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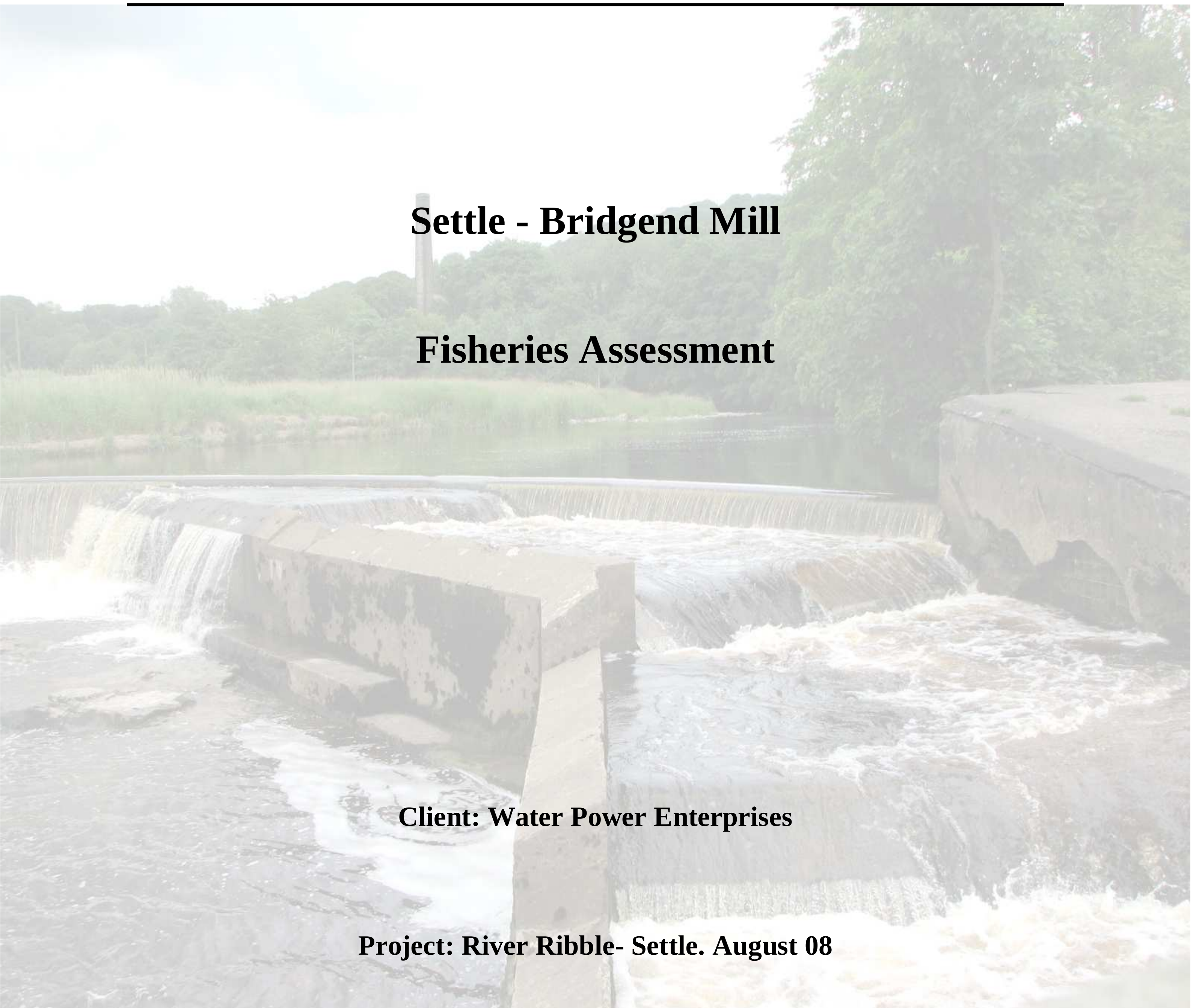

Settle - Bridgend Mill

Fisheries Assessment

Client: Water Power Enterprises

Project: River Ribble- Settle. August 08

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1 Introduction

Bridgend Mill is situated on the River Ribble in Settle on the edge of the Yorkshire Dales National Park. The mill buildings have already been converted into residential properties. Water Power Enterprises are proposing to harness the hydro potential to generate electricity using an Archimedean screw turbine. This report was commissioned to assess the potential impact on fisheries. A site visit was undertaken on the 3 July 08, during which Helen Walker (Water Power Enterprises), Dave Mann (Mann Power Consulting), Neil Handy (EA fisheries technical officer) Bob Garnett (Settle Angling Association) and John Whitham (Ribble Conservation Trust) were met on site to discuss the issues.

2 Proposal

The intention is to use an Archimedes screw turbine, see figure 1 below, as these devices are extremely fish friendly, allowing downstream migrants to pass unharmed (Kibel, 2008)
The screw diameter would be 2.6m with 0.87m depth within each chamber. Water would be drawn through the existing sluice and leat to the intake. The outflow would issue water back into the river 20m below the weir, adjacent to the entrance (bottom) of the fish pass. The initial proposal maximized the head by extending the tailrace 20-30m downstream of the pass entrance, creating a de-watered reach between the fish pass and the outflow. This was discussed at the site meeting and it was concluded that the tailrace should be confluent with the bottom of the pass to ensure there are no issues for upstream migrants, albeit with a small head loss.
The operating head is 2.1m with a maximum abstraction of 2.86 m^3s, generating up to 45 kW of electricity. A Hands off Flow (HOF) has been proposed, providing the optimum flow for the fish pass with a sweetening flow over the weir. This has been estimated at 400 l/s for the pass and 50-100 litres for the weir, giving a total of 450-500 l/s, below which the turbine would not operate.
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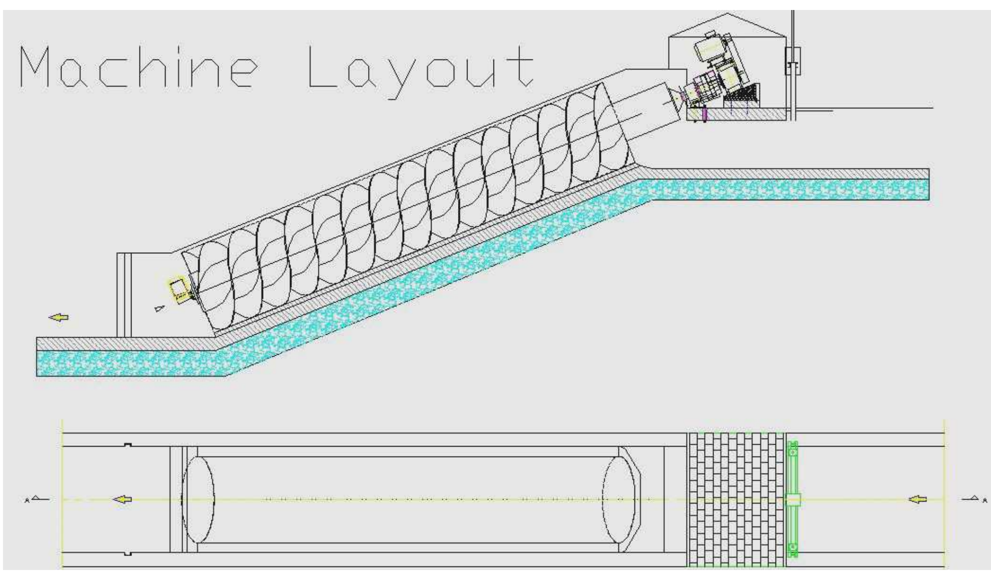


Figure 1. Diagram of Archimedes screw turbine

3 Site characteristics

Figure 2. Map of Site

The Ribble is a fast flowing upland eroding river, rising within the Yorkshire Dales National Park and flowing South West to join the Irish Sea at Southport. Total catchment above Settle is 124 km^2 with average rainfall of 1582mm. It has a number of old mills along its length, most of them now defunct. Bridgend Mill is situated on the Northern edge of Settle.

The weir is 36m long, forming a gentle arc. It is 2.1m high with boards forming the top 30cm. The face is vertical and water spills onto shallow flat rock preventing fish from jumping the weir and rendering it impassable. The fish ladder on the Eastern bank is a traditional pool pass built 40-50 years ago and provides the only route upstream. See appendix for design. Over a third of the total weir length feeds water into the top of the pass, reducing efficiency at higher flows and making it difficult for fish to ascend. The turbine would divert some of this water through the leat reducing pass energy and actually improve fish migration (see section 5.2). The pass appeared to be in reasonable condition although large boulders and debris particularly in the first and last pools significantly reduced pool depth, exacerbating the problem of energy density. Adjacent to the top of the pass, a sluice gate leads into the leat. Both appeared to be in good condition, although the leat is now partially restricted and would need to be widened to cope with the maximum design flow of the scheme.

3.1 Flow at site

Arnford gauging station (SD83885558) 14km downstream, spot gauging 2.6km below the site (SD81436329) and levels at Locks weir 1km upstream have all been used to estimate flows at Settle. The Environment Agency, however, have suggested that further spot gauging should be conducted to validate results. The flow duration curve is given in figure 3 below.

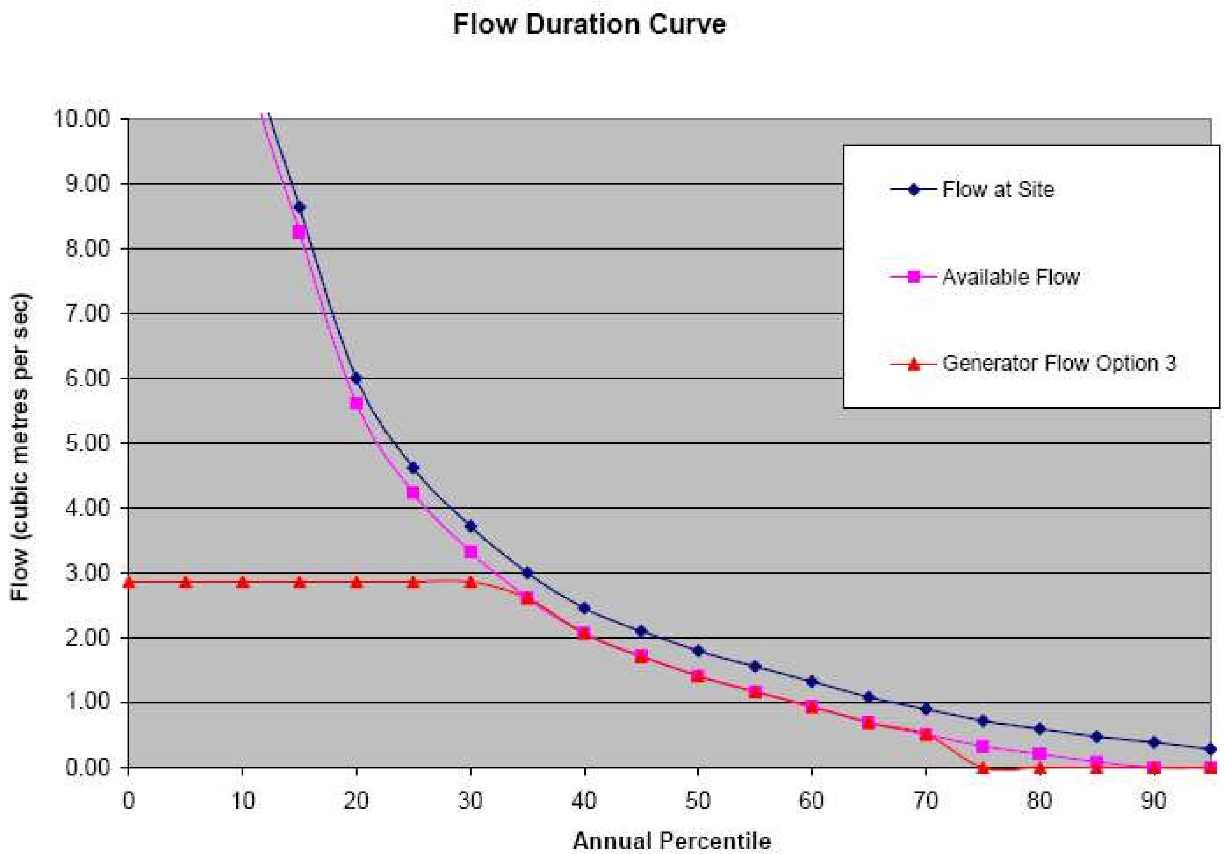


Figure 3. Graph showing annual discharge percentile for the river Ribble at Settle

4 Fishery Ecology

The Ribble is an improving salmon river that has benefited from much conservation work including juvenile stocking, mitigation to remove barriers to migration and a cull limit of 2 fish per rod season.

In the upper reaches around Settle, it is primarily a salmonid river, supporting healthy populations of brown trout and grayling. The headwaters of the Ribble, has excellent spawning and juvenile habitat and it is therefore important that migratory salmonids are able to reach this area.Lamprey are present although not common and only rarely recorded in surveys. (Neil Handy, pers. comm.). Table 1 below, shows species present, migration habit and main migration period.

Fish Species		**Migration**	**Main Migration period**
Salmon	(*Salmo salar)*	Anadromous	
Spawners	ascending		spring/summer/autumn
Kelts	descending		winter
Smolts	descending		spring.
Sea trout	(*Salmo trutta)*	Anadromous	
Upstream	ascending		summer/autumn
Post spawned	descending		winter
Brown trout	(*Salmo trutta)*	Potomadromous	
Eel	(*Anguilla anguilla)*	Catadromous	
Adults	descending		autumn
Juveniles	ascending		spring-summer
Grayling	*(Thymallus thymallus)*	Potomadromous	
Minor species			
Stickleback	(*Gasterosteus aculeatus*)	Potomadromous	
Minnow	*(Phoxinus phoxinus)*	Potomadromous	
Bull Head	*(Cottus gobio)*	Potomadromous	
Stone Loach	*(Barbatula barbatula)*	Potomadromous	

Table 1. Species present and migration habit

5 Potential Impacts on Fishery

Hydro power developments can have a number of impacts on fisheries including changed flow regimes, de-watered reaches, fish entrainment and issues of attraction flow. The main factors for this proposal are considered below.

5.1 Attraction flow

To ensure that fish find the entrance to the pass relatively quickly, the outflow of the turbine should be located near to the fish pass entrance (bottom), ensuring that the flows are confluent. The outflow region should be large enough (at least 5 square metres) so that water velocities are below 0.5m/s, reducing attraction flow (EA fish pass manual). Turbulence levels should also be low to enable fish to detect the higher velocity water (>1m/s) issued from the pass.
The recommended fish pass flow of at least 10% of the turbine take (Greg Armstrong, EA Fish Pass Panel, pers. comm.) is easily achieved as the 400 l/s flow in the pass approximates to 15% of the 2.86 cumecs maximum abstraction. In most river conditions, flow in the pass would average 20-30% of the turbine flow. 400 l/s has been estimated from the pass dimensions as providing enough flow for the pass to work efficiently, see appendix for calculation.

Presently some fish move along the right bank on the far side of the weir opposite the pass. They can not ascend the weir and would be delayed until they find the pass entrance. The turbine outflow would direct most of the attraction flow to the bottom of the pass and ensure that most fish are drawn up the left bank to the pass entrance.

5.2 Effect on Fish Pass

The fish pass currently draws a significant proportion of the total flow. It is not possible to calculate exactly how much without further hydrological investigations, however, an estimate based on the proportion of the weir feeding into the pass suggests one third to a half of the total flow depending on river levels. This figure is supported by Neil Handy (pers. comm.) who suggested approximately half the flow across most river levels.
Figures 4-7 below show the pass at different river levels. Figure 4 = 0.336 m^3/s., with the pass drawing well below the proposed HOF of 400l/s. Figure 5 = 1.15m^3/s (Q65). Approx. 400-500l/s is flowing in the pass and energy densities are well within the maximum 200 watts/m^3 (EA Fish Pass manual). Figure 6=1.78 m^3/s (Q50). A significant volume of water is in the pass with energy densities above 200 watts/$m^{3.}$ Figure 7 =14.5 m^3/s, just above Q10 with energy levels above 500 watts/m^3.

Figure 4. Pass at 0.336 m^3s, just below Q90

Figure 5. Pass at $1.15m^3s$ (Q65)

Figure 6. Pass at $1.78m^3s$. (Q50)

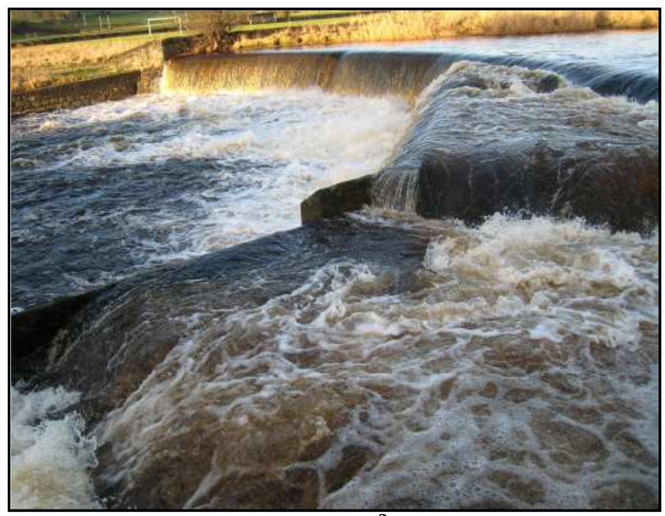


Figure 7. Pass at $14.5m^3/s$, above Q10.

Fish are unlikely to ascend the shallow reach between the bottom of the pass and the holding pool 30m downstream unless river levels are reasonably high. Abstraction will not affect the ability of fish to migrate through this section to reach the pass.

Assuming that the pass takes a third of the flow up to Q10 (after this most of the water would spill over the wings), it is possible to determine how much water is flowing through it and from this the energy densities at different river levels. The potential energy (PE) entering each pool is calculated from the equation below. The energy density (PV) is then determined by dividing PE by the pool volume (EA fish pass manual).

PE = Q.P.G.Dh

PE=Potential energy entering the pool
Q=Water flow in the pass m^3/s
P=Density of water ($1000kg/m^3$)
G= Acceleration due to gravity $9.81ms^{-1}$
Dh=Drop between pools

$$PV = \frac{PE}{V}$$

PV=Power density per unit volume.
V=Pool volume

The pool dimensions, average depth and drop were determined during a site visit, see appendix table A. These values were used together with the estimates of flow to calculate energy densities in the pass at different river levels. See Fig. 8.

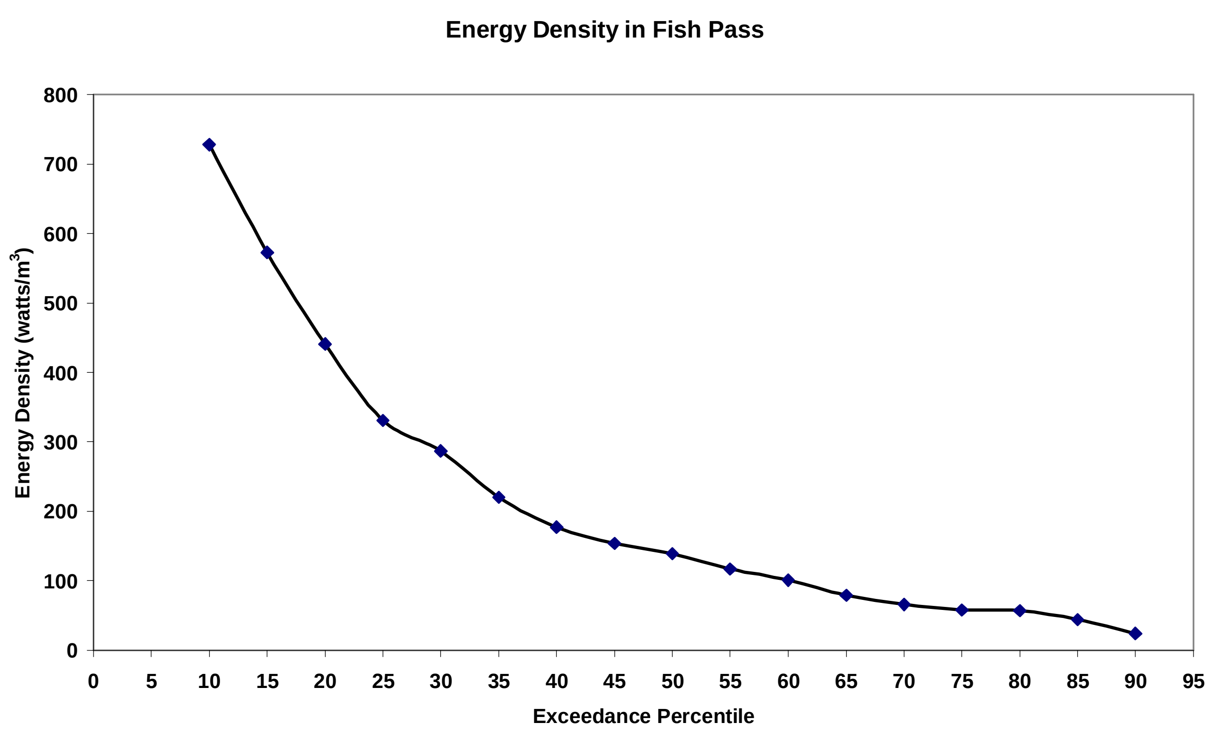
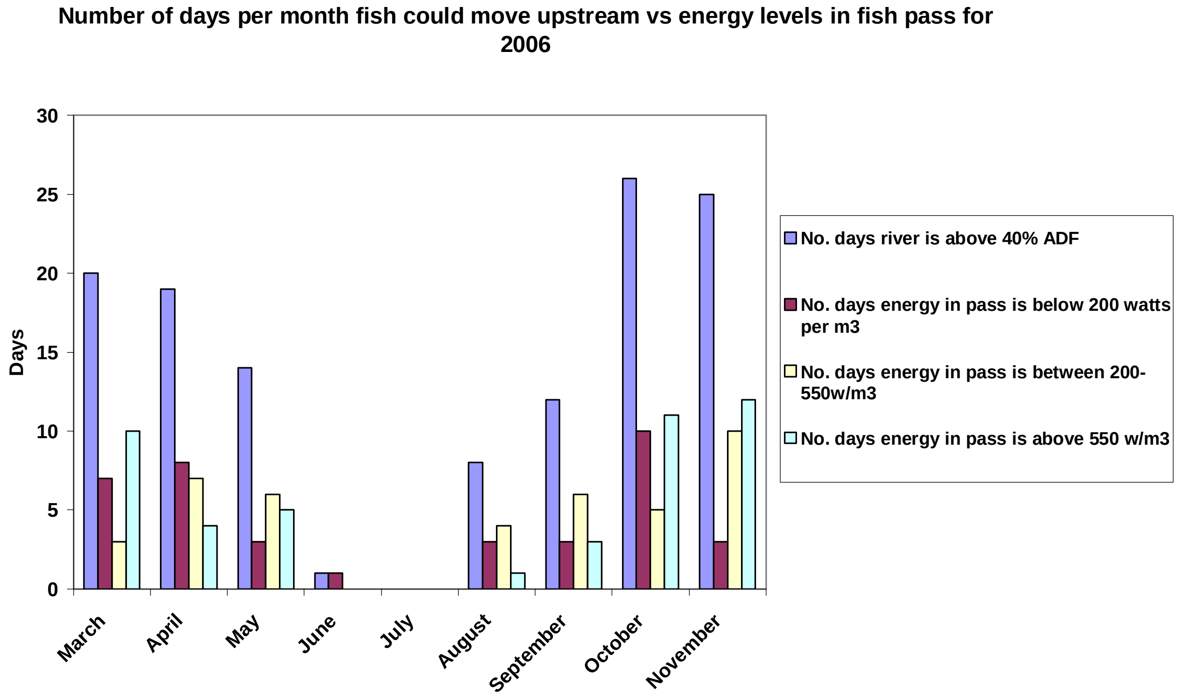


Figure 8. Energy density in fish pass against exceedance percentile. (river levels)

The number of days per month during the main migratory period (March-November) that the river was above 40% Average Daily Flow (ADF) and fish were likely to be moving upstream were calculated for 2006 and 2007. The energy density in the pass on these days was also calculated for comparison, see figure 9. 0.4 ADF is generally taken as the minimum value below which salmon are unlikely to move upstream. (Baxter 1961 Allan 1966).



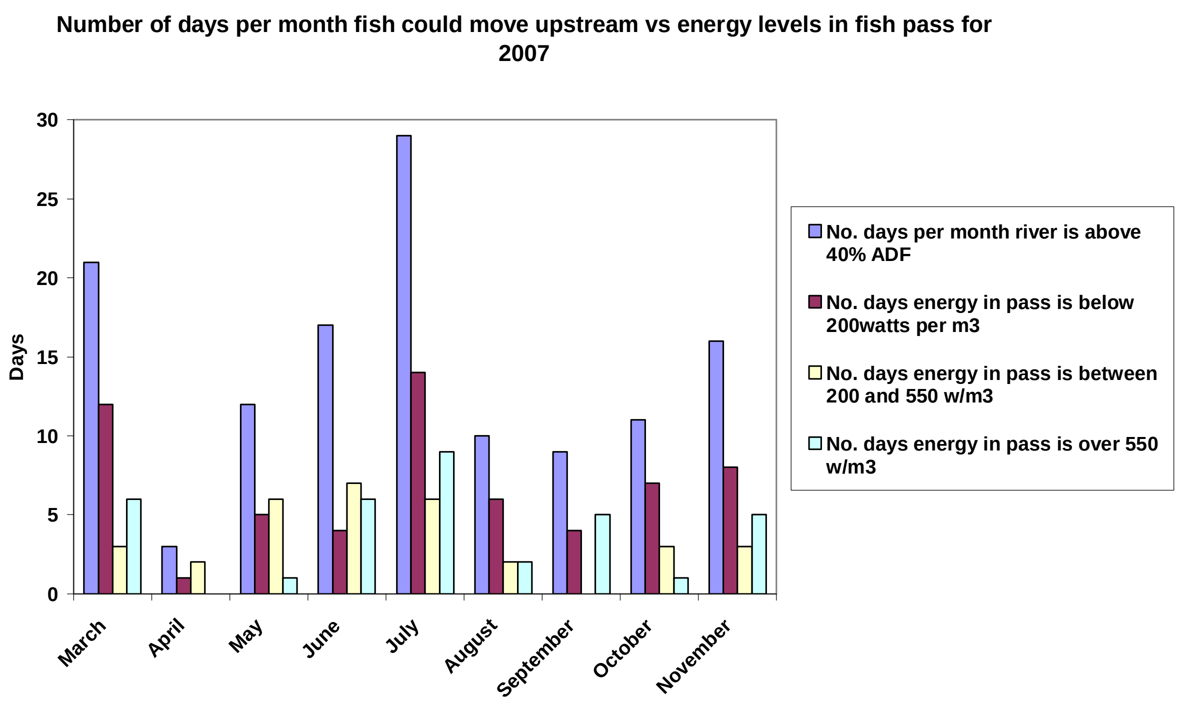


Figure 9. Days per month fish are moving upstream against energy levels in fish pass

It is evident that for about 60% of the period during which fish were migrating upstream, energy levels in the pass were significantly above 200 w/m^3. This may delay migration, particularly for smaller grilse and sea trout that would struggle to ascend if energy levels were too high.

In view of this, it is likely that drawing some of the water through the turbine and maintaining flow in the pass to around 400 l/s would improve overall efficiency and extend the migration

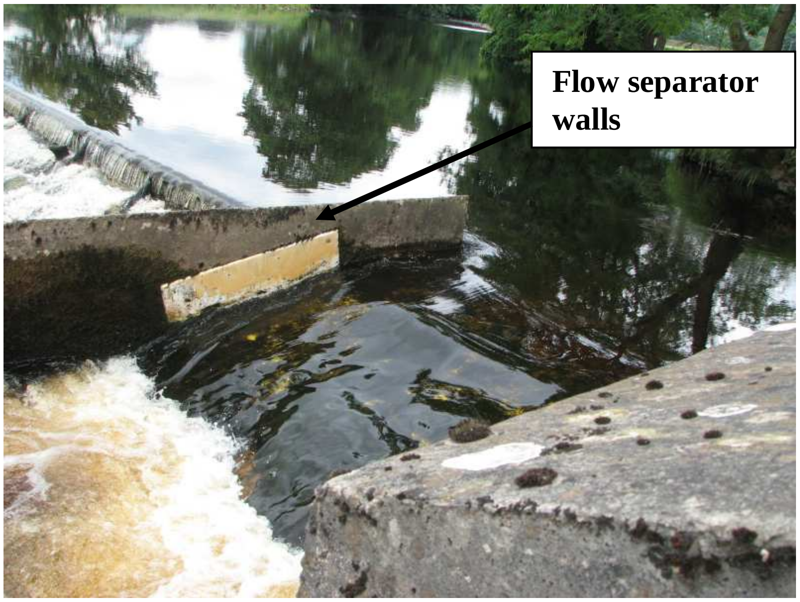


Figure 10. Fish pass at Locks weir

window.Improvements to the top of the pass, such as installing separator walls as shown in figure 10 to reduce the intake at high flows and removing boulders that currently reduce pool depth would further improve efficiency across the flow range. Currently, energy levels in the pass exceed 200watts at about Q40. The proposed abstraction could extend this to Q10, reducing delay for upstream migrants.

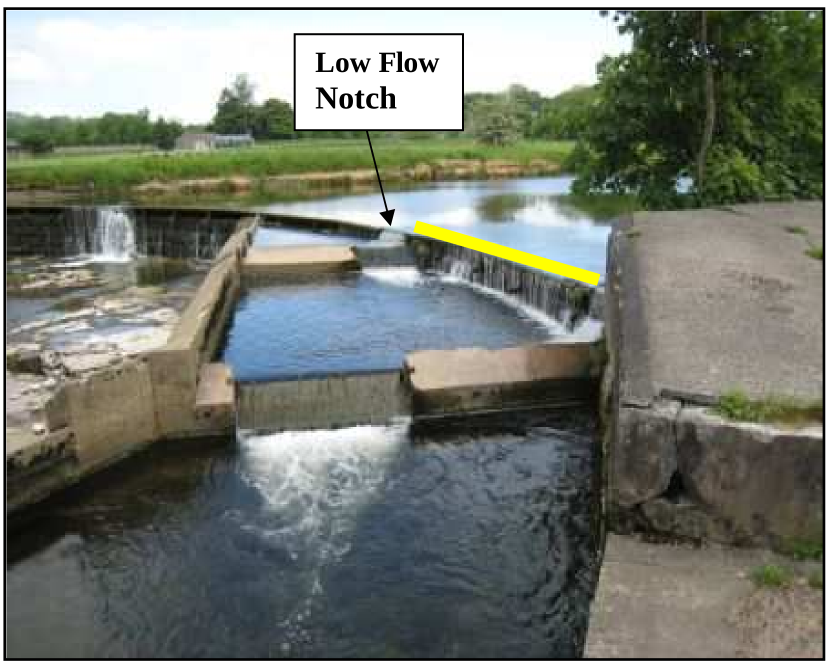


Figure10a. Modifications to reduce flow in pass and prevent fish being drawn into leat.

A short section of wall separating the intake to the sluice from the fish pass exit would be needed to prevent recently ascended fish being re-cycled through the screw. If the section of weir shown in yellow in figure 10a below was built up, it would reduce flow into the pass at high river levels and put the fish pass exit far enough away from the intake to prevent fish being re-cycled. This section already has a low flow notch; (see fig. 10a) however, this may need to be extended to ensure the pass draws most of the water at HOF.

5.3 Fish Entrainment

It is likely that smolts and kelts migrating downstream would enter the leat and reach the turbine. The proportion passing into the leat would depend on a number of factors including channel profile, marginal vegetation and position of leat inlet. A crude estimate can be made by assuming a random distribution of fish across the channel and basing it on the proportion of water passing down the leat compared to the mainstem river. Smolts are unlikely to migrate downstream in low

water conditions, below Q75; therefore the proportion of fish entrained at river levels above this was calculated. Results are shown in figure 11. The actual proportion would depend on the flows during the migration period, April-May for smolts and November-January for kelts. It seems likely that a significant number of fish, especially smolts would pass through the turbine if it runs unscreened. Extensive trials on the River Dart in Devon (section 6.1) have shown that adult and juvenile salmonids can pass the screw unharmed; therefore this is unlikely to be an issue.
If fish actively avoid the intake, the fish pass would form an effective bywash. A second bywash alongside the screw is probably not needed as the intake leat is very short (<15m) and large fish avoiding the screw could easily swim back into the main river and down the fish pass.

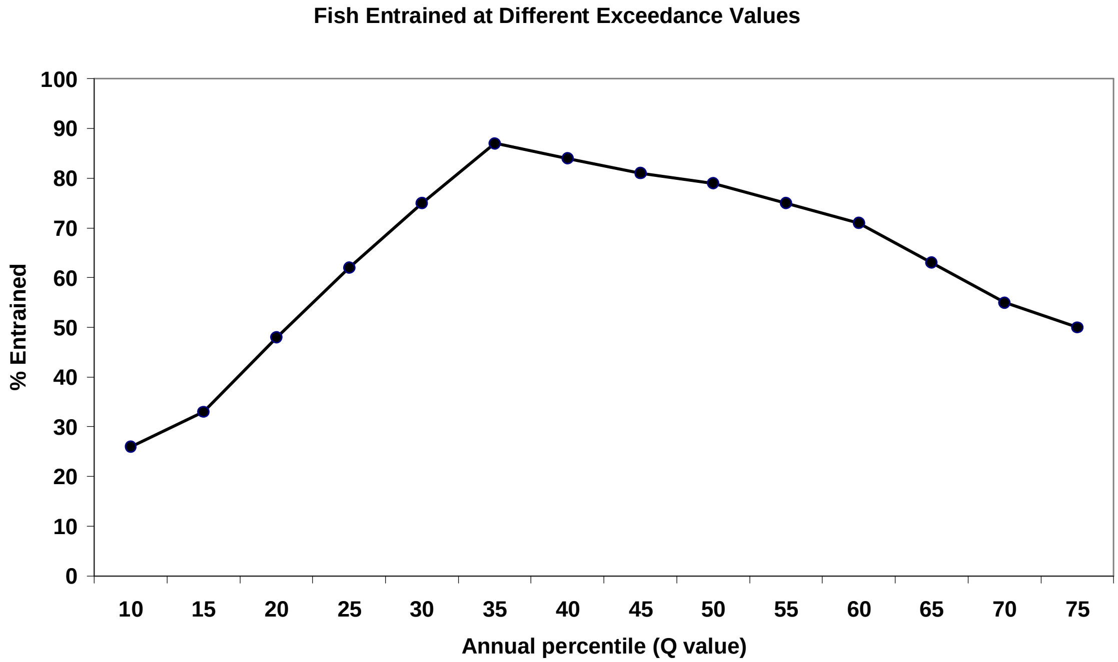


Figure 11. Proportion of downstream migrants entrained in turbine intake

5.4 Construction Phase

There were no significant areas of spawning gravel immediately below the weir likely to be affected by inadvertent release of sediment during construction; however, guidance on best practice should be sought from the EA. Any modifications to the fish pass will need formal approval and should be carried out during low river levels (below 0.4 ADF) to minimize impact on upstream migrants. The outflow channel would run alongside the entrance to the pass; it is important that any temporary structures in place such as coffer dams, piling, shuttering etc do not prevent fish from locating the pass. Again working during low water conditions should ensure disturbance is minimized.

6 Fish passage through the Archimedes Turbine

Hydraulic screw turbines are generally considered to be very fish friendly, having a slow rotational speed of 25-30 rpm and no rapid pressure changes or hydraulic shear forces. After passing the leading edge, fish remain in the same chamber of water until released at the outflow.

The first assessment of fish passage through Archimedes turbines was conducted by Dr. Hartmut Spah of Bielefeld, Germany in 2001. The turbine was smaller than the one recommended for the Ribble, having a diameter of 1.4m and processing 615 litres of water per second. 158 fish of nine species were passed through the turbine and netted at the outflow. 4.4% of the fish suffered limited damage, mainly scale loss that was deemed to be minor and generally recoverable. Chub and roach were the only species to suffer any damage; eels that traditionally experience problems passing through turbines suffered no damage at all. Table 2 summarises the results.

Species	No. Tested	Length Range (cm)	No. fish Injured	Injuries
Eel	22	36-58	0	
Grayling	3	20-36	0	
Brown trout	31	8-35	0	
Perch	19	14-18	0	
Chub	63	8-43	5	Scale loss, haematoma
Gudgeon	8	12-14	0	
Bullhead	3	11-14	0	
Dace	1	21	0	
Roach	8	16-21	2	Scale loss, haematoma

Table 2. Summary of Dr Spahs' results, showing the number that passed through of each species and the lengths of fish affected.

Dr. Spah concluded that the damage was most likely due to the leading edge becoming sharpened by stones after prolonged operation.

To resolve this issue, the turbine monitored on the river Dart by Fishtek Consulting has been installed with rubber extrusions along each leading edge, see figure 12. These serve two functions; firstly they prevent the edge from being damaged by stones and secondly any contact with larger fish is softened and extremely unlikely to cause damage. The tip speed of the end of the helix is under $4ms^{-1}$ generally regarded as the threshold impact speed below which there is no damage to fish. (Turnpenny et al, 2000).

Figure 12. Modified leading edge with rubber extrusions

A recent study conducted by Vis Advies (Vries, 2007), netted fish naturally passing through an Archimedean screw at Hooidonkse Mill on the River Dommel in Holland. A total of 289 fish, mainly small bream passed through the screw. The average size was 5.6cm, compared to 11.2cm for fish passing over the fish pass. None of the fish suffered any damage at all. This was verified by the project leader, Tim Vriese (pers. comm.) who confirmed that each fish was carefully checked for any signs of damage including limited scale loss, but none was found. Interestingly the larger fish actively avoided the screw and it was concluded that only smaller fish, unable to withstand water velocities at the intake passed through. Results of the river Dommel study are shown in table 3 below.

Species	Size range (cm)	Number	Number of fish with damage
Bitterling	4-5	5	0
Bleak	4-5	2	0
Bream	3-7	239	0
Carp	7-19	11	0
Crucian Carp	9-14	2	0
Gudgeon	11	1	0
Orfe	8-14	2	0
Pike	39	1	0
Roach	5-12	9	0
Rudd	4-11	2	0
Stickleback	1-5	5	0
Stone Loach	11-11	3	0
Tench	4-20	7	0

Table 3. River Dommel study. Size range and number of each species.

6.1 Monitoring on the River Dart

A more extensive study, conducted by Fishtek Consulting on the River Dart in Devon involved brown trout, rainbow trout, salmon and eels. Fish up to 98 cm (7.4kg) have passed through the turbine with no damage at all. Results for brown trout are shown in table 4. The turbine is very similar in size to the one proposed for the Ribble, with a diameter of 2.2m.

Turbine Operating Speed	Fish No.	Sizes affected and Damage	Percentage affected	% after correction for net
20-23 rpm	132	17cm (<10% scale loss)	3	0
		19cm (<10% scale loss)		
		22cm (<10% scale loss)		
		24cm (<10% scale loss)		
25-26 rpm	120	23cm (<10% scale loss)	2.5	0
		23cm (<10% scale loss)		
		25cm (<10% scale loss)		
29-31rpm	125	18cm (<10% scale loss)	3.2	0.2
		20cm (<10% scale loss)		
		22cm (<10% scale loss)		
		25cm (<10% scale loss)		

Table 4. Summary of brown trout results of fish monitoring on the R. Dart.

Examples of fish photographed before and after passing through are shown in figure 13 below.

before

after

Figure 13. Brown trout photographed before and after passing through the turbine.

A small number of fish (3%) sustained scale loss as they passed through the net in high water flows. The net component was evaluated by introducing fish at the end of the turbine, so they bypassed the screw, only passing through the net.

Turbulence/disorientation

Levels of turbulence within the screw and the potential to disorientate fish and increase predation by reducing the ability of fish to respond to predators (startle response time) was assessed by monitoring fish as they passed through the turbine. It was found that levels of turbulence were very low indeed and well within the range normally experienced by salmonids and probably most riverine species. Fish were not disorientated and it is unlikely the predation risk would be significantly affected.

Smolts.

Smolts were netted as they passed through on the seaward migration. A total of 249 were trapped of which 1.4% suffered scale loss of <10% (allowing for the component of net damage). Considering that these were wild fish that may already have had some prior scale loss, it is likely that passage through the turbine had either a minimal effect or no effect at all.

Kelts

Kelts up to 98cm (7.4kg) were monitored by underwater camera as they approached the intake and were then trapped in the outflow region after passing through the turbine to allow an assessment of any damage. While relatively few fish passed through, those that did suffered no damage at all, indicating that the screw is safe for large descending salmon.

Eels

A total of 160 passages were observed (Eels passed through several times with rest periods between). They were kept in holding tanks for 7 days afterwards to assess any delayed effects. One eel suffered a pinched tail, likely to be survivable. The others were unaffected. All were alive and appeared healthy after 7 days in tanks. Overall, the mortality rate was 0%, with 0.6% suffering limited and recoverable damage.
These results are in accordance with the Spah study that found no damage at all to eels.

The results from all three studies (Kibel 2008, Vries 2007, Spah 2001) are compiled in table B of the appendix.

7 Screens

7.1 Outflow Screens

It is recommended that outflow screens are not necessary as monitoring on the river Dart indicated that the outflow channel and the end of the turbine did not present any problems for fish moving upstream. Sea trout and salmon were seen to move towards the end of the screw for short periods of up to 10-20 minutes before drifting back into the main channel.

7.2 Intake Screening

A number of studies, referred to in section 6, have concluded that a wide range of fish species, including all of the species present in the Ribble can pass through Archimedes screw turbines safely. In view of this I suggest that screening is not needed other than a large spacing (110-130mm) to protect the device from logs and other large debris. If a problem does develop in due course, then screens with the appropriate spacing should be fitted retrospectively.

8 Monitoring

Monitoring fish behaviour in the tailrace region to assess how quickly they find the fish pass and assessing the numbers of salmon and sea trout ascending the river would provide useful data and address some of the concerns raised by anglers regarding possible delays at the tailrace.

In the absence of data for water flowing through the fish pass at different river levels, a number of assumptions have been made regarding the proportion of flow that is currently channeled through the pass. More accurate data would be useful to validate conclusions reached.

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10 Appendix

Pool	Area (m^2)	Mean Depth (m)	Drop (m)
1	16	0.8	0.45
2	24	1.2	0.45
3	25	1.0	0.45
4	22	0.7	0.45

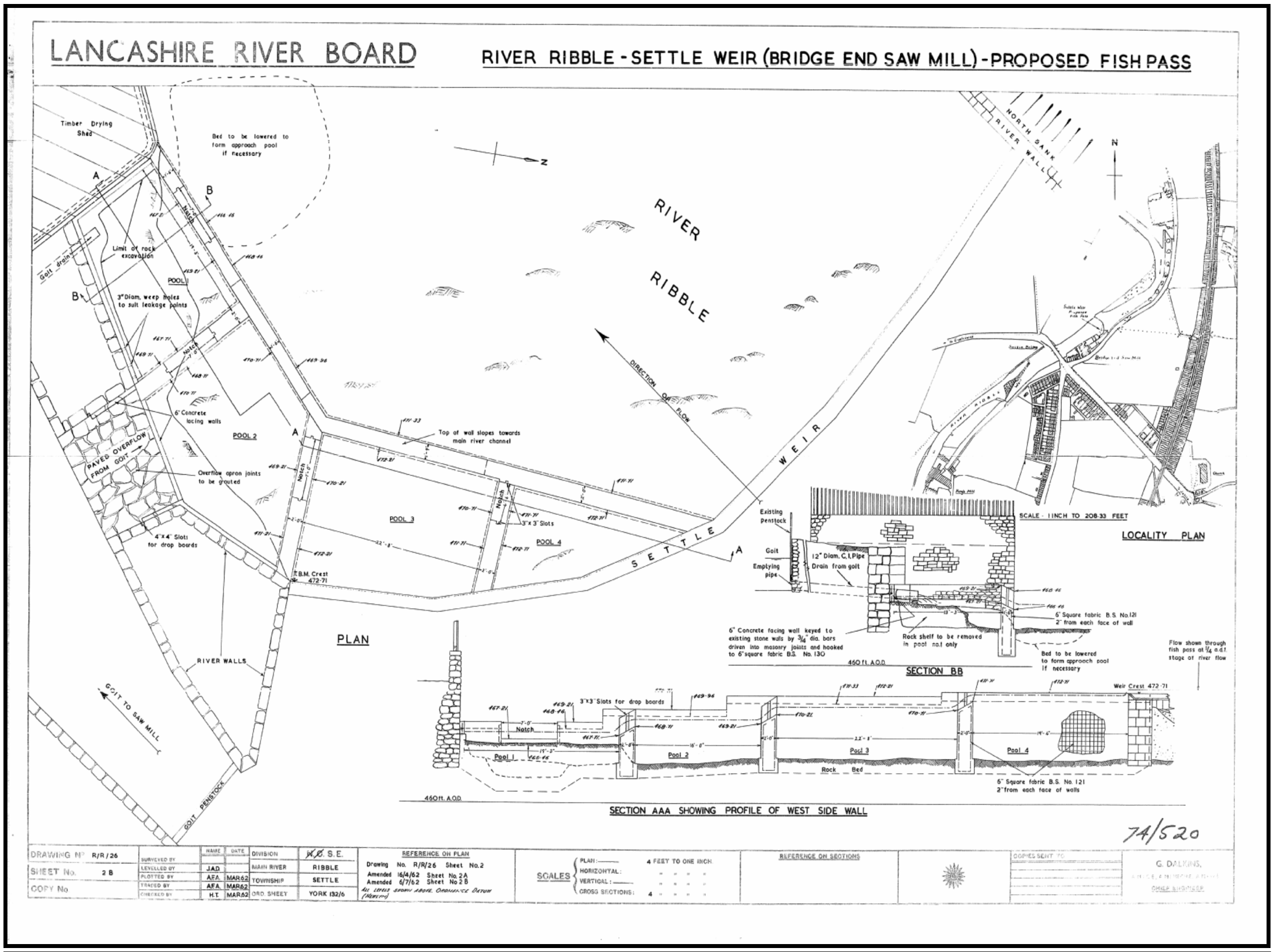
Table A. Area and mean depth of fish pass pools

Energy in pool 1 @ 400 l/s.

PE=0.4x1000x9.81x0.45
PE=1765 watts
PV=1765/12.8=**137 watts/m^3**

Species	Max. length (cm)	Number	No. affected	Damage sustained
Bitterling (Rhodeus sericius)	5	5	0	
Bullhead (Cottus gobio)	14	5	0	
Brown trout (Salmo trutta)	44	708	0	
Bream (Abramis brama)	7	239	0	
Carp (Cyprinus carpio)	19	2	0	
Chub (Leuciscus cephalus)	43	63	5	scale loss/haematoma- probably recoverable
Dace (Leuciscus leuciscus)	21	1	0	
Eel (Anguilla anguilla)	79	182	1	pinch mark to tail, recoverable
Grayling (Thymallus thymallus)	36	3	0	
Gudgeon (Gobio gobio)	14	9	0	
Perch (Perca fluviatilis)	18	18	0	
Rainbow trout (Oncorhynchus mykiss)	63	4	0	
Roach (Rutilus rutilus)	21	17	2	scaleloss/haematoma- probably recoverable
Salmon, smolt (Salmo salar)	18	249	4	recoverable scale loss
Salmon, kelt	98	9	0	
3SpinedStickleback(Gasterostues aculeatus)	5	5	0	
Stone Loach (Barbatula barbatula)	11	3	0	

Table B. Combining results from all 3 investigations. The River Dart (Kibel, 2008), German (Spah, 2001) and Dutch (Vries, 2007) studies.



Plan of Bridgend fish pass from Environment Agency archives.