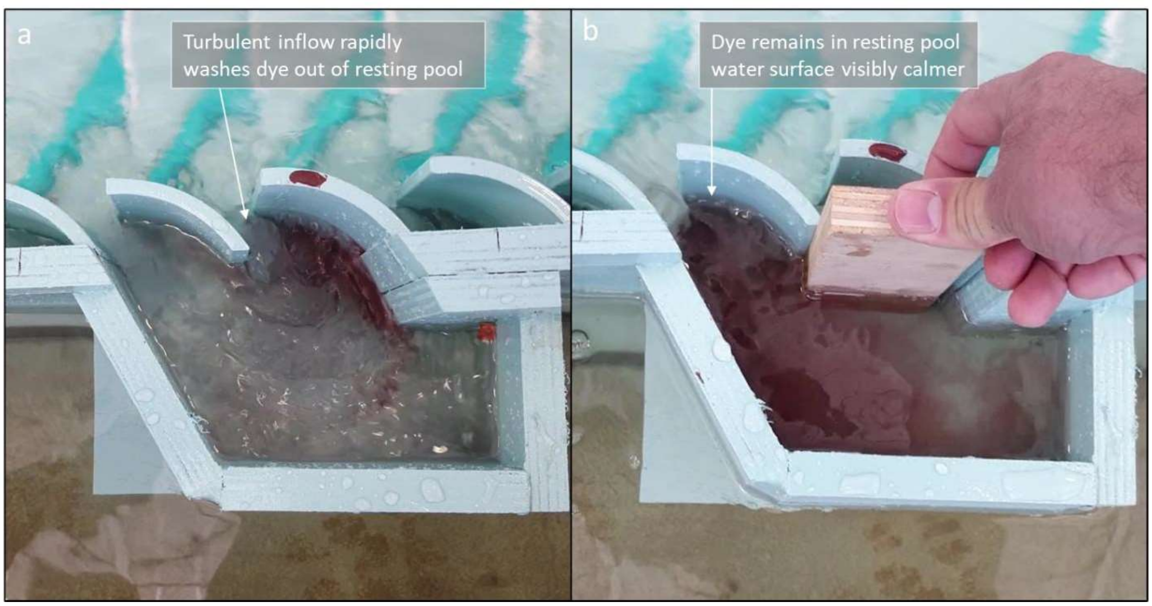

Figure 4: Resting pool with two openings compared to resting pool with one opening, H = 1.2m.

The upper resting pool is located approximately 10 m from the fishway-canoe chute weir crest and the model studies indicate that this pool becomes submerged during large floods of above about 100 m^3/s.

5.3.3 Water Flow Velocities in the Fishway-Canoe Chute

Flow velocities were measured over the chevron weir baffles at the edges of the side baffles using a pitot tube. The pitot tube was place placed on the floor of the chevron weir and represented the current velocity ca. 50 mm above the weir floor and away from the side baffle. The flow velocity over the weir floor at the edge of the side baffles will be the highest velocity that fish migrating upstream at the edge of the side baffles will encounter.

Surface flow velocities in the centre of the chute were measured by means of small wooden blocks floating on the surface and the average velocities calculated over 6 steps, i.e. a distance of 6 m. These surface velocities are important for canoeist navigating the chute. The results of these measured water velocities in the fishway-canoe chute model are given in Table 3.

Table 3: Measured current flow velocities around the side baffles near the bottom and at the centre of the canoe chute at the surface.

Damming height above weir crest (m)	Method of Measurement	H = 0.5m	H= 0.8m	H= 1.2m	H = 1.5m
Fish: Bottom flow velocity over weir at baffle (m/s)	Pitot tube	1.3	2.3	2.4	2.6
Canoes: Surface flow velocity at centre of the chute (m/s)	Floats	4.9	5.3	6.2	6.6

As shown in Table 3, the flow velocities are significantly reduced at the bottom of the chute near the side baffles compared with the surface flow in the centre of the fishway-canoe chute. During flood conditions at river discharges of 123 m^3/s (H = 1.5m) the high flow velocities of over 2.5 m/s throughout the fishway-canoe chute will be challenging for upstream migrating fish. However, these flood peaks usually only persist for short periods (hours rather than days) and should not have a significant impact on fish migrations. In addition, the low crest of the BRVAS Weir becomes inundated or partially submerged during floods greater than about 1:2 years (210 m^3/s) and should not pose a barrier to upstream migration of adult Whitefish during these conditions.

5.3.4 Discussion and Conclusion

The minimum flow depths for fish passage in baffle fishways for large migratory salmonids is considered to be about 20 cm (Larinier 2002a) and this is considered the minimum depth required in the fishway-canoe chute for adult Whitefish to migrate upstream without undue stress. The model tests showed that that water depths in important sections of the canoe-chute-fishway are suitable to allow upstream migration of adult Whitefish over the range of discharges thought to occur during their migratory period.

In addition, the water depths behind the side baffles (>0.4 m) and within the resting pools (>0.5 m) are very favourable and should create favourable conditions for the upstream migrating fish to rest and recover. As the maximum burst speed of adult Whitefish is estimated to be at least 2.5 m/s, the flow velocities in the fishway-canoe chute are within the acceptable range for upstream migration. The presence of relatively slow-flowing water behind the side baffles will also greatly assist upstream migration.

Due to the present absence of Whitefish in the Berg River at the BRVAS Weir site, post-construction monitoring of the efficiency of the combined fishway-canoe chute to facilitate Whitefish passage over the weir will not be possible in the short-term.

The option of capturing adult whitefish from the Breede River and stocking these fish into the Berg River downstream of the proposed BRVAS Weir fishway-canoe chute (when constructed) in order to test the effectiveness of the fishway, was considered. After due consideration, however, this proposal was rejected as having too high a risk to attempt using a critically endangered fish species. In addition, even if carried out with low mortalities, there would be no guarantee that the stocked fish would attempt to migrate upstream due to the unavoidable stress due to capture and transport.

As an alternative to the above, it is proposed that hydraulic measurements in the fishway-canoe chute be taken in the field by the Stellenbosch University hydraulics team once the structure has been built in the Berg River. These measured hydraulic data at various river flows could then be used instead of fish monitoring data to confirm that the structure has been built to the correct specifications to allow Whitefish passage.

In conclusion, the results from the hydraulic model tests show that the proposed fishway-canoe chute has suitable hydraulic conditions in terms of depths and current velocities to allow the upstream passage of strong-swimming fish such as adult Whitefish during the peak migratory period in spring. In addition, the flows in the centre of the canoe chute and the curved side baffles should provide suitable conditions for the safe downstream passage of canoes.

6 REFERENCES

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TRANS-CALEDON TUNNEL AUTHORITY

BERG RIVER VOËLVLEI AUGMENTATION SCHEME (BRVAS)

CONTRACT №: 21-041

BRVAS WEIR SHORT-TERM FISHWAY MONITORING PROGRAMME

FOR

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BRVAS WEIR SHORT-TERM FISHWAY MONITORING PROGRAMME

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1 BACKGROUND

The Berg River-Voelvlei Augmentation Scheme (BRVAS) Canoe Chute-Fishway has been designed to allow the safe downstream passage of canoes to cater for the annual Berg River Canoe Marathon, as well as for the upstream migration of the target fish species, namely adult Whitefish Psuedobarbus capensis (*ex Barbus andrewi*). This large indigenous species, which is only found in the Breede and Berg Rivers, is listed as "Endangered" in the International Union for Conservation of Nature (IUCN) Red List.

Whitefish populations in the Berg River have declined drastically in recent years and it is speculated that this species may even have gone extinct in this river system (Impson et al. 2017). However, as part of the Berg River Improvement Plan initiated by the provincial Department of Environmental Affairs and Development Planning (DEADP), CapeNature developed a Whitefish reintroduction plan in 2016 to re-establish this species in the Berg River.

The above Whitefish recovery initiative postulates that: *"it is envisaged that this conservation initiative by CapeNature will lead to the re-establishment of the species in the Berg River System and possible down-listing of the species by the next assessment"* (Impson et al. 2017). Thus, in anticipation of the success of the above reintroduction plan and in keeping with the precautionary principle, a fishway targeted at allowing for the natural migrations of adult Whitefish was incorporated into the proposed BRVAS Weir canoe chute.

During the breeding season in early summer, adult Whitefish undertake long-distance upstream migrations to suitable habitats for spawning purposes during medium and high river flows. Ripe fish congregate at the head of large, stony pools, at the base of rapids or in deep (1 to 1.5 m) riffles where the eggs are laid in clean gravel (Skelton 2001, Impson et al. 2017).

The other smaller indigenous fish species in the Berg River System (if indeed present at the BRVAS Weir site) are thought to only migrate short distances within reaches and an instream barrier would thus have limited impact on these species. In addition, the preferred habitat of the smaller indigenous fish species, such as Cape galaxias (*Galaxias zebratus*), Berg River redfin (*Pseudobarbus burgi*) and Cape kurper (*Sandelia capensis*), are perennial tributary streams rather than the main river channel. It appears highly unlikely that these small indigenous fish species are present at the BRVAS Weir site, as during recent baseline fish surveys for the EIA undertaken in October 2016 (The Biodiversity Company 2017), only alien or non-endemic fish species (7 species in total) were sampled at the BRVAS Weir site.

The proposed combined canoe chute-fishway on the BRVAS Weir is therefore not designed to cater for small or weak-swimming fish. It is anticipated that the relatively high current velocities and turbulence levels anticipated in structure may not allow the upstream migration of "undesirable" non-endemic and alien species present, such as sharptooth catfish (*Clarias gariepinus*) and bass (*Micropterus spp*). From a conservation perspective, this would be considered a positive impact.

The BRVAS Weir canoe chute-fishway design is presently being developed and tested at the Stellenbosch University Hydraulic Engineering Division in the Faculty of Engineering under the guidance of Prof Gerrit Basson. An important objective of the design is to create hydraulic conditions in the structure that would cater for the safe downstream passage of canoes (to accommodate the Berg River Canoe Marathon) with the additional objective of enabling the upstream migration of adult Whitefish. Although no accurate data are available, these large (25 – 60 cm in length) strong-swimming fish are considered capable of negotiating current velocities of over 2.0 m/s and turbulence levels of above about 180 watts/m^3 on their natural upstream migrations over instream barriers such as rapids.

2 AIM OF MONITORING STUDY

There is a paucity of quantitative data on the performance of existing fishways in South Africa or on the swimming ability of indigenous fish species. The canoe chute-fishway design is therefore a best estimate compromise aimed at insuring canoes can descend safely, while also creating suitable hydraulic conditions (current velocities, turbulence levels and water depths) to allow the target fish species to migrate up during medium to high flows. The proposed fishway monitoring programme is therefore designed to provide data on both the effectiveness of the combined canoe chute-fishway in terms of the internal hydraulics allowing fish passage at various flows, as well as data on the migratory behaviour and swimming ability of the target fish species, namely Berg-Breede River Whitefish.

3 FISHWAY MONITORING PROTOCOL

Fishway monitoring assessments often simply involve catching and recording fish moving through the fishway during peak migration periods by placing a trap at the upstream end or exit. This information does give an indication of what species can successfully negotiate the fishway, but these data have limited value in really assessing the effectiveness of the fishway being studied in terms of the proportion of fish that enter the fishway and those that successfully swim through to the river upstream.

To accurately assess fishway performance, information is required on the number and size composition of the target fish species attempting to migrate past the barrier, but could not find the fishway entrance, as well as the fish which entered the fishway channel but were unable to reach the top. In addition, in order to understand the environmental cues which may stimulate fish migrations of the target fish species, relevant parameters (abiotic and biotic) need to be measured during the monitoring period. In addition to data on Whitefish, migratory data on the other fish species in the river attempting to use the fishway, would also be useful in terms of insight into the upstream swimming ability of undesirable (non-endemic) species present at the BRVAS Weir site.

Details of the monitoring procedures to be used and the techniques and equipment used to collect the data will naturally have to be adapted to accommodate site-specific conditions. However, the proposed fishway monitoring programme for the BRVAS Weir canoe chute-fishway should attempt to answer the questions posed below. (Note: the term fishway in this report is also used to refer to the combined canoe chute-fishway structure).

3.1 Key Questions

3.1.1 Biological/Ecological Parameters

i. What species, size and numbers of fish successfully pass through the fishway (i.e. exit into the pool above the fishway)?

ii. What species, size and numbers of fish actively migrating are blocked by the barrier in question, i.e. accumulated downstream of the weir?

iii. What species, size and numbers of fish swim into the entrance and attempt to use the fishway (i.e. swim into the down-stream end of the fishway?

iv. What proportion of migrating fish which enter the fishway but cannot swim right up to the top – i.e. only migrate a limited distance up the structure?

v. Are there any bottlenecks in the fishway and (if any) where are they located and what is the cause?

vi. Why are the fish migrating? Reasons could include sexual reproduction, colonization/dispersion, feeding, over-wintering, etc. Some of these data can be obtained by careful analyses of the fish captured.

3.1.2 Physical Parameters

i. Do water discharge rates down the fishway impact on successful use of the fishway by the different species, or size of fish?

ii. How does the internal hydraulics in the fishway (current speed, turbulence and depths in critical areas) change at the various discharges?

iii. At what levels of stream-flow or stages of the flood hydrograph do peak migrations in the river take place?

iv. Do peak migrations in the river correspond to peak movement through the fishway – i.e. is the fishway effective (i.e. in terms of the internal hydraulics) at river flows when peak fish migrations occur?

v. When (time of day/night, season) do migrations of the various species occur?

vi. How do water quality parameters (temperature, conductivity, pH, turbidity) impact on fish migration?

vii. Are there any other environmental cues (barometric pressure, air temperature, wind, phase of the moon, etc.) that appear to influence fish migration?

3.2 Data Collection

As mentioned above, the techniques and equipment used to collect the data required to answer the questions posed above, will vary depending on site characteristics and streamflow conditions at the site. In some instances, collection of quantitative data will be virtually impossible, such as numbers of fish migrating during flood conditions, and visual estimations will have to suffice. The data collection equipment and procedures suggested below should therefore be used as a guide and adapted as the need arises.

All data collected during each monitoring session should be accurately recorded on field data sheets.

3.2.1 3.2.1 Fish Capture Methods

Details of fish capture methods as well as equipment used will vary depending on the physical constraints at the site and flow in the river at the time of sampling. Care should be taken to ensure that nets or traps placed in the fishway channel or at the fishway exit (upstream end) do not significantly modify the internal hydraulics of the fishway. The following gear should be used where appropriate:

a) Funnel trap nets/ Fyke nets.

All funnel trap nets should be sufficiently large and when placed should include areas of slow-flowing water so that the fish can be held without injury or stress for long periods and can be easily removed uninured for identification and measuring. Ideally, an appropriate funnel trap or fyke net should be placed at the fishway exit (upstream end) as well as at the fishway entrance (most down-stream end). This will enable so-called “paired sampling” to take place (see more detailed description in Section 3.2.2.f below). As the BRVAS canoe chute-fishway has a 4 m wide channel, wing-nets on the sides of the funnel traps and fyke-nets will be required to guide the migrating fish into the trap.

b) Stop-nets

The canoe chute fishway has two side chambers about halfway along the chute, jutting out from the main channel. These side chambers (1.0 m wide and 2.0 m long) are designed to act as resting pools and allow the fish migrating upstream to rest and recover away from the high velocity currents near the centre of the canoe chute-fishway channel. Vertical groves in the concrete channel side walls at both the upstream and downstream ends will allow the side chambers to be sealed off from the main channel by the placement of a stop-net. This will consist of a 2.0 m long x 1.5 m high rectangular frame covered with netting that fits tightly into the two groves in the concrete side walls. Placement of these stop-nets will enable the fish present in each side chamber to be isolated from the main channel and captured using dip nets, possibly with the help of an electro-fisher.

c) Dip nets

A variety of dip-net sizes could be used, but the size of at least one dip-net should match the internal dimensions of the side chambers (i.e. 1.0 m x 1.0 m) to ensure effective operation.

d) Other fishing gear

The standard range of fish capture methods and equipment could be used for sampling both in the fishway and in the river down-stream of the BRVAS Weir, depending on the river conditions. This gear could include electro-fishing apparatus (fish-shocker); seine nets, throw nets, fyke-nets and fish-traps. Destructive sampling gear such as gill nets should be used with caution due to the Endangered Red Data status of the Whitefish.

3.2.2 Sampling Localities

a) Down-stream Pool

It is important to establish what species and size range are present in the river immediately downstream of the BRVAS Weir that could potentially use the fishway. This fish assemblage may include non-migratory species and species that actively migrate into the fishway. The pool downstream of the BRVAS Weir should thus be sampled using a variety of appropriate fishing gear.

b) Fishway Entrance (bottom sample)

When fish are actively migrating into the fishway (i.e. swimming into the canoe chute-fishway channel) a suitable fyke net (or funnel trap) should be placed at the entrance to the chute in order to catch upstream migrating fish that attempt to enter the structure.

c) Within the fishway

As the canoe chute-fishway channel is relatively long (approximately 30 m in length), resting side-chambers (1.0 m wide x 2.0 m long) with low current velocities and reduced turbulence were incorporated into the design and jut out halfway along on either side of the chute. These side chambers can be easily and effectively sampled for fish seeking refuge from the high velocity and very turbulent water in the main flume, by using an appropriate stop-net as described above.

Comparative data of fish captured at the entrance and in the resting side-chambers should indicate whether some species or size classes enter the fishway, but have difficulties negotiating even halfway up.

d) Bottlenecks in fishway

Accumulation of fish at any point along the channel will indicate whether there are any bottlenecks within the fishway when operating at various flows.

e) Fishway exit (upstream end)

Upstream migrants that have successfully negotiated the entire length of fishway should be captured by means of funnel traps (fyke net) placed to capture all fish leaving the fishway.

f) Paired Sampling

During the period of active migration it is important to assess the effectiveness of the fishway by means of paired sampling. The objective is to compare the fish that located and entered the fishway (bottom sample) to an independent sample of fish that located, entered and successfully passed through the full length of the fishway (top sample). To achieve this, a funnel trap (or fyke net) should be placed at the top of the fishway for 24 hours, followed by a funnel trap placed at the bottom of the fishway for 24 hours. This should be done on consecutive days to provide paired samples for comparison.

3.2.3 Data Recorded

a) From the fish captured

Details of each fish captured should be recorded, including:

a) Date, time period and locality (within fishway) captured,

b) species, and

c) length and sexual condition (e.g. milt expressed from males or eggs from females when squeezed).

Fish captured during the monitoring programme should be returned unharmed to the site of capture, if possible. All Whitefish captured within the fishway migrating upstream should be placed unharmed upstream of the fishway.

b) Abiotic Data

The following water quality data from the canoe chute-fishway should be recorded during each monitoring session, e.g. once or twice (dusk and dawn) daily and more often if the water conditions change rapidly (e.g. during floods):

a) Temperature - maximum and minimum;

b) conductivity (or TDS);

c) turbidity.

Further data recorded during each monitoring session (i.e. between setting and clearing of the traps) should include:

a) headwater and tailwater levels at the barrier,

b) water flow volumes (or water depths) spilling over the weir crest,

c) weather conditions (rain, cloud cover, air-temperature, wind speed and direction, barometric pressure).

c) Incidental observations

Observations of additional factors that may possibly influence fish migration or that may be of value in understanding fish migration should be recorded for each monitoring session, such as:

a) presence of predators such as birds, otters, etc.;

b) unusual migratory behaviour, (e.g. leaping activity) or accumulations of fish at the entrance, exit or in sections of the fishway.

3.2.4 Monitoring Period and Frequency

After weir construction is complete and commissioning of the fishway is done by the Consulting Engineers responsible, an initial monitoring period of at least 2-4 weeks during the peak migratory period will be required to assess its effectiveness and to optimise its operation. Peak migrations are thought to take place after rainfall events in spring and summer when the river flow increases, but will require confirmation via on site observations.

a) Sampling Frequency

Checking and clearing of traps within the fishway should take place every 4 to 12 hours, depending on the numbers of fish migrating through the fishway. Sampling at dawn and dusk will allow diurnal migratory peaks to be determined. Variable water quality data such as water temperature, conductivity and turbidity and other abiotic parameters should be obtained daily or twice a day (dawn and dusk), if found to change significantly.

b) Hydraulic Data

Hydraulic information on the canoe shute-fishway at various river flows, such as water depths and current velocities within the fishway should be available from previous hydraulic analyses work undertaken on the models in the Stellenbosch Hydraulic Laboratory. It should be possible to calculate turbulence levels, flow depths and velocities from the discharge data recorded automatically at the BRVAS Weir. These data could be correlated with the effectiveness of the fishway at these various river flows.

3.3 Management

The information gathered during the monitoring should allow a successful operational management and maintenance plan to be put into place. This should include aspects such as:

a) the release of optimal discharges from Voelvlei Dam into the river upstream for optimum functioning of the fishway) during the proposed summer releases;

b) provision of protection to the migrants from predation (e.g. placing covers over the resting side-chambers if necessary);

c) placement of debris deflectors at the canoe chute-fishway entrance;

d) ensuring regular removal of flood debris and/or sediment from the fishway, etc.

4 CONCLUSIONS

It is anticipated that a carefully designed monitoring programme will enable the effectiveness of the BRVAS Weir canoe chute-fishway in passing the target fish species to be determined. This work may also allow minor adjustment to the structure to be made to optimise and improve the design.

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