Environment Agency

Avoncliff Weir- Comparison of Hydropower Schemes

Final Consultant's Report

5 February 2014

AMEC Environment & Infrastructure UK Limited

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Executive Summary

The Environment Agency is re-determining two water resource applications for hydropower at Avoncliff, Bradford on Avon. Two applicants have submitted competing applications for Impoundment Licences on a common weir. One application has been received for Weavers Mill and one for North Mill, both on the same weir.

The purpose of this report is to provide expert advice on the relative merits and disadvantages of each of the applications for impoundment licences. This is to assist a decision to be made by the Environment Agency on which scheme is the most environmentally sustainable and offers the greater long term public benefit.

The work has depended to a large extent on information supplied by the Environment Agency and by the applicants themselves and therefore the assessment is dependent on the quality and accuracy of this information received. Where information is incomplete or lacking, assumptions have been made based on the team's expertise and experience. These assumptions relate primarily to the scheme components, the proposed construction methods and method of operation.

A comparison of the two schemes has been undertaken based on a range of environmental and other factors identified in the Environment Agency's *Competing Hydropower Schemes* guidance document (2012).

On the basis of this comparison we advise that the most sustainable scheme and the scheme with most long-term public and environmental benefit is the Weavers Mill scheme. The report concludes that the main differentiators between the schemes lie in the areas listed below.

Energy Generation

The annual energy generated by the two schemes has been estimated using three different data sets describing the river flow and head. The approach taken has been to apply the three sets of data equally to both schemes. Two of the three estimates are based on the datasets supplied by the two applicants. The third (termed the 'final data set' in the report) uses a single head duration curve synthesised by AMEC, combined with a flow duration curve based on EA data from 1990 to September 2013.

We consider that both the data sets provided by the applicants are reliable enough to provide reasonable estimates suitable as the basis for a comparison of the two schemes. However we consider the third data set, which is based on a longer flow record together with a synthesised head duration curve, is the most reliable for comparing the schemes.

In our modelling we found that for all three data sets the electricity generation estimates for Weavers Mill were higher than for North Mill. We therefore conclude that the Weavers Mill scheme is likely to provide a higher annual energy output than the North Mill scheme.

Efficiency of Generation

The total annual flow for the Weavers Mill scheme is considerably less than that for North Mill scheme. For reasons summarised in Section 4.3.2 and discussed in Appendix C (and regardless of which data set is used) the Weavers Mill scheme would make more efficient use of the water than the North Mill scheme.

Carbon Footprint

For reasons summarised in Section 4.3.2 and discussed in Appendix C, the Weavers Mill scheme would save more carbon emissions that the North Mill scheme. The carbon footprint for the North Mill scheme is considerably higher than for the Weavers Mill scheme as it is estimated to contain a higher mass of steel and uses significantly more concrete to construct.

Flood Risk

For reasons summarised in Section 4.3.2 and discussed in Appendix C, the proposed North Mill scheme would cause an appreciable constriction in the available width of weir for flood conveyance with a potentially significant increase in flood levels. By contrast, the proposed Weavers Mill scheme would not significantly affect the conveyance of the weir under flood flows.

Contents

1. Introduction

1.1 Background

The Environment Agency (EA) is re-determining two water resource applications for Hydropower at Avoncliff, Bradford on Avon. Two applicants have submitted competing applications for Impoundment Licences on a common weir.

The purpose of this report is to provide expert advice on the relative merits and disadvantages of each of the applications for impoundment licences. This is to enable a decision to be made by the Environment Agency on which scheme is the most sustainable in environmental terms and offers the greater long term public benefit.

AMEC, supported by Duffin Associates, was commissioned to carry out this work. This work follows an earlier report by the same organisations that gave a preliminary estimate of the economic viability of the schemes.

The work has depended to a large extent on information supplied by the EA and by the applicants themselves and therefore our assessment is dependent on the quality and accuracy of this information received. Where information has been incomplete or lacking, assumptions have been made based on the team's expertise and experience. These assumptions relate primarily to the scheme components, the proposed construction methods and method of operation.

The assumptions are set out in Section 3 so that the basis of the comparative assessment can be clearly seen.

This report was originally prepared in April 2013 to support the EA's 'minded to' determination report. It has now been amended to take into account responses received from the applicants following issue of the EA's 'minded to' report.

1.2 Scope of Work

The scope of works comprises:

1. Reviewing the licence applications and all additional information submitted for development of hydropower at Weavers Mill and North Mill on a common weir at Avoncliff near Bradford on Avon;
2. Analysing the information and advising the EA of the merits and disadvantages of each scheme in terms of the factors listed in the Environment Agency's Competing Hydropower Schemes guidance and any other factors considered relevant to the particular impoundment licence applications in question;
3. Providing expert professional opinion on the relative merits and disadvantages of each application and then undertaking a comparison of the merits and disadvantages of one scheme against the other;

4. Providing a report detailing this work to enable the Environment Agency to determine which of the schemes is more environmentally sustainable and offers the greater long-term public benefit.

The work has comprised:

- Reviewing documentation provided by the Environment Agency and the applicants;
- A site visit to both applicants' sites on the same day (11th December 2012), accompanied by the respective applicants;
- Sourcing of existing baseline environmental information related to the site;
- Review of relevant generic environmental guidance;
- Sourcing of relevant technical data and technical guidance documents;
- Further technical and economic analysis of the two schemes;
- Consultation with the local authority;
- A visit to the factory premises of Weavers Mill applicant (30th August 2013);
- Production of this report.

1.3 Limitations

It should be noted that:

- This report is a technical document comparing the merits of the two schemes based on the EA's 'Competing Schemes Guidance' and where possible providing an expert professional opinion advising which of the two schemes is the most sustainable in environmental terms and provides the greater long term public benefit;
- The work has entailed reviewing documentation and background information provided by the applicants through the EA. This documentation has included scheme plans, drawings and any environmental information collated as part of their studies. Further details of capital and operating expenditure and other information were also requested from the applicants;
- A more detailed technical assessment has been undertaken for each scheme, using new information provided by the applicants where available. This has been used to inform estimates of energy generation and climate change impacts. Where new information was not forthcoming, then assumptions have been based on typical industry practice;
- The report does not reproduce any background information (except if needed to illustrate a key conclusion) or include any detailed calculations (again except to illustrate a point).

1.4 Report Structure

- **Section 2** sets out the evaluation methods and data sources used to carry out the assessment;
- **Section 3** describes the two schemes based primarily on information received from the applicants. Where information has been incomplete or lacking assumptions have had to be made based on the team's expertise and experience. These assumptions are clearly set out in this section and include the assumptions made as to scheme construction and operation;
- **Section 4** provides a comparison of the two schemes using a number of environmental, economic and sustainability criteria, primarily based on the EA's Competing Hydropower Schemes guidance. The comparison is set out in the form of a matrix provided in Appendix A and text on the key differentiators;
- **Section 5** gives the main conclusions;
- **Appendix A** contains the matrix used to compare the two schemes;
- **Appendix B** gives a list of the data sources used;
- **Appendix C** provides information on how the energy generation estimates were calculated and the data on which the estimates are based. Details of carbon footprint estimates are also given.

1.5 Study Team

The work has been carried out by a team led by AMEC Environment & Infrastructure with the following expertise:

- Bill Finlinson (Project Manager) – Water Resources and Flood Risk;
- David Kenyon – Planning and Sustainability;
- Tony Duffin – Energy Generation and Climate Change;
- Richard Boud – Renewable Energy Technologies;
- Glenn Richards – Aquatic and Terrestrial Ecology;
- Chris Prydderch – Environmental Impact Assessment.

2. Evaluation Methods and Data Sources

2.1 Evaluation Methods

2.1.1 Introduction

As set out in Section 1, AMEC was requested by the Environment Agency to provide a comparison of the merits and disadvantages of the proposed hydropower schemes at North Mill and Weavers Mill, Avoncliff, based on the factors identified in the EA's *Competing Hydropower Schemes* guidance document (2012) including those which are site and scheme specific. AMEC has also referred to the EA's *Hydropower Good Practice Guidelines (GPG)* document (2009) for further guidance in terms of evaluating the proposed schemes and their potential impacts on the local environment and population.

2.1.2 Competing Hydropower Schemes Guidance

Background

Due to recent increased interest in hydropower schemes, the Environment Agency deals increasingly with situations where hydropower schemes compete for the same site. To set out their general approach to such situations for the benefit of future applicants, the EA published their *Competing Hydropower Schemes* guidance document in December 2012 as a supplement to the advice provided in Section 5.1 of their *Hydropower GPG* 2009 document. The document sets out the EA's overall approach to hydropower schemes and identifies factors to be considered when choosing between competing schemes.

Summary of Key Considerations

In brief, the following issues are highlighted in the guidance document as being of particular importance to the EA when deciding which scheme (if any) should be licensed:

a. *The optimum use of available water resources considering for example (i) the amount of water used; (ii) the reasonable requirement for water (iii) the amount of power proposed to be generated and (iv) any adverse impacts in water resources terms.*

b. *Local and wider environmental effects of the proposed scheme. Such effects may be positive or negative and the effects considered might include, for example, changes in hydromorphology, other changes to water body status, changes to fish passage through inclusion of a fish pass, provision of appropriate screening and site layout design of the scheme to enable best measures for fish protection/passage.*

c. *Assessment and mitigation of flood risk of the proposed scheme both where a scheme requires consent from the Agency for works and in their role as adviser on flood risk with a duty to exercise a general supervision over all matters relating to flood risk.*

d. *Impact on other water users of the proposed scheme in terms of effects on protected rights of existing abstractors and lawful uses of water by others for* *agricultural, industrial, public supply or recreational purposes including fishing and on requirements of fisheries, navigation or land drainage.*

e. *The impact of the scheme in climate change terms, including both (i) carbon emissions saved by electricity generation, (ii) the amount of renewable energy generated and (iii) embedded carbon and the lifecycle carbon footprint of the scheme.*

2.1.3 Matrix Appraisal

In order to present a clear and comprehensive comparison of the two schemes, AMEC has devised a matrix-based approach to the appraisal. This allows the merits or otherwise of the two schemes to be examined side by side.

The results of the matrix appraisal are set out in Appendix A. The 'Factors' used are based on the two EA guidance documents quoted in Section 2.1.1 above. The appraisal has been based on a review of the proposed schemes according to details submitted by the applicants to the EA for consideration for water impoundment licences and subsequently, including a site visit to both schemes on 11th December 2012, a visit to the Weavers Mill applicant's factory premises on 30^{th} August 2013 and baseline information on the surrounding environment. Section 2.2 below details the sources of the data used in the preparation of this appraisal.

2.2 Data Sources

A complete list of information reviewed as part of this work and used to inform the appraisal of the proposed schemes is given in Appendix B. The key licence documents and information on the proposed schemes supplied by the applicants is given below.

2.2.1 North Mill

- WR23 EA Draft Licence Document, 2012;
- WR46 EA Draft Determination Report, 2012;
- Drawings (eWaterpower, 2012)*:*
  - Screw Sections 3-5-A3 (November 2012);
  - Plan2Screws3-6-A3 (November 2012);
  - Hydro Project Elevations 3-5-A3 (June 2012);
- "*Environmental Impact Statement*", "*Design and Access Statement*" and LVA by Brian Wooding, Chartered Landscape Architect (2011);
- Scoping Opinion, Archimedes Screw Renewable Energy Development at the North Mill, Avoncliff (Wiltshire District Council, 2012)[1];
- Untersuchungen zum ruckstau an der Wasserkraftschnecke (Typ RITZ-ATRO) der Fa. Okofish GmbH + Co. KG in Hoxter-Godelheim. November 2004 (colloquially

[1] NB This Scoping Opinion is based on a single Archimedes screw scheme, with the screw positioned either within the millrace or the weir structure. This is different from the twin screw scheme assessed in this report.

translated: Study of effect of tail-water backing-up on the performance of the Archimedes Hydro generator).

2.2.2 Weavers Mill

- WR23 EA Draft Licence Document, 2012;
- WR46 EA Draft Determination Report, 2012;
- Weavers Mill drawings (Renewables First, 2010):
  - WESD0002 Rev 3, Proposed Layout, Option 2;
  - WESD0003 Rev 1, Existing Sluice Layout;
  - WESD0004 Rev 1, Section A-A;
  - WESD0005 Rev 5, Upstream View.
- Performance curves for two ATL double-regulated Bulb Kaplan turbines.

A list of other data sources used to inform the appraisal is provided in Appendix B.

3. Assumptions

3.1 Introduction

This section describes the two schemes based as far as possible on information received from the applicants. Where information is incomplete or lacking, assumptions have been made based on the team's expertise and experience. These assumptions relate primarily to the scheme components, the proposed construction methods and method of operation. Operation and maintenance considerations are also considered briefly.

The assumptions are set out in this section so that the basis of our comparative assessment can be seen clearly. More detailed assumptions relating to the energy yield calculations and carbon footprint estimates can be found in Appendix C.

3.2 Scheme Descriptions

3.2.1 'Run-of River' Hydropower Schemes

All hydropower schemes have common elements. This report concerns 'run-of-river' hydropower at an existing weir and the common elements of such schemes are as follows:

- Upstream structures for controlling and channelling water safely into the scheme ('penstock', 'headrace', or 'leat' are typical terms used);
- Energy extraction equipment (typically a waterwheel or turbine of some type);
- Downstream structures for discharging water safely from the scheme ('tailrace', 'leat' or 'outflow' are typical terms used);
- Ancillary plant, machinery and equipment to ensure the safe, efficient and economic performance of the hydropower installation.

The specific details of the two schemes under consideration in this report are described below:

3.2.2 North Mill

The proposed North Mill hydropower scheme is described in various documents provided by the applicants and specifically drawings by eWaterpower; Hydro Project Elevations 3-5-A3 dated 1 June 2012, Screw Sections 3-5-A3 dated 19 November 2012 and Plan2Screws 3-6-A3 dated 19 November 2012. It is proposed to install two Archimedean screw turbines at the site, one of 2,700 mm diameter and the other of 3,600 mm diameter. Whilst these drawings provide some engineering detail we would expect some of the details to change should the scheme progress to a full design.

It is proposed as far as possible to construct the smaller of the two Archimedean Screws and ancillary equipment within an existing water wheel pit at the north end of the weir and adjacent to the old mill building. The configuration, size and shape of the installation appear to have been designed to minimise works to the weir and wheel pit. It is proposed to construct the larger of the two Archimedean Screws and ancillary equipment in an entirely new bay specifically built for this turbine. This will require works to the weir. A fish pass is also proposed to be sited to the south of the larger screw. The resulting width of the overall construction of twin screws and fish pass extends nearly 13 m across the weir from the north side of the river. The overall length of the construction is around 17 m (excluding trash screen) with roughly half the turbine structure located upstream and half downstream of the weir (see dimensions on drawing Plan2Screws 3-6-A3).

The turbine and associated structures are described below.

Screw Turbines

There are two screw turbines proposed at North Mill; a 2,700 mm diameter screw fitted into the space in the existing wheel pit and a 3,600 mm diameter screw in a new bay to the south of the wheel pit. The screws are of the same basic design but they have different performance parameters and peak rated power outputs as shown in Table 3.1.

Table 3.1 Screw Turbine Operating Characteristics

Screw	Location	Peak Water Flow	Peak Rated Power (Manufacturer's Figures)
2700mm diameter Screw	In existing wheel pit.	3.276 m^3/s	50kW electrical
3600mm diameter Screw	In new bay constructed within the weir.	6.757 m^3/s	105kW electrical

These figures are from documents supplied by the North Mill applicant and they bear the manufacturer's name 'Andritz'.

Each screw is manufactured and delivered as a single unit including the screw and a steel trough. This ensures the narrow gap between the rotating screw and the static trough is maintained accurately as this is important to maintain efficiency. The assembly is then lowered into a closely fitted rectangular cross section concrete bay and fixed in place. The bottom bearing passes loads into the concrete via a substantial plinth at the bottom of the bay. At the upper end the top bearing, gearbox and generator are supported on a concrete floor which in turn rests on the sides of the fore-bay. Water enters the screw under this floor after passing through the trash screen and through the sluice if it is open. In some installations water from Archimedean Screw Turbines can be witnessed as flowing out of the screw in 'pulses' in synchronism with screw 'blade' passing (both the large and small screws at Avoncliff are proposed to have four blades). The water flows into the bottom of the open concrete bay, around the bottom bearing plinth and then almost immediately discharges into the river.

The sluices are used to control water flow into the screws under certain circumstances (as noted below) but the majority of power control is achieved through speed control as both screws are to be variable speed machines. The variation of rotational speed enables the screw to maintain higher efficiency across a range of flows. The sluice and control gear are mounted to the upstream side of the concrete floor and bay sides.

At the upstream end, the rotating screw is supported by the upper bearing. The screw shaft continues upwards and connects to the input shaft of a speed-increasing gearbox which will be mounted about 1.5 m above the normal high water level. The output shaft spins at a considerably higher speed than the screw and is connected to a generator. The generated electricity leaves via power cables to a control cabinet mounted on the bank.

No independent performance data have been provided by the applicant.

Screening
A trash-screen is located upstream of the weir. It extends upwards from the bed of the river above the water level (where drawings refer to it as 'Protective 100 mm grille') to meet the underside of a horizontal concrete slab on which are mounted the screw top bearing, gearbox and generator. Horizontally, it extends from the northern river bank to meet the weir just south of the southern screw turbine. The screen is proposed to have 100 mm screen spacing to prevent large objects passing through the screws and causing damage. The area of the screen ensures a low water velocity through it to allow for removal of debris from the screen. It is understood that the screen is designed to be mainly self-cleaning with any large objects removed manually if they become lodged in the screen. In our energy estimates we have assumed the screen to be completely clear of debris and fouling. In practice, the bars will become fouled and therefore rougher than assumed and so our head loss calculations will be a slight under-estimate leading to a slight over-estimate of energy generation.

Sluice Gate
The flow of water into a screw turbine intake may be controlled using sluice gates. These are typically used under the following circumstances:

1. At low flows to prevent water flowing into the screws to ensure the weir remains wetted (this is essential to meet licence conditions);
2. At mid- to high-range flows to ensure that the appropriate volume flow of water is entering the appropriate screw so that the scheme operates efficiently (though the applicant states this volume flow will be controlled by variable speed operation);
3. At very high flows it can be used to prevent water and debris flowing through the screw (though the applicant states this will not be required as excess water may simply spill down the top of the screw. If this is true then the weir environment will be substantially changed at high flows);
4. At any time it can be used to prevent water flowing through the screw; for example for maintenance.
5. As an emergency stop measure so that water can be prevented from flowing through the screws under, for example, fault conditions. Drawings and other information from the screw manufacturer, Andritz, provided by the applicant in September 2013 clearly show an emergency top sluice (Schnellschlussklape).

In the variable speed screw turbines proposed at North Mill the power output of the turbine is largely controlled by its variable speed. However, it is important that the appropriate volume flow of water enters the screw so that it can operate efficiently and hence we would expect the sluices to be operated in such a way to ensure this is the case at high flows and certainly above the maximum volume flow through the two screws operated simultaneously)[2].

In many installations, once the river flow is greater than the maximum flow usable by the turbines then any further flow in the river spills over the weir. In a communication from the North Mill Applicant in June 2013, it is stated that after maximum flow has been reached through the screw, further water will spill down the sides of the screw potentially generating more electricity. We have no independent information to show if this would be expected to

[2] In the energy generation analysis we have assumed that the sluice is not used. This gives higher performance figures as there would be an additional head loss if the sluice were used to control water flows.

produce more electricity but our opinion is that it would be a very small increase in annual output if any and there is as much risk of it ‘drowning’ the screws so they produce less electricity. A further implication of additional spillage down the sides of the screw is that the weir would not receive this flow and so there would be a further environmental impact on the weir and weir pool generally. That is, less water will flow over the weir even at very high flows leading to an environmental impact.

Fish/Eel Pass Provision

A brush-furnished fish pass is proposed, although the specific design is not identified and would need to be agreed with Environment Agency. The fish pass is located alongside and to the south of the larger, southern screw turbine and extends a further 3 m out across the weir. Migratory fish may also swim and/or jump over the weir as is the case at present.

A separate eel pass is also proposed. This is located against the wall of the old mill and hence next to the smaller screw turbine at the north end of the weir. It is understood that a guard strip will separate the eel pass from turbulence associated with the scheme to maintain low flows favoured by elver migration.

It seems likely that many fish travelling downstream will enter and pass through the screws. To reduce the risk of some forms of damage to fish as they pass through the screws, rubber bumpers will be fitted to the leading edge of each blade, also maintaining the minimum gap width between the blades and the trough in which the screw rotates. The bumpers will be provided over the full height of the blade.

Grid Connection

The electricity generated by each screw passes to a control cabinet mounted on the bank. This includes equipment for converting the power to the appropriate frequency and voltage for grid connection. A transformer and switchgear may also be mounted on the bank as part of the grid connection equipment.

The electricity company concerned is Southern Electric Power Distribution (SEPD). This is the Distribution Network Operator (DNO) and is responsible for connections.

As the peak power output of the two screws operating together is over 50kW (they are rated at about 155kW peak) it will be required that the grid connection meets technical standard G59/2-1 of the UK electricity industry. The DNO will also require commissioning and witness tests to be carried out before automatic continuous operation can commence.

Export and import metering equipment will also be required to be fitted at a point agreed by the DNO.

We have been informed by the applicant that two possible grid connection routes are under consideration. It is understood that the most likely route is via a buried 11kV cable running alongside the property. We are told that there is also an existing wayleave for a 3-phase cable under the railway to a pole-mounted line (voltage not specified by the applicant) which has a transformer (which the applicant notes will have to be upgraded). Either type of connection is common practice. We note that until the connection offer has been made by the DNO, taken up and a deposit paid it does not guarantee that the hydro scheme can connect. This information is useful in demonstrating the degree of examination carried out in feasibility studies.

Access and Construction

We understand that the larger screw turbine may have to be delivered as a single ‘Abnormal Indivisible Load’ by virtue of its width and vehicle length. It would be prudent to consider the second turbine in this category and delivery on the same day would reduce disruption to traffic. We understand that the screw turbines, necessary cranes and other construction plant and materials can be moved into position at North Mill using public roads and making a final crossing of the railway as we understand North Mill has a right of way across the line next to the mill buildings. We note that a crane required to lift the 3600mm screw into position will require works to the riverbank and -bed (temporary lift platform) in order that its out-riggers can be firmly supported during this 15 m reach lift of 15 600 kg.

A typical construction plan would be:

- Ensure weir structure at screw locations is structurally sound and make good where not. We understand there is an undercut at the north end of the weir;
- Install coffer dams or similar to protect the working area;
- Bring necessary plant into position;
- Clear and repair wheel pit for 2,700 mm screw turbine;
- Construct concrete trough for new 2,700 mm screw turbine and eel pass in wheel pit;
- Construct concrete machinery floor above water level at top of trough and bottom bearing mount underwater at downstream end of trough;
- Excavate new site for 3,600 mm screw turbine and fish pass;
- Construct concrete trough for 3,600 mm screw turbine and fish pass;
- Construct concrete machinery floor above water level at top of trough and bottom bearing mount underwater at downstream end of trough;
- Convoy delivery of both screw turbines and crane;
- Position crane safely with out-riggers on solid supports ready for both lifts;
- Crane lift both screws into position;
- Install new sluice gear and control equipment for both screw turbines;
- Prepare weir and riverbed upstream of weir for trash screen;
- Install trash screen;
- Install electrical equipment and grid connection;
- Safety checks and commission ready for operation.

The overall process of construction is likely to take 6 to 9 months including an allowance for, for example, weather delays.

3.2.3 Weavers Mill

Weavers Mill is described in various documents provided by the applicant and specifically on a series of drawings by Renewables First Ltd, see below and Appendix B). They are not detailed engineering drawings but are scheme layouts with detail consistent with this stage of the development of the project. These drawings are dated 2010 but were revised in August 2013:

- WESD0002 Rev 3, Proposed Layout, Option 2;
- WESD0003 Rev 1, Existing Sluice Layout;
- WESD0004 Rev 1, Section A-A;
- WESD0005 Rev 5, Upstream View.

The Kaplan turbine and its ancillary equipment are to be constructed at the southern end of the weir next to the mill building. The turbine will be located immediately downstream of an existing sluice channel through the weir and works to the weir will be required to house the installation. A submerged 12.5mm trash screen and automatic chain cleaner will be installed inside the entrance to the sluice channel. Downstream the draft tube of the Kaplan bulb turbine will extend roughly 14.5m from the weir crest, with approximately the last 2m remaining under the normal water level in the river (drawing WESD0002 Revision 3).

The turbine and associated structures are described below.

Turbine

The turbine at Avoncliff is a doubly regulated Bulb Kaplan within a steel draft tube of varying cross-section and using steel of various thicknesses. This tube extends from within the existing sluice channel as far as the submerged outflow some 14.5 m downstream of the weir where water returns to the river. All the machinery is located within a water-tight, submerged containment (the Bulb). Occasional maintenance to equipment within the bulb requires the ‘wicket gates’ to be closed so no water is flowing in the tube and hence the turbine and machinery are not rotating and then access can be gained via a removable hatch above the water level. These non-rotating ‘wicket gate’ blades can be adjusted for pitch to control the way water flows onto the rotating blades which are also adjustable. This adjustment of fixed and rotating blades maintains very high efficiency across a wide range of flows. The rotating blades are mounted on a rotor which is connected to the input shaft of a speed-increasing gearbox. The output shaft is connected to a generator. The electricity generated leaves the bulb via power cables and is fed to a control cabinet and transformer mounted on the bank.

The whole mechanical engineering structure of turbine and draft tube will be supported on a concrete slab foundation. On the southern site of this is a concrete buttress wall to ensure the integrity of the weir etc at that end of the weir. At the northern side is the fish pass which doubles as a buttress wall and is also in concrete.

A control system which alters the pitch of the wicket gates and rotating blades manages start-up, power control during normal operation and shut-down. Once the maximum flow of 7.9m^3/s through the turbine has been reached then this control system prevents further flow through the turbine and any additional flow in the river will spill over the weir.

Whilst we have not been supplied with engineering drawings of this turbine we have witnessed a similar turbine for another hydro-power project under construction at the manufacturer’s site. The turbine was clearly a doubly regulated, bulb Kaplan.

No independent performance data have been provided by the applicant. However, since our analyses were carried out the applicant has provided performance curves “for two specific installations of the ATL Double Regulated bulb type Kaplan turbine (55 kW and 18 kW) using 6 pole asynchronous generators and single stage gearbox drive train”. We understand these data are for actual installed performance of two machines of the general type and design as proposed for Avoncliff.

We were asked to provide professional opinion on whether the performance indicated by the data is consistent with a Kaplan operating at the standards expected of a conventional Kaplan design. In our opinion the shape of the curves and the peak efficiencies all exhibit the behaviour we would expect to see for a well designed and performing doubly regulated Kaplan turbine of the outputs specified and are generally in line with data presented in peer reviewed, published texts.

Screening

A screen will be located within the sluice channel below the water to prevent debris and fish entering the turbine. The screen will be required to have 12.5 mm screen spacing to prevent downstream movement of fish of a size that may be damaged if they were to pass through the turbine. It will be fabricated from 5mm thick 50mm flat bar with 12.5mm gaps between each bar. An automatic chain-driven screen cleaner is to be provided, submerged below the water and called to operate when a pre-defined pressure difference is detected across the screen. This cleaner scrapes debris off the face of the screen thus ensuring full flow of water. Trash will flow across the top of the turbine tube via a trash channel.

Fish/ Eel Pass Provision

To the north of the turbine a separate baffle fish pass is proposed. Fish travelling downstream are intended to be generally directed towards the fish pass as the screen is angled in both horizontal and vertical planes to achieve this. Migratory fish may also swim and/or jump over the weir as is the case at present.

An eel pass is proposed to the southern edge of the river as they tend to travel near the banks.

Grid Connection

The electricity generated by the turbine passes to a control cabinet mounted on the bank. This includes equipment for converting the power to the appropriate frequency and voltage for grid connection. A transformer and switchgear will also be mounted on the bank as part of the grid connection equipment.

As the peak power output of the turbine is over 50kW (it is rated at about 100kW peak) it will be required to meet technical standard G59/2-1 of the UK electricity industry. The DNO will also require commissioning tests to be carried out before unmanned continuous operation can commence.

Export and import metering equipment will also be required to be fitted at a point agreed by the DNO.

We understand that the grid connection will use a buried cable (probably at 1.1kV or 11kV) running across land in front of the Cross Guns public house. It will connect using a tee joint in an existing 3-phase cable which is buried in land near the eastern side of the southern end of the aqueduct. This type of connection is common practice. We understand a grid connection offer has been made by the DNO though we do not know if this has been accepted or has lapsed. As for North Mill, this is useful but no guarantee of a connection.

Access and Construction

We understand the turbine will be delivered in components small enough to be transported on public roads in conventional transport vehicles under the aqueduct carrying the canal across the river at Avoncliff village. We also understand that the necessary cranes and other construction plant and materials can be moved into position at Weavers mill using public roads. Further, we also understand that a jack-up barge-mounted crane may be required to be located upstream of the weir for some installation operations and that this can be transported by public roads to a suitable loading-out point on the river bank in a park between the canal and river. It could then be moved downstream to the weir for craneage operations.

A typical construction plan would be:

- Ensure weir structure at turbine location is structurally sound and make good where not;
- Prepare intake region and fit stop-logs, potentially installing a coffer dam or similar whilst this is underway;
- Prepare weir and riverbed upstream of weir for trash screen;
- Bring necessary plant into position;
- Install trash screen;
- Prepare riverbed downstream of weir for concrete;
- Bring necessary plant into position;
- Pour concrete to create bay for turbine tube etc.;
- Mount turbine tube and components;
- Install electrical equipment and grid connection;
- Safety checks and commission ready for operation.

The overall process of construction is likely to take three to six months.

3.3 Scheme Operation

3.3.1 Assumed Flow Regimes

In assessing the schemes we have had to make some assumptions as to the flow regimes that will apply. This is based on the information provided and our experience of similar schemes elsewhere.

The assumed flow and operating regimes for the Archimedes screws and Kaplan turbine schemes are given in Table 3.2. The left hand column shows the flow in the river, increasing down the table.

For the North Mill scheme the second column shows how the Archimedean screws would respond/be operated and the third column shows the effect this would have on flow over the weir. The fourth column allows space for comment. Similar information is given for the Weavers Mill scheme.

The following key parameters have been adopted:

- Hands Off Flow (HOF) over the weir 0.951 m^3/s
- Permanent sweetening flow through Weavers Mill leat 0.162 m^3/s
- Start-up flow for Kaplan (required before turbine will generate) 0.45 m^3/s
- Start-up flow for smaller Archimedes Screw (see discussion below) 0.9 m^3/s
- Start-up flow for larger Archimedes Screw (see discussion below) 1.25 m^3/s
- Peak flow for Kaplan 7.9 m^3/s
- Design/Optimum Flow for Kaplan 7.0 m^3/s
- Peak flow for small 2,700mm Screw 3.276 m^3/s
- Peak flow for large 3,600mm Screw 6.757 m^3/s

For both turbines, we would expect start-up to be at roughly double the flow at shut-down. This is to avoid what are termed ‘hysteresis losses’ and related additional wear and tear caused by slight rises and falls in flow over short periods of time triggering short, often unproductive, running periods.

The Weaver’s Mill applicant notes that the Kaplan turbine will operate and generate at flows below 0.45m^3/s (approximately 0.2m^3/s is quoted). The applicant also notes that generation at such low levels is generally neglected in the energy generation calculation. We agree and have applied this approach to our estimates.

We would expect the screws to require higher start-up flows than the Kaplan turbine. This is because of their large mass and rotating inertia, the higher speedup ratio of their gearboxes and greater friction from the rubber bumpers on the blades running in the troughs. We would expect these start-up flows to be around 0.9m^3/s for the smaller 2,700mm screw and 1.25m^3/s for the larger 3,600mm screw though the turbines might continue running at lower flows than these.

The North Mill applicant has provided an email from the manufacturer stating that the screws ‘*normally using* (sic) *a min. flow of 5% to 10% of design flow*’. In the case of the 2,700mm screw, that would imply a minimum flow of 0.16m^3/s to 0.33m^3/s and for the 3,600mm screw a minimum flow of 0.34m^3/s to 0.68m^3/s. The statement in italics may not refer to start-up flow (the statement is unclear) and no information is provided on any power output at these low flows. In any event the input is likely to be only a few kilowatts of water power. Potentially this will give zero electrical output as the few kW generated will be absorbed merely keeping the screws, gearbox and generator rotating against friction.

Nevertheless, to test the impact of changing start-up flows, in the final modelling we have used a minimum flow of 0.16m^3/s for the 2,700mm screw and 0.34m^3/s for the 3,600mm screw for the start-up conditions. The results show the impact on energy generation is negligibly small, adding less than one percent to annual generation.

Table 3.2 Assumed Scheme Operation

Flow in River	North Mill – Archimedean Screw Response			Weavers Mill – Kaplan Turbine Response		
	Screws	**Weir**	**Comment**	**Turbine**	**Weir**	**Comment**
Reserve Flow, up to and including 1.113 m^3/s	No operation, sluice remains shut.	‘Reserve’ or ‘Wetting’ flow – same as existing weir flow with no hydro scheme present i.e. the same as river flow less 0.162 m^3/s leat sweetening flow.	No allowance made for potential reduction in weir flow due to flow through fish/eel passes.	No operation, sluice remains shut.	‘Reserve’ or ‘Wetting’ flow – same as existing weir flow with no hydro scheme present i.e. the same as river flow less 0.162 m^3/s leat sweetening flow.	No allowance made for potential reduction in weir flow due to flow through fish/eel passes.
Flow, between 1.113 m^3/s and 1.563 m^3/s	No operation as there is insufficient flow to start screws; sluices remain shut. Small screw needs ~0.9 m^3/s to start up.	Flow is the same as river flow less 0.162 m^3/s leat sweetening flow.	As above.	No operation as there is insufficient flow to start turbine, sluice shut. Kaplan needs ~0.45 m^3/s to start up.	Flow is the same as river flow less 0.162 m^3/s leat sweetening flow.	As above.
Flow, between 1.563 m^3/s and 2.013 m^3/s	No operation as there is insufficient flow to start screws; sluices remain shut. Small screw needs ~0.9 m^3/s to start up.	Flow is the same as river flow less 0.162 m^3/s leat sweetening flow.	As above.	Sluice opens, Kaplan turbine configures itself to allow volume flow = (actual flow – 1.113 m^3/s) and generation occurs.	Flow over weir falls back to 0.951 m^3/s.	This is a change as the weir flow would normally keep increasing as river flows increase. (No allowance made for potential reduction in weir flow due to flow through fish/eel passes).

Table 3.2 (continued) Assumed Scheme Operation

Flow in River	North Mill – Archimedean Screw Response			Weavers Mill – Kaplan Turbine Response		
	Screws	**Weir**	**Comment**	**Screws**	**Weir**	**Comment**
Flow above 2.013 m^3/s, below 5 to 6 m^3/s.	Small screw & its sluice configured to allow a volume flow = (actual flow – 1.113 m^3/s) into small screw and generation occurs.	Flow falls back to 0.951 m^3/s.	This is a change as the weir flow would normally keep increasing as river flows increase. (No allowance made for potential reduction in weir flow due to flow through fish/eel passes).	As above.	Flow remains at 0.951 m^3/s.	As above.
Flow reaches about 5 to 6 m^3/s	Economically best to swap from small screw to large screw. Large screw & its sluice configured to allow (actual flow – 1.113m^3/s) into large screw and generation occurs. Small screw stopped and its sluice closed.	Flow remains at 0.951 m^3/s.	Possible brief drop/surge over weir each time this happens as sluices change over. The small screw may have to stop to allow the large screw start. No allowance made for potential reduction in weir flow due to flow through fish/eel passes.	As above.	As above.	As above.
Flow above 5 to 6 m^3/s, below ~8.0 m^3/s.	Large screw sluice configured to allow a volume flow = (actual flow 1.113 m^3/s) into large screw and generation occurs. Small screw stopped and its sluice closed.	Flow remains at 0.951 m^3/s.	This is a change as the weir flow would normally keep increasing as river flows increase. No allowance made for potential reduction in weir flow due to flow through fish/eel passes.	As above.	Flow remains at 0.951 m^3/s.	As above.
Flow between ~8.0 m^3/s and below 9.01 m^3/s	Max flow through large screw so small screw comes back into operation. Both screws and their sluices control flows.	Flow remains at 0.951 m^3/s.	As above.	As above.	Flow remains at 0.951 m^3/s.	As above.

Table 3.2 (continued) Assumed Scheme Operation

Flow in River	North Mill – Archimedean Screw Response			Weavers Mill – Kaplan Turbine Response		
	Screws	**Weir**	**Comment**	**Screws**	**Weir**	**Comment**
Above ~9.01 m^3/s	Both screws in operation.	Flow remains at 0.951 m^3/s.	As above.	Max flow through Kaplan of ~7.9 m^3/s is reached.	Any flow above ~7.9 m^3/s passes over the weir or through the fish/eel passes.	This is a change as the weir would normally be passing more water at this river flow.
Above 9.01 m^3/s – below 11.146m^3/s	Both screws in operation.	Flow remains at 0.951 m^3/s. Weir backing-up beginning to reduce screws' output.	As above.	As above.	As above.	As above.
Above 11.146 m^3/s (Approx 25% of year), below ~75 m^3/s	Max flow through both screws (10.033m^3/s). Potentially may shut down due to weir backing-up and as output is significantly reduced whilst engineering loads increase.	Any flow above 11.146m^3/s passes over the weir or through the fish/eel passes. Weir backing-up causes significant reduction in head. Without a sluice water flows above that for maximum generation will continue to flow across the top of the screws.	This is a change as the weir would normally be passing more water at this river flow. Without a sluice there would be a substantial reduction in flows over the weir at high flows too as the sluice would otherwise prevent excess water flowing down the screws and so redirect across the weir	As above and output reduces as head drops.	As above and weir backing-up causes material reduction in head.	As above.
Flow above ~75 m^3/s Perhaps 5% of the year	The weir backs up and the head falls so that there is insufficient head for the screws to generate. Prudent practice would be for the sluices to be shut to protect screws.	All river flow now passes over the weir or through the fish/eel passes.	This is now as the situation would have been prior to the hydro scheme being operated.	As above.	As above.	As above.

Table 3.2 (continued) Assumed Scheme Operation

Flow in River	North Mill – Archimedean Screw Response			Weavers Mill – Kaplan Turbine Response		
	Screws	**Weir**	**Comment**	**Screws**	**Weir**	**Comment**
Flow above ~100 m^3/s, perhaps 1% of the year	As above.	As above.	As above.	The weir backs up and the head falls so that there is insufficient for the Kaplan to generate.	Sluice shuts to protect turbine. All flow passes over the weir and fish/eel passes.	This is now as the situation would have been prior to the hydro scheme being operated.

4. Comparative Appraisal

4.1 Environmental Context

The proposed hydropower schemes are located on opposite banks of the River Avon downstream of Bradford-on-Avon, Wiltshire, at the point at which the Avoncliff weir spans the river. The river at this point is designated as a Local Wildlife Site (Bristol River Avon LWS). The Kennet & Avon Canal LWS crosses the river by means of the Grade II* Listed Avoncliff Aqueduct approximately 125 m downstream of the weir.

Avoncliff railway station, serviced by the Bristol to Southampton line, is located adjacent to the northern bank of the river downstream of the North Mill scheme. The beer garden of Grade II Listed Cross Guns Inn meets the southern river bank downstream of the proposed scheme at Weavers Mill.

Both schemes lie within the Cotswolds Area of Outstanding Natural Beauty (AONB) and Barton Farm Country Park.

4.2 Appraisal Summary Matrix

The summary matrix provided in Appendix A presents a review of the potential merits and disadvantages of the proposed hydropower schemes at North Mill and Weavers Mill, and provides a comparison between the potential impacts of the two schemes. The factors considered in the table are based on the EA guidance documents noted in Section 2.

Where it is concluded that there is little or no difference between the two schemes for a particular factor then no further detail has been provided. However where further discussion is required, or where differentiators have been identified, these areas are covered in more detail in the following section.

4.3 Discussion

4.3.1 Ecology

The North Mill scheme has a greater flow capacity than Weavers Mill. North Mill therefore has the potential to narrow and/or delay the time period when flows over the weir permit and/or stimulate salmonid (and potentially cyprinid) migration past the weir to a greater extent than Weavers Mill. This difference may be exacerbated by water spilling over the sides of the North Mill scheme once it reaches capacity as opposed to flowing over the weir.

Both schemes incorporate a fish pass and the extent to which delayed and/or impeded migration is a difference between the effects of the two schemes on fish populations will depend on the specific details of the fish passes. There is limited design information available on the North Mill fish pass. The limited available design information on the Weavers Mill fish pass indicates that it may benefit from a screen over the turbine outflow to deflect fish away from the discharge and co-location of the fish pass entrance and the discharge.

The Kaplan (Weavers Mill) screen (12.5mm) is likely to exclude most fish, whereas the Archimedes (North Mill) screen (100mm) design ‘accepts’ that some fish (including eels) pass through the screw. The Kaplan (Weavers Mill) screen design has a mesh size of 12.5mm, which is small enough and in accordance with good practice in most circumstances. Screen mesh sizes of less than 12.5mm can be required in certain circumstances, particularly on some schemes that are within 50km of the tidal limit to protect smaller adult eels. This can be the case where the angle between the screen and the flow is greater than 20° and smaller adult eels are present. Mesh size can also be dependent on approach velocity. It is expected that screen angle, along with the maximum approach velocity will be clarified and the required mesh size verified and set accordingly at detailed design. A review of eel sizes recorded in this part of the catchment and or EA local knowledge would also assist in verifying that a 12.5mm mesh screen is appropriate.

The mechanism (bywash) by which fish migrating downstream will bypass Weavers Mill intake and cross the weir as they reach the intake screen remains subject to clarification, particularly with respect to eels. Any proposals to design the fish pass to act simultaneously as a bywash would need further clarification, recognising that some baffle fish passes are not suitable for downstream migration. Similarly verification is required that the approach velocity at the screen will be within the required/ published escape velocities of fish i.e. cyprinids, eels and lamprey; and escape distances of less than 5m from any part of the screen can be required depending on screen angle. It is anticipated that these screen/intake design details can be clarified and refined at the detailed design stage.

For most of the year the Archimedes screw is likely to create a preferential route over the weir. The FDC shows that river flows exceed the $10.033m^3/s$ turbine flows for only 25% of the year. Hence for 75% of the year, there is only HOF over the weir. Research suggests that damage to fish and stress due to passage through the screw are likely to be negligible, providing the screw incorporates certain key design features (e.g. compressible rubber edges and limits on rpm) and that these are monitored and well maintained.

Either scheme could conceivably delay migration by attracting fish to the discharge, however this effect is unlikely to cause significant mortality as the fish are likely to eventually seek an alternative route and pass via the fish pass – as stated above clarification and review of the fish pass designs is required.

Both schemes incorporate an eel pass. The extent to which the different proposed locations/designs of the two eel passes influence their effectiveness is not known. There is potentially scope for improvements/ clarifications to both, for example recent design amendments/clarifications have sought to reduce the risk of: eels being diverted behind the Kaplan and failing to find the Weavers Mill eel pass; eels emerging directly behind the Kaplan intake; and/or of turbulence at the bottom of the screw obscuring the entrance to the North Mill eel pass.

Both schemes have the potential to alter weir pool morphology. This effect is likely to be greatest associated with the Weavers Mill scheme, due to the location of the discharge. This effect is likely to lead to a redistribution of river habitats, for example fish spawning habitat. There are other minor differences for example greater marginal/ riparian/ aquatic habitat loss/ disturbance associated with North Mill and possible limited risk of juvenile waterfowl entering this scheme. However, these are localised effects only and are unlikely to be significant.

It is anticipated that licence conditions will ensure that either of the proposed schemes will incorporate the latest, good practice designs (including with respect to screen/ mesh sizes, eel pass and fish pass), to protect fish, based on the most up-to-date Environment Agency guidance, and that these features will be routinely inspected and maintained. Providing this is the case, and based on recent studies, the schemes are unlikely to differ significantly in terms of their effects on fish populations or on other ecological receptors. This is however subject to further clarification and comparison of eel pass and fish pass design detail and clarification of the Weavers Mill bywash mechanism. This is also dependent on verification that the Kaplan screen angle and mesh size (12.5mm) are appropriate for excluding adult eels from hydropower schemes in this part of the Avon catchment. Similarly clarification is required of the maximum approach velocity at the Kaplan screen to verify that it will be within the maximum escape velocity for cyprinids, eels and other fish species as stated by the applicant.

4.3.2 Energy Generation and Carbon

Background

The method used to estimate the amount of electricity generated per annum by each scheme is described fully in Appendix C. This method estimates the electricity generated from available water power using the appropriate physical equations and power curves for the turbines under consideration.

Input Data

The approach taken has been to use the flow and head data supplied by each applicant as the basis for the assessment and then to apply both sets of data equally to both schemes. Comparable approaches have been used to estimate the outputs for both schemes. A third data set was then produced synthesising the best available data for the river and this has been used to make a further estimation of annual generation.

Both applicants provided the same data for the Flow Duration Curves (FDC), sourced from the Environment Agency using data from January 1990 to December 2007. It is reasonable to assume that these data are accurate, reliable and statistically significant.

The two sets of head duration data have been measured at the site by the two applicants. The data sets are very similar as would be expected, as they refer to the same weir. The data set provided by the Weavers Mill applicant covers the period from December 2008 to May 2009 while the data set provided by the North Mill applicant covers the period from December 2012 to May 2013.

The third data set comprises a synthesised head curve based on both applicants' data sets together with flow data sourced from the Environment Agency over the period January 1990 to September 2013.

Suitability of the Input Data

For any hydropower scheme the instantaneous power and energy generated over time are functions of the head and the flow. Therefore, it is important to have accurate data on the variations of both concurrent head and the flow over time.

Ideally, for the purposes of this analysis, the applicants would have provided such data sets based on raw data measured at the site for at least 12 months and preferably considerably longer (to take into account seasonal/annual variations), together with information on the quality of the measurement sensors, their locations and associated calibrations.

Nevertheless we consider both data sets to be a reasonable basis for a comparison of the two schemes. In the case of North Mill we have been provided with the raw daily head data from

North Mill and have processed it to provide an HDC for input to our energy generation model. The FDC is from the EA data. In the case of Weavers Mill we have used the HDC and FDC provided by the applicant. We have compared the resulting Head Duration Curves (HDCs) and, while there are slight differences, the HDCs provided appear similar. They have both been collected over a period of 5 to 6 months and can be expected to be reasonably representative of the longer-term behaviour of the weir. The data also appear to represent the anecdotal behaviour of the weir, i.e. that it progressively backs-up as flow increases and consequently the head reduces (e.g. as witnessed during high flow events and shown in photographs).

Appendix C provides more detailed comment on both sets of data provided by the applicants.

The third data set uses flow measurements over the longest duration available. These data represent the most statistically significant measurements of daily flow in the river and are considered to be the best available from which to produce the FDC. The synthesised HDC makes use of both the two applicants' HDCs, as this is considered to be the most appropriate method for compiling a single data set in the absence of longer term independent measurements. When compiling the synthesised HDC we have taken our own view as to the most prudent head estimates to adopt for each flow range within the FDC and generally this is the average of the two.

We consider this third set provides the best available basis for comparison of the two schemes and hereafter in this report it is referred to as the 'final data set'.

Energy Generation Results

No independent performance data have been received from either applicant. The energy prediction estimates therefore use manufacturers' data, together with the flow and head data as described in the previous section, to estimate the output from the two schemes. For the screw turbines, application of the screw performance curves, accounting for screen and forebay losses and the effect of tail-water backing up[3] have all been included in the estimates. For the Kaplan, performance curves in published texts have been used and screen losses and flow friction losses in the tube have been estimated.

The application of these three sets of head and flow data provides the following results. It can be seen that our estimates show the Kaplan to produce more energy in all cases.

Table 4.1 Energy Generation Results

	Data from Weaver's Mill Applicant	Data from North Mill Applicant	Final Data Set	Units
Kaplan output	490	410	398	MWh/y
Screws output	464	382	363	MWh/y

It is helpful to illustrate the quantity in terms of typical household annual consumption. In the UK, OFGEM quotes typical 'medium electricity consumption' as 3,300 kWh per year per

[3] Untersuchungen zum ruckstau an der Wasserkraftschnecke (Typ RITZ-ATRO) der Fa. Okofish GmbH + Co. KG in Hoxter-Godelheim. November 2004 (colloquially translated: Study of effect of tail-water backing-up on the performance of the Archimedes Hydro generator).

household[4]. The following table shows the number of equivalent households' annual consumption that would be generated by each scheme:

Table 4.2 Equivalent Households' Annual Consumption

	Data from Weaver's Mill Applicant	Data from North Mill Applicant	Final Data Set
Kaplan output	148	124	121
Screws output	141	116	110

Discussion of Energy Generation Results

Sensitivity to Head and Flow Variation

The results and subsequent analysis show that the performance of both schemes is sensitive to flow and head variation. This is expected as the head and flow describe the energy in the river.

Turbine Suitability and Performance

Our results and hence conclusion that the generated output at Weavers Mill will be higher under the same water conditions than at North Mill is supported by the engineering and general design and operation of the two machines.

Published data on doubly regulated Kaplan turbines show this can be a more efficient machine than the Archimedes Screw. The Kaplan has a longer track record in operation and much independent data is available on its performance in situ to confirm this. Details of its design and operation allow for high efficiency to be maintained across a wide range of flows and power outputs. References[5,6,7] describe the Kaplan and its performance well. Published independent figures for its efficiency and that of ancillaries have been used in the analysis.

Using Archimedean Screws as generators is a newer application of this technology. They have a much shorter track record in commercial operation and very limited independent data on operation in situ has been published. This in turn appears to be because very little independent research on their operation has been carried out. However, even the manufacturer's published data show lower efficiency under design conditions than the Kaplan. This is supported by a qualitative analysis which highlights many reasons including the large speed ratio across the gearbox leading to a less efficient gearbox than for the Kaplan; the screw geometry that will tend to present higher drag in the water; the water flow into, down and out of the screws is visibly highly turbulent and so that energy is unavailable for electricity generation and at high powers some water is sprayed out of the screws. All the latter are sources of power loss.

[4] OFGEM Factsheet 96, 18.1.11, Typical Domestic Energy Consumption Figures. Available from www.OFGEM.gov.uk.

[5] Engineering Practice, Volume II, Mechanical and Electrical Engineering, Pub Blackie and Son, Editor J Guthrie Brown, CBE, 1970, Esp Chapter VI Kaplan and Propeller Turbines, pages 139 to 191.

[6] Marks Standard Handbook for Mechanical Engineers, various editions.

[7] Renewable Energy, Technology, Economics and Environment, Martin Kaltschmitt, Wolfgang Streicher, Andreas Wiese, 2007.

Furthermore, it is often the case that new technologies have less well understood behaviours in operation at commercial sites. It is our opinion that this is probably the case with Archimedes Screws when used as generators. Where independent data have been found these show that the technology used in sites with well-controlled heads and constant flows through the screws appear to perform close to output predicted, e.g. the River Dart[8]. However, there is anecdotal and other evidence of lower than predicted performance in other locations. Common factors appear to be unexpected damage to machinery, sites with rapidly changing flows and sites with variable heads resulting in the tail submerging.

This latter factor is important at Avoncliff as the weir is known to 'back up' considerably at higher flows. This both reduces the gross head and submerges the lower part of the screw. The submerged part of the screw churns the water and this effectively acts as a brake on the system. This braking effect then significantly reduces the power output. By comparison, the reduction in gross head reduces the power output of the Kaplan partially, but there are no significant additional losses such as the churning loss for a submerged Screw.

Energy Generation - Conclusion

Both applicants provided data to be used to calculate the potential energy generation of their respective schemes. Both applicants provided the same Flow Duration Curve data, sourced from the Environment Agency, but provided different head data based on their own independent measurements. The flow and head data have been taken from different sources (i.e. not generated from data measured over the same time period) and consequently the head duration curve may not match the flow duration curve.

We have also used the final data set to produce a single set of results. This takes the longest period, and therefore more statistically significant record, of daily flow measurements in the river together with a synthesised HDC based on the two applicants' HDCs. We consider this to be the most appropriate data set for comparing the two schemes.

Although none of the head input datasets are ideal we consider them to be a reasonable basis for this assessment and the results allow for the two schemes to be compared on a consistent basis. Our estimates show that the Weavers Mill scheme produces more energy than North Mill regardless of which of the three datasets are used and therefore we conclude that the Weavers Mill scheme is likely to provide the highest annual energy output.

Efficiency of Generation (Optimum Use of Water Resources)

In addition to assessing the annual power generation of each scheme it is important to understand how much water would be used to achieve this power generation. The maximum flow for Weavers Mill is 7.9m^3/s is considerably less than that for the North Mill scheme at 10.033 m^3/s.

Consequently, the Weavers Mill scheme would make more efficient use of the water in Wh/m^3 than the North Mill scheme as is shown in Table 4.3 below. These figures have been calculated using annual energy generated and average annual flows.

[8] River Dart Country Park Archimedes Screw System Performance Assessment, N Bard, June 2007.

Table 4.3 Generation Efficiency Results

	Data from Weaver's Mill Applicant	Data from North Mill Applicant	Final Data Set	Units
Kaplan output	3.46	3.13	3.02	Wh/m^3
Screws output	2.92	2.53	1.92	Wh/m^3

Carbon Emissions Saved

Both schemes will generate electricity which will be fed into the national grid. The electricity will displace some electricity generated from fossil fuels. The carbon saved by the schemes is in proportion to the electricity generated.

On the basis of the current standard carbon intensity of grid electricity of 0.434 kg CO_2e/kWh (DECC figures for generation-based average emissions), the amount of carbon offset will be about 170 and 210 tonnes CO_2e per annum for Weavers Mill and 164 and 200 tonnes CO_2e per annum for North Mill, depending on the power generation estimate adopted.

Using the final data set the carbon offset estimates are 173 tonnes CO_2e per annum for Weavers Mill and 157 tonnes CO_2e per annum for North Mill.

Carbon Footprint and Embedded Carbon

All stages of the life cycle of a product may result in emissions and it has recently become possible to estimate the carbon emissions – referred to as a carbon footprint. This has been done for the two proposed hydro-power projects. Further details of the approach are given in Appendix C.

The approach taken was to estimate the difference in carbon footprint between the two schemes, not the absolute carbon. Hence, where the schemes have identical or very similar elements these were assumed to be the same and not included in the assessment.

The estimates of the footprints of the differing features are based on factors for embedded carbon per tonne of material from a published independent database[9] (which also forms the basis of the EA's own carbon calculator). These factors were then applied to the masses estimated to give a carbon footprint for each element. A range of factors has been used to account for potentially different material processing for steel and concrete. All the elemental values were then summed to give a total figure for each scheme.

Taking all factors into consideration we consider that, for the North Mill scheme the estimate for the carbon footprint should be taken as around 80 tonnes CO_2e while for the Weavers Mill scheme the carbon footprint should be around 25 tonnes CO_2e.

The greater carbon footprint for North Mill is due to a higher estimated mass of steel and the use of considerably more concrete in the construction.

[9] Inventory of Carbon & Energy (ICE), Version 2.0, Prof. Geoff Hammond & Craig Jones, Sustainable Energy Research Team (SERT), Department of Mechanical Engineering University of Bath, UK.

4.3.3 Flood Risk

The main differentiator relates to the obstruction posed to flood flows presented by the North Mill scheme.

North Mill Scheme

The top of the two screws and their associated concrete channels will protrude above the existing weir level. In addition, a concrete platform will support the upper bearing and gear box etc just over a metre above the crest of the weir. The top of the screw will be higher than this level. A new sluice gate and screen will be placed across the entrance channel up to the level of the platform. The larger screw and associated sluice gate would extend approximately 4.75 m across the weir (which is approximately 65 m long between buildings).

The screw turbine and associated concrete channel will effectively prevent flood flow over the weir at this location. In addition, the sluice gate can be closed to prevent water and debris flowing through the screw. When closed the new sluice gate would provide an additional obstruction to flood flow.

A trash screen would be located upstream of the screws, angled to encourage debris to pass over the weir. In addition, a 'Protective 100 mm grille' is shown on drawings from the applicant and this extends about 1m above the water level directly on top of the trash screen. The screen could become blocked with floating flood debris from upstream, thereby providing a further obstruction.

During the site visit the applicant stated that the intention was to construct a flood relief channel under the existing building between the existing wheel pit and the bank. However, no details have been submitted. It is not clear how this would be provided under the existing building or of the extent of civil engineering works that would be required to achieve it.

The proposed North Mill scheme would cause an appreciable constriction in the available width of weir for flood conveyance with a potentially significant increase in flood levels, which could affect off-site receptors such as properties upstream. In particular, Weavers Mill is located within the floodplain as shown on the Environment Agency flood map (EA, 2013).

Weavers Mill Scheme

The turbine and housing for the Kaplan turbine would be situated immediately downstream of the existing channel through the weir, with the screen and trash rack located within the confines of the existing sluice structure. The new fish pass would not extend above the crest of the existing weir.

At present the existing sluice is kept permanently closed. It has been assumed that the new sluice would be open at all times except when required to protect the turbine at very high flows or to protect the Hands Off Flow under low flow conditions. The mill leat under the existing mill would be unchanged.

The trash screen would be located upstream of the Kaplan turbine, fully submerged below the weir level and angled to encourage debris to pass over the weir, but would not cause obstruction above the crest level of the weir.

The proposed Weavers Mill scheme would not significantly affect the conveyance of the weir under flood flows. There is potentially a very minor impact on river levels as a result of the additional structure within the river, but this would have a negligible impact on flood levels as the structure would be drowned under flood conditions and would not form a barrier to flood flows.

4.3.4 Other Factors

As demonstrated by the table in Appendix A, although there may be some minor differences in terms of the extent of potential impacts as a result of the two schemes on the other ‘Factors’ reviewed, none are deemed to be significant enough to act as key differentiators between the schemes in the licensing process.

5. Conclusions and Recommendation

A comparison of the relative merits and disadvantages of the two schemes has been carried out. For many factors we consider there are no significant differentiators between the schemes. However the following key differentiators were identified that favour the Weavers Mill scheme:

- Energy generation;
- Efficiency of generation;
- Carbon footprint; and
- Flood risk.

5.1.1 Energy Generation

The annual energy generated by the two schemes has been estimated using three different data sets describing the river flow and head. The approach taken has been to apply the three sets of data equally to both schemes. Two of the estimates use datasets supplied by the two applicants and the third uses a single head duration curve synthesised by AMEC combined with a flow duration curve based on EA data from 1990 to September 2013.

We consider that the data provided by both applicants is reliable enough to provide reasonable estimates suitable as the basis for a comparison of the two schemes. In our modelling we found that for both data sets supplied by the applicants the Weavers Mill scheme produced more energy.

We consider the third data set, which is based on a longer flow record together with a synthesised head duration curve, to be the most reliable for comparing the schemes. Using this data set (the ‘final data set’) we again found that the Weavers Mill scheme produced more energy.

For all three data sets the electricity generation estimates for Weavers Mill were higher than for North Mill. We therefore conclude that the Weavers Mill scheme is likely to provide a higher annual energy output than the North Mill scheme.

5.1.2 Efficiency of Generation

The total annual flow through the Weavers Mill scheme is considerably less than that for North Mill scheme. For reasons summarised in Section 4.3.2 and discussed in Appendix C, regardless of which data are used, the Weavers Mill scheme would make more efficient use of the water than the North Mill scheme.

5.1.3 Carbon Footprint

For reasons summarised in Section 4.3.2 and discussed in Appendix C, the electricity generation figures from either data set are considered reasonable and the Weavers Mill scheme is likely to generate more than the North Mill scheme. On this basis the Weavers Mill scheme would save more carbon emissions that the North Mill scheme. The carbon footprint for the North Mill scheme is considerably higher than for the Weavers Mill scheme due to a higher estimated mass of steel and the use of significantly more concrete in the construction.

5.1.4 Flood Risk

For reasons summarised in Section 4.3.2 and discussed in Appendix C, the proposed North Mill scheme would cause an appreciable constriction in the available width of weir for flood conveyance with a potentially significant increase in flood levels. By contrast, the proposed Weavers Mill scheme would not significantly affect the conveyance of the weir under flood flows.

5.1.5 Recommendation

On the basis of the above we advise that the most environmentally sustainable scheme and the scheme with most long-term public and environmental benefit is the Weavers Mill scheme.

Appendix A
Comparison of Proposed Hydropower Schemes

10 Pages

Avoncliff Weir – Comparison of Proposed Hydropower Schemes

Table A1 Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Climate Change				
Carbon footprint	The manufacture, transport and installation of any product including hydropower plant results in emissions of CO_2 and other greenhouse gases to atmosphere. A comparison of the emissions for North Mill and Weavers Mill has been carried out by calculating the difference in emission for parts unique to each scheme. This excludes elements common to both schemes e.g. grid connection, road transport to site. A range of factors has been used to account for potentially different material processing for steel and concrete. All the elemental values were then summed to give a total figure for each scheme. The figures used are from independent data describing the CO_2 per tonne of material used. Taking all factors into consideration, for the North Mill scheme the estimate for the carbon footprint should be taken as around 80 tonnes CO_2e. The greater carbon footprint for North Mill is due to a higher estimated mass of steel and the use of a greater amount of concrete in the construction than for Weavers Mill.	The manufacture, transport and installation of any product including hydropower plant results in emissions of CO_2 and other greenhouse gases to atmosphere. A comparison of the emissions for North Mill and Weavers Mill has been carried out by calculating the difference in emission for parts unique to each scheme. This excludes elements common to both schemes e.g. grid connection, road transport to site. A range of factors has been used to account for potentially different material processing for steel and concrete. All the elemental values were then summed to give a total figure for each scheme. The figures used are from independent data describing the CO_2 per tonne of material used. Taking all factors into consideration, for the Weavers Mill scheme the estimate for the carbon footprint should be taken as around 25 tonnes CO_2e. The smaller carbon footprint for Weavers Mill is due to a lower estimated mass of steel and concrete in the construction.	It is highly likely that the Archimedean screws will have a higher carbon footprint from manufacture and construction than the Kaplan Turbine. This is due to the larger quantity of steel and the concrete used in the construction of the Archimedean screws. The range of figures given in Appendix C reflects possible material sourcing and not the underlying inaccuracy in the figures. Either hydro-power installation could use low- or high-footprint materials.	Confidence on absolute values; medium. Confidence on relative carbon footprints; high. Estimates of masses of materials have been taken from drawings which do not have full dimensional detail. More detail of the methodology and approach is provided in Appendix C.
Energy generation	The annual electricity generation from the schemes has been estimated using a method described in Appendix C. The estimates for North Mill are: 464 MWh/yr from the twin screws using a total maximum flow of 10.033 m^3/sec through the screws, flow duration data from the EA and head duration data supplied by the applicant for the Weavers Mill scheme. This is considered to be accurate as it is based on the measured Head Duration Curve (HDC). 382 MWh/yr from the twin screws using a total maximum flow of 10.033 m^3/sec through the screws; and head duration data supplied in June 2013 by the applicants for the North Mill scheme and measured at North Mill. 363 MWh/yr from the twin screws using a total maximum flow of 10.033 m^3/sec through the screws; head duration curve synthesised from both Applicant's data sets; FDC from EA data 1990 to September 2013.	The annual electricity generation from the schemes has been estimated using a method described in Appendix C. The estimates for Weavers Mill are: 490 MWh/yr from the Kaplan with a maximum flow of 7.9 m^3/sec through the turbine, using flow duration data from the EA and head duration data supplied by the applicant for the Weavers Mill scheme. This compares with an estimate of 505MWh per year provided by the applicant for the Weavers Mill scheme, so giving good agreement. 410 MWh per year from the Kaplan using a maximum flow of 7.9 m^3/sec through the turbine; flow duration data from the EA and head duration data supplied by the applicants for the North Mill scheme in June 2013 and measured at North Mill. 398 MWh per year from the Kaplan using a maximum flow of 7.9 m^3/sec through the turbine; head duration curve synthesised from both Applicant's data sets; FDC from EA data 1990 to September 2013.	As all three estimates of the amount generated from the Archimedean screws show a lower value than the equivalent Kaplan value, it seems likely that the Kaplan turbine will generate more electricity per year than the Archimedean screws. Confidence on Kaplan output is high as this is an established technology for which much independent information is published.	The range of figures for each scheme reflects the use of different flow and head duration curves for the river. This allows the most direct comparison of the output from the two schemes. More detail of the methodology and approach is provided in Appendix C.
Water Resources				
Location on watercourse	One screw turbine to be placed within the historic water wheel pit, another alongside within the weir structure itself. North Mill is on the outside of the river bend so flow is directed towards proposed location of scheme.	Turbine to be located downstream of existing sluice in weir. Weavers Mill is on the inside of the river bend so flow is not naturally directed this way.	This is not a significant differentiator as the Kaplan turbine operation depends on head not velocity of flow.	
Efficiency of water use	The licensed flow requested for North Mill is 10.033 m^3/sec, which is considerably more than that for Weavers Mill at 7.9 m^3/sec. The estimated energy per volume flow for North Mill ranges from 2.53 Wh/m^3 to 2.92 Wh/m^3 which are lower than for Weavers Mill. Using the final single data set the energy per volume flow is 1.92 Wh/m^3 for the screws.	The licensed flow requested for Weavers Mill is 7.9 m^3/sec which is considerably less than that for North Mill at 10.033 m^3/sec. The estimated energy per volume flow for Weavers Mill ranges from 3.13 Wh/m^3 to 3.46 Wh/m^3 which is higher than for North Mill. Using the final single data set the energy per volume flow is 3.02 Wh/m^3 for the Kaplan.	Weaver's Mill makes more efficient use of the water in terms of energy generated per flow volume (Wh/m^3), whichever head data are used. The difference between the water flows also represents the additional flow which would spill over the weir under the Weaver's Mill scheme as compared to the North Mill scheme.	
Need for Water	Needs 10.033 m^3/sec water flow to operate at full capacity. Can be accommodated by the available river flows at present.	Needs 7.9 m^3/sec water flow to operate at full capacity. Can be accommodated by the available river flows at present.	Not a significant differentiator.	

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Impacts on flow pattern	Hands Off Flow (HOF) will be protected. River flows already preferentially use this side of the river but the historic water wheel is currently not working so flow patterns will change with some effect upstream and downstream of the weir.	HOF will be protected by adjustable sluice that will be closed under low flow conditions. Under higher flows the scheme will draw more flow to the sluice channel which will affect channel morphology upstream and downstream. Flow at outlet will be more concentrated, with potential scour effects on river bank.	While Weavers Mill is likely to have more effect on the existing sediment patterns in the river, this is not considered to be a significant differentiator.	
Impacts on channel and weir pool	There will be localised impacts on the channel and weir pool. Any changes due to the change in flow pattern are likely to be confined to the immediate areas above and below the weir.	There will be localised impacts on the channel and weir pool. Any changes due to the change in flow pattern are likely to be confined to the immediate areas above and below the weir.	This is not considered to be a significant differentiator.	
Implications for WFD	Any changes are not considered to be significant.	Any changes are not considered to be significant.	This is not considered to be a significant differentiator.	
Water Quality				
Chemical & Physical	Any changes likely to be localised above and below the weir due to change in flow pattern e.g. distribution of aeration and mixing.	Any changes likely to be localised above and below the weir due to change in flow pattern e.g. distribution of aeration and mixing.	This is not considered to be a significant differentiator.	
Biological	Any changes likely to be localised above and below the weir due to change in flow pattern e.g. distribution of aeration and mixing.	Any changes likely to be localised above and below the weir due to change in flow pattern e.g. distribution of aeration and mixing.	This is not considered to be a significant differentiator.	
Environmental				
Natural Environment Conservation Designations	Within Cotswold AONB. Ancient Woodland within 75 m (Becky Addy Wood). Bristol River Avon Local Wildlife Site. The scheme will result in localised river habitat modification: downstream bank reinforcements (gabions) and potential changes to weir pool morphology.	Within Cotswold AONB. Ancient Woodland within 75 m (Becky Addy Wood). Bristol River Avon Local Wildlife Site. The scheme is likely to result in river habitat modification: potential changes to weir pool morphology. Access (only) via Kennet & Avon Canal LWS: effects on this site are unlikely	No designated nature conservation sites are likely to be affected by either scheme.	

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Biodiversity	**Mammals:** Otters are likely to avoid the scheme. Scheme may be an obstacle to dispersal along the right bank – existing spraint site may be obscured. Any noise associated with discharge of water from the scheme may initially deter otter dispersal along right bank. However they are likely to become habituated. Riparian lighting can deter otter - no lighting scheme available. **Birds:** Limited loss of riparian bird habitat due to bank reinforcements. Limited risk of juvenile waterfowl entering screw. Effects on breeding birds are likely to negligible due to timing of vegetation clearance. **Reptiles:** Potentially very limited loss of reptile (grass snake) habitat due to bank reinforcements. Measures can be incorporated to prevent harm to reptiles. **Invertebrates:** Larger footprint and therefore greater loss of substrate and invertebrate habitat – however a limited/ localised effect. Potential presence of crayfish - if present there is a limited risk that they could pass through the scheme. This is unlikely to have significant effects on crayfish population. **Macrophytes:** Limited loss of marginal macrophytes and tall ruderal – localised effect. Potential for effects on Loddon pondweed (Nationally Rare) – change in distribution due to effects on weir pool morphology. Limited potential for loss of small number of plants. Presence of *Caloplaca crenulatella* (Nationally Scarce lichen) on mill structures not known – localised effects on mill structures only. **Trees:** Limited tree loss appears likely on right bank downstream of mill due to bank reinforcement. **River Habitat Modification:** Limited habitat modification associated with bank reinforcement (gabions) and installation on weir. Localised river bed reinforcement with concrete. Limited/localised change in weirpool morphology.	**Mammals:** Otters likely to avoid scheme. Riparian lighting can deter otter - no lighting scheme available. **Birds:** Effects likely to be avoided due to intake screening and timing of vegetation clearance. **Reptile:** Effects on reptile unlikely **Invertebrates:** Smaller footprint, less habitat loss. Limited risk of crayfish entering the scheme. Small juveniles could potentially pass through the mesh; however this is unlikely to have significant effects on crayfish population. **Macrophytes:** Smaller footprint - less macrophyte loss. Potential for effects on Loddon pondweed – localised removal and change in distribution due to effects on weir pool morphology. **Trees:** Tree loss unlikely, possible loss of single dead tree in garden to permit access. **River Habitat Modification:** Assembly in units and in existing weir structure. Modification to banks unlikely. Localised river bed reinforcement with concrete. Changes in weir pool morphology due to shift of discharge downstream.	**Mammals:** North Mill scheme likely to be more substantial obstacle to otter dispersal along river bank. However this is unlikely to be significant. Riparian lighting can disturb otter - no lighting schemes available for either scheme. **Birds:** Limited riparian habitat/ tree loss associated with North Mill scheme and limited risk of juvenile waterfowl entering the screw. **Reptiles:** Limited/ localised riparian habitat loss associated with North Mill scheme (bank reinforcements). **Invertebrates:** Both schemes will lead to localised loss of substrate/invertebrate habitats. Larger footprint of the North Mill scheme will lead to greater loss. Localised effect and minor difference only. **Macrophytes:** Larger footprint of the North Mill scheme will lead to greater loss of marginal macrophytes and tall ruderal vegetation. Localised effect and minor difference only. **Trees:** Limited tree loss potentially associated with North Mill scheme due to bank modification. **River Habitat Modification:** Limited bank reinforcement associated with North Mill scheme and modification to weir. Both schemes result in river bed reinforcement. Changes in weir pool morphology likely to be greatest associated with Weavers Mill scheme due to altered pattern of discharge downstream. This is not considered to be a significant differentiator.	Assumes Ecological surveys will be updated for both schemes. Assumes standard safeguards e.g. clearance of vegetation outside birds nesting season. Assumes Loddon pondweed is not specifically restricted to one part of the weir pool i.e. below/ near one scheme. Comparison of proposed grid connection work and any associated habitat/ tree/ fauna loss/ disturbance has not been undertaken as final connection details are unconfirmed. Extent/ nature of weir repair works associated with each scheme is unconfirmed.
Cultural Heritage	Within Avoncliff Conservation Area. Approximately 150 m from Avoncliff Aqueduct, Grade II* Listed Building. Approximately 105 m from The Cross Guns Inn, Grade II Listed Building. Opportunity to use existing wheel pit but will involve loss of historic fabric (removal of late nineteenth/early twentieth century water wheel) and alteration to existing wheel pit. Archimedes screw will be a relatively large structure with potential to alter the historic character of the Conservation Area. Some potential for disturbance to archaeology (water management structures such as jetties, fish-traps, sluices, weir-related fabric) as a result of construction of screw housings.	Within Avoncliff Conservation Area. Approximately 125 m from Avoncliff Aqueduct, Grade II* Listed Building. Approximately 55 m from The Cross Guns Inn, Grade II Listed Building. Limited visibility of the scheme within the Conservation Area. Some potential for disturbance to archaeology (water management structures such as jetties, fish-traps, sluices, weir-related fabric), although may be limited by nature of construction.	The Archimedes screws proposed at North Mill are the larger of the two schemes and will be more visible within Avoncliff Conservation Area as it will extend above the waterline. Construction of the Archimedes screws at North Mill will also involve loss of historic fabric of the (unlisted) North Mill building. The Kaplan turbine proposed at Weavers Mill would be built immediately downstream of the existing sluice in the weir and would not involve loss of historic fabric. Development at North Mill would represent a contemporary use of water power in a historic setting. The Archimedes screws at North Mill would be larger structures and would therefore involve a greater potential for disturbance to any archaeology within the river bed – though there is no positive evidence for such archaeology at either site.	

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Landscape & Visual impacts	Archimedes screw structures likely to be at least partially visible above water level, especially the proposed screw within the weir. Further structures associated with the development, including turbine channel and fish pass walls, and gabion baskets, will also be visible from a number of viewpoint locations including Weavers Mill and the Cross Guns Inn beer garden (see 'Recreation/ Amenity' for further receptors) A Hands Off Flow of 0.951 m^3/s over the weir has been set by the EA which will retain the visual amenity benefit of this flow cascade	Submersible bulb turbine – limited visibility however would be visible from North Mill; trash screen/ channel may also be visible on or above the weir. A Hands-Off Flow of 0.951 m^3/s over the weir has been set by the EA which will retain the visual amenity benefit of this flow cascade.	The Archimedes screw turbines proposed at North Mill are much larger than the Kaplan turbine proposed at Weavers Mill, and would be visible above the water line unlike the Kaplan – in particular the screw proposed within the weir structure itself. The other structures associated with the North Mill scheme (fish pass walls etc) would also be visible from a number of local viewpoints.	
Recreation/ Amenity	Within Barton Farm Country Park and Cotswold AONB Visible from Macmillan Way Long Distance Route/ National Trail which follows Kennet & Avon Canal towpath across aqueduct	Within Barton Farm Country Park and Cotswold AONB. Limited visibility from Macmillan Way Long Distance Route/ National Trail.	Receptors using recreation and amenity resources such as the network of local and national public rights of way in the vicinity would experience views of the Archimedes screw turbines and associated structures for the North Mill scheme, in particular the screw within the weir itself. Views of the Weavers Mill proposals would be more limited.	
Noise	Most of the noise from the Archimedean screws proposed at North Mill will be white noise from the water flowing down the screws. This will change the location of the source to the northern end of the weir as opposed to along its whole length (at high flows). The sound power is unlikely to be higher than which the weir produces currently. The exposed machinery of gearbox and generator at the top of the screws at North Mill has a slight risk of producing tonal noise which may be audible over the general background under some circumstances. As water exits an Archimedean screw, the water flow is unusual. There is some anecdotal evidence that this can produce noise which might be audible over the general background under some circumstances.	Most of the noise from the Kaplan turbine proposed at Weaver's Mill will be white noise from the water flowing into the top of the turbine and out from the bottom of the tube. This will change the location of the source to the southern end of the weir and, in the case of the exit flow, slightly further downstream as opposed to along its whole length of the weir (at high flows). The sound power is unlikely to be higher than which the weir produces currently.	A full assessment of noise effects from either site is beyond the scope of this appraisal. In any case, the differences are likely to be minimal. This issue is probably best managed using planning conditions set by the local planning authority. This is not considered to be a significant differentiator for the purposes of this assessment.	All hydropower equipment will produce three main types of noise: 1. White noise not unlike that from the weir; 2. Tonal machinery noise from rotating plant, control equipment and transformers; 3. Specific and intermittent noise due to the operational mode of the turbine and plant, e.g. 'sloshing' from the screws or noise associated with stopping or starting the turbine/ screws). Background noise from the weir is already the dominant source at this location and so is likely to drown out any new sounds.

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Fisheries				
Fish & eel pass/ screen provision	100 mm screen (and compressible rubber edges to screw) plus combined fish/ eel pass and separate eel pass.	12.5 mm screen plus separate baffle fish pass and an eel pass.	See following section.	
Impacts on fish (harm/ stress/ mortality)	**Salmonids & Cyprinids:** Screening (100 mm) intended to permit fish passage through the scheme. Design/licence criteria, including compressible rubber edges and limits on rpm, are likely to minimise harm/mortality effectively. Passage through the scheme has potential to cause stress to some fish, but is unlikely to lead to significant mortality.	**Salmonids:** Screening (12.5 mm) is likely to prevent entrainment of salmonids migrating downstream. Further clarification of bywash mechanism and maximum approach velocity is required as this not easily discerned from the revised plans. However velocity appears close to the required range. Applicant has stated that approach velocity will be in accordance with GPG. Fish unlikely to swim up the discharge structure and be harmed. However there is potential for Kaplan discharge to attract/ divert migrating salmonids, leading to delayed attempts to pass the weir and potentially stress, although unlikely to lead to significant mortality. This effect would be offset by adding a screen over the discharge that guides fish to the fish pass entrance and also co-locating discharge and fish pass entrance. **Cyprinids:** Screening (12.5 mm) is likely to prevent entrainment of cyprinids. Limited numbers of 0+ cyprinids may enter the scheme, however significant mortality is unlikely. Further clarification of bywash mechanism and maximum approach velocity is required as this not easily discerned from the revised plans. However velocity appears close to the required range. Applicant has stated that approach velocity will be in accordance with GPG.	**Salmonids:** Risk of mortality associated with both schemes is likely to be low. Protection of fish passing through Archimedes screws of North Mill scheme will rely on incorporated design features e.g. compressible rubber, which will need to be monitored and adequately maintained. There is a (limited) risk of stress associated with downstream passage through Archimedes screws, although unlikely to lead to significant mortality. This is based on a limited number of studies. Stress may be a concern in terms of cumulative effects with future schemes. Screen (12.5 mm) on the Weavers Mill scheme reduces mortality risk and will need to be monitored and maintained. There is a limited risk of Kaplan discharge attracting migrating salmonids and leading to delayed migration attempts and stress, although this is unlikely to lead to significant mortality and could be offset by screening the discharge and co-locating outfall and fish pass entrance. Further clarification of bywash mechanism and maximum approach velocity at Kaplan screen is required as this not easily discerned from the plans, also recognising that some baffle fish passes are unsuitable for downstream migration. Applicant has stated that approach velocity will be in accordance with GPG. **Cyprinids:** Risk of cyprinid mortality associated with either/ both schemes is likely to be low. Effects of stress associated with passage through Archimedes screws are based on few studies. Limited numbers of 0+ cyprinids may enter the Kaplan however significant mortality is unlikely . Further clarification of bywash mechanism and maximum approach velocity is required as this not easily discerned from the plans, also recognising that some baffle fish passes are unsuitable for downstream migration. Applicant has stated that approach velocity will be in accordance with GPG.	100 mm screen, combined fish/ eel pass, dedicated eel pass, compressible rubber edges, and appropriate limits on rpm will be included as part of North Mill scheme in accordance with latest EA guidance, secured by licence conditions. Maintenance (e.g. screw edges) also to be secured by licence conditions. Research (relatively few studies) to date shows fish stress associated with passage through Archimedes screw is negligible. 12.5 mm screen plus fish pass and eel pass included as part of the Weavers Mill scheme and monitored/ maintained, secured by licence conditions. Weavers Mill remains subject to clarification of bywash mechanism, also recognising that some baffle fish passes are unsuitable for downstream migration,, and confirmation that approach velocity is within the required maxima for cyprinids and eels. This information cannot be discerned from the plans/ information provided and relies on more detailed design. However approach velocity appears to be close to the required range.

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Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Fisheries				
Impacts on fish migration, spawning, nursery habitat	**Salmonids:** Operation at maximum flows through the screw is likely to reduce availability of water for migration over the weir. This may narrow the window available for fish to pass the weir. The magnitude of this effect would depend on specific design and flow of fish pass. Fish pass design would need clarification/review of design and verification of compliance with GPG. This effect may be exacerbated by water over topping and spilling down the sides of the screw when it reaches capacity as opposed to flowing over the remainder of the weir. Fish could feasibly be attracted to outfall turbulence. However they are likely to pass via fish pass. **Cyprinids:** This scheme may reduce number of days when flows allow cyprinid migration over weir. This effect maybe marginal as Cyprinids are unlikely to be able to migrate upstream past the weir other than in highest flows. The effect may be exacerbated by water over topping and spilling down the sides of the screw when it reaches capacity as opposed to flowing over the remainder of the weir.	**Salmonids:** Operation at maximum flows is likely to reduce availability of water for migration over the weir to a lesser extent than Archimedes screw. The magnitude of effect would depend on specific design and flow of fish pass. Baffle fish pass design would need clarification/ review of design and verification of compliance with GPG. Attractant flows at discharge could feasibly lead to attempts to run up the discharge, with delayed migration and potentially stress. This is however unlikely to lead to significant mortality and fish are likely to pass via the fish pass. This effect could be offset by screening the discharge and co-locating with fish pass entrance. **Cyprinids:** This scheme may reduce number of days when flows allow cyprinid migration over weir. This effect maybe marginal as Cyprinids are unlikely to be able to migrate upstream past the weir other than in highest flows. Changes in weir pool morphology are likely to alter spawning habitat distribution.	**Salmonids:** The weir is likely to continue to flood during spates with either scheme In place and so restrictions on fish migration resulting from either scheme are likely to be limited. Both schemes incorporate a fish pass. Differing designs could be a moderate difference, subject to detailed design review. . The greater amount of water passing through the North Mill scheme is likely to place greater restriction on migration over the weir and has the potential to narrow the migration window to a greater extent than the Weavers Mill scheme. The magnitude of this difference would however depend on specific fish pass designs and flows. The effect of reduced flow over the rest of the weir may be exacerbated by water over topping and spilling down the sides of the North Mill screw when it reaches capacity as opposed to flowing over the remainder of the weir. Attractant flows from Kaplan discharge could lead to delayed migration and potentially stress. This is unlikely to lead to significant mortality however and fish are likely to pass via the fish pass. This effect could be offset by screening the discharge and co-locating with fish pass entrance. Cumulative effects (fish stress) of multiple schemes may be a consideration in the future. **Cyprinids:** Cyprinids unlikely to pass weir other than in highest flows. Therefore any effects on the number of days when cyprinids can migrate past the weir are likely to be limited with both schemes. However the North Mill scheme would potentially have a marginally greater effect in terms of narrowing the available window for Cypinid migration due to its greater capacity. Changes in weir pool morphology are likely to lead to altered distribution of fish habitats, particularly associated with the Weavers Mill scheme, which discharges downstream of weir. However this is likely to be redistribution of habitats only.	Detailed fish pass designs to be provided for both schemes and EA to seek to optimise design and flow in accordance with GPG through licence conditions. No studies on flow parameters required for fish to pass Avoncliff weir Extent/ nature of weir repair works associated with each scheme is not known.

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Impacts on eel and lamprey.	**Eel:** Eel pass included in design as well as a combined fish and eel pass. It is unclear if turbulence at bottom of screw could obscure entrance to dedicated eel pass, however North Mill has confirmed that a guard strip will be installed to screen the pass from turbulence associated with the screw and to maintain low flows for eel migration. Adult eels are likely to pass through the scheme on way downstream. Design/licence criteria, including compressible rubber edges and rpm limits, are likely to minimise harm/ mortality. These design features would need to be monitored and/ or maintained. Passage through the scheme has potential to cause stress to some fish, but significant mortality unlikely. No lighting designs available – any lighting may influence migration routes. **Lamprey:** Design criteria, including compressible rubber blade edges and limits on RPM, are likely to minimise harm/ mortality.	**Eel:** Eel pass included in design and design improved following initial review.. Screening (12.5 mm) is likely to prevent entrainment of larger adult eels migrating downstream and is suitable for locations >50km upstream of tidal limit. Closer to the tidal limit (<50 km) smaller mesh sizes (e.g. 9 mm) can be required to protect smaller adult eels. This depends on clarification of angle between flow and screen i.e. 12.5 mm mesh is suitable for smaller adult eels only where angle is </= 20° . If angle >20 then mesh size recommended is 9 mm. Further clarification of bywash mechanism and maximum approach velocity is required as this not easily discerned from the revised plans. Applicant has stated that approach velocity will be in accordance with GPG. Some baffle fish passes are unsuitable for DS migration and this may need to be refined/clarified at detailed design. Risk of entrainment of elvers exiting the eel pass is limited by screen angle relative to exit angle. No lighting designs available – light may influence migration route. **Lamprey:** Screening is likely to prevent entrainment of most adult lamprey. Limited risk of small lamprey entering the scheme. Approach velocity appears to be close to required range.	**Eel:** Protection of eels passing through the Archimedes screws of the North Mill scheme depends on design features e.g. compressible rubber, which will need to be monitored and adequately maintained to prevent harm to eels. Stress associated with passage through Archimedes screws is unlikely to cause significant mortality. This is based on relatively few studies and may be a more important consideration in terms of stress associated with cumulative effects of future schemes. The Kaplan screen (12.5 mm) of the Weavers Mill scheme is likely to exclude most adult eels and minimise mortality and will also need to be monitored/ maintained. However screen mesh size may need to be reduced subject to clarification of angle between screen and flow and informed by local EA knowledge/fish survey data. Further clarification of Weavers bywash mechanism and maximum approach velocity is required as this not easily discerned from the revised plans. Applicant has stated that approach velocity will be in accordance with GPG. Some baffle fish passes are unsuitable for DS migration and this may need to be clarified/refined at detailed design. Risk of entrainment of eels exiting the eel pass is limited by screen angle relative to exit angle. Both schemes incorporate eel passes. Design of eel pass could be a moderate difference, subject to detailed design review. Eel pass design will need measures to exclude predators. No lighting designs available – light may influence migration route. **Lamprey:** Lamprey likely to pass through North Mill scheme. There are relatively few studies on effects on lamprey e.g. stress and mechanical damage. Other species e.g. eels do not appear to suffer significant mortality or predation after passing through the Archimedes screws. However this is based on relatively few studies. The screen on the Weavers Mill Kaplan turbine (12.5 mm) could feasibly be passed by some small lamprey, but is likely to exclude most. Similarly approach velocity set for Cyprinids and eels is suitable for lamprey. Therefore significant lamprey mortality unlikely.	Eel pass, compressible rubber edges, and appropriate limits on rpm to be included as part of North Mill scheme in accordance with latest EA guidance, secured by licence conditions. Maintenance (e.g. screw edges) also secured by licence conditions. 12.5 mm screen plus eel pass included as part of Weavers Mill scheme, to be secured by licence conditions. Closer to the tidal limit (<50 km) smaller mesh sizes (e.g. 9 mm) can be required by EA to protect smaller adult eels where angle between flow and screen is >20° and based on local knowledge. If Netham Weir is taken to be tidal limit then Avoncliffe weir is <50 km from tidal limit. Angle between screen and flow to be clarified and mesh size and approach velocity set accordingly also taking into account local EA knowledge on eels sizes in this area. Weavers Mill scheme remains subject to clarification of bywash mechanism, also recognising that some baffle fish passes are unsuitable for DS migration , and confirmation that approach velocity is within the required maxima for small adult eel and cyprinids. This information cannot be clarified from the plans/information provided. However the approach velocity appears to be close to the required range. Applicant has stated that approach velocity will be in accordance with GPG. Assumes research to date on fish stress associated with passage through Archimedes screw is conclusive (relatively few studies to date). Eel pass designs optimised through detailed design review and licence conditions.

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Impacts on anglers.	See above for effects on fish - damage/harm to fish is likely to be limited by design features providing turbines maintained e.g. compressible rubber and limits on rpm. Anglers seem likely to use the weir pool downstream of the scheme i.e. outside private land. Scheme location is likely to limit angling opportunity close to the weir near right bank. However North Miill has confirmed intention to include provision for anglers to pass the Mill on the bank to reach downstream fishing. Bank reinforcements may impede anglers' access to the right bank downstream of the screw or create a less natural but more accessible bank from which to fish if angling is permitted on private land. Any noise associated with the scheme could adversely affect anglers' experience. Similarly for visual impact.	See above for effects on fish – screen is likely to prevent most fish from entering the scheme. Anglers are likely to use the weir pool downstream of the scheme i.e. outside private land. Scheme location is likely to limit angling opportunity close to weir near left bank. However such effects are likely to be on angling from private (Weavers Mill) land or from within the channel. Changes in weir pool morphology could alter location/distribution of favoured angling locations. Although this is likely to be distribution only. Any noise associated with the scheme could adversely affect anglers' experience.	Neither scheme is likely to result in significant fish harm/ mortality. North Mill scheme is likely to be more visually intrusive and have associated bank reinforcement modification. Weavers Mill scheme is likely to alter weir pool morphology and angling locations to a greater extent due to shift in discharge downstream.	See above assumptions in relation to fish protection. No assessment of favoured angling locations or anglers preferences/ habits has been undertaken.
Flood Risk				
New or altered structures within watercourse?	The smaller screw turbine is to be placed within the historic water wheel pit with the larger one alongside it, set within the weir structure itself. The top of the larger screw and its concrete channel will protrude above the existing weir level. A concrete platform will support the upper bearing, gear box etc at a height of 27.13 m AOD. The top of the screw will be higher than this level. The larger screw and associated sluice gate would extend approximately 4.75 m across the weir. When closed the new sluice gate would provide an additional obstruction to flood flow. A 12.25 m long trash screen would be located upstream of both screws, angled to encourage debris to pass over the fish pass or weir. The fish pass would extend a further 3.0 m across the weir but with the crest at approximately the same level as the weir crest. During the site visit the applicant stated that the intention was to construct a flood relief channel under the existing building between the existing wheel pit and the bank. However no details have been submitted.	The turbine and housing for the Kaplan would be situated on the river bed immediately downstream of the existing sluice and channel through the weir, with the screen and trash rack located within the confines of the existing sluice structure. The new fish pass would not extend above the crest of the existing weir. The existing sluice is permanently closed. It has been assumed that the new sluice would be open except under low flow conditions when required to protect the HOF. The top of the Kaplan would not extend above the existing structure. A 5.5 m long trash screen would be located upstream of the Kaplan, angled to encourage debris to pass over the weir. An eel bypass conduit would extend a maximum of 1m across the weir. The mill leat under the existing mill is unchanged.	Both schemes involve new or altered structures within the watercourse. No details of the flood relief channel mentioned by the North Mill applicants have been provided. It is not clear how this would be provided under the existing building or of the extent of civil engineering works that would be required to achieve it.	No allowance has been made for a flood relief channel at North Mill.
Impacts on flow path	The 1 in 20 year flood level is estimated from Environment Agency modelling to be about 28.09 m AOD or about 2.18 m above the existing weir level. This would result in a depth of flooding over the upper bearing platform of nearly a metre. The replacement screw (replacing the existing water wheel) would potentially provide a greater barrier to flood during high flow events than the existing wheel pit. The proposed structure for the larger screw would provide an obstruction to weir flow, constricting flow within the channel during flood events. The trash screen provides potential blockage unless kept clear of debris. The fish pass would provide negligible obstruction to flood flow. North Mill is located on the outside bend of the main channel and is likely to be subject to higher flows/ velocities than Weavers Mill during some flood conditions.	The 1 in 20 year flood level is estimated from Environment Agency modelling to be about 28.09 m AOD or about 2.18 m above the existing weir level. The proposed Kaplan turbine would sit downstream of the existing sluice structure and would not protrude above the crest level of the weir or top of the sluice gate. Impacts on flow paths would be negligible. The southern side of the weir, adjacent to Weavers Mill is cut into the bank of the main channel and is thus shielded from the highest velocity flows during some flood conditions. The opening of the existing sluice to allow operation of the Kaplan turbine will significantly alter localised flow patterns upstream and downstream of the sluice channel. Increased velocities downstream will potentially impact on scour of the bank immediately downstream. The proposed trash screen would provide potential blockage unless kept clear of debris.	The proposed North Mill scheme would cause a significant constriction in the available width of weir. The proposed Weavers Mill scheme would not significantly affect the conveyance of the weir under flood flows.	

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Impacts on flow capacity	Both screws would present a barrier to flow under flood conditions. The larger screw in particular would result in a reduction in the flow capacity of the weir. During high flows the weir would be drowned out and the head difference across the weir would be negligible. Under such circumstances, the Archimedes screws would not turn. This could result in the screws presenting a barrier to flow and thus a reduction in the overall capacity of the weir, potentially causing a backing up of water upstream.	At present the sluice is permanently shut, presenting an existing barrier to flow greater than would be presented by the proposed Kaplan turbine. The Kaplan would continue to function with minimal head difference across the weir thereby providing a very small increase in flow capacity over the existing situation. The 1 m wide eel bypass conduit would likely have a negligible impact.	The proposed North Mill scheme would present a reduction in flow capacity. The proposed Weavers Mill scheme would provide a small and insignificant increase in capacity provided the screen did not become blocked.	
Impacts on floodplain	There would be a reduction in floodplain storage as a result of the additional structure within the river. The additional structure would result in an increase in water levels upstream. With reference to the Environment Agency flood map, potential receptors include: • Weavers Mill and adjacent properties; • North Mill; • The railway line on the northern bank of the river; • The access road for North Mill.	Potentially very minor impact on river levels as a result of the additional structure within the river, but this would have a negligible impact on flood levels as the structure would be drowned under flood conditions and would not form a barrier to flood flows.	The proposed North Mill scheme would cause a potentially significant increase in flood levels upstream. In particular Weavers Mill is located within the floodplain and thus an increase in flood water levels would be unacceptable with respect to this off-site receptor. The proposed Weavers Mill scheme would have a negligible effect on flood levels.	
Navigation				
Impacts on other river users	No public right of navigation - boats may only operate with the permission of the riparian owner, although it is understood that canoeists use this stretch.	No public right of navigation - boats may only operate with the permission of the riparian owner, although it is understood that canoeists do use this stretch.	Neither scheme is likely to impact upon other river users to a substantial extent.	No information on use of the river by the public has been provided or collected.
Impacts on water levels	There will be a maximum operational flow of 10.033 m^3/s through the screws.	There will be a maximum operational flow of 7.9 m^3/s through the turbine.	The North Mill proposals would present a barrier to flow under flood conditions. In particular the screw turbine within the weir would result in a reduction in the flow capacity of the weir (see 'Flood Risk' for further information)	
Community Benefits				
Provision of electricity to local community?	Not currently proposed.	Applicant suggests there is potential to supply Weavers Mill, Trout Cottage and the Cross Guns Inn public house. Several small renewable energy schemes in the UK have achieved this by technical and/or contractual means.	The Weavers Mill scheme proposes to supply electricity to some local properties whilst the North Mill scheme does not.	Based on the information provided by the applicants.
Other benefits?	Local energy source, providing security of energy supply and generating renewable energy, thereby helping the UK Government to meet its climate change obligations. Annual energy generated is equivalent to that consumed by 110 average UK households.	Local energy source, providing security of energy supply and generating renewable energy, thereby helping the UK Government to meet its climate change obligations. Energy generated annually is equivalent to that consumed by 121 average UK households.	The Weavers Mill scheme would probably generate more renewable energy per year than the North Mill scheme (see 'Climate Change' for further information).	Based on the information provided by the applicants.
Grid Connection				
Opportunities/Restrictions?	Potential SEPD grid connection available alongside railway to 11kv cable. Also an existing wayleave for a 3-phase cable under the railway to a pole-mounted line. Connection study by SEPD shows this is feasible. Habitat loss likely to be limited.	Potential SEPD grid connection available to nearby 11kV cable which is understood to be buried in land near the eastern side of the southern end of the aqueduct.. Wayleaves agreed. Connection study by SEPD shows this is feasible. Habitat loss likely to be limited.	Based on information provided there is unlikely to be any substantial difference between the two schemes.	Assumes all necessary permissions are in place for both schemes.

Table A1 (continued) Avoncliff Weir – Comparison of Hydropower Schemes

Factor	North Mill	Weavers Mill	Summary Comparison	Notes/ Assumptions
Construction				
Length of construction phase	Estimated 6 to 9 months.	Estimated 3 to 6 months.	Unlikely to be a substantial difference in the length of the construction phase of the two schemes.	Assumes all necessary permissions are in place for both schemes.
Construction access arrangements	Access via existing rail crossing from single track road - potentially unsuitable for abnormal loads. This is confirmed by the EIA scoping response from the local highways authority: "*The construction and the delivery of the screw set does pose some concern, as the narrow roads approaching the site would not be suitable for large vehicles and abnormal loads*". Negligible habitat loss. Concrete and piling – temporary turbidity and limited risk of pollution. This can be mitigated.	Proposing use of aqua dam and barge to bring in structure. Barge launch from track within 2 m of river from the adjacent Barton Country Farm Park. Crane access off-road through garden of Mill property. Temporary turbidity and limited risk of pollution.	Use of single track roads to transport large structures – likely to be abnormal loads – for the North Mill scheme potentially restrictive although the applicants state that access arrangements have been agreed.	Assumes all necessary permissions are in place for both schemes.

Appendix B
List of Data Sources

6 Pages

General

Table B1 Documents Reviewed to Inform Appraisal

Document	Date Received	Summary
Mr Tarrant doc~0932 part 1 of 3	22/8/12	Various; Presentation on Archimedean Screw at Maple Durham Mill; Chris Elliot, WRE Ltd (Western Renewable Energy Ltd), 2011. GESS-CZ s.r.o. data, 1946 conveyance for the mill – map 'land edged red' for Avoncliff Flockmills (south of river) and the whole weir
Mr Tarrant doc~0932_001 part 2 of 3	22/8/12	Above continues, full analysis and charts for the Archimedean screw.
Mr Tarrant doc~0932_018 part 3 of 3	22/8/12	Comparative merits of the two proposed hydropower schemes at Avoncliff Weir, dated 28/3/12. Copyright Martin Tarrant.
Tarrant~Earl~Variable Speed performance curve~700612~provided by Mr Tarrant	22/8/12	Chart as already seen in above.
Tarrant~Earl~Avoncliff options Variable speed screw - Kaplan~070612provided by Mr Tarrant	22/8/12	Tabular presentation of data for two schemes. Four cases showing energy yields. Cases 1 & 2 separate licences. Cases 3 and 4 combined licence.
MrTarrant~DetRep~consResponse~July12	22/8/12	July 2012 representation in respect of draft licence.
performance curve Avoncliff 68001s~bb~110612	9/8/12	Performance curves for variable speed ANDRITZ Archimedean screw
Renewable Design Consultants~H-038 Avoncliff Weir feasibility report v1 1 (4)	9/8/12	RDC for Mr Earl; Comparison of Hydropower Schemes at Avoncliff Weir, River Avon.
09081201 John Adams email	10/8/12	Email about position, dated 28/6/10.
Avoncliff Weir - Analysis of EA Determination Reports report to Steve and Ewan Earl 10 July 2012	10/8/12	RDC for Mr Earl; Analysis of EA Determination reports, further to RDC report (doc 9). Includes yield figures for 5 scenarios including split scheme.
WORK_16769481_1_Letter (Burgess Salmon_Environment Agency) - 9 August 2012	10/8/12	Letter from Burges Salmon dated 9 August 2012. Refers to various documents inc eWaterpower (agents for Ritz-Atro).
WORK_16766846_1_Steve and Ewan Earl _ Concerns about leat and sluice gate	10/8/12	Referred to in above letter from Burges Salmon (doc 13).
draft license clarification questions 25jul2012 (01)	10/8/12	eWaterpower comment on draft licence.
Flow Sequence at Avoncliff	9/8/12	Jan 1990 to end Dec 2007 flow data at Avoncliff Weir abstraction location.
WORK_16035158_1_Order received by the High Court of Justice on 11 April 2012	9/8/12	Order from High Court, dated 11/4/12 between Steven and Ewan Earl, the EA and Martin Tarrant.
FiTs changes~July12	9/8/12	Emails trails relating to announcement by DECC of new FiT rates etc.
Mr Earl doc~Hydroprojects at Avoncliff Weir~provided by Mr Earl	9/8/12	Comments by Mr Earl on Mr Tarrant's pros & cons list comparing the 2 schemes.
Weavers Mill Notes 3,9,12	4/9/12	Notes by Mr Tarrant on submissions by / on behalf of the Earls.
main-weir-flow	07/11/12	Video of River Avon and weir flow from Weavers Mill side.
Wiltshire-20120501-00090 MT pic		Photo of river under high flow conditions from Weavers Mill side.
AC1 to AC6		Photos taken at North Mill.

Table B1 (continued) Documents Reviewed to Inform Appraisal

Document	Date Received	Summary
Various		Photos and a video at Weavers Mill including leat channel.
0417_001	15/11/12	Letter and attachments ref scoping opinion request for North Mill, dated 23/11/12.
0417_015	15/11/12	Continuation/repetition of above document.
0417_030	15/11/12	Design and Access Statement (twice?) plus oecologic survey report.
0417_053	15/11/12	Architects drawings plus various emails between Wilts CC and Gemma (cond) Mahoney of EA F&B, Wilts CC and the Earls.
Let~SE Earl~inforeq~191012	26/11/12	Letter from EA requesting information on scheme.
Let~SE Earl~site visit_deadline~201112	26/11/12	Letter from EA requesting a formal site visit.
Let~Tarrant~inforeq~191012	26/11/12	Letter from EA requesting information on scheme.
Let~Tarrant~sitevisit_deadline~201112	26/11/12	Letter from EA requesting a formal site visit.
Weavers Mill Cost Analysis	13/12/12	As suggested by title.
Wiltshire-20121211--00190		Photo of Kaplan turbine.
Appendix 1 12 December 2012	13/12/12	North Mill cost analysis.
List of questions	13/12/12	Questions provided to the applicants prior to site visits by the EA and AMEC.
Answers to questions	13/12/12	Answers to the above questions.
Appendix 1 12 December 2012	13/12/12	Word document with answers to request for information raised by EA and as appendix 1 to the AMEC/DAL report.
Response from Wilt Council~Nov12	13/12/12	Correspondence from Wiltshire council re. the extent of pre-application discussions with both applicants.
WEIR DETAILS	14/12/12	pdf of cross sections, including levels, at Avoncliff weir by Larner Sing.
Weavers mill plan	18/12/12	Topo survey of weir and both river banks - Renewables First.
HEP Info Request 17 12 12	19/12/12	Details provided by the EA of other HEP schemes.
Various	19/12/12	Flow and Ecology (including fisheries) data provided by the EA.
email from Mr Tarrant	20/12/12	Emails from Mr Tarrant containing revised opinion on performance of North Mill turbine.
email from Mr Tarrant~Avoncliff 2 variable speed screws		

Water Resources and Flood Risk

- Environment Agency, 2013. What's in your backyard website (http://www.environment-agency.gov.uk/homeandleisure/37793.aspx) accessed on 10 January 2013.

Climate Change and Energy Generation

- Engineering Practice, Volume II, Mechanical and Electrical Engineering, Pub Blackie and Son, Editor J Guthrie Brown, CBE, 1970, Esp Chapter VI Kaplan and Propeller Turbines, pages 139 to 191;

- Renewable Energy, Technology, Economics and Environment, Martin Kaltschmitt, Wolfgang Streicher, Andreas Wiese, 2007;
- Marks Standard Handbook for Mechanical Engineers, various editions;
- Peak Power: Developing Micro Hydro Power in the Peak District, 2010, available from; Friends of the Peak District, *http://www.friendsofthepeak.org.uk/*;
- Untersuchungen zum ruckstau an der Wasserkraftschnecke (Typ RITZ-ATRO) der Fa. Okofish GmbH + Co. KG in Hoxter-Godelheim. November 2004 (colloquially translated: Study of effect of tail-water backing-up on the performance of the Archimedes Hydro generator);
- Inventory of Carbon & Energy (ICE), Version 2.0, Prof. Geoff Hammond & Craig Jones, Sustainable Energy Research Team (SERT), Department of Mechanical Engineering University of Bath, UK;
- Assessment and Design of Small-Scale Hydro plants, PhD Thesis, Ian Jones, University of Salford, 1988;
- Trash Control Structures and Equipment: A Literature Review And Survey Of Bureau Of Reclamation Experience, US Department of the Interior, Feb 1992.

Table B2 Additional Data Sources Received via Email

Document	Date	Summary
Renewable Design Consultants~H-038 Avoncliff Weir feasibility report v1 1 (4)	9/8/12	For original Flow Duration Curve (FDC) and Head Duration Curve (HDC) used for North Mill energy estimates.
Flow Sequence at Avoncliff	9/8/12	EA FDC used for energy estimates of both schemes.
Appendix 1 12 December 2012.docx	13/12/12	Word document with answers to request for information raised by EA and as appendix 1 to the AMEC/DAL report.
Flow Level comparison 12dec2012	13/12/12	PDF file of note by Brendan Barrow about flow and head, dated 12 December.
Performance curve 2700 fixed speed.pdf	13/12/12	PDF file of performance curve as stated.
Performance curve 2700 variable speed.pdf	13/12/12	PDF file of performance curve as stated.
Performance curve Avoncliff 6800ls.pdf	13/12/12	PDF file of performance curve as stated.

Additional Information Received After 30 April 2013

Email ref sensors Martin Tarrant	09/04/13	Email describing the sensors used for head data collection at Weavers Mill.
Sensor locations	09/04/13	Sensor locations indicated on plan drawing of weir at Weavers Mill.
Andritz Noise Assessment 2012	09/04/13	Acoustic Report, Sound Emissions From The Artern Hydro Power Installation, June 2012, acouplan consultants. Noise measurements and interpretation from Artern River hydro site with Andritz screws
Minded to determination response 6jun2013~120613	June 2013	Response by Mr B Barrow to EA Determination Report.
Level Measurement Method and results 6jun2013	June 2013	Short Report by B Barrow on North Mill 6 month data set.
Levels measurements images	June 2013	Set of photographs of equipment used for North Mill 6 month data collection.
North Mill levels data 6jun2013	June 2013	PDF format Daily data record of North Mill 6 month data collection.
Appendix 3 Amec report 6jun2013~130613	June 2013	Response by Mr B Barrow to AMEC Report.
Earl~Response to Weavers Mill report	June 2013	Response to Weavers Mill Without Prejudice report dated 4 June 2013 in respect of the AMEC Report(30/4/13)and the 'Minded To' Determination Report (30/4/13)
Avoncliff~RepfrmBBarrow~050713	June 2013	Email trail, Mr B Barrow comments on suitability of Kaplan Turbine.
Kaplan-Base-2-A3	June 2013	Drawing (unknown origin) relating to email above.
Kaplan-Base-A3	June 2013	Drawing (unknown origin) relating to email above.
Determination Considerations 30jul2013	June 2013	Further response by Mr B Barrow to 'outstanding issues' in EA Determination Report.
Notes AMEC Det Report 4613	June 2013	Response by Mr M Tarrant on AMEC report and EA Determination Report.
593 LDS Survey (9787)-TP1_250	June 2013	PDF copy of drawing by LDS Survey; topographic survey of Avoncliff Weir commissioned by Mr M Tarrant, copyright date 2009.
MT_SE1~130613~kaplan efficiency	June 2013	Email trail, Mr M Tarrant comments on efficiency curve of Kaplan Turbine.
Comments regarding Brendan Barrow's responses 24,6,13	June 2013	Response by Mr M Tarrant to Mr B Barrow's comments on various documents.
Ossberger-Earls 15-7-09	June 2013	Copy of email from Ossberger.
Ossberger-Tarrant 16-7-09	June 2013	Copy of email from Ossberger.
WESD0002 Rev 3	June 2013	Plan view, general layout of Weavers Mill proposed Hydro Scheme. Dated 2 Feb 2010.
WESD0003 Rev 1	June 2013	Elevation view, existing sluice gate layout, dated 23 July 2010.
WESD0004 Rev 1	June 2013	Elevation view, section A-A from WESD0002, dated 2 February 2010.
WESD0005 Rev 1	June 2013	Elevation view, from upstream of trash screen arrangement, dated 2 February 2010.
Determination Considerations 30jul2013	August 2013	Further comment by B Barrow on various documents and in general.

Re_Revised scheme 1	August 2013	Email ref Weaver Mill now using concrete as foundation for turbine.
Re_Comment on revised drawings	August 2013	Email from Mr Tarrant regarding water velocity through fish screen.

Additional Information Received by AMEC on or after 5th September 2013

Email from Mathias Mueller of ANDRITZ Atro GmbH dated 29/8/13	05/09/13	Quotes lowest operating flows.
Email from Chris Elliott of Western Renewables dated 13/8/13	05/09/13	Comment on start-up flows for Screws.
Email from Gregory Nau of Mann Power Consulting Ltd dated 13/8/13	05/09/13	Comment on start-up flows for Screws.
2700_4-bladed.pdf	05/09/13	Quotation No:. 09.09/W-1134 Rev 5 from Andritz for 2700mm Screw at Avoncliff
3600_4-blade.pdf	05/09/13	Quotation No:. 09.09/W-1134 Rev 4 from Andritz for 3600mm Screw at Avoncliff
Email trail dated 4/9/13 on start-up flows.	05/09/13	Various information and above emails on start-up flows.
Weavers Mill New Scheme Drawings response 25sep2013 DM comment	30/09/13	PDF document from Mr B Barrow with comments on various aspects of Weavers Mill.
ATL performance curves	4/12/13	PDF chart showing performance curves of Kaplan turbines of type proposed for Weavers Mill

Environmental

Cultural Heritage

- Wiltshire Historic Environment Record;
- Historic OS Maps (available on internet);
- Records of designated Heritage Assets (http://www.english-heritage.org.uk/professional/protection/process/national-heritage-list-for-england);
- Client and applicant supplied data (photos, drawings, scoping consultation response).

Biodiversity and Fisheries

- Oecologic (2009). Avoncliff Mill, Avoncliff, Bradford-on-Avon, Wiltshire: Ecological Survey;
- Tiplady, M. A (2006). Baseline Ecological Assessment of the Tellisford Mill Hydro-electric Power Scheme. MSc thesis;
- Environment Agency & Royal Haskoning (2009). Tellisford Mill Ecological Monitoring;
- SNIFFER WFD114: Impact of run-of-river hydro-schemes upon fish populations. August 2011;
- Kibel, P. (2007). Fish Monitoring and Live Fish Trials: Archimedes Screw Turbine, River Dart - Phase 1 Report: Live fish trials, smolts, leading edge assessment, disorientation study, outflow monitoring. Fishtek Consulting. Report for Mann Power Consulting Ltd;
- Kibel P, (2008). Archimedes Screw Turbine Fisheries Assessment. Phase II: Eels and Kelts. Fishtek Consulting. Report for Mann Power Consulting Ltd;
- Kibel P, Coe T and Pike R, (2009). Howsham Fish Monitoring: Assessment of fish passage through the Archimedes Turbine and associated by-wash. Fishtek Consulting. Report for Mann Power Consulting Ltd;
- Environment Agency data (RHS, Macrophytes, Macroinvertebrates);
- Environment Agency South West Region (Wessex Area) Fish surveys 2010/11;
- Archimedes Screw North Mill Avoncliff: Design and Access Statement;
- Wiltshire Biological Records Centre (designated sites and notable species).

Landscape and Visual; Recreation/Amenity

- MAGIC website: www.magic.defra.gov.uk;
- OS mapping: www.bing.co.uk/maps.

Appendix C
Energy and Climate Change

14 Pages

C.1 Energy Generation

Introduction

Independent estimates of the electricity likely to be generated from the two proposed schemes have been calculated. An approach based on mathematical prediction and analysis using a general purpose spreadsheet has been adopted and this is illustrated in the flow chart on the following page. This method estimates the water power available to the turbine and then converts this to the amount of electricity generated using power curves and efficiencies for the turbine and related plant under consideration.

Process of Estimation

The following steps have been taken to estimate the electricity generation for each scheme:

1. Establish the long-term average annual gross flow and concurrent gross head data to be used as exceedance data in bands, typically in 5% or 10% steps (referred to as ‘bins’) from a Flow Duration Curve (FDC) and a Head Duration Curve (HDC). The head at this weir varies significantly - this is important as it significantly affects the energy available to the turbines. Then, for each exceedance band:

2. Account for the minimum flow required over the weir and flow through the fish pass etc. to leave the flow available to the turbine. Check if the remaining flow is high enough to start the turbine or if the head is too low because the weir is ‘drowned out’ and set these latter bands to zero generation;

3. Estimate the net mean head available to the turbine in the band (bin), taking account of screens, sluices and tail effects etc;

4. Calculate the water power available to the turbine from the net head and available flow;

5. Calculate the ‘flow fraction’ to indicate the point on the turbine’s efficiency/power curve and then extract the resulting turbine power using the efficiency/power curve;

6. Limit the power output based on the maximum power possible from the turbine and also the maximum licensed flow. Calculate the total amount of electricity generated over that portion of the year at that power;

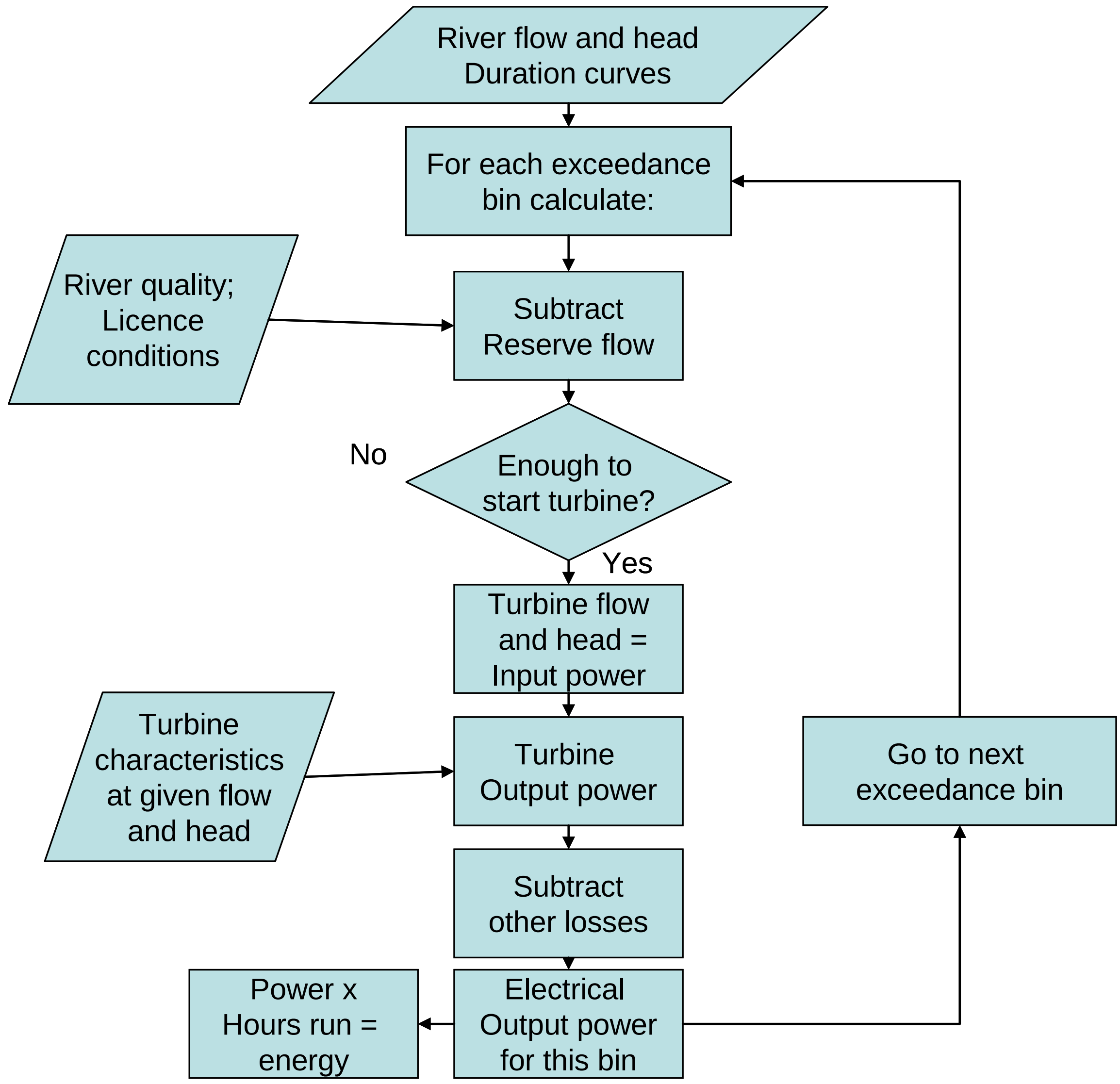
7. Sum the generated electricity for all exceedance data bands;

8. Make due allowances for maintenance downtime.

Specifically and additionally for the twin-screw arrangement:

1. Optimise the use of water by examining which of the two screws generates most electricity at a given head and flow at each point on the exceedance curve;

2. Take account of the effect of tail submersion as the head falls due to the river backing-up immediately downstream of the weir.



This method yields a prediction of the annual average electricity generated, though the actual generation in any given year will be highly dependent on the prevailing flow conditions in the river during that year.

The method is a well proven industry standard methodology and provides a sound approach to comparing the performance of different scheme options at a given location.

Data Used

Three sets of data describing the river flow and head have been used:

- The Weavers Mill applicant has provided a data set consisting of an Environment Agency FDC (1990 to 2007) together with a HDC based on the applicant's own measurements at the weir from Dec 2008 to May 2009;
- The North Mill applicant has provided a data set consisting of an Environment Agency FDC (1990 to 2007) together with head data from which AMEC has derived a HDC. The

head data are based on the applicant's own measurements at the weir from Dec 2012 to May 2013;

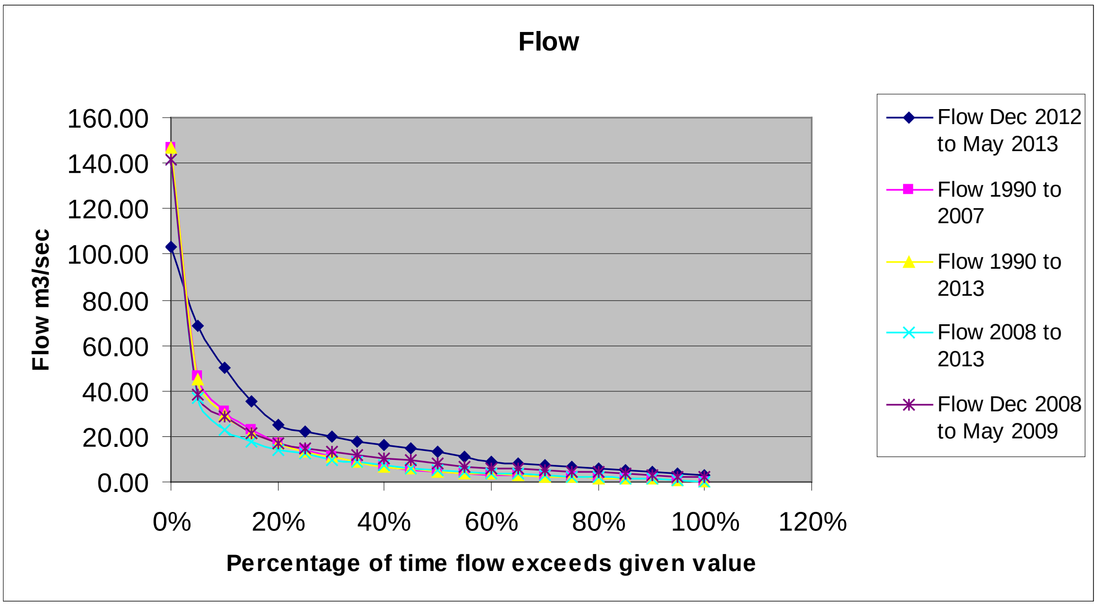
- We produced a single final data set consisting of a longer duration Environment Agency FDC (1990 to 2013) and a synthesised HDC based on the head data supplied by both the applicants.

Flow Data

The Environment Agency flow data are based on gauging station data for the Bristol Avon and extrapolation of the data from the gauging station site to Avoncliff Weir. Both applicants have used the same data for the FDCs and these data are assumed to be accurate and reliable and statistically significant. The applicants have used data measured between 1990 and December 2007.

We have recently obtained Environment Agency flow data from 1990 to September 2013 and used this in a final set of model runs to estimate the annual energy generation from the proposed schemes.

We have also carried out some analysis of the flow data comparing the various periods of flow and head data monitoring. The data are plotted below and then the main findings are listed:



The statistics and graphical presentation of the data from 1990 to 2007 and 1990 to 2013 are very similar. The maxima and minima are the same and the means differ by only 2.1%

The statistics and graphical presentation of the medium-term data from 2008 to 2013 and long term from 1990 to 2013 are also very similar. This indicates that the river flow is consistent across the medium and long-term and that the 5 year data from 2008 to 2013 is statistically representative of the long term.

The statistics and graphical presentation of the short-term data from Dec 2008 to May 2009 and long term from 1990 to 2013 are sufficiently close to indicate that the short-term data from Dec 2008 to May 2009 is reasonably statistically representative of the long term. The maxima are the same, the minimum during the period Dec 2008 to May 2009 is less than 2 m^3/s compared to the long term of 0.04 m^3/s and the mean is 13.22 m^3/s compared to the long term mean of 11.28 m^3/s. Graphically the curves run close together. This is the period during which Weavers Mill head data were gathered.

The statistics and graphical presentation of the short-term data from Dec 2012 to May 2013 and long term from 1990 to 2013 are noticeably different as can be seen on the chart. Notably, the maximum is only 103 m^3/s compared to 146.54 m^3/s for the long term and the mean is 19.58 m^3/s compared to the long term mean of 11.28 m^3/s. This indicates that the short-term flow data from Dec 2012 to May 2013 is statistically different to the long term. This is the period during which North Mill head data were gathered.

Head Data

The two sets of head duration data have been measured at the site by the two applicants. Since they refer to the same weir and as they should be expected to do for measurements of sound quality, the data sets are very similar. This is despite the fact that, as noted above, the flow statistics are noticeably different. Some general points are discussed below.

Suitability of the Input Data

For any hydropower scheme the instantaneous power and energy generated over time are functions of the head and the flow. Therefore, it is important to have accurate data on the variations of both the head and the flow over time. It is also important to have data which correlate both the head and the flow together and typically both an FDC and a HDC are produced concurrently to yield this data set. Ideally, for the purposes of this analysis, the developers would have provided such data sets based on raw data measured at the site for at least 12 months and preferably much longer together with information on the quality of sensors taking measurements, their locations and associated calibrations as well as a description of the processing.

We have compared the HDCs based on the data measured by the applicants on site and they show reasonable agreement. Although not all the raw data have been supplied by the applicants, the locations of the measurement sensors have been provided to us and appear to be appropriately sited.

The Weavers Mill head measurements were recorded from December 2008 to May 2009 and North Mill head measurements were recorded from December 2012 to May 2013. Thus each set provides around 6 months of data and over a winter/ spring period. Neither set is ideal as they may not be statistically significant compared to the long term. It would be preferable to have at least a year of data for two reasons; firstly the longer period would be more statistically significant and, secondly, it would reduce the risk of seasonal bias in the data.

The flow data relevant to the monitoring periods for head data have been examined and compared with the long term data set (see earlier discussion). The flow statistics (maximum, minimum, mean) during the period for which Weavers Mill head measurements were recorded show a good match to the long term data set and this implies the head data are likely to represent the long term. The flow statistics during the period for which North Mill head measurements were recorded were very different to the long term set, and therefore do not represent the long term (this re-iterates the advisability of longer term data monitoring).

Now, as the two head duration curves are very similar, we deduce that the variations in the statistics for the flow data during the monitoring periods do not influence the head duration curve significantly. This is not unexpected as the head duration curve should effectively form a graphical representation of the way the weir at Avoncliff responds under the range of flows across it. So long as the most common types of flows have been experienced during the monitoring period then the range of heads should be evident in the Head Duration Curve.

Consequently, we consider these data to be sufficiently sound for the purposes of initial energy generation estimates. More importantly, though they should correctly identify the *relative* merits of the two schemes.

We should again note that we have not been provided with a description of the processing of the data. A consequence of this is that our HDC for modelling may differ from that used by the applicants' in their own modelling. However we have used a consistent approach to processing both sets of data and so we consider our approach is the best means of comparing the performance of the schemes.

Synthesised Head Duration Curve

A single Head Duration Curve has been synthesised from Weavers Mill and North Mill head measurements. As we do not have access to the raw data from Weavers Mill nor the full calibrations from North Mill, this has been carried out using the processed data in the form of Head Duration Curves. This is considered a reasonable method given how close the two curves are to each other.

The Weavers Mill head measurements were recorded from December 2008 to May 2009 and North Mill head measurements were recorded from December 2012 to May 2013. Thus each set provides around 6 months of data and over a winter/spring period. Neither set is ideal as they will not be statistically significant compared to the much longer flow data set. It would be preferable to have at least a year of data for two reasons; firstly the longer period would be more statistically significant and, secondly, it would reduce the risk of seasonal bias in the data. Consequently, it is not considered to be a more statistically significant curve, merely a more appropriate representation of the way the head varies at Avoncliff. In the absence of any other measured data this is considered the best available HDC for the site.

This synthesised Head Duration Curve has then been used in energy estimation.

Application of the Data

With three data sets, work was carried out in two stages. Firstly head duration data supplied by the two applicants was applied to both schemes to quantify the effects of the two differing sets of data, each set. Paired flow and head data sets were used to estimate two different annual electricity generation figures for each scheme (four results in total), thus removing a source of potential error when comparing the two schemes. We did test using different start-up flows but this proved immaterial to the result with variations in predicted annual energy generation of around 1%.

As the data from North Mill were provided as a set of daily measurements over a period of about 6 months, we produced an exceedance curve from this data and used this in the modelling. This exceedance curve differs slightly from that provided by the Weavers Mill applicant; without access to the raw data from both applicants we cannot comment on exactly why this difference exists.

Secondly, the synthesised Head Duration Curve and the flow data from 1990 to September 2013 (the 'final data set') have been used in a final modelled case to compare the energy estimated to be generated by the two proposed schemes.

The following specific input data describing the characteristics of the turbines have also been used in the analysis:

Weavers' Mill

Input Data	Comment
Kaplan water to shaft turbine efficiency curve taken from published texts on generic devices.	This yields the efficiency of the turbine across a range of water flows.
Estimates of effect of draft tube and screen losses from standard industry formulae and based on estimated sizes of plant.	These estimate the head loss through the screen and through the draft tube of the Kaplan turbine.
Published efficiency factors for other similar plant.	Gearbox and generator efficiencies have been included.

North Mill

Input Data	Comment
Water to wire screw turbine efficiency curve from the manufacturers.	This yields the efficiency of the screws across a range of water flows. There is some concern that the curves used are for machinery design rather than energy yield assessment and therefore cannot be interpreted with confidence.
Estimates of effect of sluice, forebay and screen losses from standard industry formulae and based on estimated sizes of plant.	These estimate the head loss through the screen and from the sluice through the fore-bay to the intake of the screw.
Effect of screw submerging - taken from German paper.	This take account of the tail of the screw increasingly being submerged as the tail-waters back-up under high flows at this weir.

Assumptions

- The Weavers Mill applicant has provided a net head duration curve that we understand takes into account head losses including for the draft tube. An estimate of these head losses has been made and used to reverse the adjustment to produce a gross head exceedance curve for use in the North Mill screw calculations;
- The North Mill applicant has provided gross head data which have been provided as a typed set of daily head measurements. We have processed these to provide an exceedance curve for modelling purposes;
- A third synthesised gross Head Duration Curve has been assumed to represent the behaviour of the weir through the full year even though it is based on winter measurements (December to May in two years). We have processed this to provide an exceedance curve for modelling purposes;
- The turbine proposed at Weavers Mill is a Kaplan from a new manufacturer so although the generic design is well-established there may be small changes in design or changes due to quality of manufacture. At the time of our analyses there were no specific performance data available for the exact turbine proposed; however since that time performance data have been provided for two machines understood to be of the general type and design as proposed for Avoncliff. The data provided exhibit the behaviour we would expect to see for a well designed and

performing doubly regulated Kaplan turbine of the outputs specified and are generally in line with data presented in peer reviewed, published texts;

- The Kaplan gearbox and generator efficiencies have been estimated using published figures typical of the machinery likely to be used;
- The manufacturer's performance curves of the screws are assumed to be valid and are assumed to be 'water-to-wire' efficiencies. The screw performance curves provided are machinery designers' curves and do not directly present the efficiency across the range of power outputs/water flows required for estimating energy generation. A number of assumptions have had to be made to convert these to efficiency curves;
- It has been assumed that sluices are never used to control the flow of water into the screws and any head loss associated with these sluices has not been included;
- The performance of the screw is assumed to reduce as the river backs up and in the manner described in a published paper;
- The hands-off flow is 0.951 m3/s;
- The sweetening flow through the old leat at Weavers mill is 0.162 m3/s;
- The start-up flow for the Kaplan is 0.45 m3/s;
- In the initial modelling we used start-up flows of $0.9m^3/s$ for the 2,700 mm diameter screw and $1.25m^3/s$ for the 3,600 mm diameter screw. These are reasonable values to assume in the absence of specific figures from the applicant;
- In the modelling for the final data set we used start-up flows of $0.16m^3/s$ for the 2,700 mm diameter screw and $0.34m^3/s$ for the 3,600 mm diameter screw in line with the North Mill applicant's communication despite having no independent evidence to demonstrate these figures nor indicate the power generated at these very low flows;
- Operations and maintenance downtime has been excluded from the analysis, i.e. both systems are assumed to be perform with the same level of availability. This assumption is likely to over-estimate the generation from both schemes but may favour the screws as there is likely to be more maintenance required for two sets of screws than for a single Kaplan turbine;
- It is assumed that the head reductions in the trash screens, forebays, etc. can be estimated from standard industry formulae. It is further assumed that they remain constant despite any fouling. It is noted that the Kaplan has an automated screen cleaner whereas the screws do not. This assumption may result in an over-estimate of the energy generated by the screws;
- It has been assumed that start up-shutdown hysteresis is negligible for both machine types. This assumption may lead to a slight over-prediction of the yield from the screws because they will start and stop more frequently than the Kaplan;
- The control of the two screws has been assumed to be as we have described it. No information was provided by the applicant about the proposed control strategy.

There may be a better control strategy than we have proposed. Equally, the strategy proposed might not be entirely possible in practice;

- The peak flows of the 2,700 mm diameter and 3,600 mm diameter screws are 3.276 m3/s and 6.757 m3/s respectively;
- The peak flow of the Kaplan is 7.9 m3/s and the design/optimum flow is 7.0 m3/s.

Results

Kaplan:

- Using the Weavers Mill applicant's HDC data set, the estimated total amount generated is 490 MWh per year for a total annual flow through the turbine of 142 million m^3. This gives 3.46 Wh per m^3 of water used;
- Using the North Mill applicant's HDC data set from June 2013, the estimated total amount generated is 410 MWh per year for a total annual flow through the turbine of 131 million m^3. This gives 3.13 Wh per m^3 of water used;
- Using the longest Environment Agency FDC (1990 to 2013) and the synthesised Head Duration Curve, both at 5% intervals, the estimated total amount generated is 398 MWh for a total annual flow through the turbine of 132 million m^3. This gives a value of 3.02 Wh per m^3 of water used.

Screws:

- Using the Weavers Mill applicant's HDC data set, the estimated total amount generated is 464 MWh from the twin screws using a maximum flow of 3.276 m3/s for the 2,700 mm screw and 6.757 m3/s for the 3,600 mm screw giving a total of 10.033 m3/s. These have a total annual flow through the screws of 159 million m3. This gives 2.92 Wh per m3 of water used;
- Using the North Mill applicant's HDC data set from June 2013, the estimated total amount generated is 382 MWh from the twin screws also using a total maximum flow of 10.033 m3/s. These have a total annual flow through the turbine of 151 million m3. This gives 2.53 Wh per m3 of water used;
- Using the longest Environment Agency FDC (1990 to 2013) and the synthesised Head Duration Curve both at 5% intervals the estimated total amount generated is 363 MWh for a total annual flow through the turbine of 188 million m3. This gives 1.92 Wh per m3 of water used.

Discussion of Results

The results and subsequent analysis show that the estimated energy yield from the screws is lower than that for the Kaplan at Weavers Mill regardless of which data set is used.

Comments on Turbine Performance

Kaplan

The Kaplan turbine extracts power from the flow of the water and is a reaction machine. A double-regulated design is proposed which has continuously adjustable 'runner' blades on the rotating hub and static guide vanes ('wicket gates') to alter the flow characteristics. This means it can be adjusted to suit a particular water flow and so generate efficiently over a wide range of flows and heads. The use of these adjustments also means it does not require a sluice gate to control the power of the turbine.

There is a screen to both protect the turbine from debris and prevent the passage of fish. This screen will be required to have a 12.5 mm bar spacing though no design has been presented. This will reduce the head slightly and this has been taken into account in the net head calculation. The screen is automatically cleaned so this reduction does not materially worsen over time.

Kaplan turbines run at around 40 to 300 RPM (at Weavers Mill this is likely to be around 100 to 150 RPM) and drive a speed increasing gearbox to turn a generator at typically at 1,500 RPM. This is a variable speed machine and so power electronics will then be used to convert the variable frequency power to 50Hz mains frequency at the appropriate connection voltage. The loss of efficiencies in these conversion steps has been taken into account in the estimation of generation.

The Kaplan turbine is well understood and very many MW of capacity are installed around the world. There is a considerable body of independent data in published, peer-reviewed text books and papers. This means that reliable estimates can be made of its operational performance in real conditions.

We note that the turbine proposed at Weavers Mill is a doubly regulated Kaplan from a new manufacturer so although the generic design is well-established there are no specific performance data available for the exact turbine proposed. We understand that a few machines are operating in the field and that their performance is as expected though we have not had access to any independent data to confirm this. On a factory visit we witnessed another turbine under construction and it appeared that the company does have the capability to produce an efficient machine.

Archimedean Screws

The Archimedean screw extracts power through the weight of the water falling down the turning screw. The flow has to be matched to the speed of the turbine to maintain maximum efficiency and this is typically achieved using a sluice gate in a constant speed screw. Such a sluice causes a reduction in head at all but design flows. The sluice can also permit the shutting-off of the water flow for certain maintenance activities.

In a variable speed Archimedean screw the variation in speed to a large degree allows for regulation of power in accordance with water flow. Some manufacturers do not include a sluice to control power from a variable speed Archimedean screw. If a sluice were to be used, it will cause a reduction in net head at the screw entrance. There have been insufficient detail provided of the sluices at North Mill, but since the screws are to be variable speed this head loss has been neglected in the energy generation estimations. It is highly likely that a sluice will be fitted in order to stop the flow for maintenance. The sluice structure may cause head loss. Thus the energy generation from the screw may be over-estimated in this respect.

At the intake there is a coarse screen to protect the turbine from debris. This will reduce the head slightly and this has been taken into account in the net head calculation. The screen is not cleaned automatically so this reduction may worsen over time until it is cleaned, though this effect has not been taken into account in the estimates. Thus the energy generation from the screw will be overestimated in this respect.

Archimedean screw turbines run more slowly than Kaplans at around 20 to 40 RPM (at Avoncliff this is likely to be under 30 RPM). The shaft of the screw drives a speed-increasing gearbox to turn a generator at speeds that are typically between 1,000 RPM and 1,500 RPM for this type of application. These are likely to be variable speed machines and so power electronics will then be used to convert the variable frequency power to 50Hz mains frequency at the appropriate connection voltage. The loss of efficiencies in these conversion steps has been taken into account in the estimation of generation.

The gearbox for the Archimedean screws is likely to be less efficient than that for the Kaplan as the speed increase is greater.

There is a lack of independent data on the operation of screws in a wide range of real rivers. Furthermore, no independent peer reviewed information on the performance and operation of screws has been found in any published texts despite assistance from the IMechE library.

Only two independent technical references on screw performance were found for power curve and efficiency data. One concerns the performance of an Archimedean screw at the River Dart. The other is a German paper reporting on a series of tests.

The River Dart report confirms the claimed efficiency at three points on the curve provided by the manufacturer. Whilst this is of some interest, firstly it only confirms the performance at three points, not along the whole curve and, secondly, the installation at the River Dart allows the screw to operate in nearly ideal conditions of controlled head and flow. This is because the screw is not situated directly within the river but instead receives its flow via a headrace, with the flow leaving the screw via a tailrace. It appears that the flow and head arriving at the screw hardly vary and are normally close to the design condition for the screw; furthermore the tail of the screw is highly unlikely to be submerged beyond the design depth. Both these factors will enhance the efficiency of the screw compared to a similar screw operating on a weir in a river where water levels and flow are subject to large variations, such as is the case at Avoncliff.

The German paper reports on a series of tests of a screw where the tail water level varies. This report is particularly useful in accounting for the ‘backing-up’ of the river level below the weir at Avoncliff. This has the effect of reducing the head, submerging part of the screw (so that it must churn the downstream water) and so reducing the power output of the screw. Data from the paper have been used in the energy estimation carried out for this report.

Conclusion

Both applicants have provided data to be used to calculate the energy generation potential of their respective schemes. Both applicants provided the same Flow Duration Curve data, sourced from the Environment Agency, but have provided different Head Duration Curve data based on their own independent measurements. The flow and head data have been taken from different sources (i.e. not generated from data measured over the same time period) and consequently the head duration curve may not match the flow duration curve.

We have also used the ‘final data set’ to produce a single set of results. This takes the longest and therefore more statistically significant period of daily flow measurements in the river together with the synthesised HDC which is based on the two applicants’ HDCs. This is considered the most appropriate method for compiling a single data set in the absence of longer term independent measurements. When compiling the synthesised HDC we have taken our own view as to the most prudent head estimates to adopt for each flow range within the FDC and generally this is the average of the two. We consider this third set (the ‘final data set’) provides the best available basis for comparison of the two schemes.

Although none of the head input datasets are ideal we consider them to be a reasonable basis for a comparative assessment of the two schemes and the results allow the two schemes to be compared on a consistent basis. Our estimates show that the Weavers Mill scheme produces more energy than North Mill regardless of which of the three datasets are used and therefore we conclude that the Weavers Mill scheme is likely to provide the highest annual energy output.

C.2 Carbon

Carbon Footprint

All stages of the life-cycle of a product may result in emissions as a result of the various processes undertaken at each stage. It has recently become possible to estimate the carbon emissions that result from the various stages of a product's life as independent data on emissions has been collated which reflect standard emissions per tonne of material, for example. This is important in respect of the two proposed hydro-power schemes as it may be a differentiator between them.

Process of Estimation

The approach taken was to estimate the difference in carbon footprint between the two schemes, not the absolute carbon. Hence where the schemes have identical or very similar elements these were not assessed but assumed to be the same.

Hence, the first stage was a comparison of the two schemes to identify what differed between them. It was concluded that the following elements: transport and road access; generator; switchgear and grid connection where essentially identical or very similar and so no calculations were done for those elements. This assumption may result in an under-estimate of the carbon for the screws as there are two generators and gearboxes, for example.

The schemes were then broken down into components to enable estimation of material quantities used. Overall installation drawings, general information from manufacturers and from published sources were then used to estimate the masses of materials which would be used for the proposed schemes. For example, plan and elevation drawings provided for North Mill were used to develop an estimate of the mass of concrete to be used in North Mill.

Factors for embedded carbon per tonne of material were then identified. It was decided that the best approach was to examine a range of factors and to illustrate how there is a range of possible results depending on the source of materials. The key source of data was reference[10]. The parameter used is of kg CO_2e/kg of material. The suffix e is to show the overall emission value includes greenhouse gases other than CO_2, converted to the equivalent CO_2 figure.

These factors were then applied to the estimated masses to give a carbon footprint for each element. All the elemental values were then summed to give a total figure for each scheme.

For the structural steel used in the manufacture of the turbine, draft tube, suction piles, screws and associated troughs, three values of kg CO_2e/kg of steel have been used:

- Lower bound based on 0.45 kg CO_2e/kg of steel;
- Mid value based on 1.66 kg CO_2e/kg of steel;
- Upper bound based on 3.27 kg CO_2e/kg of steel.

The upper bound is for steels made from virgin materials, the mid value is for steels with average EU recycled content and the lower value for very high recycled content and low quality

[10] Inventory of Carbon & Energy (ICE), Version 2.0, Prof. Geoff Hammond & Craig Jones, Sustainable Energy Research Team (SERT), Department of Mechanical Engineering University of Bath, UK

steel. Three values have been used as the range from highest to lowest is so large and depends on the choice of source of material.

For the concrete only two values of kg CO_2e/kg for concrete have been used as the range is not as large as for steels:

- Lower bound based on 0.1 kg CO_2e/kg;
- Upper bound based on 0.18 kg CO_2e/kg.

The two values reflect the type of cement and aggregates used.

For the reinforcing bar within the concrete two values of kg CO_2e/kg of steel have been used as the range is not as large as for structural steels:

- Lower Bound based on 0.45 kg CO_2e/kg;
- Upper bound based on 1.4 kg CO_2e/kg.

Results

The results show the following emissions in Tonnes CO_2e:

North Mill

Element	Estimated Mass Tonnes	Tonnes CO_2e		
		Lower Bound based on 0.45 kg CO_2e/kg Steel	Mid Range based on 1.66 kg CO_2e/kg Steel	Upper Bound based on 3.27 kg CO_2e/kg Steel
2,700 mm screw	8.47	3.8	14.1	27.7
Steel Trough for 2,700 mm screw	3.14	1.4	5.2	10.3
3,600 mm screw	12.91	5.8	21.4	42.2
Steel trough for 3,600 mm screw	4.23	1.9	7.0	13.8
Sub-total	28.74	12.9	47.7	94.0

Element	Estimated Mass Tonnes	Lower Bound based on 0.1 kg CO_2e/kg	Upper Bound based on 0.18 kg CO_2e/kg
Concrete 2,700 mm screw	128.3	12.8	23.1
Concrete 3,600 mm screw	153.7	15.4	27.7
Sub-total	281.9	28.2	50.8

Element	Estimated Mass Tonnes	Lower Bound based on 0.45 kg CO_2e/kg	Upper Bound based on 1.4 kg CO_2e/kg
Steel reinforcing bar for 2,700 mm screw	1.2	0.5	1.6
Steel reinforcing bar for 3,600 mm screw	1.2	0.5	1.7
Sub-total	2.36	1.1	3.3

Element	Estimated Mass Tonnes	Lower Bound	Upper Bound
Total	313.1	42.2	148.1

Weavers Mill

Element	Estimated Mass Tonnes	Tonnes CO_2e		
		Lower Bound based on 0.45 kg CO_2e/kg Steel	Mid Range based on 1.66 kg CO_2e/kg Steel	Upper Bound based on 3.27 kg CO_2e/kg Steel
Steel installation including tube	4.0	1.82	6.72	13.23
Kaplan Turbine	5.7	2.57	9.46	18.64
Total	9.7	4.39	16.18	31.87

Element	Estimated Mass Tonnes	Lower Bound based on 0.45 kg CO_2e/kg	Upper Bound based on 1.4 kg CO_2e/kg
Steel reinforcing bar	0.5	0.225	0.7

	Estimated Mass Tonnes	Lower Bound based on 0.1 kg CO_2e/kg	Upper Bound based on 0.18 kg CO_2e/kg
Concrete for slab base	24.39	2.44	4.39
Concrete for buttress wall	10.82	1.08	1.95
Concrete Fish pass (inc wall that side)	11.86	1.19	2.13
Sub Total concrete	47.07	4.71	8.47

Element	Estimated Mass Tonnes	Lower Bound	Upper Bound
Total	57.27	9.33	41.04

Assumptions

1. Carbon calculation considers only the differences between the schemes. This means that it excludes carbon emissions from items including the manufacture of the generators, gearboxes, transportation, grid connection or maintenance. This assumption therefore slightly favours the screws where there are two generators and gearboxes and the transportation is over a longer distance;

2. The carbon emissions factors per mass of material are taken from average factors for different types of material and are assumed to be Steel 1.4 tCO_2e/t Concrete 0.14 tCO_2e/t;

3. The estimates of the masses of materials are based on the drawings provided where possible. Where not possible, measurements have been scaled from the drawings or estimated by comparison with similar engineered structures, e.g. typical steel plate thicknesses. These mass estimates may be in error by ±20% due to uncertainties in the design and so should only be used as an indication.

Discussion

The analysis shows that if both schemes use the same sources of steel, then North Mill would have more than double the carbon footprint of Weavers Mill for steel alone. The carbon footprint of North Mill is then further increased by the larger amount of concrete used for the two bays for the screws.

Taking all factors into consideration we consider that for the North Mill scheme the estimate for the carbon footprint should be taken as around 80 tonnes CO_2e while for the Weavers Mill scheme the carbon footprint should be around 25 tonnes CO_2e.

Both schemes have additional carbon footprints associated with aspects common to both, for example, the grid connection.