Department of Mechanical Engineering

Retrofit of Small Scale Hydro Schemes In Argyll and Bute

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Copyright Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Ross Laird Date: 6th September 2010

Acknowledgements

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I wish to thank all the good friends that I have made during my studies, thank you for all the support and the laughs we had along the way.

I finally wish to thank my family and fiancée for constant support and inspiration throughout my studies.

Abstract

The study is concerned with assessing the feasibility of retro fitting micro-small scale hydroelectric schemes into existing civil works (dams and weirs etc) in an attempt to reduce both the overall expenditure and carbon footprint of such developments.

The Argyll and Bute council is interested in evaluating the propensity for energy generation from two sites in Dunoon and Rothesay in Scotland. By exploiting the generation potential at the sites, the council aims to generate power to meet local demand or raise additional revenue through the governments Feed in Tariff by exporting the generated power back to the National Grid.

The objectives of the project are to assess the power generation potential of the sites in Argyll and Bute and to evaluate the revenue that may potentially be generated. Following initial site surveys, an assessment of the hydrological potential of the sites was conducted. Suitable technologies were evaluated and potential scheme layouts proposed. A technical analysis was conducted to assess the optimum energy capture of the proposed scheme. Potential costs and revenue were calculated over the twenty year lifetime of Feed in Tariffs.

It was found that the Bishops Glen site in Dunoon has the greatest potential to accommodate retro fitting of hydroelectric power plant. A 60kW turbine was found to have the optimum capacity for energy capture at the site, returning 165,000 kWh of energy per year. As there is no immediate local demand, a grid export connection was found to be the most suitable option of utilising the power generated. Due to the high costs involved in grid connections, the potential for a return on investment was found to be dependent on the availability of government grant funding. It was found that in general, retro fitting of hydroelectric schemes does have the potential to reduce overall costs involved in such developments, however the potential for a satisfactory outcome is reliant on the availability and quality of the existing site infrastructure.

"A regenerated and successful Argyll and Bute Economy will be positive in outlook and approach and view energy as an economic asset. It will consume energy in an efficient manner and openly embrace alternative energy technology as a means of generating local affordable energy to secure economic, social and environmental advantage"

- Argyll and Bute Councils vision for energy, Scotland Week, Brussels 1998

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Section I – General

1.1 Introduction

Historically the United Kingdom has had the propensity to take advantage of an abundant resource of renewable energy in the form of hydroelectric power. As the UK continues to try and meet carbon dioxide reduction targets imposed through Government legislation such as the Climate Change Act in 2008, renewable resources are being increasingly looked upon to generate power and increase energy security.

The renewable energy Feed In Tariff was introduced in April 2010 as an attempt to further fuel the momentum of decentralised renewable energy sources. In comparison to other renewable technologies, hydroelectric generation is considered to be a more mature and trusted technology, with more modest capital expenditure for equivalent levels of energy generation. As such, small scale hydro developments that were once considered infeasible may now have a greater potential to be economically viable.

The major consideration for any developer is ultimately the costs involved in a project. In addition, there are lengthy planning and legislation processes that must be adhered to in order to legitimately develop small scale hydro schemes. The most attractive solution is often the most cost effective with minimal disruption to the external surroundings and environment.

Scotland has a rich abundance of rivers and streams, weather that can provide running water and land formations that can all be combined to potentially produce electricity through hydro schemes. As a result, we have a rich heritage of existing hydro infrastructure, such as water powered cotton and grain mills, existing canals and water reservoirs, the majority of which have potential to be retro fitted with hydro electric schemes. It is therefore becoming more attractive to develop small scale hydro schemes around existing infrastructure in order further reduce the carbon footprint of such developments and in doing so reduce the initial required capital investment.

1.2 Argyll and Bute

The project is concerned with the feasibility study of retro fitting micro-small scale hydro schemes into existing civil works (dams and weirs etc) in Argyll and Bute, located on the West coast of Scotland (Figure 1). The Argyll and Bute council is interested in evaluating the propensity for energy generation from two sites – a freshwater reservoir in Bishop's Glen, Dunoon (Figure 2) and a small dammed watercourse near Kirk Dam, Rothesay (Figure 3). By exploiting the generation potential at the sites, the council aims to generate power to meet local demand or raise additional revenue through the governments Feed in Tariff by exporting the generated power back to the National Grid.

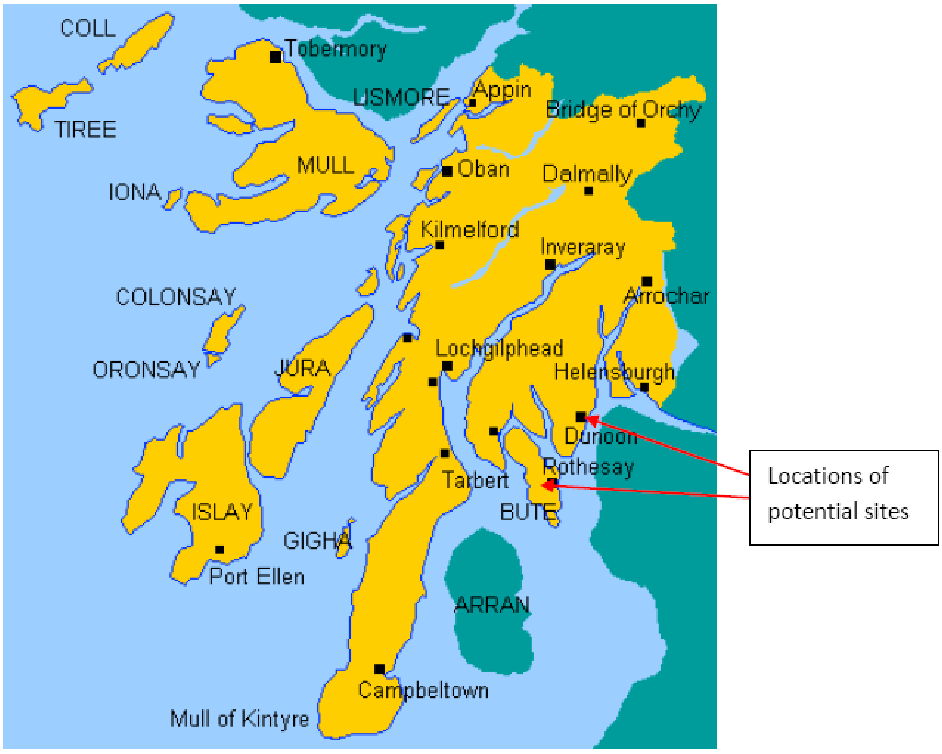


Figure 1: Map of Argyll and Bute (1)

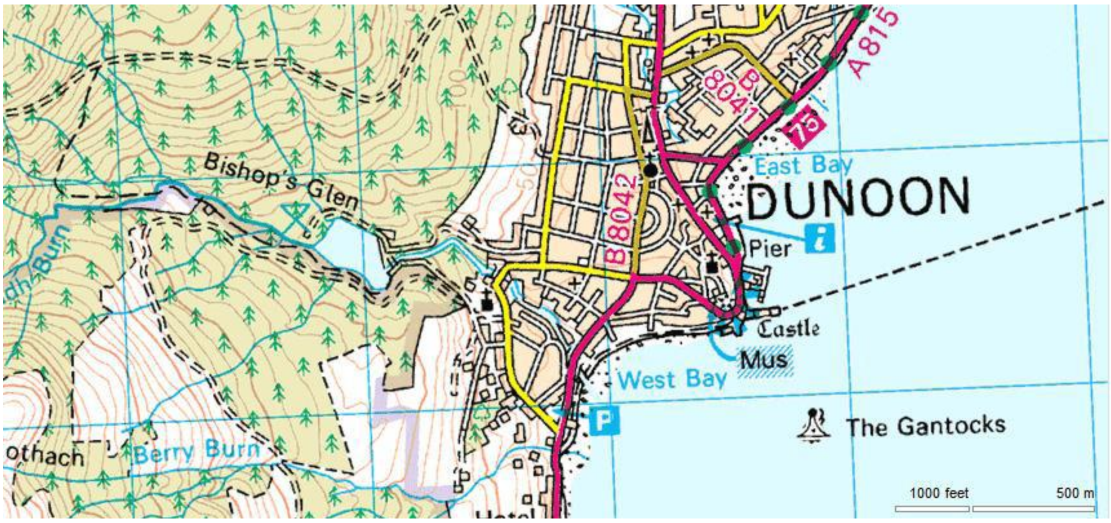


Figure 2: Bishops Glen freshwater reservoir, Dunoon (2)

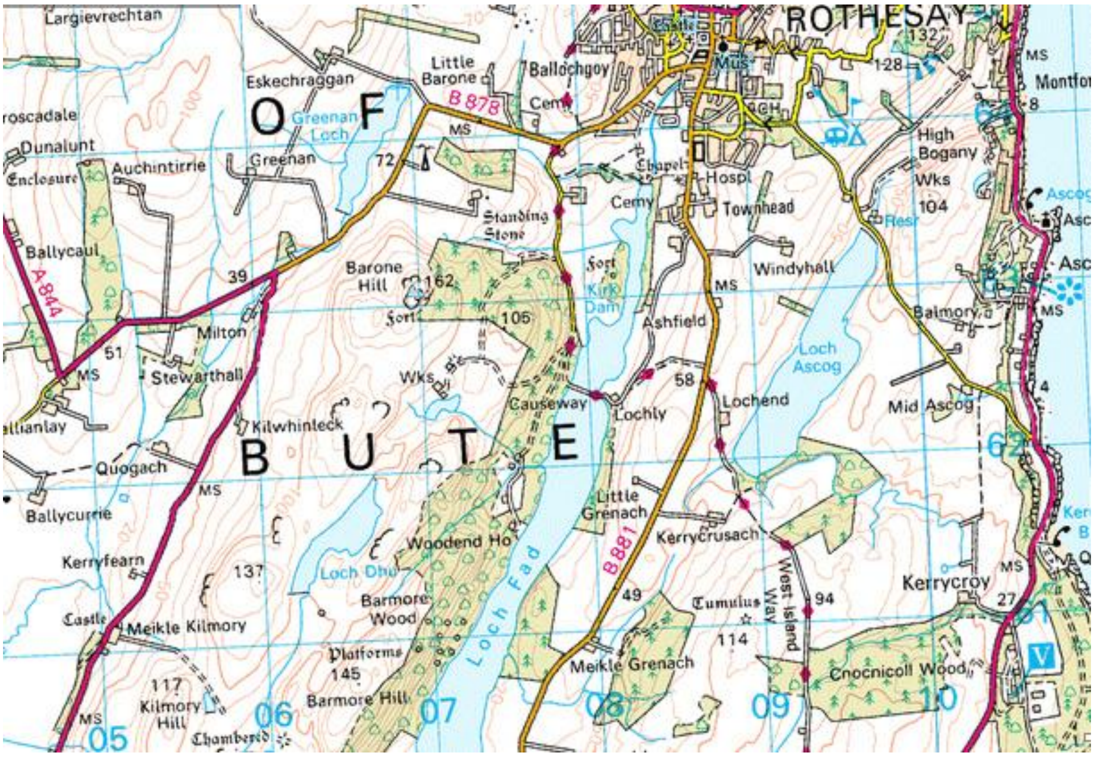


Figure 3: Kirk Dam, Rothesay (2)

Both potential sites have different individual characteristics that present the opportunity to seek a novel solution at each site

1.3 Hydroelectric Power in Scotland

As with many countries with an abundance of flowing water and significant rainfall, Scotland has had a historical affinity with using water to power turbines for non-electrical uses, such as cotton and oat mills. Scottish Hydro Electric (now part of Scottish and Southern Energy Group) was originally established during the 2nd World War under the name the North of Scotland Hydro Electric Board (NOSHEB) in 1943 by an Act of Parliament. It was formed to be responsible for generating, transmitting, distributing and supplying electricity throughout the North of Scotland, as well as a being a means to provide economic growth in the Highlands (3).

The first privately owned hydro electric power stations were built to power the aluminium smelting industry, with many further hydro schemes being built in the following years (Figure 4) before it became uneconomic due to falling electricity prices.

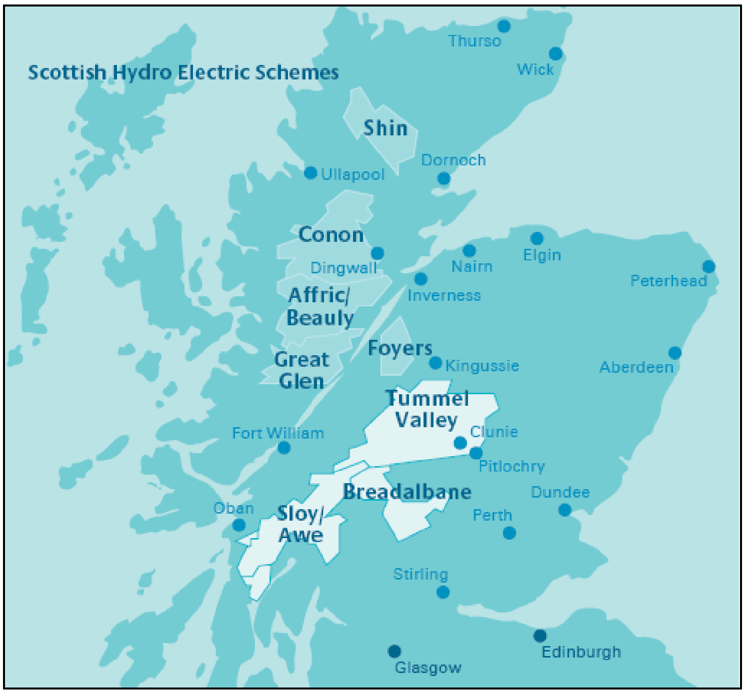


Figure 4: Major hydroelectric schemes in Scotland (3)

In 2009, Scotland’s undeveloped hydro potential was re-evaluated using the Hydrobot remote hydro modelling software which, unlike previous models, incorporated the contribution of micro-hydro resources. The amended financially viable resource was estimated at 1.2 GW of potential installed capacity across 7043 schemes (4).

The new figures effectively doubled the previous estimate of 657 MW of hydro potential from a 2008 Scottish Hydro Power Resource Study. The increase in generation potential is due to the inclusion of smaller sized schemes in the study, which as a result of the Governments Feed in Tariff incentive, make previously uneconomical developments more financially viable. Further discussion on Feed in Tariffs is given in Section 2.6.4.

1.4 Methodology

The purpose of the study is to evaluate the feasibility of retro fitting hydro schemes around an existing infrastructure at two sites in Argyll and Bute by considering the economic, social and environmental ramifications this may have. The approach taken in the study attempts to respect the maturity of the technology involved as well as the propensity for unique and individual solutions that the potential sites may possess.

The initial stage of the process is in the evaluation of current hydroelectric generation technologies which are conducted in the literature review. This allows for the study to be completed satisfactorily and for the appropriate performance characteristics of the potential schemes to be evaluated. The literature review also highlights the unique solutions that small scale hydro schemes can offer in terms of grid connection, remote off grid generation and meeting local demand.

The second stage in the process consists of the main bulk of the feasibility study. On liaising with Argyll and Bute council members, a preliminary site survey is conducted for both the Bishop’s Glen and Kirk Dam sites. The sites are evaluated for their generation potential and also their ability to meet off grid demand. Having gathered as much site information, plans and records as possible, a thorough hydrological study is conducted. Monthly flow duration curves can then be evaluated.

The third stage in the process involves the design of potential schemes. Having surveyed the sites and understood their unique characteristics and layout, this can be combined with the hydrological data calculated to design a system with the greatest energy capture potential.

With an optimal system designed around the sites geographical and flow constraints, potential micro hydro contractors can be contacted in order to provide an indicative costing for the potential hydro scheme. This cost data can then be used in conjunction with the predicted output from the scheme to analyse the potential revenue from the scheme and evaluate the annual financial projections.

Following the economic analysis, specific conclusions can be drawn on the feasibility of each site and recommendations made to Argyll and Bute council. General conclusions are also drawn on the holistic feasibility of retro fitting hydroelectric plant and further general recommendations are made.

Section II – Overview of Hydro Power Schemes

2.1 Generation

This section intends to cover the concepts and technologies that are pertinent in the retro-fitting of hydro power schemes.

2.1.1 Review of Power from Water

Water can be considered to be one of the earliest working fluids in which Man has been able to convert its stored potential energy into useful kinetic energy and work. Hydraulic power can be captured from water wherever this energy transformation takes place i.e. – wherever a water source flows from a high level to a lower level. This change in height can occur naturally through the drop of a waterfall or the undulations of a river down a hillside, but can also be man made through construction of a weir or reservoir. The main factors that govern the power available from a source are *head* and *flow rate*.

The equation for the potential energy (E_p) of water is known to be:

$$E_p = mgh \qquad [1]$$

Where m is mass, g is acceleration due to gravity and h is height. As a body of water on Earth cannot be without a mass, neither can it avoid the pull of gravity, it becomes clearly apparent the importance that the height to which it is elevated has in terms of its stored potential energy. This gross height is commonly known as "head" (H) and is shown diagrammatically in Figure 5. H is the maximum available vertical fall in the water from upstream to downstream, measured in metres (m) (5). As the fluid makes its way to the turbine, energy will be lost to friction and other inefficiencies in the pipe system. This energy loss effectively reduces the amount of head available to the turbine, which is commonly known as net head.

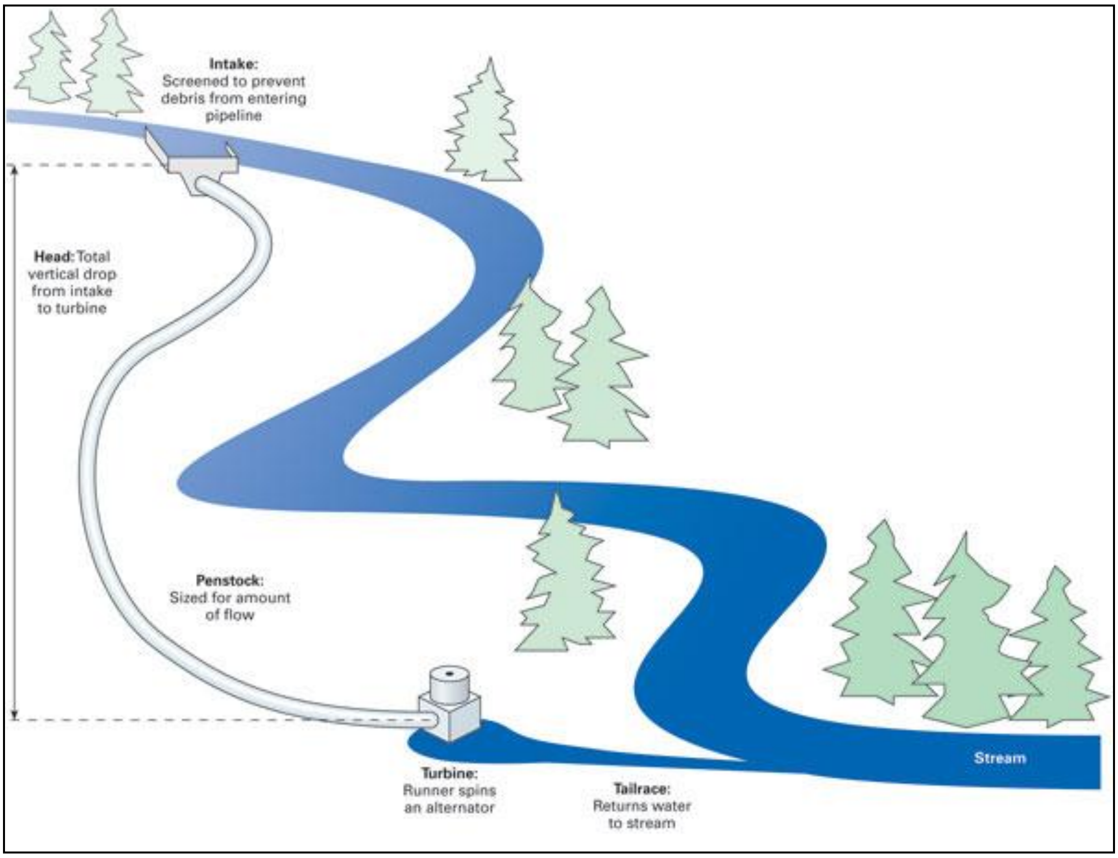


Figure 5: Head measurement of an hydroelectric scheme (6)

The second factor that determines the derivable power from a water source is the volumetric flow rate (Q) of the fluid, measured in cubic metres per second (m^3/s).

The energy generated through the combination of head and flow rate is converted into mechanical power in the turbines shaft, which in turn powers a generator to produce electricity. In addition to H and Q, the power generated by a hydro scheme is also governed by gravity, fluid density (ρ) and turbine efficiency (η), and are related by the general power equation:

$$P = \eta \rho g H Q \qquad [2]$$

Where power (P) is measured in Watts. It is apparent from equation [2] that in order to maximise the power output from a particular scheme, one should aim to maximise flow rate, head and turbine efficiency as ρ and g are constant. Equation [2] also highlights that power can potentially be derived from different combinations of H and Q, which often characterises individual schemes i.e. one may draw an equal amount of power from a scheme with high flow/low head to one with high head/low flow. The characterisation of hydro schemes is discussed in the following section.

2.1.2 Run of River Schemes

There are two general layouts of hydro electric systems that one can use to categorise the scheme. The simpler of the two is known as a "run of river" scheme (5) and as the name suggest, the layout of the scheme is dependent on the watercourse.

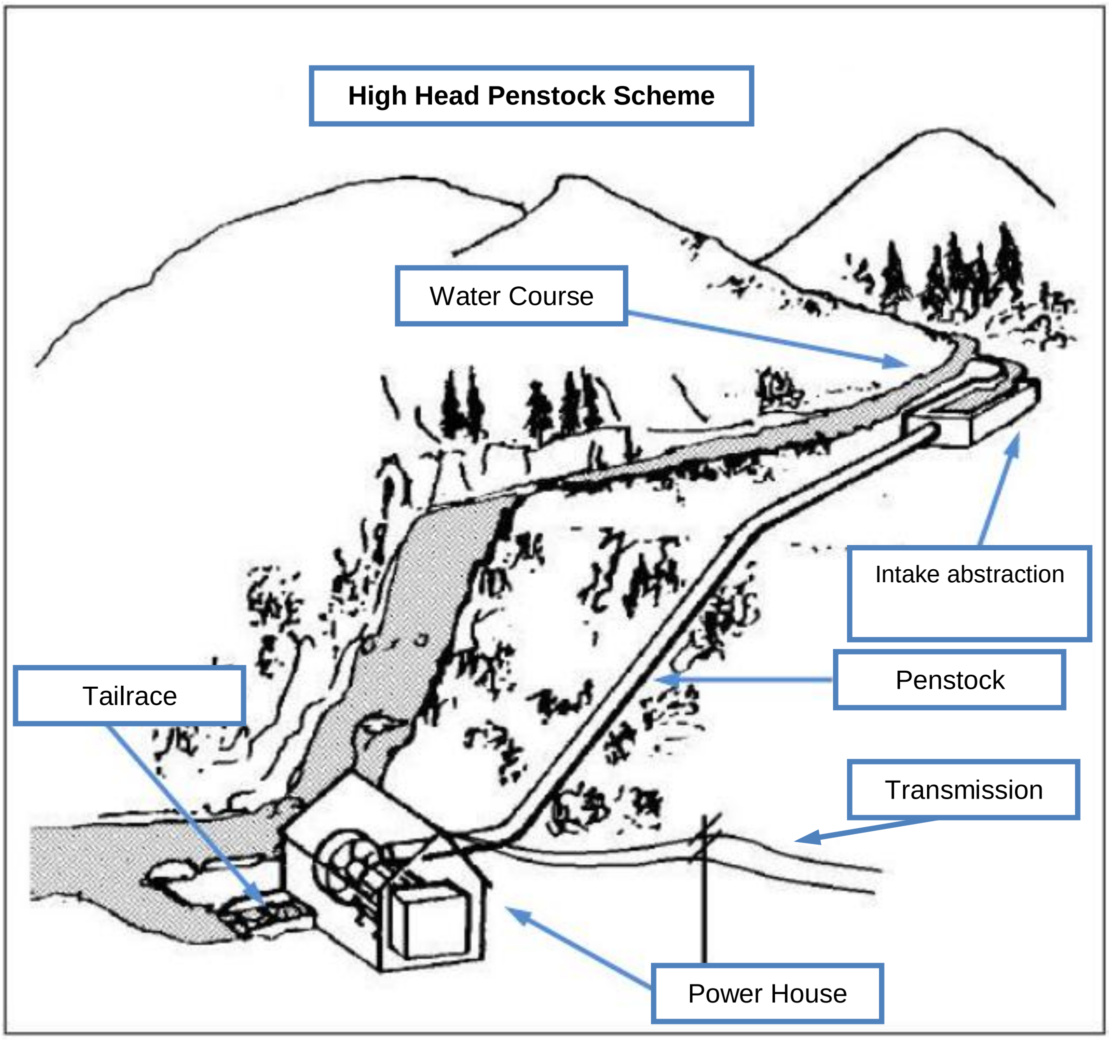


Figure 6: A high head, penstock only run of river scheme (5)

Specifically, run of river schemes do not have the capability for any reservoir or storage (5) and therefore the performance of this type of system can relies more heavily on seasonal variations in rainfall.

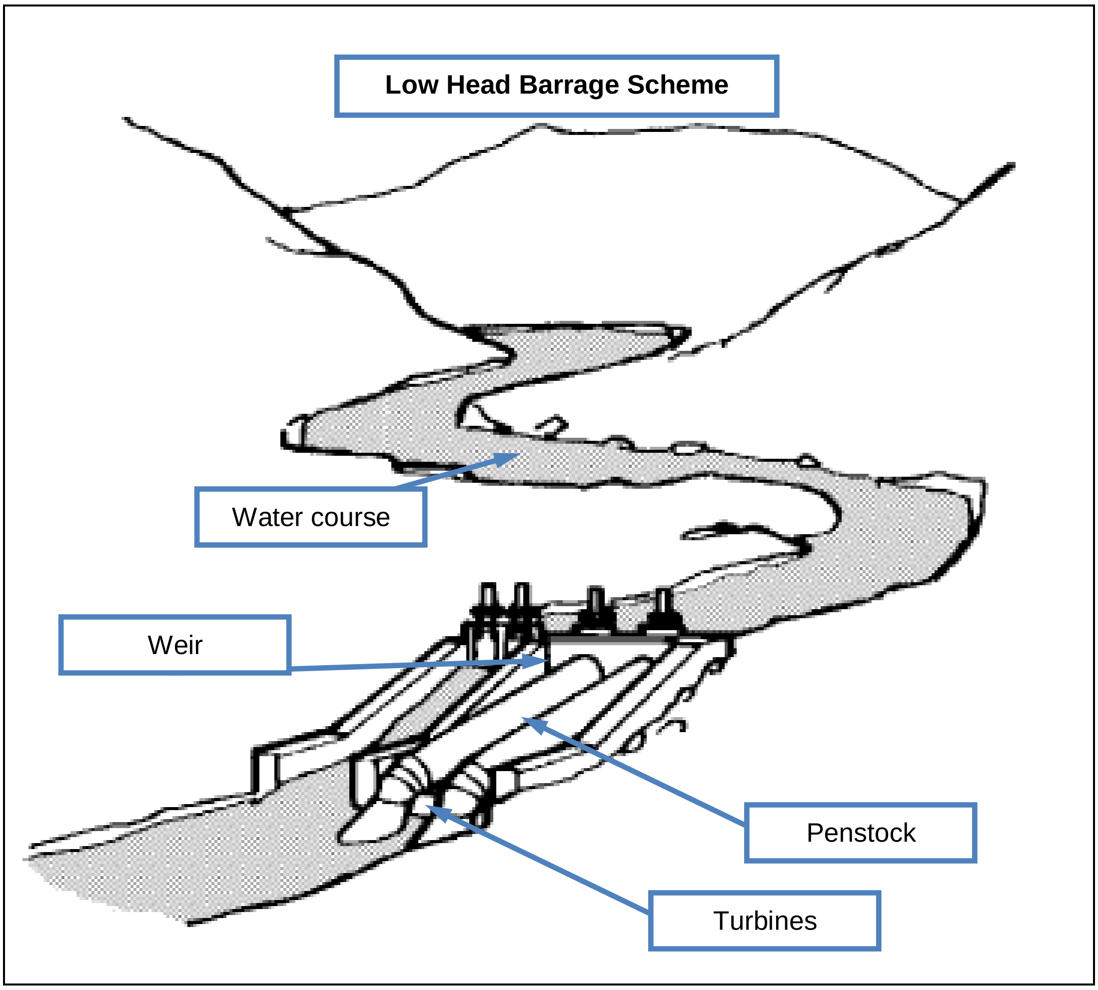


Figure 7: A low head, barrage run of river scheme (5)

The operational procedure of a high head hydro scheme (Figure 6) can be summarised as follow:

- Water is diverted from the river to in intake
- The flow of water is decelerated by entering a settling tank or forebay in which particles suspended in high velocity flows can come to rest. The intake and forebay is often protected by a trash rack (a rack of metal bars) which does not allow large floating debris to pass into the penstock and turbine
- The penstock carries the water at pressure to the turbine which is situated in the power house containing generation and control equipment
- The water flow then exits the power house through the tailrace and back into the main water course

This general operational principle remains consistent throughout all types of hydro schemes, however depending on the flow and turbine characteristics, operational principles do vary between schemes. To highlight this, Figure 7 depicts a low head, high flow 'barrage' scheme which runs on similar basic operational principles but is situated in the main water course, thus negating the requirement of a water abstraction and forebay.

Run of river schemes are used in traditional flour and cotton milling facilities where water wheels are use to drive machinery for grinding grain, oats and cotton mills. Canals built for the diversion of water for these mills are often still in existence, therefore run of river hydroelectric schemes can often be developed around this very basic existing infrastructure. As previously mentioned the island of Bute has a history of small canals and dams which can provide a source of flowing water with the potential for small scale generation.

2.1.3 Reservoirs and Storage

The second general type of hydroelectric scheme is categorised by the ability to store water in a reservoir. These dammed structures eliminate the transient nature of generation from run of river schemes and allow power to be generated at times of peak demand and dryer weather. Depending on the type of turbine and the layout of the scheme, it is also possible to construct a pumped storage system, where the majority of the reservoir drains during peak demand hours. The turbine is then reversed during times of low demand to pump water back into the reservoir.

An example of such a scheme is Sloy Power Station at Loch Sloy in Argyll and Bute (Figure 8), which is the United Kingdom's largest conventional hydroelectric power station. This reservoir style hydroelectric scheme takes water from Loch Sloy though a 3 km long tunnel and feeds the power station through 4 large diameter penstocks.

Figure 8: Loch Sloy power station (7)

With dammed structures, the additional functionality and reliability comes not only at many times the cost to run of river schemes, but there are far greater environmental impacts considering the area that may be required to flood behind the dam in order to store sufficient water resources. Reservoirs and pumped storage are often reserved for the major developers looking to generate on the scale of many MW, such as Sloy Power Station, as opposed to the more local developer looking to generate only in kW. One of the interesting factors about the Bishops Glen site is the existence of a small dammed reservoir which may provide an area of substantial storage to alleviate the transient nature of a simple run of river, flow dependant system.

Hydro schemes can be classified on the level of power output. A summary of scheme classification is given below in Table 1.

Classification	Range	Purpose
Pico	up to 5kw	Small local generation - single off grid domicile
Micro	5kW to 100kW	Small community off grid generation
Mini	100kW - 1MW	Community generation - either off or on grid
Small	1MW - 10MW	Commercial scale generation feeding grid
Medium	10MW - 100MW	
Large	100MW +	

Table 1: Scheme classification by output (8)

2.2 Types of Hydro Electric Turbines

This section aims to discuss the technical information pertinent to the different types of turbines available, their efficiencies and for which type of scheme they are typically selected for use in.

Turbines are designed to convert the energy from the flow of water into power through a mechanical shaft. There are two main classifications of hydro turbines which are defined by the form of energy used to drive the blades – either pressure or kinetic energy, which correspond to reaction and impulse turbines respectively. The specific design of turbine implemented in a scheme is generally a function of the available head, the main types of which are summarised in Table 2.

	Impulse Turbines	**Reaction Turbines**
High head	Pelton, Turgo	
Medium head	Multi-jet pelton, Turgo, Crossflow	Francis
Low head	Crossflow	Kaplan

Table 2: Turbine categorisation

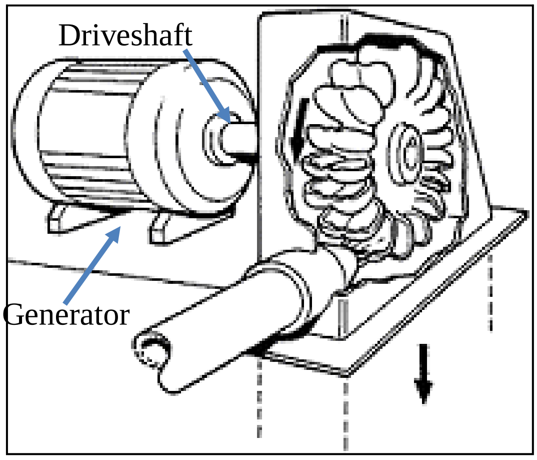
2.3 Impulse Turbines

The impulse turbine converts the pressure in the water into kinetic energy as it enters the runner in the form of a high speed jet of water. The water jet strikes buckets that are mounted on the runner, which drives the shaft connected to the generator.

2.3.1 Pelton Turbines

Pelton turbines are the most common type of impulse turbine. The pelton turbine was invented in the 1870's by Lester Allan Pelton (9). One or more nozzles create a single high velocity jet or multiple high velocity jets of water which strike bucket like blades attached to the runner causing it to rotate (Figure 9 and Figure 10). This motion drives a shaft which generates power through an electromagnetic generator (Figure 9). The generator is often connected to transmission gear to accommodate different flow rates.

Figure 9: Pelton turbine attached to a generator (10)



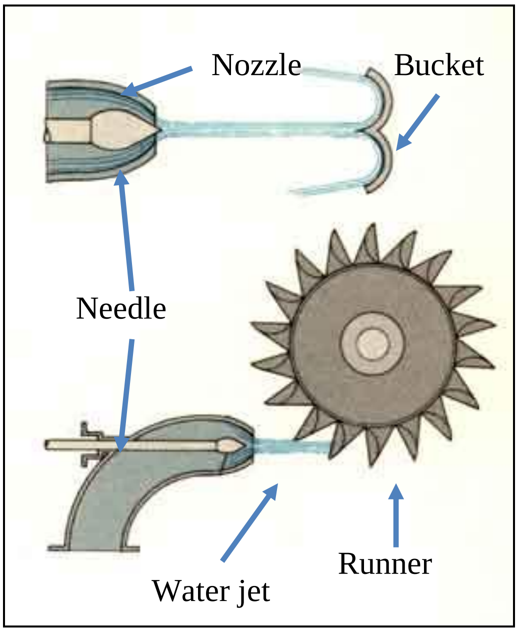


Figure 10: Jet, nozzle and bucket of a pelton turbine (10)

The energy of the discharged water jet is absorbed by the buckets due to their unique half shell shape (Figure 10). Buckets are also designed to have a cutaway at the lip which allows smooth entrance of the rotating buckets into the jet stream. When the jet hits the buckets it is split in half by the edge running down the centre of each bucket. This causes the jet to be deflected back through 180 °, which in turn increases the amount of energy absorbed by each bucket.

Pelton turbines are mainly used in high head applications; from 60m to 1000m (11) hence the pressure at the nozzle can be extremely high. The velocity of the water jet is controlled by further or lesser penetration of the needle valve through the nozzle. Nozzles often have a flow deflector that can be employed in the event of emergency shutdown. The deflector moves the direction of the flow away from the runner which in turn allows the needle valve to be closed more slowly, ensuring there is not a pressure surge in the penstock due to water hammer.

The design of pelton turbines allow more than 1 jet of water to be directed at the runner (Figure 11). Having multiple jets increases the available torque, which allows the runner to be smaller and increases rotational speed.

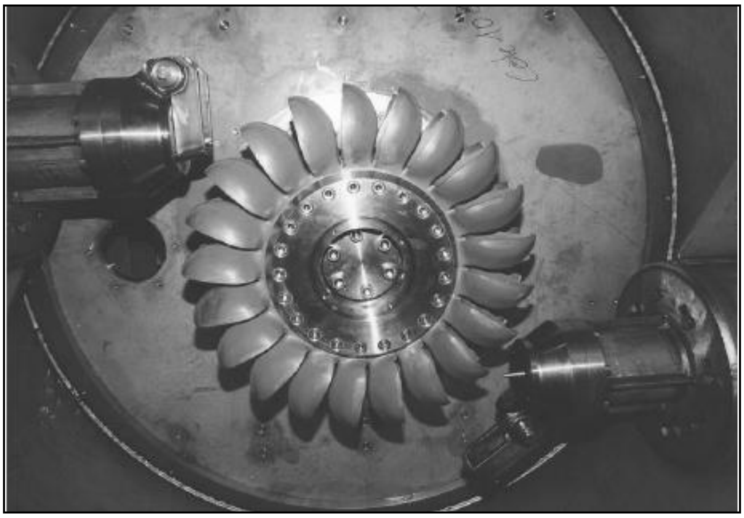


Figure 11: Multi-jet pelton turbine (11)

In addition to increasing the rotational speed of the runner, a multi-jet pelton turbine is able to achieve a higher efficiency of power generation if the flow rate falls below that of the design rate. This allows multi-jet pelton turbines to have a greater operational range, achieving high efficiencies (≈ 95%) for 10% to 100% of the design discharge, opposed to 30% to 100% for a single jet (11).

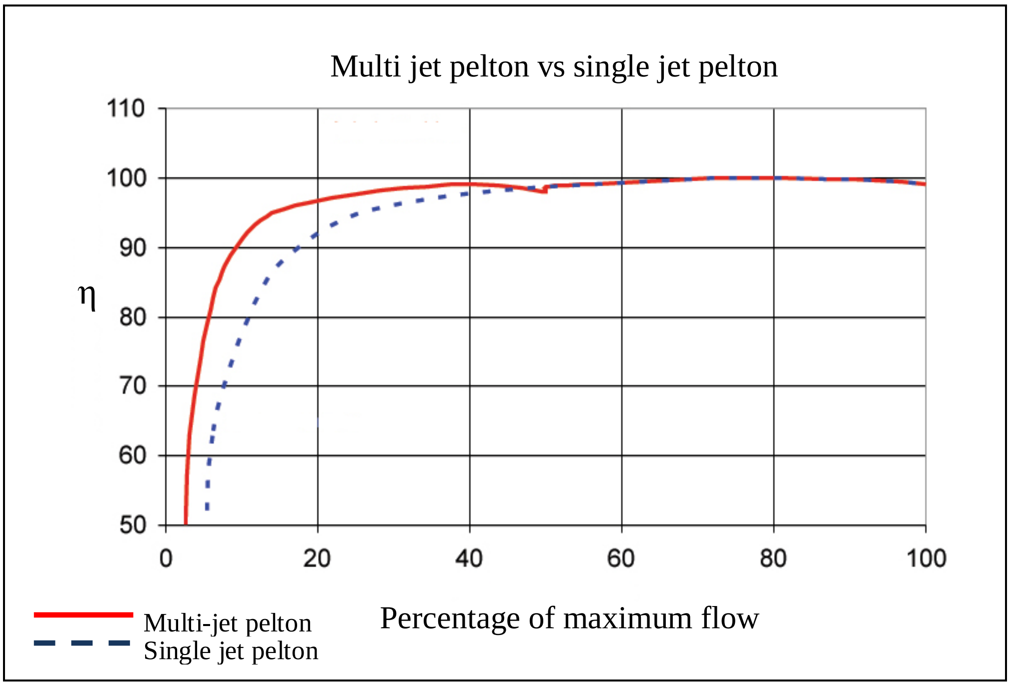
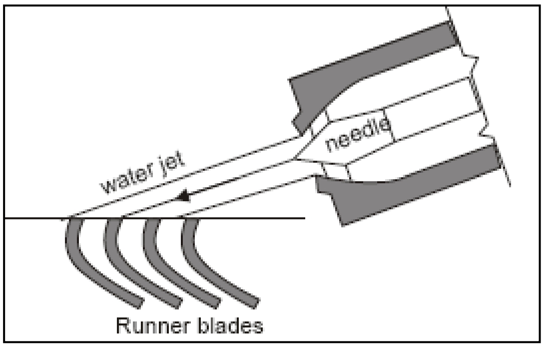


Figure 12: Typical efficiencies of multi-jet and single jet pelton turbines (12)

2.3.2 Turgo Turbines

Turgo turbines operate on similar principles to pelton wheel turbines, however they have an altogether different set up. The buckets parallel to the runner in a pelton turbine are replaced with curved blades in a turgo turbine (Figure 13). The vanes are struck by the jet of pressurised water at a typical angle of 20° (11) which exits on the opposite side. Since the incoming water and exiting jets of water do not interfere with one another, turgo style turbines can accommodate higher flow rates than similar sized pelton wheels. With higher flow rates of water, the runner on a turgo turbine can be smaller and rotate at higher speed and can sometimes be connected directly to the generator which, negating the need for a transmission.

Figure 13: Turgo turbine water jet and runner blades (11)



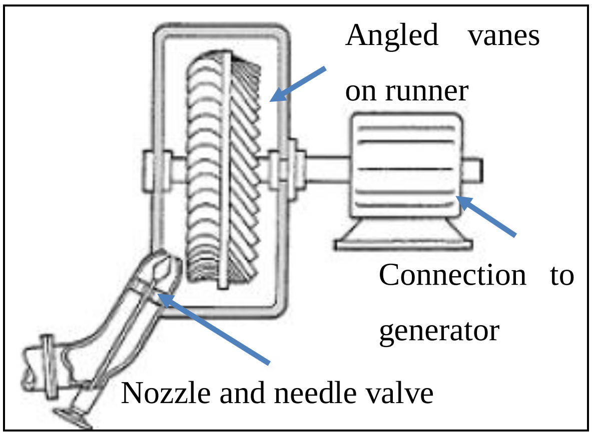


Figure 14: Typical turgo turbine set up (10)

Turgo turbines can operate from 20% to 100% of maximum design flow rate and reach efficiencies similar to that of pelton wheels in the region of 90% (11).

2.3.3 Crossflow Turbines

Crossflow turbines differ to the Pelton and Turgo types of impulse turbines in that the water acts on the blades of the turbine at lower velocity and pressure and is generally reserved for schemes that can offer higher volumetric flow rates and lower heads typically in a barrage style set up (Figure 7).

The water is directed transversely onto the runner blades through guide vanes and crosses the runner twice before exiting the turbine to the tailrace in a fashion similar to that of a basic water wheel (Figure 15). The action of passing through the turbine blades twice increases the efficiency of the turbine, however compared to other types of impulse turbines the efficiency of the Crossflow design is often lower.

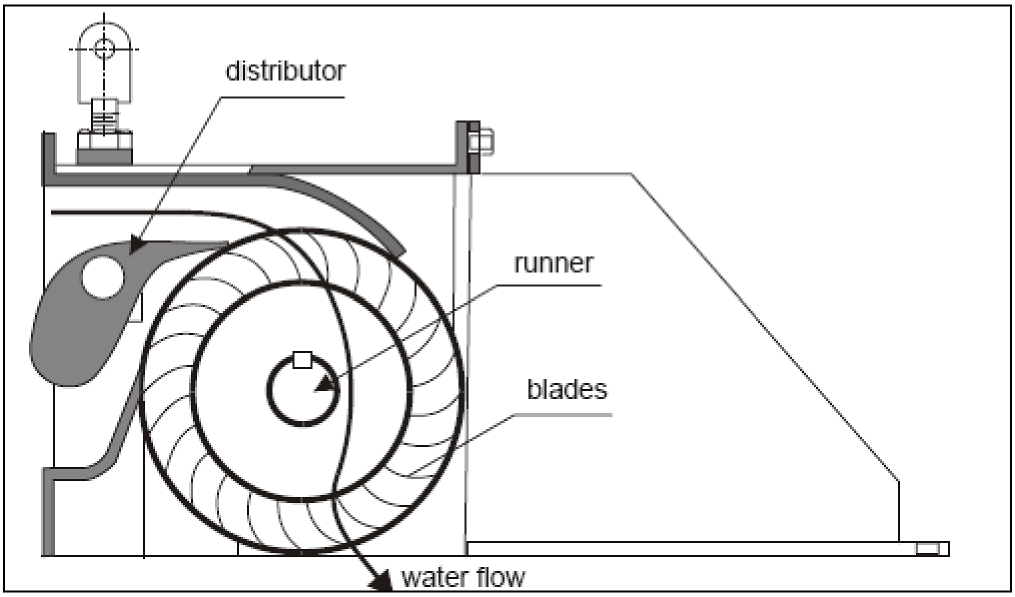


Figure 15: Schematic of a Crossflow turbine design (11)

The blades on a Crossflow turbine are mounted tangentially on a horizontal shaft allowing the flow of water to pass through. The design of different types of Crossflow turbines have been patented throughout the years, namely by Anthony Michell, Donat Banki and Fritz Ossberger leading to the turbine design being also commonly referred to as a Banki-Michell or Ossberger turbine (Figure 16).

The simple design of Crossflow turbines allow for units to be comparatively less expensive than their Pelton and Turgo counterparts, which flow permitting, offers the small scale hydro developer an alternative means of generation that is cheaper to maintain.

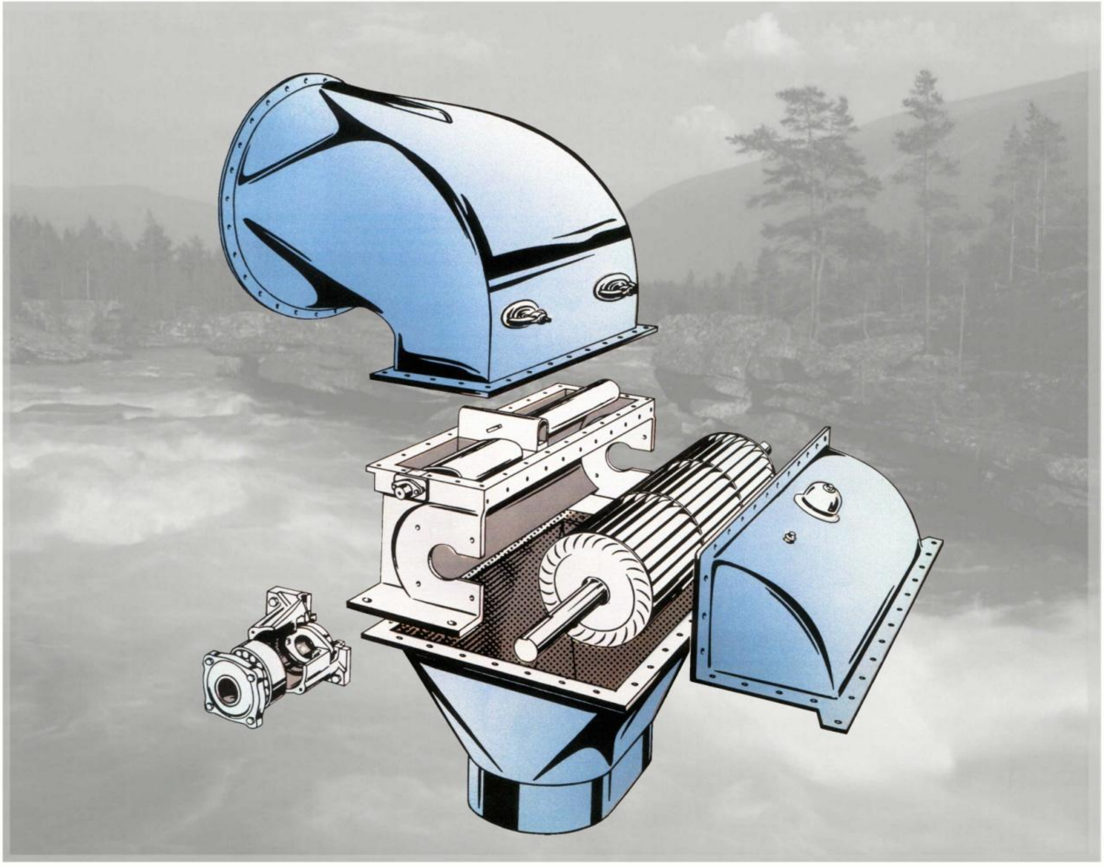


Figure 16: Horizontally mounted Ossberger turbine (13)

2.4 Reaction Turbines

Reaction turbines produce power from movement of a rotor or runner from the pressure differential created by a flowing body of water. As such, reaction turbines are better suited to extract the energy from med – low head applications with high volumetric flow rates.

2.4.1 Francis Turbines

The first main type of reaction turbine in use is the Francis turbine, which have fixed runner blades and adjustable guide vanes and are used in a wide head range of 25 to 350m (11). Similar to Pelton and Turgo impulse turbines, Francis turbines are versatile in orientation and can operate with either a vertical or horizontal axis (Figure 17 and Figure 18); however in small/micro scale applications horizontal axis turbines are more common for space reduction.

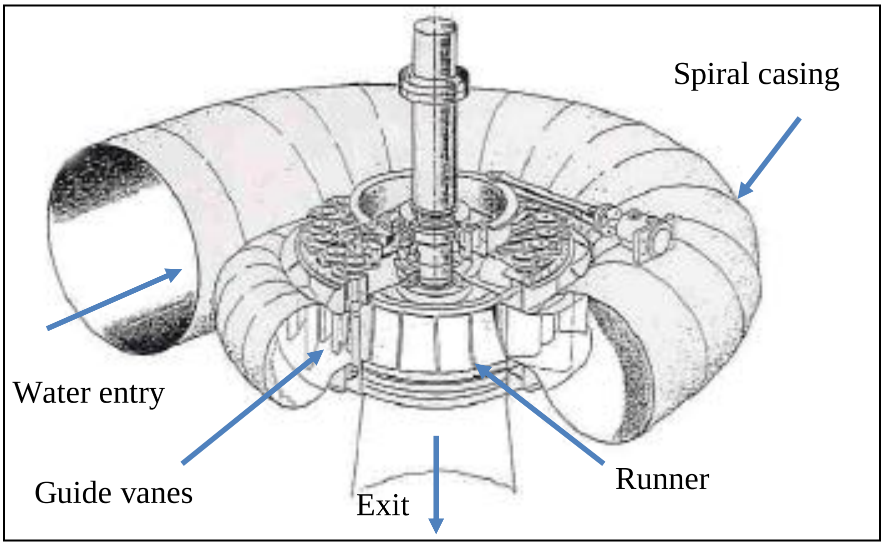


Figure 17: Vertical axis Francis turbine (11)

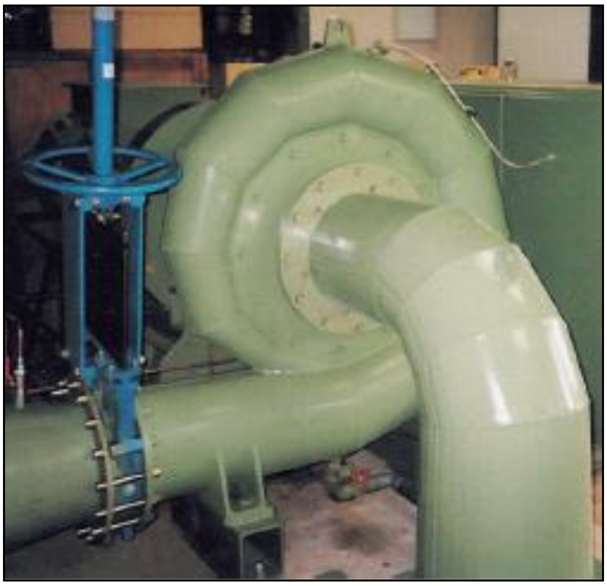


Figure 18: Horizontal axis Francis turbine (11)

The water enters the turbine through a spiral casing (Figure 18) which is designed in such a way that the tangential velocity of the water is kept constant as it enters the guide vanes. The vanes control the discharge of the flow onto the turbine runner which rotates around its axis. The runner blades are designed such that as the water passes across the blades the subsequent pressure differential and velocity forces created will cause the runner to rotate. The water then exits the turbine through a draft tube, the shape of which is designed to help decelerate the water flow and recover the pressure (Figure 18)

2.4.2 Kaplan Turbines

Kaplan turbines are of the propeller type reaction turbines and are generally used in low head applications from 2 to 40m (11). Kaplan turbines have adjustable propeller blades (Figure 19) which can increase the efficiency of the turbine over a wider range of flow rates. The ability to adjust the angle of the propeller blade differentiates Kaplan turbines from general propeller turbines that have fixed propeller blades. Along with the adjustable propeller blades, the guide vanes on a Kaplan turbine may be static or may be adjustable, which is known as “single” or “double regulation” respectively (Figure 20).

Figure 19: Kaplan turbine propeller (11)

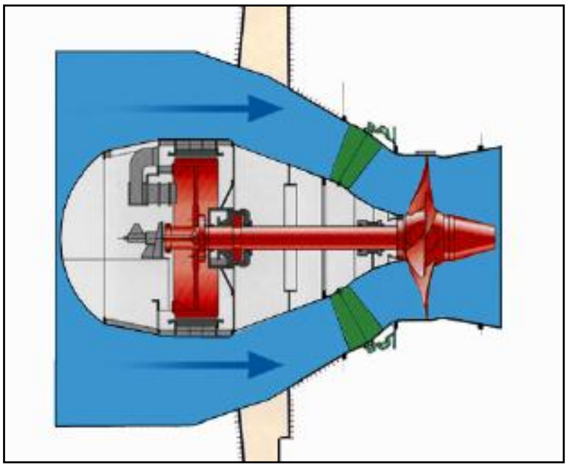


Figure 20: Double regulated Kaplan Bulb turbine (11)

Kaplan turbines extract energy from the flowing water by way of a pressure change in the fluid as it moves through the turbine and passes over the propeller blades. The turbines can be orientated many ways (Vertical, horizontal, inclined or siphoned), however the operational principal the propeller remains the same. Kaplan turbines can also be configured to have the generator contained in a waterproof bulb in the submerged flow (Figure 20). The configuration of Kaplan turbines is dependent upon the flow and site characteristics; however they generally operate under high flow conditions (11).

2.4.3 Turbine Specific Efficiency Curves

The efficiency of hydro turbines can be reduced should the available water discharge vary from that to which the turbines have been designed. The typical efficiency curves of the turbines discussed in Section 2.2 are shown in Figure 21 (11).

The efficiency curves give an indication of the operational rage one should expect from each type of turbine. Impulse turbines such as the Pelton and Turgo (not shown) are capable of operating at higher efficiencies over a wider range of flow rates which is often desirable in small scale retrofitted applications where a constant discharge cannot always be guaranteed. Generally, reaction turbines have a smaller operational range and are better suited in applications where the water discharge is constant, with the exception of the Kaplan turbine, which has adjustable vanes and runner blades that allow it to perform more efficiently over a wider range of flows.

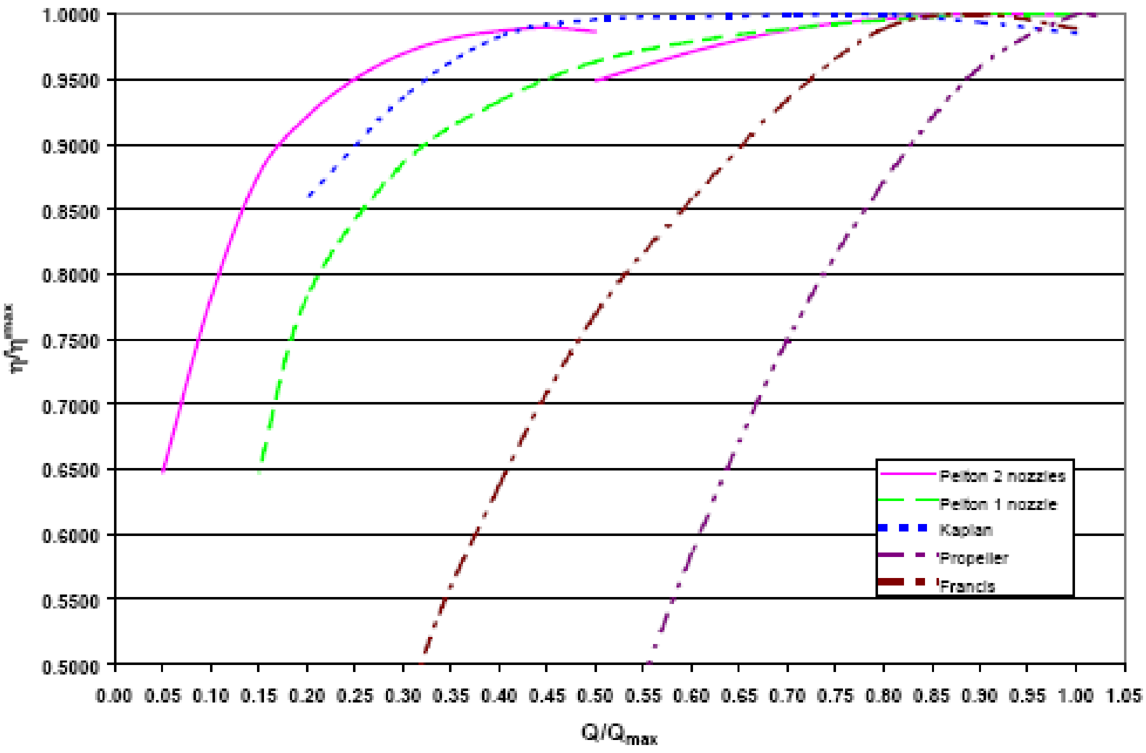


Figure 21: Typical small scale hydro turbine efficiency variations (11)

2.5 Additional Civil Works

The concept of retro fitting hydroelectric power plant is dependent upon the existence of an original infrastructure to work around – otherwise the project would simply be regarded as a new development. In this sense, it is assumed that if a scheme is to be retrofitted then there will be some form of appropriate canal/weir or dam infrastructure already in situ that will require no/minimal additional works. There are, however, certain features of hydroelectric schemes that are unlikely to exist beforehand, and are likely to be additional works requirements, which are discussed below:

2.5.1 Fish Ladder

Fish ladders are structures designed to allow the safe passage of fish around hydroelectric plant. The design of fish ladders is dependent on the layout of the site and also the breed(s) of fish one is looking to divert. Generally, fish ladders will consist of a number of concrete pools that will allow the fish to progressively swim up or down stream of the plant. Fish ladders may not always be a requirement in retrofitted schemes however, as infrastructure blocking the path of fish may already be in existence and is likely to already have some form of fish pass installed in accordance with local environmental legislative requirements.

2.5.2 Trash Racks

A trash rack is a piece of cleaning equipment that removes debris from the water before it enters the penstock and turbine where it is likely to cause damage. Small trash racks can take the form of a simple barred structure which block debris and require manual cleaning. Larger systems may require cranes and heavy lifting machinery in order to clear large amounts of debris. It is often the case that when a piece of material (vegetation and branches etc) is removed from a river it automatically becomes a waste material and is not allowed to be thrown back into the water flow (11). As such, trash racks often provide a desirable side effect to the local ecosystem by removing plastic bottles, bags and large pieces of debris that may cause an unwanted blockage further downstream.

2.6 Transmission of Power

The network of power cables that connect points of power generation to the consuming loads is known as the National Grid network. The grid consists of high and low voltage transmission lines that distribute power to consumers. In order for power to be transmitted efficiently, the power losses must be minimised. Power losses in transmission systems increase with the length of the transmission line and the square of the transmitted current (14). Transmission line lengths are impractical to reduce, as routes are often as direct as possible to reach the end consumer, therefore transmission losses are mitigated by increasing the transmission voltage, which reduces the required current. High voltage transmission lines in the UK are rated 275kV or 400kV and are used to transmit power over large distances with minimal losses. The power is then stepped down in voltage by substation transformers to 132kV or 11kV to be distributed within the local electricity network (Figure 22).

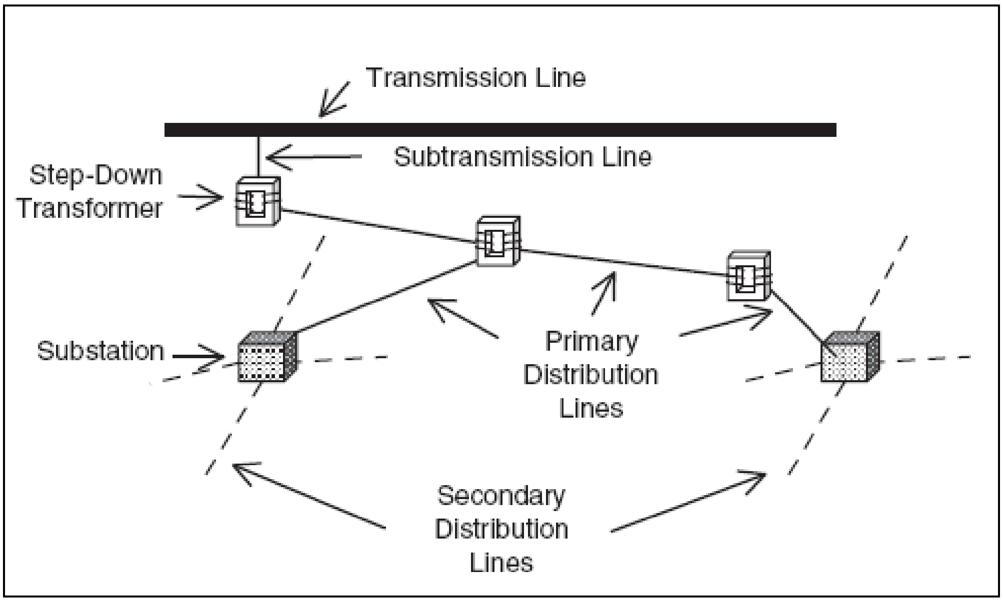


Figure 22: Schematic of transmission and distribution system

2.6.1 Grid Network Connection

All power generators wishing to connect to the distribution grid network must firstly seek permission of the Distribution Network Operator (DNO) in their region. Figure 23 shows the DNO which operate within the UK. Any power generation scheme in Argyll and Bute will therefore have to seek permission from Scottish and Southern Energy Power distribution before being permitted to connect to the national grid.

The DNO are the governing organisation that define the minimum requirements (and associated costs) that need to be satisfied in order to connect to the network in that particular region.

Typically, any renewable energy project seeking a grid connection will require a small substation to transform the electricity generated to the appropriate grid voltage (usually 11kV or 33kV depending on the distribution network). A 3-wire system would either be buried or pole mounted which would then link the generator sub-station to the nearest grid network connection (15). Renewable energy facilities generating less than 5kW require a G83 connection agreement from the DNO, whilst larger generators require a G59 agreement.

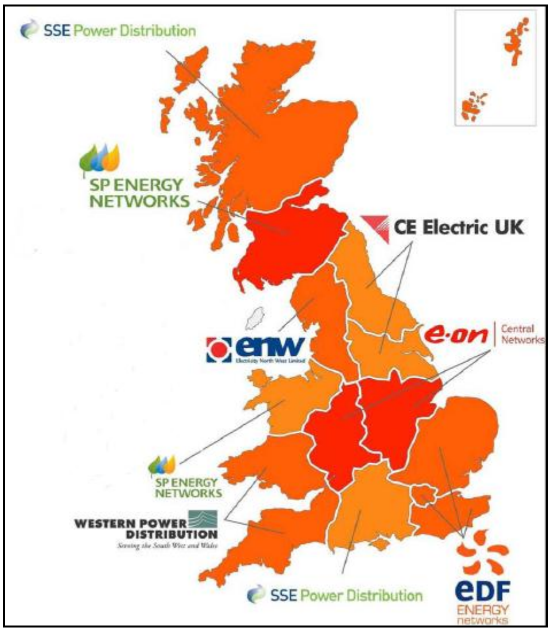


Figure 23: Distribution Network Operators in the UK (16)

2.6.2 Distributed Network

The current National Grid infrastructure originated when all of the power generated came from a small number of very large power stations in a traditional hierarchical format. The distribution system was therefore built on the assumption that power always flows from higher voltage generators to low voltage consumers, and until recently this was largely the case. The network is now beginning to migrate away from its traditional format to accommodate the growing number of small, distributed generation points and evolve into a distributed network, with a number of key drivers increasing the momentum of the change.

The increase in CO^2 emissions over the last 20 years is one of those key drivers. Traditionally, fossil fuel fired power plants have made significant contribution to the amount of CO^2 that is emitted in the UK. As UK the Government continues to try and reduce those emissions in line with carbon reduction targets for 2020 and beyond, smaller, more distributed points of generation encompassing clean, renewable energy are being looked upon to achieve this. This migration is also buoyed by advances in renewable energy technologies, providing additional avenues for power generation (17).

The introduction of the of The Department of Energy and Climate Change in 2008 to oversee energy and climate change policy has also had an effect on migrating toward a more distributed network (18). As the wholesale price for oil and gas continues to rise due to scarcity, DECC attempt to ensure that the UK has energy supplies that are secure, low carbon and are competitively priced. As such, renewable energy sources which are of an abundance in certain areas of the UK are also politically favourable.

2.6.3 Technical requirements

A hydroelectric developer who is looking to connect to the national grid will require additional pieces of electrical equipment to allow them to safely do so. Depending on the DNO and the specific requirements set out in their new connection documentation, the developer may have to pay in full or only an apportioned amount for the cost of the additional works to be carried out. As such, the connections requirements can often be extremely costly in terms of the overall budget of the project.

In order for a typical small scale hydro generator (≈3MVA) to be connected to the Scottish and Southern Power Distribution grid, there a number of key components that the DNO require to be installed (19). The connection of a generator will require a length of 11kV cable to be installed between a new circuit breaker added to the HV switchgear panel at the existing primary substation and the new substation at the customer's premises. This is shown schematically in Figure 24.

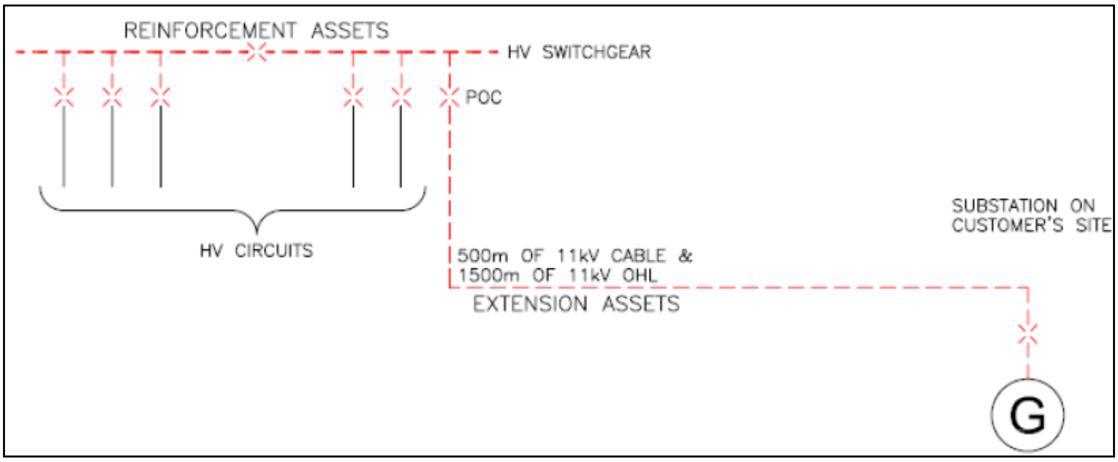


Figure 24: Schematic diagram of DNO required connection equipment (19)

2.6.4 <u>Feed In Tariff</u>

The Feed in Tariff scheme was formally introduced by the Department of Energy and Climate Change (DECC) in April 2010 (20) and is a policy that guarantees a price per kW/hr (Table 3) of power generated by means of renewable energy source over a 20 year period.

Should a consumer generate electricity from one of the eligible renewable energy sources then they would be granted a payment rate that relates to the power rating of the generation method. As such, any retro fitted hydro development from 0 – 5MW would be eligible for a tariff in the range of 4.5 – 19.9p/kWh. This price is paid to the consumer who uses the energy generated for their own local demand. Should the consumer also export the energy generated to the national grid, then they would qualify for an additional 3p/kWh for each unit exported (20).

Energy Source	**Scale**	**Generation Tariff (p/kWh)**	**Duration (years)**
Anaerobic digestion	≤500kW	11.5	20
Anaerobic digestion	>500kW	9	20
Hydro	≤15 kW	19.9	20
Hydro	>15 - 100kW	17.8	20
Hydro	>100kW - 2MW	11	20
Hydro	>2MW - 5MW	4.5	20
Micro-CHP	<2 kW	10	10
Solar PV	≤4 kW new	36.1	25
Solar PV	≤4 kW retrofit	41.3	25
Solar PV	>4-10kW	36.1	25
Solar PV	>10 - 100kW	31.4	25
Solar PV	>100kW - 5MW	29.3	25
Solar PV	Standalone	29.3	25
Wind	≤1.5kW	34.5	20
Wind	>1.5 - 15kW	26.7	20
Wind	>15 - 100kW	24.1	20
Wind	>100 - 500kW	18.8	20
Wind	>500kW - 1.5MW	9.4	20
Wind	>1.5MW - 5MW	4.5	20

Table 3: United Kingdom Feed in Tariff rates (with hydro highlighted in blue)

The aim of the policy is a greater uptake of a wide range of small-scale low carbon electricity technologies, which by greater deployment will help meet the UK 2020 renewables targets (21). The introduction of the scheme aims to create a more formal and simple to understand framework which covers a wider range of sub 5MW technologies (21). If successful, the policy will contribute to the carbon reduction targets as well as increase energy security. There is however a continuing debate on the overall effect that the Feed in Tariff will have on the wholesale electricity price, as similar schemes in Germany have recorded an increase in consumers monthly electricity costs (22).

2.6.5 Communities and Renewable Energy Scheme

Community Energy Scotland (CES) is an independent Scottish charitable organisation that can provide advice and funding for renewable energy projects in Scotland. One of the main areas of funding from CES is through the Communities and Renewable Energy Scheme (CARES), which is a financial support scheme made available by the Scottish Government to communities looking to invest in renewable energy technologies. CARES supersedes the Scottish Community and Householders Renewables Initiative (SCHRI) and supports a range of community organisations with aid in financing the installation of renewable energy technologies (25).

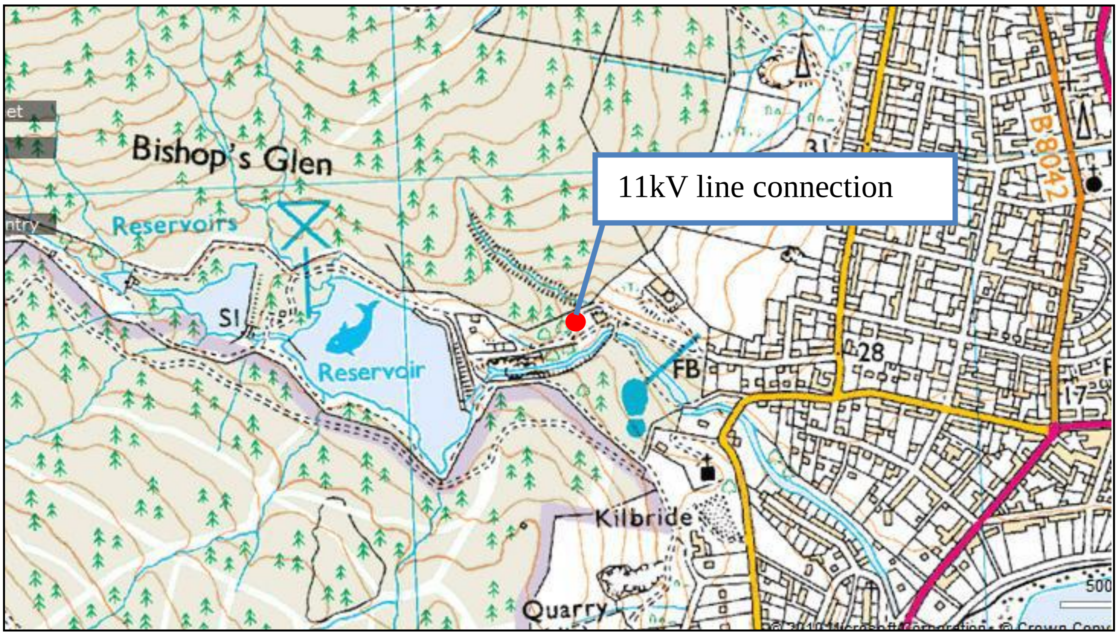
As a local authority, the Argyll and Bute Council are eligible to apply for support towards the cost of both non-capital and capital projects. Grants are available up to a maximum of £15,000 to support the funding of non-capital projects such as feasibility studies. This funding can be used to pay towards the costs associated with the feasibility studies themselves, support proposal development or fund capacity building such as raising awareness of renewable energy and skills development. Capital grants are available up to a maximum of £150,000 to pay towards the costs of installing the renewable energy generation systems, improvements required in the local infrastructure or costs of implementing fiscal regulations (25).

As hydroelectric power generation schemes are an eligible technology under CARES, Argyll and Bute council are eligible to apply for a maximum of £165,000 of grant funding to help towards the capital costs of a potential hydro electric development. In addition to CARES, CES may also be able to provide extra sources of funding if any of the Argyll and Bute hydro schemes are to gain long term income from the projects by exporting energy to the grid. The amount of funding made available is dependent on each individual application. Revenue calculations are carried out in Section 4.3 on a basis of zero, half and full levels of funding being available to the hydro schemes through CARES.

Section III - Feasibility Study

3.1 Bishops Glen

Bishops Glen is located 1.5km to the west of Dunoon in the Argyll and Bute District. The site is home to the Bishops Glen reservoir which formerly provided Dunoon with a supply of fresh water before this was transferred to Loch Eck in 1977. Bishops Glen reservoir is now a local beauty spot and is managed and maintained by the Dunoon and District Angling Club as a still water fishery. The reservoir has substantial existing infrastructure which may make it possible to retro fit a hydro electric power scheme around. There are no local loads/demand that could benefit from the potential power generated; therefore the only current option is to export the power to the grid via a nearby 3 phase 11kV line (Figure 25 and Figure 26)



11kV line connection

Figure 25: Bishops Glen reservoir, Dunoon (2)

The Bishops Glen reservoir is formed by an earth embankment dam (Figure 27) which was built in the 19th century (23). There are a further 2 smaller reservoirs located further upstream which were removed by breaching in 1983 after they were no longer required for public supply due to the transition of fresh water supply to Loch Eck. The Bishops Glen reservoir basin covers an area of 0.19km^2 with a capacity of 252,000 m^3 (23).

Figure 26: Three phase 11kV line that is local to Bishops Glen reservoir

Figure 27: Earth embankment dam (background) concrete weir (foreground)

3.1.1 Initial Site Survey

An initial site survey was conducted with David Whyte from Argyll and Bute Council. The main features of the site were recorded, measurements taken and potential sites for generation plant recorded.

The overflow of the dam consists of a compound reinforced concrete weir of three sections at different levels (Figure 27). The overflow passes down a reinforced concrete chute (Figure 28) and discharges at a waterfall into a rock basin in the gorge below the dam (Figure 29).

Figure 28: Overflow chute

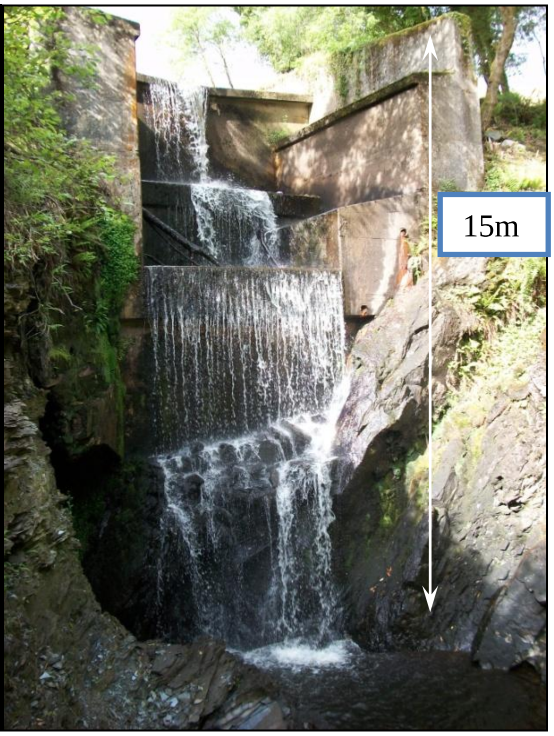


Figure 29: Waterfall into rock basin

The control of the water level of the reservoir is achieved through 3 sluice gates (two 1330x 1220mm and one 1330 x 1000mm) which are set in the upper section of the overflow chute (Appendix A-6) and an 800mm diameter scour valve downstream of the sluice gates (Appendix A-2) and approximately 3m vertically lower. The scour valve is currently operable from a man hole using a large T key, whereas the sluice gates are operated from a platform above the overflow sill by screws and a detachable lever.

From the initial site survey visual inspection and (23) there does not seem to be any immediate integrity concerns relating to the condition of the dam, weir, sluice gates, scour valve or overflow chute. The initial survey concluded that the sites existing infrastructure had potential to be retro fitted with a hydro power scheme. As such, hydrological survey stage of the feasibility study was then undertaken. Additional site survey pictures can be found in Appendix A

3.1.2 Traditional Hydrological Survey

Argyll and Bute Council record the water lever of the reservoir from a metric gauge board fixed to the wall of the overflow weir (it can be seen as the white stick located against the wall in Figure 27). Unfortunately, due to incomplete records, the water level of the weir has only been recorded on a weekly basis from 25/09/08 to 7/05/09.

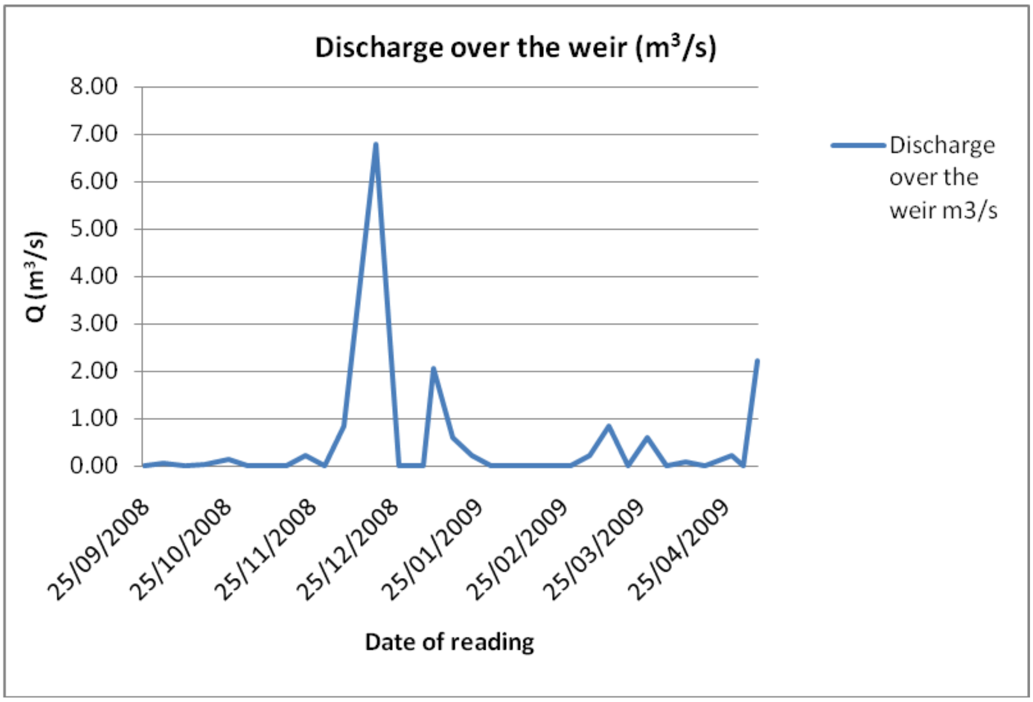


Figure 30: Varying discharge over the weir

Using the weekly water level readings that have been collated from September 08 to May 09, the discharge over the weir can be calculated from:

$$Q = 1.8(L - 0.2h)h^{1.5} \qquad [3]$$

Where:

Q is discharge in m^3/s

L is the length of the weir in m

h is the height of the level of water flowing over the weir.

Equation [3] (10) is used along with the measured water levels in Table 4 to calculate the variation of discharge.

Date	Time	Measured Water Level (cm)		Date	Time	Measured Water Level (cm)
25/09/2008	16.30	0		30/01/2009	16.55	0
02/10/2008	15.20	1.5		06/02/2009	16.40	0
10/10/2008	16.00	0		14/02/2009	15.45	0
17/10/2008	15.45	1		21/02/2009	15.25	0
26/10/2008	16.05	3.1		28/02/2009	16.15	0
02/11/2008	15.45	0		07/03/2009	16.00	4
09/11/2008	16.20	0.5		14/03/2009	15.45	10
16/11/2008	16.00	0.5		21/03/2009	10.15	0
23/11/2008	15.20	4		28/03/2009	14.00	8
30/11/2008	15.35	0		04/04/2009	14.35	0
07/12/2008	15.50	10		11/04/2009	12.10	2
19/12/2008	14.40	40		18/04/2009	13.15	0
27/12/2008	15.45	0		28/04/2009	14.50	4
05/01/2009	15.25	0		02/05/2009	9.25	0
09/01/2009	16.10	18		07/05/2009	15.20	19
16/01/2009	14.40	8				
23/01/2009	15.30	4				

Table 4: Weekly Bishops Glen water level readings

As the readings are intermittent and inconsistent with seasonal expectations, another method of calculating the expected flow rate from the weir must be used.

3.1.3 LowFlows 2000 Hydrological Survey

LowFlows 200 is a piece of software developed by Wallingford Hydro Solutions which enables the user to estimate the river flows for a given catchment area in the UK. It is recommended for use by the Centre of Ecology and Hydrology (CEH) and the Scottish Environmental Protection Agency (SEPA). In the absence of accurate measured flow data, LowFlows permits the user to calculate the natural flow characteristics of the site. In addition, LowFlows can determine the appropriate compensation flow that must be left in order to minimise the adverse environmental impact any diversion or re-distribution of water.

The catchment area for Bishops Glen is 5.18km^2 and is shown by the solid red line in Figure 31. It is this catchment area that is the primary input for the LowFlows software.

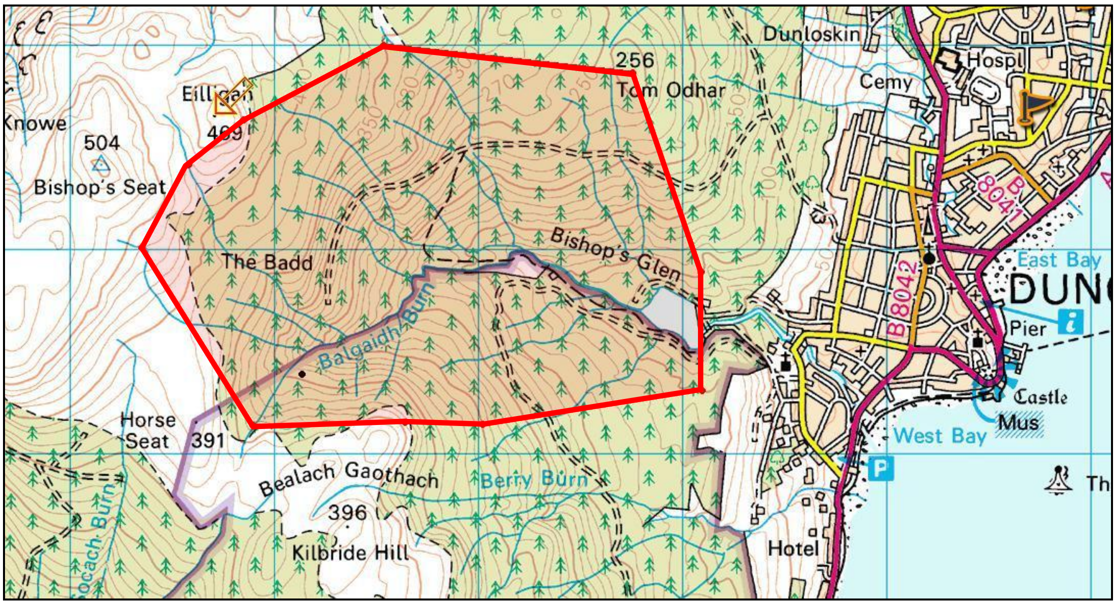


Figure 31: Bishops Glen hydrological catchment area (2)

The output from the LowFlows software is in the form of monthly flow duration curves, which are statistical probabilities of a particular flow rate occurring. Flow duration curves are calculated for each month in a year, whereby an accurate estimate of the probable flow duration can be made.

In addition to providing monthly flow exceedance curves, the LowFlows software also provides a method of gauging the annual 95% exceedance flow, this is the flow of water that is exceeded for 95% of the year and is the minimum compensation flow rate that is required by SEPA to remain flowing in the water course. A summary of the monthly data obtained from LowFlows for the Bishops Glen catchment area is given in Table 5 and Figure 32.

	Jan - June) Monthly Flow Rates Q (m^3/s)					
Percentage flow (%)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
5	1.093	1.208	0.937	0.66	0.332	0.398
10	0.84	0.741	0.698	0.409	0.199	0.257
20	0.533	0.463	0.379	0.227	0.101	0.134
30	0.376	0.312	0.266	0.138	0.059	0.079
40	0.271	0.216	0.193	0.094	0.038	0.053
50	0.191	0.158	0.144	0.066	0.025	0.038
60	0.137	0.12	0.113	0.052	0.02	0.025
70	0.097	0.083	0.088	0.038	0.015	0.017
80	0.063	0.054	0.062	0.028	0.011	0.011
90	0.04	0.029	0.04	0.019	0.008	0.008
95	0.027	0.021	0.03	0.015	0.006	0.006
99	0.016	0.012	0.021	0.01	0.004	0.005
Mean Q (m^3/s)	0.32	0.29	0.26	0.16	0.083	0.098

	July - December Monthly Flow Rates Q (m^3/s)					
Percentage flow (%)	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
5	0.509	0.751	0.832	1.065	0.959	1.171
10	0.304	0.452	0.567	0.763	0.732	0.896
20	0.169	0.254	0.321	0.482	0.442	0.551
30	0.104	0.152	0.205	0.336	0.309	0.37
40	0.067	0.095	0.132	0.229	0.21	0.256
50	0.045	0.062	0.092	0.162	0.153	0.176
60	0.03	0.04	0.062	0.108	0.114	0.121
70	0.02	0.024	0.04	0.072	0.081	0.085
80	0.013	0.015	0.025	0.043	0.055	0.058
90	0.008	0.009	0.012	0.026	0.037	0.036
95	0.006	0.006	0.009	0.018	0.026	0.025
99	0.005	0.005	0.006	0.011	0.015	0.013
Mean Q (m^3/s)	0.12	0.16	0.21	0.29	0.27	0.33

Table 5: Monthly flow durations for Bishops Glen catchment

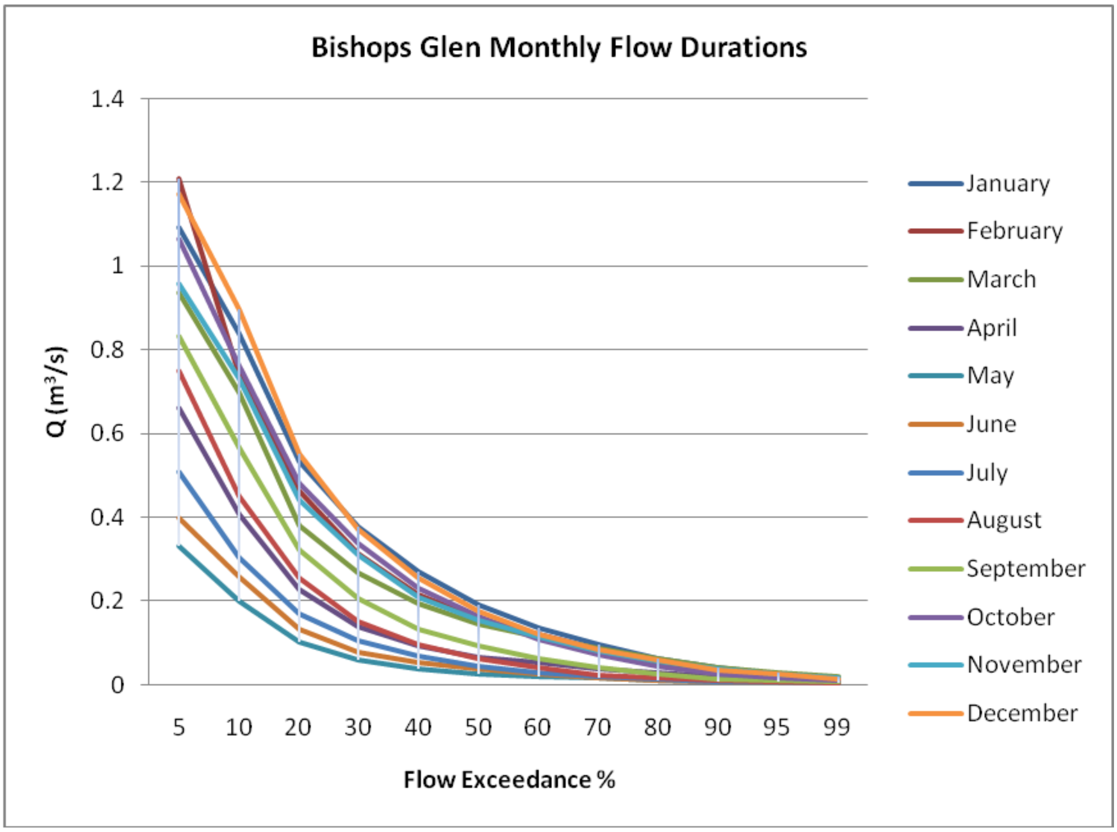


Figure 32: Bishops Glen monthly flow exceedance curves

3.1.4 Summary of Site Advantages and Disadvantages

A brief summary outlining the main pros and cons of the Bishops Glen site is given in Table 6.

Advantage	Disadvantage
There is extensive existing infrastructure including dam, weir, sluice gates, overflow spillway	There is no immediate local demand to which a retro fitted hydro scheme could supply
There is a nearby 11kV 3 phase line connection	
The catchment area of the reservoir can supply usable levels of discharge	
There is a relatively steep head drop of 20m over a short distance that would accommodate a small scale hydro scheme	
Site is accessible to heavy machinery, maintenance and emergency	

Table 6: Summary of Bishops Glen advantages and disadvantages

3.2 Kirk Dam

The proposed site for retro fit of a hydro scheme at Kirk Dam is an earth embankment dam that crosses the relatively flat grassy plain near the larger Kirk dam reservoir in Rothesay, Figure 33. The interest in Argyle and Bute council assessing the hydro feasibility of the Kirk Dam site stems from the availability of local demand in the form of a community owned swimming pool, also shown in Figure 33. The site is ideally located to provide an off-grid source of energy that could be used to supplement the existing heating and lighting loads within the pool complex

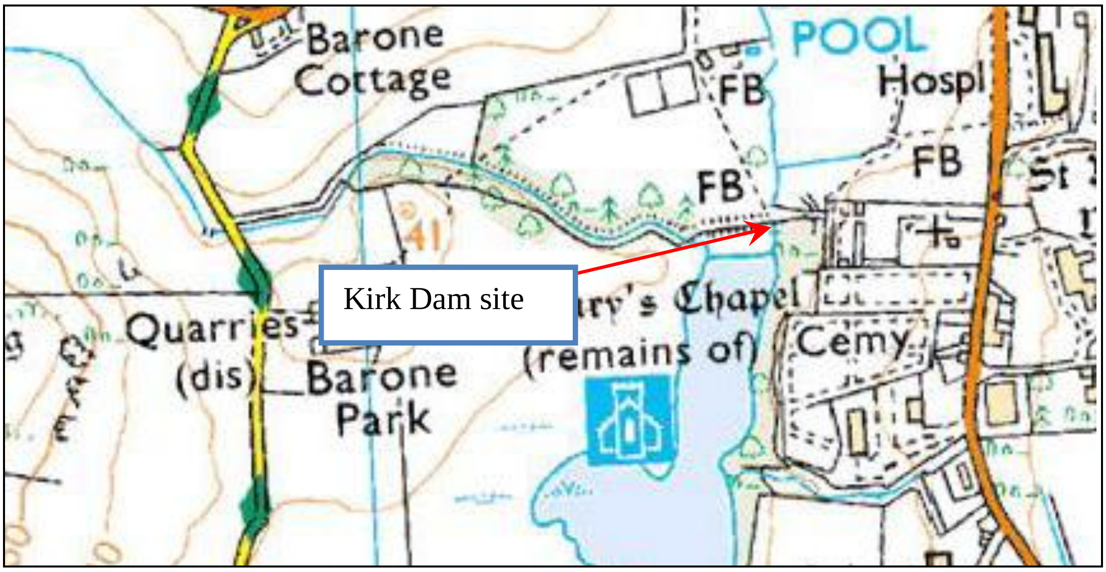


Figure 33: Proposed site for retro fit of hydro scheme

The site is approachable via a footpath next to the cemetery and playing fields, where a culvert of diameter 800mm connects the upstream and downstream ends of the embankment. The potential site at Kirk Dam has no further heavy civil infrastructure, besides a small wooden dam of questionable integrity. The area immediately surrounding the water course that leads to the embankment consists of long grasses and marsh (see Figure 34 and Figure 35). Both the sides of the embankment are fenced off for safety. There is a metric measuring gauge attached to the safety fence, however there are currently no known records of water depth readings.

Additional site photographs of the Kirk Dam site are located in Appendix B.

Figure 34: View of water course entering the earth embankment dam

Figure 35: View of water course approaching embankment dam

3.2.1 Initial Site Survey

An initial site survey was conducted with David Whyte of Argyll and Bute Council. On the day of the site survey, there was no/little flowing water, however there are historical accounts of occasional high water flows in the region. This is also corroborated by high water marks that have been left on the green fence, shown in Figure 36.

Figure 36: High water mark left after recent flooding

The site has a head drop of 1 – 2 m between the entrance to the embankment and the exit through the culvert on the other side. From OS maps the potential catchment area for the dam is estimated to be in the region of 1km^2, and is shown in Figure 37.

The quality of the water on the day of the site visit was poor. There were high amounts of mud and silt suspended in the water which could potentially be damaging to turbine blades and nozzles (Appendix B-3)

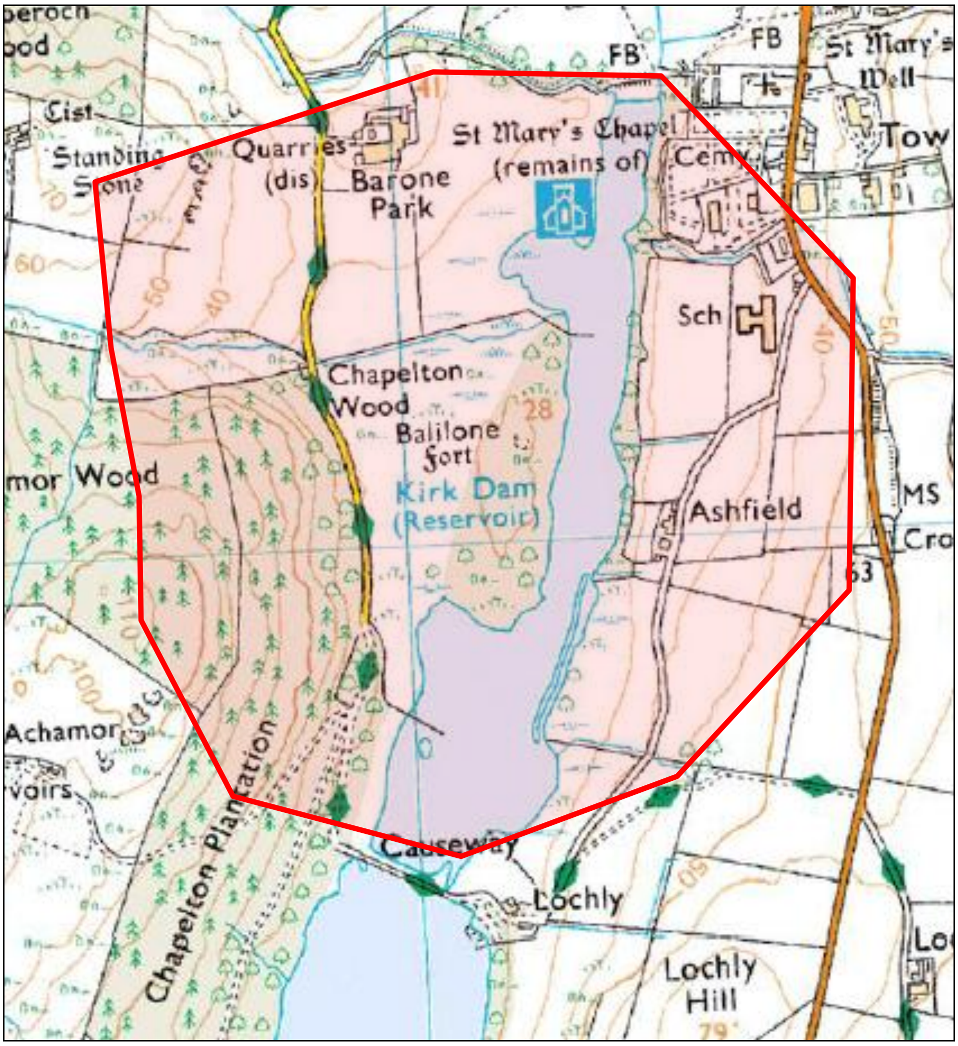


Figure 37: Estimated catchment area of Kirk Dam

There were high amounts of dead grass and other suspended debris blocking the embankment culvert at one side (Appendix B-4). Should a trash rack be installed, the nature of the surrounding area suggests that regular cleaning would be required to avoid any major blockages from grass build up. Access to the site is by a footpath which may prove difficult for heavy machinery and diggers.

A large amount of work is expected to be involved in bringing the existing infrastructure up to a standard that could accommodate a hydroelectric scheme. The flat nature of the site catchment area, high water marks shown in Figure 36 and local reports suggest that the site is prone to flooding after heavy rainfall which would present additional challenges and costs in designing and building a suitable hydroelectric scheme.

3.2.2 Kirk Dam Site Advantages and Disadvantages

A brief summary outlining the main pros and cons of the Kirk Dam site is given in Table 7.

Advantage	Disadvantage
There is a local swimming pool owned by Argyll and Bute Council that could be an outlet for potential power generated	Extensive works would be required to ensure the safe working of any retro fitted hydro electric plant due to the limited amount of existing infrastructure at the site.
	Geology of surrounding area would require substantial canal and trash rack construction to mitigate turbine damage
	Transient flow rates expected due to the high dependency on rainfall – this makes sizing an appropriate turbine extremely difficult
	The site could only accommodate a low head scheme, which in order to generate power would require much higher flow rates than an equivalent rated high head scheme
	Limited access to the site for heavy machinery, maintenance and emergency

Table 7: Summary of Kirk Dam advantages and disadvantages

3.3 Feasibility Conclusions from Initial Site Surveys

Both sites have a mixture of desirable and undesirable aspects which have contributed to the initial feasibility assessment. The conclusions that can be drawn from the initial site surveys and hydrological studies are that the Bishops Glen site has the greatest potential for retro fitting of a small scale hydro scheme. There is sufficient existing infrastructure in the form of a reservoir, dam, weir and spillway that would provide an excellent starting point for development of a hydroelectric scheme. As there are no immediate local demands for energy nearby, the power generated from the Bishops Glen site would be required to be exported to the grid. This brings additional financial obstacles to the development in the form of expensive switch gear and grid connection costs.

Although there are indications that the site at Kirk Dam may be able to support a low head hydroelectric scheme, it is found to be unsuitable for the purposes of retro fitting, as summarised in Table 7. Extensive works would be required to be carried out in the embankment area to house any potential turbine and generation equipment. In addition, the possibility of regular flooding of the catchment area introduces additional risk to such a project. A detailed hydrological study using the LowFlows software was not undertaken as there are currently no existing records of water levels with which to corroborate findings. As the catchment for the Kirk Dam site is essentially flat, the difficulty in assessing where the water flow is likely to run off would present additional uncertainty in any LowFlows analysis of the area.

Section IV - Technical Analysis

4.1 Basic Design of Bishops Glen Site

Following on from the initial site surveys, a retro fit hydro scheme can now be appropriately designed around the existing infrastructure. This will incorporate:

- An intake point where water can be abstracted from the reservoir
- Penstock dimensions and location
- Turbine type and rating
- Power house location
- Grid connection

In general, the location of the retro fitted scheme is suggested to be built around the weir/spillway and waterfall of the reservoir as this point has the most immediate access to a sufficient net head.

4.1.1 Abstraction Point

There are three points on the existing reservoir infrastructure that are potential locations to construct the intake of the retro fitted hydro scheme (Figure 38) and are describe below.

1) This is the location of a 304.8mm diameter supply pipe that was formerly used to supply Dunoon with fresh water. The pipeline is currently blocked off at the outlet to the reservoir and the valves closed (23). From the initial survey, it was found to be accessible from a manhole shaft. This could potentially provide a point of access for the scheme to be connected, however the exact condition of the outlet is unknown and substantial civil works would be required to excavate the pipe for inspection. The penstock would be then directly connect to this point and run to the turbine situated in the power house.

2) An alternative location to tap into the reservoir is via the existing scour valve located mid-way down the spillway (see Appendix A-2). This would be accessible for inspection; however a trash rack for debris filtering would be required to be constructed at the entrance to the pipeline. In addition, the scour valve would not be able to retain its functionality; therefore an addition scour valve may have to be constructed at extra cost.

3) The third potential site would involve a construction around the weir and sluice gate area of the reservoirs spillway. This would provide the simplest of the solutions, as a section of the weir may be removed to give way to an intake construction. This point would also provide the simplest trash rack solution of the potential intake sites. The penstock could then be run directly down the spillway to the location of the power house in the basin below the waterfall.

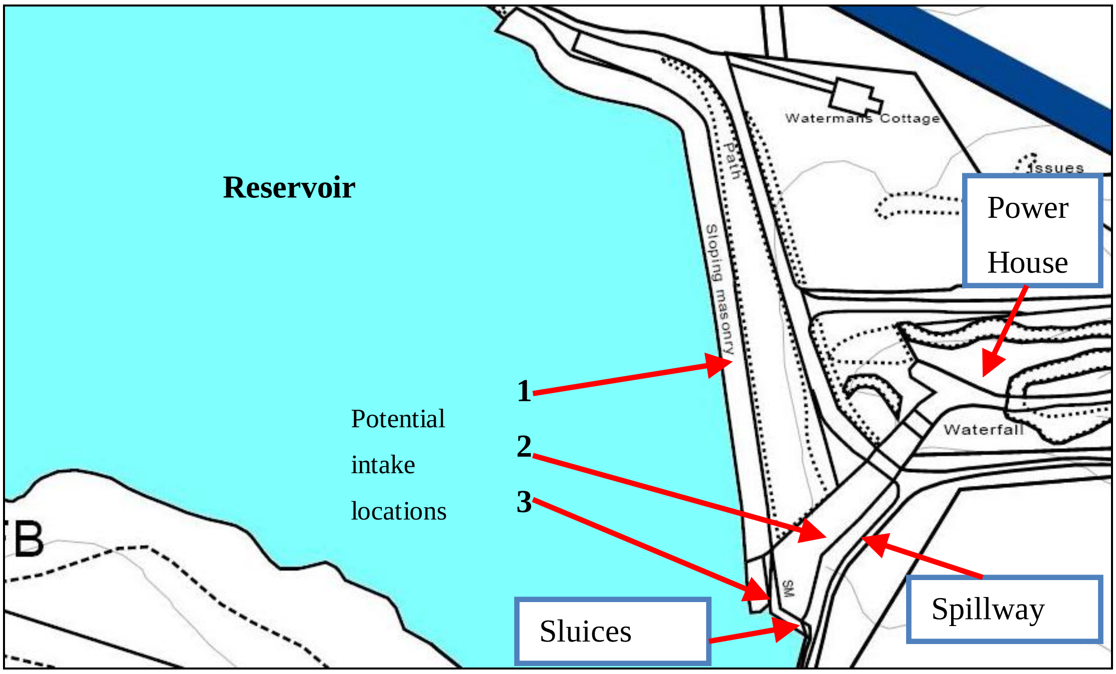


Figure 38: Potential site layout

4.1.2 <u>Power House Location</u>

In order to maximise the available head of a scheme, the power house is aimed to be positioned the lowest possible point. The rock basin below that waterfall offers a location where the power house can be situated that has a 20m head drop from the intake and is less than 500m to the nearest 11kV 3 phase grid connection.

4.2 Technical Analysis of Bishops Glen

This section focuses on combining the hydrological data gathered from LowFlows with power and efficiency calculations in order to ascertain an acceptable power rating of turbine and calculate the annual probable power generated from such a scheme. An iterative process was adopted in order to calculate an optimum power rating of turbine and pipeline/penstock diameter* that would maximise energy capture for the given site characteristics. This could then be combined with the annual hydrological flow data and equation [2]. Microsoft Excel was used to calculate the expected performance of the scheme for given monthly flow durations, penstock diameter, and hydraulic gradient

Parameter	Value
Kinematic Viscosity (5)	1.31E-06
Roughness Coefficient (mm) (11)	0.003
Pipe Diameter (m)*	0.2
Penstock cross sectional Area (m^2)	0.008
Flow Velocity (m/s)	4.546
Discharge Rate(m^3/s)	0.036
Intake Elevation (m)	70
Generator Elevation (m)	40
Net Head (m)	30
Pipe Length (m)	200
Hydraulic Gradient	0.152
Typical Turbine Efficiency (%)	90

Table 8: Proposed site parameters

The Colebrook-White equation (11) (equation [4]) was used to calculate the discharge that could be taken under gravity for given pipeline parameters:

$$U = -2\sqrt{(2gDS)}\log\left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51\upsilon}{D\sqrt{2gDS}}\right) \qquad [4]$$

Where:

U = Fluid velocity (m/s)

g = gravitational acceleration (m/s^2)

e/D = pipeline relative roughness (mm)

D = pipeline diameter (m)

ν = kinematic viscosity of fluid (m^2/s)

S = hydraulic gradient of the pipeline from the intake to power house

The head loss due to friction in the pipeline/penstock is also calculated. This is important in small diameter lines as, depending on how small the diameter is relative to the fluid velocity, the pipeline may be likely to become choked. The head loss due to friction (h_f) is calculated using the Darcy Weisbach equation [5]:

$$h_f = f\left(\frac{L}{D}\right)U^2/2g \qquad [5]$$

The Darcy friction factor (f) is found from the implicit form of the Colebrook-White equation [6] which converges after 4 iterations:

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{R_e\sqrt{f}}\right) \quad [6]$$

The head loss is calculated for each exceedance flow rate and varying pipeline diameter in order to obtain the optimum solution. A power rating of turbine can then be assessed to best capture the available energy. Typical cut in and cut out flow rates of 35% and 125% of the rated flow are used in order to calculate a range in which the turbine will be generating power to an efficiency of 90%. Outside this range the turbine is assumed not to generate. The results in Table 9 show the variation in the amount of energy that is captured from each turbine/pipeline configuration, using the hydrological flow data calculated in Section 3.1.2. Full calculation tables are appended in Appendix C: Probabilistic Monthly Flow Duration Calculations.

Turbine Rating	30 (kW)	60 (kW)	90 (kW)	120 (kW)	150 (kW)
Pipe Diameter (m)	Energy Generated per year (kWh) for each rating/diameter configuration				
0.1	0	0	0	0	0
0.2	57743	38734	20395	9119	577
0.3	131945	164793	143025	124763	99809
0.4	157129	227407	260728	274361	253748
0.5	157272	228492	265362	287178	289553
0.6	157315	228763	266333	289403	292893
0.7	157331	228864	266693	290161	293911
0.8	157338	228907	266848	290478	294348
0.9	157341	228928	266922	290624	294557
1	157343	228939	266961	290694	294666

Table 9: Capacity for energy capture of varying turbines

A more clear comparison on the overall energy capture capacity of the turbine/pipe configurations is shown in Figure 39.

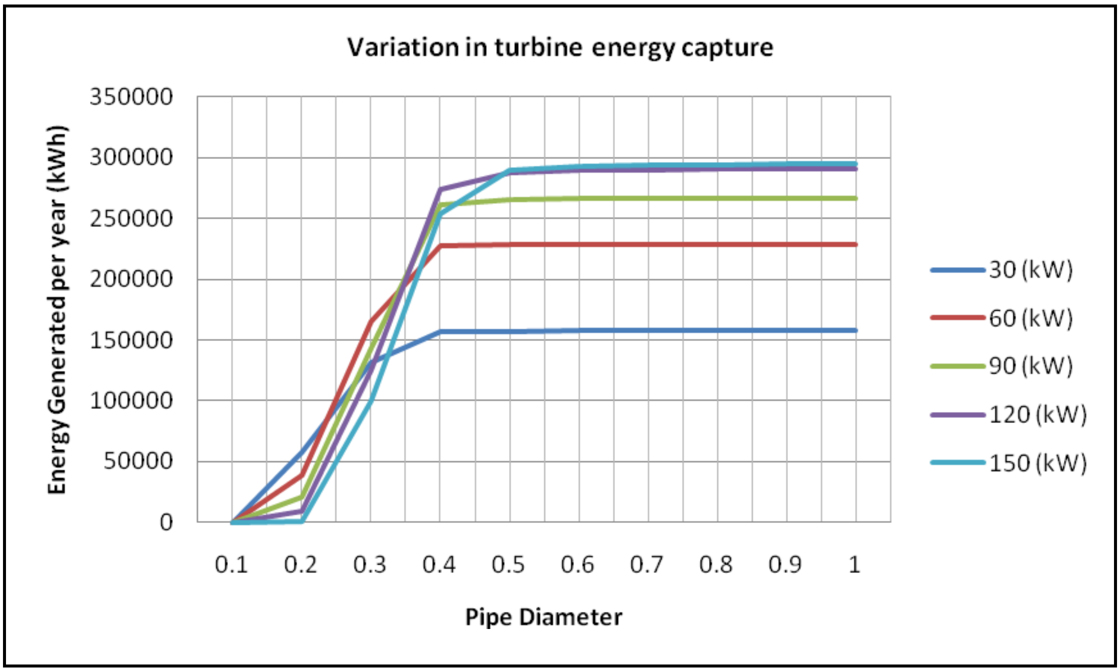


Figure 39: Variation in turbine energy capture

The graph of potential energy capture of the varying turbine sizes illustrates the balance that has to be met by appropriately sizing the pipeline and turbine together to achieve maximum energy capture.

The curves in Figure 39 show that for a pipeline/penstock diameter of 0.3m, there is little benefit to be had from increasing the rating of the turbine above 60kW. Note the point at which the all 60 kW + turbines converge around an annual energy generation of 200,000 kWh. This is caused by the limitation of the discharge due to the pipeline diameter, therefore higher rated turbines are unable to generate more than the pipe capacity will allow. The curves eventually flatten as diameter increase, as no further energy can be generated than those define by the available flow rate.

It is therefore a 60kW Pelton Turbine along with a 0.3m diameter pipeline and penstock that is used in the further revenue calculations in the following section.

4.3 Revenue Calculations

The estimated annual income (Table 10) from the proposed Bishops Glen scheme is calculated from the total energy generated and exported to the grid, multiplied by the feed in tariff rate of 20.8p/kWh (17.8p/kWh for generation plus 3p/kWh exported).

Energy Generated per year (kWh)	Gross revenue per year (£)
164792.91	£34,276.92

Table 10: Estimated annual income from FITs

The annual income from FITs forms the basis of the revenue calculations which have been carried out over a 20 year period. It should be noted that the expectant service life of hydroelectric schemes are often much greater than 20 years, however the Feed in Tariff payment rate is only guaranteed for 20 years.

General values of Capital Expenditure (Capex) and Operational Expenditure (Opex) depending on the power rating of the scheme have been derived from the British Hydro Associations Response to Feed in Tariffs (24) which contains data on 170 built or in build small scale hydro schemes. Best fit curves were plotted in order to quantify the average Opex and Capex for a typical scheme and as such, create a platform on which to gauge subsequent Capex and Opex assumptions. In addition, as the Bishops Glen reservoir is to be retro fitted, appropriate measures were taken to reduce the Capex.

4.3.1 Scenario A - No External Sources of Funding are Secured

As outlined in Section 2.6.5, a community owned hydro electric scheme may be eligible for assistance through the Scottish Governments CARES scheme. The financial feasibility of the potential development at Bishops Glen has initially been assessed on the basis that Argyll and Bute council would have to outlay the entire Capex, assuming securing CARES grants and additional sources of funding is unsuccessful. The initial assumptions for the calculations are outlined in Table 11.

		Reference
Transmission Cost	£200,000	(19)
Est. Cost of Pipe	£19,000	(5) (10) (11)
Est. Cost of Turbine	£50,000	(5) (10) (11)
Groundwork/Power House	£10,000	(5) (10) (11)
Estimated Capex	£279,000	
Estimated Opex	£9,050	(24)

Table 11: Cost assumptions

Tax rate	35	%
Long term interest rate	7	%
Long term inflation rate	2	%
% of profits to debt repayment	100	%

Table 12: Interest rates used in long term calculations

Year	Investment Balance	Generation Income	Debt Interest Repayment	Annual Opex	Total Outgoings	Pre-Tax Profit/Loss	Net Profit/Loss	Cumulative Profit/Loss	Debt Capital Repayment
1	£279,000	£34,277	£19,530	£9,050	£28,580	£5,697	£3,703	-£275,297	£3,703
2	£275,297	£34,962	£19,271	£9,231	£28,502	£6,461	£4,199	-£271,098	£4,199
3	£271,098	£35,662	£18,977	£9,416	£28,392	£7,269	£4,725	-£266,373	£4,725
4	£266,373	£36,375	£18,646	£9,604	£28,250	£8,125	£5,281	-£261,091	£5,281
5	£261,091	£37,102	£18,276	£9,796	£28,072	£9,030	£5,870	-£255,222	£5,870
6	£255,222	£37,844	£17,866	£9,992	£27,857	£9,987	£6,492	-£248,730	£6,492
7	£248,730	£38,601	£17,411	£10,192	£27,603	£10,998	£7,149	-£241,581	£7,149
8	£241,581	£39,373	£16,911	£10,396	£27,306	£12,067	£7,844	-£233,738	£7,844
9	£233,738	£40,161	£16,362	£10,604	£26,965	£13,196	£8,577	-£225,160	£8,577
10	£225,160	£40,964	£15,761	£10,816	£26,577	£14,387	£9,352	-£215,809	£9,352
11	£215,809	£41,783	£15,107	£11,032	£26,139	£15,645	£10,169	-£205,639	£10,169
12	£205,639	£42,619	£14,395	£11,253	£25,647	£16,972	£11,032	-£194,608	£11,032
13	£194,608	£43,471	£13,623	£11,478	£25,100	£18,371	£11,941	-£182,666	£11,941
14	£182,666	£44,341	£12,787	£11,707	£24,494	£19,847	£12,901	-£169,766	£12,901
15	£169,766	£45,228	£11,884	£11,941	£23,825	£21,403	£13,912	-£155,854	£13,912
16	£155,854	£46,132	£10,910	£12,180	£23,090	£23,042	£14,978	-£140,877	£14,978
17	£140,877	£47,055	£9,861	£12,424	£22,285	£24,770	£16,100	-£124,776	£16,100
18	£124,776	£47,996	£8,734	£12,672	£21,407	£26,589	£17,283	-£107,493	£17,283
19	£107,493	£48,956	£7,525	£12,926	£20,450	£28,506	£18,529	-£88,964	£18,529
20	£88,964	£49,935	£6,228	£13,184	£19,412	£30,523	£19,840	-£69,124	£19,840

Table 13: 20 year revenue forecast with no external funding

Due to the high Capex that is incurred for an appropriate grid connection to the Scottish and Southern Distribution Network, the overall 20 year cumulative balance of the Bishops Glen project should no external grants or funding be secured, is estimated to come in at a loss in the region of £70,000.

4.3.2 Scenario B – Half of the Maximum Available Funding is Secured

The calculations are repeated on the basis that, through CARES, the Argyll and Bute council secures £82,500 of funding available. The results of the analysis are given in Table 14. The interest rates and costs are again derived from Table 11 and Table 12.

Year	Investment Balance	Generation Income	Debt Interest Repayment	Annual OpEx	Total Outgoings	Pre-Tax Profit/Loss	Net Profit/Loss	Cumulative Profit/Loss	Debt Capital Repayment
1	£196,500	£34,277	£13,755	£9,050	£22,805	£11,472	£7,457	-£189,043	£7,457
2	£189,043	£34,962	£13,233	£9,231	£22,464	£12,498	£8,124	-£180,919	£8,124
3	£180,919	£35,662	£12,664	£9,416	£22,080	£13,582	£8,828	-£172,091	£8,828
4	£172,091	£36,375	£12,046	£9,604	£21,650	£14,725	£9,571	-£162,520	£9,571
5	£162,520	£37,102	£11,376	£9,796	£21,172	£15,930	£10,355	-£152,166	£10,355
6	£152,166	£37,844	£10,652	£9,992	£20,644	£17,201	£11,181	-£140,985	£11,181
7	£140,985	£38,601	£9,869	£10,192	£20,061	£18,541	£12,051	-£128,934	£12,051
8	£128,934	£39,373	£9,025	£10,396	£19,421	£19,952	£12,969	-£115,964	£12,969
9	£115,964	£40,161	£8,118	£10,604	£18,721	£21,440	£13,936	-£102,029	£13,936
10	£102,029	£40,964	£7,142	£10,816	£17,958	£23,007	£14,954	-£87,074	£14,954
11	£87,074	£41,783	£6,095	£11,032	£17,127	£24,656	£16,027	-£71,048	£16,027
12	£71,048	£42,619	£4,973	£11,253	£16,226	£26,393	£17,156	-£53,892	£17,156
13	£53,892	£43,471	£3,772	£11,478	£15,250	£28,221	£18,344	-£35,548	£18,344
14	£35,548	£44,341	£2,488	£11,707	£14,196	£30,145	£19,594	-£15,954	£19,594
15	£15,954	£45,228	£1,117	£11,941	£13,058	£32,170	£20,910	£4,956	£20,910
16	£0	£46,132	£0	£12,180	£12,180	£33,952	£22,069	£27,025	£0
17	£0	£47,055	£0	£12,424	£12,424	£34,631	£22,510	£49,536	£0
18	£0	£47,996	£0	£12,672	£12,672	£35,324	£22,960	£72,496	£0
19	£0	£48,956	£0	£12,926	£12,926	£36,030	£23,420	£95,916	£0
20	£0	£49,935	£0	£13,184	£13,184	£36,751	£23,888	£119,804	£0

Table 14: 20 year revenue forecast with £82, 500 external funding

The results based on attaining half the available funding through CARES indicate a payback period of 15 years and overall profit in the region of £120,000.

4.3.3 Scenario C – Maximum Available Funding is Secured

The revenue calculations are repeated on the basis that, through CARES, the Argyll and Bute council secures the maximum funding available of £165,000. The results of the analysis are given in Table 15. The interest rates and costs are again derived from Table 11 and Table 12.

Year	Investment Balance	Generation Income	Debt Interest Repayment	Annual OpEx	Total Outgoings	Pre-Tax Profit/Loss	Net Profit/Loss	Cumulative Profit/Loss	Debt Capital Repayment
1	£114,000	£34,277	£7,980	£9,050	£17,030	£17,247	£11,211	-£102,789	£11,211
2	£102,789	£34,962	£7,195	£9,231	£16,426	£18,536	£12,049	-£90,741	£12,049
3	£90,741	£35,662	£6,352	£9,416	£15,767	£19,894	£12,931	-£77,810	£12,931
4	£77,810	£36,375	£5,447	£9,604	£15,051	£21,324	£13,861	-£63,949	£13,861
5	£63,949	£37,102	£4,476	£9,796	£14,272	£22,830	£14,840	-£49,109	£14,840
6	£49,109	£37,844	£3,438	£9,992	£13,430	£24,415	£15,870	-£33,240	£15,870
7	£33,240	£38,601	£2,327	£10,192	£12,519	£26,083	£16,954	-£16,286	£16,954
8	£16,286	£39,373	£1,140	£10,396	£11,536	£27,838	£18,095	£1,809	£18,095
9	£0	£40,161	£0	£10,604	£10,604	£29,557	£19,212	£21,021	£0
10	£0	£40,964	£0	£10,816	£10,816	£30,149	£19,597	£40,618	£0
11	£0	£41,783	£0	£11,032	£11,032	£30,751	£19,988	£60,606	£0
12	£0	£42,619	£0	£11,253	£11,253	£31,367	£20,388	£80,994	£0
13	£0	£43,471	£0	£11,478	£11,478	£31,994	£20,796	£101,790	£0
14	£0	£44,341	£0	£11,707	£11,707	£32,634	£21,212	£123,002	£0
15	£0	£45,228	£0	£11,941	£11,941	£33,286	£21,636	£144,638	£0
16	£0	£46,132	£0	£12,180	£12,180	£33,952	£22,069	£166,707	£0
17	£0	£47,055	£0	£12,424	£12,424	£34,631	£22,510	£189,217	£0
18	£0	£47,996	£0	£12,672	£12,672	£35,324	£22,960	£212,178	£0
19	£0	£48,956	£0	£12,926	£12,926	£36,030	£23,420	£235,598	£0
20	£0	£49,935	£0	£13,184	£13,184	£36,751	£23,888	£259,486	£0

Table 15: 20 year revenue forecast with £165,000 external funding

The results based on attaining all of the available funding through CARES indicate a potential 8 year payback period with and overall project profit of £260,000.

Section V - Conclusions and Recommendations

The feasibility of the two sites in Argyll and Bute were assessed for their propensity to accommodate the retro fitting of hydro power plant in order to generated power for both on and off grid uses. Conclusions and recommendations are made on the existing capacity of both sites and further discussion is offered on the means to which the feasibility of these sites and other similar developments may be improved to better meet the needs of hydro developers and local communities.

5.1 Conclusions

5.1.1 Bishops Glen

From the feasibility assessment the Bishops Glen site is deemed to have the most potential to accommodate retro fitting of hydro power plant. The key factors that lead to this conclusion are the availability of adequate water flow, head height and the extensive existing site infrastructure.

The energy capture potential of Bishops Glen was evaluated around the hydrological assessment of the expected flow durations using the LowFlows 2000 software. As a result it is expected that an optimally sized 60 kW turbine will generated in the region of 165,000 kWh of energy per year, that if it were exported back to the grid could generate an annual income of £34,000.

As there is no immediate local demand in the vicinity of the Bishops Glen reservoir, all the energy generated would have to be exported back to the grid, which from indicative cost in Scottish and Southern Power Distribution costing guide (19), is likely to be in the region of £200,000.

In light of the extensive Capex required due to the transmission costs, three scenarios of potential funding through the most likely avenue of external funding, the Scottish Governments Community and Renewable Energy Scheme were considered. If Argyll and Bute council were to be unsuccessful in obtaining any grant funding for the project, then it is deemed financially unfeasible due to the extensive grid connection charges. However, should the council obtain between half or all of the available funding through the CARES, then the potential payback period and net profit are likely to be in the region of 15 to 8 years and £120k to £260k respectively.

5.1.2 Kirk Dam

The Kirk Dam is deemed to have insufficient head and insufficient existing infrastructure to be able to currently accommodate the retro fitting of hydroelectric generations and transmission equipment. Although a small amount of head is available, any potential low head scheme would require flow rates which are currently unachievable at the site. In order to achieve a viable scheme, extensive works would be required to divert water from surrounding catchment areas in order to provide the flow rates required to drive a low head turbine. As there are currently means to record water levels at the site, it is advisable that regular records are now taken, which would form the basis of any future feasibility studies. Although it is deemed inappropriate to retro fit a scheme around the existing infrastructure, the Kirk Dam site is ideally located near an Argyll and Bute Council owned swimming pool. This would present an ideal opportunity to supply off grid power for hot water heating and lighting should a completely new development be undertaken in future.

5.1.3 General

Retro fitting of hydroelectric power schemes is highly dependent on the available existing infrastructure at potential sites. Without an existing infrastructure to build upon, the cost benefits of retro fitting small scale hydro power schemes are lost to the additional Capex required, as seen in the Kirk Dam site. Although Kirk Dam has a ready and waiting local demand in the form of the community swimming pool, the costs likely to be incurred would outweigh the benefits of developing the site. The overarching goal of retro fitting small scale hydroelectric schemes is not only to reduce the cost of a renewable form of energy production, but also to reduce the carbon footprint of the overall project through minimising the civil works required. Unfortunately, this goal is unattainable in sites such as Kirk Dam, due to the substantial development required.

Small reservoirs, canals, weirs, spillways and abstractions may all have potential to be retro fitted with generation equipment, however the feasibility of the overall project falls on the specific site characteristics, and requires there to be a potential for both generation and transmission of the energy. The Bishops Glen site is assessed to have potential for generation as it has a reasonable available head and sufficient water flow to drive a 60kW pelton turbine. The Bishops Glen site highlights the desirability of a local demand in increasing the feasibility of retro fitted projects, as high grid connection costs can overwhelm potential small scale renewable developments, even in light of the Feed in Tariff. Even though the site is deemed to be an excellent candidate for retro fitting, the overall feasibility of a small scale development lies in its ability to gain external funding in order to overcome the high grid connection charges.

The grid connection charges of schemes can to an extent be mitigated by applying to the appropriate local organisation for supplementary grants for renewable energy community projects. In addition to this, connection charges can be reduced should further decentralised renewable energy generation projects in the local vicinity be developed in future. By grouping together the grid connection of local renewable energy developments such as other small scale hydroelectric, wind and biomass schemes, the overall cost to upgrade the network infrastructure will be subsequently reduced for each project.

5.2 Recommendations

In line with the work carried out within this thesis, there are a number of valid recommendations that can be proposed specifically to the sites covered within this study, but also general recommendations can be made towards the concept of retro fitting renewable energy systems.

5.2.1 Bishops Glen

Appropriate requirements and permissions should be attainted from the Argyll and Bute District Angling Club who currently maintain the reservoir for angling purposes.

It is recommended that in line with SSEPD Network Charges document, Section 7 that a transmission feasibility study be undertaken by SSE at a cost of £500. Non-capital grant funding for the costs of this study can be applied for through CARES.

A full inspection of the integrity of the existing civil works infrastructure and pipe work at the Bishops Glen site is recommended to be conducted to ascertain the current condition and expectant design life before commencement of any future works. Non-capital grant funding for the costs of this study can be applied for through CARES.

5.2.2 General

It is recommended that UK and Scottish Governments recognise that carbon emissions are not only reduced through renewable energy generation, but also by utilising existing infrastructure when doing so, further reducing the carbon footprint of developments. In light of this, differentiation should be made legislatively between projects that involve the retro fitting of renewable energy equipment, and those which are to be developed from design conception. If this is achieved, additional avenues of funding should be made available to those developments which involve retro fitting, as to increase financial feasibility of such projects and encourage a greater uptake.

The feasibility of similar small scale hydro projects can be can be more accurately calculated if accurate and regular records of water flow are taken. The basic measuring stick approach is only adequate for calculating the instantaneous flow at the time of measurement. In order to accurately predict the flow duration of a potential site through measurement, current meters can be installed and flow can be recorded over the course of a year and beyond. This in turn will produce a more accurate assessment of the power potential of a site. It is recommended that for sites similar to those studied within this thesis that current meters are installed in order to accurately gauge the monthly flow durations.

Sites that hold definite generation potential but with no current off grid demand, such as the Bishops Glen reservoir, should be identified by local authorities and considered when future complimentary developments arise. These may take the form of local community projects that would introduce an electricity demand that would be a potential outlet for the originally infeasible off grid renewable energy project. Conversely, when sites of small scale community renewable energy generation are identified, local authorities should examine other potential renewable energy generation options in the local vicinity that would have the propensity to benefit from sharing grid connection cost.

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LIST OF APPENDICES

APPENDIX A – Bishops Glen Site Survey Photographs

A-1: View of weir and chute from footbridge

A-2: View of chute and scour valve exit

A-3: Scour valve exit

A-4: View of main weir spillway

A-5: View of spillway and overflow sluice gates

A-6: Close up of overflow sluice gates

A-7: Rock pool in gorge below waterfall

A-8: Potential site of turbine house

A-9: Earth embankment and concrete chute

A-10: Access road for heavy equipment and maintenance

APPENDIX B – Kirk Dam Site Survey Photographs

B-1: View of small wooden dam next to embankment

B-2: View of muddy canal and extensive grass land approaching embankment

B-3: View of high levels of debris, grass and mud in water

B-4: Debris blocking entrance to culvert

B-5: Downstream view of water course, very slow moving water

B-6: Just visible is culvert exit sitting below the water line

APPENDIX C - Probabilistic Monthly Flow Duration Outputs

Appendix C contains the calculated probabilistic power outputs for each month based on an optimum pipeline diameter of 0.2m and turbine rating of 60kW. Similar calculations were carried out for 30kW, 90kW, 130kW and 150kW rated turbines, but which have not been appended.

Exceed	Prob of any flow	Jan															31
Prob.	occurring	flow	value	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output			Capturing		kWh
0.050	0.050	1.093	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.000	0.000			choked	0.0	0.0
0.100	0.050	0.840	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.000	0.000			choked	0.0	0.0
0.200	0.100	0.533	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.000	0.000			choked	0.0	0.0
0.300	0.100	0.376	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.000	0.000			choked	0.0	0.0
0.400	0.100	0.271	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.000	0.000			choked	0.0	0.0
0.500	0.100	0.191	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.000	0.000			choked	0.0	0.0
0.600	0.100	0.137	0.164	5.220	798819	0.012	0.012	0.012	0.012	17.216	18.511	1.851			Generating	18.5	1377.2
0.700	0.100	0.097	0.117	3.724	569889	0.013	0.013	0.013	0.013	9.250	21.434	2.143			Generating	21.4	1594.7
0.800	0.100	0.063	0.080	2.546	389668	0.013	0.014	0.014	0.014	4.613	17.931	1.793			Generating	17.9	1334.1
0.900	0.100	0.040	0.052	1.639	250849	0.015	0.015	0.015	0.015	2.069	12.700	1.270			insufficient flow	0.0	0.0
0.950	0.050	0.027	0.034	1.066	163173	0.016	0.016	0.016	0.016	0.950	8.592	0.430			insufficient flow	0.0	0.0
0.990	0.040	0.016	0.022	0.684	104723	0.018	0.018	0.018	0.018	0.427	5.614	0.225			insufficient flow	0.0	0.0
1.000	0.010	0.000	0.008	0.255	38967	0.022	0.022	0.022	0.022	0.073	2.114	0.021			insufficient flow	0.0	0.0
											Total	7.733					4306.0

Exceed	Prob of any flow	Feb															28
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.050	**0.050**	1.208	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.00	0.00			choked	0.0	0.0
0.100	**0.050**	0.741	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.00	0.00			choked	0.0	0.0
0.200	**0.100**	0.463	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.00	0.00			choked	0.0	0.0
0.300	**0.100**	0.312	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.00	0.00			choked	0.0	0.0
0.400	**0.100**	0.216	0.223	7.093	1085445	0.011	0.012	0.012	0.012	30.000	0.00	0.00			choked	0.0	0.0
0.500	**0.100**	0.158	0.187	5.952	910848	0.012	0.012	0.012	0.012	21.935	13.31	1.33			Generating	13.3	894.8
0.600	**0.100**	0.120	0.139	4.425	677048	0.012	0.013	0.013	0.013	12.695	21.24	2.12			Generating	21.2	1427.1
0.700	**0.100**	0.083	0.102	3.231	494391	0.013	0.013	0.013	0.013	7.129	20.50	2.05			Generating	20.5	1377.3
0.800	**0.100**	0.054	0.069	2.180	333653	0.014	0.014	0.014	0.014	3.476	16.04	1.60			insufficient flow	0.0	0.0
0.900	**0.100**	0.029	0.042	1.321	202140	0.015	0.016	0.016	0.016	1.399	10.48	1.05			insufficient flow	0.0	0.0
0.950	**0.050**	0.021	0.025	0.796	121771	0.017	0.017	0.017	0.017	0.560	6.50	0.32			insufficient flow	0.0	0.0
0.990	**0.040**	0.012	0.017	0.525	80369	0.019	0.019	0.019	0.019	0.266	4.33	0.17			insufficient flow	0.0	0.0
1.000	**0.010**	0.000	0.006	0.191	29225	0.024	0.024	0.024	0.024	0.044	1.59	0.02			insufficient flow	0.0	0.0
										mean	7.23	8.67					3699.2

Exceed	**Prob of any flow**	**Mar**															31
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.0500	**0.0500**	0.9370	0.2228	7.0934	1085445	0.0114	0.0119	0.0118	0.0118	30.00	0.00	0.00			choked	0.0	0.0
0.1000	**0.0500**	0.6980	0.2228	7.0934	1085445	0.0114	0.0119	0.0118	0.0118	30.00	0.00	0.00			choked	0.0	0.0
0.2000	**0.1000**	0.3790	0.2228	7.0934	1085445	0.0114	0.0119	0.0118	0.0118	30.00	0.00	0.00			choked	0.0	0.0
0.3000	**0.1000**	0.2660	0.2228	7.0934	1085445	0.0114	0.0119	0.0118	0.0118	30.00	0.00	0.00			choked	0.0	0.0
0.4000	**0.1000**	0.1930	0.2228	7.0934	1085445	0.0114	0.0119	0.0118	0.0118	30.00	0.00	0.00			choked	0.0	0.0
0.5000	**0.1000**	0.1440	0.1685	5.3635	820738	0.0119	0.0124	0.0123	0.0123	18.10	17.71	1.77			Generating	17.7	1317.4
0.6000	**0.1000**	0.1130	0.1285	4.0903	625904	0.0124	0.0129	0.0129	0.0129	10.99	21.57	2.16			Generating	21.6	1604.8
0.7000	**0.1000**	0.0880	0.1005	3.1990	489520	0.0129	0.0135	0.0134	0.0134	7.00	20.41	2.04			Generating	20.4	1518.3
0.8000	**0.1000**	0.0620	0.0750	2.3873	365314	0.0137	0.0142	0.0141	0.0141	4.10	17.15	1.71			insufficient flow	0.0	0.0
0.9000	**0.1000**	0.0400	0.0510	1.6234	248413	0.0147	0.0152	0.0151	0.0151	2.03	12.59	1.26			insufficient flow	0.0	0.0
0.9500	**0.0500**	0.0300	0.0350	1.1141	170480	0.0159	0.0163	0.0162	0.0162	1.03	8.95	0.45			insufficient flow	0.0	0.0
0.9900	**0.0400**	0.0210	0.0255	0.8117	124207	0.0170	0.0173	0.0173	0.0173	0.58	6.62	0.26			insufficient flow	0.0	0.0
1.0000	**0.0100**	0.0000	0.0105	0.3342	51144	0.0209	0.0208	0.0208	0.0208	0.12	2.77	0.03			insufficient flow	0.0	0.0
										mean	8.29	9.68					4440.5

Exceed	**Prob of any flow**	**Apr**															30
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.6600	0.2228	7.09338	1085445	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.4090	0.2228	7.09338	1085445	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.2270	0.2228	7.09338	1085445	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.1380	0.1825	5.80916	888930	0.0117156	0.012232112	0.0121884	0.012192	20.97	14.55	1.45			Generating	14.5	1047.6
0.4	**0.1**	0.0940	0.1160	3.69239	565018	0.0126236	0.013147701	0.0130996	0.0131039	9.11	21.40	2.14			Generating	21.4	1540.7
0.5	**0.1**	0.0660	0.0800	2.54648	389668	0.0134925	0.014002297	0.0139527	0.0139575	4.61	17.93	1.79			Generating	17.9	1291.1
0.6	**0.1**	0.0520	0.0590	1.87803	287380	0.0142967	0.014778643	0.0147298	0.0147346	2.65	14.25	1.42			insufficient flow	0.0	0.0
0.7	**0.1**	0.0380	0.0450	1.43239	219188	0.0150889	0.015531789	0.0154853	0.0154901	1.62	11.28	1.13			insufficient flow	0.0	0.0
0.8	**0.1**	0.0280	0.0330	1.05042	160738	0.0160939	0.016472843	0.0164316	0.016436	0.92	8.47	0.85			insufficient flow	0.0	0.0
0.9	**0.1**	0.0190	0.0235	0.74803	114465	0.0173285	0.01760893	0.0175772	0.0175807	0.50	6.12	0.61			insufficient flow	0.0	0.0
0.95	**0.05**	0.0150	0.0170	0.54113	82804	0.0186551	0.018807299	0.0187894	0.0187915	0.28	4.46	0.22			insufficient flow	0.0	0.0
0.99	**0.04**	0.0100	0.0125	0.39789	60886	0.0200701	0.020061546	0.0200626	0.0200625	0.16	3.29	0.13			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0050	0.15915	24354	0.0254368	0.024614936	0.0247248	0.0247099	0.03	1.32	0.01			insufficient flow	0.0	0.0
										mean	7.93	9.77					3879.4

Exceed	**Prob of any flow**	**May**															31
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.3320	0.2228	7.09338	1085445	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.1990	0.2228	7.09338	1085445	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.1010	0.1500	4.77465	730627	0.0120891	0.01261199	0.0125661	0.01257	14.61	20.39	2.04			Generating	20.4	1516.8
0.3	**0.1**	0.0590	0.0800	2.54648	389668	0.0134925	0.014002297	0.0139527	0.0139575	4.61	17.93	1.79			Generating	17.9	1334.1
0.4	**0.1**	0.0380	0.0485	1.5438	236236	0.0148622	0.015317365	0.01527	0.0152749	1.86	12.05	1.21			insufficient flow	0.0	0.0
0.5	**0.1**	0.0250	0.0315	1.00268	153432	0.0162544	0.016621712	0.0165815	0.0165858	0.85	8.11	0.81			insufficient flow	0.0	0.0
0.6	**0.1**	0.0200	0.0225	0.7162	109594	0.0174977	0.017763068	0.0177329	0.0177363	0.46	5.87	0.59			insufficient flow	0.0	0.0
0.7	**0.1**	0.0150	0.0175	0.55704	85240	0.0185299	0.018695101	0.0186758	0.018678	0.30	4.59	0.46			insufficient flow	0.0	0.0
0.8	**0.1**	0.0110	0.0130	0.4138	63321	0.0198804	0.019894805	0.0198931	0.0198933	0.17	3.42	0.34			insufficient flow	0.0	0.0
0.9	**0.1**	0.0080	0.0095	0.30239	46273	0.0214794	0.021287681	0.0213116	0.0213086	0.10	2.51	0.25			insufficient flow	0.0	0.0
0.95	**0.05**	0.0060	0.0070	0.22282	34096	0.0232352	0.022784302	0.0228425	0.0228349	0.06	1.85	0.09			insufficient flow	0.0	0.0
0.99	**0.04**	0.0040	0.0050	0.15915	24354	0.0254368	0.024614936	0.0247248	0.0247099	0.03	1.32	0.05			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0020	0.06366	9742	0.0333358	0.030796624	0.0311709	0.0311134	0.01	0.53	0.01			insufficient flow	0.0	0.0
										mean	6.04	7.64					2850.9

Exceed	Prob of any flow	Jun															30
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.3980	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.2570	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.1340	0.1955	6.2	952250.7	0.0115913	0.012104559	0.0120617	0.0120652	23.81	10.68	1.07			Generating	10.7	768.8
0.3	**0.1**	0.0790	0.1065	3.4	518745.3	0.0128131	0.013335619	0.013287	0.0132914	7.79	20.89	2.09			Generating	20.9	1504.0
0.4	**0.1**	0.0530	0.0660	2.1	321475.9	0.0139904	0.014484432	0.0144351	0.0144399	3.25	15.59	1.56			insufficient flow	0.0	0.0
0.5	**0.1**	0.0380	0.0455	1.4	221623.6	0.0150551	0.015499852	0.0154532	0.015458	1.65	11.39	1.14			insufficient flow	0.0	0.0
0.6	**0.1**	0.0250	0.0315	1.0	153431.7	0.0162544	0.016621712	0.0165815	0.0165858	0.85	8.11	0.81			insufficient flow	0.0	0.0
0.7	**0.1**	0.0170	0.0210	0.7	102287.8	0.0177718	0.018011848	0.0179843	0.0179874	0.41	5.49	0.55			insufficient flow	0.0	0.0
0.8	**0.1**	0.0110	0.0140	0.4	68191.9	0.0195296	0.019585267	0.0195786	0.0195794	0.20	3.68	0.37			insufficient flow	0.0	0.0
0.9	**0.1**	0.0080	0.0095	0.3	46273.1	0.0214794	0.021287681	0.0213116	0.0213086	0.10	2.51	0.25			insufficient flow	0.0	0.0
0.95	**0.05**	0.0060	0.0070	0.2	34095.9	0.0232352	0.022784302	0.0228425	0.0228349	0.06	1.85	0.09			insufficient flow	0.0	0.0
0.99	**0.04**	0.0050	0.0055	0.2	26789.7	0.024782	0.024075626	0.0241691	0.0241565	0.04	1.45	0.06			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0025	0.1	12177.1	0.0311013	0.029105867	0.029393	0.0293502	0.01	0.66	0.01			insufficient flow	0.0	0.0
										mean	6.33	7.99					2272.7

Exceed	**Prob of any flow**					**Jul**											31
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.5090	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.3040	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.1690	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.1040	0.1365	4.3	664870.7	0.0122791	0.01280347	0.0127566	0.0127607	12.28	21.36	2.14			Generating	21.4	1589.0
0.4	**0.1**	0.0670	0.0855	2.7	416457.5	0.0133283	0.013842107	0.0137926	0.0137973	5.21	18.71	1.87			Generating	18.7	1392.4
0.5	**0.1**	0.0450	0.0560	1.8	272767.5	0.0144435	0.014919013	0.0148705	0.0148753	2.41	13.64	1.36			insufficient flow	0.0	0.0
0.6	**0.1**	0.0300	0.0375	1.2	182656.8	0.0156663	0.016074329	0.0160305	0.0160352	1.16	9.55	0.95			insufficient flow	0.0	0.0
0.7	**0.1**	0.0200	0.0250	0.8	121771.2	0.0170922	0.017393087	0.0173592	0.017363	0.56	6.50	0.65			insufficient flow	0.0	0.0
0.8	**0.1**	0.0130	0.0165	0.5	80369.0	0.0187855	0.018923899	0.0189076	0.0189095	0.27	4.33	0.43			insufficient flow	0.0	0.0
0.9	**0.1**	0.0080	0.0105	0.3	51143.9	0.0209482	0.020828159	0.020843	0.0208412	0.12	2.77	0.28			insufficient flow	0.0	0.0
0.95	**0.05**	0.0060	0.0070	0.2	34095.9	0.0232352	0.022784302	0.0228425	0.0228349	0.06	1.85	0.09			insufficient flow	0.0	0.0
0.99	**0.04**	0.0050	0.0055	0.2	26789.7	0.024782	0.024075626	0.0241691	0.0241565	0.04	1.45	0.06			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0025	0.1	12177.1	0.0311013	0.029105867	0.029393	0.0293502	0.01	0.66	0.01			insufficient flow	0.0	0.0
										mean	6.22	7.84					2981.3

Exceed	**Prob of any flow**	**Aug**															31
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.7510	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.4520	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.2540	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.1520	0.2030	6.5	988782.0	0.0115248	0.012036015	0.0119937	0.0119971	25.53	8.01	0.80			Generating	8.0	595.9
0.4	**0.1**	0.0950	0.1235	3.9	601549.7	0.0124885	0.013013076	0.0129654	0.0129696	10.22	21.57	2.16			Generating	21.6	1605.0
0.5	**0.1**	0.0620	0.0785	2.5	382361.5	0.01354	0.014048496	0.0139989	0.0140037	4.46	17.70	1.77			insufficient flow	0.0	0.0
0.6	**0.1**	0.0400	0.0510	1.6	248413.2	0.0147134	0.015176159	0.0151283	0.0151332	2.03	12.59	1.26			insufficient flow	0.0	0.0
0.7	**0.1**	0.0240	0.0320	1.0	155867.1	0.0161997	0.016571082	0.0165305	0.0165349	0.87	8.23	0.82			insufficient flow	0.0	0.0
0.8	**0.1**	0.0150	0.0195	0.6	94981.5	0.0180738	0.018284973	0.0182606	0.0182634	0.36	5.10	0.51			insufficient flow	0.0	0.0
0.9	**0.1**	0.0090	0.0120	0.4	58450.2	0.0202705	0.020237285	0.0202413	0.0202408	0.15	3.16	0.32			insufficient flow	0.0	0.0
0.95	**0.05**	0.0060	0.0075	0.2	36531.4	0.0228197	0.022433185	0.0224827	0.0224763	0.07	1.98	0.10			insufficient flow	0.0	0.0
0.99	**0.04**	0.0050	0.0055	0.2	26789.7	0.024782	0.024075626	0.0241691	0.0241565	0.04	1.45	0.06			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0025	0.1	12177.1	0.0311013	0.029105867	0.029393	0.0293502	0.01	0.66	0.01			insufficient flow	0.0	0.0
										mean	6.19	7.80					2200.9

Exceed	**Prob of any flow**	**Sept**															30
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.8320	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.5670	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.3210	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.2050	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.4	**0.1**	0.1320	0.1685	5.4	820737.8	0.0118641	0.01238377	0.0123391	0.0123429	18.10	17.71	1.77			Generating	17.7	1274.9
0.5	**0.1**	0.0920	0.1120	3.6	545534.9	0.0127007	0.01322427	0.0131759	0.0131803	8.54	21.22	2.12			Generating	21.2	1528.0
0.6	**0.1**	0.0620	0.0770	2.5	375055.3	0.0135888	0.014095861	0.0140463	0.014051	4.30	17.47	1.75			insufficient flow	0.0	0.0
0.7	**0.1**	0.0400	0.0510	1.6	248413.2	0.0147134	0.015176159	0.0151283	0.0151332	2.03	12.59	1.26			insufficient flow	0.0	0.0
0.8	**0.1**	0.0250	0.0325	1.0	158302.5	0.0161463	0.016521471	0.0164805	0.0164849	0.90	8.35	0.84			insufficient flow	0.0	0.0
0.9	**0.1**	0.0120	0.0185	0.6	90110.7	0.0182934	0.018482791	0.0184608	0.0184633	0.33	4.85	0.48			insufficient flow	0.0	0.0
0.95	**0.05**	0.0090	0.0105	0.3	51143.9	0.0209482	0.020828159	0.020843	0.0208412	0.12	2.77	0.14			insufficient flow	0.0	0.0
0.99	**0.04**	0.0060	0.0075	0.2	36531.4	0.0228197	0.022433185	0.0224827	0.0224763	0.07	1.98	0.08			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0030	0.1	14612.5	0.0294391	0.027819315	0.0280479	0.0280147	0.01	0.79	0.01			insufficient flow	0.0	0.0
										mean	6.75	8.44					2802.9

Exceed	Prob of any flow	Oct															31
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	1.0650	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.7630	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.4820	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.3360	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.4	**0.1**	0.2290	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.5	**0.1**	0.1620	0.1955	6.2	952250.7	0.0115913	0.012104559	0.0120617	0.0120652	23.81	10.68	1.07			Generating	10.7	794.4
0.6	**0.1**	0.1080	0.1350	4.3	657564.4	0.0123019	0.012826286	0.0127793	0.0127835	12.03	21.42	2.14			Generating	21.4	1593.4
0.7	**0.1**	0.0720	0.0900	2.9	438376.3	0.0132042	0.013720736	0.0136714	0.013676	5.72	19.29	1.93			Generating	19.3	1435.4
0.8	**0.1**	0.0430	0.0575	1.8	280073.7	0.0143688	0.014847637	0.0147989	0.0148038	2.53	13.95	1.39			insufficient flow	0.0	0.0
0.9	**0.1**	0.0260	0.0345	1.1	168044.2	0.015943	0.016332526	0.0162903	0.0162948	1.00	8.83	0.88			insufficient flow	0.0	0.0
0.95	**0.05**	0.0180	0.0220	0.7	107158.6	0.0175862	0.017843529	0.0178142	0.0178175	0.45	5.74	0.29			insufficient flow	0.0	0.0
0.99	**0.04**	0.0110	0.0145	0.5	70627.3	0.0193668	0.01944117	0.0194323	0.0194334	0.21	3.81	0.15			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0055	0.2	26789.7	0.024782	0.024075626	0.0241691	0.0241565	0.04	1.45	0.01			insufficient flow	0.0	0.0
										mean	6.55	7.87					3823.2

Exceed Prob.	Prob of any flow occurring	Nov															30
		flow	value	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	0.9590	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.7320	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.4420	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.3090	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.4	**0.1**	0.2100	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.5	**0.1**	0.1530	0.1815	5.8	884058.8	0.0117257	0.012242425	0.0121987	0.0122023	20.76	14.81	1.48			Generating	14.8	1066.3
0.6	**0.1**	0.1140	0.1335	4.2	650258.1	0.0123249	0.012849438	0.0128024	0.0128065	11.79	21.47	2.15			Generating	21.5	1545.7
0.7	**0.1**	0.0810	0.0975	3.1	474907.6	0.0130152	0.013535117	0.013486	0.0134906	6.62	20.12	2.01			Generating	20.1	1448.9
0.8	**0.1**	0.0550	0.0680	2.2	331217.6	0.0139109	0.014407758	0.0143583	0.0143632	3.43	15.95	1.60			insufficient flow	0.0	0.0
0.9	**0.1**	0.0370	0.0460	1.5	224059.0	0.0150217	0.015468368	0.0154216	0.0154264	1.69	11.50	1.15			insufficient flow	0.0	0.0
0.95	**0.05**	0.0260	0.0315	1.0	153431.7	0.0162544	0.016621712	0.0165815	0.0165858	0.85	8.11	0.41			insufficient flow	0.0	0.0
0.99	**0.04**	0.0150	0.0205	0.7	99852.4	0.0178691	0.018099982	0.0180734	0.0180765	0.39	5.36	0.21			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0075	0.2	36531.4	0.0228197	0.022433185	0.0224827	0.0224763	0.07	1.98	0.02			insufficient flow	0.0	0.0
										mean	7.64	9.02					4060.8

Exceed	**Prob of any flow**	**Dec**															31
Prob.	**occurring**	**flow**	**value**	U(m/s)	Re	Colebrook iterations			friction coef	hf (m)	Power	Output					kWh
0.05	**0.05**	1.1710	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.1	**0.05**	0.8960	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.2	**0.1**	0.5510	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.3	**0.1**	0.3700	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.4	**0.1**	0.2560	0.2228	7.1	1085444.6	0.0113644	0.011869927	0.0118289	0.0118322	30.00	0.00	0.00			choked	0.0	0.0
0.5	**0.1**	0.1760	0.2160	6.9	1052103.1	0.0114174	0.011924892	0.0118834	0.0118867	28.64	2.59	0.26			Generating	2.6	193.0
0.6	**0.1**	0.1210	0.1485	4.7	723320.9	0.012109	0.01263212	0.0125861	0.01259	14.34	20.53	2.05			Generating	20.5	1527.8
0.7	**0.1**	0.0850	0.1030	3.3	501697.3	0.0128888	0.013410482	0.0133616	0.0133661	7.32	20.62	2.06			Generating	20.6	1534.3
0.8	**0.1**	0.0580	0.0715	2.3	348265.6	0.0137791	0.014280402	0.0142309	0.0142357	3.76	16.57	1.66			insufficient flow	0.0	0.0
0.9	**0.1**	0.0360	0.0470	1.5	228929.8	0.0149566	0.015406715	0.0153597	0.0153645	1.75	11.72	1.17			insufficient flow	0.0	0.0
0.95	**0.05**	0.0250	0.0305	1.0	148560.8	0.0163672	0.016726183	0.0166867	0.016691	0.80	7.86	0.39			insufficient flow	0.0	0.0
0.99	**0.04**	0.0130	0.0190	0.6	92546.1	0.0181817	0.018382182	0.0183589	0.0183616	0.34	4.98	0.20			insufficient flow	0.0	0.0
1	**0.01**	0.0000	0.0065	0.2	31660.5	0.0236944	0.023170325	0.0232385	0.0232295	0.05	1.72	0.02			insufficient flow	0.0	0.0
										mean	6.66	7.81					3255.1