Hydropower on Hebden Water, Dog Bottom

Pre-feasibility study

April 2011

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Supported in partnership by:

Hydropower on Hebden Water, Dog Bottom

Pre-Feasibility Study

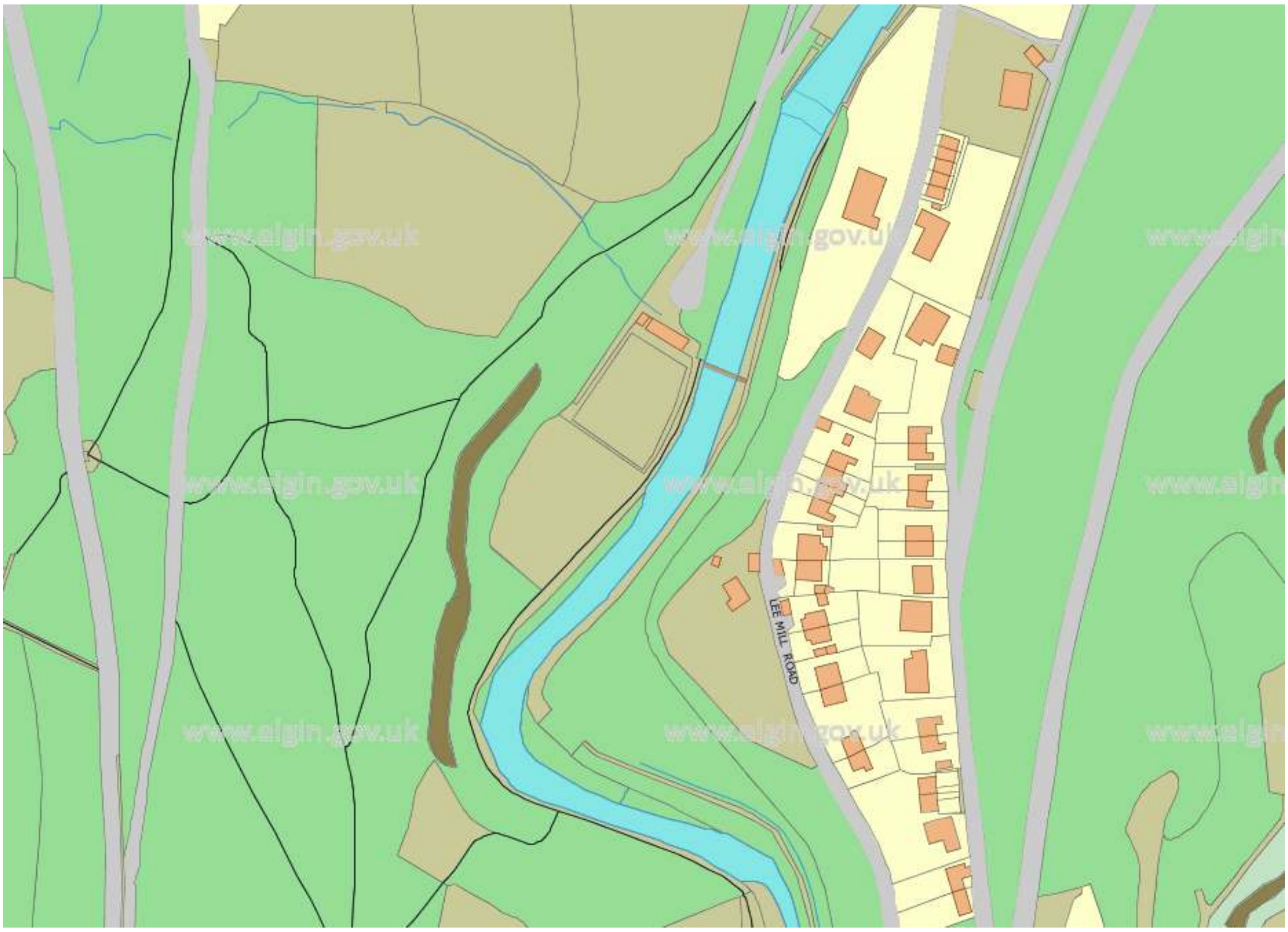
Introduction and site observations

The potential hydropower site is partly based on an old mill site's infrastructure on Hebden Water at Dog Bottom, Hebden Bridge; the weir on Hebden Water (just below the old Lee Mill site - marked at the top of the maps below) and the original sluice gates and goit are still present, though in poor condition. The goit and mill ponds are mostly filled in with silt and there are a number of mature trees (some with preservation orders) growing around the site that could affect the layout of a scheme.

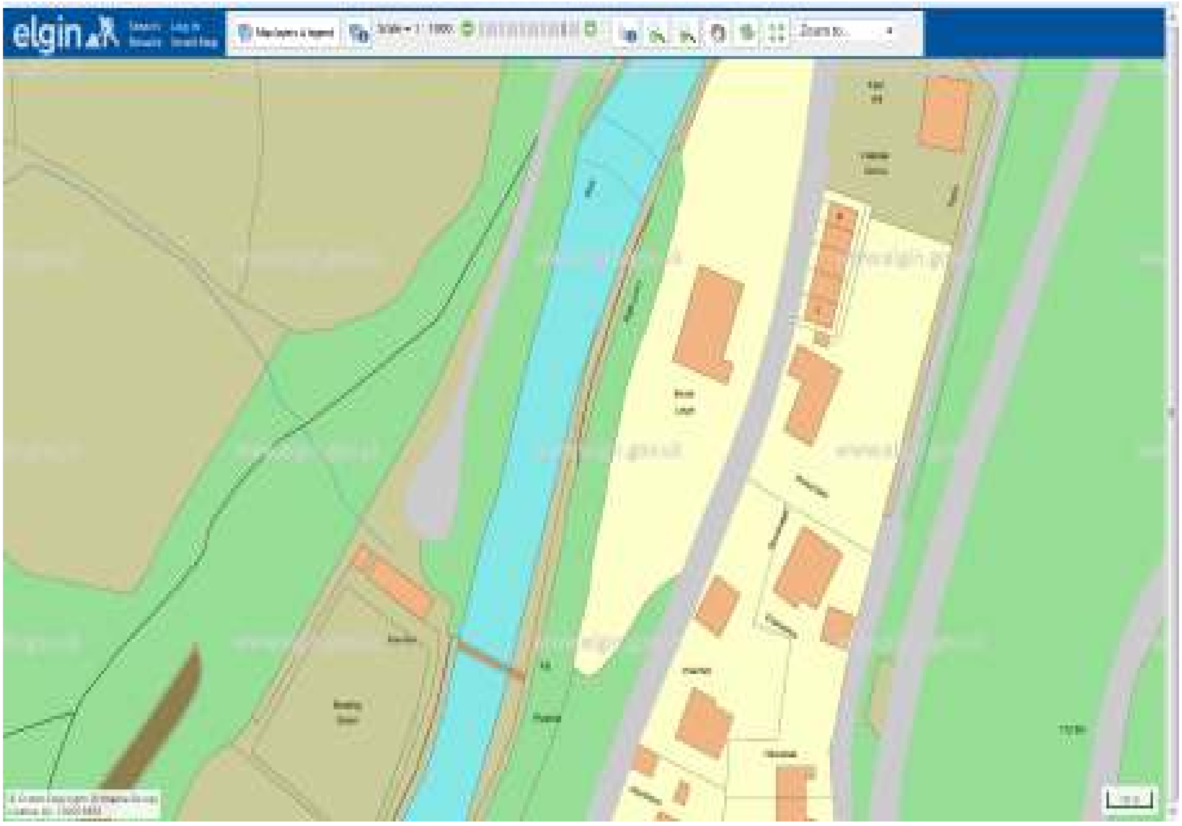
This study recommends that the goit could be dredged and backfilled to allow for a pipe to be put in place leading to a small turbine house at the edge of the first mill pond (near the existing mill pond overflow to minimise alterations to the original infrastructure. The potential turbine site is approximately 260 metres downstream at the overflow of the old mill pond. The goit continues from this site an additional 270 metres to the site where Foster Mill was; however using the full length of the system to maximise head would mean a significant depleted stretch of water on a very visible and visited section of river. Using the full length of the infrastructure would be technically possible but it is felt that the Environment Agency would limit the amount of water to be used further – so the maximum potential output would be no greater (and costs higher) than placing the turbine at the edge of the mill pond.

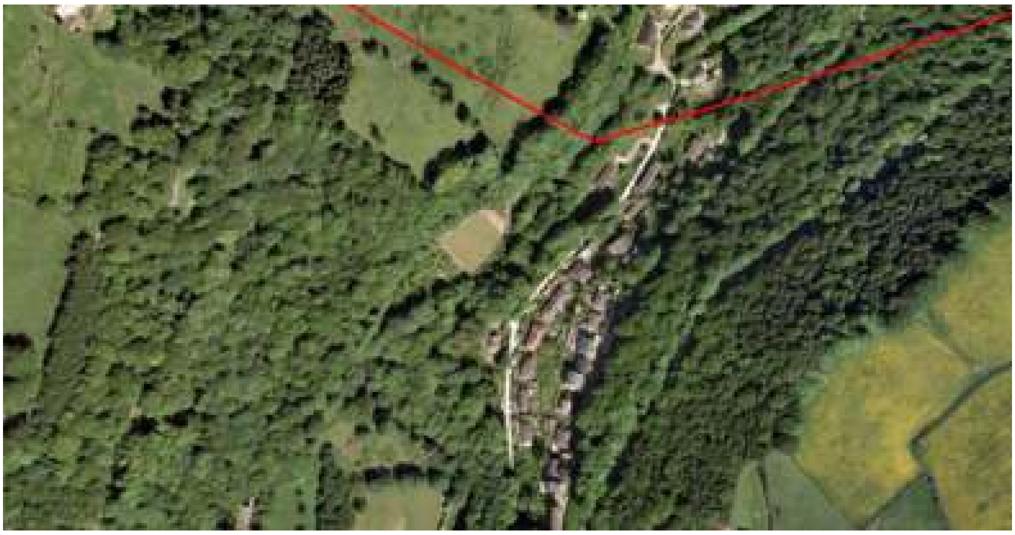
Hebden Water is a typical Pennine watercourse - although the flow regime is a mixture of compensation flow and natural flow – a detailed description of the flow (both modelled via Low Flows and from EA data) is included in this pre-feasibility study.

It is expected that a fisheries, ecology and/or environmental impact study (as well as detailed scheme design etc) will be necessary to gain approval for the scheme from the EA (The good practice guidelines annex to the environment agency hydropower handbook explains what the requirements are). However a pre-application can be made to the EA to find out what the requirements will be.



Indicates potential route of pipe





Head & flow

Two quantities make up the available power potential at a hydropower site: a Volume Flow Rate of water ***Q***, and a Pressure Head ***H*** (Head is the available vertical fall in the water, from the upstream level to the downstream level).

Head

Measured at 6.76 metres gross – for the purposes of this study I shall use a net head of 5.5 metres (to account for losses due to pipe friction and siting of the equipment – it might not be possible to achieve the maximum measured head as the turbine house can't be placed at that point).

Flow

Low-Flow Estimates from WHS-LowFlows
www.hydrosolutions.co.uk

Catchment Characteristics
Region England: North-East
Area Dales & Ridings (27)
Boundary source Imported polygon
Catchment Area (km^2) 32.14
Grid-resolution used for derivation of catchment characteristics (m) 50
Runoff (mm) 925.3
BFI 0.298

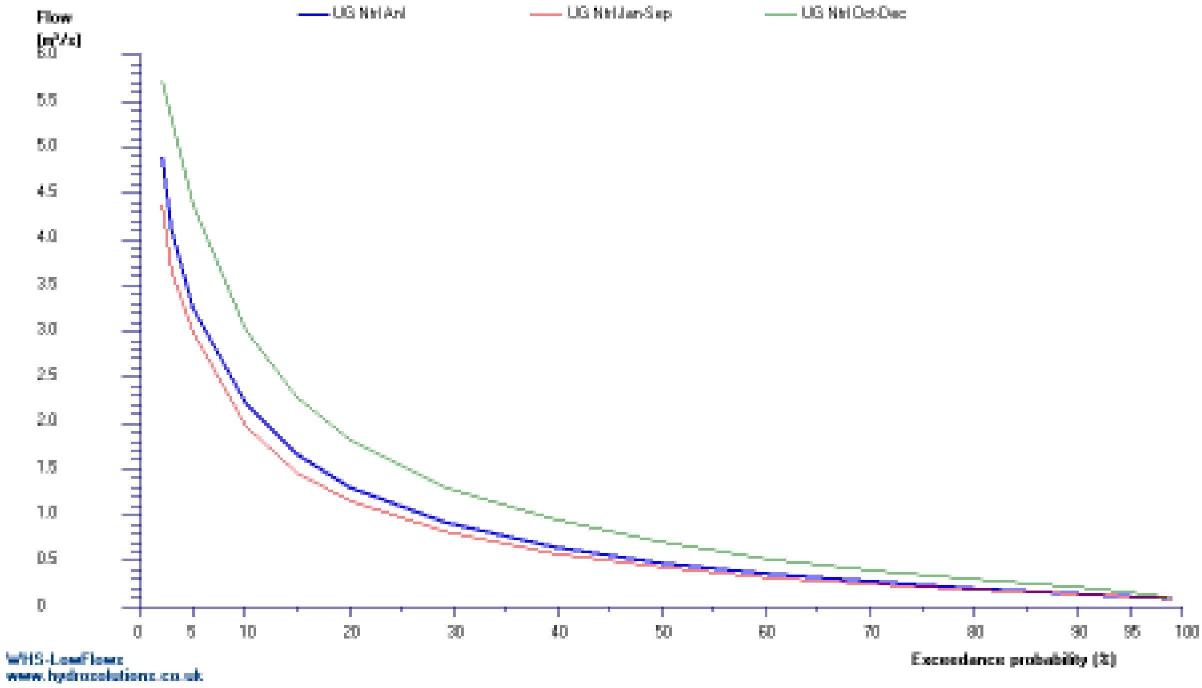
Period	Ntrl Qmean (m^3/s)	Ntrl Q95 (m^3/s)
Annl	0.943	0.121
Jan	1.448	0.238
Feb	1.158	0.201
Mar	1.177	0.200
Apr	0.871	0.152
May	0.592	0.126
Jun	0.437	0.101
Jul	0.487	0.0928
Aug	0.686	0.0974
Sep	0.766	0.0992
Oct	0.985	0.116
Nov	1.279	0.183
Dec	1.432	0.239

Low-Flow Estimates from WHS-LowFlows
www.hydrosolutions.co.uk

Lee Mill to goit on Hebden Water F/D (UG)
Ntrl FD series at annual resolution (ungauged)
Basin-name: Lee Mill to goit on Hebden Water
Outlet at: SD993288

(Based on catchment characteristics derived at grid-resolution of 50 m)
Annual mean flow 0.94 m³/s
Q95 0.12 m³/s

	P (%)	Q (m³/s)
1	5.000	3.303
2	10.00	2.249
3	20.00	1.319
4	30.00	0.915
5	40.00	0.659
6	50.00	0.486
7	60.00	0.366
8	70.00	0.280
9	80.00	0.203
10	90.00	0.145
11	95.00	0.121
12	99.00	0.0890



Compensation flow and total flow information from the EA:

January to September
Gorple into Graining Water - 2,700 m3/d
Widdop into Graining Water - 3,240 m3/d
Walshaw Dean Lower into Alcomden Water - 3,780 m3/d (a total of 9,720 m3/d = 112.5l/s)

October to December
Gorple into Graining Water - 10,800 m3/d
Widdop into Graining Water - 12,960 m3/d
Walshaw Dean Lower into Alcomden Water - 15,120 m3/d (a total of 38,880 m3/d = 450l/s)

Total flow
Qmean - Average Flow - 1229 l/s
Q95 flow exceeded 95% of the time - 288 l/s
Q50 Median flow- flow exceeded 50% of the time - 789 l/s
Q10 flow exceeded 10% of the time - 2498 l/s

EA guidelines on flow allowed for hydro schemes:

7.4. Mean Flow (Q_{mean})
As its name implies, the mean flow at a particular point in a river is the average of all flow measurements taken over a long period of time. Over a single year, the mean flow is the total volume of water delivered to the river from the catchment area in that year, divided by the number of seconds in a year. Relative to the Flow Duration Curve, Q_{mean} is typically in the range Q_{30} for very flashy upland rivers to Q_{40} on lowland and high baseflow rivers, meaning that flows are greater than this for 30% and 40% of the time respectively.

7.5. Depleted reach
The depleted reach is between the point where water is abstracted from the river and the point where it is returned (Figure 1 and section 3 and 4). The length of the depleted reach may range from the upstream water level to the downstream water level over the face of the weir (where the generating equipment is incorporated into or adjacent to, the weir) to many hundreds of metres, where water is conducted along a pipeline or open channel (a 'leat' or 'mill race') to the generating plant and until the water rejoins the main channel. A very long depleted reach may sometimes gain flow from tributaries. Longer depleted reaches on flashy rivers (**$Q_{95}:Q_{mean} \leq 0.1$**) may require a Hands-Off Flow in excess of Q95.

7.6. Hands-Off Flow or Level
For both environmental and aesthetic reasons, a certain minimum flow needs to be reserved to continue over the weir and down the depleted reach. The Agency will normally set a **Hands-Off Flow (HOF) or Level** as a condition on hydropower schemes, such that when the flow or level falls below the set value, abstraction must stop. To ensure that the HOF is complied with, hydropower abstraction will be unable to start operating until the flow is above the HOF by a quantity that is at least equal to the 'turbine start up flow' (see section 6.9). In some cases generation may start or stop at flows considerably higher than the HOF (especially flashy rivers where **$Q_{95}:Q_{mean} \leq 0.1$** and the maximum design flow is more than 10 times the HOF). The residual flow in the river may therefore be greater than the HOF, and after generation has stopped may also naturally fall below the HOF. The amount of residual flow, and factors such as flow variability, may become more important as the length of the depleted reach increases, and it will often result in issues with fish migration.

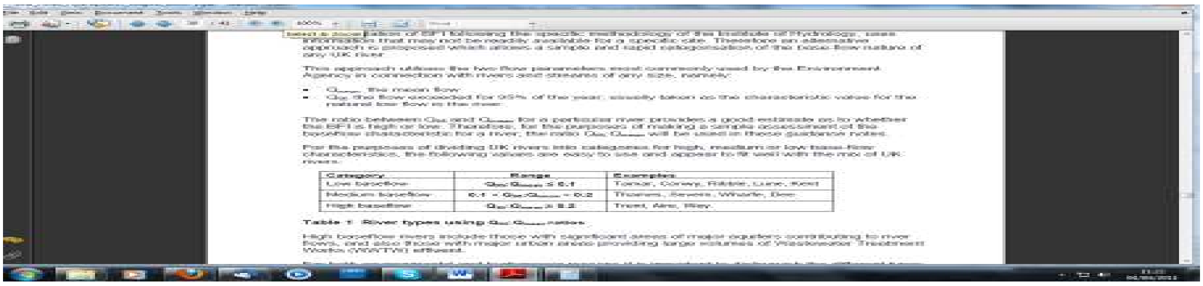
7.7. Base Flow Index and the Ratio of Q_{95} to Q_{mean}
Base Flow Index (BFI) is a term developed by the Institute of Hydrology to describe how river flow regimes vary with geology. It is intended to provide a measure of how much the river flow is affected by stored sources, such as permeable rock, which enables the 'base flow' in the river to be sustained in dry conditions (high BFI value), unlike rivers derived from clay or hard rock catchment areas, which would have a low BFI value. For practical purposes, the BFI is a parameter which describes how widely the flow on a particular river varies on a daily basis and between wet and dry seasons. A 'flashy' river with high winter peaks but low summer flows would have a low BFI because the typical low flow is a small proportion of the mean flow.
The calculation of BFI following the specific methodology of the Institute of Hydrology, uses information that may not be readily available for a specific site. Therefore an alternative approach is proposed which allows a simple and rapid categorisation of the base-flow nature of any UK river.

This approach utilises the two flow parameters most commonly used by the Environment Agency in connection with rivers and streams of any size, namely:
• Q_{mean} the mean flow

• Q_{95} the flow exceeded for 95% of the year; usually taken as the characteristic value for the natural low flow in the river.

The ratio between Q_{95} and Q_{mean} for a particular river provides a good estimate as to whether the BFI is high or low. Therefore, for the purposes of making a simple assessment of the baseflow characteristic for a river, the ratio $Q_{95}:Q_{mean}$ will be used in these guidance notes.

For the purposes of dividing UK rivers into categories for high, medium or low base-flow characteristics, the following values are easy to use and appear to fit well with the mix of UK rivers:



Category	Range	Examples
Low baseflow	$Q_{95}:Q_{mean} \leq 0.1$	Tamar, Conwy, Ribble, Lune, Kent
Medium baseflow	$0.1 < Q_{95}:Q_{mean} < 0.2$	Thames, Severn, Wharfe, Dee
High baseflow	$Q_{95}:Q_{mean} \geq 0.2$	Trent, Aire, [illegible]

Table 1 River types using $Q_{95}:Q_{mean}$ ratios

High baseflow rivers include those with significant areas of major aquifers contributing to river flows, and also those with major urban areas providing large volumes of Wastewater Treatment Works (WWTW) effluent. For both environmental and hydropower reasons it is important to distinguish the different types of rivers as indicated by the $Q_{95}:Q_{mean}$ ratio. Acceptable hydro schemes where the hydro unit is 'on weir' may be very different hydrologically for a high baseflow river compared to a low baseflow (flashy) river.

Note: Where rivers are significantly impacted by abstraction (see CAMS results) it may be necessary to compare the gauged Q95 (Qg95) with the natural Q95 (Qn95). Qn values will be used in setting HOFs.

7.8. Maximum Design Flow (Q_o)

Typically a hydropower developer will choose a design flow for the scheme which allows it to use a good proportion of the higher flows, but also to continue to operate down to reasonably low flows so that output can be sustained for as much of the year as possible. Common practice has been to use Q_{mean} flow as the design flow. From an environmental perspective, a high design flow reduces the flow variability in the deprived reach, particularly on flashy rivers. A maximum design flow greater than Q_{mean} is unlikely to be acceptable and may need to be less on very flashy rivers.

7.9. Turbine start-up flow

Two factors must be considered in the start/stop of a hydropower generating unit.
(a) a water turbine only achieves a worthwhile efficiency when it can pass a good proportion of its design flow, typically between 15% and 30% depending on machine type. The turbine will also shut down when the available flow falls below this minimum operating value or start up flow.
(b) the turbine control system needs to add an additional margin to be sure that the turbine will not shutdown as soon as it starts up, and then 'hunt' around the start-up condition, switching on and off.

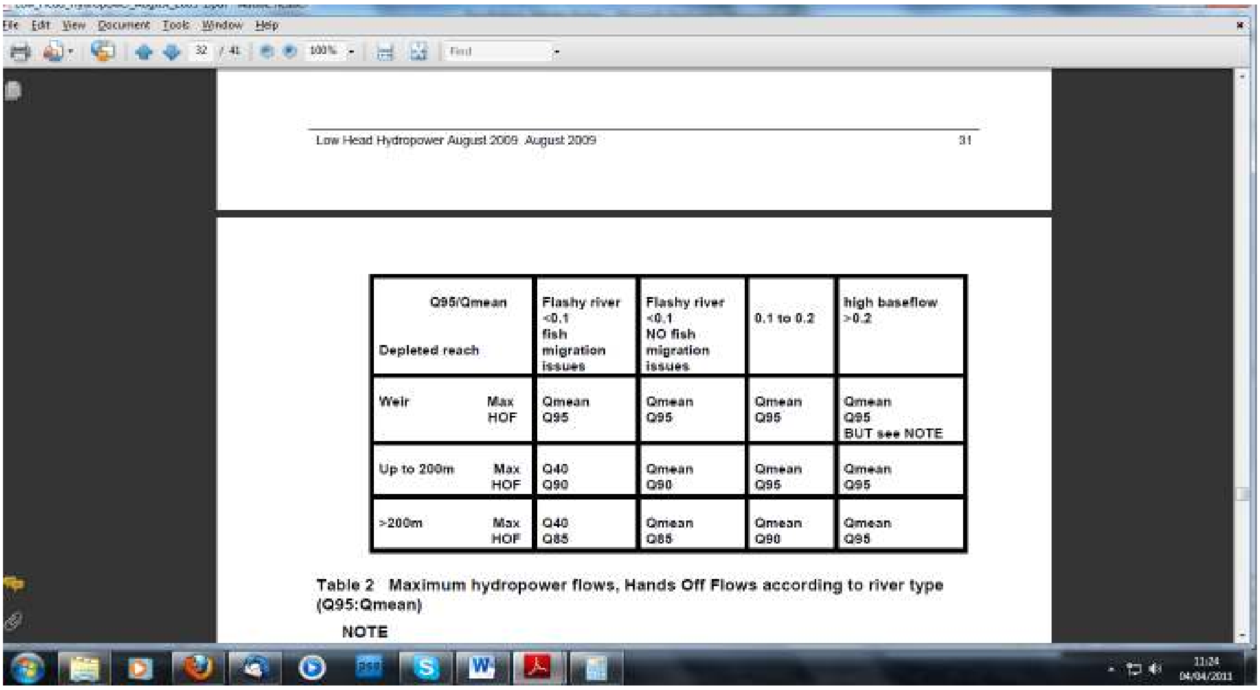
To observe the HOF, the hydropower turbine will be unable to start generating until the flow exceeds the HOF by the start up flow and will need to stop generating when the flow in the river falls to the HOF + start-up flow. For compliance purposes, generation cannot take place when flows are below the HOF or Hands-Off Level at the point specified in the permit.

7.10. Flow "Pulsing"

With a well designed low-head scheme, flow pulsing (caused by drawing the water level below the crest level of the weir, and then stopping generation to allow the water level to pond up behind the weir) should never occur. The design and control system must ensure this cannot happen. The requirement to maintain a specified flow over the weir while generating, and a HOF at which generation must cease will prevent pulsing.

7.11. Matrix of Design Flow and Hands Off Flow

Table 2 presents a table of default minimum flows relating to river types using the Q95:Qmean ratios (Table1). The maximum flow that may be considered for hydropower is Qmean



Low Head Hydropower August 2009 August 2009 31

Q95/Qmean Depleted reach		Flashy river <0.1 fish migration issues	Flashy river <0.1 NO fish migration issues	0.1 to 0.2	high baseflow >0.2
Weir	Max HOF	Qmean Q95	Qmean Q95	Qmean Q95	Qmean Q95 BUT see NOTE
Up to 200m	Max HOF	Q40 Q90	Qmean Q90	Qmean Q95	Qmean Q95
>200m	Max HOF	Q40 Q85	Qmean Q85	Qmean Q90	Qmean Q95

Table 2 Maximum hydropower flows, Hands Off Flows according to river type (Q95:Qmean)

NOTE

NOTE

On large high baseflow rivers where the turbine is 'on weir', and a fish pass is installed OR there are NO fish migration issue, it is possible to consider a residual flow over the weir that is set for amenity criteria (see sections 4 & 5). The values in this table are intended for low head schemes. Further work is required on high head schemes especially where there are long depleted reaches.

Proposed flow for the scheme

According to the above guidelines and EA flow data, Hebden Water is classified as a high baseflow river (**Q95:Qmean: 288:1229 = 0.23)** and therefore the flow allowed for a hydro scheme could be the flow between Q95 and Qmean = 941 l/s.

Using the natural flow data for this site (not including the compensation flow) the baseflow index is 1.2 – i.e. a medium baseflow site. This would mean a flow between Qmean and Q90 is available for a hydro power scheme – around 800 litres per second NOT including the compensation flow.

This study proposes using a lower flow than above as the depleted stretch of river is used/seen by locals and visitors and supports a wide variety of flora and fauna. A detailed fisheries and/or environmental impact assessment is expected to be required which, if rare native species, migratory salmonid fish are shown to exist here, would mean a lower flow could be recommended.

A flow of no more than 500 litres per second for a hydro scheme is recommended by this study.

Output & revenue

Power Calculations

$P = Q \times H \times e \times \gamma$ - Where:
P is the power in watts
Q is the flow in litres per second
H is the head in Metres
e is the factor used to account for (in)efficiency, that is 0.7
γ is the specific weight of water (9.81kN/m3).

500 x 5.5 x 0.7 x 9.81 = 18,884 Watts or 18.9kWp

Performance and capacity factor information.

A turbine designed for 5.5 metres of head and 500 litres/sec design flow would generate a peak electrical output of 18.8kW. However, as the Feed in Tariff for schemes of less than 15kWp is higher, it is possible to reduce the flow still further to have the scheme generate a peak output of 14.9kW. This would mean a flow of 395l/s would be used – allowing for the scheme to operate at maximum output for 6 months a year (and still maintain a good generation efficiency down to 20% of design flow – 80 litres a second.

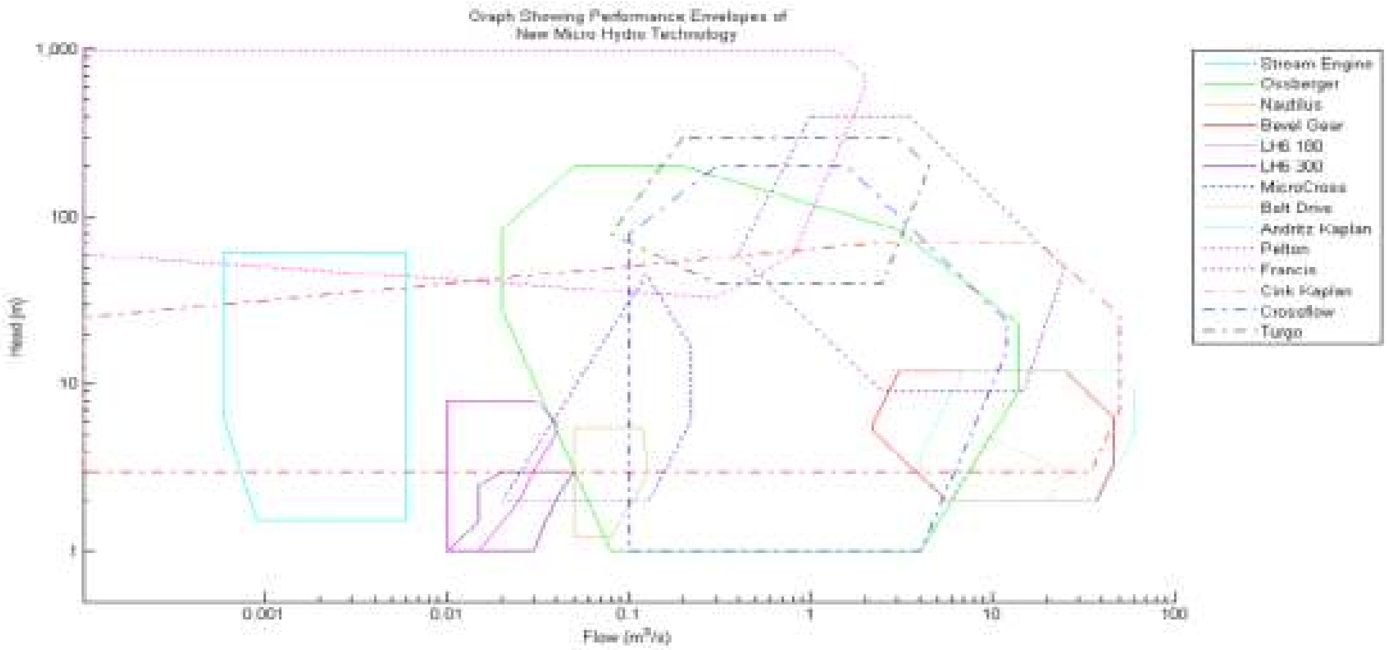
The electricity generated in one year from a 14.9kWp system could be 81,000 kWh/year (at 60% annual capacity factor – much higher than the generally accepted figure of 35-40% for micro hydro schemes as the flow used is lower).

The FiT rate for hydropower generation (systems less than 15kWp) is £0.209 per kWh (fixed for 20 years) giving an annual income of £16,929 per year. The additional export tariff of £0.03 (assuming all electricity is exported) could provide an additional £2,430. This export tariff could be increased to as much as £0.09 if a private Power Purchase Agreement is entered into with a large consumer (such as the Co-op group) – however this is not always possible.

Scheme options

Head and flow – turbine choice

The head and flow available at the site will suit a range of turbines as can be seen from the graph below (N.B. Ossberger and MicroCross turbines are brand names for crossflow turbines). The main turbine types as per the graph below are Crossflow/Ossberger (the same thing) and Kaplan (double regulated to achieve maximum efficiency).



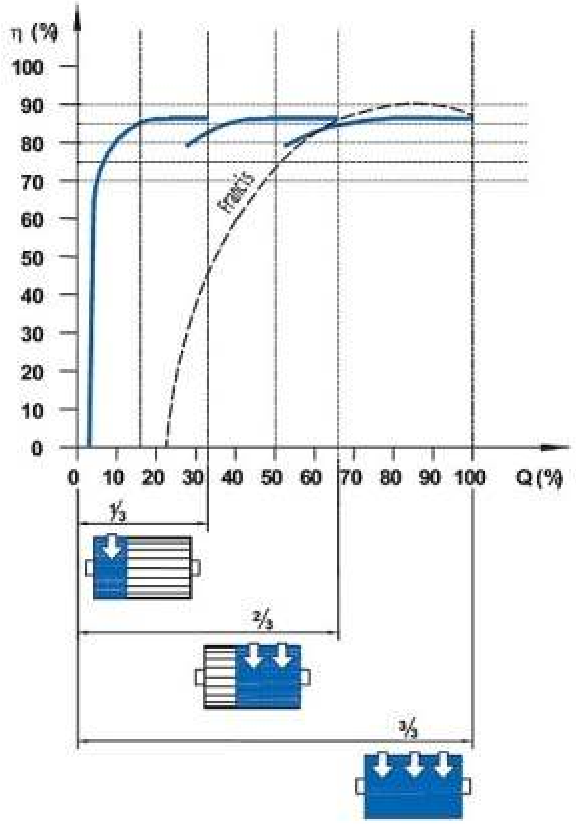
The only type of turbine likely to be cost-effective for this head and flow is a crossflow turbine. The peak efficiency of a crossflow turbine is slightly less than a double regulated Kaplan turbine; however, the crossflow turbine has a flat efficiency curve under varying load. This is a variable-flow machine which, in a multi-cell version, can still operate at 10% of design flow. It will run sufficiently fast to allow a low-cost belt-drive to connect to the generator.

A crossflow turbine is self-cleaning with regard to ‘soft’ debris such as leaves, but requires a reasonably fine screen to keep out twigs and stones of a size which might jam between the runner blades. Crossflow turbines are available from Ecowave and Valley Hydro in the UK and Cink in the Czech Republic. Machines some consider more robust and efficient are available from Ossberger and WKV in Germany, at significantly greater expense.

Particularly with small run-of-the-river plants, the flat efficiency curve yields better annual performance than other turbine systems, as small rivers' water is usually lower in some months. The efficiency of a turbine determines whether electricity is produced during the periods when rivers have low flows. If the turbines used have high peak efficiencies, but behave poorly at partial load, less annual performance is obtained than with turbines that have a flat efficiency curve.

Due to its excellent behaviour with partial loads, the crossflow turbine is well-suited to unattended electricity production. Its simple construction makes it easier to maintain than other turbine types; only two bearings must be maintained, and there are only three rotating elements. The mechanical system is simple, so repairs can be performed by local mechanics.

Another advantage is that as mentioned it can often clean itself. As the water leaves the runner, leaves, grass etc. will not remain in the runner preventing losses. Therefore, although the turbine's efficiency is somewhat lower, it is more reliable than other types. No runner cleaning is normally necessary, e.g. by flow inversion or variations of the speed. Other turbine types are clogged more easily, and consequently face power losses despite higher nominal efficiencies.



There will need to be a screening system installed at weir where the flow can be screened for debris and (depending on EA requirements) for fish and/or other fauna. Screening systems can either be automated (with a belt style over the goit intake screen that rotates removing debris) or be a fixed screen (or bar type) that would require manual cleaning (which, during autumn can be several times a day). I would recommend a self-cleaning screen to ensure that the turbine can continue to operate unimpeded at all times.

The screened flow would then enter a 300-450mm diameter pipe that could be buried in the old open goit channel. The pipe would follow the contour line (dropping slightly) until it reaches the old mill pond overflow where a curve could direct the water down slope to the turbine house (sited below the old mill pond wall but above the high flow point in the river). The longer section of pipe can be standard twinwall drainage pipe (sufficient for heads of 5 metres) the final section could require a higher rating of pipe to be used (e.g. PVC or HDPE pipe).

A turbine house would need to be constructed over the turbine to protect it from the elements and animals (and people!). Planning permission would be required as per Calderdale Council's usual planning regulations.

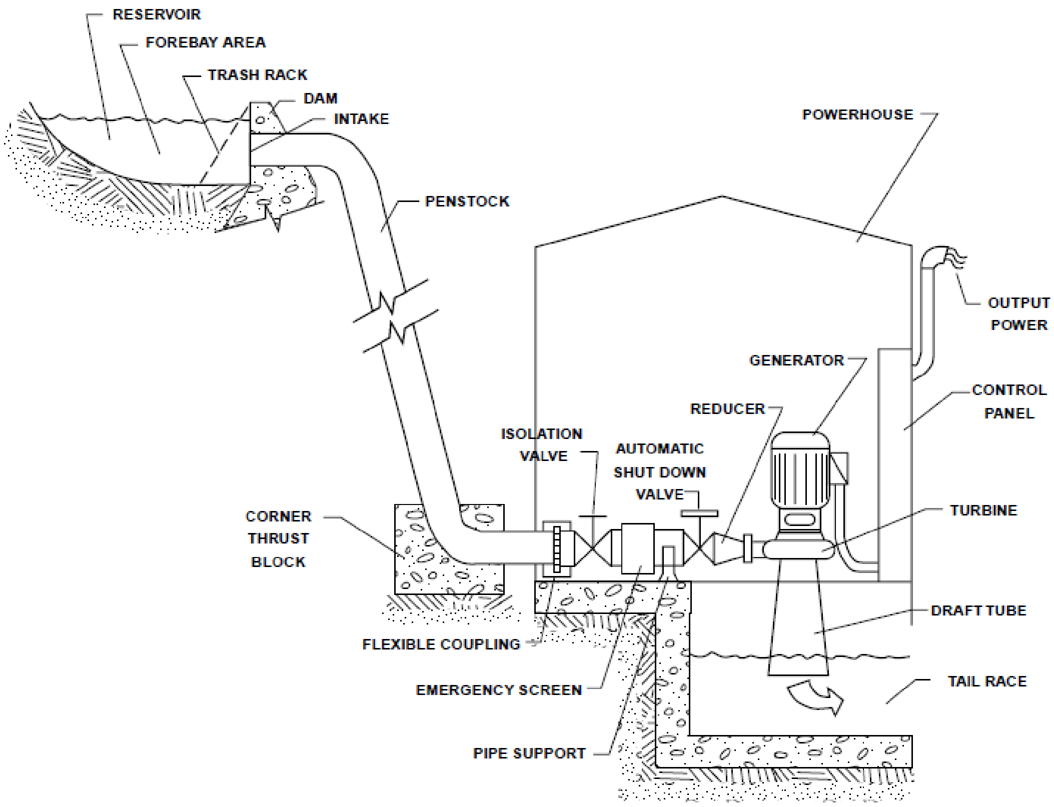
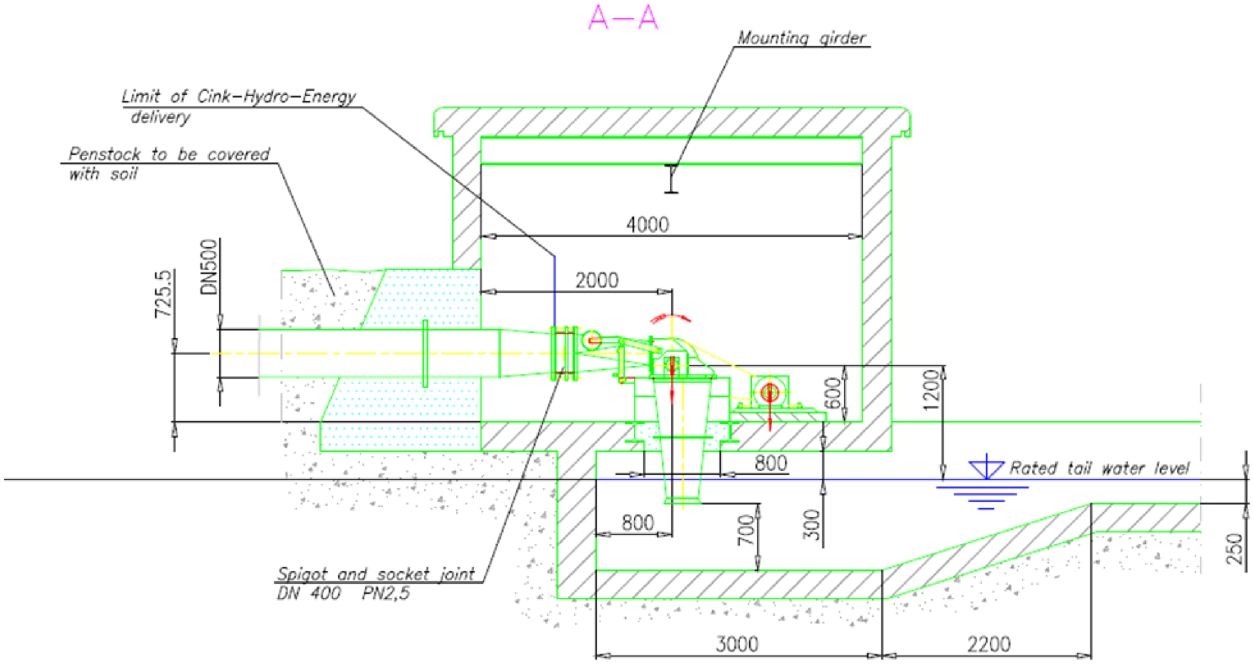


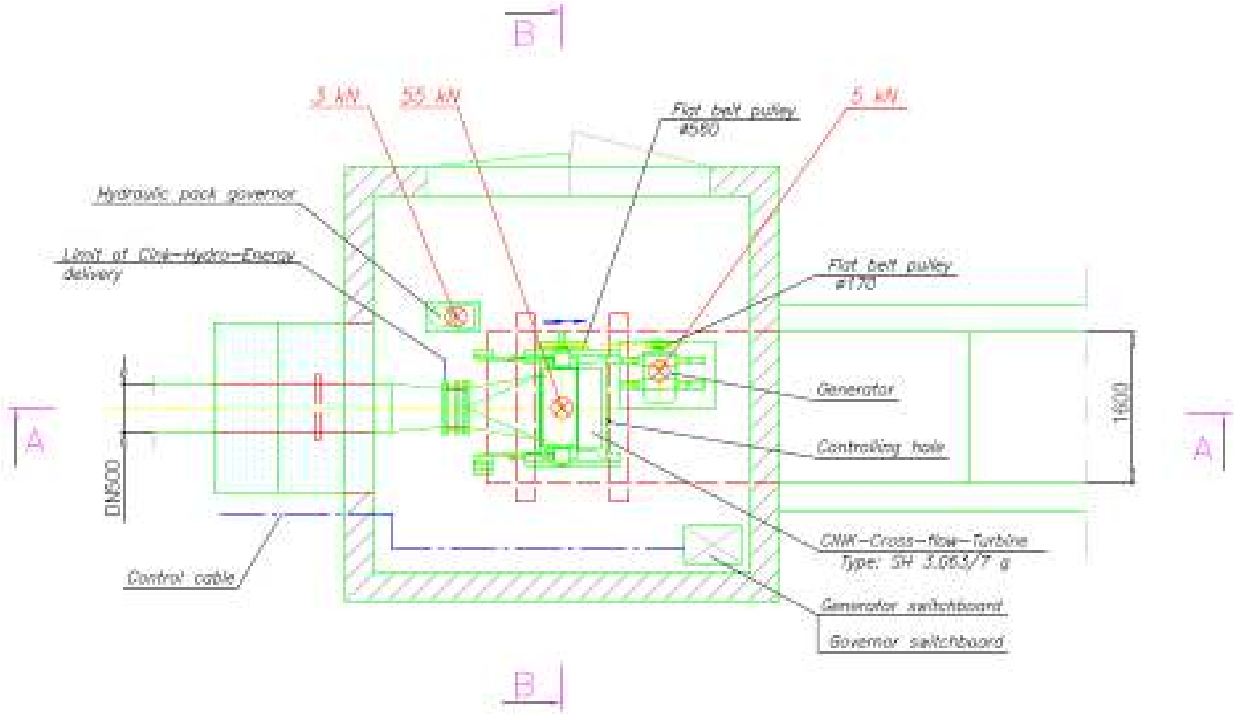
Image from: www.varspeedhydro.com – N.B. shows Francis style turbine

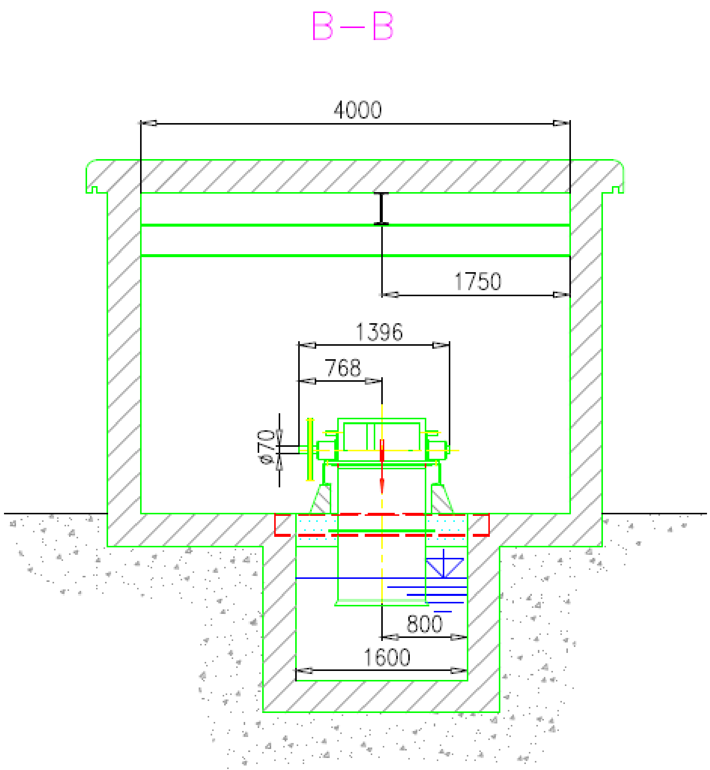
To achieve the maximum head at the site a draft tube could be required – which, if used, adds an additional complexity to the design and planning aspect. The image above shows a complete micro hydro system that employs a draft tube – this would mean excavating a section of bank/river bottom to allow for a tail race in which the draft tube is placed so that the bottom of the draft tube is permanently underwater.

This would have to be discussed with Calderdale planning and the Environment Agency to establish if there would any objections to this approach.

The following images (from Cink - http://www.cink-hydro-energy.com/en) are detailed drawings showing the layout of a crossflow turbine using a draft tube.


A–A
Mounting girder
Limit of Cink–Hydro–Energy delivery
Penstock to be covered with soil
4000
2000
DN500
725,5
600
1200
800
Rated tail water level
800
700
300
250
Spigot and socket joint
DN 400 PN2,5
3000
2200


B
5 kN
55 kN
Flat belt pulley
5 kN
Hydraulic pack governor
Limit of Cink–Hydro–Energy delivery
Flat belt pulley
Generator
Controlling hole
1600
A
A
DN500
Control cable
CINK–Cross–flow–Turbine
Generator switchboard
Governor switchboard
B



Control System
The control system will enable fully automatic operation of the turbine. It continuously monitors the headwater level, and will open or close the turbine valve in small adjustments, according to whether the upstream level is rising or falling. When there is insufficient water to generate power, the turbine will shut down completely, and will automatically restart when the river is replenished.

Grid connection
15kW (or less); check with DNO that up to 15kW can be absorbed on single phase network

DIY options and FiT
The feed in tariff, introduced in April 2010, are only available to hydro schemes that use both accredited installers and equipment – see table below for the latest hydro tariffs:

Yearly Tariff Period	Installations registered in FIT Year 1 (01 April 2010 - 31 March 2011)		Installations registered in FIT Year 2 (01 April 2011 - 31 March 2012)
Description	Tariff received until 31 March 2011	Tariff received between 01 April 2011 and 31 March 2012*	Tariff received until 31 March 2012*
Hydro generating station with total installed capacity of 15kW or less	19.9 pence per kilowatt hour	20.9 pence per kilowatt hour	20.9 pence per kilowatt hour
Hydro generating station with total installed capacity greater than 15kW but not exceeding 100kW	17.8 pence per kilowatt hour	18.7 pence per kilowatt hour	18.7 pence per kilowatt hour
Hydro generating station with total installed capacity greater than 100kW but not exceeding 2MW	11 pence per kilowatt hour	11.5 pence per kilowatt hour	11.5 pence per kilowatt hour
Hydro generating station with total installed capacity greater than 2MW	4.5 pence per kilowatt hour	4.7 pence per kilowatt hour	4.7 pence per kilowatt hour

Accredited installers and products are listed at the website below:

Installers: http://www.microgenerationcertification.org/mcs-consumer/installer-search.php
Products: http://www.microgenerationcertification.org/mcs-consumer/product-search.php

All products referred to in this document are MCS accredited.

This situation means that a completely DIY approach would not necessarily allow the system to access the feed in tariff – unless retrospective accreditation is pursued, which is possible – but not guaranteed and could also cost as much as using accredited installers and products in the first place.

If a totally DIY approach is taken – using equipment that is not accredited – then the price paid per kWh is likely to be around £0.03 (current market rates – some renewable energy suppliers may pay more, perhaps up to £0.05 per kWh).

Costs

The initial broad-brush estimates for the electro-mechanical equipment and installation costs would be as follows:

Ecowave
Turbine £12,750
Generator, Control panel, cabling £8,000
Intake screen £2,000
Fixtures & fittings £2,500
Detailed design & project management £3,500
Workshop assembly, installation and commissioning £7,500
Transport, contingency & sundries £3,000
Total excl. VAT £38,500

Optional Additions
WKV or Ossberger turbine +£10,000
Self-cleaning screen +£3000

Cink
The net price of the required hydroelectric unit would be approximately € 45.000,- FCA Sadov (Incoterms 2010) including:
One crossflow turbine (Pt = 16 kW approx.) with accessories, speed transmission, an asynchronous generator a switchboard and a control system operating parallel to the grid. In the attachement you will find a drawing of a similar project so that you know how each component of the power plant is placed.

In addition, work would be required for:
Running the power cable to the network connection.
Gaining planning and licensing permissions, as appropriate.

Civil work costs
Digging
Pipe
Repairing weir intake
Turbine house

License applications and project management

I would anticipate total project costs to be as per the Calderdale Performance reward application:

Permissions applications and detailed design (EA, planning etc.). £5,000
Turbine, generator, control panel and all associated eqpt.: £50,000
Turbine house: £5,000
Pipe: £5,000
Screening eqpt: £5,000
Civil works: £10,000
Project management: £10,000
Grid connection: £10,000
Total = £100,000

Next steps

A formal license from the Environment Agency will be required, as will planning permission. The main environmental criteria to be satisfied would involve fish-protection, flood defence and the amount of water to be taken in dry conditions.

The logical next steps to develop the scheme would be:

- Identify and agree use of the weir with weir owner
- Complete the pre-license application forms for the Environment Agency to assess the scheme.
- Discuss pipe and turbine house design and location with Calderdale planning dept.
- Find a local grid connection point and apply to District Network Operator to ascertain whether the local network can absorb up to 15kW on a single phase network connection.
- Obtain quotes and appoint MCS accredited hydro engineer/company to design the scheme and manage the project, or appoint various individual contractors (civil works, commissioning, installing, electrical etc.).
- Commission the scheme design and other supporting documents and studies to present to the EA and local planners and in order to define the civil works requirements.
- Obtain firm quotes for the cost of the electro-mechanical equipment and civil works.
- Prepare a formal application for the EA and planners.