3 Belle Vue Close, Stroud, Glos. GL5 1ND
+44 7792 319313 corin.hughes@cantab.net www.corinhughes.co.uk

Llangollen Low Carbon Trust River Dee Hydropower

Preliminary Site Assessment

Document Control

Version Control

Version	Date	Comments
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Distribution List

Name	Position	Company
Corin Hughes	Hydropower Consultant	Corin Hughes
Michael Hughes	Hydropower Design Engineer	Michael Hughes
Alec Gannon	Hydropower Contractor	Alec Gannon
Silas Jones	Energy Officer	Cadwyn Clwyd

Related Documents

Document	Version
Llangollen tender.pdf	0

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The performance of hydropower systems is impossible to predict with certainty due to the variability in the amount of rainfall from location-to-location and from year-to-year.

Any estimate of performance contained in this report is based upon the best available information but is given as guidance only and should not be considered as a guarantee.

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Executive Summary

Overview

Site surveys were carried out on 25 and 26 January 2010. At each site, the resource was assessed, along with the existing civil and electrical infrastructure. Measurements were taken of the water level at various points. All levels were referenced to a temporary bench mark at each site. Sketches were made where necessary. Photographs were taken of the main channel, impoundments and nearby electrical infrastructure. Figure 2 shows the locations of all the sites considered in this report and gives a quick summary of each. Sites with annotations in red boxes are not recommended to proceed. Sites with annotations in green boxes are all worth further study. Table 1 summarises key data for the recommended sites.

Llangollen Hydro Preliminary Site Assessment – Summary of Key Data	Horseshoe Falls, Dee Valley Water side	Corn Mill	Horseshoe Falls, British Waterways side	Mile End Mill	Unit
Rated power	99	5	12	29	kW
Capital expenditure	728,298	124,382	148,647	312,297	£
Annual operating expenditure	20,510	700	1,300	2,900	£/year
Generated electricity after all losses	433,573	23,564	52,646	125,851	kWh/year
Value of generated electricity	100,849	7,154	13,351	29,273	£/year
Internal rate of return	**11.3**	**2.4**	**7.2**	**7.7**	**%**
Simple payback time	9	19	12	12	years
Homes provided for	233	13	28	68	
Avoided CO2 emissions	99	5	12	29	tCO2/year

Table 1 – Summary of key data.

Next Steps

The next step is to decide which sites to progress to the feasibility study stage. Note that the feasibility study in this case includes part 1 of the Environment Agency process (preliminary enquiry and site visit) along with network analysis and detailed design. All feasibility work will be programmed to complete by December 2010, subject to Environment Agency timescales. Figure 1 shows a Gantt chart which gives estimated timescales for the different project stages. Overall timescales would be similar for each of the recommended projects, but the time required for individual project stages and work items will be more site-specific.

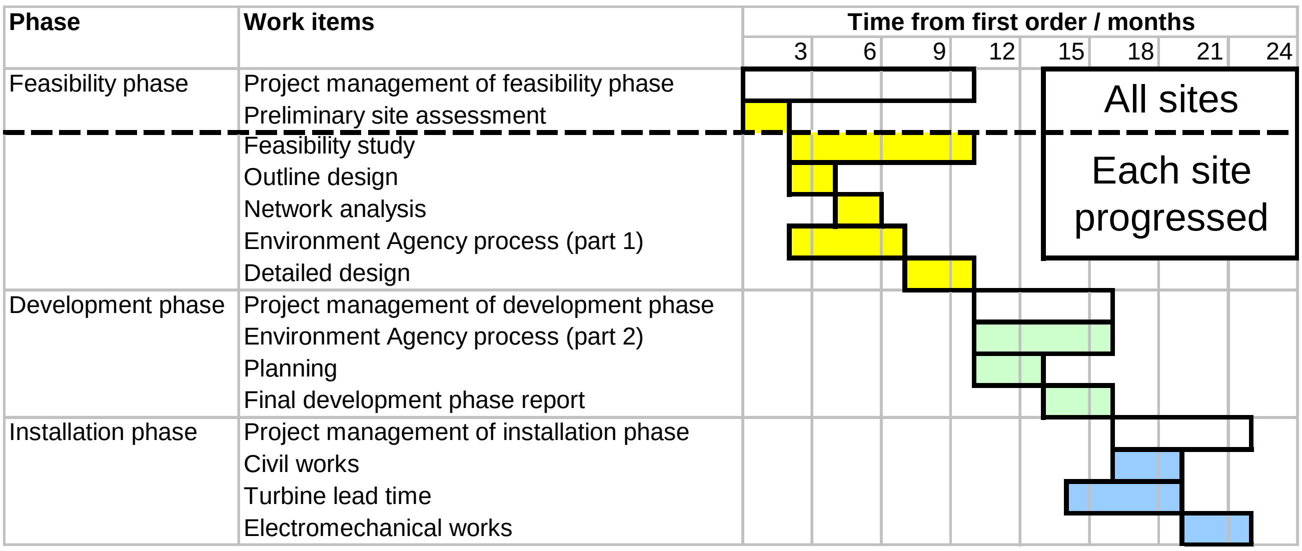

Figure 1 – Gantt chart showing project stages and estimated timescales.

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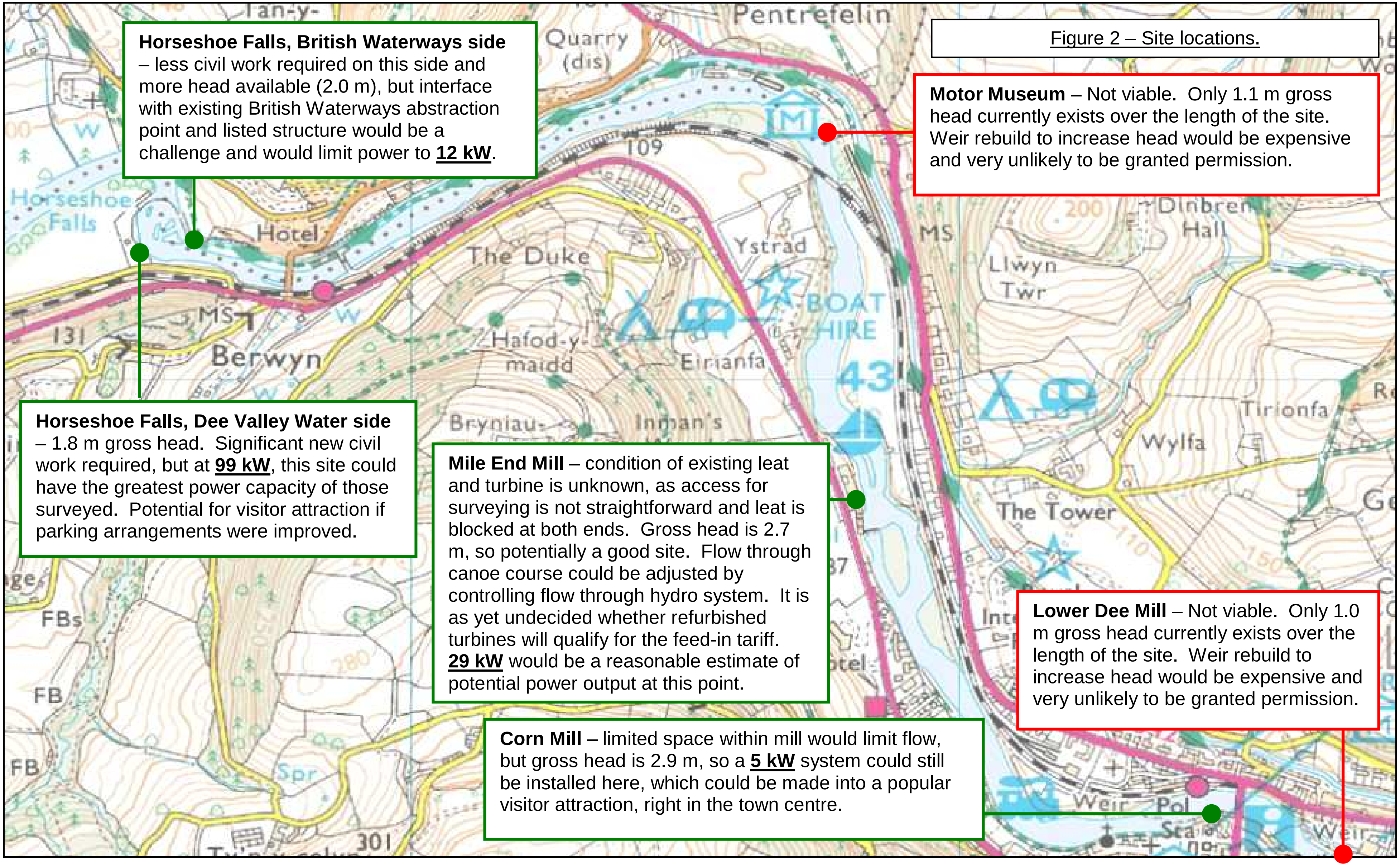

Figure 2 – Site locations.

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+44 7792 319313 corin.hughes@cantab.net www.corinhughes.co.uk

1. General

1.1. Hydropower system function

The power generated by a hydro system depends on the available head and flow.

Head is first seen as a difference in upstream and downstream water levels, but for practical power generation, the change in head must be made to occur over the small distance occupied by the turbine runner. Most of the civil design of a hydro system is concerned with this task – bringing the water to opposite ends of the turbine runner such that nearly all of the head change occurs across the runner.

The change in head across a turbine runner is manifest either as a change in pressure (e.g. in a Kaplan or Francis turbine), a change in velocity (e.g. in a crossflow, Turgo or Pelton turbine) or a change in gravitational potential (e.g. in a waterwheel or Archimedes screw). This change in head gives rise to the runner's angular velocity and the flow through the runner gives rise to its torque. The product of angular velocity and torque is power. Power is thus transferred from the water to the turbine and then through a drive which transmits the power to the shaft of the generator and hence to the connected electrical load.

A control system is used to monitor both the electrical conditions and the available flow and regulates the system accordingly.

Modern micro-hydropower systems use a water level sensor in the intake area to regulate how much water passes through the turbine. The water level sensor measures the upstream water level and adjusts the turbine operating regime to make sure that any reserve flow requirements are maintained through the depleted reach. The whole control process is automatic.

At or above the maximum rated flow of the system, the turbine would operate at maximum power output. Any surplus flow would continue over the weir and follow the natural watercourse. Below maximum rated flow, the signal from the water level sensor would be used to adjust the flow through the turbine to maximise energy production from the available flow in the watercourse. If a reduction in upstream water level was detected, the flow through the turbine would be reduced. If the water level then stayed static, the turbine would continue operating with the same flow. If the water level continued to fall, the flow would be further reduced. If it rose the flow would be increased.

Flow is controlled in different ways depending on the system. It could be done by the opening and closing of a sluice gate, valve or wicket gate, or by direct control of the turbine runner speed.

This process occurs constantly, so the system is effectively infinitely variable and constantly aiming to maintain the upstream water level. If more flow was available than could pass through the turbine and the upstream water level continued to rise, the excess water would flow over the weir and follow the natural watercourse. If the upstream water level continued to fall even when the turbine was passing its minimum flow, then it would shut down automatically and allow the water level to recover. Once recovered, the turbine would restart automatically.

The function of the hydro system is shown in the annotated Sankey diagram in figure 3.

It is important to understand the side effects of hydro system operation. Two main side effects are noise and heat. These will be minimised as part of system design and the resulting system will meet all applicable planning and safety requirements.

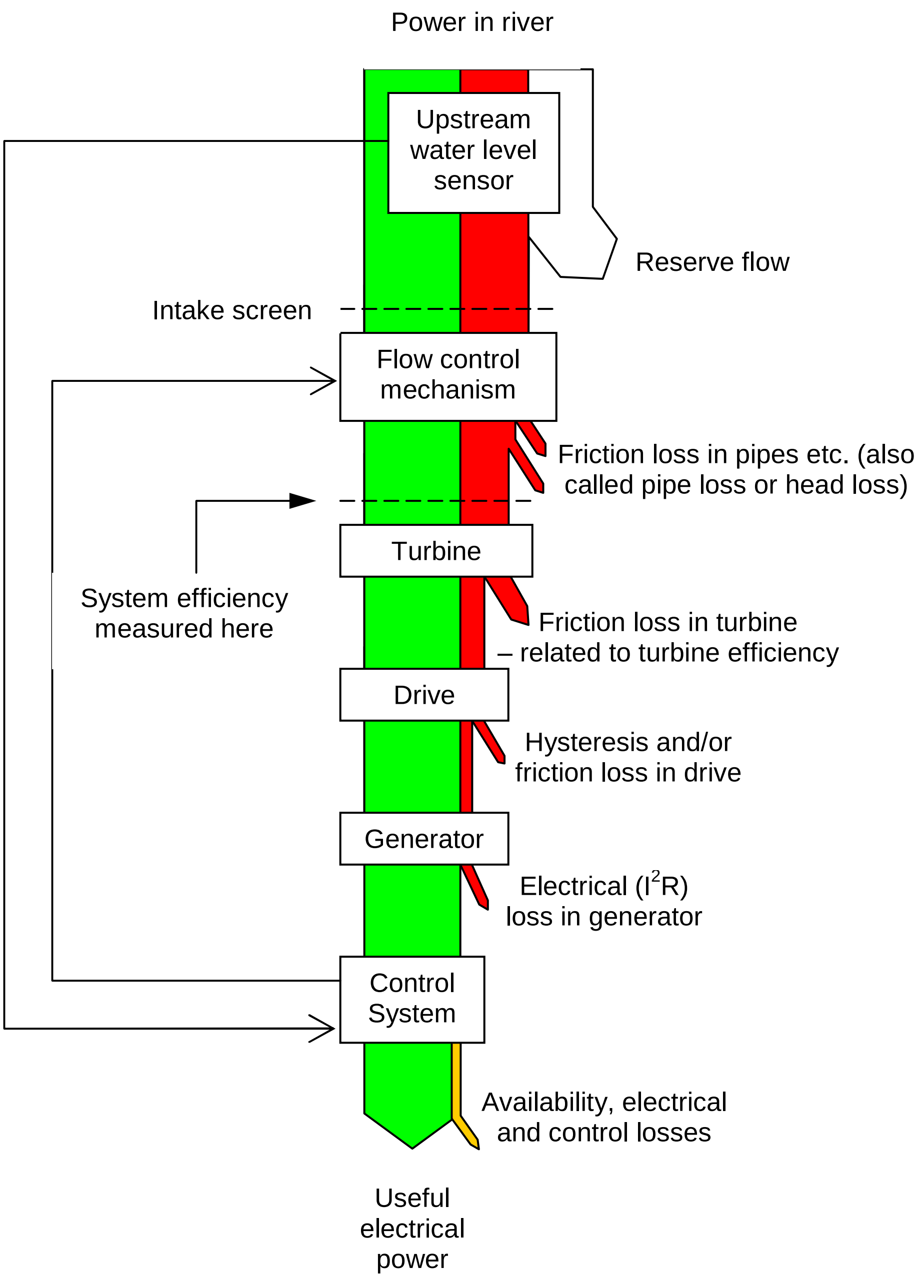


Figure 3 – Sankey diagram showing hydro system function.

1.2. Head

Gross head is the measured drop in water level between the upstream and downstream end of a hydropower system.

Net head is the head seen across the turbine runner.

Head loss from gross head to net head is a pressure loss caused by the water flowing around bends or hydraulically inefficient shapes, or by skin-friction as the water rubs against a pipe or channel wall. A good system design will keep head losses to a minimum, but losses of at least 10% of the gross head should still be expected.

1.3. Flow

The flow in the Dee is gauged at Manley Hall, approximately 22 km downstream of Horseshoe Falls and daily mean flows are available from 1937 onward at http://www.nwl.ac.uk/ih/nrfa/webdata/067015/g067015.csv. The mean flow at Manley Hall has remained pretty constant over the years at about 31 m^3/s, but the Q95 has more than doubled from around 4 m^3/s pre-1967 to 8.85 m^3/s for the period from 1977 to 2006. These higher than natural low flows over the last few decades have been maintained by releases from major river regulating reservoirs Celyn and Brenig. Operation has been relatively stable since 1977 (impounding at Brenig started in August 1975), so the 30 years of data from 1977 to 2006 have been used.

The catchments between each site and the gauging station at Manley Hall were drawn. Tables 2, 6, 10 and 14 list the vertices of the polygons which approximate these catchments.

For each catchment polygon, an analysis using LowFlows software was made and the resulting flow duration curve was then subtracted from that at Manley Hall in the following way to give an estimate of the flow duration at each site:

$Q_{XX,\ Manley\ Hall} - Q_{XX,\ site\ to\ Manley\ Hall} = Q_{XX,\ site}$,

where Q_{XX} is the flow exceeded for XX % of the year.

1.3.1. Water abstraction for hydropower

Abstraction for hydropower is non-consumptive abstraction, meaning the water is returned to the watercourse immediately after use.

The Environment Agency has published a good practice guide, which specifies that hydropower systems should be designed with a rated flow no greater than the mean flow in the watercourse. The mean flow in the River Dee at Llangollen is approximately 26 m^3/s. None of the hydropower systems outlined in this report propose to take anywhere near this flow, with the greatest abstraction proposed being 10.2 m^3/s at Horseshoe Falls, Dee Valley Water side.

1.3.1.1. Reserve flow (or hands-off flow)

The Environment Agency guide also specifies what flow should be left in the river at all times as a *reserve flow*, in support of river ecology. Q95, about 8 m^3/s in the Dee at Llangollen, is the minimum allowable reserve flow for three of the four sites recommended in this report, with Mile End Mill requiring a slightly higher reserve flow of Q90, or about 8.4 m^3/s, because of the longer *depleted reach* proposed there. A depleted reach is any stretch of river which sees a smaller than natural flow because water has been diverted elsewhere, such as through a hydro system.

The above reserve flow requirements have been assumed throughout this report. If the project progresses, one of the next steps would be to consult with the Environment Agency (EA) to check which licences would be required for the project and to and confirm the reserve flow requirements.

1.3.2. Other abstractions and discharges

Conversations with British Waterways have established that two abstraction licences are in operation just above Horseshoe Falls: one up to 16 Mgal/day (million gallons per day) for Llangollen Canal and another up to 10 Mgal/day for United Utilities, which feeds Hurleston Reservoir. Both abstractions are conveyed by the Llangollen canal. The maximum abstraction at that point would therefore be 26 Mgal/day = 1.37 m^3/s.

The actual abstraction described above and, moreover, the net abstraction or discharge upstream of each site is already accounted for in the flow duration curve for each site. However, what is not accounted for is the net abstraction or discharge that occurs *between* each site and the Manley Hall gauge.

Further work during the feasibility study stage will aim to establish the net abstraction or discharge between the chosen sites and the Manley Hall gauge and mean flow estimates will be adjusted accordingly. The required adjustment to mean flow at each site is likely to be small – on the order of ± 2 m^3/s, which would not be large enough to affect the conclusions of this report.

1.4. Legal requirements

1.4.1. Environment Agency licences and consents

Necessary licences and consents will include

- land drainage consent

and one or more of the following:

- impoundment licence,
- abstraction licence,
- transfer licence.

The likelihood of obtaining the necessary licences will be discussed in particular detail with the permitting officer as part of the feasibility study.

1.4.2. Planning permission

Planning permission will be required for this development. A planning enquiry letter will be sent to the local planning authority for each scheme chosen for further work. A planning officer will usually respond to an enquiry letter within three months. The officer's response will list key local and regional policies under which the application will be assessed and may offer further information and advice.

1.4.3. Land ownership

Land ownership will be dealt with as part of the feasibility study.

Leaseholders, freeholders and mortgagors should be informed of the planned work at all sites progressed.

1.4.4. Insurance

Installing a hydro system may affect liability insurance policies, so insurance companies should be advised of this project if it goes ahead, so that any changes in cover can be arranged.

1.4.5. DNO permission to grid connect

Micro-hydropower systems connect to the grid via single- or three-phase mains connection units. Systems with rated currents less than 16 A per phase use units with G83 relays and systems with rated currents more than 16 A per phase use units with G59 relays. For G83 connections, the distribution network operator (DNO) is notified of the connection following installation, but for G59 connections, permission to connect has to be obtained in advance and commissioning tests have to be witnessed by a suitably qualified person, who then forwards the test results to the relevant distribution network operator.

For each site, electrical tests would be carried out at the proposed connection point to establish the strength of the grid at this point. This work would be done as part of the feasibility study stage. If the results of these tests indicated that an electrical upgrade would be required, a budget cost would be obtained for this work. Following receipt of all other necessary consents, licences and permissions, formal grid connection permission would then be sought, along with a quote for any grid upgrade work required.

To get the greatest benefit from the generated electricity, the system would have to connect to an existing electrical installation and the electricity would have to be used on-site as far as possible. The system would have to be owned, technically, by the owner of the existing electrical installation and then leased back to the system operator, i.e. the community group. This arrangement would greatly simplify the grid connection process and would minimise cost.

At Horseshoe Falls, Dee Valley Water side, the above paragraph does not apply as there is currently no electricity demand on the site. In this case, a new generation connection would be installed and all the electricity would be exported.

G83 and G59 mains connection units are available as standard products. A typical mains connection unit is shown in figure 4.

Figure 4 - Mains connection unit / hydropower system controller.

In terms of physical layout, from the generator, the power would be transferred to the mains connection unit (which is also the hydropower system controller) via an armoured cable. The mains connection unit is approximately 500 mm x 500 mm x 300 mm (H x W x D) and is normally wall mounted in an easily accessible, weatherproof area. Systems above about 25 kW may require slightly larger mains connection units. From the mains connection unit, the power could connect straight into the main distribution board of an existing or new installation. It could then be consumed on site and/or exported to the grid.

1.4.6. Relevant land designations

The following land designations are relevant to obtaining both planning permission and Environment Agency licences and consents:

The proposed schemes will fall within both the River Dee SSSI (Site of Special Scientific Interest) and the River Dee and Bala Lake SAC (Special Area of Conservation). Version 10 of the Core Management Plan for the River Dee and Bala Lake SAC, which also includes information about SSSI features, can be found at the following link, accessed 15 February 2010: http://www.ccw.gov.uk/idoc.ashx?docid=601bc11b-69fc-4418-9235-5cb2fdcfed9c&version=-1&lang=en.

The River Dee and Bala Lake SAC has been notified for its features of European importance, which include:

- Annex I habitats – Water courses of plain to montane levels with the *Ranunculion fluitansis* and *Callitricho-Batrachion* vegetation.

- Annex II species primary reason for selection – Atlantic salmon *Salmo salar* and floating water plantain *Luronium natans*

- Annex II species present as a qualifying feature but not a primary reason for site selection are – sea lamprey *Petromyzon marinus*, brook lamprey *Lampetra planeri*, river lamprey *Lampetra fluviatilis*, bullhead *Cottus gobio* and European otter *Lutra lutra*.

The River Dee SSSI has been notified for its nationally important transition through a range of river types. Other reasons include club tailed dragonfly *Gomphus vulgatissimus* and fluvial geomorphology.

The following extracts from the Core Management Plan are especially relevant:

Conservation status and management requirements of Feature 4: Brook lamprey *Lampetra planeri*, section 5.5, pp 52-3:

> "The [Horseshoe Falls] weir is believed to present a barrier to the upstream migration of lamprey. The structure should therefore be modified to enable such fish to reach the river beyond it.
>
> "Entrainment in water abstractions directly impacts on population dynamics through reduced recruitment and survival rates. Information on likely rates of entrainment of lamprey ammocoetes is required before acceptable levels can be assessed. In addition, screening must be of a standard sufficient to prevent any significant effect on the lamprey population."

The above extract is repeated in section 5.6 in relation to river lamprey and also in section 5.4 in relation to sea lamprey, although the action plan summary (section 6) does not indicate any conservation management issues for sea lamprey this far upstream. The conservation management issues for the relevant units (5 and 6) are summarised as follows:

> "FEATURE 5: Brook lamprey *Lampetra planeri* and FEATURE 6: River lamprey *Lampetra fluviatilis*
>
> "Conservation status: Unfavourable un-classified
>
> "Actions currently identified: To instigate a survey that, if necessary includes the destructive sampling of a small numbers of ammocoetes, in order to gain some understanding of the distribution and abundance of the species within the SAC.
>
> "To instigate a survey that identifies spawning sites"

The proposed schemes would not be expected to improve nor worsen the overall conservation status. Any necessary removal of vegetation could be balanced by an equivalent mitigation measure, e.g. the management and/or fencing off of bankside vegetation elsewhere.

1.5. Annual Energy Production

1.5.1. Data used in calculations

Some generalised and some site specific data are used in calculations.

Acceleration due to gravity, density of water and number of hours in a year are assumed constant at 9.81 m/s^2, 1000 kg/m^3 and 8760 respectively.

Net head is assumed to be 90 % of gross head at all sites and system efficiency, taken to be the product of rated turbine efficiency, drive and generator efficiency, is assumed constant at 60 %. These parameters will, in fact, vary slightly from site to site, so will be revised at the feasibility study stage and again in the final development phase report once the design has been fixed.

To simplify calculation at this stage, the rated power of the system has been calculated from the above parameters and the chosen rated flow. Annual energy production has then been estimated by assuming a capacity factor of 50 % for all sites. Again, the capacity factor will vary slightly from site to site, so will be revised at the feasibility study stage and beyond, using a more sophisticated analysis.

System availability, grid availability, electrical losses, control losses and loss of net head at high flows have each been accounted for in the capacity factor assumed in this report. Net head tends to reduce at high flows because the tailrace water level tends to increase faster than the headrace water level. This effect is felt more at some sites than others.

1.5.2. Metering, monitoring and communications

A ‘total generation meter’ would be installed and readings would be taken by the system operator at regular intervals (e.g. approximately every month or every quarter). Readings would then be reported to the electricity supplier.

The total generation meter is a standard electronic electricity meter which records the total amount of renewable electricity generated, regardless of whether it is consumed on site or exported. The recorded ‘total generation’ is used to claim the feed-in tariff (FIT) and levy exemption certificates (LECs).

An export meter may also be installed by your electricity supplier, but most suppliers use a formula to estimate how much electricity is used on site and how much is exported to the grid, as this is a cheaper method for them and the Client rarely loses out.

There are a number of datalogging and communications devices that can be added to a small hydropower system for various purposes. These are not included in the cost estimates in this report, but they may be added as extra items at a later stage.

1.6. Financial Analysis

Many project variables effectively have been fixed with the recent announcement regarding feed-in tariffs. It is now sensible to fix the project lifetime at 20 years from an accounting perspective, since this is the lifetime of the relevant feed-in tariff. Also, it is sensible to set the projected cash flow inflation to 2 %, the UK government’s target consumer price index, since feed-in and export tariffs are both linked to inflation.

5 p/kWh has been assumed for the electricity export/offset value across all sites except Corn Mill, where 10 p/kWh has been assumed, because of the high on-site demand and relatively low power of the proposed generator at that site. Export and offset values will be revised at the feasibility study stage and beyond, using a more sophisticated analysis, which will include data on actual electricity use and cost.

0.46 p/kWh has been assumed for the levy exemption certificate value across all sites.

The total of the feed-in tariff, export/offset value and levy exemption certificate value gives the total value of the generated electricity, which is either 23.26 p/kWh or 25.36 p/kWh, depending on the size of the system.

As always, the project feasibility is sensitive to the final capital cost of the project and, more critically, to the method by which the project is financed and what rate of return the investor is willing to accept.

2. Horseshoe Falls, Dee Valley Water side

2.1. Resource

2.1.1. Head

Gross head was measured to be 1.832 m between points A and B in figure 6.

Net head would be approximately 90 % of gross head, i.e. **1.649 m**.

2.1.2. Flow

Figure 5 shows the flow duration curve for the site. The area under the curve represents the volume which passes down the river in a typical year.

The area marked grey represents the volume likely to be diverted through a hydropower system on the Dee Valley Water side of the falls in a typical year.

The white band below the grey band in figure 5 represents the reserve flow required, in this case Q95.

Larger flows would still pass over the weir whenever the river flow exceeded the rated flow of the hydro system plus Q95.

Table 2 lists the vertices of a polygon which represents the catchment between the site and the gauging station at Manley Hall. A LowFlows analysis of this catchment polygon was made and the resulting flow duration curve was then subtracted from that at Manley Hall to give the flow duration curve for the site as shown in figure 5 and summarised in table 3.

Easting	Northing
334900	341400
332000	335700
326500	333200
323900	333100
322600	335000
314800	330900
307900	333900
311800	339500
314600	339500
316500	339400
317100	339900
316500	340800
319600	343200
318600	346300
317200	346700
321200	349300
323300	349500
324400	348800
332000	343200
334100	343000

Table 2 – Horseshoe Falls to Manley Hall catchment polygon.

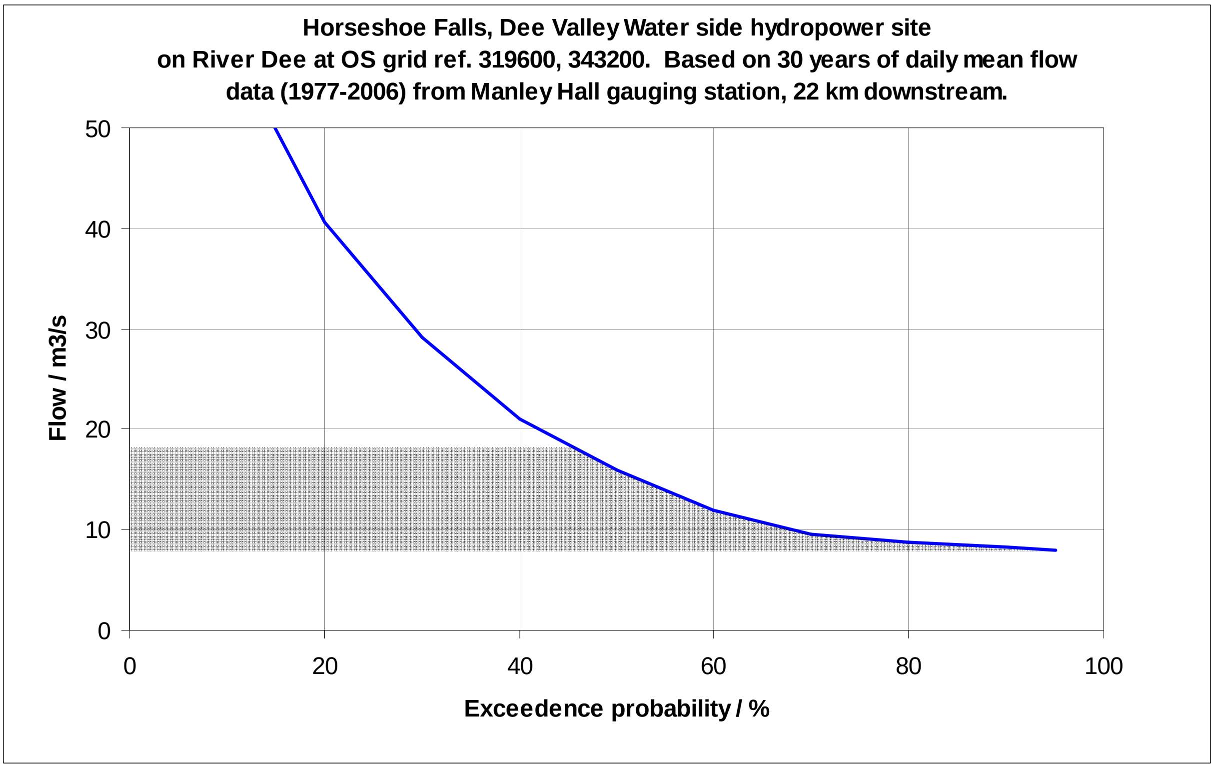


Figure 5 – Flow duration curve for Horseshoe Falls, Dee Valley Water side.

Percentage Exceedence / %	Flow / m³/s
Q_5	77.42
Q_{10}	59.00
Q_{20}	40.57
Q_{30}	29.08
Q_{40}	20.99
Q_{50}	15.94
Q_{60}	11.98
Q_{70}	9.49
Q_{80}	8.76
Q_{90}	8.23
Q_{95}	7.99
Q_{mean}	$Q_{33.1}$ = 26.28

Table 3 – Summary of annual flow duration at Horseshoe Falls.

2.1.3. Existing Infrastructure

The Horseshoe Falls weir, located at OS grid reference 319600, 343200 was built by Thomas Telford between 1804 and 1806. It is made of stone and cast iron and is just over 140 m in length. The vertical downstream face of the weir is 1.2 m in height, though only about half of this drop is apparent as a fall of water when viewed from the riverbanks.

The river widens immediately below the falls, with a corresponding drop in flow velocity. This forms a depositional environment, as is evident from the several river islands that have formed in the channel. The water level drops about half a meter over the weir itself, then continues to fall over rapids immediately downstream of the weir. The fall over the rapids occurs gradually over about 200 m when measured along the western bank, but more abruptly on the eastern side.

On the west side, just upstream of the weir, is an intake with a coarse screen where water was once abstracted to supply the town. The intake is no longer used, and the town is supplied instead from boreholes. Pipes will run underground from the intake to the nearby Water Works building, which has an overhead, three-phase grid connection.

Vehicle access to the site is via a narrow entrance off a narrow road.

Figures 6-11 show views of the intake, of the whole site, and of a potential tailrace site.

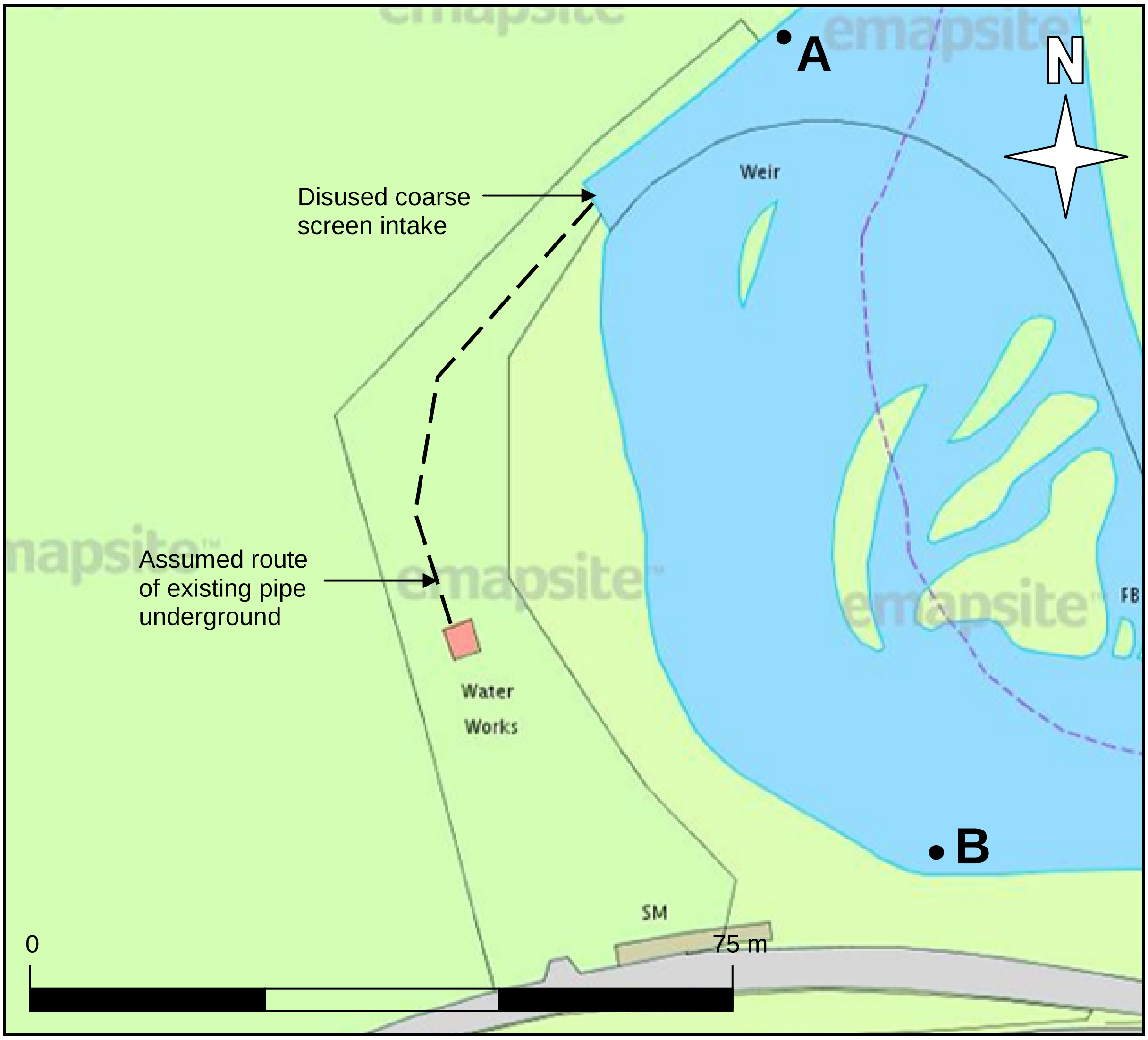


Figure 6 – Map of site. Scale is approximate. Gross head was measured between points A and B.

Figure 7 – Dee Valley Water screen and intake.

Figure 8 – Dee Valley Water screen and intake.

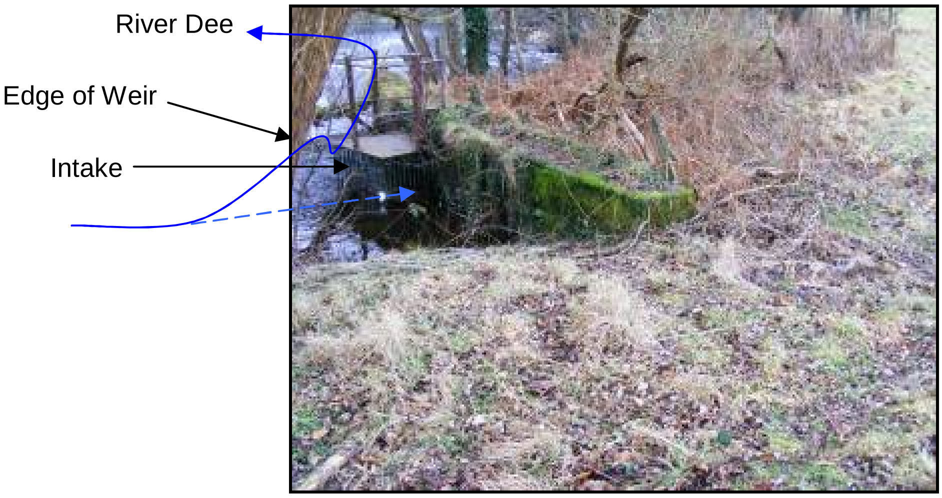


Figure 9 – Dee Valley Water Screen and intake.

Figure 10 – Dee Valley Water building.

Figure 11 – River bank 100 m below the Dee Valley Water intake.

2.2. Legal requirements

2.2.1. Environment Agency consents and licences

A preliminary enquiry (WR48) form will be sent to the Environment Agency if this scheme is chosen for further work. A permitting officer will usually respond to a preliminary enquiry within five months of submission.

The scheme will require land drainage consent. It may also require an impoundment licence and/or an abstraction licence.

It has been assumed that a fish pass will be required at this site. The Environment Agency will advise on precisely what provision is necessary for fish passage. There may be an opportunity to share the cost of the overall works with the Environment Agency, given that the modification of Horseshoe Falls weir to allow fish to reach the river beyond it is already singled out as a requirement in the Core Management Plan.

The hydropower system intake would need to be screened. The hydropower system would be designed so that it would have minimal impact on the biodiversity of the river.

2.2.2. Planning permission

The weir (and the adjacent stone-lined pound) is a Grade II listed structure. It is listed as a fine early C19 weir, part of one of the earliest river regulation schemes carried out in Britain and of group value with other listed structures on the Llangollen Canal. Listed building consent would be required before starting any work.

2.3. Design

2.3.1. Civil design

No changes would be made to the structure of the existing weir.

The intake would be sited immediately upstream of the existing Dee Valley Water intake, and would have a screen to restrict debris from entering the leat. Where the Dee Valley Water pipes cross the path of the leat, they would be lowered if necessary so that they run beneath the leat. A spillway near to the intake would reduce the risk of damage to the leat in times of high flow. The leat would feed into a forebay with a silt clearance sluice, another spillway and the intake screen for the turbine. The turbine is sited as far downstream as the steep side of the riverbank allows, maximising the available head.

2.3.1.1. Intake screens

A screen approach velocity of 0.25 m/s would be the likely maximum the Environment Agency would allow. Assuming an operational flow of 10.2 m^3/s, this means an intake screen area of 40.8 m^2 would be required. Assuming a new Archimedes screw turbine were installed, a screen with a bar spacing of 100 mm would be adequate.

2.3.2. Electromechanical design

2.3.2.1. Turbine

The recommended turbine for this site would be a 4 m diameter Archimedes screw turbine. Other turbine types, e.g. Kaplan, would be technically feasible, but would require a more involved screening regime.

2.3.2.2. Drive

The drive would be a gearbox coupled via a high speed belt drive to the generator.

2.3.2.3. Generator

A variable speed Archimedes screw would use an inverter connected, permanent magnet, synchronous generator and could be initially grid connected, but later retrofitted with a second, stand-alone inverter to enable operation during power cuts if this were desired.

2.3.2.4. Grid connection (via mains connection unit)

The hydro system would connect to the grid under the G59 specification. The best value location for connection would be inside the Dee Valley Water building. Both the existing supply to the building and the pole-mounted transformer would probably need upgrading.

2.3.3. Whole system design

2.3.3.1. System layout

Drawings 004.01.01 and 004.02.02 respectively show a plan and an elevation of the proposed system layout, the aim being to show the different elements of the system in context.

2.4. Annual Energy Production

2.4.1. Annual energy production

The rated power, or maximum electrical power, is calculated as follows:

Rated power = net head
× rated flow
× acceleration due to gravity
× density of water
× system rated efficiency

= 1.649 × 10.2 × 9.81 × 1000 × 0.6

= **99 kW.**

Annual energy production is then calculated as follows:

AEP = rated power
× number of hours in a year
× capacity factor

= 99.0 × 8760 × 0.5

= **433,573 kWh/year.**

2.5. Financial Analysis

2.5.1. Benefits

2.5.1.1. Financial benefits

The value of generated electricity is made up of an export/offset value, plus a Feed-in tariff (FIT), plus a Levy Exemption Certificate (LEC). Assumed values for these parameters are given in table 5.

2.5.1.2. Social and environmental benefits

Every kWh of electricity produced by the hydropower system would offset a kWh produced by conventional means (mainly coal and gas). This gives rise to avoided CO_2 emissions as shown in table 5.

In addition to this, use of renewable resources lessens our reliance on finite supplies of fossil fuel and thus contributes to energy security.

2.5.2. Costs

Estimates of project cost are given in table 4, together with items already ordered/completed.

CAPITAL EXPENDITURE

Phase	**Work items**	**Description**	**Cost / £** Archimedes screw
	Preliminary site assessment	Site surveys, report writing and meeting to decide which schemes to progress.	4,097
Feasibility phase	Feasibility study	Project management of feasibility phase Update outline design. EA process part 1: Submit WR48 preliminary enquiry form and supporting material to Environment Agency. Liaison with Environment Agency. Site meeting with Environment Agency and survey site in more detail. Network analysis: Connection estimate. Liaison with Distribution Network Operator. Liaison with local planning authority. Detailed design of hydro system. Feasibility study report. Apply for Environment Agency licences and consents.	9,900
Development phase	Project management of development phase		5,000
	EA process part 2	Follow up applications made in EA process part 1 and obtain licences and consents, including land drainage consent.	3,000
	Planning	Planning application for hydropower system.	2,000
		Planning Application fee.	*1,675*
	Final development phase report	Update detailed design to EA and planning authority requirements.	13,250
		Obtain quotes for installation phase.	4,400
		Updated revenue estimate, updated financial analysis.	2,400
Installation phase (including commissioning)	Project management of installation phase		6,000
	Civil works (materials and delivery)	Reinforced concrete for channel, fish pass and turbine support structure, steel for screens and fences.	151,250
	Civil works (labour)		151,250
	Electromechanical works (materials and delivery)	Turbine, drive, generator, brake, control system, inverters, relays, level sensor, sluice gate, grid connection, metering, site electrics.	344,076
	Electromechanical works (labour)		30,000
	TOTAL		**728,298**

Table 4 – Project cost estimates.

2.5.3. Analysis

2.5.3.1. Results

Table 5 shows the base case financial analysis.

Green and orange cells show inputs to the analysis and intermediate results. Red cells show outputs.

Financial parameter	Value	Unit
Turbine	Archimedes screw	
Lifetime	20	years
Estimated electricity export/offset value	5.00	p/kWh
Feed-in tariff (FIT) value	17.80	p/kWh
Levy exemption certificate (LEC) value	0.46	p/kWh
Capital expenditure	728,298	£
Annual operating expenditure	20,510	£/year
Generated electricity after all losses	433,573	kWh/year
Value of generated electricity	100,849	£/year
Projected import base price one-off increase	0	%
Projected (cash flow) inflation (FIT is RPI linked)	2	%
Discount rate	5	%
Internal rate of return	**11.3**	**%**
Simple payback time (inflation = discount = 0 %)	9	years
Complex payback time (at 5 % discount rate)	11	years
Net present value (at 5 % discount rate)	473,474	£
Environmental parameter	**Value**	**Unit**
Avoided CO2 emissions per kWh generated	0.000537	tCO2/kWh
Avoided CO2 emissions	233	tCO2/year
Homes provided for	99	

Table 5 – Base case financial analysis.

3. Corn Mill

3.1. Resource

3.1.1. Head

The gross head is limited at this site by the vertical distance between the water level immediately upstream of the weir and the discharge water level of the turbine into the wheel pit, as the downstream water level is far below the level of the bottom of the wheel pit.

Gross head was measured at 2.184 m.

Net head would be approximately 90 % of gross head, i.e. **1.966 m**.

3.1.2. Flow

Figure 12 shows the flow duration curve for Corn Mill. The area under the curve represents the volume which passes down the river in a typical year.

The area marked grey represents the volume likely to be diverted through the proposed hydropower system in a typical year. This would only be a small proportion of the mean flow available for hydropower, because the limited space inside the building effectively limits the size of system that could be installed.

The white band below the grey band in figure 12 represents the reserve flow required, in this case Q95.

Larger flows would still pass over the weir whenever the river flow exceeded the rated flow of the hydro system plus Q95.

Table 6 lists the vertices of a polygon which represents the catchment between the site and the gauging station at Manley Hall. A LowFlows analysis of this catchment polygon was made and the resulting flow duration curve was then subtracted from that at Manley Hall to give the flow duration curve for the site as shown in figure 12 and summarised in table 7.

Easting	Northing
334900	341400
332000	335700
326500	333200
323900	333100
322600	335000
314800	330900
307900	333900
311800	339500
314600	339500
316500	339400
317100	339900
319900	341500
321400	341600
321700	343000
323100	343300
322500	344200
323000	344300
322700	344900
324400	348800
332000	343200
334100	343000

Table 6 – Corn Mill to Manley Hall catchment polygon.

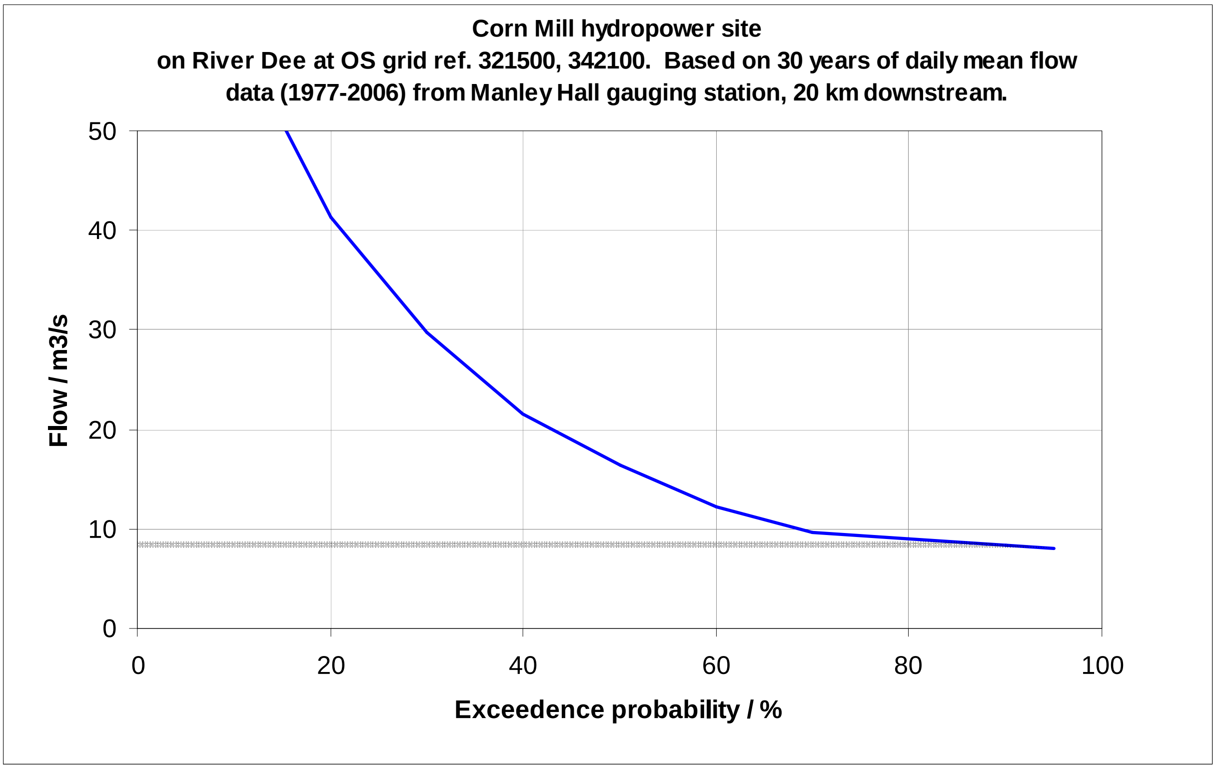


Figure 12 – Flow duration curve for Corn Mill.

Percentage Exceedence / %	Flow / m³/s
Q_5	79.39
Q_{10}	60.43
Q_{20}	41.52
Q_{30}	29.82
Q_{40}	21.58
Q_{50}	16.41
Q_{60}	12.33
Q_{70}	9.75
Q_{80}	8.96
Q_{90}	8.37
Q_{95}	8.10
Q_{mean}	$Q_{33.1}$ = 26.95

Table 7 – Summary of annual flow duration at Corn Mill.

Flow usable for hydropower at this site is therefore limited not by the Q_{95} flow in the river, but by the capacity of the largest turbine that can fit in the available space, which is 465 l/s.

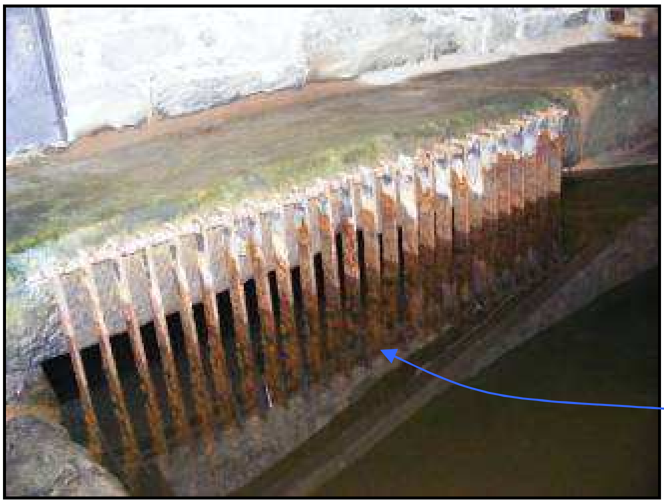
3.1.3. Existing Infrastructure

The Corn Mill is located on the southern bank of the river Dee at OS grid reference 321500, 342100. It is now a flourishing inn. There is a partial weir, a head race, a breast shot wheel in a wheel pit inside the building and a tail race which runs in a tunnel under the building for the first part of its length. The tailrace ends above the downstream water level. Some services, possibly electric cables and hot water supplies, have been taken through the tail race tunnel and the wheel pit. The breast shot wheel has some damage and the axle now ends at the wall. The condition of the bearings could not be established, and the sluices were mostly submerged and could not be thoroughly inspected.

Access to the wheel pit is constrained: it is via the low tailrace tunnel or the viewing aperture in the external wall.

Figures 13-19 show views of the headrace, intake screen and tailrace.

Figure 13 – Sluice in wall of Corn Mill headrace.



Flow from weir

Figure 14 – Corn Mill screen and intake.

Chain drive

Figure 15 – Corn Mill main sluice gate, control and part of wheel (bottom left).

Figure 16 – Corn Mill breast shot waterwheel. Cast iron and wood with flat paddles.

Figure 17 – View back up Corn Mill tailrace tunnel.

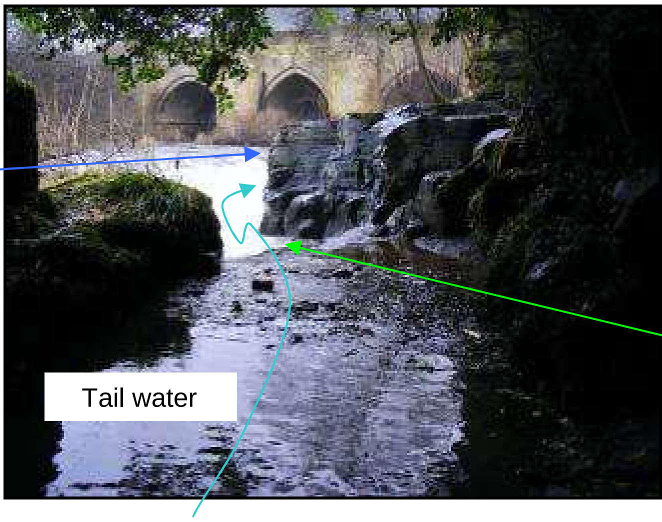


Figure 18 – View along Corn Mill tailrace.

Figure 19 – Corn Mill electrical installation, showing three-phase main meter (top right) and main distribution board with spare ways (top left).

3.2. Legal requirements

3.2.1. Environment Agency consents and licences

A preliminary enquiry (WR48) form will be sent to the Environment Agency if this scheme is chosen for further work. A permitting officer will usually respond to a preliminary enquiry within five months of submission.

It is hoped that no fish pass would be required in this instance, given that the weir at the upstream end of the site is incomplete, and does not currently present an artificial impediment to fish passage. If a fish pass were required, the scheme would probably not be feasible. The Environment Agency will advise on precisely what provision, if any, is necessary for fish passage.

The hydropower system intake would need to be screened. Screens may also be required at the downstream end of the hydropower system. The hydropower system would be designed so that it would have minimal impact on the biodiversity of the river.

The scheme will require land drainage consent. It may also require an impoundment licence and/or an abstraction licence. The likelihood of obtaining the necessary licences will be discussed in particular detail with the permitting officer.

3.3. Design

The feed-in tariff would account for about two-thirds of the revenue at this site. To obtain the feed-in tariff, the chosen prime mover (waterwheel or turbine) must be an MCS-accredited product. There is currently no breast shot waterwheel supplier who is likely to seek MCS accreditation for their product, so if a new or refurbished waterwheel were to be used, it could either run as a non-MCS system, with limited revenue, or an organisation would have to be set up to seek accreditation for the desired waterwheel “model” proposed.

A new turbine is assumed, as the installation would then obtain the feed-in tariff more easily and with less risk.

The best site for the new turbine is the point in the system where there is the highest available head, which is in the wheel pit, and so something would have to be done with the wheel. It may be possible to place it over the headrace or the tailrace, or on the outside wall of the building, or it could be made smaller and remain in the wheel pit above the new turbine. Schemes can be conceived which would keep the wheel intact and in situ, but they are likely to be more costly to construct and so will not be discussed at this stage.

3.3.1. Civil design

The proposed system would be sited in the wheel pit. Some modification of existing structures would be necessary.

3.3.1.1. Intake screens

A screen approach velocity of 0.25 m/s would be the likely maximum the Environment Agency would allow. Assuming an operational flow of 0.465 m^3/s, this means an intake screen area of 1.86 m^2 would be required. There is no maximum approach velocity applicable to tailrace screens, so the area required could be reduced to some extent.

Assuming a new Archimedes screw turbine were installed, screens with a bar spacing of 100 mm would be adequate.

3.3.2. Electromechanical design

3.3.2.1. Turbine

The recommended turbine for this site would be a 1.3 m diameter Archimedes screw, which is the largest diameter that could be installed via the tailrace tunnel. This size of screw has a maximum flow of 465 l/s.

3.3.2.2. Drive

The drive would be a gearbox coupled via a high speed belt drive to the generator.

3.3.2.3. Generator

A variable speed Archimedes screw would use an inverter connected, permanent magnet, synchronous generator and could be initially grid connected, but later retrofitted with a second, stand-alone inverter to enable operation during power cuts if this were desired.

3.3.2.4. Grid connection (via mains connection unit)

The hydro system would connect to the grid within the building under either the G83 or G59 specification, depending on whether a single- or three-phase system was installed. Three phase is available on site, but it may be better value to connect to just one of the phases.

3.3.3. Whole system design

3.3.3.1. System layout

Drawings 003.01.01 and 003.02.01 respectively show a plan and an elevation of the proposed system layout, the aim being to show the different elements of the system in context.

3.4. Annual Energy Production

3.4.1. Annual energy production

The rated power, or maximum electrical power, is calculated as follows:

Rated power = net head
× rated flow
× acceleration due to gravity
× density of water
× system rated efficiency

= 1.966 × 0.465 × 9.81 × 1000 × 0.6

= **5.4 kW.**

Annual energy production is then calculated as follows:

AEP = rated power
× number of hours in a year
× capacity factor

= 5.4 × 8760 × 0.5

= **23,564 kWh/year.**

3.5. Financial Analysis

3.5.1. Benefits

3.5.1.1. Financial benefits

The value of generated electricity is made up of an export/offset value, plus a Feed-in tariff (FIT), plus a Levy Exemption Certificate (LEC). Assumed values for these parameters are given in table 8.

3.5.1.2. Social and environmental benefits

Every kWh of electricity produced by the hydropower system would offset a kWh produced by conventional means (mainly coal and gas). This gives rise to avoided CO_2 emissions as shown in table 8.

In addition to this, use of renewable resources lessens our reliance on finite supplies of fossil fuel and thus contributes to energy security.

3.5.2. Costs

Estimates of project cost are given in table 9, together with items already ordered/completed.

3.5.3. Analysis

3.5.3.1. Results

Table 8 shows the base case financial analysis.

Green and orange cells show inputs to the analysis and intermediate results. Red cells show outputs.

Financial parameter	Value	Unit
Turbine	Archimedes screw	
Lifetime	20	years
Estimated electricity export/offset value	10.00	p/kWh
Feed-in tariff (FIT) value	19.90	p/kWh
Levy exemption certificate (LEC) value	0.46	p/kWh
Capital expenditure	124,382	£
Annual operating expenditure	700	£/year
Generated electricity after all losses	23,564	kWh/year
Value of generated electricity	7,154	£/year
Projected import base price one-off increase	0	%
Projected (cash flow) inflation (FIT is RPI linked)	2	%
Discount rate	5	%
Internal rate of return	**2.4**	**%**
Simple payback time (inflation = discount = 0 %)	19	years
Complex payback time (at 5 % discount rate)	29	years
Net present value (at 5 % discount rate)	-27,840	£
Environmental parameter	**Value**	**Unit**
Avoided CO2 emissions per kWh generated	0.000537	tCO2/kWh
Avoided CO2 emissions	13	tCO2/year
Homes provided for	5	

Table 8 – Base case financial analysis.

CAPITAL EXPENDITURE			
Phase	**Work items**	**Description**	**Cost / £**
			Archimedes screw
	Preliminary site assessment	Site surveys, report writing and meeting to decide which schemes to progress.	4,097
Feasibility phase	Feasibility study	Project management of feasibility phase	
		Update outline design.	
		EA process part 1: Submit WR48 preliminary enquiry form and supporting material to Environment Agency. Liaison with Environment Agency.	
		Site meeting with Environment Agency and survey site in more detail.	
		Network analysis: electrical test at proposed connection point, connection estimate. Liaison with Distribution Network Operator.	
		Liaison with local planning authority.	
		Detailed design of hydro system.	
		Feasibility study report.	
		Apply for Environment Agency licences and consents.	9,900
Development phase	Project management of development phase		2,500
	EA process part 2	Follow up applications made in EA process part 1 and obtain licences and consents, including land drainage consent.	1,500
	Planning	Planning application for hydropower system.	1,000
		Planning Application fee.	*335*
	Final development phase report	Update detailed design to EA and planning authority requirements.	2,500
		Obtain quotes for installation phase.	1,200
		Updated revenue estimate, updated financial analysis.	1,200
Installation phase (including commissioning)	Project management of installation phase		3,000
	Civil works (materials and delivery)	Turbine support structure, screens.	10,000
	Civil works (labour)	Waterwheel - removal and reinstallation elsewhere.	10,000
	Electromechanical works (materials and delivery)	Turbine, drive, generator, brake, control system, inverters, relays, level sensor, sluice gate, total generation meter, cable, ancillary items.	57,150
	Electromechanical works (labour)		20,000
	TOTAL		**124,382**

Table 9 – Project cost estimates.

4. Horseshoe Falls, British Waterways side

4.1. Resource

4.1.1. Head

Gross head was measured to be 1.973 m between the water levels at points A and B in figure 21. Some vegetation would need to be cleared and some other debris removed to allow the full head to be developed.

Net head would be approximately 90 % of gross head, i.e. **1.778 m**.

4.1.2. Flow

Figure 20 shows the flow duration curve for the site. The area under the curve represents the volume which passes down the river in a typical year.

The area marked grey represents the volume likely to be diverted through the proposed hydropower system in a typical year. This would only be a small proportion of the mean flow available for hydropower, because the civil structures already in place on that side of the weir, some of which are part of a scheduled monument, effectively limit the size of system that could be installed.

The white band below the grey band in figure 20 represents the reserve flow required, in this case Q95.

Larger flows would still pass over the weir whenever the river flow exceeded the rated flow of the hydro system plus Q95.

Table 10 lists the vertices of a polygon which represents the catchment between the site and the gauging station at Manley Hall. A LowFlows analysis of this catchment polygon was made and the resulting flow duration curve was then subtracted from that at Manley Hall to give the flow duration curve for the site as shown in figure 20 and summarised in table 11.

Easting	Northing
334900	341400
332000	335700
326500	333200
323900	333100
322600	335000
314800	330900
307900	333900
311800	339500
314600	339500
316500	339400
317100	339900
316500	340800
319600	343200
318600	346300
317200	346700
321200	349300
323300	349500
324400	348800
332000	343200
334100	343000

Table 10 – Horseshoe Falls to Manley Hall catchment polygon.

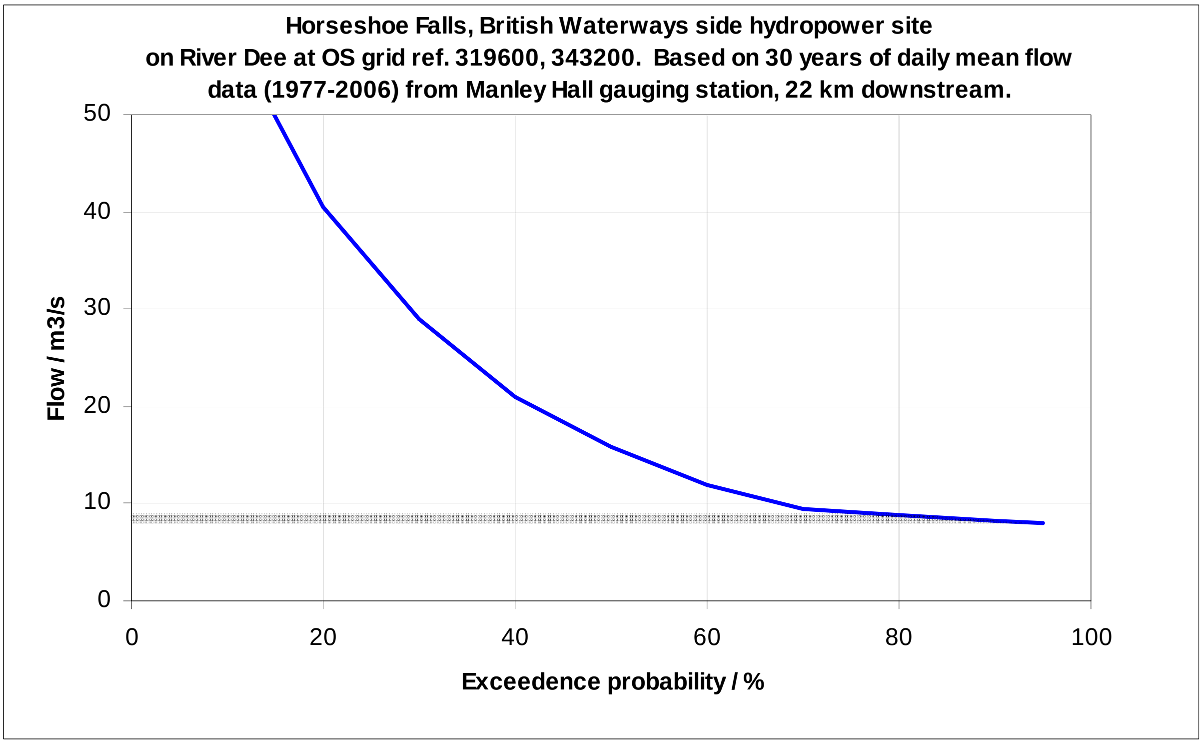


Figure 20 – Flow duration curve for Horseshoe Falls, British Waterways side.

Percentage Exceedence / %	Flow / m³/s
Q_5	77.42
Q_{10}	59.00
Q_{20}	40.57
Q_{30}	29.08
Q_{40}	20.99
Q_{50}	15.94
Q_{60}	11.98
Q_{70}	9.49
Q_{80}	8.76
Q_{90}	8.23
Q_{95}	7.99
Q_{mean}	$Q_{33.1}$ = 26.28

Table 11 – Summary of annual flow duration at Horseshoe Falls.

4.1.3. Existing Infrastructure

The Horseshoe Falls weir, located at OS grid reference 319600, 343200 was built by Thomas Telford between 1804 and 1806. It is made of stone and cast iron and is just over 140 m in length. The vertical downstream face of the weir is 1.2 m in height, though only about half of this drop is apparent as a fall of water when viewed from the riverbanks.

The river widens immediately below the falls, with a corresponding drop in flow velocity. This forms a depositional environment, as is evident from the several river islands that have formed in the channel. The water level drops about half a meter over the weir itself, then continues to fall over rapids immediately downstream of the weir. The fall over the rapids occurs gradually over about 200 m when measured along the western bank, but more abruptly on the eastern side.

On the eastern side, just upstream of the weir, there are a set of intake screens leading to a stone-lined pound. Water is abstracted from here into the Llangollen canal and this abstraction is regulated by a valve in the pipe which runs beneath the pump house. A sluice gate halfway along the pound has been removed and replaced with a concrete dam, which has a small iron sluice gate at its base. This sluice gate is presumably used when de-silting the pound.

Vehicle access to the site is not straightforward and is via a steep field.

Figures 21-31 show views of the pound and of the main channel, its banks and impoundments.

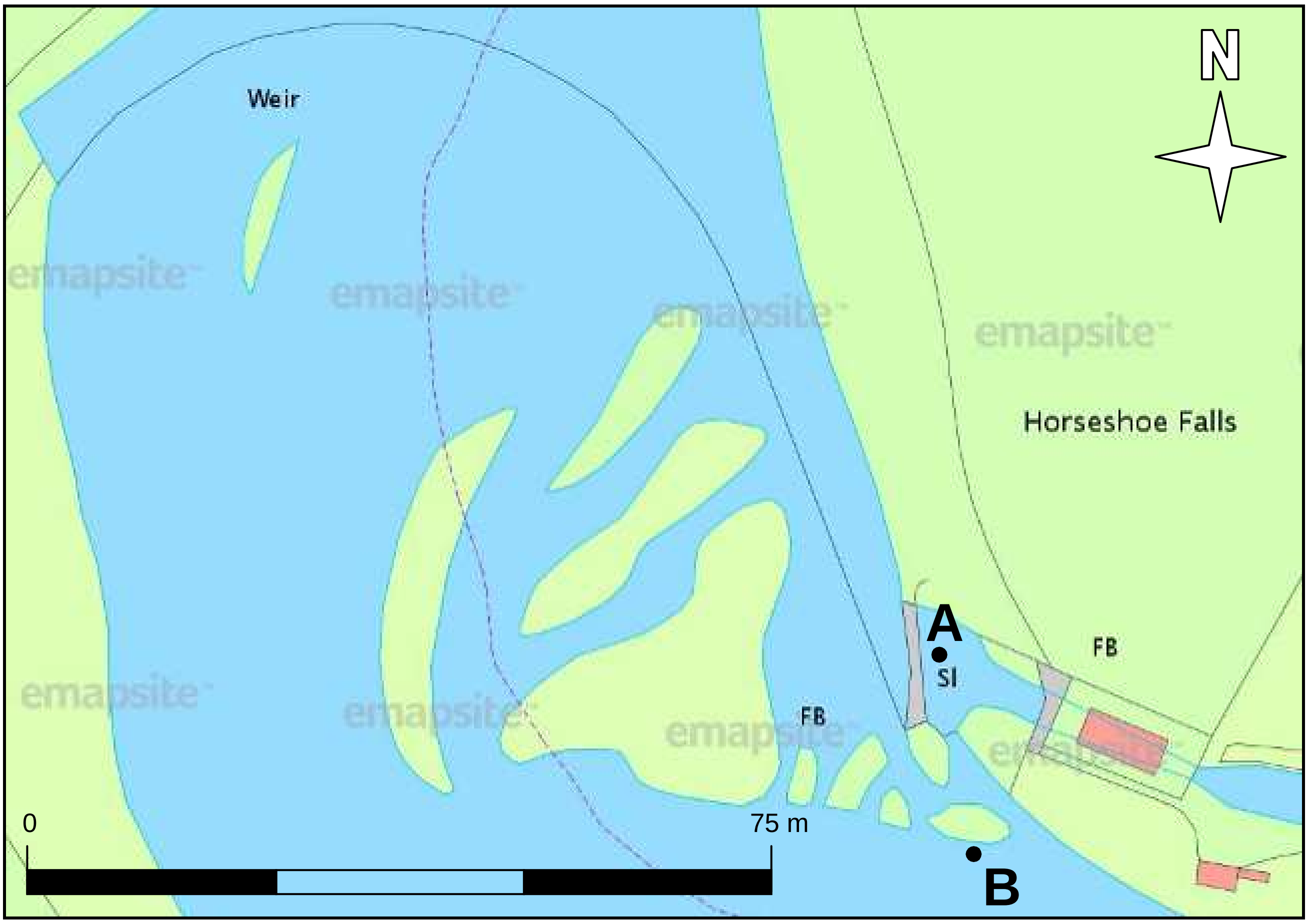


Figure 21 – Map of site. Scale is approximate. Gross head was measured between points A and B.

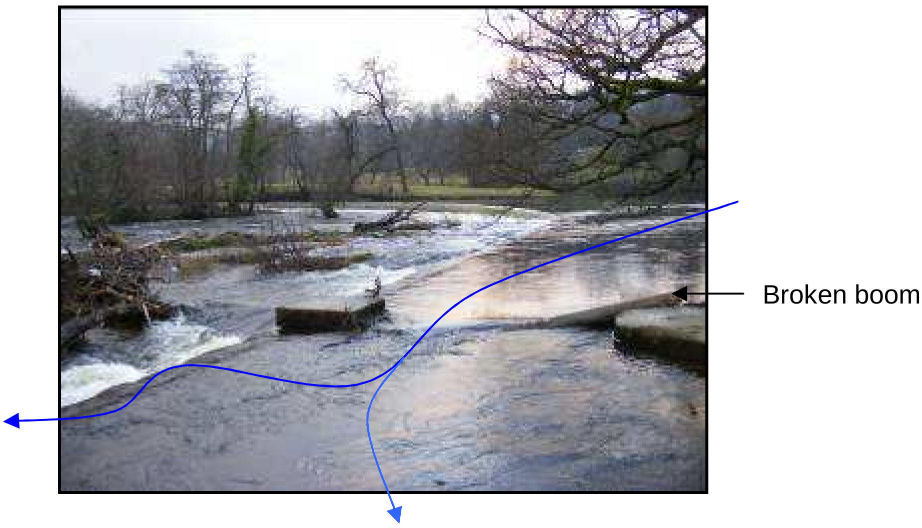


Figure 22 – Boom (broken) just upstream of British Waterways intake.

Figure 23 – Intake screens at entrance to British Waterways installation.

Figure 24 – Existing British Waterways installation, taken from other side of river.

Figure 25 – pump house, pound and footpath.

Figure 26 – Canal abstraction (left), pound clearance sluice (middle), River Dee (right).

Figure 27 – Pound clearance sluice with sluice gate in concrete dam.

Figure 28 – Provision for stoplog boards in pound.

Figure 29 – Close up of stoplog board slots in pound clearance sluice.

Figure 30 – 10 mm and 4 mm screens used for part of the year.

Figure 31 – Recent (last 20 years) flood level according to British Waterways operative.

4.2. Legal requirements

4.2.1. Environment Agency consents and licences

A preliminary enquiry (WR48) form will be sent to the Environment Agency if this scheme is chosen for further work. A permitting officer will usually respond to a preliminary enquiry within five months of submission.

The scheme will require land drainage consent. It may also require an impoundment licence and/or an abstraction licence.

The Environment Agency's good practice guide indicates a preference for 'on-weir' schemes, such as is proposed here.

It is hoped that no fish pass would be required in this instance, given the on-weir position of the proposed scheme, the position of the existing intake screens, the relatively small abstraction proposed (see figure 20), and the difficulty of incorporating a fish pass into the scheduled ancient monument that includes both the weir and the masonry of the British Waterways installation. If a fish pass were required, the scheme would probably not be feasible. The Environment Agency will advise on precisely what provision, if any, is necessary for fish passage.

The hydropower system intake would need to be screened. The existing screens in the British Waterways installation exceed the screening requirements for an Archimedean screw, so no changes to the existing screening regime would be required. A third abstraction from the pound would cause the screen approach velocity to increase. The implications of this on system sizing and operation are discussed in section 4.3.1.1.

Behavioural screens are unlikely to be required at the downstream end of the hydropower system because of the near impossibility of upstream passage through the screw into the pound. The hydropower system would be designed so that it would have minimal impact on the biodiversity of the river. Safe downstream fish passage would be possible through the turbine for any fish that happened to find their way into the pound, e.g. via the canal.

4.2.2. Planning permission

The weir (and the adjacent stone-lined pound) is a Grade II listed structure. It is listed as a fine early C19 weir, part of one of the earliest river regulation schemes carried out in Britain and of group value with other listed structures on the Llangollen Canal. Listed building consent would be required before any work took place.

4.3. Design

4.3.1. Civil design

The existing weir, pound and intake screens are well maintained and could support a small hydropower system with no major changes to the structures already in place.

The proposed system would be sited in the pound clearance sluice, in place of the concrete dam in figure 26. The existing sluice gate would be moved from the centre to the edge of the sluice to allow space for the installation of the turbine.

4.3.1.1. Intake screens

A screen approach velocity of 0.25 m/s would be the likely maximum the Environment Agency would allow. This implies a maximum flow through the screens of 2.518 m3/s, assuming 50 % blockage and a screen area of 20.14 m^2. The intake screens currently pass up to 26 Mgal/day, equivalent to 1.367 m^3/s. An additional flow of up to 1.150 m3/s would therefore be available for hydropower at the site.

It is unlikely that Cadw would allow intake screen cleaners to be installed on site. Cadw are the organisation who deals with listed structures such as the Horseshoe Falls weir and they would be concerned about any proposed structure which could affect the aesthetics of the site. The screens would therefore require manual clearing at least once a day and more often during autumn.

Screens with 4 mm bar spacing are installed for two months of the year, from mid-February to mid-April, in order to discourage lamprey from entering the canal. These fine screens are particularly prone to clogging and need to be cleared every day, even with the relatively small flow that is currently abstracted through them. It is likely that the proposed hydropower system will have to be shut down for this period each year. This anticipated downtime has been accounted for in the capacity factor assumed in section 3.4.3. 10 mm screens are in place for a further four months of the year (mid-April to mid-August) and ~25 mm screens are in place for the remaining six months of the year.

4.3.2. Electromechanical design

4.3.2.1. Turbine

The recommended turbine for this site would be a 1.7 m diameter Archimedes screw turbine. Other turbine types, e.g. fixed flow propeller, would be technically feasible, but would require changes to the screening regime at the site.

4.3.2.2. Drive

The drive would be a gearbox coupled via a high speed belt drive to the generator.

4.3.2.3. Generator

A variable speed Archimedes screw would use an inverter connected, permanent magnet, synchronous generator and could be initially grid connected, but later retrofitted with a second, stand-alone inverter to enable operation during power cuts if this were desired.

4.3.2.4. Grid connection (via mains connection unit)

The hydro system would connect to the grid under the G59 specification.

The best value location for connection would be the existing three-phase installation in the British Waterways pump house.

4.3.3. Whole system design

4.3.3.1. System layout

Figure 32 shows a plan of the proposed system layout, the aim being to show the different elements of the system in context.

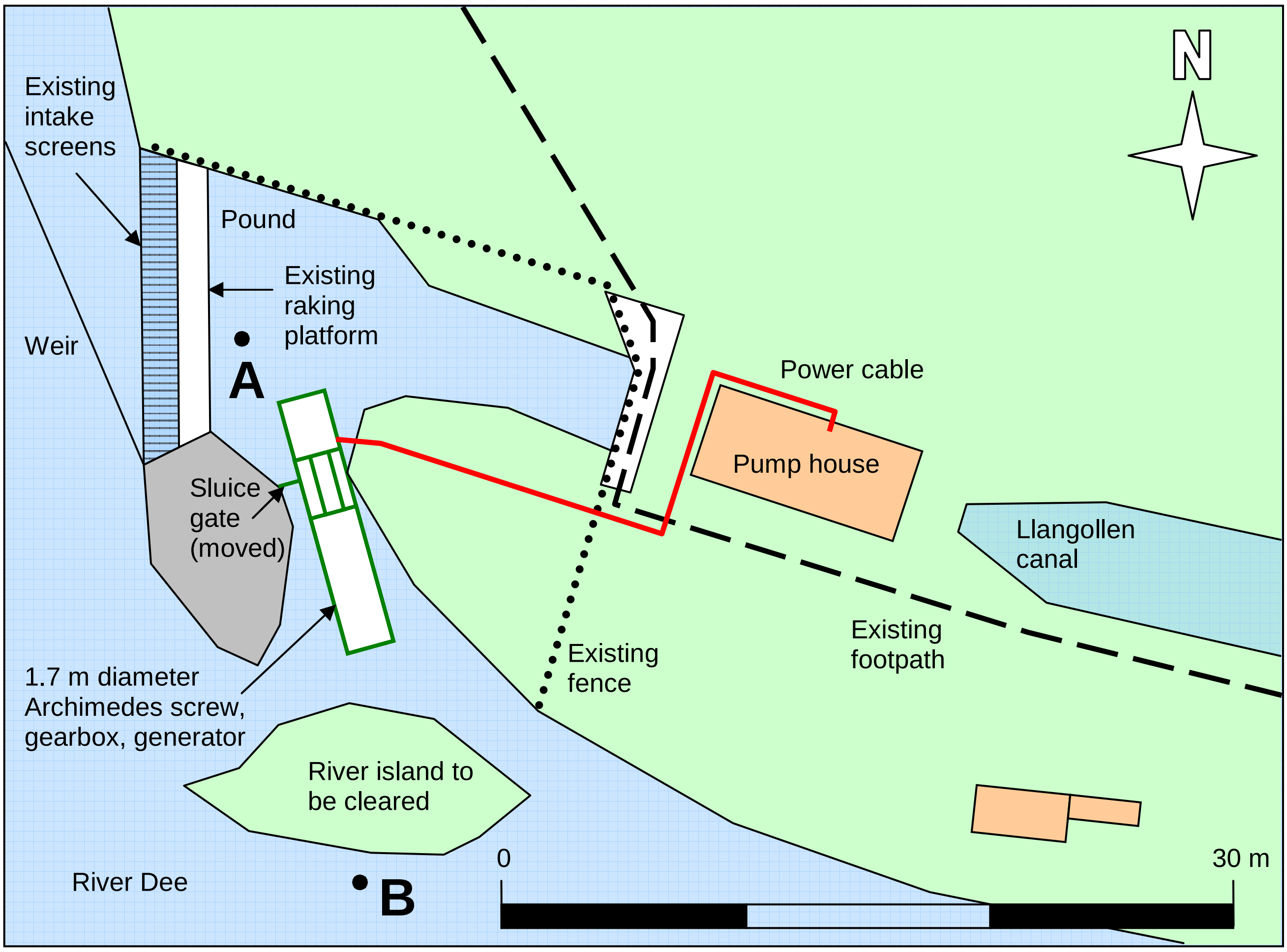


Figure 32 – Proposed system layout. Scale is approximate. Gross head measured between points A and B.

4.4. Annual Energy Production

4.4.1. Annual energy production

The rated power, or maximum electrical power, is calculated as follows:

Rated power = net head
× rated flow
× acceleration due to gravity
× density of water
× system rated efficiency

= 1.778 × 1.150 × 9.81 × 1000 × 0.6

= **12.0 kW.**

Annual energy production is then calculated as follows:

AEP = rated power
× number of hours in a year
× capacity factor

= 12.0 × 8760 × 0.5

= **52,650 kWh/year.**

4.5. Financial Analysis

4.5.1. Benefits

4.5.1.1. Financial benefits

The value of generated electricity is made up of an export/offset value, plus a Feed-in tariff (FIT), plus a Levy Exemption Certificate (LEC). Assumed values for these parameters are given in table 12.

4.5.1.2. Social and environmental benefits

Every kWh of electricity produced by the hydropower system would offset a kWh produced by conventional means (mainly coal and gas). This gives rise to avoided CO_2 emissions as shown in table 12.

In addition to this, use of renewable resources lessens our reliance on finite supplies of fossil fuel and thus contributes to energy security.

4.5.2. Costs

Estimates of project cost are given in table 13, together with items already ordered/completed.

4.5.3. Analysis

4.5.3.1. Results

Table 12 shows the base case financial analysis. Green and orange cells show inputs to the analysis and intermediate results. Red cells show outputs.

Financial parameter	Value	Unit
Turbine	Archimedes screw	
Lifetime	20	years
Estimated electricity export/offset value	5.00	p/kWh
Feed-in tariff (FIT) value	19.90	p/kWh
Levy exemption certificate (LEC) value	0.46	p/kWh
Capital expenditure	148,647	£
Annual operating expenditure	1,300	£/year
Generated electricity after all losses	52,646	kWh/year
Value of generated electricity	13,351	£/year
Projected import base price one-off increase	0	%
Projected (cash flow) inflation (FIT is RPI linked)	2	%
Discount rate	5	%
Internal rate of return	**7.2**	**%**
Simple payback time (inflation = discount = 0 %)	12	years
Complex payback time (at 5 % discount rate)	16	years
Net present value (at 5 % discount rate)	31,619	£
Environmental parameter	**Value**	**Unit**
Avoided CO2 emissions per kWh generated	0.000537	tCO2/kWh
Avoided CO2 emissions	28	tCO2/year
Homes provided for	12	

Table 12 – Base case financial analysis.

CAPITAL EXPENDITURE			
Phase	**Work items**	**Description**	**Cost / £**
			Archimedes screw
	Preliminary site assessment	Site surveys, report writing and meeting to decide which schemes to progress.	4,097
Feasibility phase	Feasibility study	Project management of feasibility phase	
		Update outline design.	
		EA process part 1: Submit WR48 preliminary enquiry form and supporting material to Environment Agency. Liaison with Environment Agency.	
		Site meeting with Environment Agency and survey site in more detail.	
		Network analysis: electrical test at proposed connection point, connection estimate. Liaison with Distribution Network Operator.	
		Liaison with local planning authority.	
		Detailed design of hydro system.	
		Feasibility study report.	
		Apply for Environment Agency licences and consents.	9,900
Development phase	Project management of development phase		2,500
	EA process part 2	Follow up applications made in EA process part 1 and obtain licences and consents, including land drainage consent.	1,500
	Planning	Planning application for hydropower system.	1,000
		Planning Application fee.	*335*
	Final development phase report	Update detailed design to EA and planning authority requirements.	2,500
		Obtain quotes for installation phase.	1,200
		Updated revenue estimate, updated financial analysis.	1,200
Installation phase (including commissioning)	Project management of installation phase		3,000
	Civil works (materials and delivery)	Turbine support structure.	10,000
	Civil works (labour)		10,000
	Electromechanical works (materials and delivery)	Turbine, drive, generator, brake, control system, inverters, relays, level sensor, sluice gate, total generation meter, cable, ancillary items.	91,415
	Electromechanical works (labour)		10,000
	TOTAL		**148,647**

Table 13 – Project cost estimates.

5. Mile End Mill

5.1. Resource

5.1.1. Head

Gross head was measured to be 2.712 m between the water levels at points A and B in figure 34.

Net head would be approximately 90 % of gross head, i.e. **2.441 m**.

5.1.2. Flow

Figure 33 shows the flow duration curve for Mile End Mill.

The area under the curve represents the volume which passes down the river in a typical year.

The area marked grey represents the volume likely to be diverted through a hydropower system at Mile End Mill in a typical year. This would only be a small proportion of the mean flow available for hydropower, because the civil structures already in place effectively limit the size of system that could be installed.

Table 14 lists the vertices of a polygon which represents the catchment between the site and the gauging station at Manley Hall. A LowFlows analysis of this catchment polygon was made and the resulting flow duration curve was then subtracted from that at Manley Hall to give the flow duration curve for the site as shown in figure 33 and summarised in table 15.

Easting	Northing
334900	341400
332000	335700
326500	333200
323900	333100
322600	335000
314800	330900
307900	333900
311800	339500
314600	339500
316500	339400
317100	339900
319900	341500
319900	343500
320800	342800
321300	344700
322700	344900
324400	348800
332000	343200
334100	343000

Table 14 – Mile End Mill to Manley Hall catchment polygon.

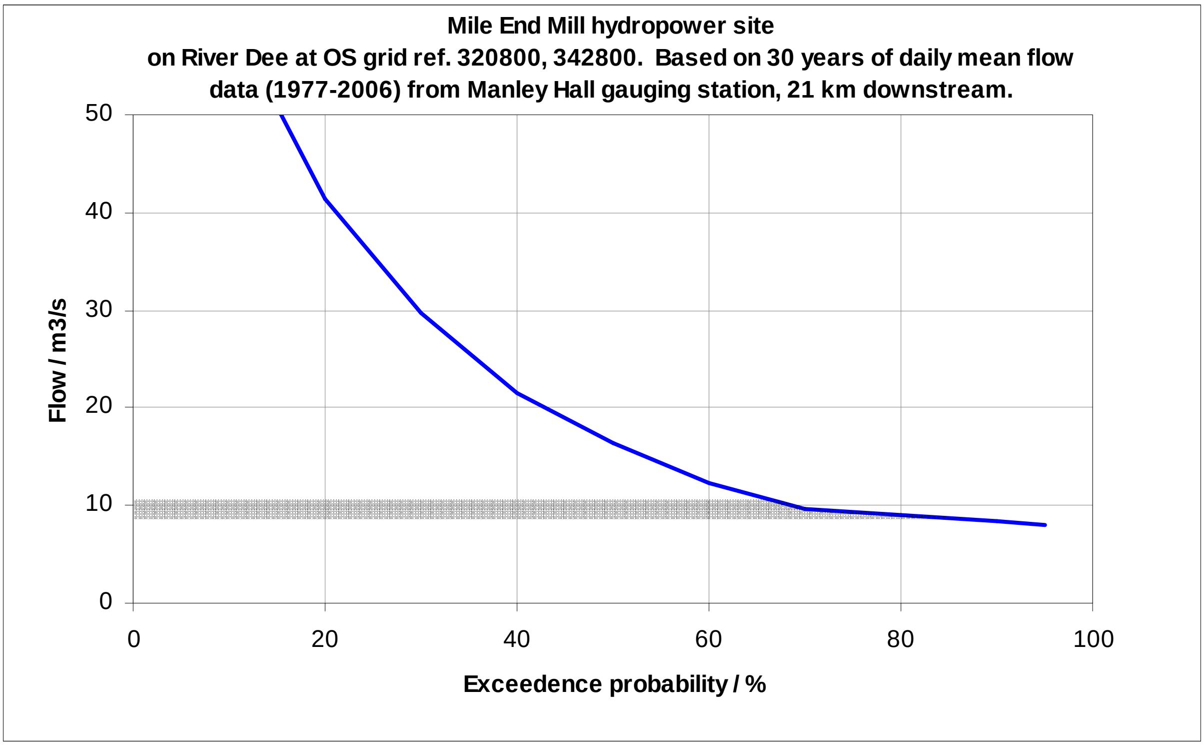


Figure 33 – Flow duration curve for Mile End Mill.

Percentage Exceedence / %	Flow / m³/s
Q_5	79.09
Q_{10}	60.22
Q_{20}	41.37
Q_{30}	29.71
Q_{40}	21.50
Q_{50}	16.35
Q_{60}	12.29
Q_{70}	9.72
Q_{80}	8.93
Q_{90}	8.36
Q_{95}	8.09
Q_{mean}	$Q_{33.1}$ = 26.85

Table 15 – Summary of annual flow duration at Mile End Mill.

5.1.3. Existing Infrastructure

Mile End Mill is located on the western bank of the river Dee at OS grid reference 320800, 342800. Originally a woollen mill, it was damaged by fire some time before WWII. The old stone building was then rebuilt of brick and stone salvaged from the old building. During WWII it became a munitions factory and after the war until its closure in the mid 1970s, it was a sheet metal works producing farm equipment for companies like Jones Balers and accessories for Black and Decker and many other companies. The factory traded under the name of Deeside Broadhurst Ltd. It now houses among other things a canoe manufacturing enterprise and a canoe shop.

In the past, a turbine beneath the mill buildings provided power to run the mill. It was not possible to access the turbine, or the culvert which runs under the mill buildings and car park on the day of the site visit. Access to the turbine is via the canoe shop and involves taking part of the carpet up! The intake to the culvert, just upstream of the car park and the tailrace exit were both blocked, so it was not possible to access the culvert from either end. All that is known of the culvert is that it is reported to be 12 feet high and 8-10 feet wide.

The existing weir is shown in figures 34-41. A rock stratum in the riverbed forms the basis for the weir, which has then been modified in places by the addition of brick (figure 36) and concrete (figure 37) to form a structure with a uniform crest level. The weir once extended right across the channel, but now only the western half is intact. The eastern half appears disrupted. It was probably modified at some point to ease upstream fish passage.

The upstream water level measured on the day of the site visit was only 245 mm below the crest of the weir at its western edge, probably not much lower than when the turbine was operational.

The old turbine is reported to be a vertical axis machine, with a lower bearing that is probably made of lignum vitae – a hard, dense, self-lubricating wood that is useful for underwater bearing applications.

There is good access from the main road to the car park.

Figures 34-42 show views of the main channel, its banks and impoundments. Figure 43 shows the electrical installation in the canoe manufacturing workshop.

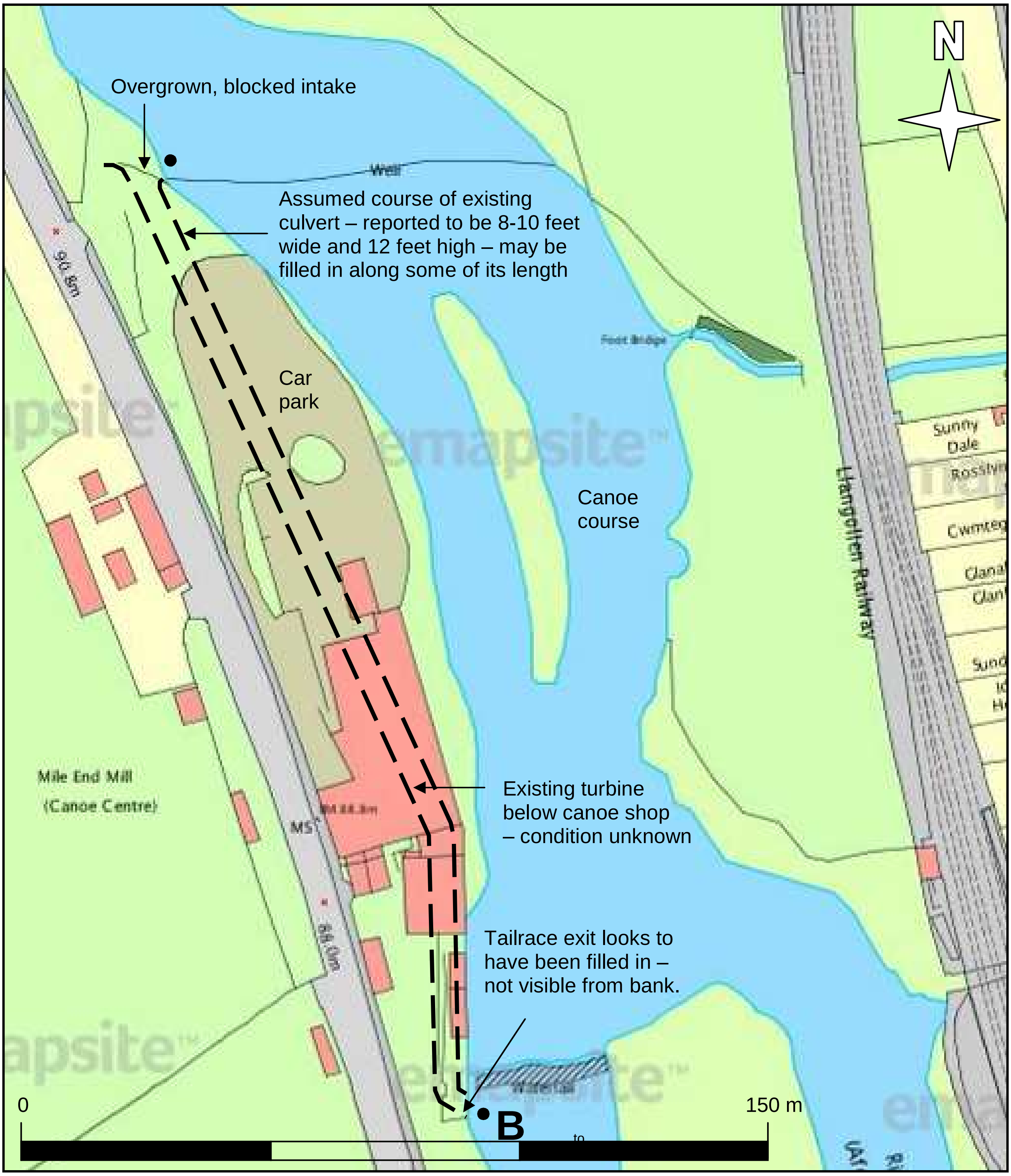


Figure 34 – Map of site. Scale is approximate.

Figure 35 – View upstream from top floor of mill.

Figure 36 – Intact part of weir where it meets the western bank.

Figure 37 – Intact part of weir extending out into river.

Figure 38 – Disrupted part of weir.

Figure 39 – Curved masonry structure in western bank adjoining western end of weir. Leat intake would have been immediately to the left of this.

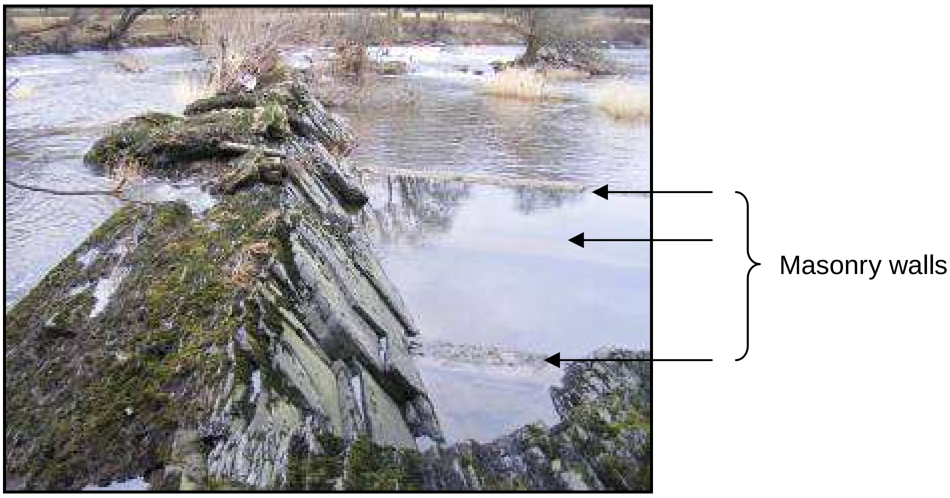


Figure 40 – Historic fish pass? Three masonry walls step down in height below the weir at its western edge.

Figure 41 – Leat intake.

Figure 42 – Waterfall at downstream end of site.

Figure 43 – Existing electrical installation in canoe manufacturer's workshop.

5.2. Legal requirements

5.2.1. Environment Agency consents and licences

A preliminary enquiry (WR48) form will be sent to the Environment Agency if this scheme is chosen for further work. A permitting officer will usually respond to a preliminary enquiry within five months of submission.

The Environment Agency has recently issued a hydropower good practice guide, which is a useful reference. This guide indicates a preference for 'on-weir' schemes, such as is proposed here.

It is hoped that no fish pass would be required in this instance, given that the weir at the upstream end of the site has already been largely removed, meaning the depleted reach, which would be carrying the vast majority of the flow (see figure 33), does not currently present an artificial impediment to fish passage. If a fish pass were required, the scheme would probably not be feasible. The Environment Agency will advise on precisely what provision, if any, is necessary for fish passage.

The hydropower system intake would need to be screened. Screens may also be required at the downstream end of the hydropower system. The hydropower system would be designed so that it would have minimal impact on the biodiversity of the river.

The scheme will require land drainage consent. It may also require an impoundment licence and/or an abstraction licence. The likelihood of obtaining the necessary licences will be discussed in particular detail with the permitting officer.

5.3. Design

5.3.1. Civil design

Civil design is a large unknown in this case, as access to the culvert which runs under the mill was not possible on the day of the site visit. From what can be seen, it is clear that substantial amounts of earth and rubble would need to be removed from both the intake and the tailrace exit. In addition, both ends of the culvert would need to be modified, especially at the tailrace end, where the riverbank has been extended into the channel and probably now covers the old tailrace exit.

Some repairs may be necessary to the culvert, once opened.

Given the current feed-in tariff arrangements, it would be more cost effective to remove the existing turbine and install a new one in its place, though this may change with time. Assuming a new turbine was installed, the civil works would need to be modified to support this.

The cost of reopening, repairing and modifying the culvert and the flow it can convey once open are critical factors in determining the feasibility of the scheme. For the purpose of this preliminary site assessment, an operational flow of 2 m^3/s has been assumed as a reasonable flow to expect the culvert to convey, though it should be noted that a flow of up to 26.85 m^3/s, that is the mean flow in the river at this point, is available for hydropower. This means that if the culvert can convey more than 2 m^3/s, then the rated power, energy capture, and revenue would all increase. The cost would also increase, but not by as much as the revenue because of economies of scale.

Substantial further work, including a survey of the culvert, would be necessary as part of the feasibility study stage in order to determine cost and revenue estimates with greater accuracy.

5.3.1.1. Intake screens

A screen approach velocity of 0.25 m/s would be the likely maximum the Environment Agency would allow. Assuming an operational flow of 2 m^3/s, this means an intake screen area of 8 m^2 would be required. There is no maximum approach velocity applicable to tailrace screens, so the area required could be reduced to some extent.

Assuming a new Archimedes screw turbine were installed, screens with a bar spacing of 100 mm would be adequate.

5.3.2. Electromechanical design

5.3.2.1. Turbine

Assuming an operational flow of 2 m^3/s and assuming no change to the current feed-in tariff arrangements, the recommended turbine for this site would be a 2.4 m diameter Archimedes screw turbine. Other turbine types, e.g. Kaplan or fixed flow propeller, or indeed possible refurbishment and reuse of the existing Francis turbine, may all be technically feasible, but would require a much more demanding screening regime at the site.

If the Department for Energy and Climate Change ever agree a suitable feed-in tariff band for refurbished turbines, then refurbishment and reuse of the original Francis turbine may be worth investigating further, but for the purpose of this report, the above Archimedes screw turbine is assumed.

5.3.2.2. Drive

The drive would be a gearbox coupled via a high speed belt drive to the generator.

5.3.2.3. Generator

A variable speed Archimedes screw would use an inverter connected, permanent magnet, synchronous generator and could be initially grid connected, but later retrofitted with a second, stand-alone inverter to enable operation during power cuts if this were desired.

5.3.2.4. Grid connection (via mains connection unit)

The hydro system would connect to the grid within the building under the G59 specification.

5.3.3. Whole system design

5.3.3.1. System layout

Figure 44 shows a plan of the proposed system layout, the aim being to show the different elements of the system in context.

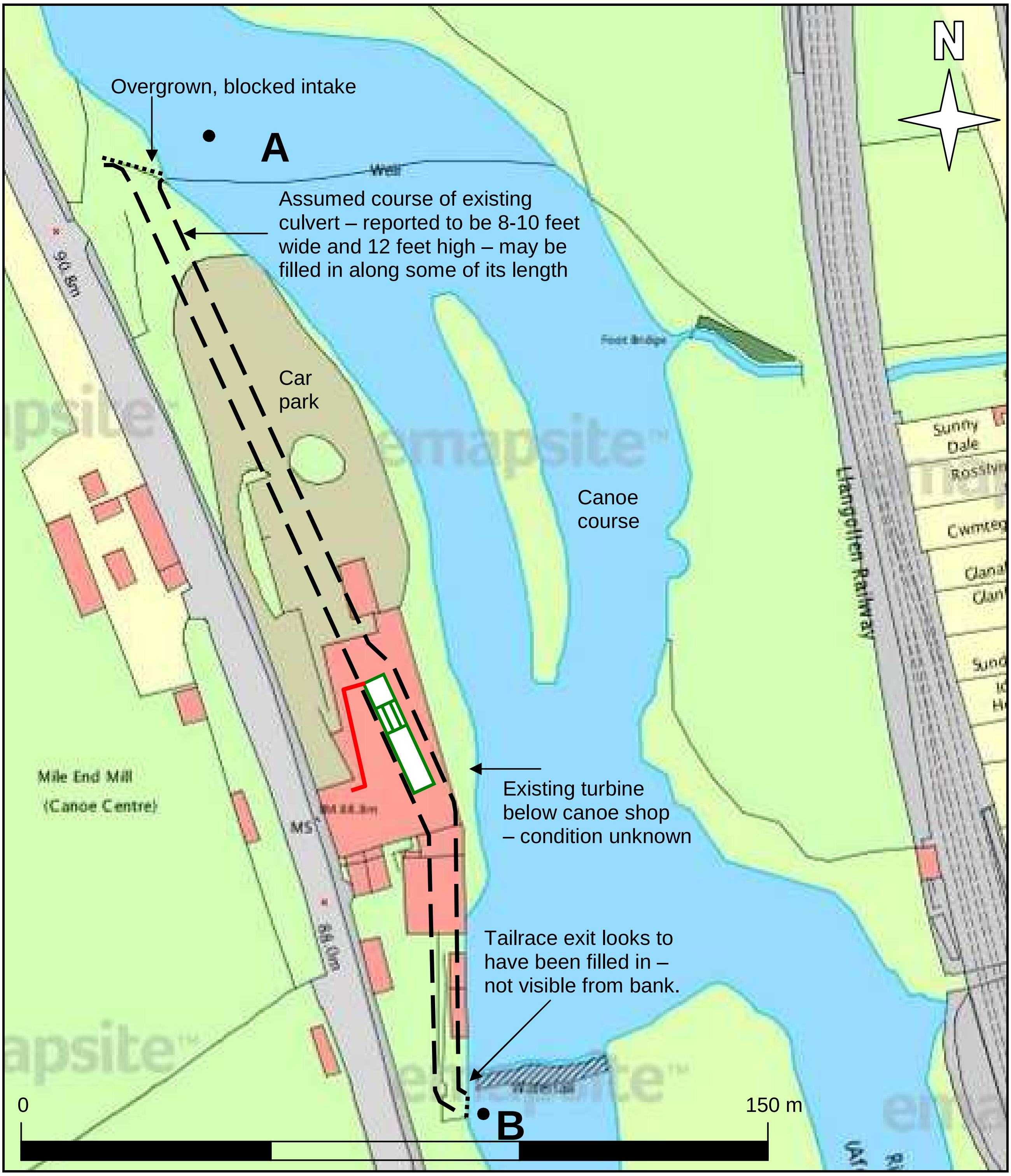


Figure 44 – Proposed system layout. Scale is approximate. Gross head was measured between points A and B.

5.4. Annual Energy Production

5.4.1. Annual energy production

The rated power, or maximum electrical power, is calculated as follows:

Rated power = net head
× rated flow
× acceleration due to gravity
× density of water
× system rated efficiency

= 2.441 × 2 × 9.81 × 1000 × 0.6

= **29 kW.**

Annual energy production is then calculated as follows:

AEP = rated power
× number of hours in a year
× capacity factor

= 12.0 × 8760 × 0.5

= **125,861 kWh/year.**

5.5. Financial Analysis

5.5.1. Benefits

5.5.1.1. Financial benefits

The value of generated electricity is made up of an export/offset value, plus a Feed-in tariff (FIT), plus a Levy Exemption Certificate (LEC). Assumed values for these parameters are given in table 17.

5.5.1.2. Social and environmental benefits

Every kWh of electricity produced by the hydropower system would offset a kWh produced by conventional means (mainly coal and gas). This gives rise to avoided CO_2 emissions as shown in table 17.

In addition to this, use of renewable resources lessens our reliance on finite supplies of fossil fuel and thus contributes to energy security.

5.5.2. Costs

Estimates of project cost are given in table 16, together with items already ordered/completed.

CAPITAL EXPENDITURE			
Phase	**Work items**	**Description**	**Cost / £**
			Archimedes screw
Feasibility phase	Preliminary site assessment	Site surveys, report writing and meeting to decide which schemes to progress.	4,097
	Feasibility study	Project management of feasibility phase	
		Update outline design.	
		EA process part 1: Submit WR48 preliminary enquiry form and supporting material to Environment Agency. Liaison with Environment Agency.	
		Site meeting with Environment Agency and survey site in more detail.	
		Network analysis: electrical test at proposed connection point, connection estimate. Liaison with Distribution Network Operator.	
		Liaison with local planning authority.	
		Detailed design of hydro system.	
		Feasibility study report.	
		Apply for Environment Agency licences and consents.	9,900
Development phase	Project management of development phase		2,500
	EA process part 2	Follow up applications made in EA process part 1 and obtain licences and consents, including land drainage consent.	1,500
	Planning	Planning application for hydropower system.	1,000
		Planning Application fee.	*335*
	Final development phase report	Update detailed design to EA and planning authority requirements.	2,500
		Obtain quotes for installation phase.	1,200
		Updated revenue estimate, updated financial analysis.	1,200
Installation phase (including commissioning)	Project management of installation phase		3,000
	Civil works (materials and delivery)	Disposal of spoil from leat, leat lining, turbine support structure, screens. Disposal of old turbine.	70,000
	Civil works (labour)	Removal of old turbine, clearance and lining of leat, site preparation.	75,000
	Electromechanical works (materials and delivery)	Turbine, drive, generator, brake, control system, inverters, relays, level sensor, sluice gate, total generation meter, cable, ancillary items.	130,065
	Electromechanical works (labour)		10,000
	TOTAL		**312,297**

Table 16 – Project cost estimates.

5.5.3. Analysis

5.5.3.1. Results

Table 17 shows the base case financial analysis. Green and orange cells show inputs to the analysis and intermediate results. Red cells show outputs.

Financial parameter	Value	Unit
Turbine	Archimedes screw	
Lifetime	20	years
Estimated electricity export/offset value	5.00	p/kWh
Feed-in tariff (FIT) value	17.80	p/kWh
Levy exemption certificate (LEC) value	0.46	p/kWh
Capital expenditure	312,297	£
Annual operating expenditure	2,900	£/year
Generated electricity after all losses	125,851	kWh/year
Value of generated electricity	29,273	£/year
Projected import base price one-off increase	0	%
Projected (cash flow) inflation (FIT is RPI linked)	2	%
Discount rate	5	%
Internal rate of return	**7.7**	**%**
Simple payback time (inflation = discount = 0 %)	12	years
Complex payback time (at 5 % discount rate)	15	years
Net present value (at 5 % discount rate)	82,209	£
Environmental parameter	**Value**	**Unit**
Avoided CO2 emissions per kWh generated	0.000537	tCO2/kWh
Avoided CO2 emissions	68	tCO2/year
Homes provided for	29	

Table 17 – Base case financial analysis.

6. Motor Museum

The gross head at the Motor Museum site was measured to be 1.088 m, which is too low for a hydro system to be viable at this site. A weir rebuild to increase head would be expensive and very unlikely to be granted permission.

7. Lower Dee Mill

The gross head at the Motor Museum site was measured to be 1.041 m, which is too low for a hydro system to be viable at this site. A weir rebuild to increase head would be expensive and very unlikely to be granted permission.