# TWIN - CHANNEL VERTICAL - SLOT FISHWAY DESIGNS AND TESTS

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RA Heath • M Ross

WRC Report No. KV 197/07

Water Research Commission

# TWIN - CHANNEL VERTICAL - SLOT FISHWAY DESIGNS AND TESTS

Report to the
Water Research Commission

by

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## ACKNOWLEDGEMENTS


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|---|---|
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# 1 INTRODUCTION

The presence of existing barriers to migration in rivers (weirs, dams, road bridges, causeways, etc) is considered to be a major factor responsible for the reduction in numbers and distribution of many migratory fish and invertebrate species throughout South Africa. Most indigenous species in this country carry out annual migrations within river systems for a number of reasons such as to optimise feeding, to promote dispersal, avoid unfavourable conditions and to enhance reproductive success. Impassable man-made barriers to migration are partly responsible for the threatened status of a number of Red Data species in southern Africa according to Paul Skelton (personal communication).

A Water Research Commission project (WRC project K5/1409) on *Guidelines for the planning and design of fishways in South African* (Bok *et al.,* 2007) (WRC Report TT 287/07) identified the problem that very flat slopes are required for fishways which must accommodate the wide variety of fish sizes often found in Southern African rivers. This has lead to the idea of providing two fishways at a barrier, one aimed at small fish with small drops between the pools and small pools and the other with larger drops and larger pools. To deal with the large variation in water levels often experienced in the South African rivers a vertical slot design was favoured. The idea of containing both the small and the large fishway in one structure led to the development of an alternative fishway design - a Twin Channel Vertical Slot fishway. This design was tested in both the laboratory and in the field and the results of these tests is described in this report.

# 2 THE RATIONALE BEHIND THE TWIN CHANNEL VERTICAL SLOT FISHWAY.

If a single fishway has to cater for small and large fish, the slope of the fishway becomes very flat. According to the guidelines described above (Bok *et al.,* 2007) small fish and weak swimmers can only deal with a drop between the pools of 75 mm. Large fish needs a pool that is at least 2.5 times the length of the largest fish catered for. If fish up to 1m must use the same fishway, the pool must be at least 2.5m long. If both fish have to pass through the same fishway, the maximum allowable slope will be 75/2500 or 1/33. Such flat sloping fishways will be long, expensive and normally difficult to fit in at a barrier. In many cases it will be cheaper and more practical to build two fishways, one dealing with the smaller fishes and another dealing with the larger fishes.

# 3 DIMENSIONING OF THE TWIN CHANNEL VERTICAL SLOT FISHWAY

The dimensions of any fishway are normally determined by the ability of the weakest swimmer as well as the largest fish to be catered for. The allowable velocities and turbulence levels for inland species are summarized in Table 1.

**Table 1**: **General maximum values of hydraulic parameters recommended for fishways designed for inland fishways.**

| Target species and size range | Turbulence (Watts/m$^3$) | Drop between pools (mm) | Mas water velocity (m/s) |
|---|---|---|---|
| Very small fish (<40 mm) and/or weak swimmers (1*) | 150 | 100 | 1.4 |
| Medium sized fish (40 – 100 mm) and/or moderate swimmers (3*) | 180 | 150 | 1.7 |
| Large sized fish (>100 mm) and/or strong swimmers (5*) | 220 | 200 | 2.0 |

Where:

* Perceived swimming ability rating (SAMigratoryBiota database), 1=weak swimmer, 3=moderate swimmer, 5=strong swimmer.

The drop between the pools determines the maximum velocity in the fishway and for most of the weak swimming inland species this drop must not be more than 100 mm. The length of the pools is determined by the largest fish to be accommodated and it is often sufficient to only allow for fish up to 400 mm in a typical South African fishway. Such fish would require a minimum effective pool length of 1.0m. Such a fishway will therefore have to have a minimum slope of around 1/10 if both the small and larger fish must be accommodated in one fishway. If weaker swimmers and larger fish must be catered for very flat slopes will result as illustrated in Table 2. In the latter case twin channel fishways, resulting in steeper allowable slopes can be considered.

Analysis showed that if a twin channel vertical slot fishway is considered, channel widths of 1.0m and 0.5m will be sufficient to cater for most migrating species in South Africa's inland rivers. In the analysis the proposed standard layout of a vertical slot fishway is used (Figure 1).

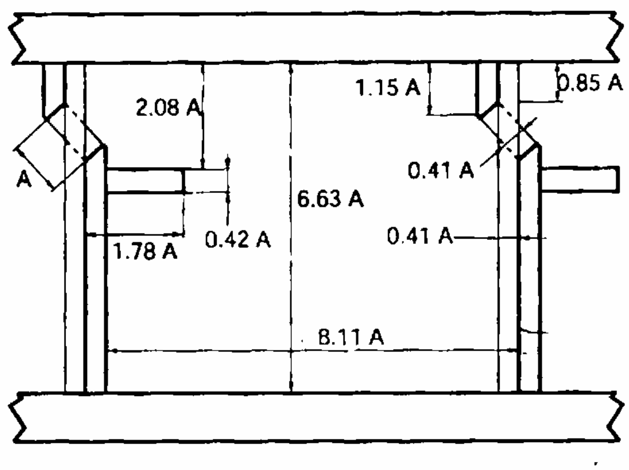



**Figure 1: Recommended layout of vertical slot fishway (From Lariner *et al.,* 2002).**

In discussions with the engineers at Department of Water Affairs and Forestry (DWAF), it became clear that if a relatively wide wall is used to separate the two channels, construction and access for maintenance and monitoring will be simplified. A 500 mm wide separation wall was proposed. It was further proposed to remove the separation wall in areas where the water level in adjacent pools was the same. The resulting fishway is shown in Figure 2. Hydraulic analysis of the proposed fishway shows that at a slope of approximately 1/7, this fishway will cope with all three categories of fish shown in Table 1and is further illustrated in Table 2.

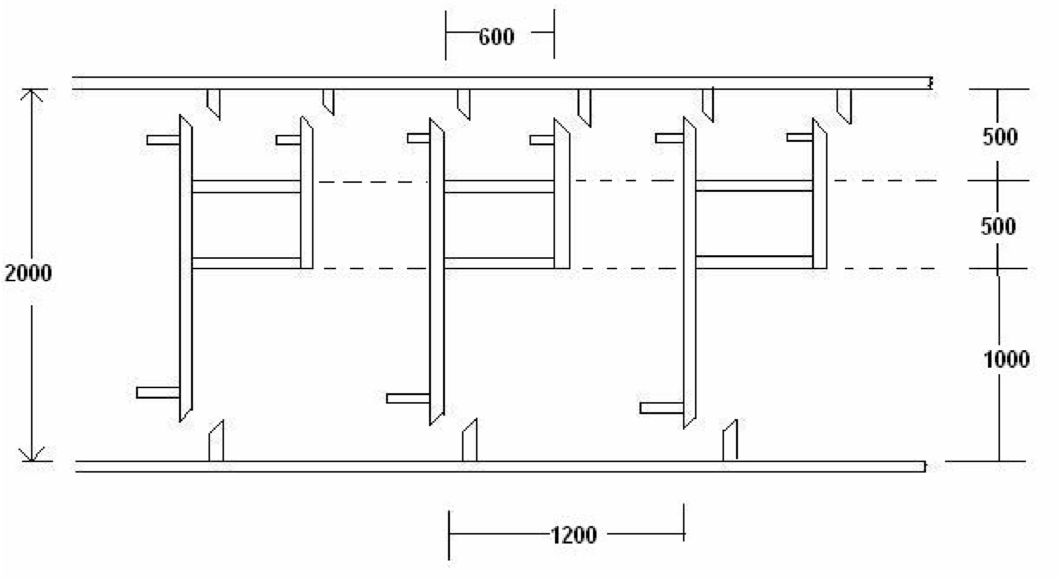



**Figure 2: Plan view of proposed Twin Channel Vertical Slot Fishway**

**Table 2: Velocity and Turbulence in Twin Channel Vertical Slot Fishway at slope of 1/7:**

| Channel | Width | Length | Drop | Slope | Velocity | Turbulence |
|---|---|---|---|---|---|---|
| | (m) | (m) | (m) | | (m/s) | (watt/m$^3$) |
| Small | 0.5 | 0.6 | 0.085 | 1/7 | 1.3 | 170 |
| Large | 1.0 | 1.2 | 0.170 | 1/7 | 1.8 | 210 |

Fish smaller than 40 mm and weak swimmers should therefore be able to comfortably negotiate the small channel whereas the pools in the larger channel are long enough to allow for fish up to 480 mm to move through at turbulence levels and velocities well below their capability.

# 4 TESTS WITH THE TWIN CHANNEL VERTICAL SLOT FISHWAY IN THE DWAF LABORATORIES

## 4.1 Models tested

DWAF constructed two models of this fishway. The first model was a small scale model to establish if the principle of such a fishway was sound. Once this was established a full scale model was built and calibrated in their hydraulic laboratories in Pretoria. Photographs of this model are shown in Plates 1 and 2. For more information please refer to Appendix A.

**Plate 1: DWAF model**

**Plate 2: Views of DWAF model**

### 4.2 Tests performed

A number of hydraulic calibration tests as well as limited tests with fish were performed in the DWAF hydraulic laboratories in Pretoria. In these tests the twin channel vertical slot were built into the downstream slope of a Crump gauging weir. The slope of the fishway was therefore 1/5, i.e. considerably steeper than the 1/7 slope described above. The idea was to see how well the fish will cope with such a steep slope which can easily be fitted into any new Crump weir structure.

In the DWAF tests, an Ogee sill was constructed in each slot to ensure that the pools are filled with water at the start of flow. Rocks were placed in the pools up to the level of the crests of the sills.

The hydraulic analysis of the DWAF model is shown in Table 3.

**Table 3: Velocity and Turbulence in Twin Channel Vertical Slot Fishway at slope of 1/5.**

| Channel | Width | Length | Drop | Slope | Velocity | Turbulence |
|---|---|---|---|---|---|---|
| | (m) | (m) | (m) | | (m/s) | (watt/m$^3$) |
| Small | 0.5 | 0.6 | 0.120 | 1/5 | 1.5 | 260 |
| Large | 1.0 | 1.2 | 0.240 | 1/5 | 2.2 | 330 |

The drop between the pools and therefore the velocity in the wider channel exceeds the allowable values for large fish in Table 3. The velocity in the narrow channel exceeds the allowable value for very small fish. The turbulence values in both channels exceed the allowable value for large fish. This fishway, at such a steep slope, therefore does not comply with the norms specified in the guidelines (Bok *et al.*, 2007). Tests with small portable models of this and other vertical slot and sloping weir fishways in the field and in the laboratories however revealed that many species, especially when they are on a migration run, far exceeded the velocities and turbulence levels specified in Table 3.

### 4.3 Test results:

The tests in the DWAF full scale model revealed the following:

- The hydraulic calibration of the model agreed closely to the theory. This allows the theory to be used with confidence in the design of the fishways. It also allows the inclusion of this fishway in gauging weirs without any compromise to the accuracy of the gauging weirs.
- The rocks near the crest of the Ogee sill washed down into the downstream pool, exposing the steep downstream slope of the sill. This is shown in Plate 3. This made it difficult for the fish to negotiate the sills, especially in the wider channel with the higher drops.

- Most of the fish that succeeded in moving up the fishway therefore made use of the narrow channel. It was thought that the effective pool length in the wider channel was insufficient for the fish to be able to negotiate the drop of 240 mm.

- Although some fish made it through the fishway, many showed unwillingness to attempt moving upstream. This was probably caused by stress due to poor water quality and the fish not being in a migratory mode.

**Plate 3: Downstream face of Ogee spillway**

## 5 TESTS WITH A PORTABLE TWIN CHANNEL VERTICAL SLOT MODEL

### 5.1 Model design and construction

A 1/2.5 scale model of the twin channel vertical slot model was constructed to be able to test the performance of the design in the field. In this model the channels were 200 mm and 400 mm wide with slot widths of 30 mm and 60 mm respectively. The basic layout of the model is shown in Figure 3.

The model was built in three sections to facilitate easy transport. (Plates 4 to 12 illustrate the main features of the model). The three sections are all the same width (800 mm inside dimension), allowing for a simple connection between the three sections (see Plates 8 and 9). The two channels are formed by a series of baffles that can easily be removed to make the channel lighter during transport and assembly (see Plates 4 and 5).

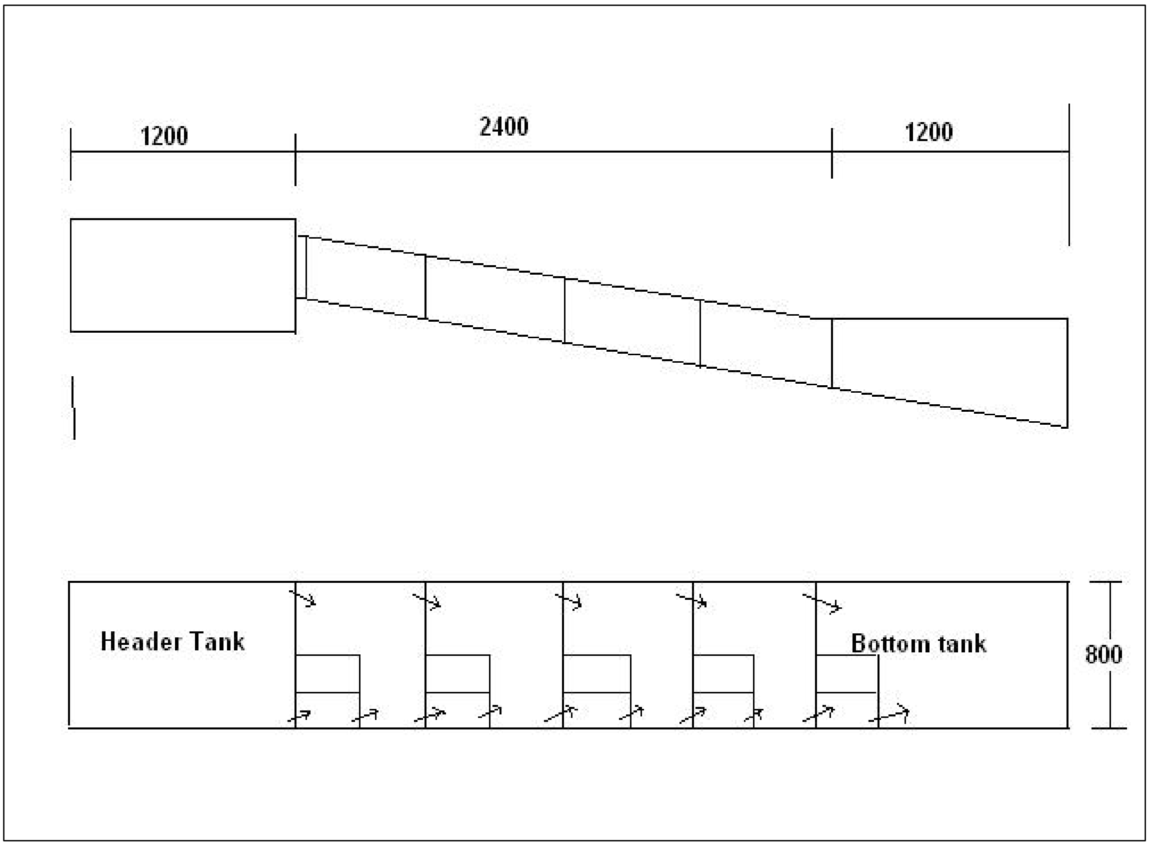



**Figure 3: Side and Top view of model**


**Plate 4: General setup**


**Plate 5:  View up Channel**


**Plate 6: Baffle Detail**


**Plate 7: Model on stands**


**Plate 8: Connection between channel and bottom tank**


**Plate 9: Connection between top tank and channel**


**Plate 10: Channel with baffles removed**


**Plate 11: Empty channel looking down from header tank**


**Plate 12: Baffle details**

## 5.2 Initial hydraulic tests with model

A number of initial tests were done with the model in which the hydraulics of the system was checked and the influence of placing rocks on the bottom and sills in the slots was investigated.

These tests showed that without rocks on the bottom or sills in the slots, supercritical flows occur downstream of the slots at low flows. This will probably create difficulty for some small deep bodied species which will have problems in negotiating the fast flowing shallow water.

When a sill is placed in the slot, with the sill height equal to or greater than the drop between the pools, the pools will fill up with water before starting to spill. This creates very calm pools but result in a waterfall effect downstream of the sill which may be difficult for some species to overcome. The sill also causes a discontinuity, breaking up the continuous slope that is formed without the sills. This discontinuity is expected to adversely affect especially the weak swimmers and crawling species that move along the bottom.

The best configuration seemed to be to place at least two layers of rock along the bottom as shown in Plate 13.

The continuous rock strata on the bottom forms a riffle effect at low flows which looks quite attractive and will allow species that normally migrate through shallow riffles to optimally use the fishway. At high flows the rock strata reduces the velocities at the bottom, again facilitating the movement of species that migrate along the bottom.

The flow pattern is illustrated in Plates 14 and 15.

**Plate 13: Rock strata on bottom**

**Plate 14: Low flow through narrow slot**


**Plate 15: Low flow through wide slot**

The rocks used along the bottom must be of sufficient size not to be washed out by the flowing water. Larger rocks are therefore required in and just downstream of the slots whereas smaller rocks will remain stable in the pools. This arrangement leads to some extent to pool formation at low flows without causing high vertical drops and velocities just downstream of the slots.

The flow conditions in these tests were found to be very attractive and no negative effects caused by the removal of the dividing wall at every second small pool could be observed. The removal of the rather thick dividing wall created a nice resting pool after every second small pool and in every large pool.

### 5.3 Field tests in the Kowie River

A series of tests were performed with the portable twin channel vertical slot fishway in the Kowie River. In these tests the ability of small migrating mullet (*Myxus capensis*) and Moonies (*Monodactylus falciformus* ) to negotiate the fishway set up at a slope of 1/5 were tested under a variety of flow conditions. For more information please refer to Appendix B.

The general setup of the model is shown in Plates 16 to 19.

**Plate 16: Fishway set up on the lower shelf at the base of the Kowie River weir**

**Plate 17: Fishway channel without stones on bottom at ca 8 ℓ/sec discharge**


**Plate 18: Fishway channel showing stones on bottom at low flows (large fishway channel).**

**Plate 19: Fishway channel at high flow (18.9 ℓ/sc)**

In the tests in the Kowie River with rock strata on the bottom 60 to 80% of *Myxus capensis* and *Monodactylus falciformus* of between 35 mm and 60 mm made it through fishway in 20 – 30 minutes at flows between 2.9 ℓ/s and 11.6 ℓ/s. The drops between the pools at the 1/5 slope was 50 mm and 100 mm in the narrow and wide fishway respectively (velocities of 1.0m/s and 1.4m/s).

The turbulence levels were between 200 and 260 watt/m$^3$ (respectively) during successful tests. At high flows (18.9 ℓ/s) the success rate of both species tested dropped dramatically. No clear reason for the drop in performance could be found as velocities and turbulence levels should theoretically not increase at the high flows. Possible reasons offered for the poor results at high flows were that the particular species tested prefer to migrate through shallow fast water and that the beneficial influence of the rock strata on the bottom reduces with increasing flow depths.

## 5.4 Tests at Jonkershoek

A limited series of tests were also performed at the Cape Nature Conservation aquarium at Jonkershoek. The setup in these tests was identical to those at the Kowie River i.e. a slope of 1/5 with rock strata on the bottom. The setup is shown in Plates 20 and 21. For more information please refer to Appendix C.

Tests were run overnight and it was found that 87% of the Berg River Redfins of 50 to 80 mm in length made it up this fishway. The success rate of the Cape Kurper and Cape Galaxias were very low (0% and 18% respectively)

The reason for the low success rate of the Cape Kurper and Cape Galaxias is not clear. The fish was collected from pools in the rivers and they were obviously not in a migrating mode. The question was also raised whether these species do indeed migrate and whether they need to migrate. The tests were however unsuccessful to determine the swimming abilities of these species.

## 5.5 Converting model results to full scale fishways

The calibration of the twin channel vertical slot fishway is indicated in Appendix D.

The model laws for scaling up the hydraulics from models to prototype are well established and could be used with confidence. The laws for scaling fish size are less well known and will require further verification. The law used in this report is based on tests in the French fishway program. According to Larinier (personal communication) the length scale of the fish ($n_{lfish}$) should be equal to the length scale of the model ($n_l$) to the power 0.6, i.e. $n_{lfish} = n_l^{0.6}$. If we therefore use a length scale for the model of 2.5, the lengths of the fish used in the model should be multiplied by $(2.5)^{0.6}$ or a factor of 1.73. A fish of 40 mm used in the model should then convert to a length of approximately 70 mm in the prototype.


**Plate 20: Portable model of a Twin Channel Vertical Slot Fishway model used for tests at Jonkershoek**


**Plate 21: Single layer of rock was placed on the bottom of model.**

Three species were used in the tests, i.e. Berg River Redfins, Cape Kurper and Cape Galaxias. In these tests only a relatively low flow rate of 2.6 ℓ/s was used.

If we convert the result of the small portable model to that of a full scale fishway with slots of 75 mm and 150 mm, a slope 1/5 and drops between pools 125 mm and 250 mm (velocities 1.6 to 2.2 m/s), we can expect that fish of 60 mm to 100 mm should move through fishway in 30 to 45 minutes at flows of 29 ℓ/s to 115 ℓ/s. Turbulence levels will be between 320 and 410 watt/$m^3$.

## 6 CONCLUSIONS

The following conclusions can be drawn from the Twin Channel Vertical Slot Fishway studies:

- The twin channel vertical slott fishway shows great promise as a fishway that will cope with a wide range of fish sizes at a relatively steep slope for a wide range of water levels upstream of the barrier.
- Continuous rock strata placed along the bottom of the fishway seems to improve the flow pattern and the ability of fish to negotiate the fishway at low flows.
- There are indications that the fishway becomes less effective at very high flows, especially if built at slopes as steep as 1/5.
- At a 1/5 slope such a fishway can be built into Crump weirs, but at this slope the velocities and turbulence levels will exceed the levels recommended in this guidelines. To reduce the velocities and turbulence levels to those recommended in the guidelines slope of between 1/8 and 1/10 will be more appropriate. Tests with the portable model do however indicate that most of the stronger swimmers will be able to deal with the 1/5 slope.
- The use of portable fishways in determining the swimming abilities and behaviour of migrating fish in the field can provide useful data for future fishway designs.

## 7 RECOMMENDATIONS

The following recommendations can be made:

- There are strong indications that many South African fish species can overcome velocities and turbulence levels much higher than quoted in the literature. It is strongly recommended that the twin channel vertical slot fishway as described above, constructed at a slope of 1/5, be built into a Crump fishway. This fishway should be fitted with a properly designed monitoring system and a detailed monitoring programme should be undertaken over a period of at least two years. If such a fishway proves successful it will open the way for cheaper fishway designs in South Africa.
- The size of the fishway recommended is much smaller than used for general purpose fishways in the past.

There is a real concern that the narrow slots used in the fishway will easily be blocked by debris. It is imperative that where this type of fishway is used the fishway entrance should be constructed to discourage the penetration of debris into the fishway and that regular maintenance of the fishway should be undertaken.

Many fishways in South Africa with wider slots or notches in the weirs between the pools become ineffective due to debris blockages and a lack of maintenance.

- Research into the migratory needs of the weaker swimmers should be undertaken. Virtually all the species tested in field tests during this project proved to be relatively strong swimmers which will cope with velocities and turbulences far exceeding the values recommended in these guidelines. The cost of a fishway is largely determined by the weakest swimmers to be provided for and the abilities of these weaker swimmers should be established as a matter of urgency.

# APPENDIX A

## RESULTS FROM THE PRELIMINARY BIOLOGICAL TESTS

## OF THE

## TWIN CHANNEL VERTICAL SLOT FISHWAY AT

## THE HYDROMETRICS LABORATORIES, DWAF

**M. Ross, P. Kotze & B. Niehaus**

**RAUECON**

## 1. INTRODUCTION AND BACKGROUD

Extensive testing and experimentation under both field and laboratory conditions of the standard vertical slot fishway experimental prototype channel has been undertaken over the past two years. It has proven that the principle of the design is sound; however, it fails to operate effectively over a wide range of flows that typifies the flow regimes of South African rivers. This is by no means a design fault, as the experimental channel was constructed according to international literature standards, but its application internationally has historically been mainly aimed at the salmon industry. It therefore only needed to cater for adult salmon all of uniform size ranges and superior swimming abilities. As a consequence, the experimental fishway channel also only was able to cater for a certain size range of fish and species, and therefore it suffers limited application when constructed to bypass migrational barriers in areas that have a high diversity of fish species and size ranges. It has also been identified that not only adult fish actively migrate, sub-adult fish do the same, and therefore these relatively smaller (and by definition, weaker swimming) individuals also need to be adequately catered for. A fishway therefore needed to be designed that allowed passage for both smaller and larger fish, but could still be effective over large fluctuations of discharge rates.

A design was subsequently proposed that theoretically was able to cater for these short-comings of the original design. A collaborative effort “brainstormed” the original idea that was proposed by Jan Rossouw. Design drawings were distributed to all of the members of the “fishway team”, with their feedback being incorporated into the new “Twin Channel Vertical Slot Fishway”. The principle is that there would be two channels constructed side by side. The one channel would have buckets of half of all of the dimensions of the other one, and therefore would incorporate twice as many buckets. This meant that the drop between the successive pools of the smaller channel was exactly half of that of the larger buckets. There would then also be incorporated a linkage between the two channels after every second large (and every fourth smaller) bucket. This would provide for a resting area for fish that are attempting upstream passage through the channel. This junction also allowed for the fish to choose turbulence and drop levels that better suited them, and therefore would further facilitate their upstream passage through the channel.

A small-scale model was built at the DWAF hydrometrics laboratories in Pretoria, where the hydraulic aspects could be ascertained (Plate A.1). A full-scale model was then also built within the same laboratory that was incorporated onto a model standard crump weir. It formed part of a flow-through system that was capable of pumping an accurately-determined water volume. The pumps are able to operate at any given discharge (within their upper pumping limits) (Plate A.2).

**Plate A.1: Twin Channel Vertical Slot Fishway experimental scale model.**

**Plate A.3: Sloping sills and substrate incorporated into a modified design.**

**Plate A.2: Various views of the full-scale Twin Channel Vertical Slot Fishway model.**

## 2. METHODS AND MATERIALS

### 2.1. Fish

Fish were caught during a field trip to the Crocodile River (North West Province) to supplement the fish that were housed in the aquarium at the University of Johannesburg (UJ). They were then allowed time to acclimate to laboratory conditions. All of the fish were then taken through to the DWAF laboratories to do biological tests using the Twin Channel Vertical Slot Fishway model. Table A.1 is a list of the experimental fish species used, together with their size ranges.

**Table A.1: Fish species used throughout the experimental procedure.**

| Species | Size range (SL) (mm) | Number of individuals used |
|---|---|---|
| *Labeo capensis* | 80 – 300 | 23 |
| *Labeo molybdinus* | 70 – 100 | 17 |
| *Labeobarbus aeneus* | 120 – 300 | 8 |
| *Labeobarbus marequensis* | 60 – 100 | 12 |
| *Clarias gariepinus* | 340 | 1 |
| *Oreochromis mossambicus* | 25 – 40 & 180 – 200 | 7 |
| *Tilapia sparrmanii* | 60 – 80 | 8 |
| *Barbus trimaculatus* | 40 – 55 | 11 |
| *Barbus unitaeniatus* | 45 – 55 | 7 |
| *Barbus paludinosus* | 40 – 55 | 6 |
| *Micralestes acutidens* | 45 – 55 | 2 |
| *Mesobola brevianalis* | 25 – 30 | 8 |
| *Austroglanis sclateri* | 85 – 90 | 2 |

### 2.2. Experimental design.

The fishway channel setup was filled with water and it was given time to circulate. The fish were confined to the vicinity of the fishway channel by constructing nets that stopped them from entering the drains. Fish that successfully negotiated the channel were also then caught in nets that separated the exit of the larger channel from the exit of the smaller one. The pump was set at an average flow and the fish were allowed time to acclimate to the system. The response of the fish was then tested at various discharge rates, and the successful fish were recorded and returned to the system.

## 3. RESULTS AND DISCUSSION

### 3.1. 8-10 November 2006.

The initial experiments were booked to run for the duration of three days (8-10 Nov). The first day mainly concentrated on finalising the construction of the holding nets and the fishway channel. The fish were placed within the bottom holding tank relatively late during the day.

An unforeseen setback was that the system water (as it is stored in an underground sump) was relatively colder than the water that the fish were housed and transported in from UJ. They therefore experienced a temperature change from 25°C down to 18°C. This had an adverse effect on the swimming abilities of the fish, with them being noted to be very lethargic and reluctant to negotiate up the channel. The only results that were obtained therefore were when the fish were caught and "forced" through a slot opening. Most of the time, however, they were merely washed back downstream. The cold water conditions meant that the fish were even battling to maintain their position in the water column. The fish were then removed and placed in a holding tank overnight, in the hope that they would have a chance to acclimate to colder temperatures for testing to commence the following day.

The following day saw much of the same lack of results being obtained, but there was an increased effort from some of the fish, showing that they were slowly being acclimated to the colder temperature. Therefore the hydraulic characteristics were concentrated on and potential improvements were discussed. It was proposed that the fish would be returned to the laboratory, where they would be acclimated to a temperature that was colder than that of the fishway system at DWAF, so that the fish would be potentially stimulated to attempt upstream passage as they would be going from colder to relatively warmer water. The fish were therefore returned to the UJ laboratory for a 2 week acclimation period to a temperature of 16.5°C.

### 3.2. 23-24 November 2006.

The same group of fish were returned to the system at DWAF for further testing of the new twin channel vertical slot fishway channel on 23 November. A few modifications had been made to the design in the interim that were thought to improve the success rate of the fish from the last testing phase. These modifications included:

- The sills were designed in a way that there was no "break-away" of the water that flowed over it. This was done by sloping the previously-vertical downstream edge of the sill (Plate A.3).
- Prioritising the flow through the smaller channel by lowering the sill at the exit (water entrance) of the channel by the height of the sills throughout the channel.
- Substrate to be placed in the channel.

The fish were placed in the channel and it was noted that they were more active than when compared to the previous testing period. The fish were allowed an hour in the channel at an average flow rate (approximately 45ℓ/s) without any disturbance. This period allowed for the viewing and explanations of a hydraulic crump weir model to be demonstrated at DWAF head office.

On returning to the channel, it was found that no fish had successfully negotiated the channel. The fish moved up the channel if physically forced to do so, but they were reluctant to attempt the channel themselves. Various attempts to get them to move up the channel were undertaken by manipulating the hydraulic conditions within the system.

These included:

- Retaining the discharge rate (65ℓ/s), but decreasing the volume of the receiving tank (where the fish were). This had limited effect, but some fish did move up the channel (Table A.1).
- Retaining the decreased volume of the receiving tank and decreasing the discharge rate from 65ℓ/s to 55ℓ/s. The fish were allowed 20 minutes before the fish that were successful were caught and returned to the tank. The results are summarised in Table A.1.
- Further decreasing the discharge rates at fixed intervals, with the successful fish caught out and returned to the receiving tank. These results are summarised in Table A.1.

**Table A.1: Results of the DB fishway channel testing at DWAF at various discharge rates. The size ranges of the successful fish are also given.**

| Channel condition | Discharge rate (Q) (ℓ/s) | Fish species successful | Size range (mm SL) | Channel selected by fish |
|---|---|---|---|---|
| DB vertical slot with sills & pebble substrate | 75 | none | none | none |
| | 65 | Lcap & Tspa | 4xLcap (90-140)<br>1xTspa (90) | smaller |
| | 55 | Tspa, Buni, Lmol & Lcap | 4xTspa (80-100)<br>1xBuni (35)<br>1xLcap (120)<br>1xLmol (65) | smaller |
| | 45 | none | none | none |
| | 35 | Lcap | 1xLcap (65) | smaller |
| | **25*** | none | none | none |
| | **15**** | none | none | none |
| | 8 | Lcap, Laen, Tspa, Lmol, Lmar | 7xLcap (90-300)<br>5xLaen (120-300)<br>7xLmol (60-110)<br>4xLmar (75-100)<br>Tspa (65-100) | Mixed smaller & larger |
| | 5 | Lcap, Tspa | 6xLcap (65-220)<br>3xTspa (80-100) | smaller |

***Decreased the bottom tank volume.**
****Water flow favouring smaller channel.**

The results from Table A.1 show that the fish were more stimulated to move up the channel when the water volume within their holding tank and the discharge rate was decreased. The smaller channel was also almost exclusively chosen by the fish. This was perceived as a type of “necessity movement” that can be compared to when fish migrate to escape unfavourable conditions within their present environment. A much increased success rate was therefore noted when the flow rate was reduced to 8ℓ/s. This potentially shows that fish stimulated to move during a *change* (reduction) in discharge rate rather than a sustained increased rate. This is comparable to receding flood waters of a river. The idea of designing and constructing a fishway that is able to cater for fish migrations at the natural average discharge rate of the river, as well as for when the river was experiencing receding discharge rates. This would have to be worked out as an average. It was concluded that it is unnecessary for a fishway to work optimally during periods of high flows. This is reiterated by the fact that the majority of migrational barriers experience drown-out conditions during these periods of high flow.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The results obtained through the experimentation at DWAF were disappointing. The fish were generally reluctant to move up the channel, making measuring the success rate of the channel difficult. More importantly, some specific conclusions and “lessons learnt” were produced from the testing episodes.

- Fish were shown to favour the smaller channel, possibly due to the drops from one bucket to the next within the larger channel being too great for them to overcome. It was therefore recommended that the drops be reduced within this channel. This could be achieved by making the ratio of small buckets to larger ones 3:2, as apposed to the existing 4:2. This would have minimal design and cost implications as the “junction” between the two channels would merely have to be shifted.

- There was a definite improvement when the sills had a slope that inhibited that the water had a “break-away” effect. There was therefore no air cavity when the water flowed over the sills that could inhibit the passage of the fish.

- Hydraulic characteristics were vastly improved by the addition of a substrate. The vertical velocity of the water when it encountered the far edge of the bucket was greatly reduced by the substrate.

- Sills within the buckets definitely aided in there being an increased volume of water within each bucket, especially at low flows. These sills also allowed for the substrate to be kept within the buckets and not be washed downstream during high flow periods.

- By prioritising the water flow through the smaller channel allowed the fishway to run optimally over a wider range of discharges. The smaller channel ran optimally during periods of low discharges, when it is perceived that the vast majority of migrating fish would be the smaller ones anyway.

At higher discharges, the larger channel began to flow optimally, but the smaller channel was still able to successfully cater for smaller and weaker-swimming species.

- The limitations of this type of testing must be realised and it must be noted that fish under natural conditions, receiving natural stimuli to migrate have a non-comparable will and ability to overcome obstacles. The laboratory testing is therefore an underestimation of the swimming abilities of the fish. These conservative parameters that are laid down from this type of testing do, however, ensure maximum possible success rates within river systems under natural conditions.

## 5. ACKNOWLEDGEMENTS

The design and construction team that built the small scale as well as the full scale model at the hydrometrics laboratories of DWAF in Pretoria are acknowledged for their effort and willingness to entertain our “small changes here and there”.

# APPENDIX B

## TWIN CHANNEL VERTICAL SLOT FISHWAY TRIALS:

## KOWIE RIVER EBB & FLOW WEIR

## 21 TO 23 NOVEMBER 2006

**Anton Bok, Jan Rossouw and Hylton Lewis**

## INTRODUCTION

The primary aim of the present series of field trials was to test the effectiveness of the new "Twin Channel Vertical Slot" Fishway designed and built by Jan Rossouw. Details of the design and dimensions of this previously untested prototype, which consists of a large and small vertical slot fishway combined within one fishway channel, are given in Appendix 1 and in photographs 1 to 6.

These field trials on the Kowie River are a continuation of the assessment of the suitability and relative effectiveness of vertical slot fishways for passing the Red Data catadromous freshwater mullet, *Myxus capensis* and the Cape moony *Monodacytulus falciformis*.

## METHODS

The present trials with the Twin Channel Vertical Slot Fishway were carried out in the field in an attempt to use actively migrating fish under natural riverine conditions. The experimental procedure is designed to ensure that actively migrating fish under "natural" conditions are used in the swimming trials. This is achieved by placing the portable fishway below existing barriers to migration, such as the Kowie River Ebb & Flow Weir, and netting and placing actively migratory fish into the lower section of the fishway receiving water from the river.

The percentage of fish that successfully negotiate the fishway by swimming up into the header pool under various discharges is then determined. This procedure allows the effectiveness of the fishway to be accurately determined under the experimental conditions of fishway slope and discharge. In addition, the effect of adding stones to the bottom of the fishway channel was also tested.

During the experimental trial over 21 to 23 November 2006 described here, large numbers of juvenile freshwater mullet *Myxus capensis* of about 30 to 80 mm fork length, had accumulated below the weir. These fish were captured with dip and seine nets and placed into the lower pool of the fishway at the start of each experimental run. Downstream movement was prevented by means of a stop net placed across the channel downstream of the first baffle in the lower holding pool or by means of small stop nets placed within the baffle slots in the lower fishway pool itself.

It must be noted, however, that unlike during previous trials at the Kowie River weir, only a very small percentage of these mullet appeared to be actively attempting to migrate past the weir. During active migrations thousands of mullet jump onto the first low ledge at the base of the weir, but only small numbers (less than about 50 fish) were seen showing this behaviour during these trials. The reduced "migratory urge" may have resulted in lower success rates in the present trials compared to previous trials.

However, large numbers of juvenile Cape moonies *M. falciformis,* 40 to 75 mm in length, were migrating through the fishway located on the Kowie Ebb and Flow Weir itself at this time. These actively migrating fish were easily captured within the Kowie Fishway channel by means of dip nets and were used in the experimental trials.

As in previous trials, the fishway was set up on the lower ledge of the weir, and water was supplied via siphon pipes from the upstream impoundment. The flow rates or discharges through the fishway were varied by adjusting the number and size of siphon pipes used. Details of the experimental procedures used for these trials have been described in previous reports.

Details of the conditions at the study site and the experimental set up during the 21 to 23 November 2006 fishway swimming trials are shown in plates B.1 to B.6.

To minimise handling, the length and accurate determination of fish numbers used in the trials were determined after the 30 min trial run period. When large numbers of fish were captured, a sub-sample of at least 20 to 30 fish were measured (fork length) and the remainder counted to determine the percentage of fish that a) successfully negotiated the fishway, b) fish that showed no movement, i.e. remained in the bottom fishway pool into which they were initially placed.

**RESULTS**

The results obtained during the experimental trials over the 21 to 23 November 2006 using the Twin Channel Vertical Slot Fishway are summarized in Tables B.1 and B.2 below. These data are presented graphically in Figures B.1 and B.2 below.

In brief, the data show that the Twin Channel Vertical Slot Fishway design is effective in passing small fish (ca 30 to 80 mm in length) with low flows (2 to 12 ℓ/sec) through the fishway channel. The success rates obtained are comparable with those obtained in previous trials at the Kowie Ebb and Flow weir using the standard vertical slot fishway with only a single slot in the channel.

However, direct comparisons with success rates obtained during previous fishway trials at the Kowie Weir may be affected by the “migratory mode” of the fish used during the experimental runs. As mentioned earlier, the mullet at the site during the present trails did not show the same urgent migratory behaviour compared to earlier trials. This reduced migratory urge most likely had a negative impact on the success rates achieved during these Twin Channel Vertical Slot Fishway trials.

The data also indicated that:

- The placement of stones on the fishway floor had a significantly positive effect on success rates of both species.
- At high flows (18.9 ℓ/sec) the fish (both mullet and moonies) struggled to negotiate the fishway. At these high flows (18.9 ℓ/sec) the fish showed obvious signs of stress and relatively large numbers tended to get impinged against the stop nets placed in the slots of the lower fishway pool. As shown in Table B.2, when the flow rate was reduced to 7 – 9 l/ sec after 20 minutes at these high flows, the number of fish successfully migrating through the fishway increased dramatically in the following 20 minutes.
- Further trials using different species and larger fish are recommended to confirm these data.

**Table B.1: Fishway trials on 21 & 22 November 2006 at Kowie River Weir with Twin Channel Vertical Slot Fishway set at 1:5 gradient WITHOUT stones on bottom. Fish from both the top cage and bottom pool were counted and measured after the trial run so as to reduce stress.**

| Trial No. | Q (ℓ/s) | Vslot (m/s) small/ large | Turbulence (Watts/m$^3$) small/large | Species | Total No. used | Fish reaching top of Fishway | | | Mean length (& range) (mm) | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Time (min) | No. of fish | % success | Successful | Not successful | |
| 1A | 2.9 | 1.0/1.4 | 185/312 | MFAL | 245 | 0-10 | 41 | 17 | 52 (43-66) | 54 (49-75) | Fish taken from Kowie Weir Fishway, but many did not attempt to swim up fishway. Most used small fishway |
| | | | | | | 10-20 | 27 | 11 | | | |
| | | | | | | Total | 68 | 28 | | | |
| 1B | 2.9 | 1.0/1.4 | 185/312 | MFAL | 84 | 0-10 | 2 | | | | Fish taken from Kowie Weir Fishway, but many did not attempt to swim up fishway. Majority used small fishway |
| | | | | | | 10-20 | 41 | | | | |
| | | | | | | Total | 43 | 51 | - | - | |
| 1C | 2.9 | 1.0/1.4 | 185/312 | MCAP | 16 | 0-10 | 4 | | | | First fish took 54 s to reach top. In late afternoon, fishway in deep shadow, lack of light inhibiting movement? |
| | | | | | | 10-20 | 5 | | | | |
| | | | | | | Total | 9 | 56 | 41 (33-51) | 39 (6-43) | |
| 2A | 2.9 | 1.0/1.4 | 185/312 | MCAP | 34 | 0-10 | 4 | | | | Fish netted below weir, not actively migrating at the time |
| | | | | | | 10-20 | 10 | | | | |
| | | | | | | 20-30 | 9 | | | | |
| | | | | | | Total | 23 | 68 | 43 (39-55) | 41 (36-64) | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MFAL | 23 | 0-10 | 2 | | | | Fish taken from Kowie Weir Fishway, may have been tired due to high turbulence conditions at the time |
| | | | | | | 10-20 | 5 | | | | |
| | | | | | | 20-30 | 3 | | | | |
| | | | | | | Total | 10 | 43 | 52 (46-60) | 50 (33-64) | |
| 2B | 2.9 | 1.0/1.4 | 185/312 | MFAL | 39 | 0-30 | 17 | | | | Fish placed in 1st pool of fishway and prevented from moving down by means of stop nets in baffles |
| | | | | | | Total | 17 | 44 | - | - | |
| 3A | 8.7 | 1.0/1.4 | 208/261 | MFAL | 46 | 0-30 | | | | | Fish taken from Kowie Weir Fishway, many fish did not attempt to migrate |
| | | | | | | Total | 28 | 61 | 52 (42-69) | 52 (45-63) | |
| 4A | 11.6 | 1.0/1.4 | 204/260 | MFAL | 84 | 0-30 | | | | | Fish taken from Kowie Weir Fishway, many fish did not attempt to migrate |
| | | | | | | Total | 38 | 45 | 51 (44-65) | 50 (45-57) | |

**Table B.2: Fishway trials on 22 & 23 November 2006 at Kowie Weir with Twin Channel Vertical Slot Fishway set at 1:5 gradient WITH STONES on bottom. It must be noted that the accuracy of the data is approximate, as fish numbers were estimated when netted and not counted individually when stocked so as to reduce stress. Due to the rocks within the fishway, some fish remain hidden under the rocks within the fishway at end of the trial run, when total fish numbers were counted. This could result an overestimate of the success rates.**

| Tial No. | Q (ℓ/s) | Vslot (m/s) small/ large | Turbulence (Watts/$m^3$) small/large | Species | Total No. used | Fish reaching top of Fishway | | | Mean length (& range) (mm) | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Time (min) | No. of fish | % success | Successful | Not successful | |
| 5A | 2.9 | 1.0/1.4 | 185/312 | MFAL | 67 | 0-30 | 41 | 61 | 52 (41-64) | 55 (43-74) | Moonies appeared to struggle to swim through or over rocks in shallow water |
| | | | | MCAP | 34 | 0-30 | 25 | 73 | 60 (37-83) | 50 (39-84) | Mullet looked comfortable moving through and over stones. Both fishways used by fish, and appeared to move between channels regularly |
| 6A | 11.6 | 1.0/1.4 | 204/260 | MFAL | 87 | 0-30 | 70 | 81 | - | - | First fish through fishway in 20 sec. Most fish appeared to use larger channel fishway |
| | | | | MCAP | 104 | 0-30 | 72 | 69 | - | - | Mullet appeared comfortable, moving between the two fishway channels |
| 6B | 11.6 | 1.0/1.4 | 204/260 | MFAL | 80 | 0-30 | 50 | 63 | - | - | First fish moved through in about 12 secs, both fishway channels used, but fish appeared to favour larger channel |
| | | | | MCAP | 119 | 0-30 | 72 | 61 | - | - | |
| 7A | 2.9 | 1.0/1.4 | 185/312 | MCAP | 180 | 0-20 | 130 | 70 | 35 (27-47) | - | Fish started moving downstream again, out of top cage after about 15 min |

Table B.2: (Continued)

| Trial No. | Q (ℓ/s) | Vslot (m/s) small/ large | Turbulence (Watts/$m^3$) small/large | Species | Total No. used | Fish reaching top of Fishway | | | Mean length (& range) (mm) | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Time (min) | No. of fish | % success | Successful | Not successful | |
| 8 | 8.7 | 1.0/1.4 | 208/261 | MCAP | 100 | 0-20 | 66 | 66 | 37 (27-77) | - | Both channels used by the fish, movement between channels common. Note that fish from previous trial, left hidden in stones may have influenced results |
| 9 | 11.6 | 1.0/1.4 | 204/260 | MCAP | 180 | 0-20 | 131 | 73 | - | - | Note that fish from previous trial, left hidden in stones may have influenced results, both channels used by fish |
| 10A | 18.9 | | 193/291 | MCAP | 110 | 0-20 | 20 | 18 | 37 (27-48) | - | High numbers (10 –20) of fish impinged against stop nets, fish appeared stressed |
| 10B | 18.9 | | 193/291 | MFAL | 120 | 0-20 | 3 | 2.5 | 52 (47-56) | - | Fish remained in resting area between lower 2 pools |
| | 7.3 | | | | | 20-40 | 54 | 45 | 52 (46-62) | - | Flow reduced to 7.3 ℓ/s after 20 min, fish allowed to move for a further 20 min. & fish chased out of bottom pool |
| 10C | 18.9 | | 193/291 | MFAL | 90 | 0-20 | 19 | 21 | 49 (44-58) | - | Fish “herded” from lower pool to encourage movement up the fishway |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7.3 | | | | | 20-40 | 36 | 40 | 49 (40-60) | - | Flow reduced to 7.3 ℓ/s after 20 min, fish allowed to move for a further 20 min. & fish chased out of bottom pool |
| 10D | 18.9 | | 193/291 | MCAP | 80 | 0-20 | 6 | 8 | 59 (47-77) | - | Fish remained in resting areas and under rocks |
| | 8.7 | | | | | 20-40 | 48 | 60 | 53 (42071) | - | Flow reduced to 8.7 ℓ/s and further 20 min allowed for fish to move up fishway |

**Figure B.1. Success of *M. falciformis* at diferent discharges with and without stones on floor of fishway**

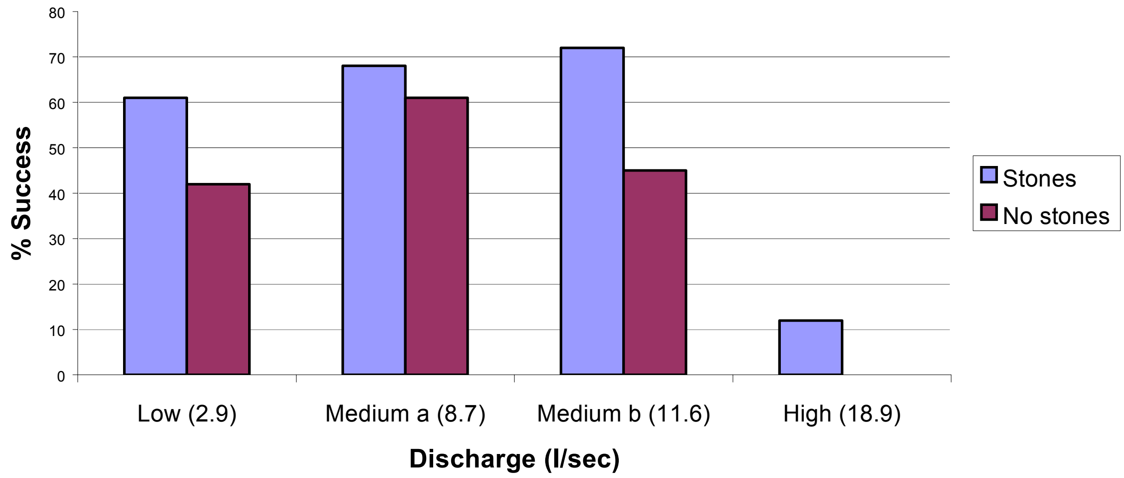
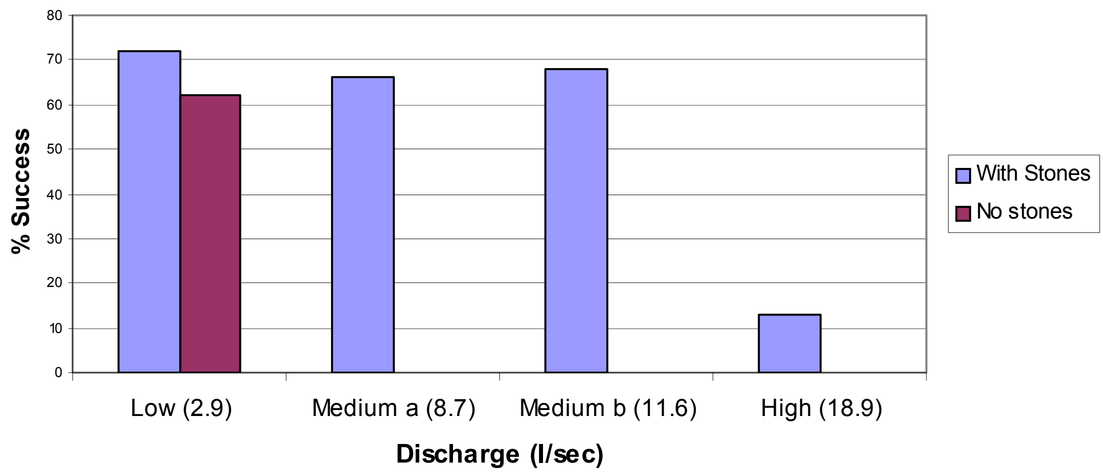



**Figure B.2. Success of *M. capensis* through fishway at varius discharges with and without stones on floor of fishway**



# APPENDIX B 1

## Description of the design of Jan Roussouw's

## Twin Channel Vertical Slot Fishway

**Portable Model of Twin Channel Vertical Slot Fishway**

1. Design Parameters
    a. Must be able to be assembled by two people
    b. Must operate within a flow range from 0 to 15 ℓ/s
2. Proposed dimensions
    a. Prototype channels of 1000 mm and 500 mm wide with 500 mm wall separating two channels
    b. Model scale of 1:2.5 will result in two channels 400 mm and 200 mm wide with 200 mm wall separating two channels
    c. Slot widths of 60  and 30 mm to comply with BFPP(2002) Figure B.9
    d. Wall between baffles removed where water levels in the two channels are the same i.e. every second pool in smaller channel
3. Model layout
    a. Model layout is shown in Figure B.1:

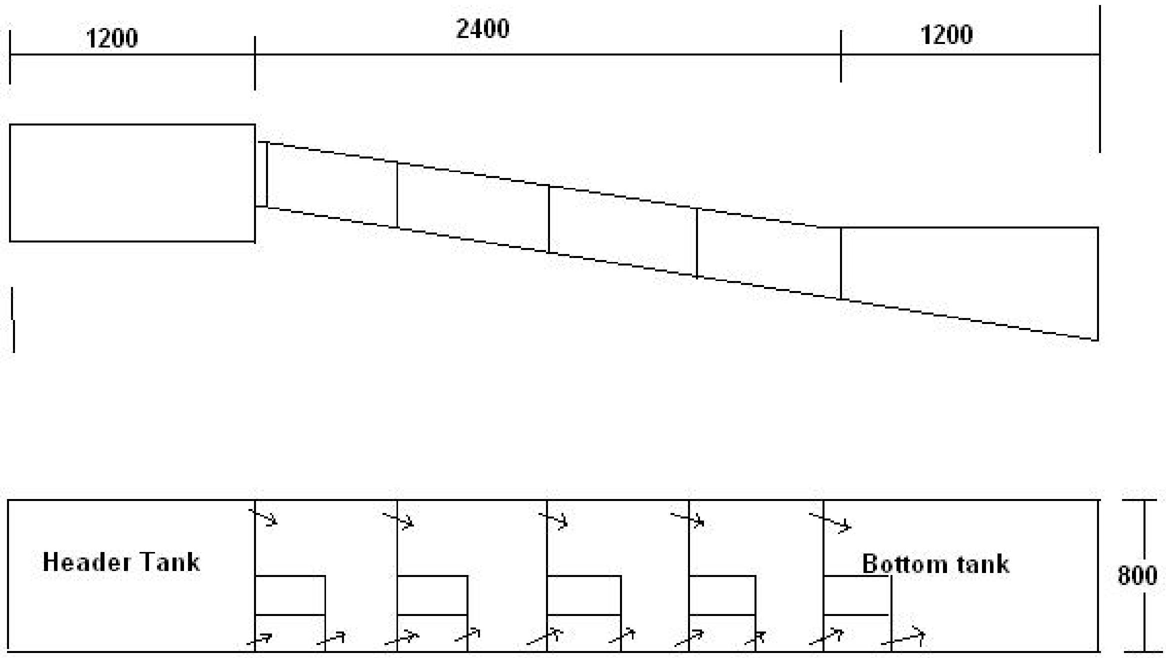



**Figure B.1.1: General Set Up**

b. Basically the model consists of three sections, i.e. a header tank, a channel section and a bottom tank, all 800 mm wide. The header and bottom tank are both 1,2 m long and the channel is 2,4 m long. These dimensions are chosen to make maximum use of standard plywood sheets with dimensions of 1,22 m x 2,44 m.

**Plate B.1:** Setting up the fishway at the Kowie Weir

**Plate B.2:** Fishway set up on the lower shelf at the base of the Kowie weir

**Plate B.3:** Fishway during a trial run with covering net over channel and siphon pipes

**Plate B.4:** Fishway channel without stones on bottom at ca 8 ℓ/sec discharge


**Plate B.5:** Fishway channel showing stones on bottom at low flows (large fishway channel).

**Plate B.6:** Fishway channel at high flow (18.9 ℓ/sc)

# APPENDIX C

# TESTS WITH A

# TWIN CHANNEL VERTICAL SLOT FISHWAY MODEL

# AT JONKERSHOEK

**J Rossouw**

**MARCH 2007**

## INTRODUCITON

A very limited test program was undertaken at the Jonkershoek fly fishery to determine the swimming ability of a few Western Cape fish species. The tests were undertaken during March 2007 using a portable model of a Twin Channel Vertical Slot Fishway model (Plate C.1). The observations during these tests are given in Appendix C.1.

## MODEL SET-UP

The standard portable model of the Twin Channel Vertical Slot Fishway was used in the tests. The two channels were 200 mm and 400 mm wide and the two channels were connected at every second small pool, creating a resting space between the two channels (Plate C.2). The model was set up at a slope of 1/5 and a single layer of rock was placed on the bottom (Plate C.3). A flow of 3.1 l/s was used in the tests and an electrical swimming pool pump was used to recirculate the water through the system. The hydraulics of the system at this flow rate was as follows:

| Channel | Slot width | Drop between pools | Max velocity | Turbulence* |
|---|---|---|---|---|
| | mm | mm | m/s | Watt/m$^3$ |
| 200 mm | 30 mm | 50 mm | 1.0 | 190 |
| 400 mm | 60 mm | 100 mm | 1.4 | 360 |

* Turbulence mainly dissipated by rocks on the bottom.

## FISH SPECIES USED IN THE TESTS

Three fish species were used in the tests. Details of the species used are shown in the table below.

| Species | Size range | Number of fish used |
|---|---|---|
| Berg River Redfins (*Pseudobarbus burgi*) | 50-90 mm | 22 |
| Cape Kurper (*Sandelii capensis*) | 30-100 mm | 9 |
| Cape Galaxias (*Galaxias zebratus*). | 15-40 mm | 22 |

## TEST PROCEDURE

The water was circulated through the system and flow conditions allowed to stabilize. Fish were introduced into the bottom chamber of the fishway and allowed to acclimatize. The fish were then herded close to the first slot and prevented from moving downstream by a net across the cross section of the chamber. The fish arriving at the top was caught, counted and removed from the system and the number of fish arriving at various intervals was recorded. Test durations varied from 3 to 15 hours.

## RESULTS

The results for the three species are summarized in the table below.

| Species | Number used | Number successful | % successful |
|---|---|---|---|
| **Redfins** | **22** | **19** | **86** |
| **Cape Kurper** | **9** | **0** | **0** |
| **Galaxias** | **22** | **4** | **18** |

From the table above it can be seen that the most successful migrators were the redfins where 19 out of 22 fish (or 86%) made it up the fishway during a 3 hour test. The first 5 fish arrived at the top after 10 minutes and the bulk (68%) of the redfins within about 1 hour.

The galaxias showed very little inclination to move up the fishway. Two fish of about 30 mm in length made it up the fishway during the first 2 hours of the tests and another two were found in the top tank at the end of the test, about 15 hours after the start of the test. The low success rate of only 4 fish out of a total of 22 (or 18%) during such a long test indicate that:

- the drops between the pools and/or the turbulence in the pools were too high for the fish to be able to move upstream
- The fish were not in a migratory mode
- The fish species are not migrators

The Cape kurpers showed no inclination to migrate and no fish progressed up the fishway. The reason for this must be similar to the reason for the low success rate with the galaxias.

All the Cape Kurper and Galaxias were collected from pools in the river system and seemed to prefer to stay in the deeper water at the bottom of the fishway.

This seems to indicate that the reason for the low success rate with these fish species was that the fish were not in a migratory mode during the tests.

## CONCLUSIONS

A single test with each species using a single flow rate is insufficient to define the swimming ability and behaviour of the species tested. Testing with fish that are not in a migratory mode is also not expected to give representative results with respect to the swimming ability of the fish. It was however encouraging to see that most of the redfins and a few of the galaxias made it up the fishway.

## FUTURE OF TESTING AT JONKERSHOEK

The setup of an experimental fishway at the Flyfishery and Nature Conservation offices at Jonkershoek have a number of spin-offs above the obvious benefit obtained from the tests that can be conducted at the site. During the setup of the model and the few days of testing, many of the nature conservation officers, personnel, fly fisherman, school kids and members of the public visited the model (Plate C.4). This afforded Ryan, who was conducting the tests, to explain the need, use and working of fishways to a wide variety of people. A semi permanent display with posters and a working model will afford the opportunity to educate the general public with respect to fishways.

Keeping the model in a working condition will also stimulate future research into the migratory behaviour of the Western Cape fish species. Discussing the possibilities with Dean Impson and Pierre de Villiers of Cape Nature conservation (Plate C.5); I suggested that we should find a student to do a thesis on the migratory requirements and behaviour of the Western Cape species. This suggestion was met with a lot of enthusiasm and they will hopefully try and set up such a program through the University of Stellenbosch with financial support from the WRC.


**Plate C.1: Portable model of a Twin Channel Vertical Slot Fishway tests at model used for Jonkershoek**


**Plate C.2: Configuration of twin channels**


**Plate C.3: Single layer of rock was placed on the bottom of model.**


**Plate C.4: Twin Channel Vertical Slot Fishway used for education purposes**


**Plate C.5: Discussions with Cape Nature re use of fishway model at Jonkershoek.**

**<u>Fish-way model testing observations at Jonkershoek, Stellenbosch 7th – 12th March 2007</u>**

**Wednesday 7th March**

The recirculation system was completed and tested for leaks. All is running well and the model will be tested with Mozambican Tilapia (*Oreochromis mossambicus*) tomorrow.

**Thursday 8th March**

Mozambican Tilapia (*Oreochromis mossambicus*) were caught for the initial tests (T1) mainly to check the system's "fish friendliness" before the more fragile fish are put through the system.

The Electric pump runs at 2,2 ℓ/s. The fish went in at 12am there were 20 Mozambicans ranging in size from 10 cm to 2 cm. After 1hour a single 10 cm fish had made it to the top. The test had to be stopped due to a pipe collapsing. The pipe was replaced with a high-pressure piping and the second test started (T2) at 16:40. The water level was lowered and the tilapia were encouraged into the first step of the ladder as they had previously been sitting quite comfortably in the bottom compartment. A Mozambican Tilapia of about 5 cm was seen making a valiant effort to pass the bottom two steps, but then returned to the bottom. The flow rate was measured at 3,3 ℓ/s as the intake pipe was opened up in an attempt to reduce the suction pressure on the pipes. The test was stopped after an hour at 17:40 when 1 fish was found at the top step, 2 in the 2nd step from the top and the rest remained in the bottom step.

**Friday the 9th March**

The third test (T3) was started at 9:33am once the system had been running for a while. 22 Berg River Redfins (*Pseudobarbus burgi*) and 9 Cape Kurper (*Sandelii capensis*) were introduced to the bottom chamber. Having seen no attempts at movement against the flow I decided to encourage the fish into the first step after 10 min.

9:33am – Test start

9:45am – push to 1st step

9:55am – 5 Berg River Redfins at the top +/- 8 cm average size

10:05am – nothing

10:17am – nothing

10:27am – 6 Berg River Redfins up +/- 9 cm average size

10:37am – 2 Berg River Redfins of +/- 5 cm average size at the top

10:48am – 2 Berg River Redfins of 5 cm average size at the top

10:55am – Level dropped to T3(2) to encourage Cape Kurper at the bottom to move. 2 Berg River Redfins were found at the top of +/- 3 cm average size.

11:05am – nothing

11:17am – nothing

11:30am – nothing

11:38am – removed obstructing rocks to even the flow rate as per Dean and Pierre's recommendation.

11:45am – 1 Berg River Redfin of +/-5 cm at the top

12:42am – 1 Berg River Redfin +/-5 cm at the top

12:45am – Test stopped.

One Berg River Redfin in the 2nd compartment from the top. All the Cape Kurper were still at the bottom. This may be due to disease stress as White Spot (Ich) had killed approximately 14 of these fish leading up to the test.

I propose retesting with fresh Cape Kurper of varying sizes that I hope to collect from the Eerste River on Monday.

19 Berg River Redfins of 22 made it to the top in 3 hours at a flow rate of 3,12 ℓ/s

0 of 9 Cape Kurper made attempts to move up the ladder.

**Monday 12th March**

Friday's test with the Cape Kurper and Berg River Redfins saw quite a few of the fish taking a lot of strain, especially the Cape Kurper which seemed to have been quite badly affected by white spot (ich). As a result there was a fair bit of ammonia in the water and it was decided to empty the model and allow it to dry out over the weekend. Having dried out we swept it clean to rid it of any remaining parasites in the dried sediments and repaired any potential holes in the piping. This was done on Monday morning and by 14:00 in the afternoon we were ready to start testing the Cape Galaxias (*Galaxias zebratus*).

14:00 – 15:00 the system was left to run for an hour with the fish in a container in the bottom compartment to allow them to acclimatise.

15:20 – fish were released into the system just below the bottom step. There were 22 in total ranging in size from 15 to 40 mm. Quite a few managed to escape to the bottom chamber where they were promptly netted and moved up to the 1st step.

16:50 – Having checked the top net at regular intervals we've found no fish seem to have moved or attempted to move up and have decided to leave the test running overnight.

17:30 – Just before I was set to go home I checked the top chamber to find 2 Galaxias there and one in the step below the top chamber.

**Tuesday 13th March**

8:30 – No more fish have moved up. The test will continue to run while we have our meeting with CapeNature (Dean Impson, Pierre de Villiers, Jan Russouw and Ryan Weaver).

11:30 – The test was stopped and the remaining fish netted out of the fish-way. Two more fish were found under the mesh cage at the top bringing the total to four that made it through the system. These fish were approximately 30 mm in size.

**Conclusion**

Having tested these three endemic cape species we have managed to ascertain that two of the three (Cape Galaxias and Berg River Redfin) are able to swim through the ladder at a flow rate of 3,12 ℓ/s and a gradient of 1:5. Of these two the Berg River Redfin moved up the system quite quickly and easily and is clearly a very strong swimmer. The Cape Kurper made no attempt to move up the fish-way, however this may be due either to stress from infection with White Spot or they are simply not a migrational fish species. It may be better to work out the migrational time of this species and then test the fish in the field at that time in order to get more accurate results.

# APPENDIX D

## CALIBRATION OF A

## TWIN CHANNEL VERTICAL SLOT FISHWAY

**Jan Rossouw**

## INTRODUCTION

The Twin Channel Vertical Slot Fishway was designed to enable the use of steep fishways for a wide variety of fish sizes. One possible use would be to incorporate the fishway into Crump gauging weirs. If the fishway can be built at a slope of 1/5 it will fit nicely into the 1/5 downstream slope of the Crump weir.

DWAF built a 1/1 scale model of such a fishway in their hydraulics laboratory in Pretoria. The model consisted of two channels, 0.5 m and 1.0 m wide respectively. The slots were 0.076 m and 0.152 m wide with a 0.133 m high Ogee sill in the narrow slot and a 0.266 m Ogee sill in the wider slot.

The water levels associated with flows varying between 0.006 $m^3/s$ and 0.082 $m^3/s$ were accurately recorded.

## THEORY

With free flow over the Ogee spillway the discharge is given by:

$$Q_f=C_d\ 2/3\ b\ (2g)^{0.5}\ H_1^{3/2}$$

Where $Q_f$ = discharge in $m^3/s$

$C_d$ = discharge coefficient for Ogee spillway

b = spillway width (0.152 m ans 0.076 m in model)

g = 9.81 $m/s^2$

$H_1$ = head on spillway

When the water level downstream of the spillway is higher than the spillway crest, submerged flow occurs and the discharge must be reduced by a factor K where

$$K= (1-(H_2/H_1)^{1..5})^{0.385}$$

Where $H_2$=the water level downstream of the crest relative to the crest level

At high levels of submergence the formula for a vertical slot applies i.e.:

$$Q= C_d\ b\ H_1\ (2g\ DH)^{0.5}$$

with DH = drop between the pools

## COMPARISON BETWEEN THEORY AND MEASUREMENTS

The results of a comparison between the theoretical and recorded discharge is shown in the table below. In the table the theoretical discharge in the two channels $Q_{slot}$ were calculated using a discharge coefficient of 0.64. The total discharge ($Q_{tot}$) in the two channels is compared to the recorded discharge ($Q_{dwaf}$) in the table below. The ratio between the theoretical discharge and the recorded discharge is shown below.

| **Vertical slot with ogee sill** | | |
|---|---|---|
| | **Narrow** | **Wide** |
| Slot width | 0.076 | 0.152 |
| Slope | 0.200 | 0.200 |
| Fishway width | 0.504 | 1.008 |
| Pool length | 0.616 | 1.233 |
| Drop | 0.123 | 0.247 |
| Cd | 0.640 | 0.640 |
| Sill height | 0.133 | 0.266 |

| **Narrow fishway** | | **Wide fishway** | | **Total** | | |
|---|---|---|---|---|---|---|
| **H1** | **Qslot** | **H1** | **Qslot** | **Qtot** | **Qdwaf** | **Qtot/Qdwaf** |
| **m** | **$m^3/s$** | **m** | **$m^3/s$** | **$m^3/s$** | **$m^3/s$** | |
| 0.1224 | 0.0062 | 0.0106 | 0.0000 | 0.0062 | 0.0060 | 0.9755 |
| 0.1907 | 0.0109 | 0.0577 | 0.0040 | 0.0149 | 0.0149 | 0.9998 |
| 0.2300 | 0.0137 | 0.0970 | 0.0087 | 0.0224 | 0.0222 | 0.9926 |
| 0.2620 | 0.0160 | 0.1290 | 0.0133 | 0.0293 | 0.0292 | 0.9972 |
| 0.2993 | 0.0226 | 0.1663 | 0.0195 | 0.0382 | 0.0381 | 0.9987 |
| 0.3275 | 0.0248 | 0.1945 | 0.0246 | 0.0454 | 0.0447 | 0.9851 |
| 0.3784 | 0.0286 | 0.2454 | 0.0349 | 0.0594 | 0.0592 | 0.9961 |
| 0.4048 | 0.0306 | 0.2718 | 0.0403 | 0.0667 | 0.0668 | 1.0008 |
| 0.4528 | 0.0343 | 0.3198 | 0.0497 | 0.0798 | 0.0820 | 1.0275 |

**CONCLUSION**

The differences between the theoretical and recorded discharges all remain below 3%.

The theory used to establish the relationship between head ($H_1$) and discharge (Q) can therefore be used with confidence.

Since this relationship is well established, DWAF can also build this type if fishway into their gauging weirs without compromising the accuracy of their flow gauging.