Analysis Documents

- Hydrology Assessment
- Energy capture prediction graph for proposed options
- Cost-benefit calculation for proposed options
- Overview of alternative machinery options
- Fish screening considerations

- Plan layouts for Options 1, 2 & 3 (separate documents)
- Section sketches for Options 1, 2 & 3 (separate documents)

Work continuation form (separate)
Customer feedback form (separate)

Hydrology Assessment

Pontwelly (Llandysul 717)

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Flow duration curve

Flow data was obtained from the Natural Resources Wales (NRW) Llanfair gauging station. Although there is data from this station reaching back several decades, the data back to 2002 was corrected in 2010 to a current standard, whereas older data was not. Also, data from more recent decades has been a more reliable guide to current (and likely near future) trends than has data from earlier decades. For these reasons, full-year data from Llanfair for September 2002 to September 2012 only has been used in the present analysis.

The gauging station lies some distance upstream of the site at Pontwelly, and its data therefore omits some 20km^2 of the river's total catchment area at this site. The gauged data was therefore adjusted upwards by 3.9% to represent the increased catchment size.

The data is analysed statistically and broken down into different flow bands, each occurring for 5% of the year. Each band then represents the percentile flow available, or the minimum flow that is in the river for that percentage of the year. For example, a Q90 flow means that for 90% of the year the flow will be at this level or more. This data has been used to produce a Flow Duration Curve of flows at this site. Presenting the data in this form indicating how often a given flow may be expected to occur (see overleaf).

When proposing a hydropower scheme, two important hydrological factors which need to be established are how much water may be taken by the proposed scheme – the Design Flow - and how much water must be left in the river – the Residual Flow.

Residual flow

The installation of a hydro scheme could hypothetically divert all of the water that currently passes over the weir into the hydro system. Protection of the river environment means that this must not happen. Thus NRW seeks to minimise the length of 'depleted reach' created by a scheme. Ensuring that a residual water flow continues to bypass the turbine is achieved by NRW imposing a minimum residual flow as a condition of the abstraction licence.

Often NRW may agree to the residual flow being set at the Q95 percentile of the river's annual flow. This is the default minimum as stated in NRW guidance. If NRW deems the depleted reach to exceed 200m, or if there are other concerns, a residual flow of Q90 or higher may instead be requested. In some cases of particular sensitivity, NRW will also ask for the river flow to be split between the hydro system and the depleted reach according to a percentage value. This will reduce output, and will need additional controls. A further consideration is that the flow which bypasses the turbine/s must also be sufficient to supply any fish passes or other required services.

This site is located in a sensitive SAC/SSSI and moreover the proposed depleted reach is potentially lengthy at 300m to 550m. Therefore for present purposes it is assumed that an unusually protective value of Q85 will be acceptable. This should serve any required fish passage measures plus the weir crest, so that no additional provision for these is needed.

The curve here indicates that the Q85 flow is 3.66 m^3/s. This would therefore be the minimum residual flow left to bypass the turbine at all times, before operation could take place – the pink line superimposed on the curve.

Design flow

NRW's guidelines state that the maximum take likely to be licensed is the annual mean flow of the river at the site. The Flow Duration Curve at this site makes this 16.2 m^3/s (Q32.5). Below this licensable maximum, there will be non-technical factors which influence the design flow, such as total budget, sizing for demand, steps in capital costs and returns, etc. However there may also be site constraints (such as culverts, leats and turbine footprint) which restrict the design flow to less than the licensable maximum.

At this site, the river's mean flow is larger than could practicably be abstracted through intakes and leats of the size likely to be considered for a community scheme of acceptable impacts. This site derives power from a fall in height which is only gained by moving a good distance along a leat network which no longer exists. Any intake and leats must now be created from scratch. The velocity of the water in the leat network must remain within certain limits in order to maintain optimal head at the turbine. The larger the flow, the larger the cross-section of channels required to convey it at the desired velocity. Escalating the size of the new channels needed here for greater flow is not only costly, but also highly likely to be at odds with NRW's aspirations for the site.

NRW has expressed an intent to place a further limitation on the amount of flow which may be abstracted at any given time – namely, no more than 40% of any flow available above the agreed residual flow. This requirement proposed by NRW has been included in the present modelling, with a significant impact on income, proportionate to the flow taken.

For these reasons, the present study has limited itself to considering flows rather lower than the mean flow, aiming instead for the usually lucrative 100kW sizing (Options 1b & 2) with an alternative to illustrate how total project cost might be reduced (Option 3). (Upsizing the single turbine in Option 2 gives diminishing returns no better than those presented.) A maximum practical design flow of no more than 5 m3/s has the benefit of placing a more modest demand on the depleted reach.

If NRW were to decree that a new fish pass must be co-located alongside the turbine, NRW guidelines require that such a fish pass will take a minimum of 10% of the hydropower design flow, in which case this amount must be allocated from the total flow which enters the intake, and the leat size increased to accommodate this.

Under NRW guidelines, none of the proposed options would place excessive demands on water resource.

Details must be worked out with NRW during licensing to inform the design. Agreeing residual flow (especially with regard to fish pass operation) will be a question for discussion with NRW during the pre-application process for an abstraction or impoundment licence. The agreed flow regime will be stipulated within the licence finally granted for the scheme.

In rare cases, it has been possible to agree a lower than usual value which will improve the annual energy capture: but again due to the sensitivity of the Teifi this is highly unlikely.

As the Archimedean screw turbine installation operates with only the coarsest of debris screening, and will create a through channel past the weir with an invert level below the weir crest, it is anticipated that the movement of bedload will be facilitated by (i.e. through) the new structures. Thus while the new system will reduce flows over the weir crest, this does not prejudice hydromorphology (gravel/sediment transport).

Further considerations

It is also advisable to obtain any available NRW data on known abstractions from and discharges to the river in case these significantly modify predictions of flow.

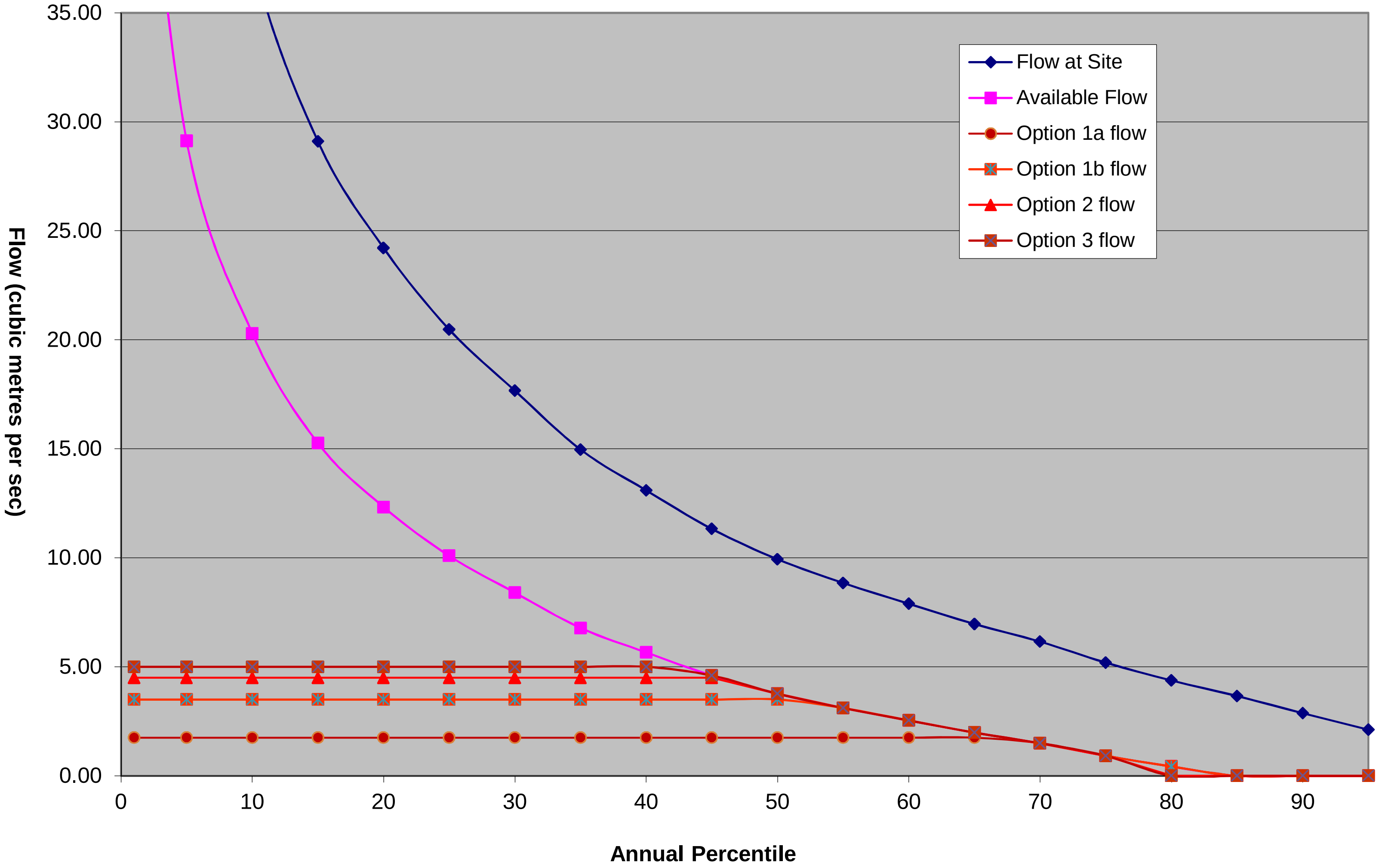
% of Year	*Llandysul from 9/2002-9/2012 gaugings at Llanfair*
0	208.882
1	85.178
5	52.200
10	37.474
15	29.098
20	24.214
25	20.473
30	17.667
35	14.965
40	13.094
45	11.327
50	9.935
55	8.847
60	7.894
65	6.963
70	6.154
75	5.191
80	4.373
85	3.659
90	2.872
95	2.117
99	1.517
100	1.237
Mean flow	16.205

Percentile flow data for the Teifi at Pontwelly, modified by area from Llanfair

Below, the red lines (for the 4 options) show how the maximum design capacity sets a limit on how much flow can be exploited for generation. For a given option, output is calculated from the area under the red line (and how head varies - see below).

Pontwelly
Llandysul 717

Flow Duration Curve



Head duration curve

The height that the water falls over the site is known as the head, and varies with the flow in the river. Site measurements on 26th-27th June 2013 indicated that a maximum gross head of 5m (with a rebuilt weir) could be achieved when the flow is at Q83 - here assumed to be around the lowest flow when generation would take place.

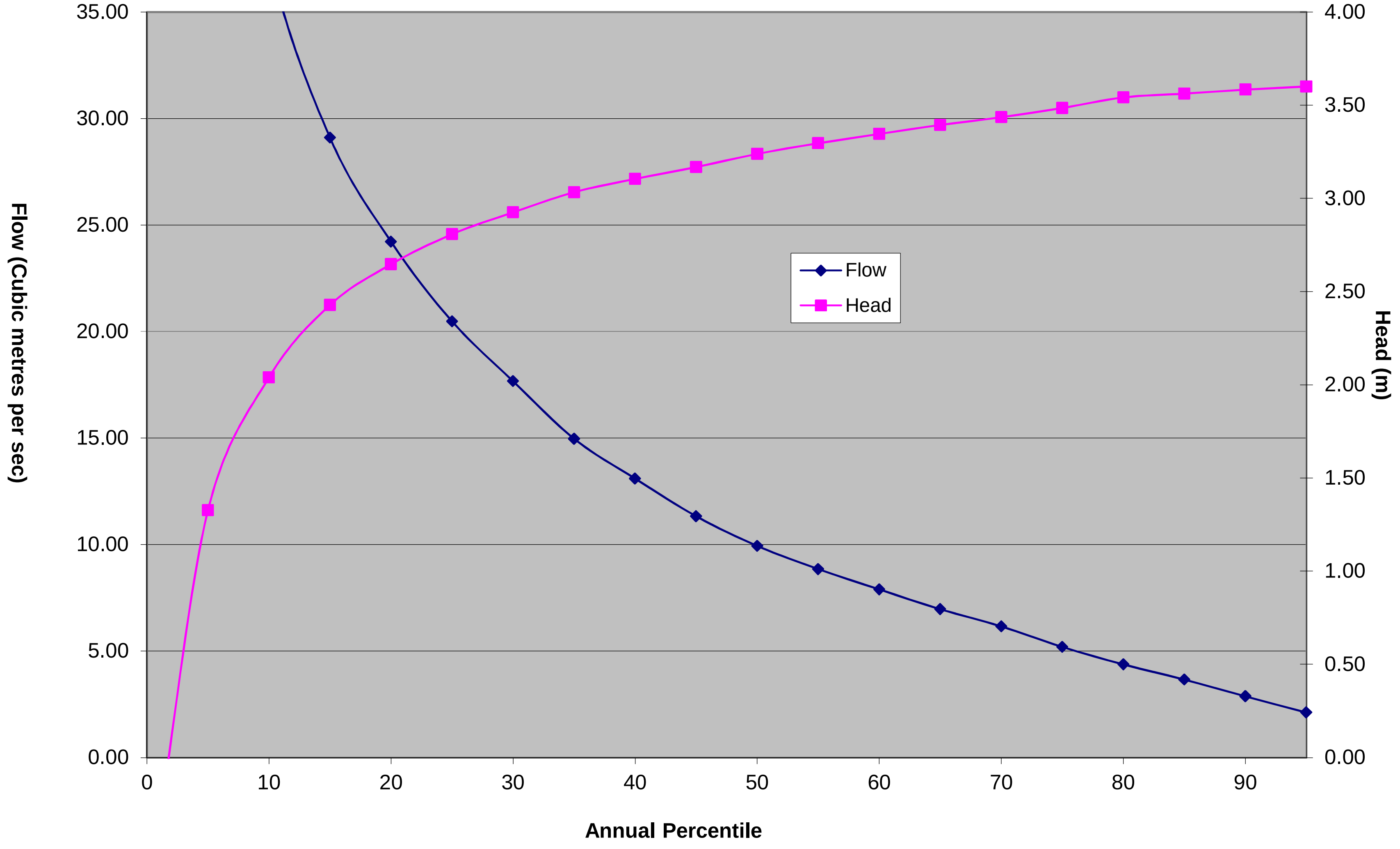
When the flow is high, the tail water rises, which reduces the effective head across the site. This reduces the output of the generator, and may indeed stop it altogether if the head is too small for the system to function effectively. The magnitude of this problem is highly site-specific, depending on the width of the weir and on the nature of the downstream channel. An estimate can be determined from the flow data and observations on site, and a curve has been produced from the available data to date. If the scheme proceeds then additional measurements must be taken to refine this, for example by deploying depth sensor dataloggers for a representative period.

However in the majority of conditions, productive head should be maintained. A well-designed Archimedean screw system of this scale can continue generating at significant power even when rising tailwater greatly reduces the head – recent experience with a 100kW system showed it was still producing 50kW when head was reduced by ~50%.

Additional head will be lost due to friction, as the water moves past the coarse screen at the intake and flows over the surface roughness and any bends or constrictions in the intake and outflow channels. The net head available for generation will be reduced accordingly. For this study, conservative estimates of head loss have been applied for the known constraints in each layout, but the final value will be dependent on the shape and dimensions of the structures constructed.

The curve below is an example which was derived for Option 2.

Head Duration Curve



Energy Capture Calculations

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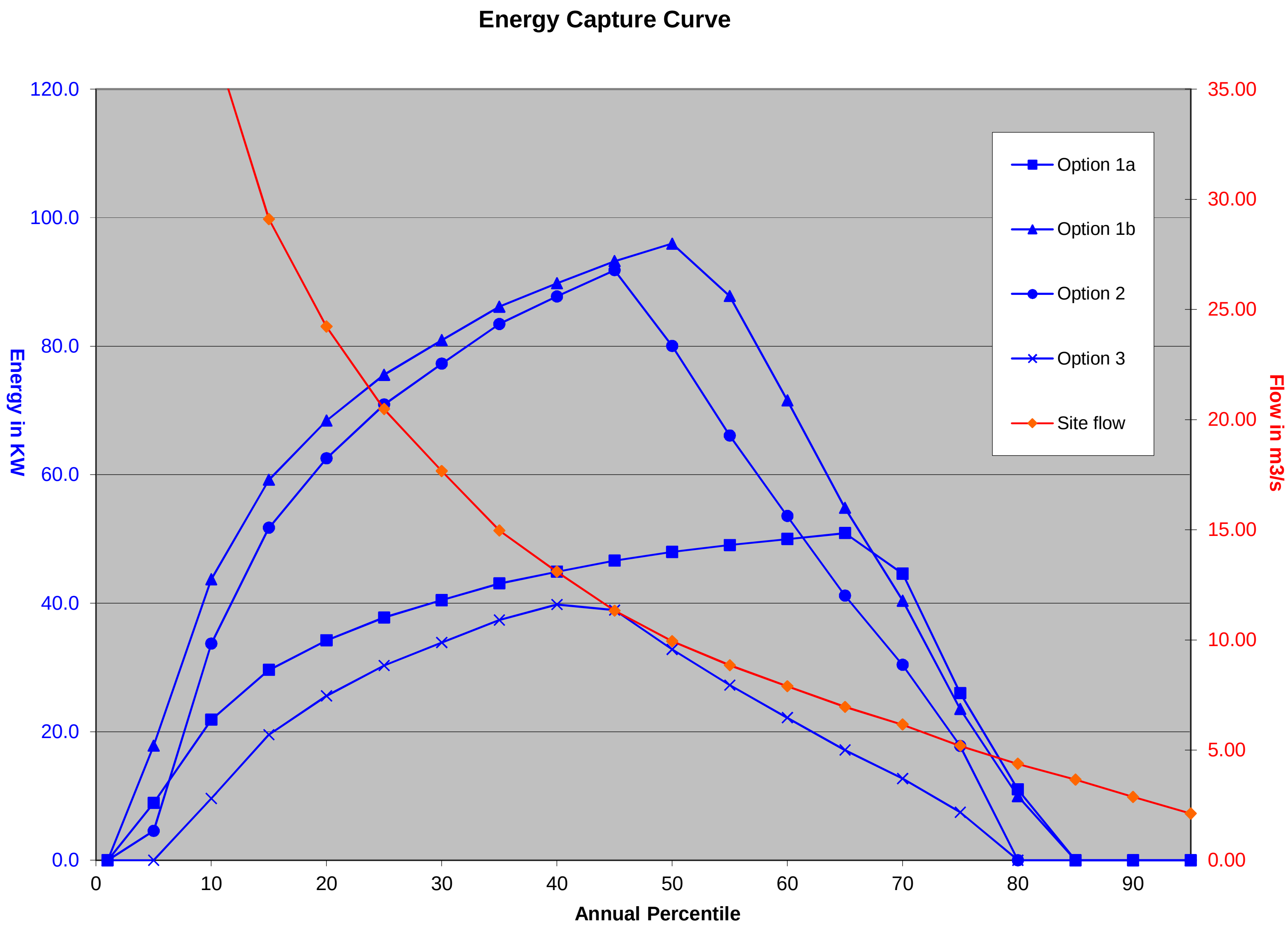
Energy Capture Curve

The combined results of the flow and head duration curves can be used to estimate a typical annual energy capture curve, which is shown opposite. The total energy produced can be calculated from the area underneath the blue curves.

Peak output is achieved when there is just enough water to run the screw at maximum capacity, but before the head is reduced due to high flows. When the flow is high (on the left of the chart), the energy output is restricted by the low head, and when the flow is low (on the right of the chart), the energy output is restricted by the lack of water to operate the screw at maximum capacity.


Energy Capture Curve
Energy in KW
Flow in m3/s
Annual Percentile
Option 1a
Option 1b
Option 2
Option 3
Site flow
0.0
20.0
40.0
60.0
80.0
100.0
120.0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
0
10
20
30
40
50
60
70
80
90

Cost/Benefit Calculation

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Cost/benefit calculation

The results of cost/benefit calculations for the proposed options, taking into account the predicted flows based on the site's hydrology, are summarised for the client in the table below.

Pontwelly
Llandysul 717

Cost / Benefit Analysis	Llandysul	Option 1a	Option 1b	Option 2	Option 3
27 July 2013		Utilise former resource (rebuild weir)	Enlarge former resource (rebuild weir)	Shortened scheme (rebuild weir)	Short scheme (without rebuilding weir)
Max Flow m³/s		1.75	3.50	4.50	5.00
Max Power kW		51	100	100	40
No. screws		1	1	1	1
Design study fee	MPCL Budget Quotation	£8,570	£8,570	£8,570	£8,570
Detailed project plan fee	MPCL Budget Quotation	£38,333	£43,661	£37,540	£15,654
Application fees, planning & consenting	Published rates	£2,600	£2,600	£2,600	£2,600
Preliminary studies, planning & consenting	Estimate based on past experience	£35,000	£35,000	£30,000	£20,000
Debris screen	MPCL Budget Quotation	£7,770	£8,880	£9,990	£11,100
Inlet sluice gate	MPCL Budget Quotation	£11,100	£17,760	£18,870	£22,200
Archimedean screw	MPCL Budget Quotation	£77,376	£104,281	£102,068	£67,180
Gearbox and coupling	MPCL Budget Quotation	£16,120	£28,732	£32,091	£21,738
Generator	MPCL Budget Quotation	£4,695	£6,640	£6,640	£4,509
Emergency brake	MPCL Budget Quotation	£4,833	£4,912	£5,412	£3,890
Control and grid connect system	MPCL Budget Quotation	£17,760	£19,758	£19,758	£17,760
Enhancement for variable-speed operation	MPCL Budget Quotation	£8,510	£10,005	£10,005	£8,510
Safety cover to screw	MPCL Budget Quotation	£8,870	£12,171	£11,702	£9,725
Other recommended ancillary features	MPCL Budget Quotation	£11,027	£11,312	£9,662	£7,525
Delivery	Budget Quotation	£3,885	£3,885	£11,100	£3,885
Craneage	Budget Quotation	£4,000	£4,000	£4,000	£4,000
Land acquisitions, wayleaves, divert services	allowance	£100,000	£100,000	£10,000	£50,000
Weir, including a fish pass	allowance	£900,000	£900,000	£900,000	£50,000
Intake and new leat	allowance	£345,000	£385,000	£403,000	£205,000
Pond works	allowance	£30,000	£30,000	£30,000	£0
Culvert works	allowance	£50,000	£200,000	£0	£0
Forebay / stilling chamber	allowance	£30,000	£40,000	£12,000	£35,000
Excavation at discharge	allowance	£25,000	£25,000	£20,000	£20,000
Screw supporting structure	allowance	£60,000	£70,000	£60,000	£50,000
Power house	allowance	£20,000	£20,000	£20,000	£10,000
Access track protection/reinstatement	allowance	£50,000	£50,000	£50,000	£50,000
Electric connection and electrician fees	Estimate based on past experience	£30,700	£30,700	£30,700	£30,700
Construction project management and CDM	Budget Quotation: 5% scheme costs	£90,832	£104,152	£88,850	£34,136
Installation supervision	MPCL Budget Quotation	£3,300	£3,300	£3,300	£3,300
Commissioning	MPCL Budget Quotation	£5,100	£5,100	£5,100	£5,100
Total Installation		**£2,000,381**	**£2,285,418**	**£1,952,958**	**£772,082**
Cost per kW		**£39,223**	**£22,854**	**£19,530**	**£19,302**
Annual Costs:					
Operational costs	Estimate based on similar projects	£500	£500	£500	£500
Insurance	Estimate from 2012 insurers' rates	£9,579	£10,978	£9,371	£3,626
Rates	Estimate based on 2010 R&E ratings	£3,302	£5,272	£4,114	£1,752
Meter reading & FITs admin	Estimate based on similar projects	£2,481	£2,481	£2,481	£2,481
Equipment maintenance	Estimate based on similar projects	£1,548	£2,086	£2,041	£1,344
Total Annual Costs		**£17,410**	**£21,317**	**£18,508**	**£9,703**
Annual Income:					
Energy capture kWh	Calculation from measured data	251923	428723	366002	152151
Carbon dioxide saved (tonnes)	Based on 0.43 tonnes per MWh	108	184	157	65
Capacity factor		56%	49%	42%	43%
Electric sales to the grid	Current rates	£11,396	£20,236	£17,100	£6,408
Savings by using own electricity	Current rates	£2,400	£2,400	£2,400	£2,400
Feed-in-tariff (FIT) Sales	Current rates	£50,914	£86,645	£73,969	£30,750
Total revenue		£64,710	£109,281	£93,469	£39,557
Total Annual Income		**£47,300**	**£87,964**	**£74,961**	**£29,854**
Simple payback period (years)		**42.3**	**26.0**	**26.1**	**25.9**
Return on Investment		**2.4%**	**3.8%**	**3.8%**	**3.9%**

Pontwelly
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Alternative Machinery Options

and

Fish screening considerations

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Overview of alternative hydropower machinery options

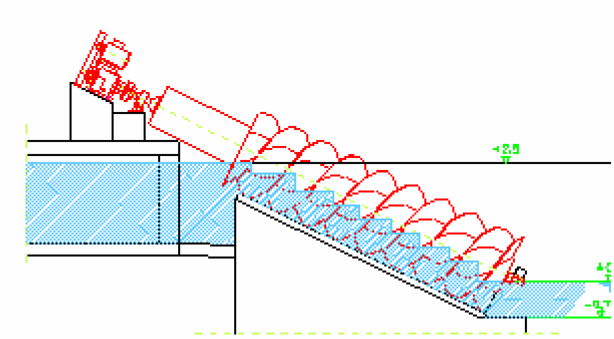
There are a number of quite different types of machinery that can be used to generate hydroelectricity, each having advantages and disadvantages for a particular location. All systems have some kind of gearing mechanism that drives a generator, but where they differ is in the method used to convert the power of falling water to mechanical rotation.

All turbine types will require a failsafe means of stopping the equipment. For low-head equipment this typically consists of a valve or inlet sluice gate that can fall by gravity to stop the flow of water.

All types will require a trash screen, with a bar spacing sufficient to keep out any size of debris that could be potentially damaging to the turbine type in question. Fish exclusion screening is also type-specific and is discussed separately.

Archimedean screw

This consists of an Archimedean screw operating in reverse, so that the falling water turns the screw, which in turn drives a generator.



<u>Advantages</u>

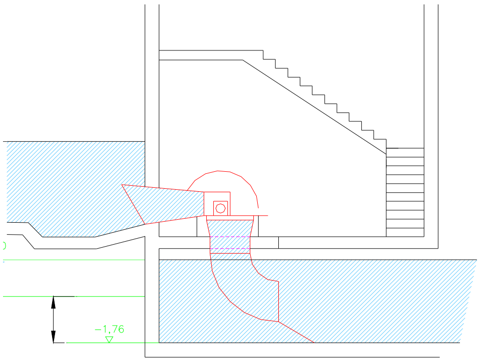
- The screw turns quite slowly (<60 rpm), preventing injury to fish from contact with moving blades.
- Large chambers of water are maintained at all times, allowing fish and debris to pass slowly down through the machine.
- The swim bladders of fish are not affected, as the water pressure remains constant.
- No fine screening is therefore required, reducing installation and maintenance cost.
- Leaves and debris can simply pass through the screw, reducing need to clear the trash screen.
- No head loss is caused by fine screening or pressure pipes, so the highest net head is available for generation.
- No draft tube is required, reducing the civil costs of deeper excavation.
- High efficiency is maintained over a wide variation of flows, in particular for low flows.
- On environmental and fish-protection grounds, the Archimedean Screw has been singled out as a preferred technology in Environment Agency (EA) recommendations. Hence some of our projects have appeared as case studies in EA and DECC literature.
- For educational and promotional purposes, the turbine is exposed to view and is seen operating

<u>Disadvantages</u>

- Kaplan systems operating in optimum conditions have slightly higher turbine efficiency.
- Low turbine speed requires the use of a speed increaser to drive the generator
- The ecological benefits of an open turbine mean a larger size and more evident presence.

Propeller or Kaplan turbine

This consists of a rotating blade, rather like those used for aeroplane propellers, located within a sealed tube. It is a reaction turbine, relying on pressure differences to turn the blades. This machine operates most efficiently at a fixed design flow, so for sites with variable flows, a Kaplan system is used. The angle of the blades changes in response to the flow conditions.

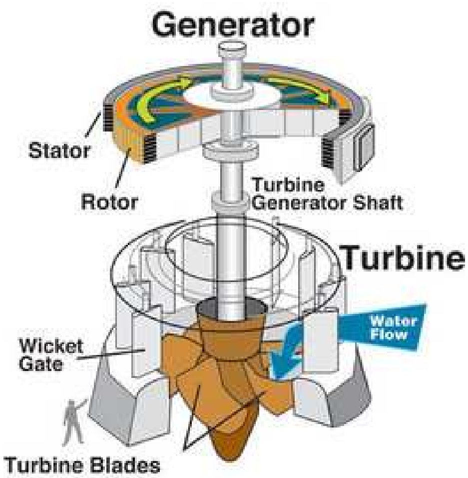


Advantages

- At design flow no other system is as efficient when comparing peak turbine efficiency.
- Higher turbine speed reduces losses introduced by speed increasers.

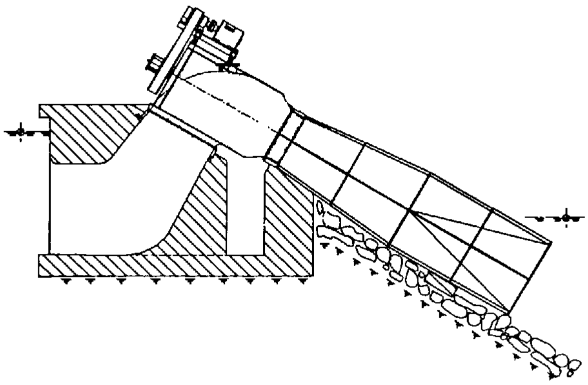
Disadvantages

- Fine fish screening is required, which will increase the maintenance overhead.
- Head loss is introduced by the fine screens and in pressure pipes, reducing the overall net head available for generation.
- Efficiency at low flow rates is poor for a propeller system, when compared with an Archimedean screw.
- Complex control system requires either manual adjustment with varying flow or expensive automation.
- High capital cost.



Siphon Propeller

This system has the same rotating propeller blade as the Kaplan, but the water intake is arranged so that it can only flow by siphonic action. This simplifies the control mechanism and reduces the civil works required to install a system over an existing weir.



Advantages

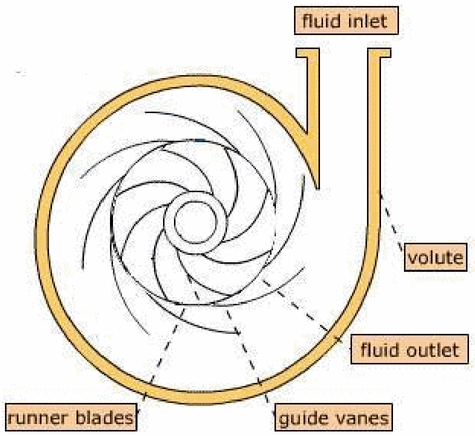
- An inlet gate is not required due to the siphon system.
- Civil works are reduced, although some excavation for the draft tube is still required.
- The turbine and generator are well located for servicing and flood protection.

Disadvantages

- Fine fish screening is required, which will increase the maintenance overhead and reduce the effective head.
- Only works efficiently at fixed flows, which can have a large impact on the overall annual energy capture.
- Flood protection can be difficult if located over an existing weir.

Francis

This consists of a system of guide vanes and blades arranged in a spiral casing. It is a reaction turbine, relying on pressure differences to turn the blades.



Advantages

- High efficiency at design flow.
- Possibility of sourcing a second hand system.

Disadvantages

- Fine fish screening is required, which will increase the maintenance overhead and reduce the effective head.
- Efficiency reduces sharply at low flows, which will decrease the potential power output during the summer months.

Crossflow

A crossflow turbine is an impulse turbine, relying on the kinetic energy of the water striking the blades to spin the turbine.

Advantages

- Small machinery size
- Improved part-load efficiency can be achieved, by varying the width of the turbine blade over which the water is directed.
- Debris is naturally thrown off the blades

Disadvantages

- Turbine is sensitive to debris; hence a fine screen will be required to protect it, which will increase the maintenance overhead and impact on the effective head available. NB: The Archimedean screw and waterwheel do not suffer from this problem to the same extent.

Waterwheel

A traditional waterwheel could be connected to a gearbox to drive a generator.

Advantages

- A slow turning waterwheel has a high visual appeal and would restore an historic feature.
- Large chambers of water are maintained at all times, allowing fish and debris to pass down through the wheel at low speeds.
- The swim bladders of fish are not affected, as the water pressure remains constant.
- No fine screening is required, reducing installation and maintenance costs.
- Part-load efficiency is good, enabling it to operate for most of the year.

Disadvantages

- Efficiency will be lower than most turbines.
- The maximum output will be limited by the amount of water that can be passed through the wheel.
- The often-large wheel sizes can be expensive and increase the maintenance overheads.
- NRW has observed that the assumed fish-friendliness of waterwheels, particularly modern designs, has not been demonstrated in formal tests.

Fish screening considerations

If a type of turbine other than an Archimedean screw or a waterwheel were to be chosen, the intake would have to be screened to exclude aquatic vertebrates.

There are many variations on methods of excluding fish and all have advantages and disadvantages. These are described in some detail in the EA's '*Best Practice Guide for Intake and Outfall Fish Screening'* (Turnpenny and O'Keeffe, 2005). Broadly speaking, screens fall into two types: physical fine mesh, and behavioural (acoustic, electrical).

Physical screens need to have a mesh size small enough to prevent the fish passing through, and the actual design will need to be determined after discussion with NRW. A typical requirement for a river with lamprey would be 2.5mm. The finer screens are expensive, can require a fully-automatic cleaning system, and would reduce the effective head available for hydro generation.

Any physical screen must be designed so that fish are not held against it by the flow of water through it. Since fish may be impinged on the fine screen at water velocities above 0.5m/s, keeping the velocity below this requires the underwater area of the fine screen in m^2 to be approximately twice the flow rate in m^3/s.

Screen with 12mm spacing, showing restriction to flow caused by debris

In practice this means that a large screen area is required, which will need to be kept clear of debris for the flow to be unimpeded. Cleaning can either be done manually or by installing an automatic screen-cleaning system, but either way this will affect the total costs of the scheme. Therefore, to provide adequate protection, it is recommended to angle such screens to divert any excluded species and debris over the weir.

Behavioural acoustic screens work by injecting a 'curtain' of bubbles into the water, which deters the fish from passing through it; noise can also be injected into the bubbles. This system has the advantage of not requiring cleaning and maintains the full head of water. Due to the nature of their design, they are not guaranteed to be 100 % effective, as well as being ineffective at excluding eels and lampreys. Therefore suitability depends on local fish populations and NRW's view as to whether it is acceptable to permit some injury or mortality. Moreover, acoustic screens require some power to operate and can be costly to install.

However, in an Archimedean screw installation, it is not necessary to exclude fish from the intake. Therefore intake screening requirements are typically limited to providing only a coarse screen to safeguard against larger debris and to exclude mammals.

It is also possible that a screen is required on the outflow to prevent fish from swimming into the tailrace. Again various types are available, but the best solution is usually an electric pulse screen, as this does not impede the flow of water. This momentarily stuns the fish, allowing the water to wash them back away from the intake, and is not considered to cause any lasting harm.

However, tests on Archimedean screw systems have shown that fish are not harmed by approaching the outflow from the screw; so, provided that they can find alternative routes upstream, no screening should be required. In our experience, schemes are not required to apply this.

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Work continuation form

Would you like us to proceed to the next stage of work? [Please refer to services sheet enclosed]

Yes ☐ No ☐

If 'Yes', which option from the Feasibility Study do you want to develop?

Option 1a ☐ Option 1b ☐ Option 2 ☐ Option 3 ☐

Comments:

I hereby authorise Mann Power Consulting Ltd to proceed to the next stage of development for the site named above.

Signed ______________________________ Date ____________________

Printed ______________________________ Position ____________________

Please return to MPCL in the envelope provided

MannPower Consulting Limited

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Llandysul 717

Customer feedback form

1. Did the report you have just received provide you with all the information you expected?

   Yes ☐ No ☐

2. If you answered ‘No’, please let us know what other information you expected to receive:

3. How would you rate the service you received from Mann Power Consulting Ltd?

   Excellent ☐ Good ☐ Satisfactory ☐ Poor ☐ Very poor ☐

   Comments:

4. If you are not continuing the work right away, is this because:

   You have decided not to proceed with the development at all ☐
   You have decided not to install an Archimedean Screw ☐
   You are awaiting further information from statutory bodies ☐
   You are awaiting confirmation of funding ☐
   Other: [please give details]

5. Would you like us to contact you in the future regarding this development?

Yes ☐ No ☐

If 'Yes', when?

PLEASE RETURN YOUR COMPLETED FORM TO MPCL IN THE ENVELOPE PROVIDED.

THANK YOU!

For office use only

FS ☐ DS ☐ DPP ☐ GC ☐