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A FEASIBILITY STUDY INTO A PROPOSED MICRO HYDRO GENERATING STATION ON THE INVERAILORT DEER FOREST ESTATE

THESIS SUBMITTED AS PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE
"ENERGY SYSTEMS AND THE ENVIRONMENT"

BY

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DECLARATION OF AUTHOR'S RIGHTS

In loving memory of Colin and Moira Brown……….

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I mention a huge thanks to all the agencies, companies and individuals who supplied myself with the vast amount of information, data and advice in the completion of this thesis.

Abstract.

This thesis examines the possibility of the construction of a micro hydro generating plant on the Inverailort Deer Forest Estate. This is conducted in the form of a feasibility analysis of the attainable water and the ground characteristics within a potential area of the estate.

Two possible sites were considered for the study; the first of these was at an altitude of 45-50m above sea level and the second site at an altitude of approximately 75m. Both sites were fed by the rain catchment area of a large corrie on the estate, which flows down through the sites via a series of waterfalls, and due to the geography of both sites gave two different catchment area sizes, these being 9.96km² and 7.47km² respectively. Flow monitoring of the watercourse did not exist, therefore all hydrological data such as annual and monthly volumetric flow rates were calculated from the historical Meteorological Office rainfall data using the area rainfall method. This data was used to construct tables of flow rates so that a power analysis of the proposed sites in question could be conducted. From this the objective was to find which site had the maximum attainable power output that could be utilised in an environmentally sustainable manner and to produce projected costs for the construction of the proposed scheme.

This study has confirmed that a micro hydro generating plant is financially feasible for a total estimated cost of approximately £133,000 and would have a simple payback period of 4.2 years. The proposed scheme would require the construction of an overflow type dam, through which a 400mm diameter penstock would supply a modular standardised Crossflow turbine rated at 100kW, connected to the Estates' own locally distributed network, providing power to the local housing or the near-by fish hatchery. The total cost to the Estate owner would be dependent on the availability of funding from various federal and regional government grants.

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Image acknowledgements.

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Chapter 1.

Introduction.

General.

Over recent years the demand for energy not only nationally, but globally has increased dramatically with countries like India and China, devouring natural resources at an explosive rate to fuel thriving economies. This places huge strains on the world's finite resources, while ever increasing the production of CO_2, fuelling global warming. Britain like many other countries, has committed itself to meet international emission reduction targets outlined in the Kyoto Agreement. Current and future renewable energy technologies have a vital role in this commitment, more funding into research and the use of renewable energy production is required to meet these committed targets.

Scotland itself has massive potential for renewable energy production and already has 10% of its energy produced by hydro electric plants. To further this, the installation of wind farms on and offshore are set to bypass 1GW soon, with the wind farm industry now delivering just under 10% of the countries electricity needs. By the end of 2007, 1.2GW of electricity from wind farms should be generated, around 25% of the Scottish Executive's Climate Change Programme carbon reduction target. At this pace of progress the Scottish Executive's goal of delivering 18% of Scotland's electricity needs by 2010 will be reached three years early and the projected target of 40% by 2020 hit five years early.

Although Scotland utilised most of its large scale hydro projects in the 1950's and 60's, Scotland still has the potential for many smaller micro hydro projects that could be used to power local rural areas. The reasons for the slow uptake in the past about these projects were the large capital costs and the local environmental impacts. With ever increasing electricity costs, more and more of these forgotten micro hydro sites are looking more attractive and feasible, due to higher efficiencies from generating equipment, low maintenance, long infrastructure lives and the introduction of various regional and national funding schemes. A feasibility study is used to support any planning application and funding application, and is an important part of the process for any proposed renewable energy scheme.

This thesis investigates the feasibility of installing a micro hydro scheme in a rural area and the implications of such a scheme with respect to the technology used, the finance possible and environmental impact to the area.

Methodology.

The purpose of this thesis is to analyse the technical, financial and environmental feasibility of a micro hydro installation on the Inverailort Deer Forest Estate.

The first stage of the study was firstly recognise the principles of extracting electricity from a water source and the types of hydroelectric schemes used. This continued with the investigation into an understanding of the technology and the components required to complete a hydroelectric system, these included the various types of turbine, mechanical plant and civil works . By performing this literature review it was made clear what information and components would be required, and how the overall performance could be calculated.

A literature review of the various legal and environmental considerations required to build a hydroelectric plant, along with a financial evaluation of a scheme was also conducted.

Several visits to the proposed sites were made, and the sites were photographed and surveyed with the help of Ordnance Survey maps, to gain an understanding of the lye of the land. As there is no monitoring equipment on the waterway or any historical flow rates, rainfall data from the Meteorological Office weather station nearby was used in conjunction with the Ordnance Survey maps to calculate the volumetric flow rates for the site.

Capital costs, ongoing annual costs and possible sources of finance were considered to identify if the proposed micro hydro installation could be cost effectively built and maintained.

It must be dually noted that many costs have been assumed with advice from professional individuals and other means. This has been done, due to the rise of interest and installation of such smaller hydro systems, the market has become increasingly more commercially sensitive, with few manufacturers and suppliers willing to disclose specifications and costs of their product and systems.

Brief overview.

Chapter 1. Introduction

A general introduction to the subject, structure and methodology used in this thesis.

Chapter 2. Literature review

A review of literature relevant to the field of hydroelectric power generation, the main concepts, classification bandings, components and types of hydroelectric schemes available.

Chapter 3. Technology review

A look at the technology used within the hydroelectric generating field, the various types of turbine, mechanical plant and civil work required to build a hydroelectric plant.

Chapter 4. Legal and planning

An insight into the various legal and environmental considerations required to build a hydroelectric plant.

Chapter 5. Cost & economics

The financial evaluation of a hydroelectric scheme.

Chapter 6. Feasibility study

The proposed location, sites, potential power, environmental considerations, civil works and generating equipment, along with the costings and potential revenue available.

Chapter 7. Discussion

A look at the reasons for choice of equipment and possible options available for the scheme, including the social, environmental and economic implications of the proposed scheme.

Chapters 8 & 9. Recommendations & Conclusion

Presenting recommendations, conclusion and the potential for further study.

Chapter 2.

Hydro Power Basics.

In this section an explanation on the historical background of the theory of extracting power from water and the development into hydroelectric power.

Background History.

The conversion of kinetic energy into mechanical energy is not a new idea. As far back as 2000 years ago wooden waterwheels were used to convert kinetic energy into mechanical energy.
The Egyptians and the Persians pioneered the waterwheel for the irrigation of the Nile and Euphrates Valleys, so water power may well have contributed to the evolution of the ‘Fertile Crescent’ in the Mesopotamian region that has become known as one of the ‘Cradles of Civilisation’. However, there is no one place, nor one time, that one can select as the source of the idea of waterpower. It might be argued that this is due to the lack of documentary and archaeological evidence, but it seems more likely that the developments occurred in parallel in different parts of the world. The Romans were responsible for the widespread adoption of the horizontal waterwheel with paddles and a vertical shaft, which often replaced animal or slave powered mills. They were very simple in construction, with no gearing and drove a set of millstones directly above the wheel this type of mill spread as far as Scandinavia and the Shetlands, Western Scotland, Ireland and possibly Wales, and became known as the Norse Mill or Grist Mill. (Figure 1)

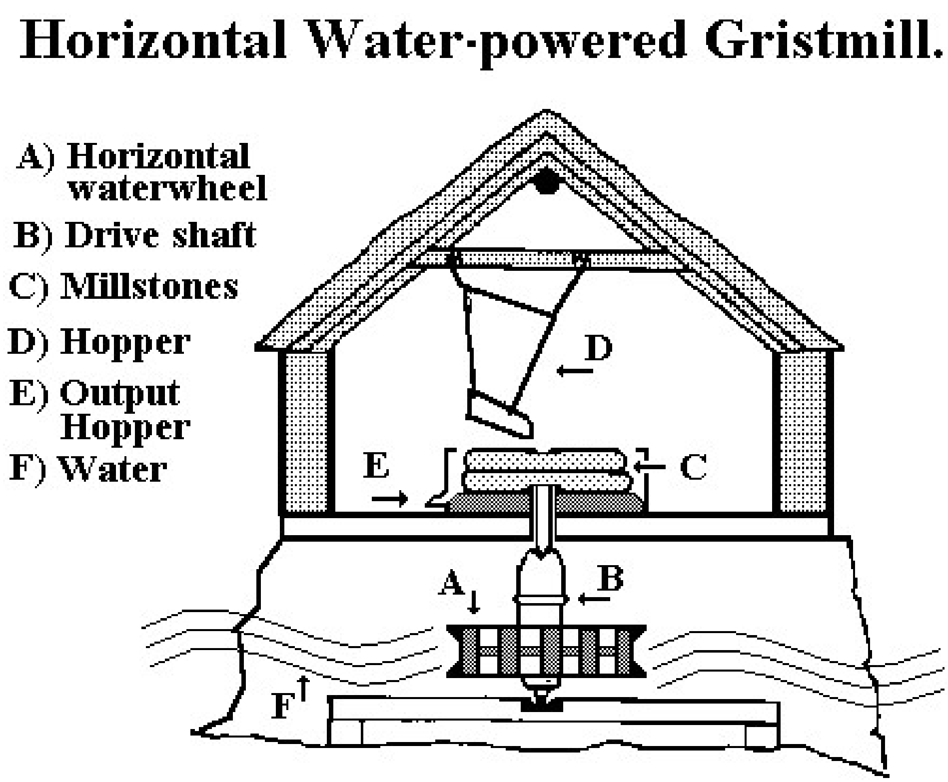


Figure 1.

Examples can been seen reconstructed in the Shetlands. Although not as efficient as the vertical geared wheels, the horizontal wheel did acquire some refinements, such as the cupped paddles, which improved the efficiency of the transfer of energy from moving water to the wheel. This is an interesting pre-echo of the cupped blades of the Pelton Wheel turbine, a patent of Lester Pelton in 1860.

The use of a horizontal wheel or runner with a vertical shaft survives in some of the most efficient water turbines in use today, the Francis Turbines. The vertical waterwheel was first used by the Egyptians before 100 BC and was well known to the Romans before the time Christ. Vitruvius, in 'De Architectura' written around 15 BC, has a description that has all the hallmarks of an undershot vertical waterwheel. However, just as important as the change from a horizontal wheel to a vertical one, is the use of a gearing system, so that the vertical plane of the wheel could be translated through 90 degrees to the horizontal plane of the millstones. Also, by using 'step-up' gearing, the flexibility in the uses of waterpower was increased considerably.

The waterwheel, a distant grandfather of the impulse turbine, played an important role in prompting engineers such as John Smeaton of England (1724-1792) to study and improve it until its efficiency had reached about 70 percent.

Engineers Zuppinger in 1846 and Schwamkrug in 1850 initiated development of a turbine using the same basic principles as the waterwheel. An important step away from the waterwheel was initiated at that time with the development of a waterspout or nozzle that directs a high-velocity stream of water against blades set in a wheel. Along with this development and the description of an efficient waterwheel as stated by Poncelet in 1826, a group of engineers from California set out to develop an impulse turbine with efficiency higher than that of the waterwheel. Among this group was Lester A. Pelton (1829-1908), who was responsible for the development of a highly efficient impulse wheel that bears his name to this day.

Eric Crewdson improved the already efficient Pelton wheel, or turbine, in 1920. This improvement led to the development of the Turgo wheel, which boasts even higher efficiency and simpler construction than either the Pelton wheel or the waterwheel.

Nevertheless, impulse wheels have been upstaged in recent years by more complex and efficient reaction turbines. Reaction turbines also use water momentum, but pressure forces are added for increased torque. The Kaplan or propeller turbine, developed around the time that Lester Pelton was perfecting his impulse machine, has been a very popular machine throughout its history. The Kaplan turbine's high efficiency under low pressures accounts for its growing popularity today because many installations have high flows but low heads. Other reaction turbines developed around the same time include the Francis turbine and other propeller machines.

Hybrid impulse turbines, which circumvent some basic drawbacks of full impulse machines, are known as cross-flow turbines. A.G.M. Michell patented the first cross-flow turbine in 1903. Professor Donat Banki also developed a cross-flow turbine in 1917 that bears his name today. Because these turbines are simple to build, they have been widely used in developing countries where both low cost and simple technology are imperative.

What is Hydropower?

"Hydro" comes from the Greek word hydra, meaning water.

Hydroelectric power is electricity produced by the movement of fresh water from rivers and lakes. At higher ground, water has stored gravitational energy that can be extracted by turbines as the water flows down stream. Gravity causes water to flow downwards and this downward motion of water contains kinetic energy that can be converted into mechanical energy, and then from mechanical energy into electrical energy via hydroelectric power stations.

Head and Flow.

Hydraulic power can be obtained where a flow of water falls from a higher plane to a lower plane. This could be in a stream running down a hillside, a river over a waterfall, a weir or from a reservoir discharge back in to a main outlet.

The amount of power available from a hydro scheme depends on the 'head' and the ‘flow’ rate of the water. The head is the height difference between the inlet to the hydro turbine and its outlet. (Figure 2)

The gross head is the maximum vertical drop available to the water from the top of the fall to the water level below. The actual head seen by a turbine is slightly less than gross head due to losses while transferring the water into and away from the turbine, and is therefore called the net head.

The flow rate (Q) in the water source is the volume of water passing per second.

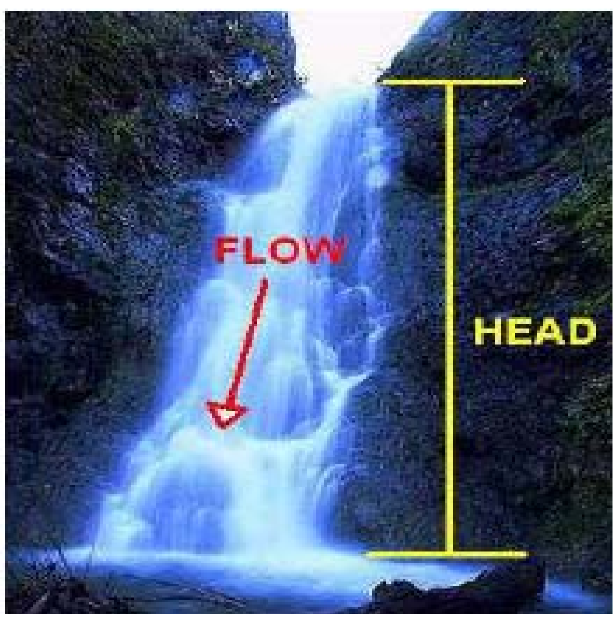


Figure 2.

This can be shown by the equation:

Energy released = m g H

m = mass of water
g = gravity
H = gross head or vertical distance

Power and Energy.

The mass of the water is its density (ρ) multiplied by its volume (V) so that the equation changes to:

Energy released = V ρ g H

The water enters the turbine at a rate Q value in cubic meters per second m^3/s, and be can be expressed in terms of power. The S.I. unit for power is the Watt.

Therefore:

Gross Power = ρ Q g H Watts.

Where:

ρ = 1000 kg/m^3
g = 9.81 m/sec^2
Q = volumetric flow rate m^3/sec
H = gross head in meters

However the power produced by the turbine cannot equal the gross power because of losses such as friction in pipe work and conversion machinery i.e. turbines and generators.

A hydro turbine can have between 80% to over 90% hydraulic efficiency, although this will reduce with size. A typical micro hydro system (<100kW) will tend to be 60% to 80% efficient. (Ref 25)

Therefore:

Net Power = η ρ Q g H Watts

Where:

η = hydraulic efficiency of turbine
ρ = 1000 kg/m^3
Q = volumetric flow rate m^3/sec
g = 9.81 m/sec^2
H = gross head in meters

Hydropower classification.

Hydroelectric power schemes can be banded into 5 broad categories, these being:

Large hydro power plant produces more than **50 MW** of total capacity
Medium hydro power plant produces **20-50 MW** of total capacity
Small hydro plant produces **5-20 MW** of total capacity
Mini hydro plant produces **1-5 MW** of total capacity
Micro hydro plant produces **1000 kW** or less of total capacity

It must be noted that size designation does vary among different countries and the point is that hydro power plants come in all sizes. (Ref 3, 5)

Main components of a scheme.

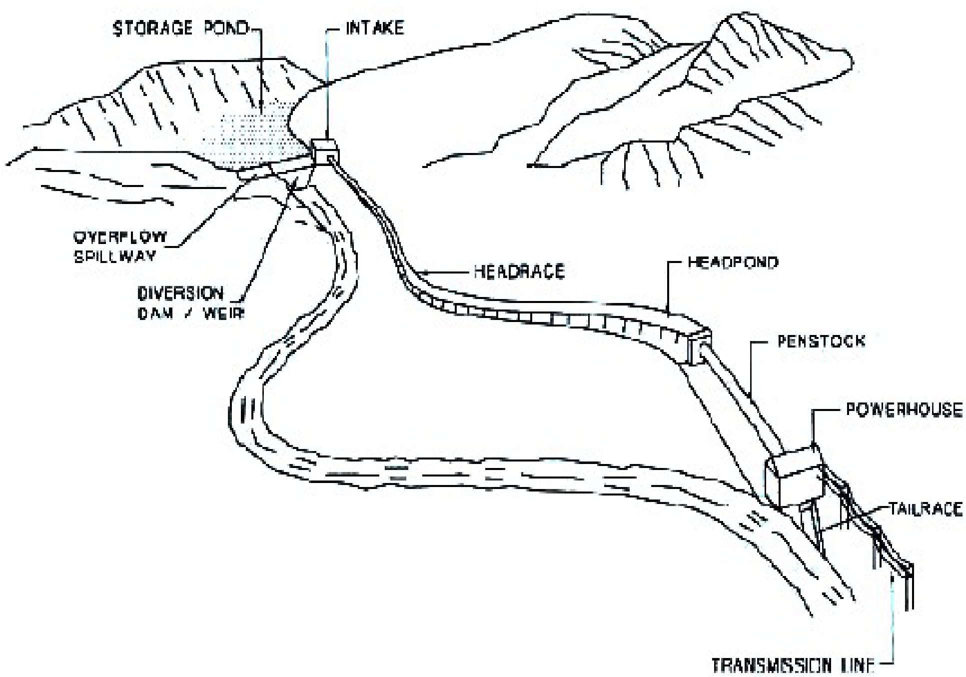


Figure 3.

A typical hydropower plant includes a dam, reservoir, penstocks (pipes), a powerhouse and an electrical power substation, as seen in Figure 3. The dam stores water and creates the head diverted via the intake to the headrace, down to the head pond or forebay tank. A penstock or pressure pipe carries the water from the reservoir to turbines inside the powerhouse; the water rotates the turbines, which drive generators that produce electricity. After leaving the turbine, the water is discharged down a tailrace into the river or stream. Hydropower uses a well-established and reliable technology and can deliver very high efficiencies.

Types of Hydro Schemes.

The three main types of hydroelectric scheme are **Run-of-the-River, Diversion** or **Canal** and **Storage.** (Ref 23)
Most hydropower plants are conventional in design, meaning they use one-way water flow to generate electricity.
A **Run-of-the-River** (Figure 4) scheme utilises the use of a dam, usually in the form of a weir, which does not stop the flow of the river and is used as an overflow, but diverts some of the flow through a trash screen to remove larger debris. After the flow passes through the trash screen, it enters the penstock (a pipeline) towards the turbine.
Run-of-the-river hydroelectric plants use little, if any, stored water to provide water flow through the turbines. Although some plants store a day or week's worth of water, weather changes - especially seasonal changes - cause run-of-river plants to experience significant fluctuations in power output.

Figure 4. 980MW Long Spruce Dam

A **Diversion or Canal** system is where the water is diverted from its original river or stream towards the turbine, through the use of a long penstock or an open feeder canal, (Figure 5) called a 'leat'. The flow in the river or stream channel is altered considerably.

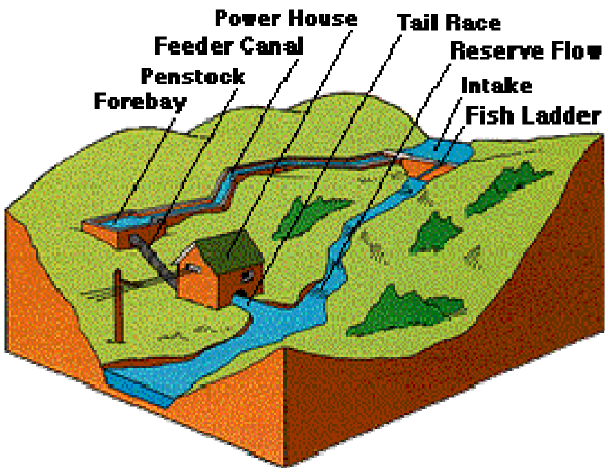


Figure 5.

A **Storage** scheme utilises impoundment of water upstream of the power plant using a dam or the use of an existing lake or loch, which allows the complete control over the flow of water downstream. An important factor to this type of scheme is that it uses extensive civil works and that any dam or reservoir storing over 25,000m³ has to comply with the Reservoirs Act 1975. Storage plants have enough storage capacity to offset seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year. Large dams can store several years' worth of water.

In contrast to conventional hydropower plants, **Pumped Storage** (Figure 6) plants re-use water. Water is passed through it, by storing it in catchment areas below the station and then pumping it back up to the higher catchment dams above the station in a closed circuit arrangement. During off-peak hours (periods of low energy demand), some of the water is pumped into an upper reservoir and re-used during periods of peak-demand.

When pumping is required, a reversal of roles occurs. The generator becomes an electric motor, receiving electricity from a nearby power station, and operates the turbine as a pump. The turbine receives energy instead of delivering it. However, in some pumped storage schemes there are two sets of equipment. One set is for generating and the other is for pumping. The use of pumped storage increases the total amount of power generated by the hydro power station, but this increase is not renewable. The pumps are run by non-renewable sources allowing excess electrical energy to be stored as the potential of energy of water raised to the height of the dam. The amount of renewable energy produced by the hydro power station remains the same.

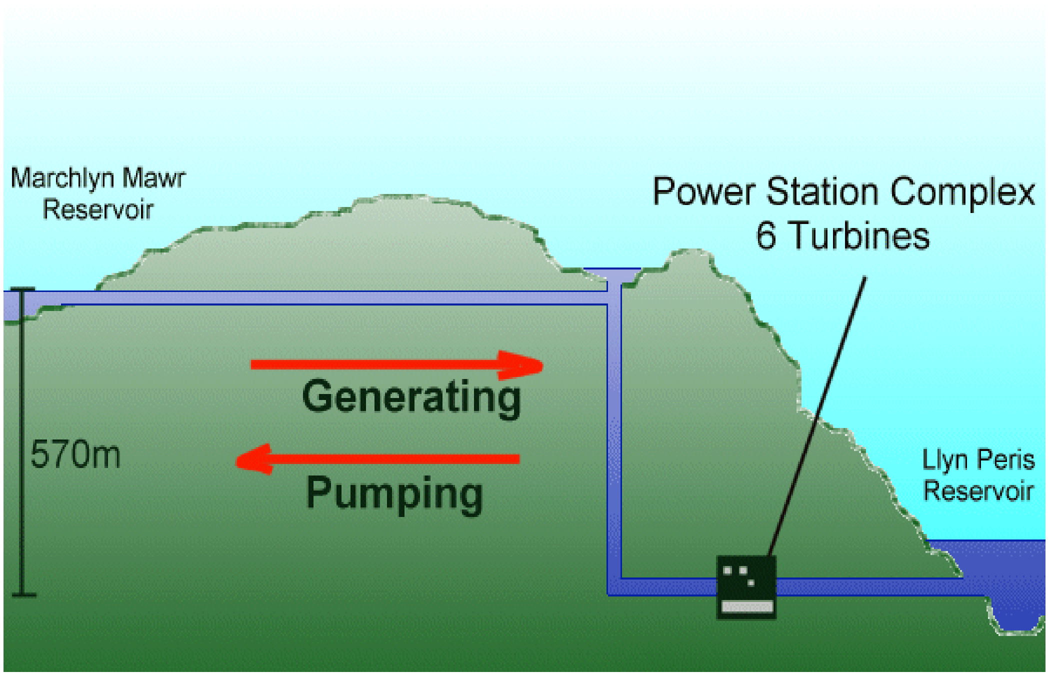


Figure 6. Dinorwig, Wales.

Chapter 3.

Technology.

In this section, electrical and mechanical equipment characteristics are explained to aid further in the selection of specific waterpower devices. Modern hydro technology uses specially designed water turbines. Some turbines operate at low heads of less than 10m. Water for a hydro-electric power station's turbines can come from a specially constructed dam set high up in a mountain range, or simply from a river close to ground level. As water sources vary, water turbines have been designed to suit the different locations. Largely head and quantity of water available at a particular site determine the design used.

Turbine types.

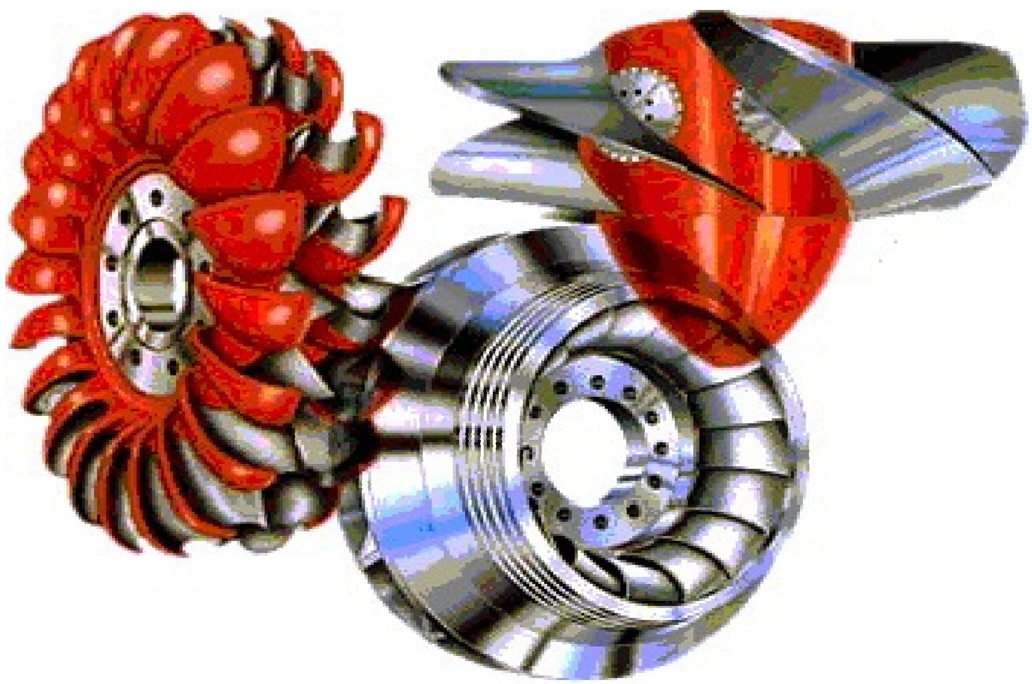


Figure 7.

The purpose of a turbine is to converts energy in the form of falling water into rotating shaft power. The selection of the best turbine for any particular hydro site depends on the site characteristics, the dominant ones being the head and flow available. Selection also depends on the desired running speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in the selection. All turbines have power-speed design characteristics, as they will tend to run more efficiently at a particular speed, head and flow combination. Turbines can be classified as high head, medium head or low head machines.

Turbines are grouped under the following two headings: impulse turbines and reaction turbines, as shown in the table below.

	High Head	**Medium Head**	**Low Head**
Impulse Turbines	**Pelton Turgo Multi-Jet Pelton**	**Cross-Flow/ Banki Multi-Jet Pelton Turgo**	**Cross-Flow/ Banki**
Reaction Turbines		**Francis**	**Propeller Kaplan**

Table 1.

The advantages of reaction turbines include:

- High efficiencies;
- Excellent power output at low heads;
- Numerous designs that provide easy tailoring to specific installations
- The flexibility of choosing either horizontal or vertical installation.

The disadvantages of reaction turbines include:

- Efficiency at specified heads and discharges but inefficiency when these vary;
- The need for accuracy in installation design;
- The possibility that cavitation will occur;
- The potential that non-uniform forces will destroy the runner;
- Very strict design tolerances;
- Costly civil works
- High manufacturing costs.

The advantages of impulse turbines include:

- Low water discharge requirements;
- The efficient use of high heads;
- Small physical size yet high power output;

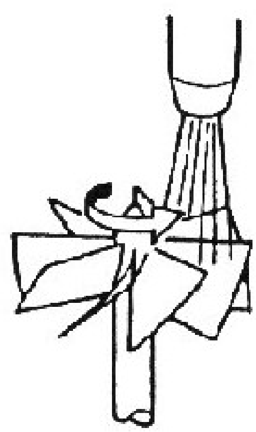
- High efficiencies;
- Simple design;
- Simple civil works;
- Low maintenance;
- Low cost; and
- Low labour input.

The disadvantages of impulse turbines include:

- Poor power output under low heads;
- The possibility of increased wear and tear due to operation at high speed;
- Very strict manufacturing specifications for other than crossflow
- The complexity of regulating the speed of the turbine.

Impulse turbines.

Impulse turbines derive their power from a jet stream striking a series of blades or buckets. A distinct feature of an impulse turbine runner is that it operates in air.



The momentum of a high-speed water jet turns impulse turbines.

Figure 8.

Pelton Turbine.

Figure 9. Figure 10.

The Pelton wheel is probably the best known of the tangential flow impulse turbines. Invented by a Californian mining engineer, it has changed little in the last hundred years. It is efficient over a very wide range of flows but at lower heads the speed is a bit too low for convenient belt drives. The Pelton wheel is used where a small flow of water is available with a 'large head'. It resembles the waterwheels used at water mills in the past. The Pelton wheel has small 'buckets' all around its rim (Figures 9, 10). Water from the dam is discharged from one or more nozzles very high speed hitting the buckets, pushing the wheel around (Figure 11). The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet (Figure 12). The cutaway on the lower lip allows the following bucket to move further before cutting off the jet propelling the bucket ahead of it and also permits a smoother entrance of the bucket into the jet.

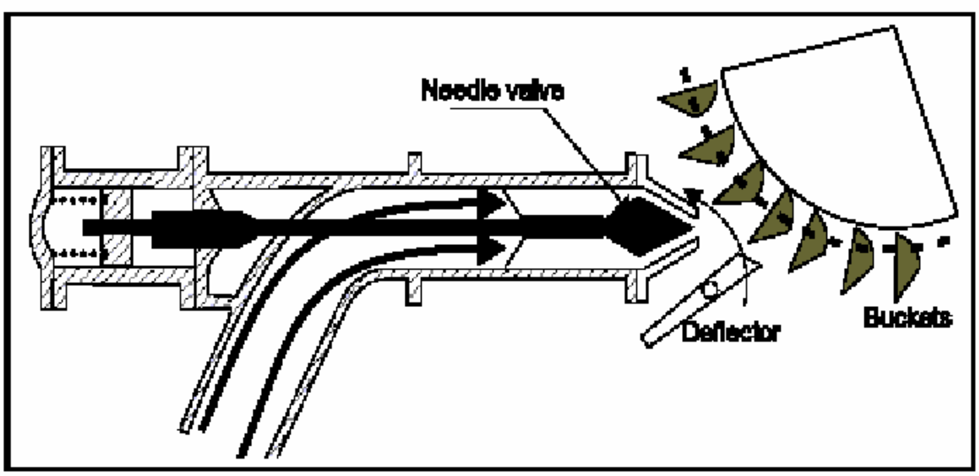


Figure 11.

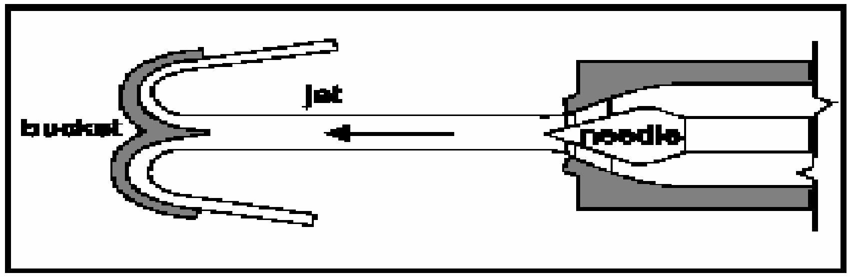


Figure12.

Having two or more jets enables a smaller runner to be used for a given flow and increases the rotational speed. The required power can still be attained and the part-flow efficiency is especially good because the wheel can be run on a reduced number of jets with each jet in use still receiving the optimum flow.
Two Pelton Wheels can be placed on the same shaft either side by side or on opposite sides of the generator. This configuration is unusual and would only be used if the number of jets per runner had already been maximised, but it allows the use of smaller diameter and hence faster rotating runners (Figure 13).

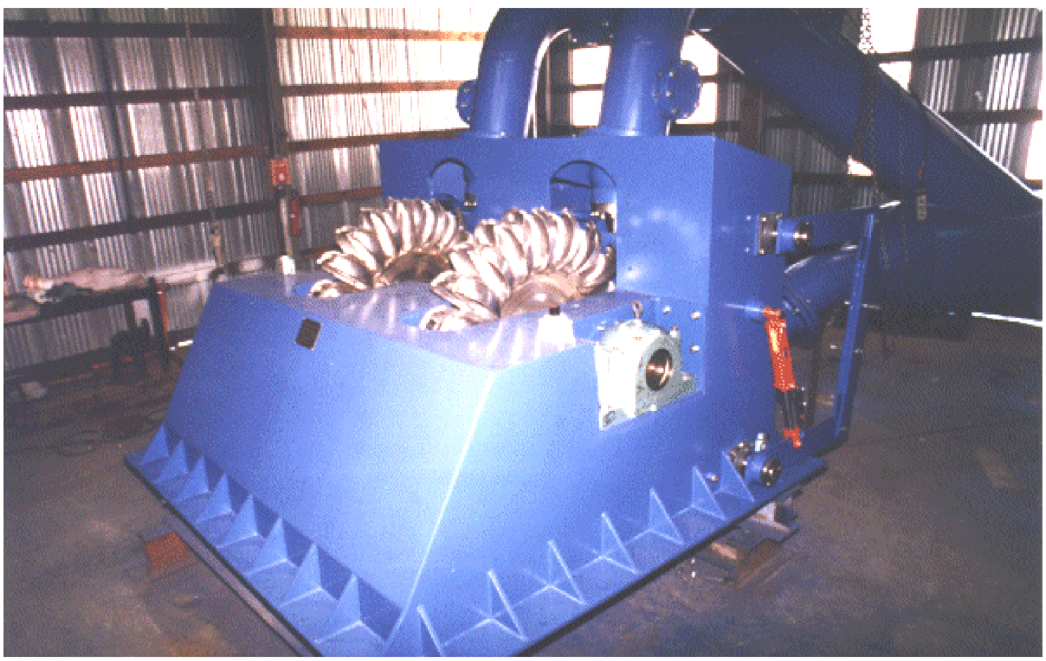


Figure 13.

Turgo Turbine.

Figure 14.

Figure 15.

Figures 16.

Eric Crewdson invented the Turgo impulse in 1920; it is used for heads of 12 meters or more. The Turgo Impulse design allows a large water jet to be directed at an angled runner blade, usually approximately 20°, giving the turbine a higher specific speed, and therefore a smaller physical size (Figure 17). The rugged design is particularly suited to schemes having abrasive solids in suspension.

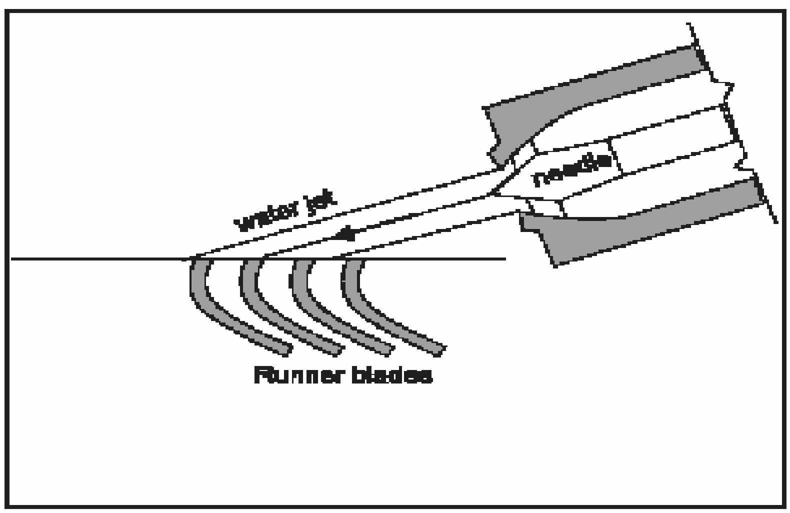


Figure 17.

Because power output from the turbine can be regulated using rapid acting deflectors without affecting the water flow, the Turgo Impulse Turbine has been applied on many irrigation and water treatment schemes where continuity of water flow is essential. It has several disadvantages. Firstly it is difficult to fabricate since the buckets or vanes are more complex in shape and overlap, it also experiences axial loading on the runner that has to be quelled by a suitable bearing on the shaft, usually a roller bearing.

Crossflow Turbine.

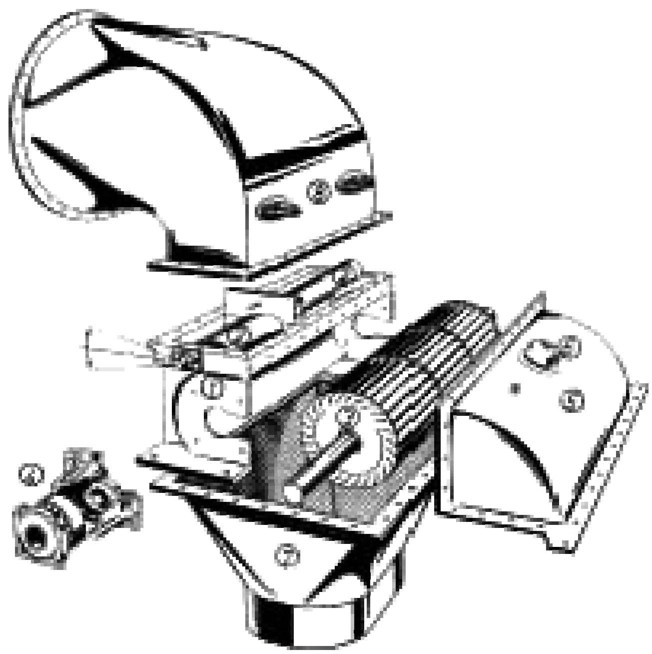


Figure 18.

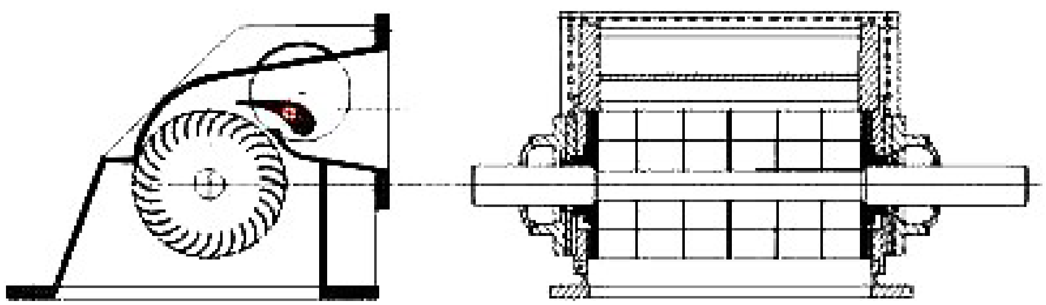


Figure 19.

The Crossflow Turbine actually had two inventors, firstly A. G. M. Michell, an Australian engineer who obtained a patent for it in 1903. The Hungarian Prof. Donat Banki later invented the turbine independently in Germany in 1919 while working with Ganz in Budapest, where it became known more widely between 1917 and 1919 through a series of publications as the "Banki Crossflow Turbine" or as it's sometimes called the "Mitchell Crossflow Turbine". The present more widespread use of the cross-flow turbine is largely due to the efforts of the Ossberger company in Weissenburg, Bavaria, (Figure 18, 19) contributing a number of original ideas to Mitchell's design, based on their own research work, and world patents cover the various stages of this steady development.

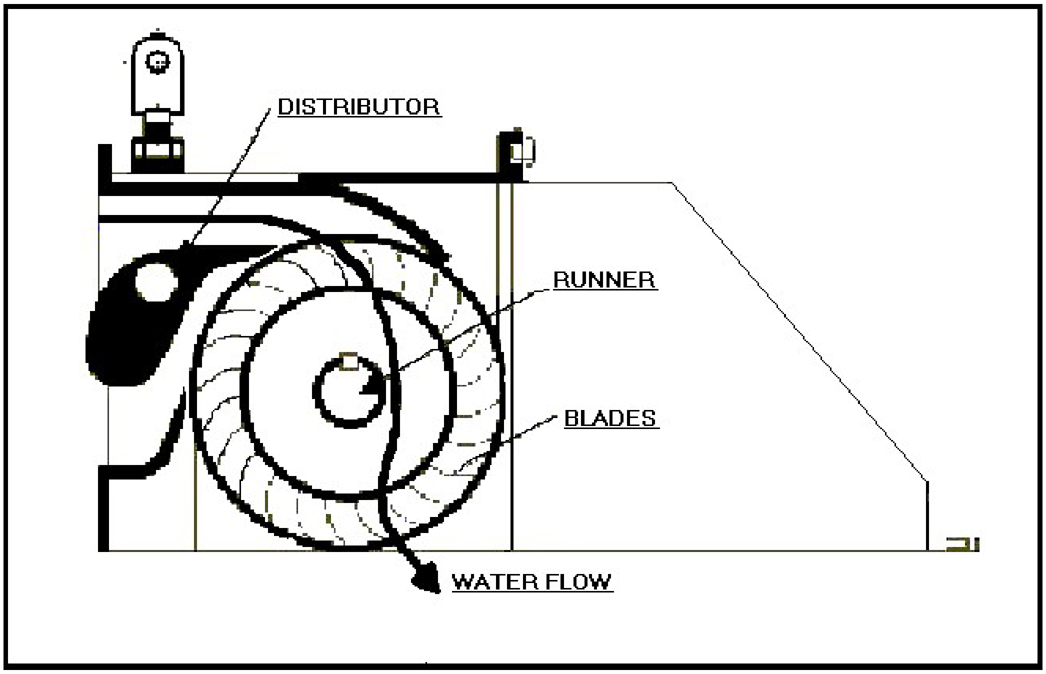


Figure 20.

In the crossflow turbine the water, in the form of a sheet, is directed into the blades tangentially at about mid way on one side. The flow of water "crosses" through the empty centre of the turbine and exits just below the centre on the opposite side. Thus the water strikes blades on both sides of the runner. (Figure 20) It is claimed that the entry side contributes about 75% of the power extracted from the sheet of water and that the exit side contributes the remainder. The main characteristic of the cross-flow turbine is that it uses a broad rectangular jet of water that travels through the turbine only once but travels across each runner blade twice, once in each direction. This machine is therefore a turbine with two velocity stages, the water filling only part of the runner at any one time. As far as energy utilization is concerned, the use of two velocity stages provides no immediate advantages. The arrangement represents, however, a very skilful design, which removes the water in a simple manner, after it has passed through the runner without producing any backpressure. The addition of a draft tube to the cross-flow turbine represents an idea implemented by Ossberger to enhance the turbine's performance. Ossberger use an air valve in the draft tube to help regulate the head by introducing air in the draft tube.

Furthermore, this flow mechanism makes the turbine self-cleaning. During the first strike, suspensions and impurities, which reach the turbine, are pressed against the blanket of the runner. During the second strike, after a half rotation these would then be washed out. This mechanism contributes to the long functioning period and reliability of the turbine.

They are generally built as multi-cell turbines, where the runner can be sectioned off to allow the smaller cell to utilise small water flows and the larger cell to use medium water flow and when both cells are opened together they utilise the full flow of the water. (Figure 21)

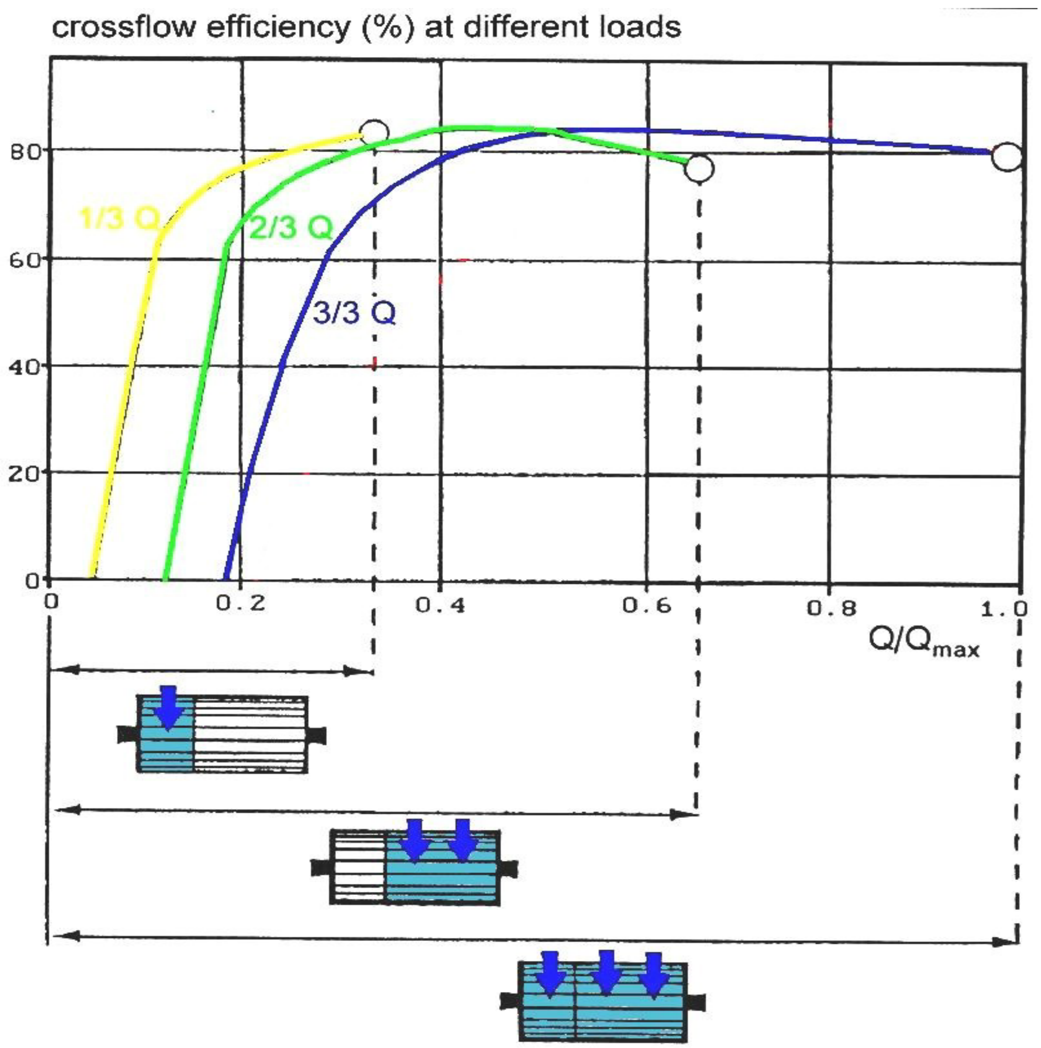
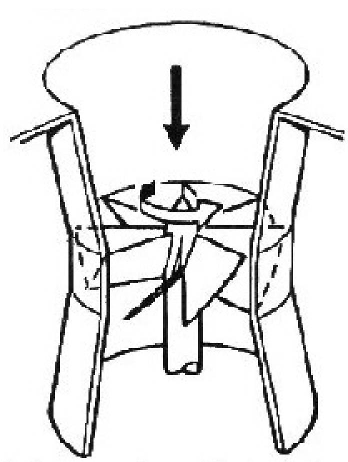

crossflow efficiency (%) at different loads
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1.0
Q/Qmax
1/3 Q
2/3 Q
3/3 Q

Figure 21.

Reaction Turbines.

Reaction turbines use both velocity and pressure forces to produce power. Consequently, large surfaces over which these forces can act are needed. Also, flow direction as the water enters the turbine is important. They are distinguished from impulse type turbines by having a runner that always functions within a completely water filled casing.



Hydrodynamic lift forces acting on the runner blades turn reaction turbines.

Figure 22.

Francis.



Figure 23. Figure 24. Figures 25.

The Francis turbine is used where a large flow and a high or medium head of water is involved. The Francis turbine is also similar to a waterwheel in that it looks like a spinning wheel with fixed blades in between two rims (Figures 23, 24, 25). This wheel is called a 'runner'. A circle of guide vanes surrounds the runner and controls the amount of water driving it. Water is fed to the runner from all sides by these vanes causing it to spin. Francis turbines are radial flow reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. Francis turbines include a complex vane arrangement surrounding the turbine itself (also called the runner) which can be seen in Figures 26, 27. Water is introduced around the runner through these vanes and then falls through the runner, causing it to spin. Velocity force is applied through the vanes by causing the water to strike the blades of the runner at an angle. Pressure forces are much more subtle and difficult to explain, and in general, the flowing water causes pressure forces. As the water flows across the blades, it causes a pressure drop on the back of the blades; this in turn induces a force on the front, and along with velocity forces, causes torque.

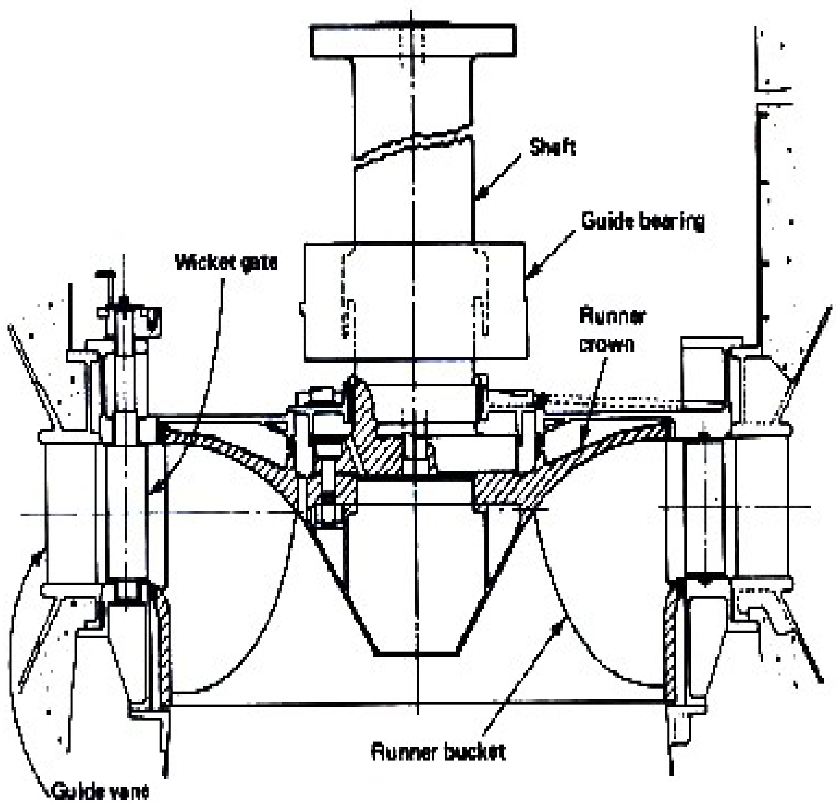


Figure 26.

Francis turbines are usually designed specifically for their intended installation; with the complicated vane system, they are generally not used for micro hydropower applications. Because of their specialized design, Francis turbines are very efficient yet very costly.

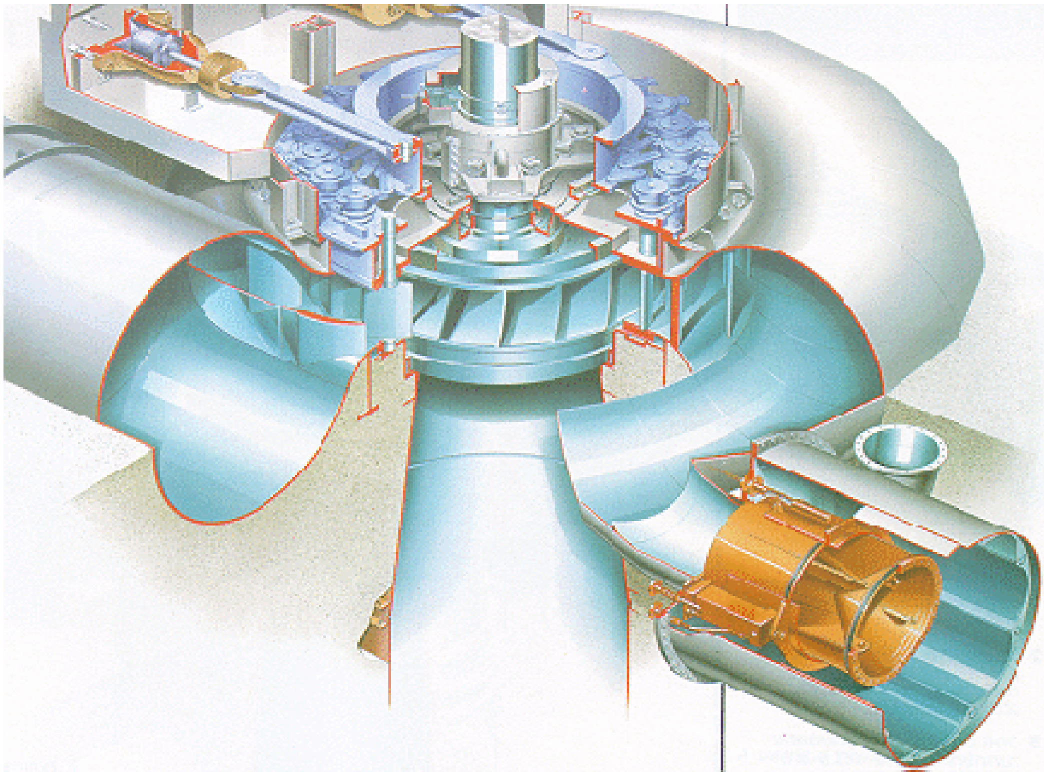


Figure 27.

Propeller.

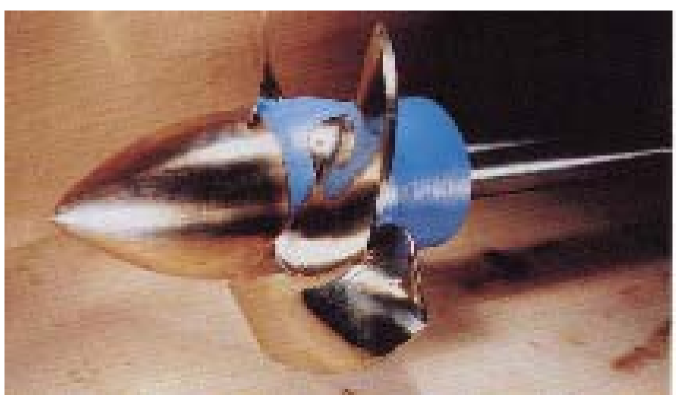


Figure 28.

Propeller type turbines are designed to operate where a small head of water is involved. These turbines resemble ship's propellers (Figure 28). The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube (Figures 29, 30). The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates ("wicket gates") just upstream of the propeller.

Figure 29. Figure 30.

This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed. The part-flow efficiency of fixed-blade propeller turbines tends to be very poor. However, with some of these the angle (pitch) of the blades can be altered to suit the water flow.

The Propeller turbine in its simplest form is like a ship's propeller running in a tube. As the water flows through the propeller rotates. Special coatings are used for increased corrosion and abrasion resistance. For lowland and old mill sites the propeller turbine is ideally suited since it is compact and fast running even on low heads.

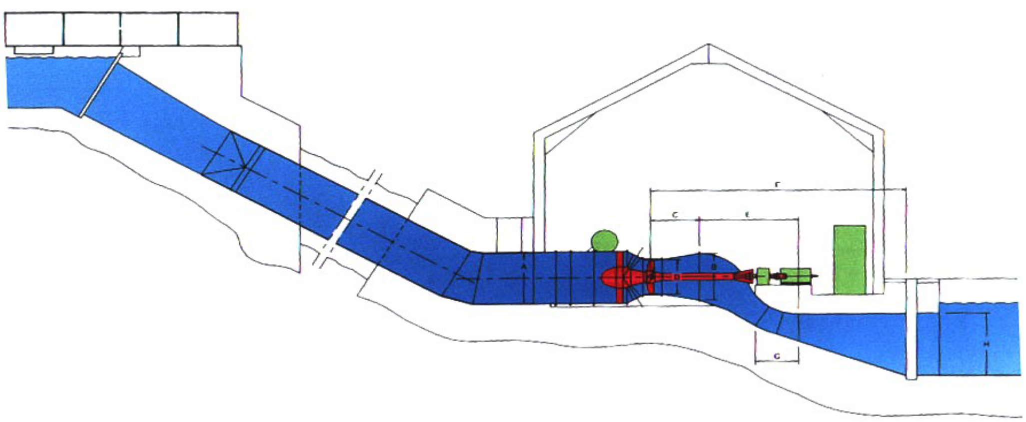


Figure 31.

The angle of the bend can be between 30 and 90 degrees but standard layouts are either 45 or 90 degrees (Figure 31). A penstock can be used for higher heads up to 15 metres and the turbine runner 'setting' can be lowered to avoid cavitation by inserting a length of parallel tube between the bend and the turbine casting. Existing civil works associated with old mills, navigation locks or irrigation structures often lend themselves to the installation of this type of turbine. The Siphon layout is used for small turbines and axial-flow pumps, where the unit is installed 'Over a Wall'.

Kaplan.

Figure 32.

Figure 33.

Figures 34.

Large-scale hydro sites make use of more sophisticated versions of the propeller turbines (Figures 32, 33, 34). Varying the pitch of the propeller blades together with wicket gate adjustment enables reasonable efficiency to be maintained under part flow conditions. For good efficiency water needs to be given some swirl before entering the turbine runner, where the swirl is absorbed by the runner and the water that emerges flows straight into the draft tube. Methods for adding inlet swirl include the use of a set of guide vanes mounted upstream of the runner with water spiralling into the runner through them. Another method is to form a 'snail shell' (Figure 37) housing for the runner in which the water enters tangentially and is forced to spiral into the runner. Such turbines are known as variable pitch or Kaplan turbines. Water flows into the turbine casing and passes the runner blades through to the draft tube then to the tailrace (Figures 35, 36).
Various configurations of Kaplan turbines exist and can be mounted horizontally, vertically or angled in the same way as propeller turbines. This type of turbine has a high efficiency over a wide range of heads and outputs and has a high specific speed. (Ref 7)

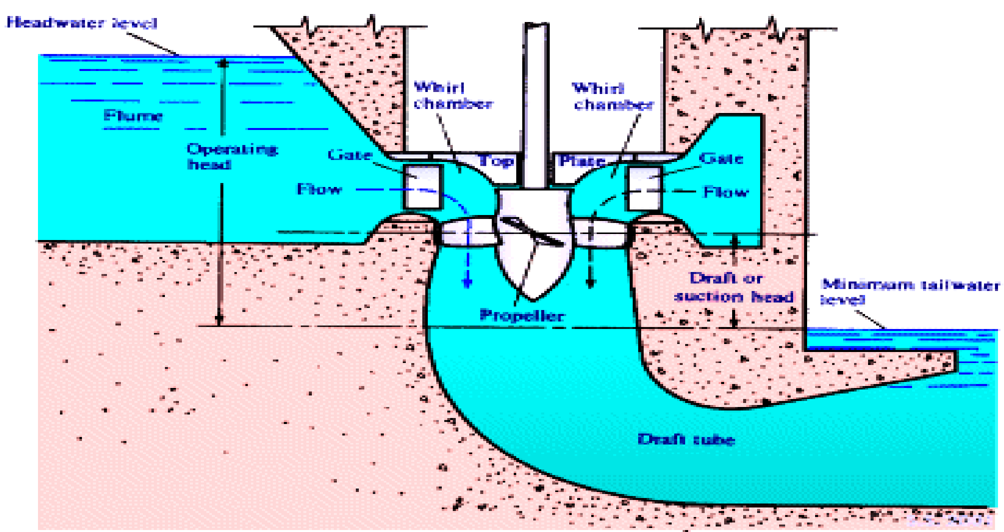


Figure 35.

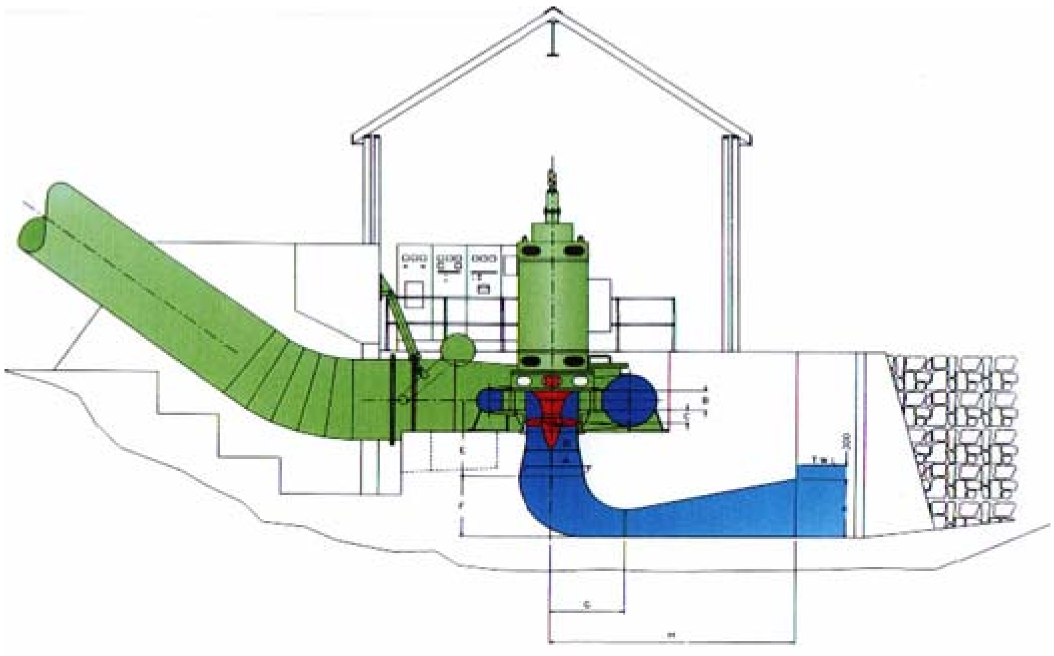


Figure 36.

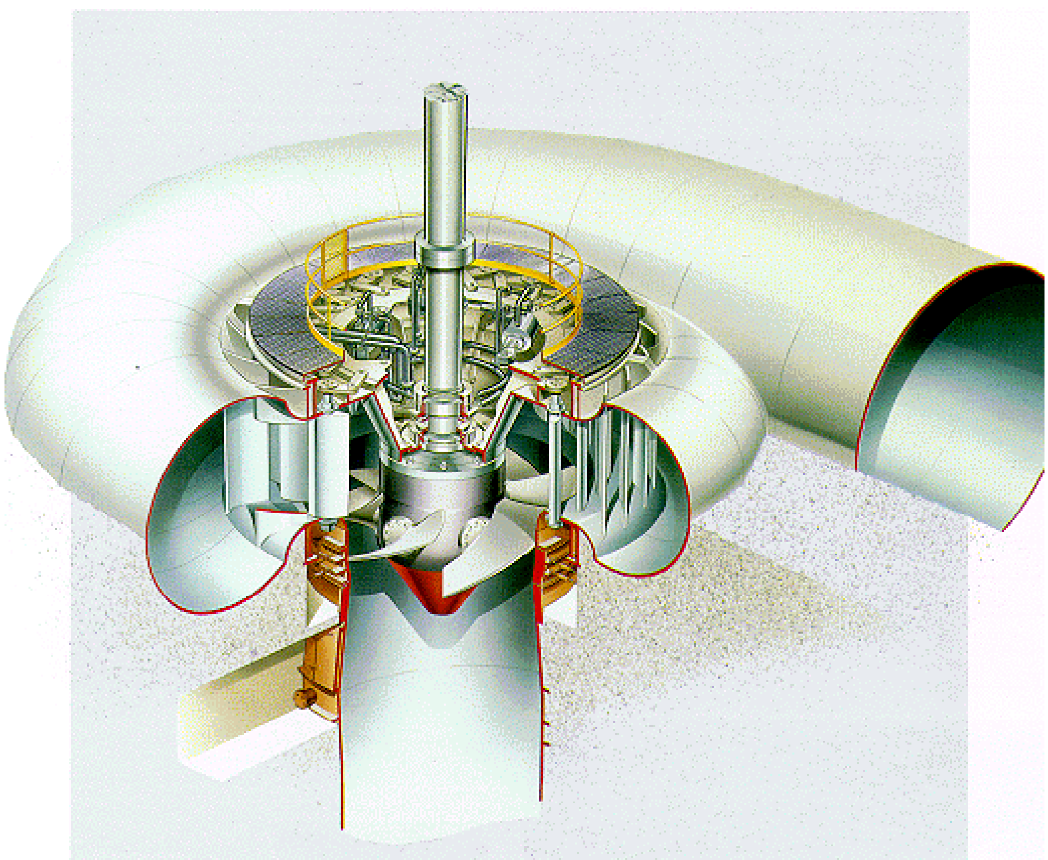


Figure 37.

Turbine Efficiency.

A significant factor in the comparison of the various turbine types is their relative efficiencies both at their design and at reduced flows. Typical efficiency curves are shown in Figure 38.

An important note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Francis turbine falls away more sharply if run below half their normal flow, as does the Crossflow turbine, but the multi-celled Crossflow turbine retains a high efficiency but with a reduced output. Most fixed pitch propeller turbines perform poorly except above 80% of full flow.

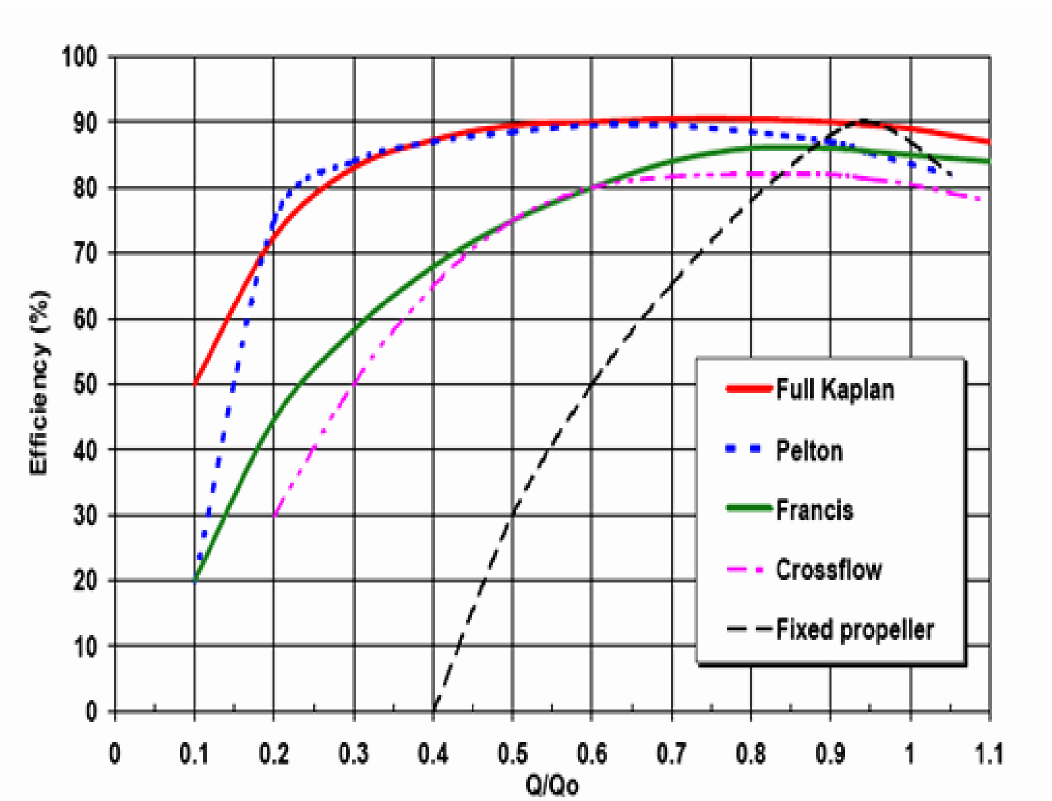


Figure 38.

Governors.

The turbine usually drives the generator through either a gearbox, through a pulley and belt system, or directly using shock-absorbing brushes. The governor modulates the generator speed in order to control the electrical frequency of generation. The governor does this by detecting the change in the electrical load output of the generator, and then altering the flow of water into the turbine using valves. They can be linked to a level switch situated in the storage reservoir so that the flow through the turbine is also dependent on the level, and hence the water flows. Governors can either be mechanical (Figure 39) or electrically operated. (Ref 4)

Figure 39.

Generators.

Generators can be either of a **Synchronous** or **Asynchronous** type.
In a synchronous generator the frequency of the electricity produced is directly related (i.e. synchronous) with the rotational speed of the shaft. Therefore at 50 Hz generation, the shaft rotates at a fixed sub multiple of 50 Hz, depending on the gearing ratio. This type of generator must be designed to withstand the high runaway speeds that can sometimes occur during hydroelectric turbine system faults. They often have to be specially designed, thus increasing their cost considerably. These generators come in single phase (for small systems) and three phase (for larger outputs), and the single-phase type is more commonly known as an alternator. (Ref 17)
Within induction generation or asynchronous generation a motor is used as a generator. This type of generator is simple in construction containing fewer parts, making it cheaper and more reliable than synchronous generators. It can withstand 200% runaway speeds without harm, and has no brushes or other parts to require maintenance. In this type of generator power enters the grid when the speed of rotation has a frequency greater that that of the grid. This is called slip. Usually systems are designed for maximum power to be entering the grid at a slip of about 10%. Power is actually drawn from the grid to provide the magnetic field until running speed is achieved, when power is then produced. (Ref 17) When operating in conjunction with a large power grid, a standard single or three-phase motor may be used as a generator. Hydro power plants designed as asynchronous installations are usually more economical than synchronous generating sets. In the past, asynchronous plants were equipped with minimal equipment.

Civil Works.

Dams.

Dams are classified into a number of different categories according to hydraulic design, use and materials comprising the structure. (Ref 18)

Figure 40. Storage Dam, Grande Dixence Dam, Switzerland.

Storage dams are constructed for irrigation, drinking water supply and hydroelectric power generation (Figure 40). Also such facilities are used in flood control, and all dams must be designed to withstand the high water levels and surges of a 100-year flood occurrence, and the amount of reservoir seepage that may be permitted.
Diversion dams were traditionally built to provide head for diverting water flow into canals or pipelines. This dam has two classification types, overflow and non-overflow.
An **Overflow** dam is designed to allow the water to cascade over the crest of the dam, in a controlled manner, as to keep the reservoir behind the dam at a minimum level. Due to this the materials used in the construction of an overflow dam need to be of suitable resistance to water erosion, such as steel, concrete, masonry and in some cases even wood (Figure 41).
Non-overflow dams have spillways to prevent over the reservoir overflowing (Figure 42). This type of dam enlarges the choice of materials and designs that can be used, often utilising composite structures, using rock and earth filling in their construction.

Figure 41. Overflow Dam - Pen-y-Garreg Dam, Elan Valley, Wales.

Figure 42. Non-overflow Dam - Contra Dam, Switzerland.

In the construction of modern dams concrete is used extensively and concrete dams have two distinct types, the gravity and arch. (Figures 43, 44) The concrete gravity type is used mainly in the small-scale reservoirs, whereas the concrete arch is used predominantly in large-scale water impoundment. The arch style is easily recognised due to its dramatic shape and size

Figure 43. Concrete Gravity Type - Birecik Dam on Euphrates River, Turkey.

Figure 44. Concrete Arch Type - Hoover Dam on Colorado River, U.S.A.

The most common dam construction within the UK is the earth fill dam, using cheap, readily available local materials that require minimum processing. The foundations required in earth fill dams are not as stringent as for other types of dams, (Ref 11) often using rock on the waterside and face side of the dam as an erosion barrier and to provide extra strength the structure (Figure 45). Due to the materials used, adequate spillways must be provided to prevent surges and overflows.
Rock fill dams use rock of all sizes to provide stability and an impervious membrane to provide water tightness. (Ref 11) The membrane may be an upstream facing of impervious soil, like clay, a concrete slab or steel plates. Like the earth fill dams, rock fill dams are subject to damage or destruction by water erosion caused by overflow waters and so must be provided with suitable spillway capacity.

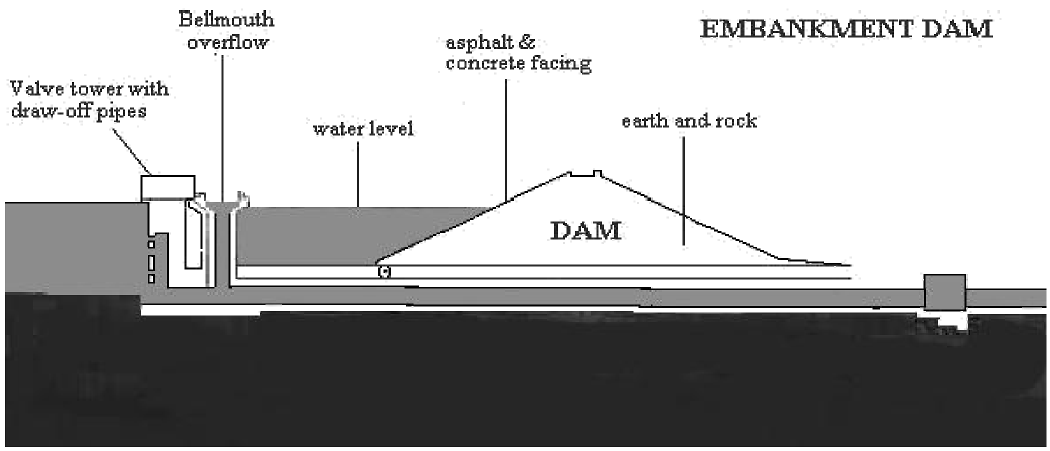


Figure 45.

Canals and Channels

The canal or channel – also called a ‘leat’ or ‘lade’ – is a method of diverting the water from a river or stream to the intake of the turbine. Various types of canal that are in use these being:

- A simple earth unlined channel.
- The earth excavation where the channel is lined and sealed using clay or cement slurry.
- Masonry linings.
- Concrete channels.
- Flumes and aqueducts made from galvanised sheet steel, pipes or wood.

Sealing is the application of a thin layer of material with no structural strength and serves only to reduce friction and leakage. Lining is any method of adding structural strength to the channel walls. Earth infills are also used instead of aqueducts, and these usually carry a pipeline across depressions in the terrain. (Ref 17)

Forebay Tank or Surge Tank.

A forebay tank is required for canal headrace schemes to spill surplus water and provide small balancing storage for the turbine on start-up and during rapid load changes.
The diverted water from the stream or river may contain harmful abrasives such as sand and peat in suspension, which would cause extensive and expensive damage to the turbine plant. The use of a forebay limits the exposure of such suspensions to the turbine. The harmful particles are removed by flowing the water through a silt tank to allow the water and the contained particles to settle out. Larger materials entering the forebay, such as leaves, twigs, branches and other floating debris are stopped entering the pipeline intake to the turbine by using a trash screen. Trash screens come in all shapes and sizes with varying filter sizes. There are elaborate mechanical self-cleaning or simple galvanised screens, able to be hand cleaned during autumn months. Careful design of the forebay tank is essential to ensure the entrance to the penstock will always be fully submerged. The excess water exits over a spillway in the forebay, away from the pipeline area and is disposed to a watercourse.

Pipeline or Penstock.

The pipeline is probably the most expensive part of any hydroelectric development and is therefore prudent in putting some effort to minimise the length and cost. The pipeline itself must be able to tolerate sudden changes in water pressures, and to resist adequately internal and external forces, such as the changing weather conditions for the sited area. Due to these factors pipelines are subject to British Standards classifications. Ductile cast iron, glass fibre, reinforced plastic and asbestos cement are subject to BS3601. In most cases the pipeline or penstock is test to its maximum pressure when first installed. (Ref 1)
As all materials have various advantages and disadvantages the choice of pipeline material is very important for a long and reliable working lifetime. Penstocks can be constructed from a variety of materials such as UPVC, medium density (MD) and high density (HD) polyethylene (PE), ductile iron, mild steel and concrete. (Ref 17)
UPVC is widely used in micro-hydro because it is relatively cheap and is widely available in a variety of sizes from 25mm to 500mm in diameter. It is suitable for high-pressure use, has good friction loss characteristics and is corrosion resistant, but suffers from being fragile in the respect to low temperatures and damage from falling rocks or trees.
Polyethylene pipes range in sizes from 25mm to 1m in diameter and are very expensive. It is the most versatile of the materials as it is flexible and can be coiled, this making it very advantageous when used in underground pipelines. An alternative to polyethylene pipes is ductile iron, which is cheaper, and quite a popular material in the construction of micro-hydro applications. Usually coated internally with cement, this reduces friction losses and gives better corrosion resistance. This practise does make the pipes heavy and cumbersome to install and are bolted together by a flexible seal or a flanged end plate.

The use of mild steel is used for its cheapness and is easily available in a wide range of diameters and pipe wall thicknesses. It is resistant to external damage from falling rocks and trees, but when buried suffers from long term corrosion and needs to be protected by painting or some other form of anti-corrosion coating to give an expected life of 15 years plus. Mild steel piping is heavy but can come in convenient lengths, easier for movement and is jointed either by welding or bolted flanges.
Concrete penstocks have many disadvantages; these being that concrete cannot tolerate moderate pressures and are brittle causing easy fracturing. Movement and the laying of concrete pipes is difficult due to heavy weight, and can be inadequately jointed due the rubber o-rings used, which require precise alignment for a tight seal.

Trash screens.

The trash screen or 'trash rack' filters out river-borne debris before it reaches the turbine. It is an extremely important component of the whole scheme, and can be one of the more expensive items. The large majority of operating problems and maintenance costs can be traced back to the screening system so investment in a robust design will pay for itself in the long run.
The standard screening solution, which has been used since the days of waterwheels, is to place a rack of bars in front of the intake, with the bars spaced so that a rake can be used to drag the accumulated debris up to the top of the screen (Figure 46).
The screen is a hindrance to the flow and introduces a slight head loss. Therefore the bar-spacing should be the maximum that will still trap debris large enough to damage the turbine. (Ref 25)

Figure 46.

Rakes (trash screen cleaners) (Ref 25)

A robotic rake. These come in a variety of designs, but usually involve one or more rakes operated by a hydraulic ram. Some designs require only a single rake which can index along the screen; otherwise two or more rakes can operate side by side (Figure 47). These systems are usually very robust, partly because they can keep their drive mechanisms out of the water at all times. Their main disadvantages are the visual presence of the equipment and the slightly greater health and safety risk posed by unattended operation of the equipment.

Figure 47.

A rake-and-chain cleaner. A bar is moved up the screen by a chain drive at each end (Figure 48). The bar deposits the collected debris in a channel running the length of the screen. The channel can be flushed clean by a water supply (pumped if necessary), washing the debris towards a side spillway.

Figure 48.

The grab-and-lift cleaner. A robust alternative to the robotic rake, a single set of 'jaws' indexes along the screen and lifts the material straight into a skip (Figure 49).

Figure 49.

Coanda screens. These are applicable only for high and medium head schemes, require no raking because they utilise the Coanda Effect to filter out and flush away debris and silt particles, allowing only clean water into the intake system. Precisely positioned, finely spaced horizontal stainless steel wires are built into a carefully profiled screen which is mounted on the downstream face of the intake weir. Clean water is collected in a chamber below the screens, which is connected directly to the turbine penstock (Figure 50).

Figure 50.

Chapter 4.

Legal and Planning issues.

Legal.

There are a considerable amount of Governmental Acts and local authorities' guidelines that have to be taken into consideration, and any proposed hydro electric scheme would be considered by the local and federal authority if informal and formal consultations where sought through the development stages of the process.

Planning.

Any hydroelectric development that is rated above 1 MW must have the Secretary of State's permission of approval for the construction and must be developed with the consultation of the Secretary of State's Fisheries Committee as well as the local planning authority. The planning department would indicate whether planning permission is required and also whether other related procedures, such as building regulations approval or the submission of an environmental statement are necessary.

Natural and cultural heritage.

Hydro developments are often located in rural areas, some parts of which are valued for their nature conservation interest. Each proposal should be considered to determine the degree of sensitivity. This will in part be affected by the fit with the landscape, and effect on natural and cultural heritage features including the potential impact on wild land. Sensitive and imaginative design of the scheme and ancillary buildings and facilities can successfully minimize some effects, but will not necessarily be an alternative for careful initial site selection. Early dialogue with SNH is recommended. (Ref 24)

Impoundment.

Two legal Acts that must be adhered to, if any scale of water is impounded, are the Water Resources Act 1963 and the Reservoirs Act 1975. Within the Water Resources Act 1963 a licence must be granted if the proposed hydroelectric scheme utilises the impoundment of water. If the impoundment of water is greater than 25,000m³ and is above the local ground level, then under the Reservoirs Act 1975, the reservoir must be designed and periodically inspected by a qualified engineer.

Licenses to generate and supply.

Under the Electricity Act 1989 a license to generate is not required of those exporting less than 10 MW from a single generating station, or of those providing less than 10 MW to a single consumer, or related consumer on the same site. However anyone wishing to generate more than 1MW must have a generating licence from the Secretary of State for Scotland, under the terms of the above Act. A license to supply is not required of persons supplying less than 500kW, nor is it required from ‘own generation’, which is defined as that where more than 51% of the output of a generating station is provided to either a single consumer, or related consumers on the same site as that station. (Ref 17)

Environmental Impact.

The impact of a hydroelectric scheme on the local and overall environment must be assessed prior to any commencement of the scheme, and is an important factor that should be included in any preliminary feasibility study. An important factor is the amount of water that can be abstracted from the river or stream, in order to supply a sufficient flow of water downstream, in which to adequately support flora and fauna in a healthy, oxygenated supply. This is known as the compensation flow.
The use of local readily available materials such as stone and wood should be used in the tradition and style of the existing buildings so that the visual impact any of the construction of the hydro scheme must be kept to a minimum. Camouflaging of any buildings, penstocks and small dams can be done using scrubs and trees that are common in the area and their use should reflect the same pattern and density as the local surroundings, as not to draw attention to the site.
Access roads used in the construction of the site must be routed, designed and managed sensitively, and for a hydro scheme a single track may be used, possibly a temporary floating or rafted track which can be partially or fully removed after construction and the vegetation reinstated. (Ref 15)
Acoustic noise from the turbine, generator and transformers can be detrimental to a hydro scheme and the use of noise deadening materials is required to minimise the noise from such facilities.
If possible the penstock pipeline and all form of cabling should be buried at the legislated depth and clearly marked or plotted to easy maintenance and quick identification for future site development. Some of the problems associated with a hydro scheme can be seen below in Figure 51.

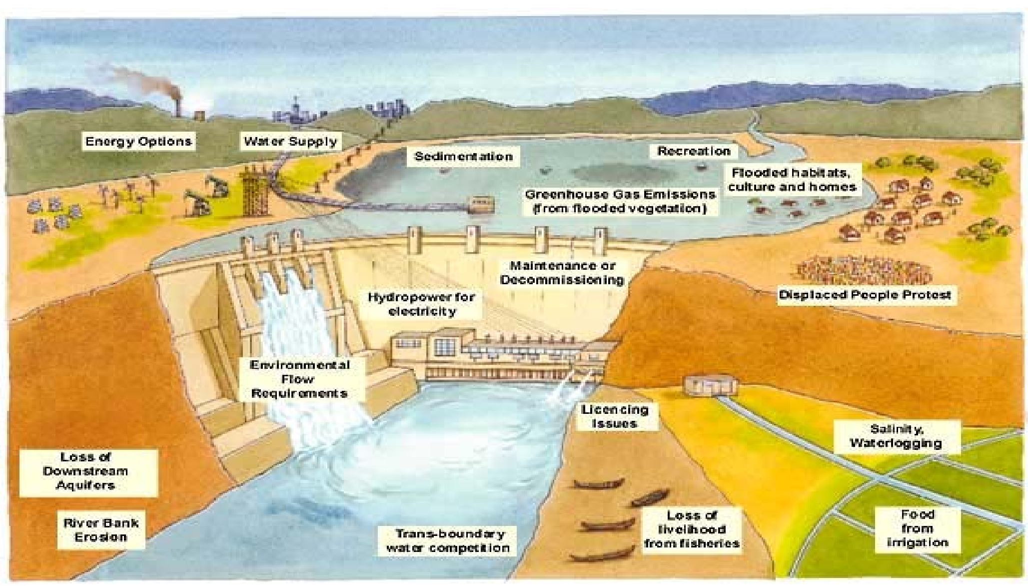


Figure 51.

Water Regime.

The Scottish Environment Protection Agency (SEPA) has a duty to promote the cleanliness of controlled waters and to conserve, so far as practicable, water resources. Consultation with SEPA should, therefore, be undertaken for all proposed hydro developments, both for small-scale projects covered by planning legislation and larger schemes authorized under the Electricity Act 1989. The EU Water Framework Directive requires a system of abstraction and impoundment control. (Ref 24)

Fisheries.

For each project the requirements of Salmon and Freshwater Fisheries Act for sluice gates, gratings and fish ladders (Figure 52) must be met, under Sections 12 and 15 of the Act.
Care is required with the protection of all species of fish, particularly migratory species such as salmon and sea trout. Consultation with the local District Salmon Fishery Board is advised when a hydro scheme is proposed and throughout the planning process. (Ref 24)

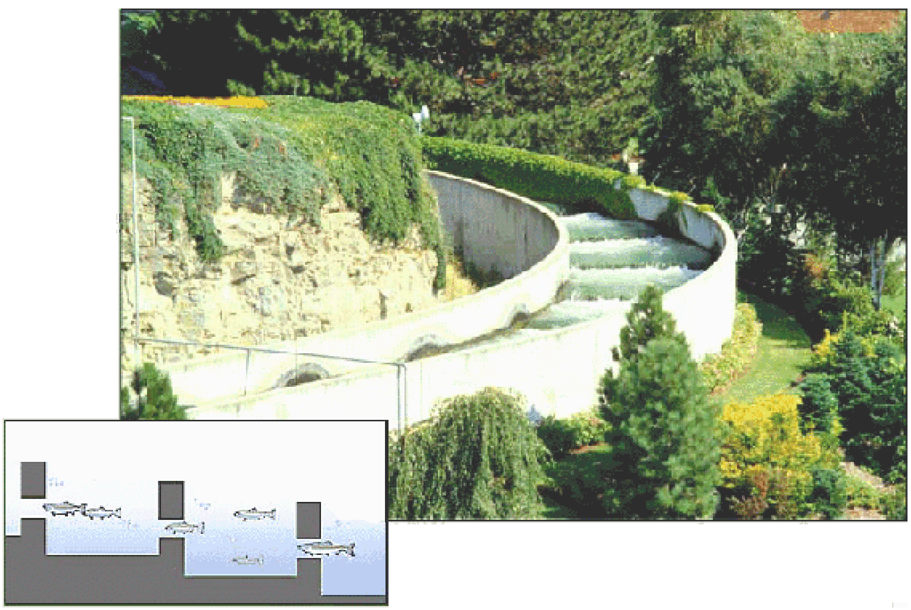


Figure 52.

Aquatic Habitats and Species.

Different species will be affected in different ways, some of which such as the freshwater pearl mussel are protected under the EC Habitats Directive. Discussion with SNH will provide guidance on the species, which require to be considered in a particular location. Experience has shown that by careful design it is possible to reconcile hydro schemes with conservation of the natural heritage. (Ref 24)

Chapter 5.

Cost and Economics.

Financial Evaluation.

Hydro schemes are high cost development, but recently experience has shown that hydro schemes have a life expectancy of up 30 years or more. They are also a risk, as most of the cost must be met at the start of the project.

When all the desired technical equipment is chosen, it should be costed to provide an assessment of the total capital costs. These should cover all possible outgoings such as:

- Dams and diversion weirs.
- Intake structures, trash screens.
- Automatic screen cleaning (if required).
- Channels, canals and tailraces.
- Forebay tanks
- Pipelines
- Turbines and generators.
- Powerhouse.
- Electrical protection and switchgear.
- Automatic flow control
- Transformers.
- Transmission.
- Access roads.
- Installation and commission of plant.
- Additional works, excavation, bank protection, etc.
- Engineering fees.
- Contingencies.

The price of each kWh produced by the hydro scheme needs to be determined, which allows the gross income calculation. Additional costs for the annual operation and maintenance should be taken into account. These should include:

- Rates.
- Adequate insurance indemnity, to cover all possible eventualities.
- Maintenance
- Regional electrical company charges, such as availability charge, use of system tariff, administration fees etc.

A 2% figure for operation and maintenance cost can be added to the total capital costs.
Knowing all the expenses of the hydro scheme development, the net income can be determined. Payback period of the hydro scheme is easily calculable, and is a common financial indicator of the economic feasibility. Payback period is used when the finances of such a scheme are seen in terms of fixed annual sums, which do not vary greatly year by year. Simple payback does

not take account of the depreciation of money over time of factors such as inflation and interest rates.

$$\textbf{Simple payback} = \frac{\textbf{Total Capital Cost}}{\textbf{Annual Revenue – Annual Expenditure}}$$

Discounted payback does, however, but to use this method it is necessary to establish an appropriate discount rate.
Present value (PV) can be found, knowing the constant annual sums arising in the future, given a discount or interest rate (r), multiplying the repeated future sum (the annuity) by the discount factor, for the number of years (n).

$$\textbf{PV= Net Annual Income} * \frac{(1 + r)^{n} - 1}{R^{*} (1 + r)^{n}}$$

The net present value (NPV) is the present value of the net earnings (PV), minus the project capital costs (C).

$$\textbf{NPV + PV – C}$$

The internal rate of return (IRR) is the discounted rate at, which NPV =0. The NPV of the project earnings might be for example £1500 at the discounted rate of 12%. If the discount rate is higher, the NPV is less. In this case a discount rate of 15% may show a NPV of zero. The project is therefore said to have an IRR of 15%.

Chapter 6.

Feasibility Study.

Site location.

The proposed hydroelectric scheme is located on a privately owned land estate called the Inverailort Deer Forest Estate; this estate is located next to the village of Inverailort, 37 kilometres due west of Fort William just south of the A830 road to Arisaig and Mallaig, depicted by the red circle on the map in Figure 53.

Image produced from the Ordnance Survey Get-a-map service. Image reproduced with kind permission of Ordnance Survey and Ordnance Survey of Northern Ireland.

Figure 53.

The Inverailort Deer Forest Estate covers some 50 km² of land; mountainous regions make up most of the land on the estate, which includes several mountain corries within its boundaries.

Within the Estate there is a sizeable area that has the potential but has not yet been exploited for hydroelectric power generation. One such area is known as Coire a' Bhùiridh, shown in Figure 54, and makes up a large part of the western area of the estate, and has the most potential for the existence of a hydroelectric scheme. As circled in Figure 54, the most noticeable feature of this corrie is the shape, almost amphitheatre like in appearance, with only one main stream outlet for the corries' drainage.

Ordnance Survey

Ordnance Survey of Northern Ireland

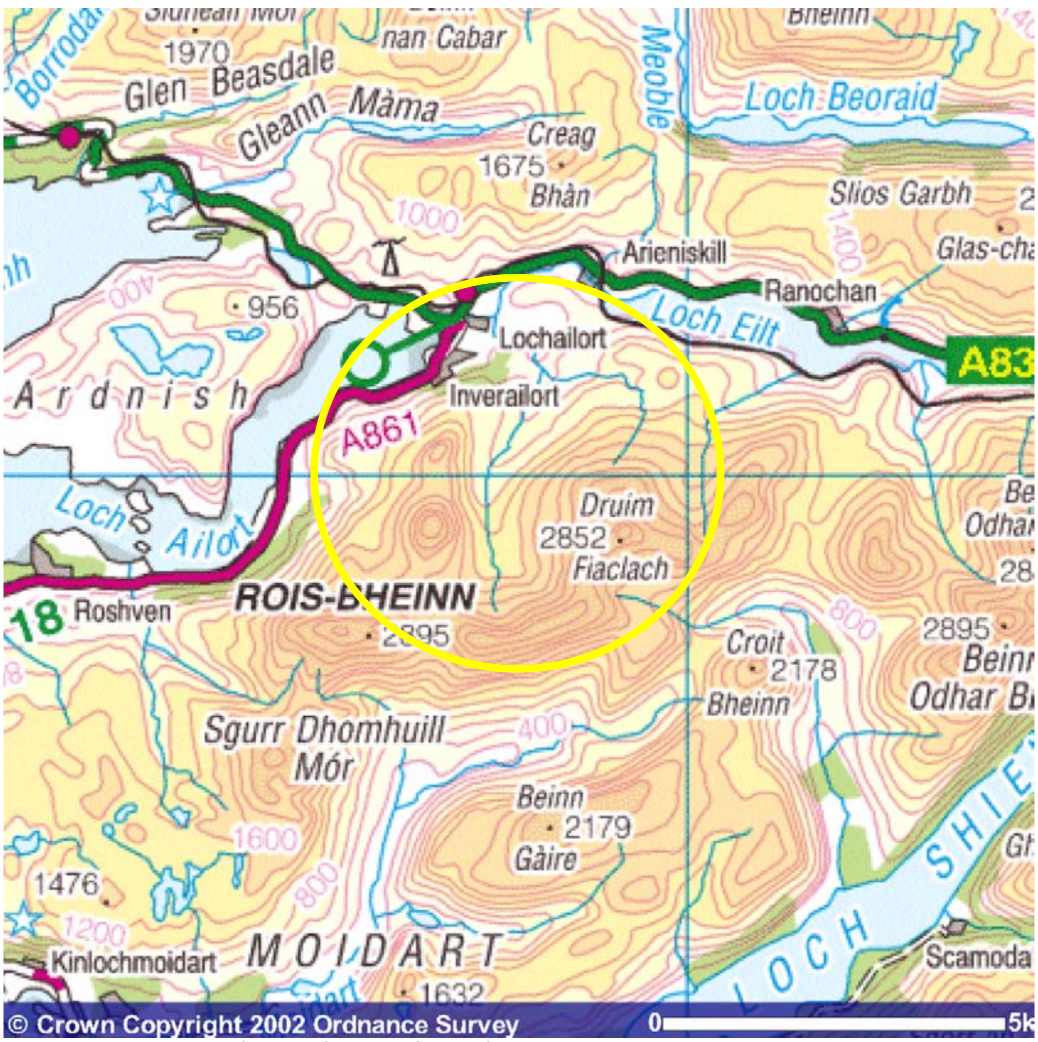


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Figure 54.

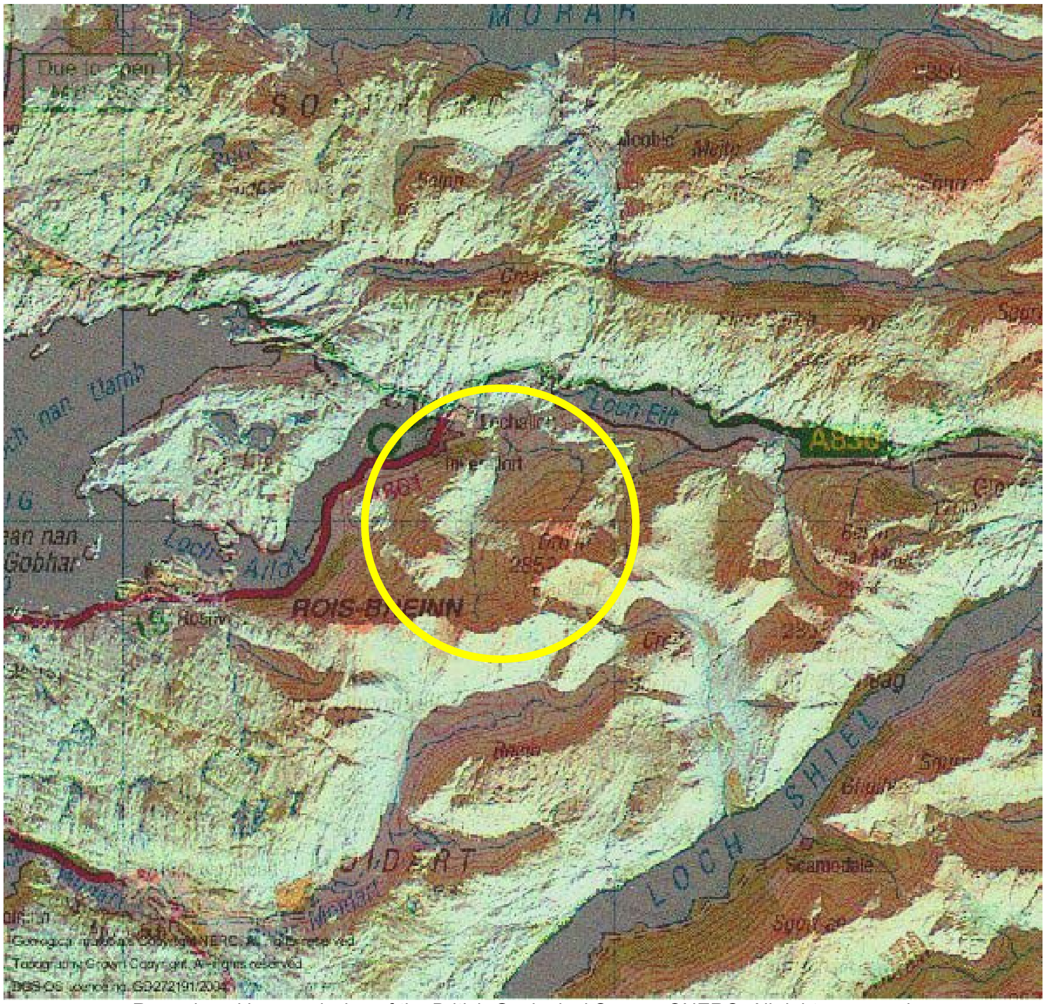


Figure 55.

In Figure 55 this natural feature is more clearly seen on a contoured photograph with the corrie inside the yellow circle. This photo shows the corrie to have high and steep boundaries on three sides ranging from 800m in the south face, down to 300m in height on the western and eastern faces of the corrie.

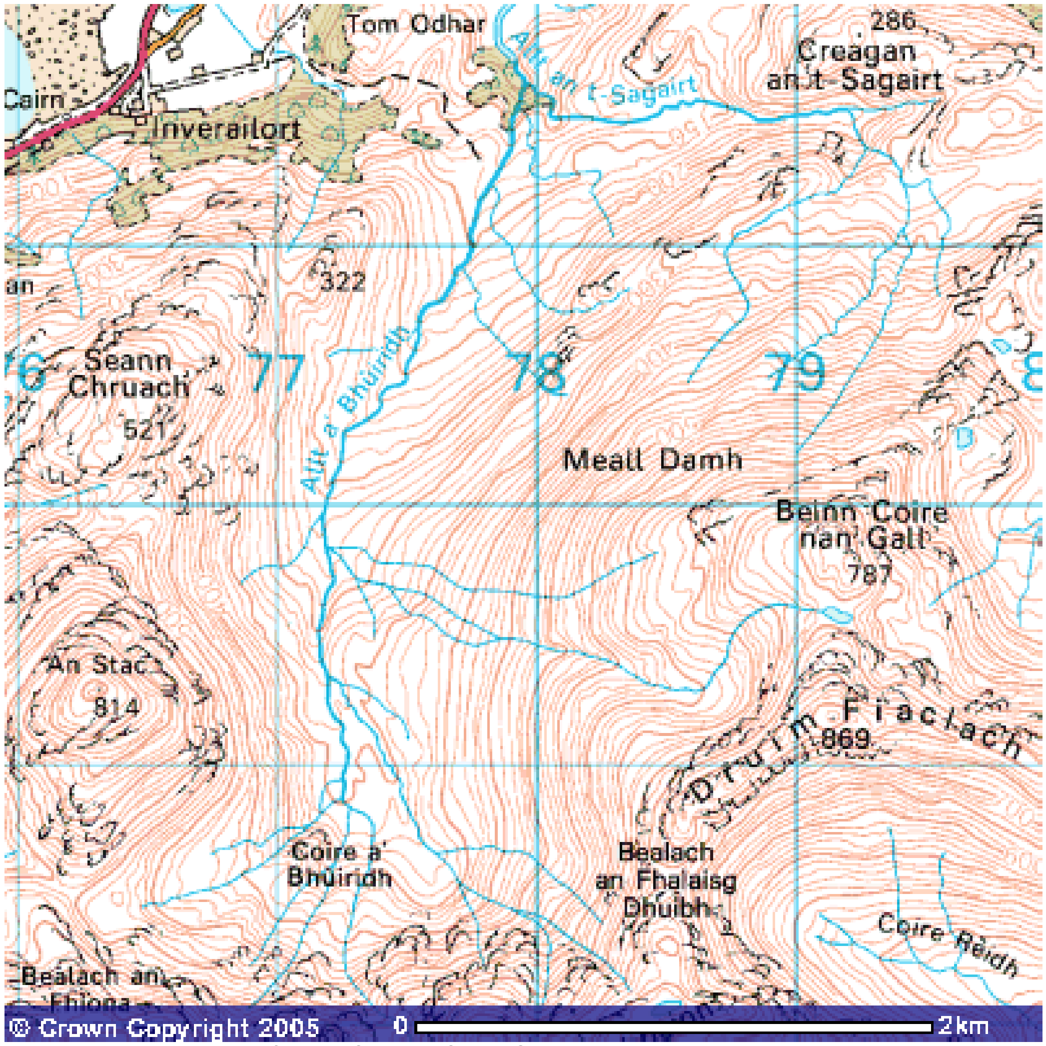


Image produced from the Ordnance Survey Get-a-map service. Image reproduced with kind permission of Ordnance Survey and Ordnance Survey of Northern Ireland.

Figure 56.

In Figure 56 there is a fully contoured Ordnance Survey Map showing the main catchment area with small streams converging into a single outlet draining the corrie, called Allt a’ Bhùiridh, which flows down the mountain slope via a series of picturesque waterfalls where it is joined by a second outlet stream called Allt an t-Sagairt from Coire an t-Sagairt to the east and other small hillside tributaries. This flows out of the mountain down to the Roti Burn which in turn flows into the River Ailort and on into Loch Ailort, a sea loch in the Sound of Arisaig.

Possible sites.

For the purposes of this thesis all grid coordinates have been taken using the Ordnance Surveys' Pathfinder Maps, using 8 figure grids.

- 275 (Moidart) (NM 67/77) 1:25 000, edition A, reviewed 1995
- 262 (Arisaig & Lochailort) (NM 68/78) 1:25 000, edition A,

There were two possible sites for the proposed hydroelectric scheme investigated. Both these sites were on the flow of the burn called Allt a' Bhùiridh, the single outlet of water from the entire corrie.

- Site 1 – Grid location 7794 8163, Pathfinder Map 262 (Arisaig & Lochailort) (NM 68/78) 1:25 000, edition A,

- Site 2 – Grid location 7790 8151, Pathfinder Map 262 (Arisaig & Lochailort) (NM 68/78) 1:25 000, edition A,

The first site was at an altitude of 50 meters, and is at the base of one of the waterfalls, which has a sizeable pool at its base (Figure 57). This first site captures the entire flow of water from the Coire a' Bhùiridh and a second burn called Allt an t-Sagairt that runs down from a small corrie called Coire an t-Sagairt, that is on the western side of Creag Dhearg, the eastern wall of Coire a' Bhùiridh.

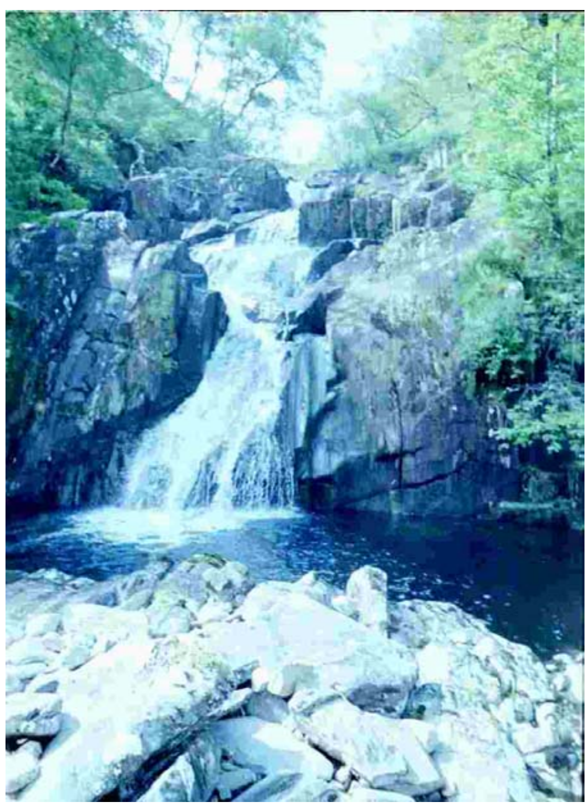


Figure 57.

The second site to be looked at was located further into the main corrie and was at an altitude of 75 meters on the flow of Allt a' Bhùiridh (Figure 58). The second site is also at the top of the first series of waterfalls (Figure 59) that flows down to Site 1. Site 2 loses at least 25% of the total catchment area of the corrie as it loses the flow of Allt an t-Sagairt, and has a much smaller pool in the surrounding area, but has the advantage of more altitude.

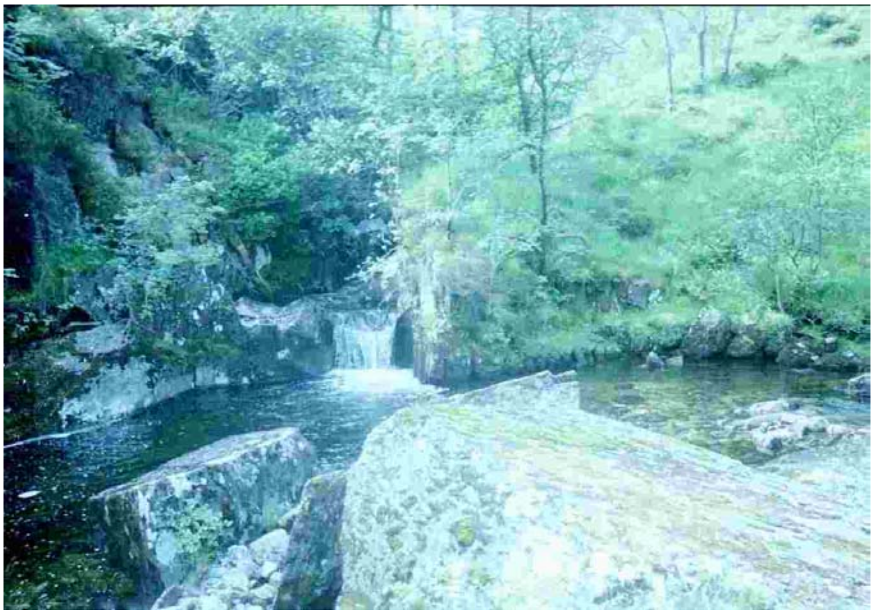


Figure 58.

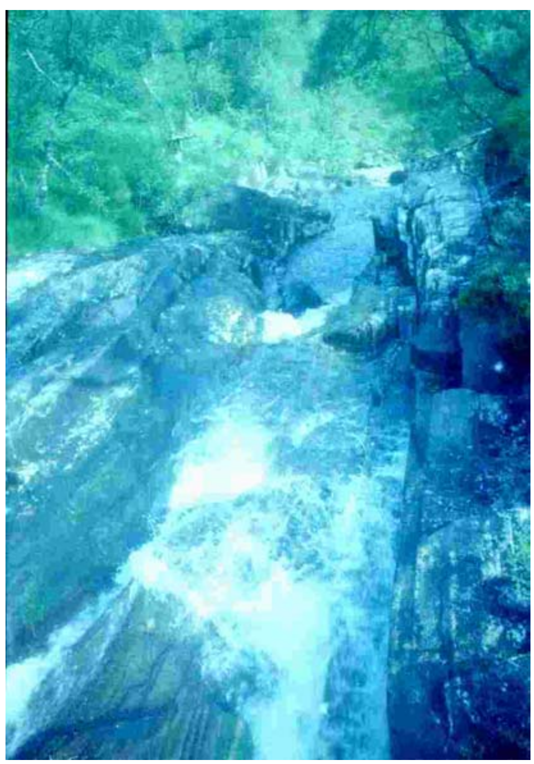


Figure 59.

Rainfall Data.

The heart of any hydroelectric scheme is the water available that falls on the catchment area. From the preliminary data from the Meteorological Office (Met Office) seen in (Figure 60), it shows that the area in question has some of the highest average rainfall levels in the United Kingdom between 1961 and 1990, between 2400mm and 3200mm of rain, shown by the red circle.

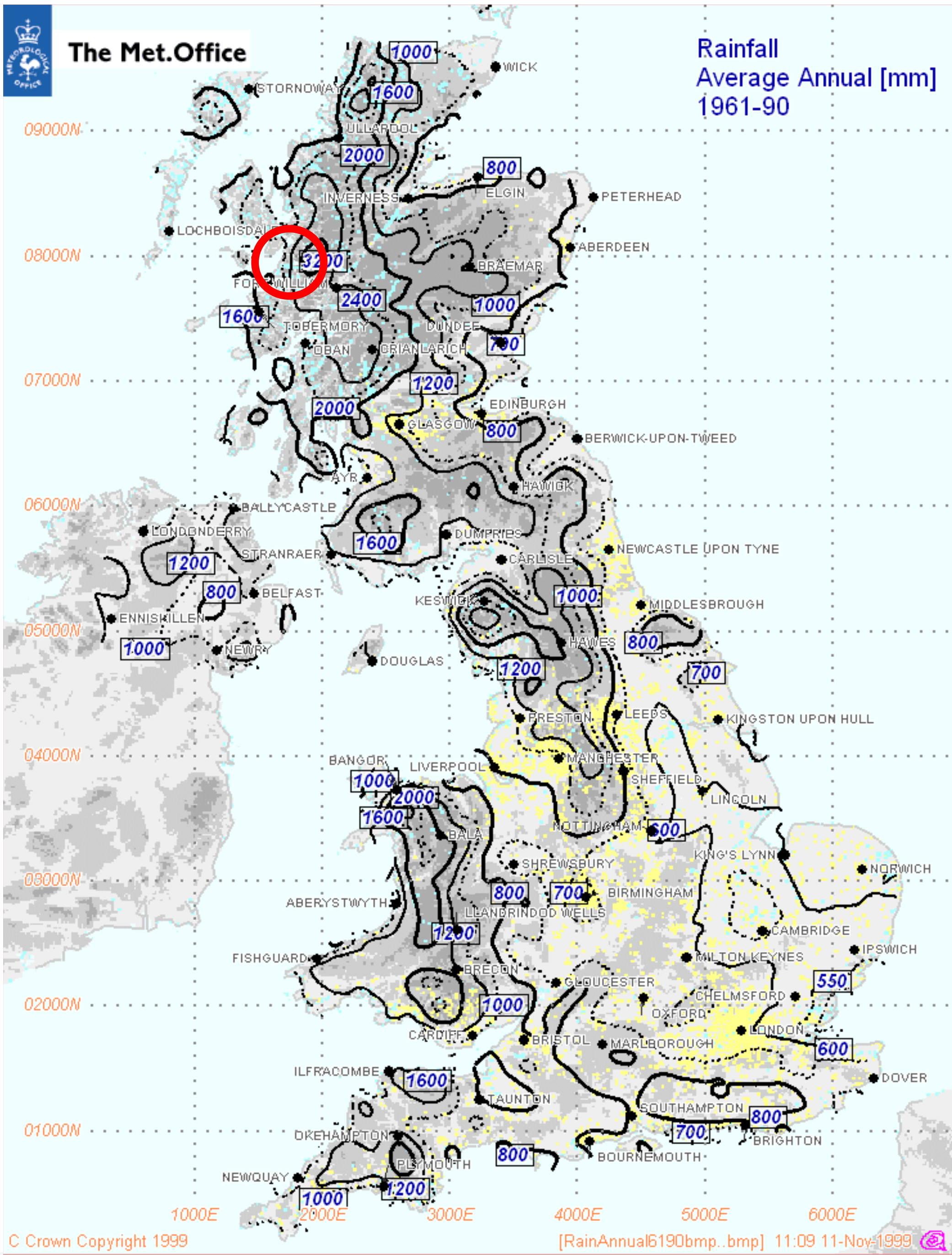


Figure 60.

More accurate rainfall data was required and fortunately a Meteorological Office (Met Office) weather station is positioned at Lochailort:

- National Grid Reference = 1764E 7816N
- Altitude = 2 metres
- Latitude = 56:87 N
- Longitude = 05:67 W

This weather station has been in operation since 1971 and the last 30 years worth of rainfall data has been used to assess the site. The full rainfall data can be seen in Appendix 2. As can be see in Figure 61, showing the annual rainfall, it can be clearly seen that there is a substantial amount of precipitation on the area. The annual average of rainfall is 2369 mm per year. Figure 62 shows the monthly averages of rainfall on the corrie over the past 30 years.

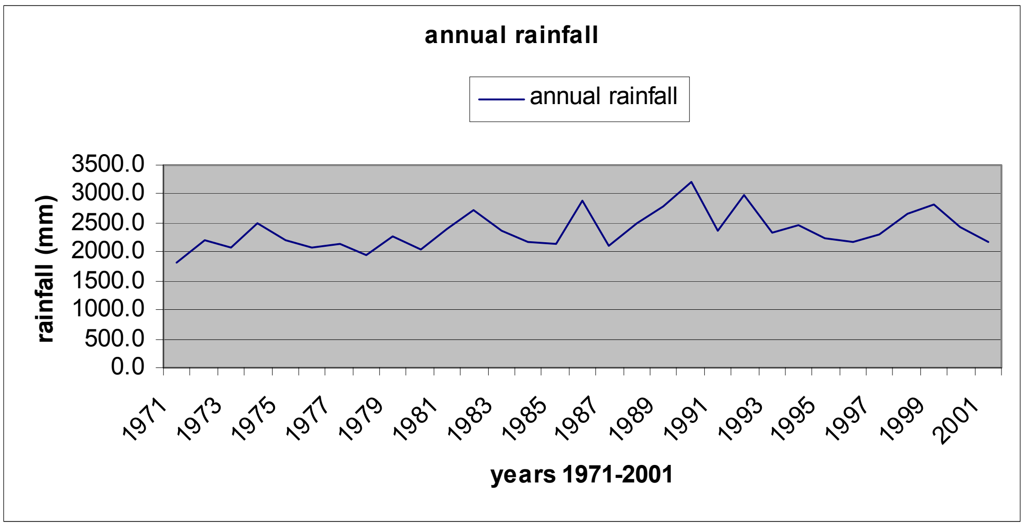


Figure 61.

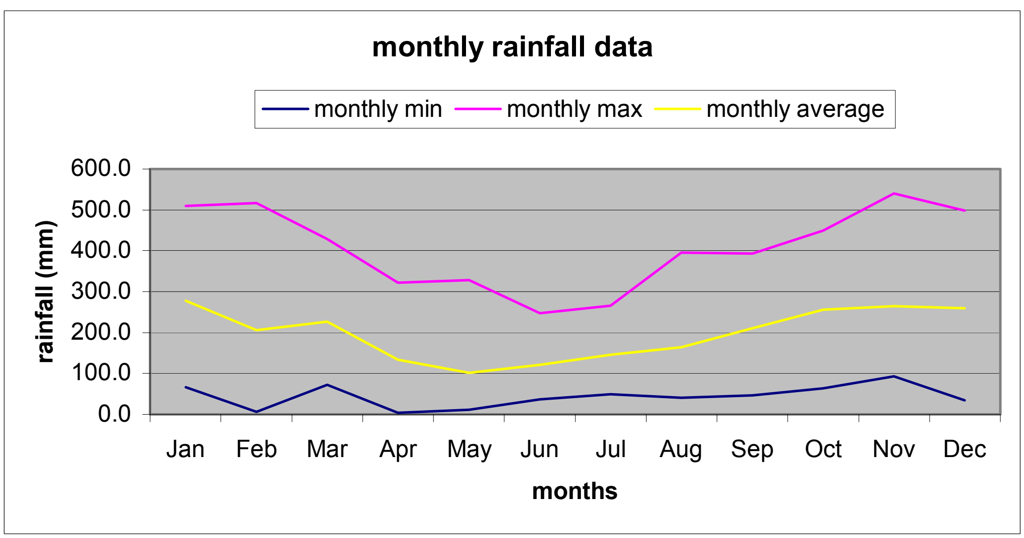


Figure 62.

This high average rainfall level over the corrie catchment area is equivalent to an annual flow of 0.748 cubic meters per second (cumecs).
Due to fluctuating rainfall levels as shown in Table 2, it is necessary to value a minimum and maximum volumetric flow rate using the Met Office rainfall data, the results can be see in Table 2, clearly showing a variation of flow rates ranging from 0.162m^{3}s to 1.517m^{3}s.

Annual Volumetric Flow Rates

	Rainfall (mm)	Flow rate (m3/s)
Annual Minimum	1802.5	0.569
Annual Maximum	3206.8	1.013
Annual Average	2369.0	0.748

Monthly Volumetric Flow Rates

	Rainfall (mm)	Flow rate (m3/s)
Monthly Minimum Average	43.5	0.162
Monthly Maximum Average	407.9	1.517
Annual Monthly Average	197.4	0.734

Table 2.

Geology.

The proposed area is made up of Metamorphic and Archean rocks as can be seen in more detail in Appendix 3 and 4. An overview of the local geology can be seen in Figure 63, with the proposed catchment area circled in yellow. Along the A830 road at Glenfinnan the exposed rocks show granite gneiss, with thin quartzo-felspathic veins separated from one another by more micaceous rock. There are also very conspicuous veins of light coloured pegmatite (extremely coarse-grained granite consisting of quartz and feldspar) exposed all along the A830. Continuing past Glenfinnan, near Creag Ghobar the hillside to the north of the A830 shows complex folding, which has affected the Moine Schists, together with the abundant veins of pegmatite. At Lochailort the A830 turns left on to the A861 towards Kinlochmoidart and the type of rock present nearly the entire way is Moine Schist, cut by Tertiary dykes, which is weathered to a dark brown colour. (Ref 13)
Considering the bedrock is not particularly porous, and seepage of rainfall run-off into the ground will be low, it can be estimated to be less than 100mm per year. (Ref 12)

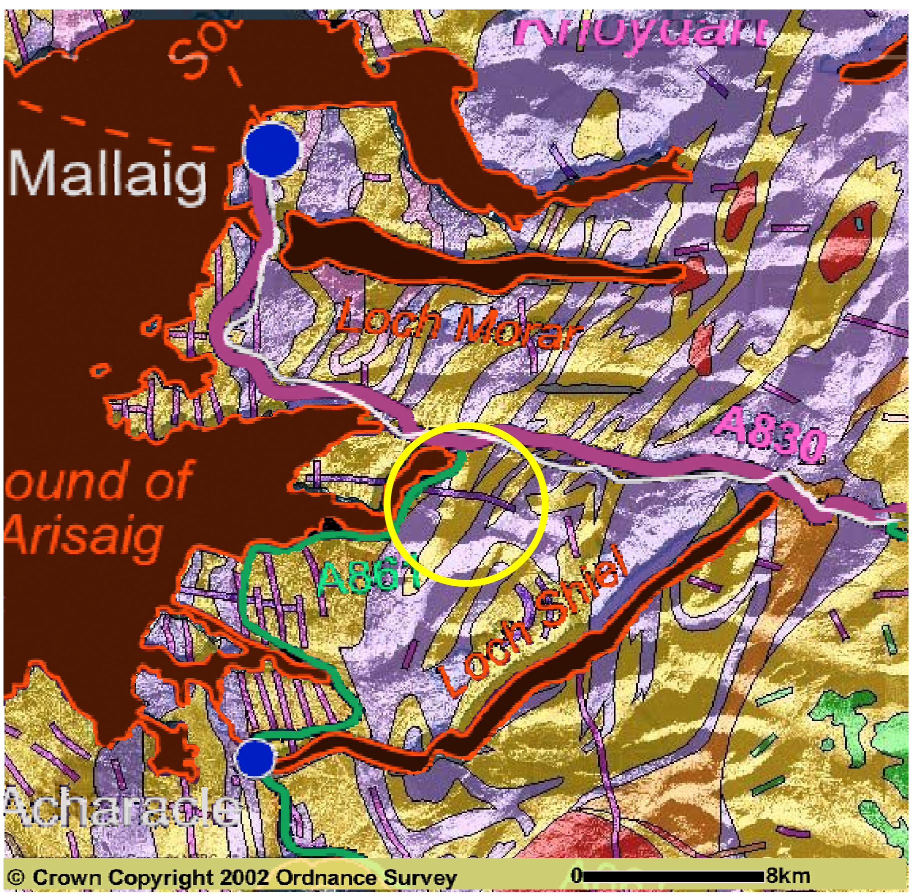


Figure 63.

Hydrology.

Rainfall on the catchment area is essential to the potential to any hydroelectric scheme, the more rain the greater the flow of the streams and burns (Figure 64), the greater the amount of electricity that can be generated.

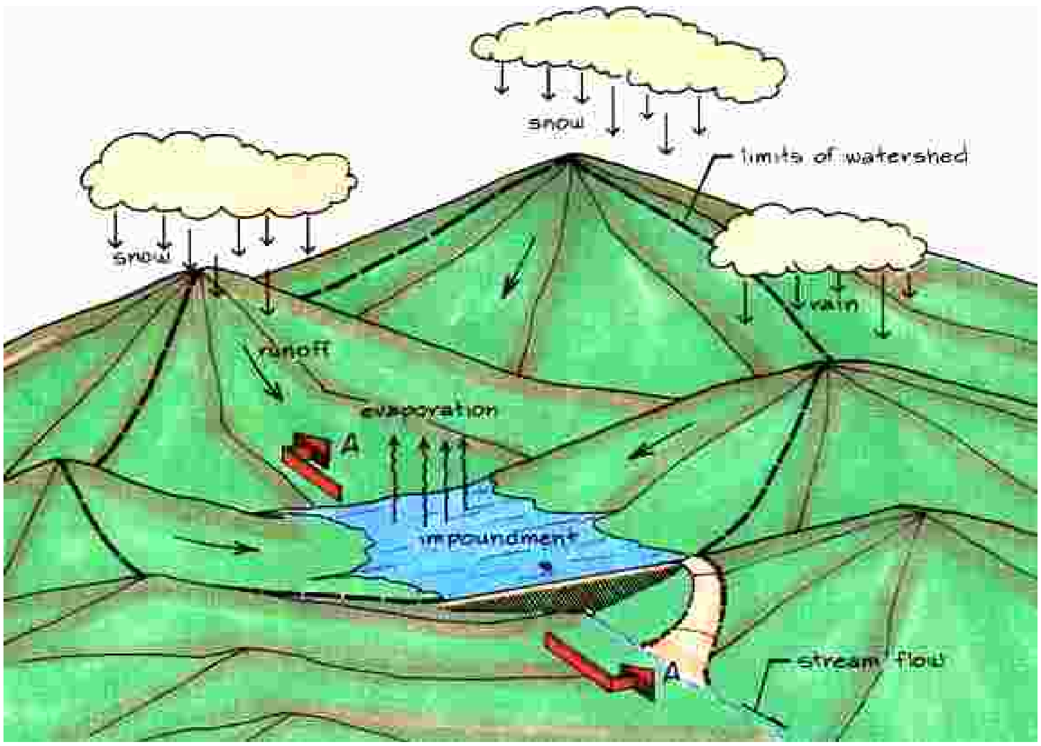


Figure 64.

The proportion of rainfall running off the catchment area and into the river depends on factors including topography, catchment wetness, soil and vegetation type, temperature and levels of wind in the area (Figure 65).

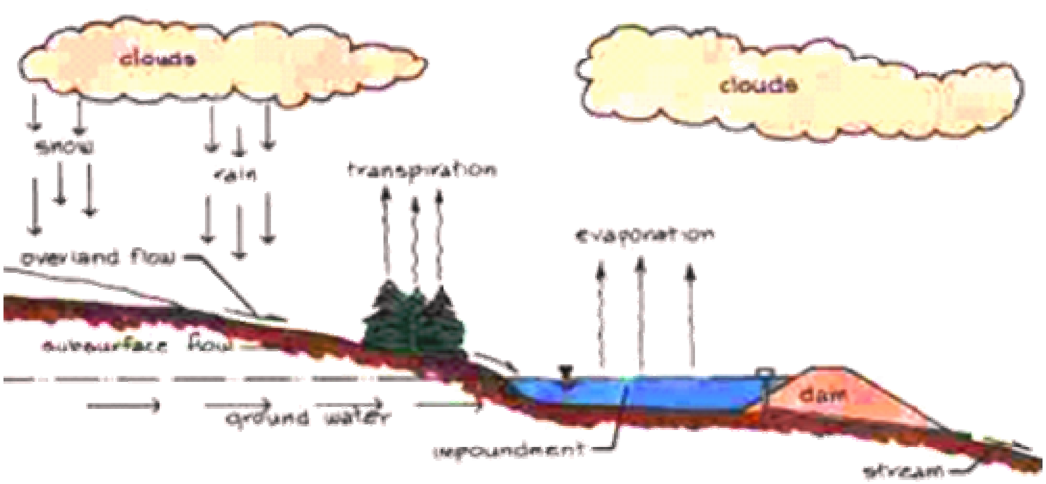


Figure 65.

The response time is the period from the time of rainfall to the time water will get into the burn. The relationship between the quantity falling on the catchment and the amount of water entering the river is called the rainfall run-off relationship. (Ref 4)
The hydrology study has employed the area rainfall method for determining the flow of Allt a' Bhùiridh. This method has been used because of the extensive rainfall data available and it should be possible to forecast the lowest and maximum flow in the burn with a degree of accuracy and whether it is possible to power a hydraulic turbine.
As the catchment area was determined, and the annual and monthly rainfall for the Inverailort area, as well as the evaporation and transpiration then the average monthly flow in the burn can be calculated.

Run-off = Rainfall – (Evaporation and Transpiration) *(E&T)*

From the rainfall into the catchment area, the run-off in forested and unforested area can be determined. From the rainfall data and knowing the catchment area size, the average daily flow and annual daily flow (ADF) for the area can be calculated. The ADF should ideally be calculated from daily or hourly actual river flow measurements, taken by Government Hydrologists over many years, as should the flow duration curve (FDC).
The FDC is determined by plotting the percentage of time for which a particular flow is exceeded, against the flow, and since the power output from a turbine is directly proportional to the flow passing through it, the flow duration curve can be used in conjunction with the turbine efficiency curves to give the output for any flow rate (Ref 17). Owing to time constraints, direct flow measurements were only taken once, at two possible sites for the proposed hydroelectric scheme, both on the same day in summer. Therefore the data obtained cannot be recognised as an accurate picture to assess the yearly outflow of Allt a' Bhùiridh and Allt an t-Sagairt.

Catchment Geography.

The catchment area for the two proposed hydro scheme sites is 9.96km², although being in the same area and on the same watercourse; the proposed sites have two different catchment area sizes. Site 1 takes into account the entire catchment area, but Site 2 loses 25% of the total catchment due to altitude and the fact that it loses the flow from Allt an t-Sagairt on the eastern side of the corrie.

Catchment Area Size:

Site 1 – 9.96 km²

Site 2 – 7.47 km²

Interception.

The catchment area for the proposed hydroelectric scheme has little or no forestation; the only woodland is the small non-coniferous area at the base of the corrie, where the proposed scheme would be built within. Within this area the two burns run down from the corrie and flow into the Roti Burn, which cuts directly through the only woodland nearby. In Figure 66 a circled area of the picture shows the burn and the surrounding land is shown, it also shows the small presence of wood landed area in relation to the corrie itself.

Figure 66.

Studies have shown that water interception losses for this type of mountain terrain can range between 15-25% due vegetation density. The Meteorological Office suggests a figure of 15% for the evaporation and transpiration level for this kind of hillside terrain, and this will be used to eliminate any possible over-estimation of the water flow level, which equates to 355.35 mm/y, using the annual average rainfall figure of 2369mm. This brings the average rainfall figure down to 2013.65mm, equivalent to an annual average flow of 0.636 cubic meters per second (cumecs).

Run-off.

The Run-Off has been calculated for an unforested area implying that the existing woodland surrounding the area is negligible in proportion to the entire catchment area; therefore a 15% reduction in the total volume of rainfall is assumed. The rainfall data used is the monthly averages determined from the data shown in Appendix 2.

Site 1 – Run-off data

Month	Rainfall Average (mm)	Unforested Vol (m3)	Less 15% E&T (m3)	Total Volume (m3)
January	277.5	2763900	414585	2349315
February	205.5	1535085	230262.75	1304822.25
March	226.2	2252952	337942.8	1915009.2
April	134	1334640	200196	1134444
May	101.9	1014924	152238.6	862685.4
June	121.3	1208148	181222.2	1026925.8
July	146.1	1455156	218273.4	1236882.6
August	164.6	1639416	245912.4	1393503.6
September	211.2	2103552	315532.8	1788019.2
October	256.3	2552748	382912.2	2169835.8
November	264.4	2633424	395013.6	2238410.4
December	260	2589600	388440	2201160

Table 3.

Site 2 – Run-off data

Month	Rainfall Average (mm)	Unforested Vol (m3)	Less 15% E&T (m3)	Total Volume (m3)
January	277.5	2072925	310938.75	1761986.25
February	205.5	1535085	230262.75	1304822.25
March	226.2	1689714	253457.1	1436256.9
April	134	1000980	150147	850833
May	101.9	761193	114178.95	647014.05
June	121.3	906111	135916.65	770194.35
July	146.1	1091367	163705.05	927661.95
August	164.6	1229562	184434.3	1045127.7
September	211.2	1577664	236649.6	1341014.4
October	256.3	1914561	287184.15	1627376.85
November	264.4	1975068	296260.2	1678807.8
December	260	1942200	291330	1650870

Table 4.

ADF – Average Daily Flow.

Site 1 – ADF

Month	Total Volume (m3)	Average Daily Flow (m3/d)	Average Daily Flow (m3/s)
January	2349315	75784.4	0.877
February	1739763	62134.4	0.719
March	1915009.2	61774.5	0.715
April	1134444	37814.8	0.438
May	862685.4	27828.6	0.322
June	1026925.8	34230.9	0.396
July	1236882.6	39899.4	0.462
August	1393503.6	44951.7	0.520
September	1788019.2	59600.6	0.690
October	2169835.8	69994.7	0.810
November	2238410.4	74613.7	0.864
December	2201160	71005.2	0.822
ADF	**-**	**54969.4**	**0.636**

Table 5.

Site 2 – ADF

Month	Total Volume (m3)	Average Daily Flow (m3/d)	Average Daily Flow (m3/s)
January	1761986.25	56838.3	0.658
February	1304822.25	46600.8	0.539
March	1436256.9	46330.9	0.536
April	850833	28361.1	0.328
May	647014.05	20871.4	0.242
June	770194.35	25673.1	0.297
July	927661.95	29924.6	0.346
August	1045127.7	33713.8	0.390
September	1341014.4	44700.5	0.517
October	1627376.85	52496.0	0.608
November	1678807.8	55960.3	0.648
December	1650870	53253.9	0.616
ADF	**-**	**41227.1**	**0.477**

Table 6.

Compensation Flow.

Site 1 – Compensation Flow

Month	Average Daily	Average Daily	Compensation	Turbine
	Flow (m3/d)	Flow (m3/s)	Flow (m3/s)	Flow (m3/s)
January	75784.4	0.877	0.03	0.847
February	62134.4	0.719	0.03	0.689
March	61774.5	0.715	0.03	0.685
April	37814.8	0.438	0.03	0.408
May	27828.6	0.322	0.03	0.292
June	34230.9	0.396	0.03	0.366
July	39899.4	0.462	0.03	0.432
August	44951.7	0.520	0.03	0.490
September	59600.6	0.690	0.03	0.660
October	69994.7	0.810	0.03	0.780
November	74613.7	0.864	0.03	0.834
December	71005.2	0.822	0.03	0.792

Table 7.

Site 2 – Compensation Flow

Month	Average Daily	Average Daily	Compensation	Turbine
	Flow (m3/d)	Flow (m3/s)	Flow (m3/s)	Flow (m3/s)
January	56838.3	0.658	0.03	0.628
February	46600.8	0.539	0.03	0.509
March	46330.9	0.536	0.03	0.506
April	28361.1	0.328	0.03	0.298
May	20871.4	0.242	0.03	0.212
June	25673.1	0.297	0.03	0.267
July	29924.6	0.346	0.03	0.316
August	33713.8	0.390	0.03	0.360
September	44700.5	0.517	0.03	0.487
October	52496.0	0.608	0.03	0.578
November	55960.3	0.648	0.03	0.618
December	53253.9	0.616	0.03	0.586

Table 8.

Power Analysis of Sites 1 and 2.

This section contains the power analysis of both proposed sites.

To attain power values it was required to estimate the pipeline length from the proposed site a turbine house site.

Grid Ref 7785 8175 was chosen to be the site for both proposed sites turbine house. This would give pipe lengths of 150m for Site 1 and 250m for Site 2 and the proposed turbine house.

3 different pipe diameters were tried to create a model to work from, to approximate the power that could be extracted from both sites. These diameters being 0.5m, 0.4m and 0.3m

Full flow was used and 50% of the ADF was used for both sites to give a fuller understanding of the available power with respect to the flow.

80%+ transmission efficiency acceptable.

Site 1.

Catchment area size	9.96	km²
Site altitude above sea level	45-50	m
Gross Head	35	m
Pipe Length	150	m

Table 9.

0.5m pipe diameter.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.847	290.817	243.486	162.308	83.72	55.76
February	0.689	236.568	211.090	140.713	89.23	59.43
March	0.685	235.195	210.158	140.091	89.35	59.51
April	0.408	140.087	134.796	89.855	96.22	64.08
May	0.292	100.258	98.319	65.539	98.07	65.31
June	0.366	125.666	121.847	81.233	96.96	64.58
July	0.432	148.327	142.047	94.689	95.77	63.78
August	0.490	168.242	159.077	106.041	94.55	62.97
September	0.660	226.611	204.217	136.131	90.12	60.12
October	0.780	267.813	230.848	153.884	86.20	57.41
November	0.834	286.354	241.168	160.763	84.22	56.09
December	0.792	271.933	233.236	155.475	85.77	57.12
Averages	**0.606**	**208.156**	**185.857**	**123.894**	**90.85**	**60.51**

Table 10.

0.5m pipe diameter using 50%ADF.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.423	145.237	139.342	92.885	95.94	63.90
February	0.334	114.679	111.777	74.510	97.47	64.91
March	0.342	117.426	114.310	76.199	97.35	64.83
April	0.204	70.043	69.382	46.250	99.06	65.97
May	0.146	50.129	49.887	33.253	66.28	99.52
June	0.183	62.833	62.356	41.566	99.24	66.09
July	0.216	74.164	73.379	48.914	98.94	65.90
August	0.245	84.121	82.975	55.311	98.64	65.69
September	0.330	113.306	110.506	73.663	97.53	63.95
October	0.390	133.907	129.286	86.182	96.55	64.30
November	0.417	143.864	138.134	92.080	96.02	63.95
December	0.396	135.967	131.129	87.411	96.44	64.23
Averages	**0.302**	**103.806**	**101.039**	**67.352**	**94.96**	**67.77**

Table 11.

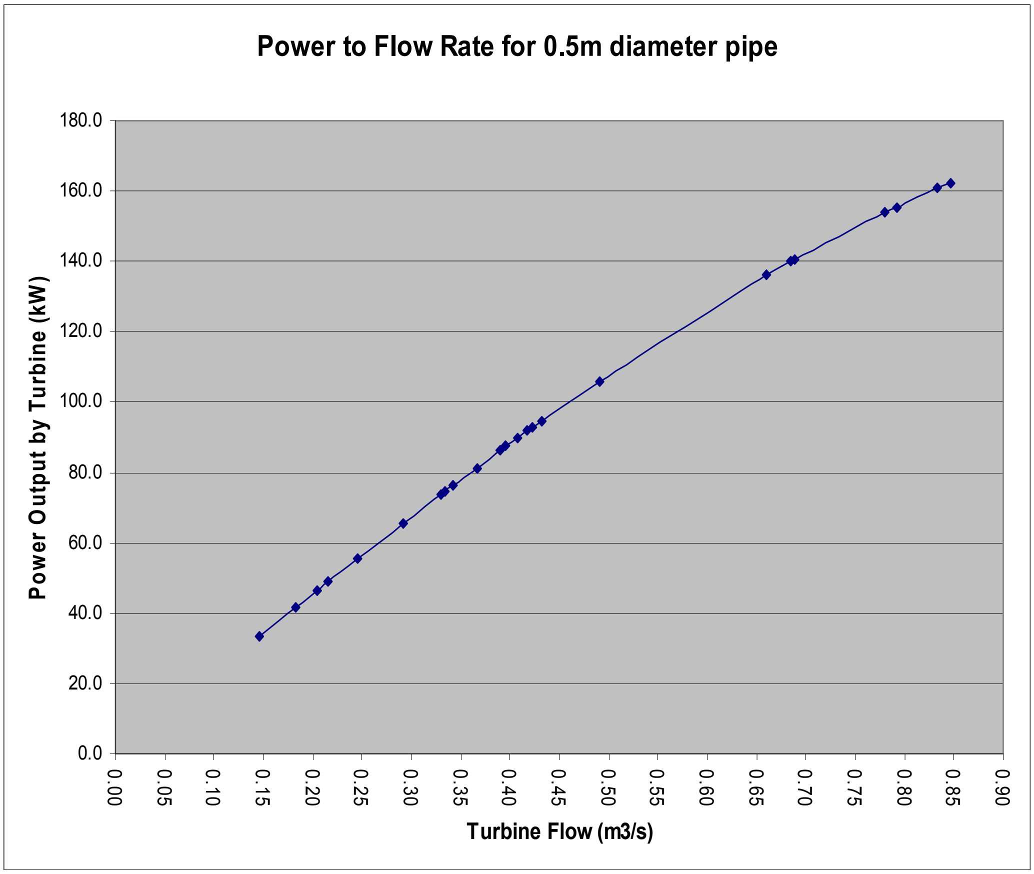


Figure 67.

The 0.5m diameter pipe produces power figures from 33.25kW to 162.3kW from flow rates of 0.146m³/s to 0.847m³/s.

The highest transmission efficiency of 99.24% is produced at a flow rate of 0.183m³/s producing 41.55kW

The lowest acceptable efficiency of 83.72% is produced at a flow rate of 0.847m³/s producing 162.3kW.

The Annual ADF of 0.606m³/s produces 123.89kW at 90.85% transmission efficiency.

This therefore gives a working power range of 41.55kW to 123.89kW at between 99.24% and 90.85% transmission efficiency, with the turbine being able to produce a maximum of 162.3kW at 83.72% transmission efficiency.

0.4m pipe diameter.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.847	290.817	146.373	97.572	50.57	33.52
February	0.689	236.568	158.816	105.867	67.13	44.71
March	0.685	235.195	158.789	105.849	67.51	44.95
April	0.408	140.087	123.942	82.620	88.48	58.92
May	0.292	100.258	94.340	62.887	94.10	62.67
June	0.366	125.666	114.012	76.000	90.73	60.42
July	0.432	148.327	129.162	86.100	87.08	57.99
August	0.490	168.242	140.275	93.507	83.38	55.53
September	0.660	226.611	158.270	105.503	69.84	46.51
October	0.780	267.813	155.006	103.327	57.88	38.55
November	0.834	286.354	148.458	98.962	51.84	34.53
December	0.792	261.633	156.457	104.292	59.80	39.83
Averages	**0.606**	**207.298**	**140.325**	**93.541**	**72.36**	**48.18**

Table 12.

0.4m pipe diameter using 50%ADF.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.423	145.237	127.245	84.822	87.61	58.35
February	0.334	114.679	105.822	70.541	92.28	61.46
March	0.342	117.426	107.917	71.937	91.90	61.21
April	0.204	70.043	68.025	45.346	97.12	64.68
May	0.146	50.129	49.389	32.923	98.52	65.62
June	0.183	62.833	61.376	40.913	97.68	65.06
July	0.216	74.164	71.768	47.841	96.77	64.45
August	0.245	84.121	80.625	53.745	95.84	63.83
September	0.330	113.306	104.763	69.835	92.46	61.58
October	0.390	133.907	119.806	79.862	89.47	59.59
November	0.417	143.177	125.940	83.952	87.96	58.58
December	0.396	135.967	121.025	80.795	89.14	59.37
Averages	**0.302**	**103.749**	**95.308**	**63.543**	**93.06**	**61.98**

Table 13.

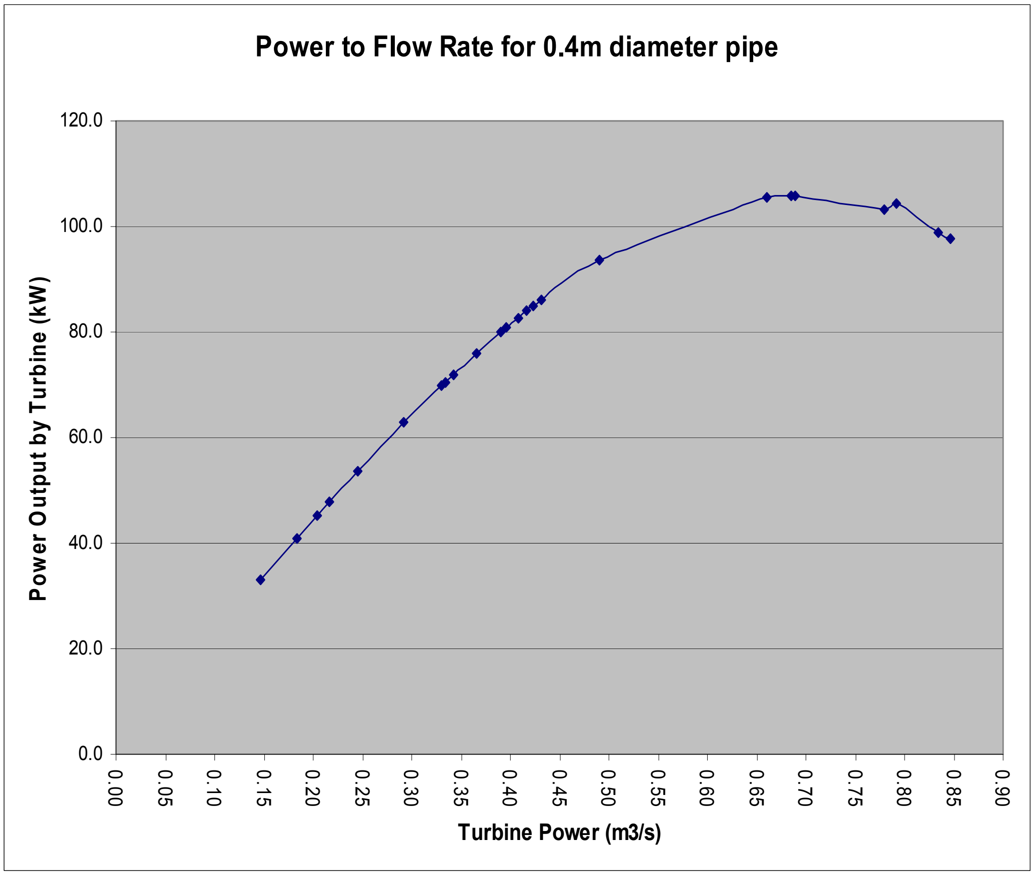


Figure 68.

The 0.4m diameter pipe produces power figures from 32.92kW to 105.86kW from flow rates of 0.146m³/s to 0.847m³/s.

The highest transmission efficiency of 98.52% is produced at a flow rate of 0.146m³/s producing 32.92kW

The lowest acceptable efficiency of 83.38% is produced at a flow rate of 0.490m³/s producing 93.5kW.

The Annual ADF of 0.606m³/s produces 93.54kW at 72.36% transmission efficiency.

This therefore gives a working power range of 32.92kW to 93.5kW at between 98.24% and 83.38% transmission efficiency, with the turbine being able to produce a maximum of 105.86kW at 67.13% transmission efficiency.

0.3m pipe diameter.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.847	290.817	-317.872	-211.894	-109.30	72.80
February	0.689	236.568	-91.077	-60.712	-38.50	-25.64
March	0.685	235.195	-86.777	-57.845	-36.90	-24.57
April	0.408	140.087	72.053	48.030	51.43	34.26
May	0.292	100.258	75.318	50.207	75.12	50.03
June	0.366	125.666	76.554	51.031	60.92	40.57
July	0.432	148.327	67.567	45.040	45.55	30.34
August	0.490	168.242	50.390	33.590	29.95	19.95
September	0.660	226.611	-61.379	-40.915	-27.09	-18.04
October	0.780	267.813	-207.554	-138.356	-77.50	-51.61
November	0.834	286.354	-294.737	-196.471	-102.93	-68.55
December	0.792	271.933	-225.714	-150.461	-83.00	-55.28
Averages	**0.606**	**208.156**	**-78.602**	**-52.396**	**-17.69**	**0.35**

Table 14.

0.3m pipe diameter using 50% ADF.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.423	145.237	69.420	46.275	47.80	31.83
February	0.334	114.679	77.355	51.565	67.45	44.92
March	0.342	117.426	77.355	51.565	65.88	43.87
April	0.204	70.043	61.539	41.022	87.86	58.51
May	0.146	50.129	47.012	31.338	93.78	62.46
June	0.183	62.833	56.694	37.792	90.23	60.09
July	0.216	74.164	64.069	42.708	86.39	57.53
August	0.245	84.121	69.389	46.255	82.49	54.94
September	0.330	113.306	77.307	51.533	68.23	45.44
October	0.390	113.907	74.486	49.652	55.63	37.05
November	0.417	143.177	70.541	47.022	49.27	32.81
December	0.396	135.967	73.761	49.169	54.25	36.13
Averages	**0.302**	**102.082**	**68.244**	**45.491**	**70.77**	**47.13**

Table 15.

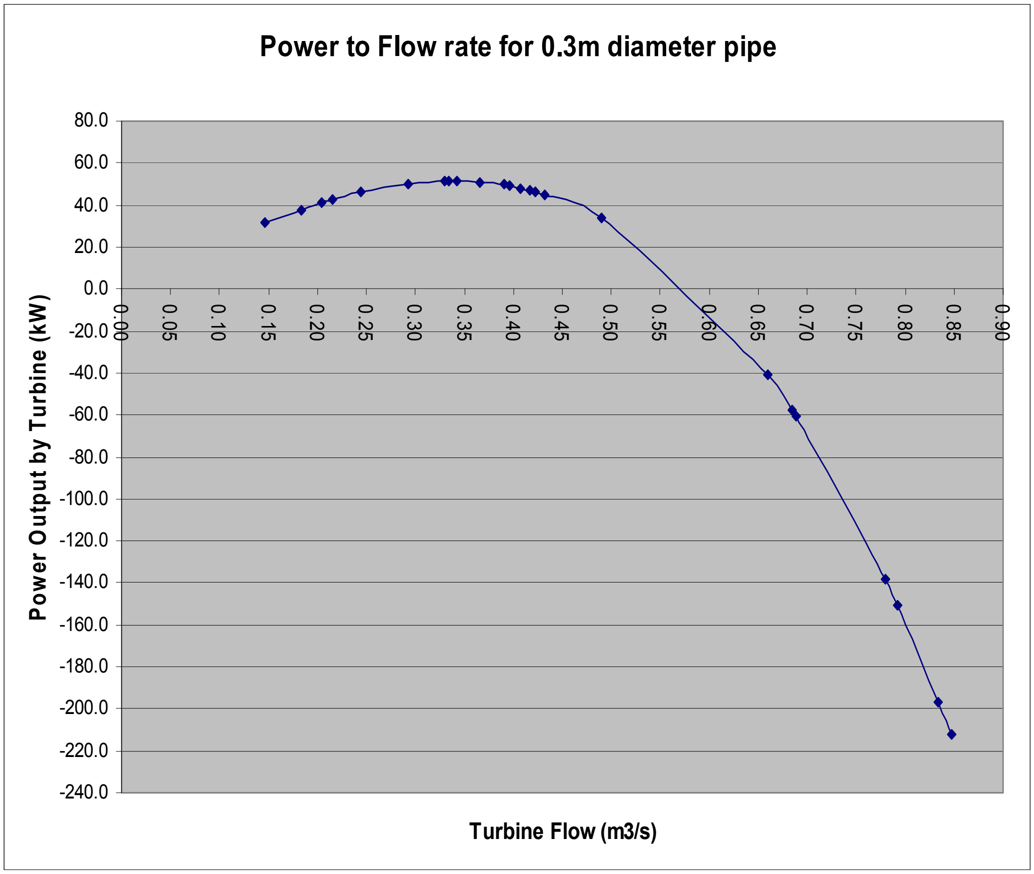


Figure 69.

The 0.3m diameter pipe produces power figures from 31.33kW to 51.65kW from flow rates of 0.146m³/s to 0.847m³/s.

The highest transmission efficiency of 93.78% is produced at a flow rate of 0.146m³/s producing 31.33kW

The lowest acceptable efficiency of 82.49% is produced at a flow rate of 0.245m³/s producing 46.25kW.

The Annual ADF of 0.606m³/s produces -52.39kW at -17.69% transmission efficiency.

This graph and tables show negative values, this shows that the pipe diameter is too small to handle the larger flow rates. With the respect to the power figures a maximum flow rate of 0.490m³/s is allowed before the pipe is effectively choked by the flow rate, thus creating an overflow at the inlet pipe or the weir.

This therefore gives a working power range of 31.33kW to 46.25kW at between 93.78% and 82.49% transmission efficiency, with the turbine being able to produce a maximum of 51.56kW at 65-67.45% transmission efficiency.

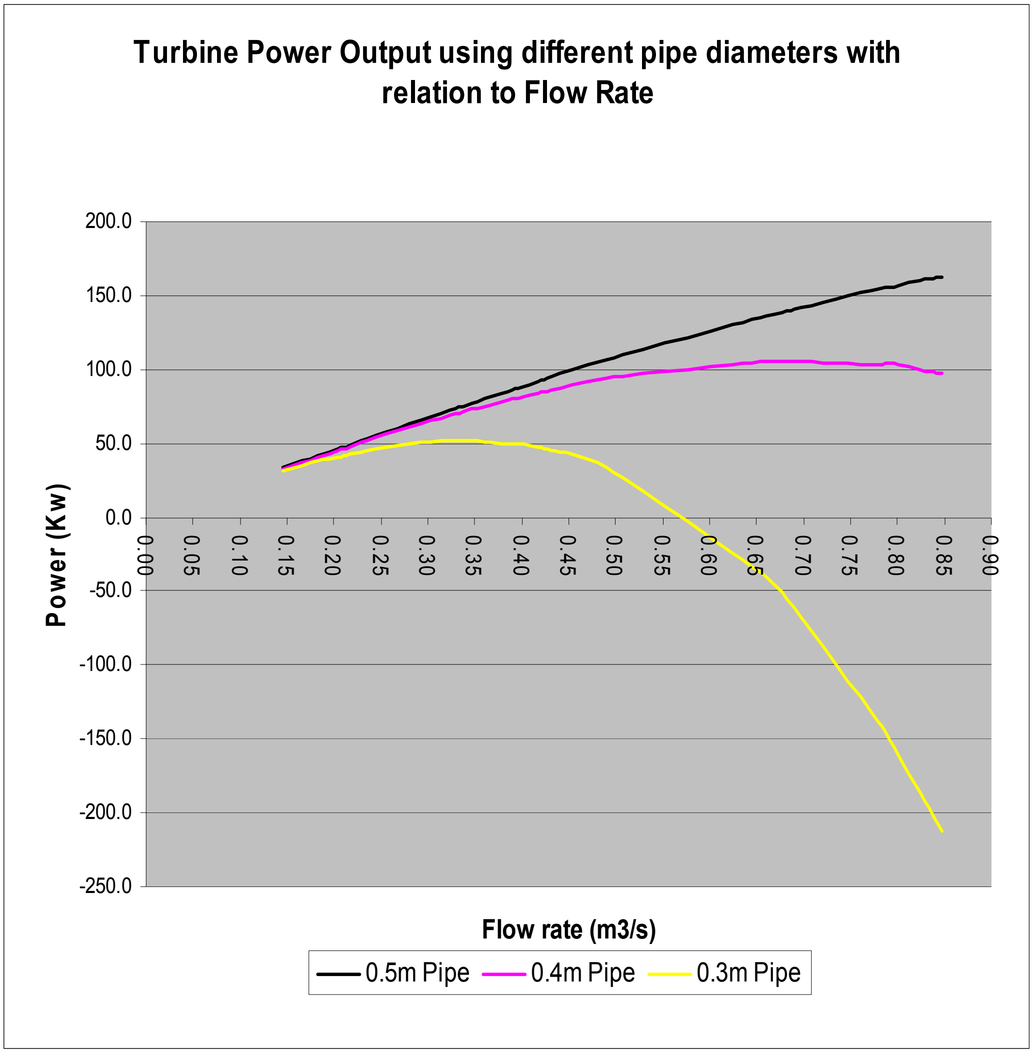


Figure 70.

This graph shows a comparison between the different pipe diameters and the power values. It was found that the smaller pipe diameter of 0.3m too small to handle the flow rates therefore the pipeline is effectively choked by the flow and overflow at the intake occurs, or over the dam as overflow.

Site 2

Catchment area size	7.47	km²
Site altitude above sea level	75	m
Gross Head	65	m
Pipe Length	250	m

Table 16.

0.5m pipe diameter.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.628	400.444	368.291	245.503	91.97	61.25
February	0.509	324.564	307.444	204.942	94.73	63.09
March	0.506	322.651	305.832	203.867	94.79	63.13
April	0.298	190.020	186.584	124.377	98.19	65.40
May	0.212	135.182	133.945	89.288	99.08	65.99
June	0.267	170.253	167.781	111.843	98.55	65.63
July	0.316	201.497	197.401	131.587	97.97	65.25
August	0.360	229.554	223.497	148.983	97.36	64.84
September	0.487	310.536	295.541	197.008	95.17	63.38
October	0.578	368.562	343.493	228.972	93.20	62.07
November	0.618	394.068	363.426	242.260	92.22	61.42
December	0.586	373.663	347.539	231.669	93.01	61.94
Averages	**0.447**	**285.083**	**270.065**	**180.025**	**95.52**	**63.62**

Table 17.

0.5m pipe diameter using 50%ADF.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.314	200.222	196.203	130.789	97.99	65.26
February	0.255	162.601	160.488	106.955	98.68	65.72
March	0.253	161.325	159.223	106.138	98.70	65.73
April	0.149	95.010	94.580	63.047	99.55	66.30
May	0.106	67.590	67.436	44.953	99.77	66.44
June	0.134	85.445	85.132	56.749	99.63	66.35
July	0.158	100.748	100.236	66.817	99.49	66.26
August	0.180	114.777	114.098	76.005	99.34	66.16
September	0.244	155.586	153.700	102.456	98.79	65.79
October	0.289	184.281	181.147	120.753	98.30	65.47
November	0.309	197.034	193.204	128.790	98.06	65.31
December	0.293	186.831	183.566	122.365	98.25	65.44
Averages	**0.224**	**142.621**	**140.751**	**93.818**	**98.88**	**65.85**

Table 18.

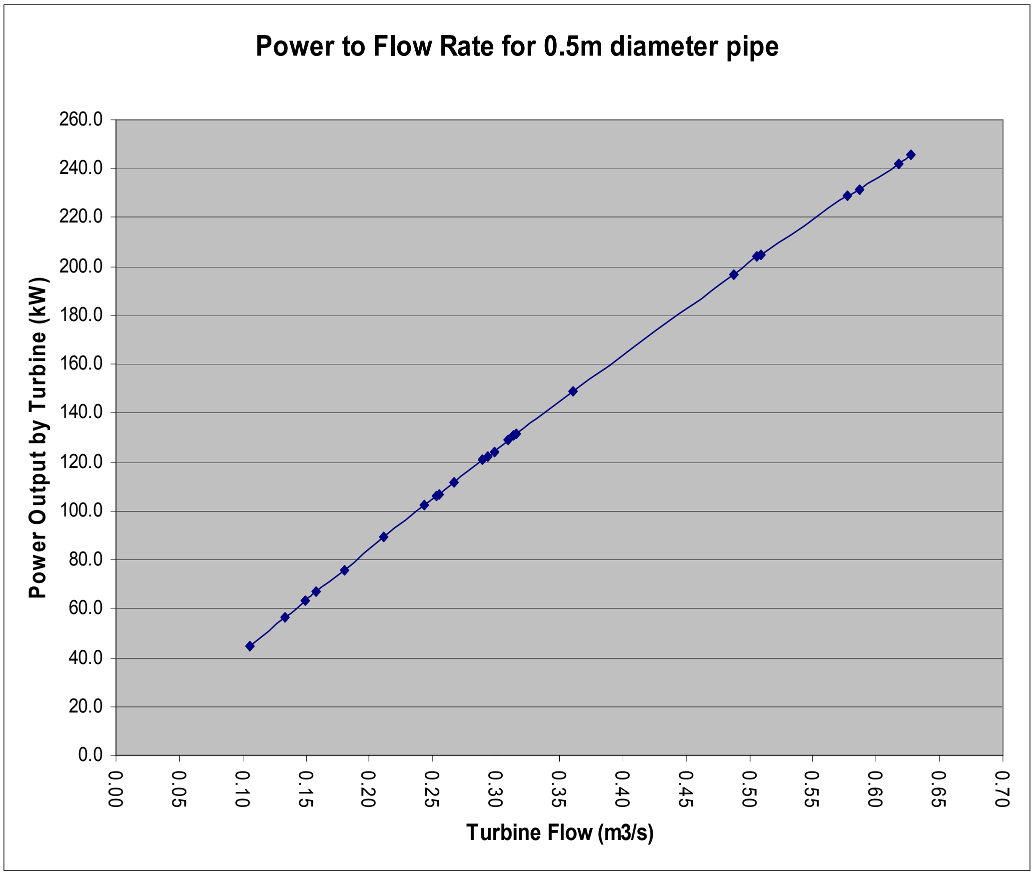


Figure 71.

The 0.5m diameter pipe produces power figures from 44.95kW to 245.50kW from flow rates of 0.106m³/s to 0.628m³/s.

The highest transmission efficiency of 99.77% is produced at a flow rate of 0.106m³/s producing 44.95kW

The lowest acceptable efficiency of 91.97% is produced at a flow rate of 0.628m³/s producing 245.50kW

The Annual ADF of 0.447m³/s produces 180.02kW at 95.52% transmission efficiency.

This therefore gives a working power range of 44.95kW to 180.02kW at between 99.77% and 95.52% transmission efficiency, with the turbine being able to produce a maximum of 245.50kW at 91.97% transmission efficiency.

0.4m pipe diameter.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.628	400.444	302.319	201.526	75.50	50.28
February	0.509	324.564	272.318	181.527	83.90	55.88
March	0.506	322.651	271.323	180.864	84.09	56.01
April	0.298	190.020	179.532	119.678	94.48	62.93
May	0.212	135.182	131.407	87.596	97.21	64.74
June	0.267	170.253	162.711	108.463	95.57	63.65
July	0.316	201.497	188.996	125.985	93.80	62.47
August	0.360	229.554	211.069	140.699	91.95	61.24
September	0.487	310.536	264.775	176.499	85.76	56.79
October	0.578	368.562	292.058	194.686	79.24	52.78
November	0.618	394.068	300.556	200.351	76.27	50.80
December	0.586	373.663	293.938	195.939	78.66	52.39
Averages	**0.447**	**285.083**	**239.250**	**159.484**	**86.37**	**57.50**

Table 19.

0.4m pipe diameter using 50% ADF.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.314	200.222	196.203	130.789	97.99	65.26
February	0.255	162.601	160.488	106.955	98.68	65.72
March	0.253	161.325	159.223	106.138	98.70	65.73
April	0.149	95.010	94.580	63.047	99.55	66.30
May	0.106	67.590	67.436	44.953	99.77	66.44
June	0.134	85.445	85.132	56.749	99.63	66.35
July	0.158	100.748	100.236	66.817	99.49	66.26
August	0.180	114.777	114.098	76.005	99.34	66.16
September	0.244	155.586	153.700	102.456	98.79	65.79
October	0.289	184.281	181.147	120.753	98.30	65.47
November	0.309	197.034	193.204	128.790	98.06	65.31
December	0.293	186.831	183.566	122.365	98.25	65.44
Averages	**0.224**	**142.621**	**140.751**	**93.818**	**98.88**	**65.85**

Table 20.

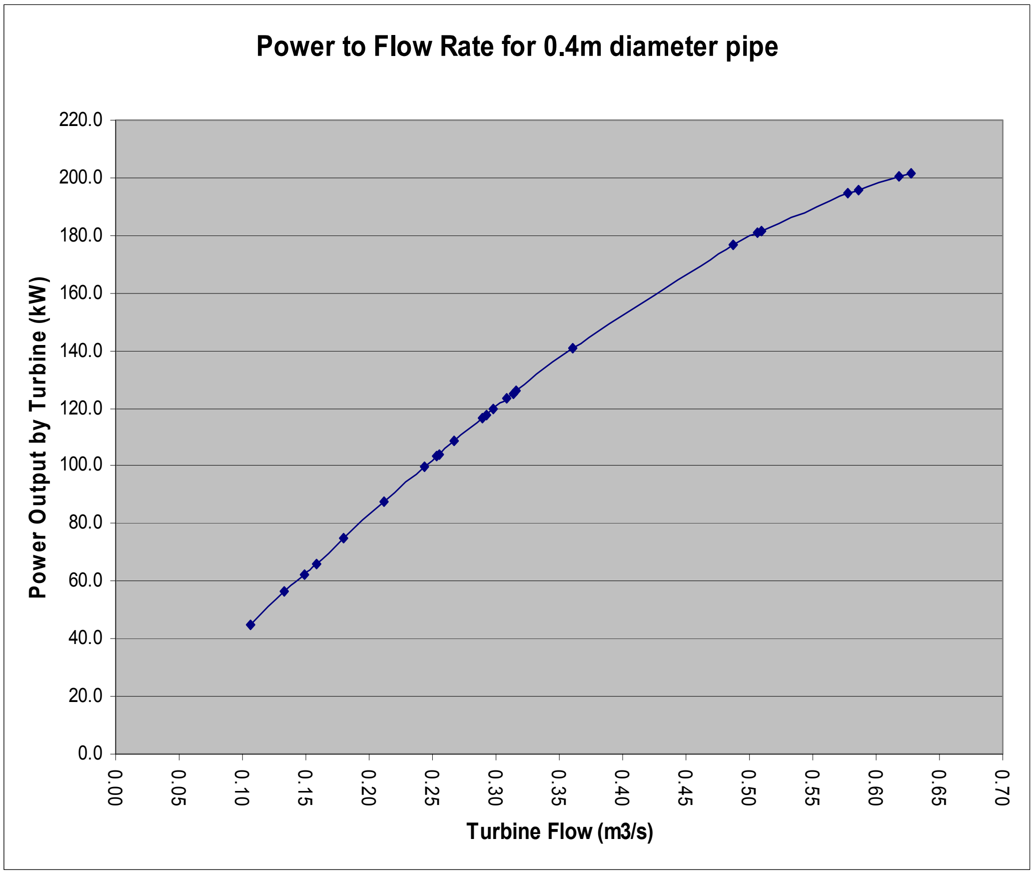


Figure 72.

The 0.4m diameter pipe produces power figures from 44.95kW to 201.52kW from flow rates of 0.106m³/s to 0.628m³/s.

The highest transmission efficiency of 99.77% is produced at a flow rate of 0.106m³/s producing 44.95kW

The lowest acceptable efficiency of 83.90% is produced at a flow rate of 0.509m³/s producing 181.52kW.

The Annual ADF of 0.447m³/s produces 159.48kW at 86.37% transmission efficiency.

This therefore gives a working power range of 44.95kW to 159.48kW at between 99.77% and 86.37% transmission efficiency, with the turbine being able to produce a maximum of 201.52kW at 75.5% transmission efficiency.

0.3m pipe diameter.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.628	400.444	-13.054	-8.702	-3.26	-2.17
February	0.509	324.564	104.399	69.592	32.17	21.42
March	0.506	322.651	106.356	70.897	32.96	21.95
April	0.298	190.020	145.838	97.216	76.75	51.11
May	0.212	135.182	119.274	79.508	88.23	58.76
June	0.267	170.253	138.474	92.307	81.33	54.17
July	0.316	201.497	148.816	99.201	73.86	49.19
August	0.360	229.554	151.660	101.097	66.07	44.00
September	0.487	310.536	117.703	78.461	37.90	25.24
October	0.578	368.562	46.174	30.780	12.53	8.34
November	0.618	394.068	0.010	0.007	0.00	0.00
December	0.586	373.663	37.703	25.133	10.09	6.72
Averages	**0.447**	**285.083**	**91.946**	**61.291**	**42.39**	**28.23**

Table 21.

0.3m pipe diameter using 50% ADF.

Month	Turbine Flow (m3/s)	Gross Power to Turbine (kW)	Net Power to Turbine (kW)	Power Output by Turbine (kW)	Transmission Efficiency (%)	Overall Efficiency (%)
January	0.314	200.222	148.535	99.013	74.19	49.41
February	0.255	162.601	134.918	89.936	82.97	55.26
March	0.253	161.325	134.289	89.517	83.24	55.44
April	0.149	95.010	89.487	59.652	94.19	62.73
May	0.106	67.591	65.602	43.731	97.06	64.64
June	0.134	85.445	81.428	54.280	95.30	63.47
July	0.158	100.749	94.164	62.769	93.46	62.25
August	0.180	114.777	105.040	70.020	91.52	60.95
September	0.244	155.587	131.334	87.547	84.41	56.22
October	0.289	184.281	143.982	95.979	78.13	52.04
November	0.309	197.034	147.777	98.508	75.00	49.95
December	0.293	186.831	144.836	96.548	77.52	51.63
Averages	**0.224**	**142.621**	**118.449**	**78.958**	**85.58**	**57.00**

Table 22.

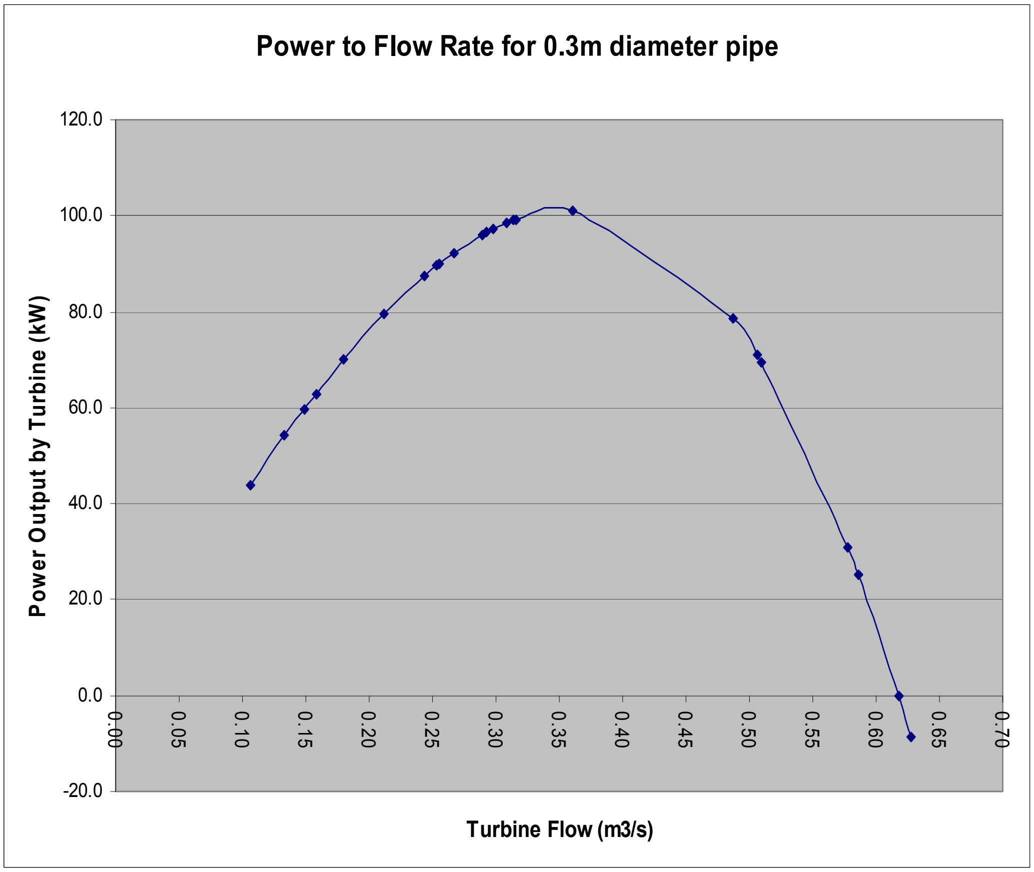


Figure 73.

The 0.3m diameter pipe produces power figures from 43.73kW to 0.007kW from flow rates of 0.106m³/s to 0.618m³/s.

The highest transmission efficiency of 97.06% is produced at a flow rate of 0.106m³/s producing 43.73kW

The lowest acceptable efficiency of 81.33% is produced at a flow rate of 0.267m³/s producing 92.30kW.

The Annual ADF of 0.447m³/s produces 61.29kW at 42.39% transmission efficiency.

This therefore gives a working power range of 43.73kW to 92.30kW at between 97.19% and 81.33% transmission efficiency, with the turbine being able to produce a maximum of 101.09kW at 66.07% transmission efficiency.

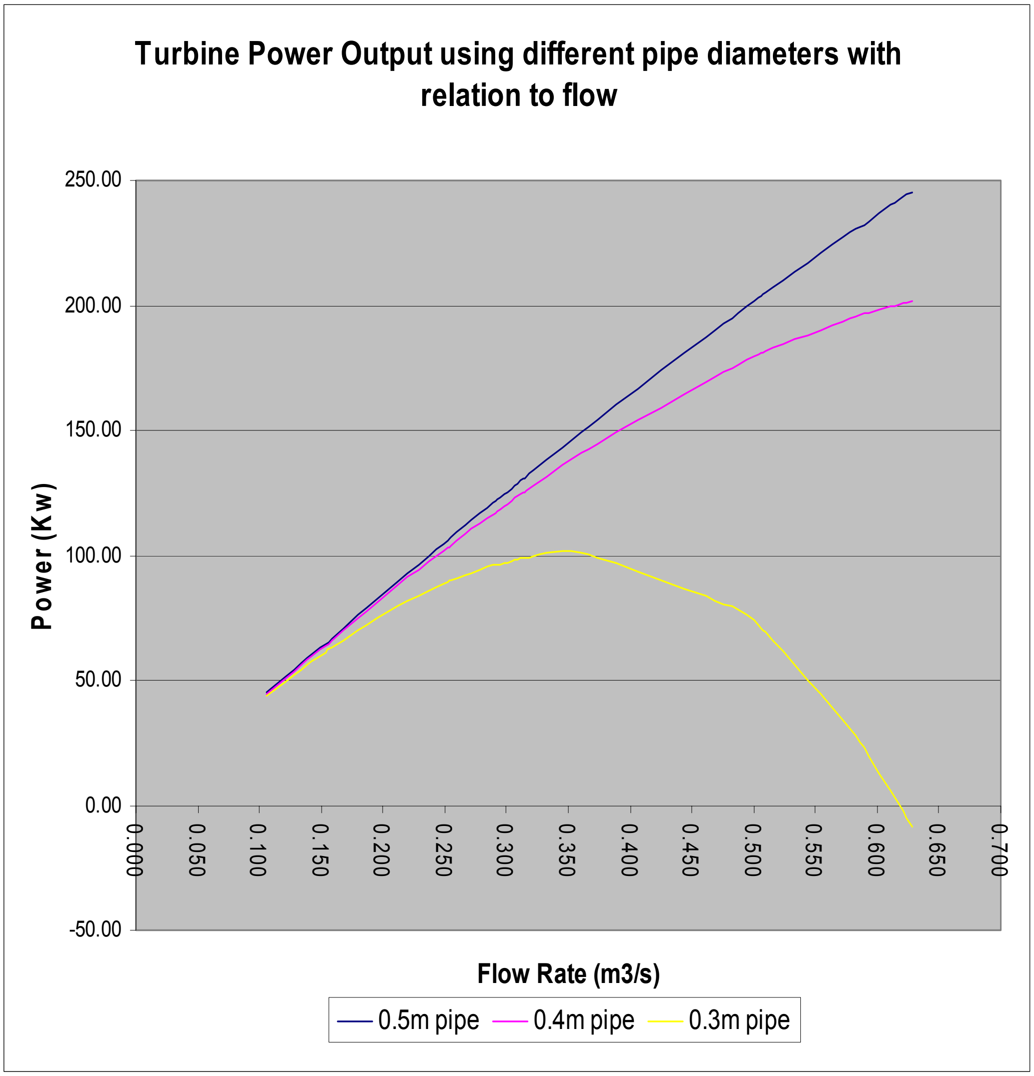


Figure 74.

This graph shows a comparison between the different pipe diameters and the power values. It was found that the smaller pipe diameter of 0.3m too small to handle the flow rates therefore the pipeline is effectively choked by the flow and overflow at the intake occurs, or over the dam as overflow.

General technical feasibility.

Both sites have been analysed for their prospective potential power outputs, and from this analysis it show that Site 2 would be more favoured due to the higher outputs that can be attained.

This type of proposed small hydro electric scheme is a tried and tested method of generating electricity which is clean, reliable and has a long life with little maintenance.

The proposed scheme itself is of a simple layout, although site assess and construction of the weir at Site 2 proposes a technical challenge; which can be overcome. The main obstacle for this development would be to try to keep the costs of construction to a minimum to ensure financial viability.

The estate owner has three possible options available to him to utilise the electricity generated by the scheme. These being;

Option 1. The electricity generated by the proposed scheme may be used at the point of generation on the estate; to supply workers homes, local utilities, or a fish hatchery that lies on the estate grounds, in place of electricity supplied by the local electricity company.

Option 2. Entirely export the produced electricity via the local grid distribution network by agreement with the Distribution Network Operator (DNO).

Option 3. To consume as much of the power as possible on site as in Option 1, as it is nearly always financially advantageous to do so and only export the surplus into the grid network as a subsidiary income to the estate.

If the scheme is to produce power for export to the local network, there should be early discussions with the DNO who will specify the system protection and metering equipment, and will also provide an estimate of connection costs and the best location for feeding into their system.

Proposed scheme layout.

The proposed scheme would be of a simple layout with a reinforced concrete overflow weir incorporating a trash screen cage. The weir would include an intake pipe connected to a buried penstock flowing down to the turbine house located on the edge of the woods. From the turbine and generator the power would go to the transmission lines for use. This simple layout is similar to the on shown in Figure 75.

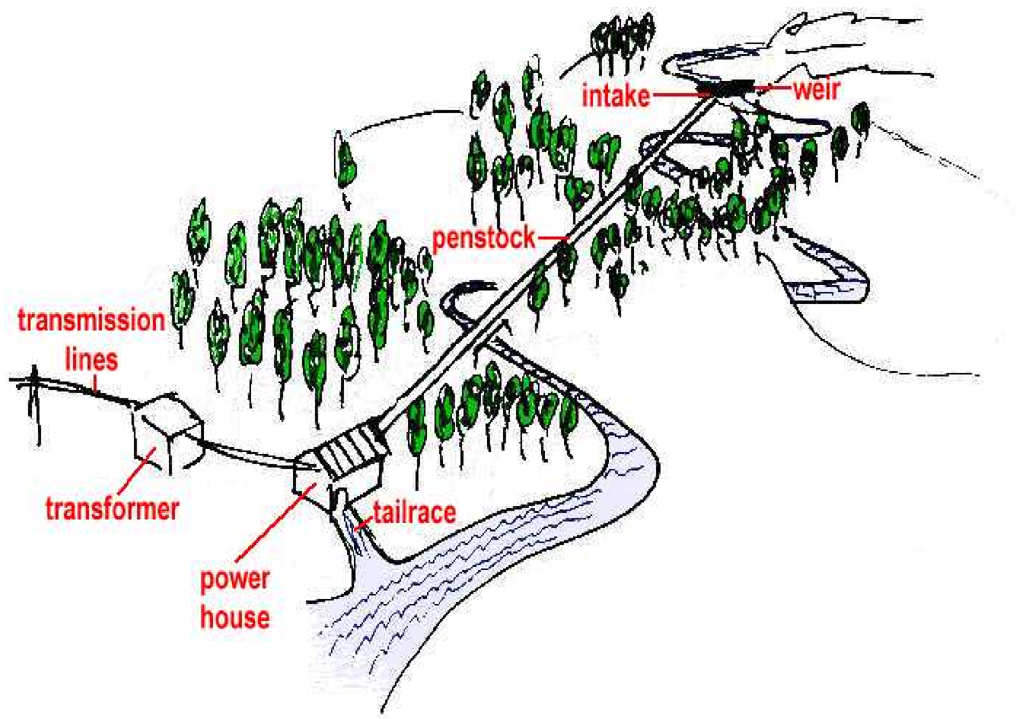


Figure 75.

Figure 76 shows the proposed scheme at Site 2 in relation to the surrounding area and main catchment area, showing the location of the weir, the proposed route of the penstock down the hillside to the turbine house.

Catchment area size	7.47	km²
Site altitude above sea level	75	m
Gross Head	65	m
Pipe Length	250	m

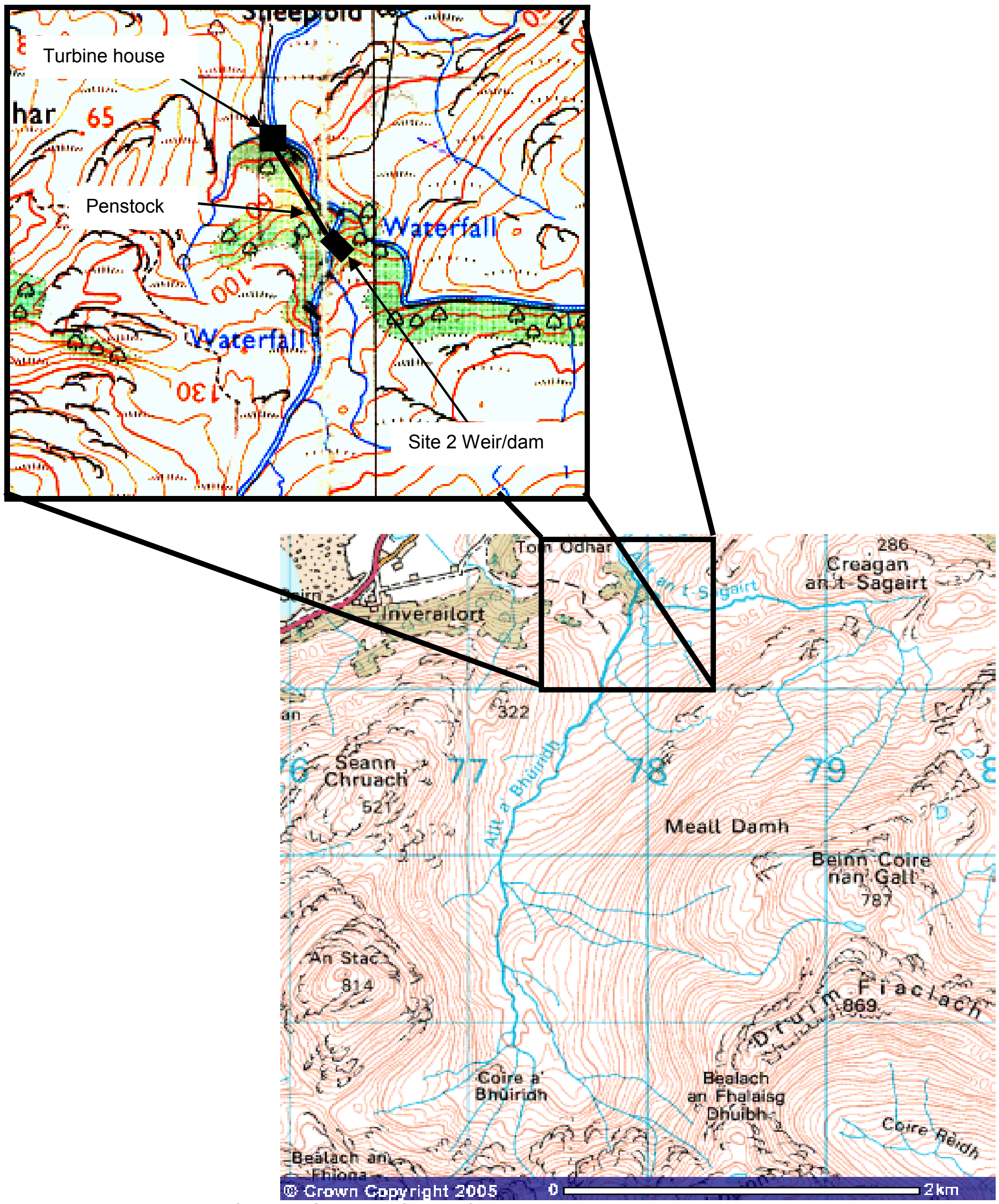


Image produced from the Ordnance Survey Get-a-map service. Image reproduced with kind permission of Ordnance Survey and Ordnance Survey of Northern Ireland.

Figure 76.

Generating equipment.

The basis lay-out of the turbine would be as delivered as an all-in-one containerised package, a so called “Plug in and Play” standardised unit, seen in Figure 77. This type of packaged unit provides all the electrical and mechanical equipment built on to a steel cradle. The system would have a maximum rating of 100kW and would include:

- the turbine
- generator
- control system

The proposed IT/NHT 100kW MiniPak system matches the requirements of the proposed scheme and the estimated total cost of this system = £68300

The turbine selected form this proposed scheme would be a crossflow turbine. This is type of turbine is chosen as it maintains a good efficiency at part flow and is applicable to the broadest range of head and flow of all turbines.

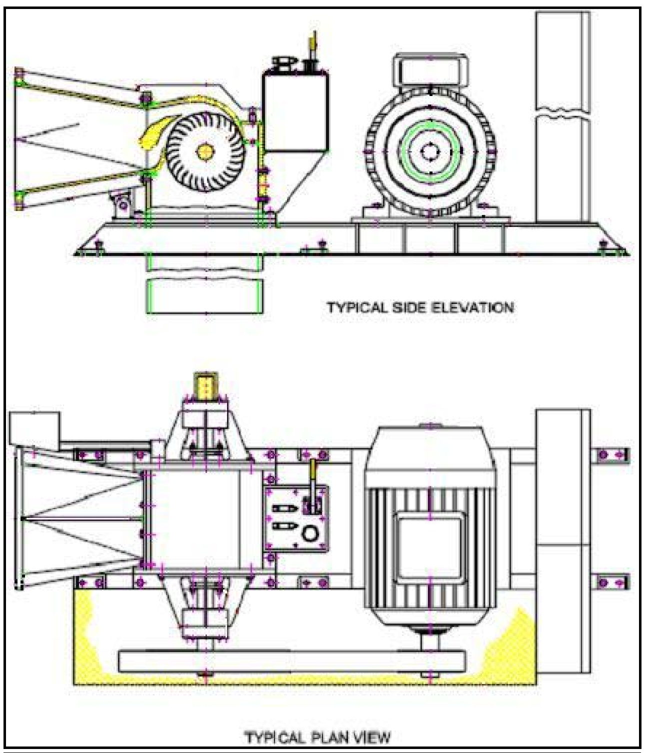


Figure 77.

The generator specifications would be chosen on the final outcome for the use of the power generated.
The control system would be a PLC (S7-200) system with G59 configuration and display all the information to the user, of all the major parameters to do with the working system. The control panel enclosure is mounted on the end of the steel cradle, giving easy access to electrical and mechanical controls.

Civil works.

Weir and intake.

The construction of a weir and intake would take place at Site 2, shown in Figure 78 by the yellow highlighted area. This is the best position at Site 2 to construct the weir and would give a large pond behind it and also use the least build material.

Figure 78.

The weir itself would be of an overflow design, which allows any excess water to flow over the entire crest of the weir, then down a Rip Rap front, thus aerating the water flow down to Site 1. The weir would also incorporate the intake pipe at the lowest elevation with a galvanised screen cage connected to the pond side of the intake. The grid size of the trash screen would suit maximum permissible particle size allowed through turbine.
The area would have to be cleaned of debris, loose and weathered rock, and vegetation that would interfere with construction. The weir is approximately 10m in length, 1.5 m high and a base 1m wide, reducing to 0.5m at the top. Construction of the weir would be of Class C40 concrete with a 5% air entrainment to improve susceptibility to frost damage.
The weir would be constructed in formwork, in accordance with the design, allowing weir constructed in two sections, one main section on formation above water level, and the second section at existing outlet of pool. The ends of the weir may need permanent sandbagging or equivalent to conform to the natural sidewall profile. The mass of concrete will be cast directly onto a prepared base, where steel reinforcing mesh is connected to dowels drilled into the rock bed between the rock and concrete, this is due to the weight of

the concrete will not be enough to resist the hydrostatic pressure of the contained mass of water.
Figure 79 and 80 show a basic assumed design and construction (not to scale) of the overflow weir intended, and a basic cross-sectional view of the weir.

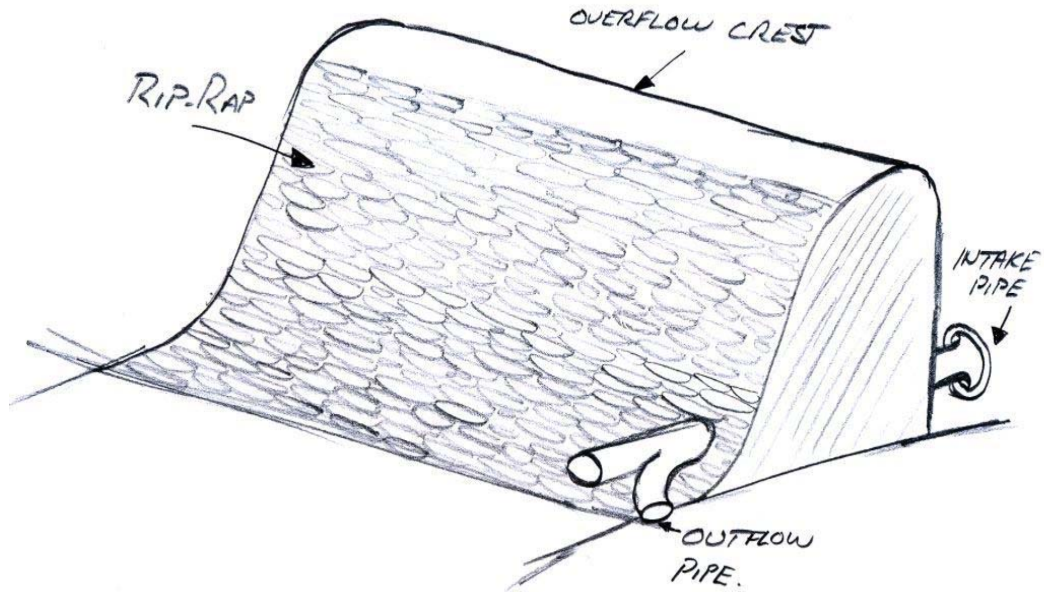


Figure 79.

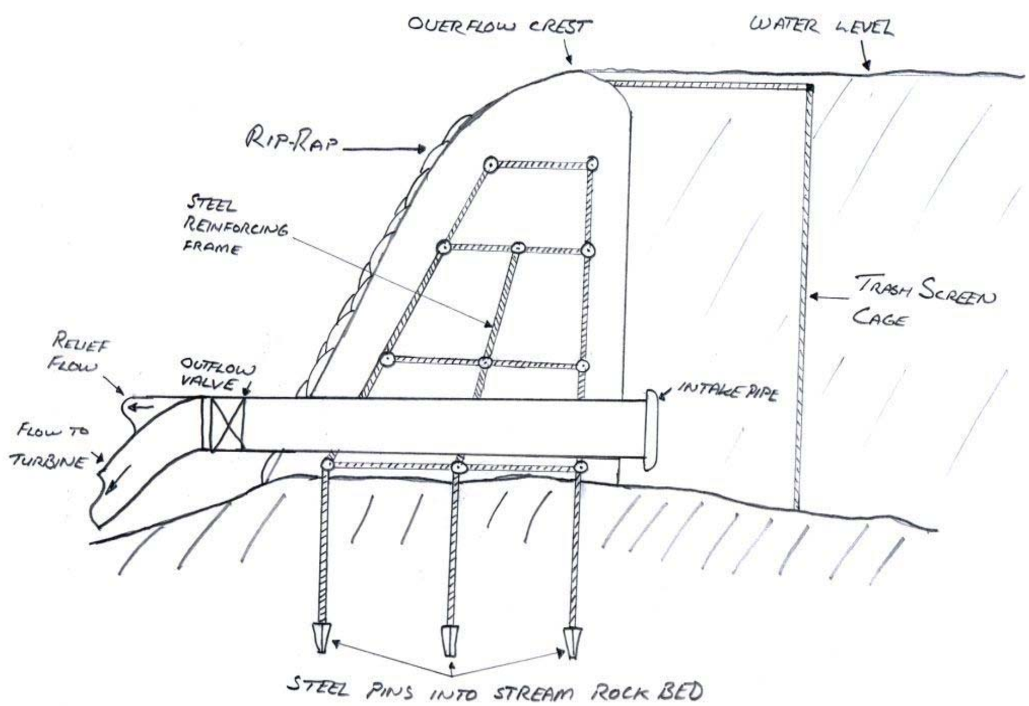


Figure 80.

Penstock.

The penstock would carry the water down a 250m long, 400mm internal diameter HDPE (High Density Polyethylene) pipeline down from the intake through the weir to the turbine house. The HDPE pipework would be connected with the sections butt-welded together, and once the pipework is fully installed should be pressure tested to 6 bar to ensure of no leaks in the seals or joints. The pipework should be buried or laid above ground on sandbags or dry mix concrete haunches every 5m to secure the pipeline.

Turbine house.

The turbine house would be located at Grid location 7785 8175, Pathfinder Map 262 (Arisaig & Lochailort) (NM 68/78) 1:25 000, edition A.
The turbine house would sit on the edge of the woodland surrounding the proposed site which could be easily camouflaged using local trees and scrubs. The turbine house would be of a containerised construction, housing the turbine, generator and control system, built on a steel cradle. With this so called "Plug in and Play" standardised unit, the only requirement for civil works would be the construction of a reinforced concrete mounting plinth incorporating the turbine draft tube or tailrace for the turbine to expel flow into the Roti Burn.

Site assess.

There is an estate track that runs up into the corrie to the west of the proposed site on the outside of the woodland area, and within the wood there is a rough track near the proposed site. It is assumed that a track constructed of Type 1 aggregate 100m in length and approximately 4m wide could be laid down to the proposed site for the construction of the overflow weir and penstock. This would need general clearance of shrubs and trees with the in-situ surface material excavated down to a depth of 0.25m and the material stockpiled for re-instatement of the road, disposal or use elsewhere on the estate. The Type 1 would be laid 0.15m thick and compacted to create the access road, which could be upgraded during the works as required. At the end of the construction of the development this road could easily be camouflaged using the surrounding woodland's scrubs and ferns.

Costs.

The civil works costing strategy is based on a basic costing of the intended job based on plant, labour and materials in the crudest form. The costs provided are based on the Civil Engineering Standard Method of Measurement; included costs are for labour, plant and all terrain vehicles, tippers etc. Some costs have been assumed, and a contingency of 30% has been added to cover smaller items overlooked at this stage (power supply, PPE, telephone charges etc - even construction details which have been overlooked, and if an alternative design is used the quantities would have to be reduced or increased. Table 23 shows a costing breakdown for the civil works.

Number	Item Description	Unit	Quantity	Rate	Amount
A	**Quantity Items**				
A223	Provision of as built drawings	sum			100
A250	Testing of materials (concrete)				60
A277	Allowance for dealing with all water (ground, surface and standing) during the construction of the Works to include establishment, maintenance and renewal of all associated plant and disposal of pumped waters in accordance with the Special Conditions forming part of the Conditions of Contract	sum			500
A415	Provide the sum of £2000.00 for plant	sum			2000
A416	Percentage adjustment to provisional sum for plant	-12.50%			-250
	Contractors accommodation, supervision, attendances				100
	Establish concrete plant				300
	Mobilisation (Fixed)				500
D					
D1	**Demolition and Site Clearance**				
D10	General Clearance				
	General site clearance within boundaries to include hedges, shrubs, small trees; to include associated stumps, and timber post and wire fences	ha			600
E					
E4	**Earthworks**				
E421	General Excavation				
	General excavation of Public Highway not exceeding 0.25m	m2	400	0.4	160
E422.1					
	General excavation of rock or artificial hard material (to prepare formation for weir).	m2	10	30	300
E5					
E532	Disposal of excavated material of site	m^3	400	3.15	1260
	Excavation Ancillaries				
E7					
E712	Filling Ancillaries				
E8	Trimming of filled surfaces – Type 1, Public Highway	m2	400	0.2	80
E810	Landscaping				
	Landscaping to road (camouflage)	sum			800
	Total				
I					
I992.1	**Pipeworks - Pipes**				
I992.2	400mm diameter HDPE pipe to turbine house. Including all connections and water pressure tested.	m	250	40	10000
	400mm diameter HDPE pipe through weir.	m	2	40	80
K	Total				
	Pipework – Manholes and Pipework Ancillaries				
	Manually operated galvanised gate valve for 400mm diam inlet/outlet.	nr	1	300	300
R					
R114	**Roads and Paving**				
	Granular type 1 depth 150mm thick in carriageway reconstruction, Public Highway	m2	400	3	1200
	C40 mass concrete (5% air) to include all formwork. Weir and turbine house plinth including tailrace	m3	20	100	2000
X					
	Miscellaneous				
X113					
	Galvanised screen cage to intake.	nr	1	200	200
	Sub-total				20290
	Add 30% contingency				6087
	Total			**£**	**26377**

Table 23.

Grid connectivity.

The nearest National Grid power line is located 1.5 kilometres from the proposed sites' turbine house. The National Grid runs into Fort William at 33kV 3 phase on pylon lines and from this is stepped down via transformers to 11kV 3 phase for distribution out of Fort William to local areas running along side of the railway lines parallel to the A830 to Arisaig and then to Mallaig. The proposed development would have to be compatible with the National Grid lines or the Inverailort rural network, depending on the intended use of the proposed scheme's energy.

There are associated costs connecting to the Grid, and the work can only be carried out by the local electricity board (Scottish Hydro Electric) who charge the following costs.

Local Grid connection charge = £120000

Overhead power lines 3 phase = £35000 per km

Underground power lines 3 phase = £70000 per km

This local network consists of:

Fish farm hatchery – 415 volts 3 phase (on Estate)
Inverairlort Inn – 240 volts single phase (on A830)
Local houses – 240 volts single phase (on Estate)

Annual Energy Capture.

Annual energy capture is the term used to describe the total number of electricity units which can be generated at one site over a year.

Annual Energy Capture = Power Output at Rated Flow x Capacity Factor x Hours in a year

Where: Power output = 100kW
Capacity factor = 0.4
Hours in a year = 8760

Therefore: Annual Energy Capture = 100kW x 0.4 x 8760hours

= **350400 kWh**

It must be noted that the capacity factor used is a very conservative figure and is used for baseline figures only. The proposed site could possibly have a higher figure of approximately 0.65 due to annual rainfall figures.

Environmental and Visual impact.

Planning consent.

The Highland Council Planning and Development Service would assess the planning application. The authority would take into consideration any input and objections placed by the Scottish Natural Heritage and SEPA (Scottish Environmental Protection Agency). The wildlife and protected areas of concern to these agencies concerns can be seen in Appendices 5, 6 & 7.

Visual impact.

There would be some visual impact from the proposed scheme but it is felt that it would be in no way detrimental to the surrounding area. Although the proposed development would be constructed on a privately owned estate, it would be desirable for the hydro scheme to be as environmentally friendly and as unobtrusive as possible. The weir although being of reinforced concrete in construction would be have a "Rip Rap" facing, made of locally sourced stone, camouflaging the weir. Also being of an overflow design would keep the water flow aerated and keep the visual effect of the surroundings, that being of a waterfall.
The only visual feature that would be seen at the weir, would be the intake pipe connected to the penstock with the outflow valve at one side. Over time this would be overgrown with foliage, but requires to be kept clear of debris to reduce the risk of equipment failure.
The penstock being buried as much as possible, and if not could be faced with local stone, making it look like an old dry stone dyke running through the woodland. The turbine house would be hidden using local scrubs, trees, ferns and stone and would blend well into its surroundings. The assess road built during the construction of the scheme would become overgrown at the edges and in patches of the road with local ferns and grasses, hiding it well and only visible if on the road itself.

Aquatic Habitats and Species.

The proposed scheme would pose no impact to fish as there was none found at Site 2 due to the altitude above Site 1 waterfall.
The proposed scheme would create a large pond at Site 2 and is thought it would create a friendly environment for local species, i.e. frogs etc.

Wildlife.

As the land on which the proposed scheme is to be built on, is a deer forest estate with wild deer roaming freely, the scheme is seen not to have any impact on the well being of any deer species. Although the presence of protected species such as badgers and red squirrels is of concern (Appendix 7), and would require consultation if any of these animals were found within the boundaries of the construction site of the proposed scheme in general.

Financial Viability.

Capital Costs.

A break down of the total capital costs for the proposed scheme is shown below.

		Grid Connection	Grid+Rural Connection	Non-Grid Connected
		£		£
Civil Works		26377	26377	26377
Dam				
Pipeline				
30% Contingency				
Turbine Pack		68300	68300	68300
Turbine Pack				
Generator				
Control System				
Turbine House				
Grid Connection (Overland)		212500	212500	
Step-up Transformer	40000			
Grid Connection to Scottish Hydro	120000			
3 Phase Power lines from Turbine to Grid				
1.5km Overground	52500			
1.5km Underground (Optional)	105000			
0.5km Overground (Non-Grid)			17500	17500
Auto Change-Over Switchgear		1000	1000	1000
Cables		10000	10000	10000
External Costs		10000	10000	10000
Total		**£328,177**	**£345,677**	**£133,177**

Table 24.

Annual running costs.

Modern, automated equipment requires very little maintenance. The cost of routine inspections and an annual service should come to no more than 2% of the capital cost of the scheme. As the machinery ages, there will eventually be extra costs associated with replacing seals and bearings, a new generator, etc., but these should not occur for at least 10 years.

Potential annual income.

As we have seen the Annual Energy Capture = **350400 kWh**

Therefore if sold at 9.8pkWh = **£34339.20**

(The price of 9.8pKwh is taken from the Non-Fossil Purchasing Agency website www.nfpa.co.uk)

If bought from Scottish Hydro Electric at 10p/kWh = **£35040**

Scheme payback period.

Using the Simple Payback method shown below, able 25 shows the yearly payback for each proposed scheme.

$$\text{Simple Payback} = \frac{\text{Total Capital Cost}}{\text{Annual Revenue} - \text{Annual Expenditure}}$$

Years	Grid Connected	Grid+Rural connection	Non-Grid Connected
1	£27776	£27426	£31676
2	£55552	£54852	£63352
3	£83328	£82278	£95028
4	£111104	£109704	£126704
5	£138880	£137130	£158380
6	£166656	£164556	
7	£194432	£191982	
8	£222208	£219408	
9	£249984	£246834	
10	£277760	£274260	
11	£305536	£301686	
12	£333312	£329112	
13		£356538	
14		£383964	
15			
No. Years to Payback	11.8 years	12.6 Years	4.2 Years

Table 25.

Maximising revenue.

As the Estate owner operates 'clean' electricity plant they can generate revenue by selling:

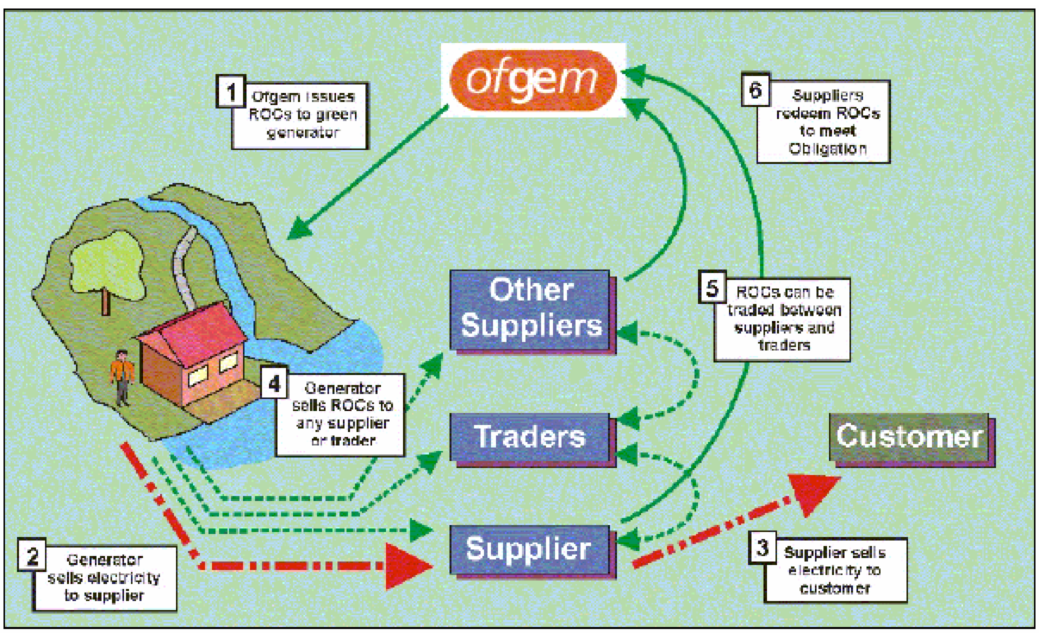
- The electricity itself.
- Renewable Obligation Certificates.
- Levy Exemption Certificates.

If the electricity generated by the hydro-scheme can be sold directly to an electricity company the price p/kWh would be lower than that if buying from the electricity company.
Alternatively, there is an electrical load close to where the power is being generated, the estates' fish hatchery. It would be more beneficial to use the hydropower to feed that load, so displacing electricity that would otherwise be bought in from the grid. For some small schemes, some electricity companies are willing to enter into a special contract which will balance the energy generated against the energy consumed on site on an annual or quarterly

basis. Furthermore, business customers who would otherwise have to pay an extra 0.43 p/kWh for the Climate Change Levy will make that additional saving on any hydroelectricity they buy from the scheme.

Renewable Obligation Certificates (ROCs).

Electricity generated from renewable sources can be used to obtain Renewable Obligation Certificates (ROCs) issued by Ofgem, and is the name given to the digital certificates which holds details of exactly how a unit of electricity was made, by whom and finally who bought and used it. Electricity supply companies require these in order to prove they are meeting the governments' targets of generating a minimum of 10% of their electricity output from sustainable sources. These ROCs are traded separately to the actual electricity itself and work as a bonus premium on top of the price paid for the unit. ROCs have a market value in the range 3p – 4.5p per kWh which will vary over time depending on how well these companies are doing in reaching their targets. If they have not managed to produce the required amount of green energy themselves, they must buy ROCs on the open market to make up the shortfall. If they fail to buy the required amount fines can be imposed, and provides the financial incentive to encourage generators to invest in Renewable Energy Schemes of their own, and private developers. This process is shown below in Figure 81.



Courtesy of Ofgem

Figure 81.

Levy Exemption Certificates (LECs). (Ref 25)

Green electricity which is sold into the grid will generate Levy Exemption Certificates (LECs) which can be sold on to business customers to enable them to avoid paying the full Climate Change Levy. The LECs can be sold for up to 90% of the Levy value.

Electricity Traders. (Ref 25)

There are several options on who to approach to obtain the maximum income for your scheme. Not only will any one of the main electricity supply companies (Powergen, Npower, etc.) make an offer for your output (including the ROCs, LECs, etc.), it is also possible to approach a range of specialist electricity trading companies which focus purely on getting the best price for renewable energy schemes. The British Hydro Association (BHA) would be able to advise on which companies are offering the best deal for mini-hydro generation.

Financial assistance.

There are various grants and loans which are available for the development of renewable energy projects at this time, but the only way of being able to find out how much exactly would be given to this type of project, an application would have to be made.
There are also a wide range of regional funding mechanisms available which can offer grants towards small-scale renewable energy projects. District and County Councils are able to advise on the availability of such funds.

Grants.

The Scottish Executive operates grant schemes which can help with the funding of renewable projects and the Scottish Community and Household Renewables Initiative (SCHRI) is being run jointly by EST and Highlands and Islands Enterprise on behalf of the Scottish Executive. This Initiative offers grants, advice and project support, and SCHRI funding can be used by householders and community groups to install small scale renewable energy schemes, such as hydro, wind, solar water, heat pumps and solar power.

Households can get 30 per cent of the capital costs of installing the system, up to £4000. Community groups are eligible for capital grants of up to £100,000, and up to £10,000 funding for a feasibility study. Under SCHRI there is no set grant funding. The amount of funding awarded is determined on a case by case basis with the average grant being in the region of 50 per cent. Projects with exceptional demonstration value or groups with limited resources may be eligible for a higher percentage of funding. Businesses may apply provided that they form part of a community consortium, and that the project is non-profit distributing. The scheme will support micro hydro, but is not limited to. Householders and community groups in the Highlands can access information on SCHRI from Highlands and Islands Enterprise, and from the Energy Savings Trust.

Further sources of funding for renewable projects, some of which are more generic business support / start-up orientated include:

- Carbon Trust incubator programme
- Carbon Trust venture capital

The Carbon Trust provides funding for innovative research and demonstration projects that have significant potential to reduce UK greenhouse gas emissions; application deadlines are quarterly. The Innovation programme is targeted at housing sector projects (involving local authorities or housing associations) that reduce carbon emissions. Grants pay up to 70% of the cost of a feasibility study, and 50% of implementation costs.

- European Structural Funds
- Regional Selective Assistance

Regional Selective Assistance (RSA) Scotland can help with capital investment projects which will create or safeguard jobs in the Assisted Areas of Scotland.

- Business Growth Fund

The Business Growth Fund aims to improve the availability of finance for start up and growing companies in Scotland. The Fund provides loans and equity investments between £20,000 and £100,000 to businesses which show ambition to grow, and that satisfy various criteria relating to their size and commercial viability.

- Scottish Co-Investment Fund
- Scottish Institute for Enterprise
- SMART / SPUR and SPUR PLUS

SMART, SPUR and SPUR PLUS support projects, which represent a significant technological advance for the UK sector or industry concerned.
They are aimed at helping small and medium sized businesses improve their competitiveness by developing new, highly innovative and commercially viable products or processes.

- DTI's capital grants scheme under the Technology Programme

Consultancy assistance.

Local enterprise companies, local authorities and other agencies also offer grants to help offset the costs of hiring consultants to develop and grow businesses. Again, the Business Gateway should be able to give advice on what's available locally.

Tax breaks. (Ref 25)

As a business investment, hydro projects are 100% tax-deductible in the year that the investment is made. For domestic and all other VAT-paying developers, the government has reduced the VAT payable on hydro-electric plant to 5%. Since many components of a hydro-scheme are not obviously "hydro-electric plant" on their own, the best advantage of this tax-break will be obtained by requesting a hydro installer to procure all hardware for the scheme which he can then genuinely pass on as part-and-parcel of the overall hydro-plant.

Chapter 7.

Discussion.

The feasibility study was completed and the results obtained. These results illustrate that there is potential for a micro hydro generating plant on the Inverairlort Deer Forest Estate.

A Crossflow turbine, the most efficient turbine at the available head and flow rate (Figure 82) was selected, and other factors such as ease of and costs of maintenance, the ability for the turbine to cope with particle matter through the turbine blades, as the water flowing from the corrie would most likely on contain abrasive soil and peat traces, also helped in its selection. The "Plug and Play" system that is available also lowers costs as it would be an off-the-shelf design with the specifications of the site matched to the entire system in a single containerised package.

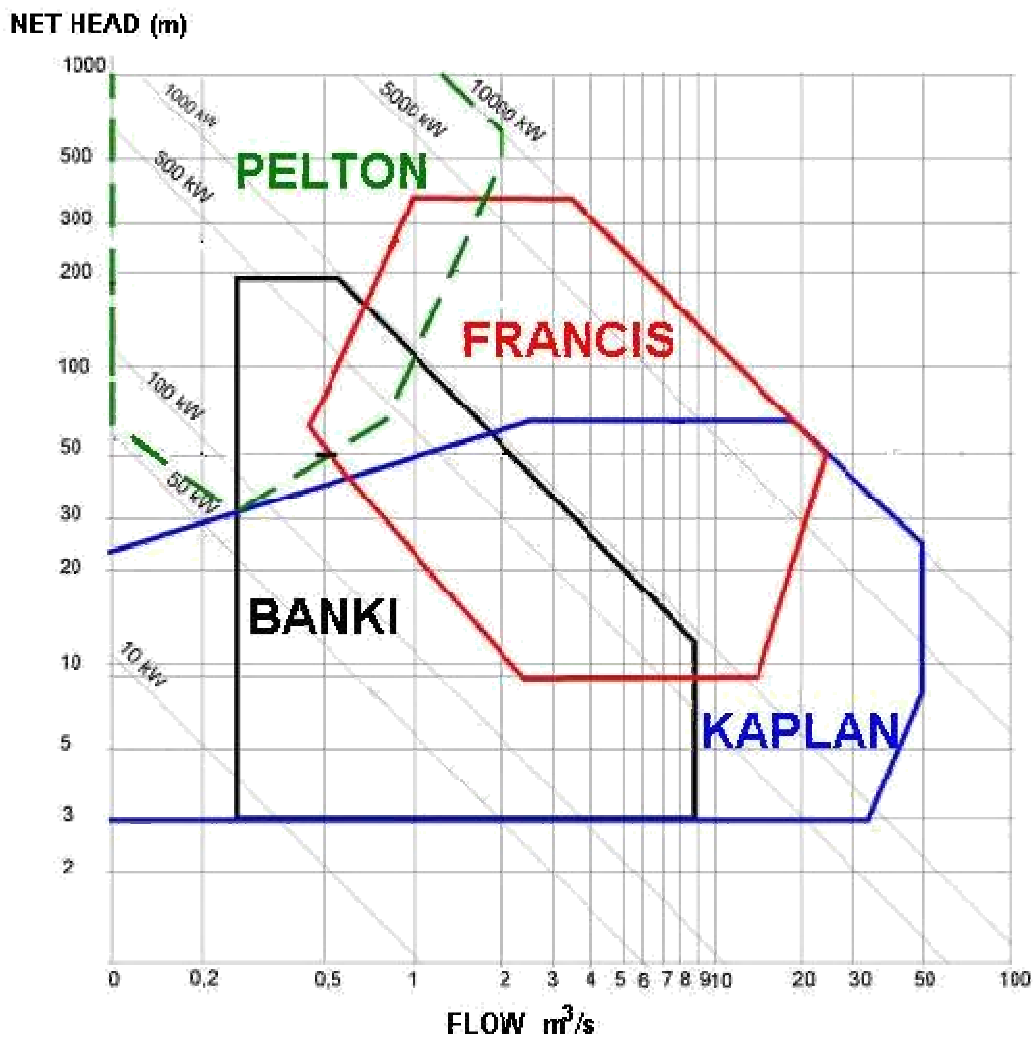


Figure 82.

The choice between sites 1 and 2 has got a lot to do with practicality of access, routes for pipe work etc. In terms of assess Site 1 would be easier to develop, but would have a lower output. Site 2 is a little bit trickier to construct with some heavy groundwork's having to be done to get the site prepared for the construction of the dam/weir.

The dam for Site 1 would have to be 2/3 times larger than that of the Site 2 dam, due to the lye of the land so to speak, and C40 concrete at £90 - £120 a cubic metre means the civil works costs would increase. Looking at Site 1, if you go for a 200 kW system it will run below peak for most of the time and the stream will practically disappear. A 100 kW system would work flat out for much of the year; output would fall a bit in the summer but so would demand.

At Site 2 the fact that using a 200kW system would basically remove the stream from flowing down to Site1, but even at full capacity the system only uses 75% of the water available, because Site 2 loses 25% of the catchment but gains altitude. Another option is to use a 50kW max 'plug and play' multi cell Crossflow system; this would give a higher capacity figure and would still leave enough flow to tip the weir for environmental reasons. This would also be a more conservative power figure to supply the local network and not the main grid. Using a 100kW max 'plug and play' multi cell Crossflow system, down a 500mm diameter HDPE penstock, even using 50% of ADF or less would still produce enough power to look attractive, and if the energy production is based around this assumption and a capacity factor of 0.4 for an average would make the annual energy capture 350400 kWh. Although if the capacity factor was higher it would make more money for the estate in the long run.

From the power analysis a 500mm diameter penstock looks the most practical, although the use of a 400mm diameter HPDE penstock linked to the 100kW system would keep the pressure at the turbine more constant, providing a more sustained level of power output over a period of time.

For any system there is a trade-off between high power and capacity factor, so a compromise is inevitable. Using the stream up completely to produce the maximum power available, thus removing the stream, would not get planning permission for environmental reasons. Whereas installing a lower capacity system would not be financially viable, giving low output and a longer payback period. Also surplus could not be supplied to the local grid for financial gain to the estate.

Social, environmental and economic factors.

The affects of an energy system or plant on a local rural community can be summarised into three main categories.

- Social
- Environmental
- Economical

Social.

The social changes involved with this development would that estate staff would have increased responsibilities with the upkeep and maintenance of the weir and plant facilities. It would also be a talking point with the community and may show a level of local pride in the scheme and its construction if the estate staff build the scheme themselves and are self sufficient to an extent.

Environmental.

The implications to the local environment would be minimal with the water source from the corrie only being a mountain run off and would have no environmental impact to the flora, wildlife or spawning fish within the area of the development. Although it is noted that the weir itself would have a Rip-Rap facing on it made from local sourced boulders and this would also help with its camouflaging, as too the turbine house and assess road would be hidden using local scrubs and plant life to blend into the environment. The scheme itself would be emission free and the present required needs for fossil fuel to heat homes could be offset by this development. It would show an ideal approach and help raise awareness to renewable energy within the local area and possibly further projects.

Economical.

The economical implications of the scheme would not only benefit the estate owner but also the local community as the energy produced could be either fed to the local grid, saving the community an annual saving in electricity bills or revenue from supplying the main grid.
The type of system considered would rely heavily from funding as all hydroelectric schemes require a large capital investment at the start of the project.

Chapter 8.

Recommendations.

This thesis has illustrated the potential of a micro hydro generating plant on the Inverailort Deer Forest Estate, although there are a number of considerations and recommendations to be submitted for thought.

Since any hydro scheme requires a substantial up-front investment, it is clearly essential that the project is implemented correctly and with robust engineering and equipment. To the estate owner there are two options open to him. Firstly handing over the entire project to a contractor to complete the project, from the owner's point of view, this greatly simplifies the management of the job. However, since the main contractor is taking on most of the risks and unknowns, this will inevitably be reflected in the cost of the tender.

The other option is to do the work hand in hand with a supplier. It may be possible for the estate owner and his workforce along with local contractors to share the tasks of implementing the scheme with the equipment supplier, possibly using second hand or refurbished generating plant i.e. turbine, generator and transformer. This approach can lead to significant savings on the project cost, but requires the responsibilities of the different parties to be very clearly defined. Even if the owner is keen to adopt a DIY approach, there are certain activities where professional inputs will be essential to ensure the technical viability of the scheme.

Due to the various grants and funding schemes available, how the proposed scheme is constructed and commissioned would inevitably be taken into account when the scheme is submitted for funding and planning. Some funding would only be granted if a professional contractor specialising in this type of scheme is used or if the scheme is completed to a specification provided by the equipment supplier or hydro-power consultant.

This thesis has shown that there are a number of grant and funding schemes open to this type of project and a more in depth review of these schemes linked to the economic viability would be prudent due to the service these schemes expect.

A vital piece of data for this thesis was unobtainable, that being the electricity demand loads for the estate housing and the fish hatchery. These would greatly help the proposed scheme's use and specification and a study into these demand load profiles would be of considerable help, so to help match supply and demand.

Chapter 9,

Conclusion.

The aim of this thesis have been accomplished successfully. This feasibility study has shown that there is sufficient rainfall over a sizeable area, through a single outlet at an appropriate height to warrant the possibility of a micro hydro generating station constructed on the Inverailort Deer Forest Estate.

The results have shown from the analysed rainfall data, that there is the potential to produce anywhere up to 162.30kW from Site 1, to 245.50kW at Site 2.

From this analysis of both proposed sites, Site 2 would be potentially the best site to develop into a micro hydro plant. This site would consist of a 100kW multi cell Crossflow turbine system, of a standardised form, incorporating the generator and control system in a containerised package. The turbine would be fed through a 400mm diameter HDPE, 250m long penstock connected to an overflow weir built at Site 2.

Three possible uses of the produced power were considered, these being a solely grid connection supplying the main distribution network, secondly a main grid and rural (or local) grid connection, where power would supply the estates own network with the excess being exported to the main grid for financial gain, and finally a non-grid connected system supplying only the estates own power network. The costs of these are shown below with time it would take to payback the cost of the proposed systems.

Grid Connection	Grid+Rural Connection	Non-Grid Connected
£328,177	£345,677	£133,177
11.8 years	12.6 Years	4.2 Years

Table 26.

The power produced would feed the estates' fish hatchery and the excess could be used to power local housing within the community. Although there are certain civil works difficulties to overcome. The recommendation is technically sound, but where the economics play a major role in the decision to build the proposed scheme. Where the final costs of this project would be driven and determined by grant and funding assistance.

As electricity becomes more expensive to rural communities it is important to consider utilising any renewable energy resource available.

Further research.

This thesis has illustrated that within the grounds of the Inverailort Deer Forest Estate, there is a potential of a hydroelectric generating scheme although small in comparison to major schemes it has the capacity to generate power to not only the local population but the national grid.

Further research work would involve two areas of interest to the project. Firstly a study into the local grid within the estate to find out the load demand for domestic use and also the commercial load demand on a salmon hatchery that is within the estate. An idea of this would allow for a more detailed study into the load demand profile for the estate and would allow a hydroelectric scheme to be better tailored to this demand profile.

The second area of further study would be a proposed Site 3 which lies further up in altitude to Site 2 on the same water source.

- Proposed Site 3 – Grid location 7790 8145, Pathfinder Map 262 (Arisaig & Lochailort) (NM 68/78) 1:25 000, edition A,

Site 3 (Figure 83) has an altitude of 105m above sea level on the flow of Allt a' Bhùiridh out of the Coire a' Bhùiridh and this site is the top waterfall in the series that flows down to Site 1 and Site 2. The waterfall at Site 3 flows into a sizeable pool which is walled on all sides by natural rock creating a natural pond. The flow out of this natural pond flows out down into another smaller pond and then down to Site 2 (Figure 84). Site 3 lies about 100m from Site 2 but has 30m more in altitude and therefore it would be possible to use the calculated ADF figures in the potential power that could be attained. With respect to the civil works at Site 3 a smaller, but higher weir could be constructed to create a reservoir which could would be deep and hold plenty of water due to the high natural rock sides as seen in Figure 84. One serious consideration would be the assess to Site 3, it is located at the top of the forested area in a deep gully with the ground sloping at nearly a 45 degree angle down to the pool (Figure 85). Due to the location of Site 3 being at the edge of the forested area it could possibly be visible, and therefore have planning and environmental implications to the proposed site development. This also would affect the construction of the pipeline to the turbine house which would certainly have to cut through surrounding rock and then hug the hillside till its path down to the turbine. Due to different pipeline lengths, altitude and the ADF of this site, the proposed multi-cell crossflow used in the thesis for Site 2 would change to a different turbine type. Although the turbine type might change there are many manufacturers that built so called "Plug and Play" turbine systems of all types that might suit the characteristics of this site along with the investigated load demand profile to the estate. Both these areas of research would require further consideration and investigation.

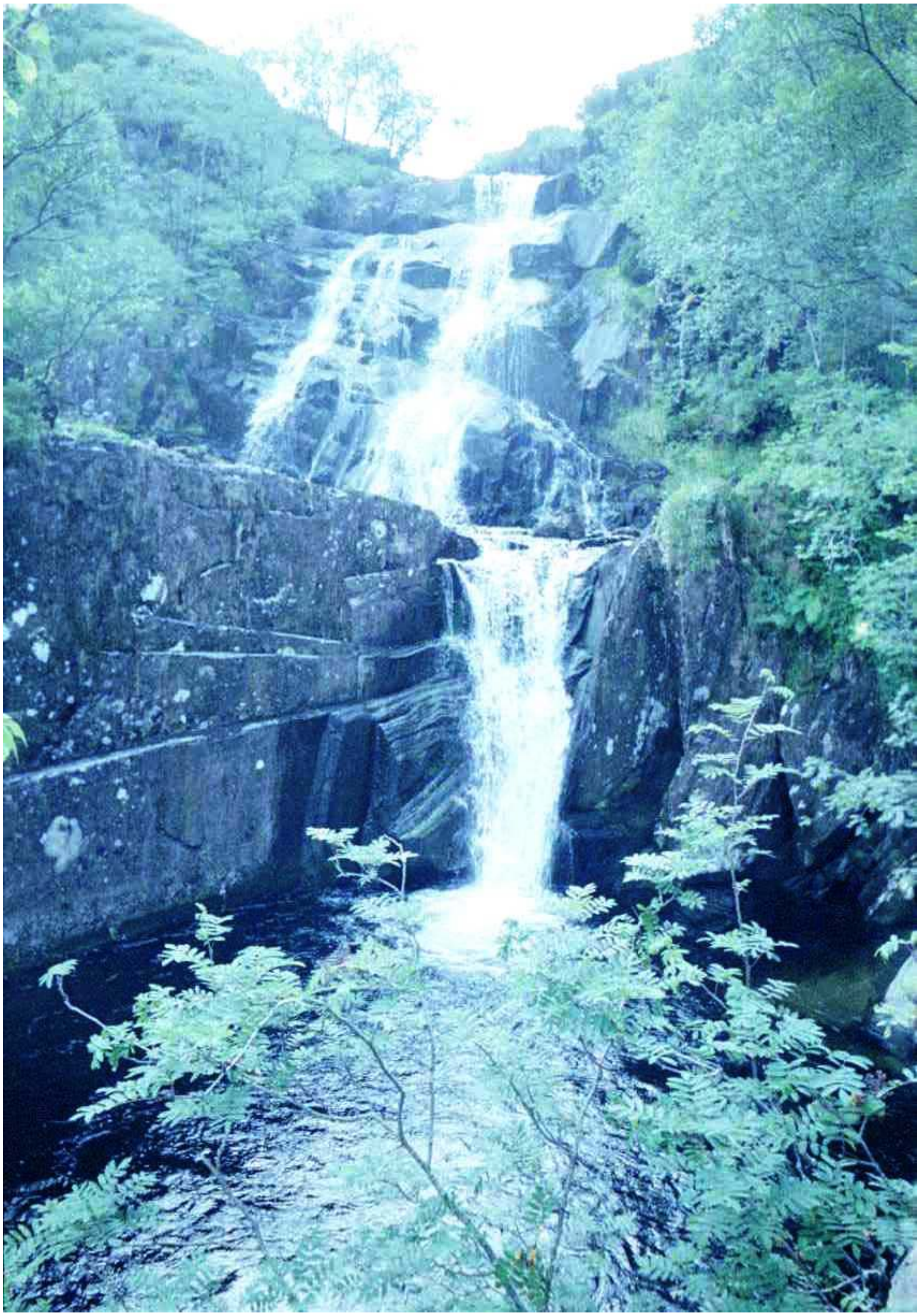


Figure 83.

Figure 84.

Figure 85.

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Useful Addresses.

Scottish Natural Heritage
2 Anderson Place
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The Woodland Trust
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Grantham
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Tel 014765 74297

The Crown Estate
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Tel 0131 220 1366

National Trust for Scotland
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Tel 0131 226 5922

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Institute of Terrestrial Ecology
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Department of the Environment Transport, and the Regions Environmental Protection
Statistics Division
Room A105
Romney House
43 Marsham Street
London
SW1P 3PY
Tel 0171 276 8246

Appendices.

- Appendix 1 – map of full corrie
- Appendix 2 – full rainfall data from The Met Office
- Appendix 3 – geology map of UK.
- Appendix 4 – geological map of Inverairlort Estate area.
- Appendix 5 – Map of Scotland showing landscape conservation, designated areas 1997.
- Appendix 6 – Map of Scotland showing nature conservation, statutory protected areas 1997.
- Appendix 7 – Map of Scotland showing distribution of red deer, roe deer, badgers and red squirrels.

Appendix 1.

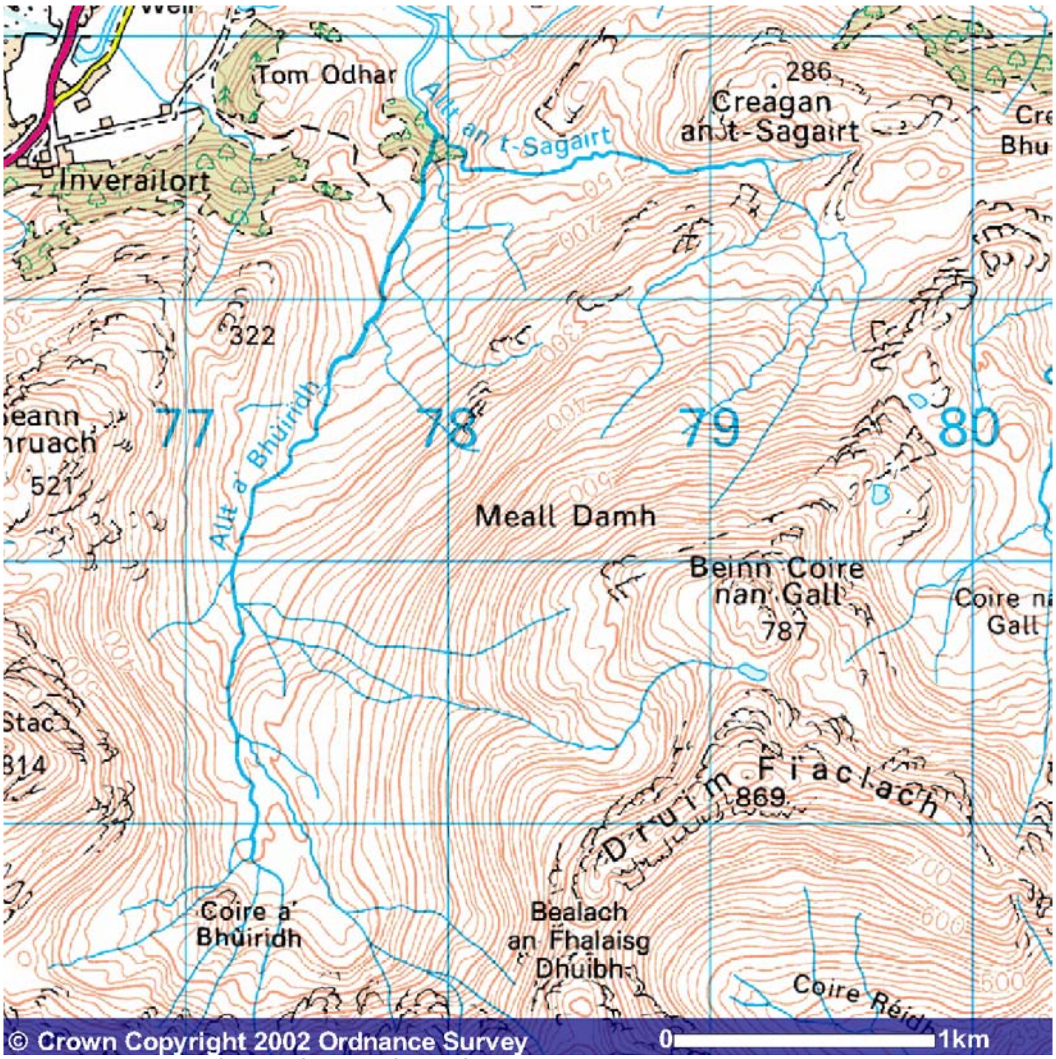


Image produced from the Ordnance Survey Get-a-map service. Image reproduced with kind permission of Ordnance Survey and Ordnance Survey of Northern Ireland.

Appendix 2.

TABLE OF MONTHLY RAINFALL TOTALS (MM)

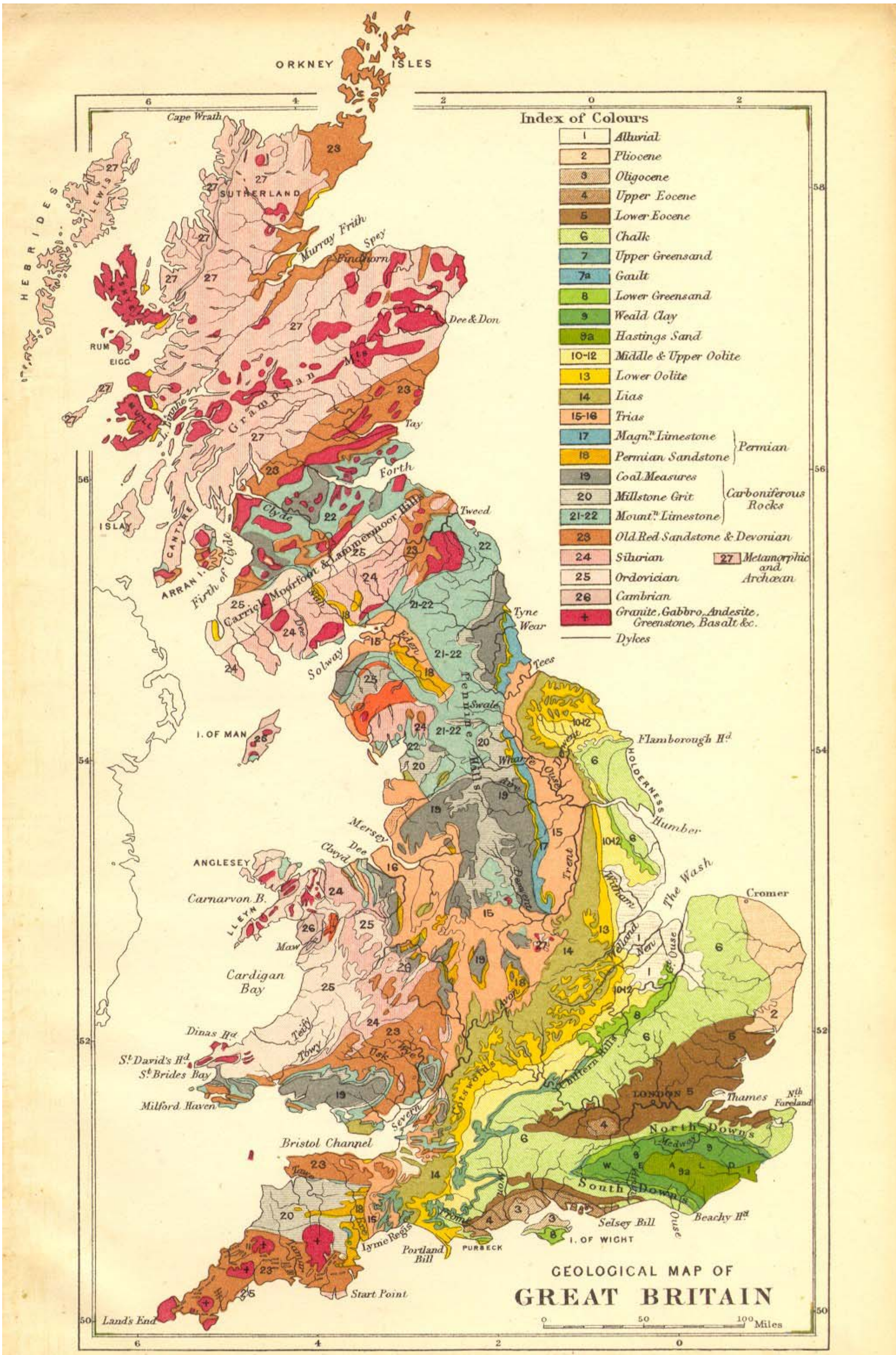
INVERAILORT
NGR = 1764E 7816N
Altitude = 2 metres
Latitude = 56:87 N Longitude = 05:67 W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1971	180.9	188.9	142.1	39.2	107.3	131.1	64.5	113.9	101.6	273.0	261.9	198.1	1802.5
1972	227.6	94.4	151.9	322.5	188.0	198.8	81.2	162.4	70.2	190.6	246.8	256.2	2190.6
1973	171.9	232.5	174.2	97.1	138.8	219.8	107.3	180.7	155.0	82.2	230.8	282.8	2073.1
1974	488.6	236.3	80.1	3.6	124.7	102.6	164.3	168.5	237.8	174.6	331.0	398.6	2510.7
1975	467.6	69.7	129.6	207.3	45.7	95.6	167.1	111.6	260.8	115.7	299.0	226.6	2196.3
1976	331.0	158.1	183.6	184.8	178.2	184.2	149.2	40.4	101.1	195.9	240.5	127.9	2074.9
1977	204.9	136.3	260.9	210.6	98.1	59.4	97.0	86.2	244.7	313.7	316.6	111.1	2139.5
1978	199.2	108.5	367.5	28.7	63.0	80.0	106.2	89.8	323.3	231.7	279.6	81.8	1959.3
1979	166.3	86.7	223.4	126.2	116.0	131.1	197.0	175.3	236.4	191.7	352.9	259.1	2262.1
1980	148.5	146.1	111.6	28.6	11.5	224.7	112.3	157.7	393.5	198.0	199.3	301.2	2033.0
1981	325.8	154.3	199.2	78.2	95.1	188.1	138.0	125.6	290.7	250.4	454.4	98.8	2398.6
1982	300.2	297.6	280.7	84.8	133.9	42.5	62.9	271.8	335.3	240.9	346.0	319.7	2716.3
1983	350.8	79.1	308.2	80.0	81.3	134.4	131.4	77.3	210.6	449.2	93.0	381.8	2377.1
1984	250.4	140.0	122.2	111.2	17.6	123.6	102.8	90.5	222.2	349.5	306.0	333.7	2169.7
1985	97.4	100.2	88.4	211.2	96.4	80.9	262.8	338.4	243.6	189.3	159.1	282.2	2149.9
1986	281.8	6.0	370.5	140.3	327.9	61.2	143.4	117.6	122.1	272.1	539.4	498.9	2881.2
1987	65.9	115.8	264.9	96.1	120.6	56.5	159.0	189.8	257.6	329.7	182.2	280.0	2118.1
1988	363.2	234.4	300.3	47.3	49.0	36.7	265.2	278.3	237.3	212.6	156.0	302.2	2482.5
1989	482.3	415.2	346.1	90.5	80.2	99.5	103.4	395.7	174.3	388.8	119.4	93.1	2788.5
1990	414.8	487.5	420.2	195.8	59.5	147.3	131.9	198.4	371.8	330.7	132.1	316.8	3206.8
1991	281.7	88.4	228.6	231.0	73.3	114.8	132.0	138.7	198.6	263.1	428.2	175.6	2354.0
1992	199.0	366.0	365.2	223.0	138.3	64.9	171.1	364.6	240.0	202.7	365.3	276.3	2976.4
1993	509.7	218.7	230.8	178.8	71.0	90.7	258.2	127.7	46.2	64.1	158.4	388.3	2342.6
1994	255.8	122.1	428.7	196.8	63.9	246.9	113.7	140.8	187.9	156.0	193.9	356.5	2463.0
1995	354.1	321.6	255.0	106.4	114.3	68.9	172.1	62.7	156.6	447.2	145.0	34.0	2237.9
1996	166.9	265.3	85.0	170.2	113.8	136.0	189.9	80.1	138.7	429.7	309.1	78.1	2162.8
1997	99.7	516.7	199.7	194.0	99.0	65.0	166.3	99.1	215.4	128.9	212.6	306.4	2302.8
1998	286.6	385.5	199.8	92.9	74.2	139.5	198.8	262.3	107.5	282.8	263.8	353.6	2647.3
1999	403.1	211.4	235.1	210.7	135.1	166.7	184.2	125.9	256.7	199.2	314.8	376.9	2819.8
2000	297.8	308.2	186.6	64.7	99.0	108.5	48.7	171.4	186.0	392.0	254.4	319.1	2436.4
2001	228.9	78.6	72.4	102.4	43.3	160.1	146.9	159.2	224.4	400.5	306.2	243.6	2166.5

monthly min	65.9	6.0	72.4	3.6	11.5	36.7	48.7	40.4	46.2	64.1	93.0	34.0
monthly max	509.7	516.7	428.7	322.5	327.9	246.9	265.2	395.7	393.5	449.2	539.4	498.9
monthly average	277.5	205.5	226.2	134.0	101.9	121.3	146.1	164.6	211.2	256.3	264.4	260.0

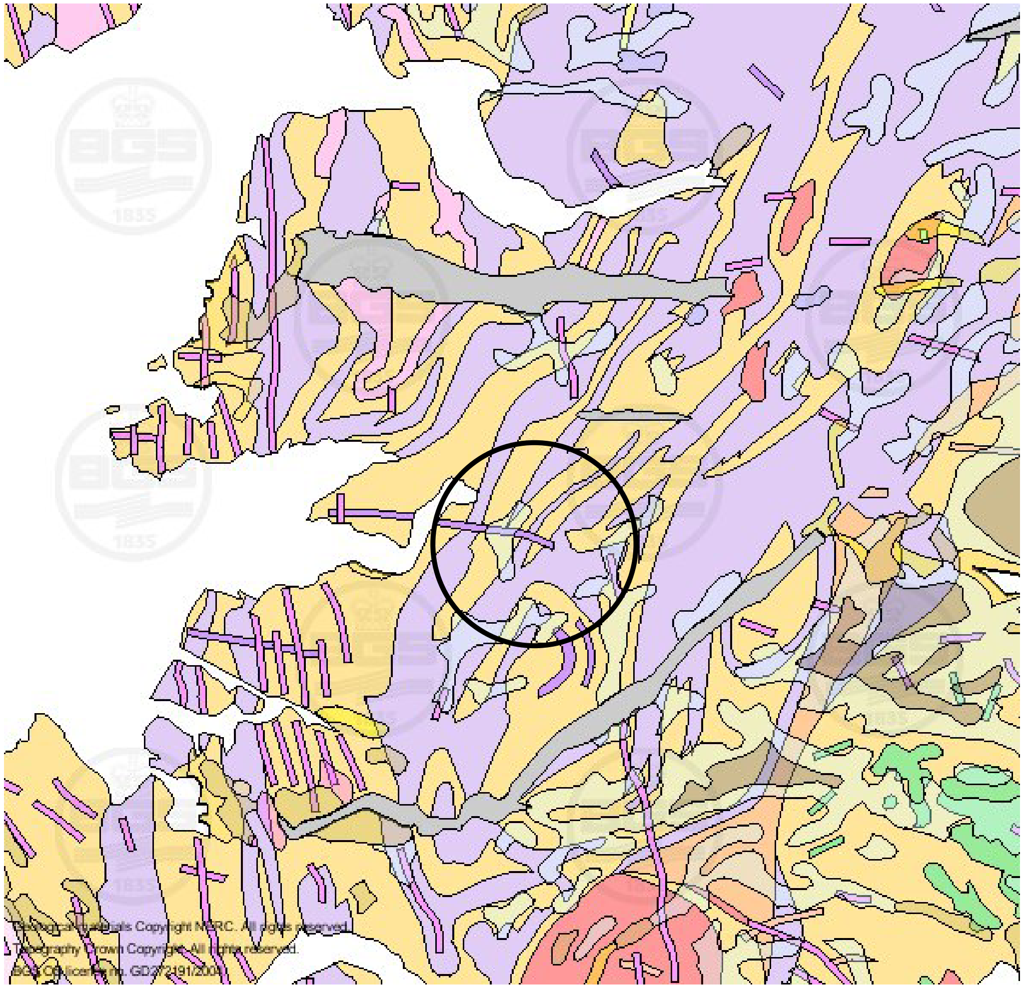
annual min	1802.5
annual max	3206.8
annual average	2369.0

Appendix 3.



After Horace B. Woodward (1904), Stanford's Geological Atlas, based on Reynold's Geological Atlas of 1860 and 1889. Ian West, 2000.

Appendix 4.

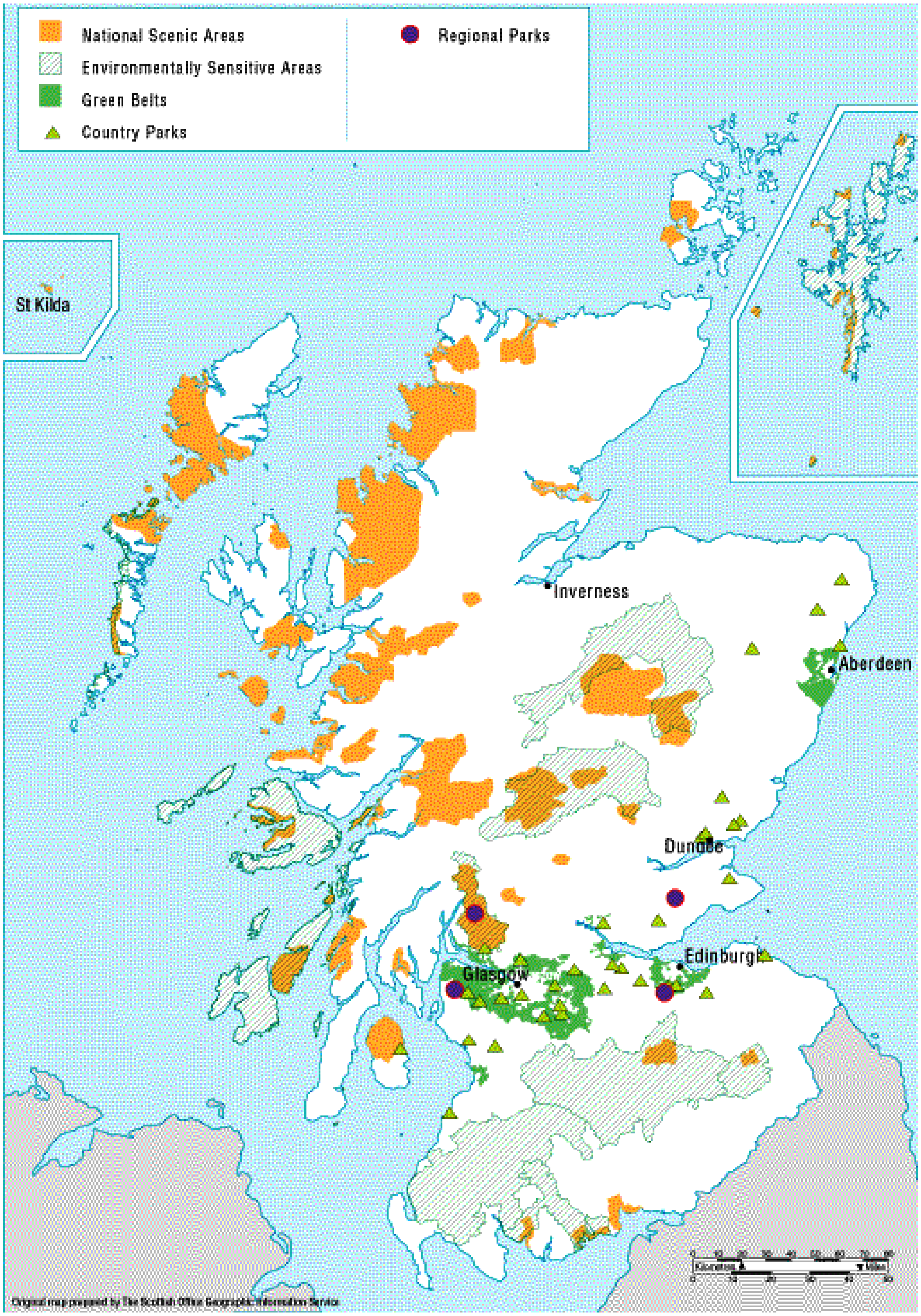


	Superficial deposits
	Boulder clay and morainic drift
	Peat
	Landslip
	Alluvium (including River Terrace Deposits in Scotland)
	Raised Beach and marine deposits
	Glacial sand and gravel

	Bedrock geology
	Quartz-feldspar-granulite
	Undifferentiated MOINE
	Mica-schist, semi-pelitic schist and mixed schists
	Basalt dolerite, camptonite and allied types
	Undifferentiated gneiss
	Porphyrite, lamprophyre and allied types
	Quartzite
	Granitic gneiss
	Granite, syenite, granophyre and allied types
	Foliate granite, syenite and allied types
	Marble
	Rhyolite, trachyte, felsite, elvans and allied types
	Epidiorite, hornblende-schist and allied types
	Upper, middle and lower lias, Lower Jurassic
	Basalt and spilite

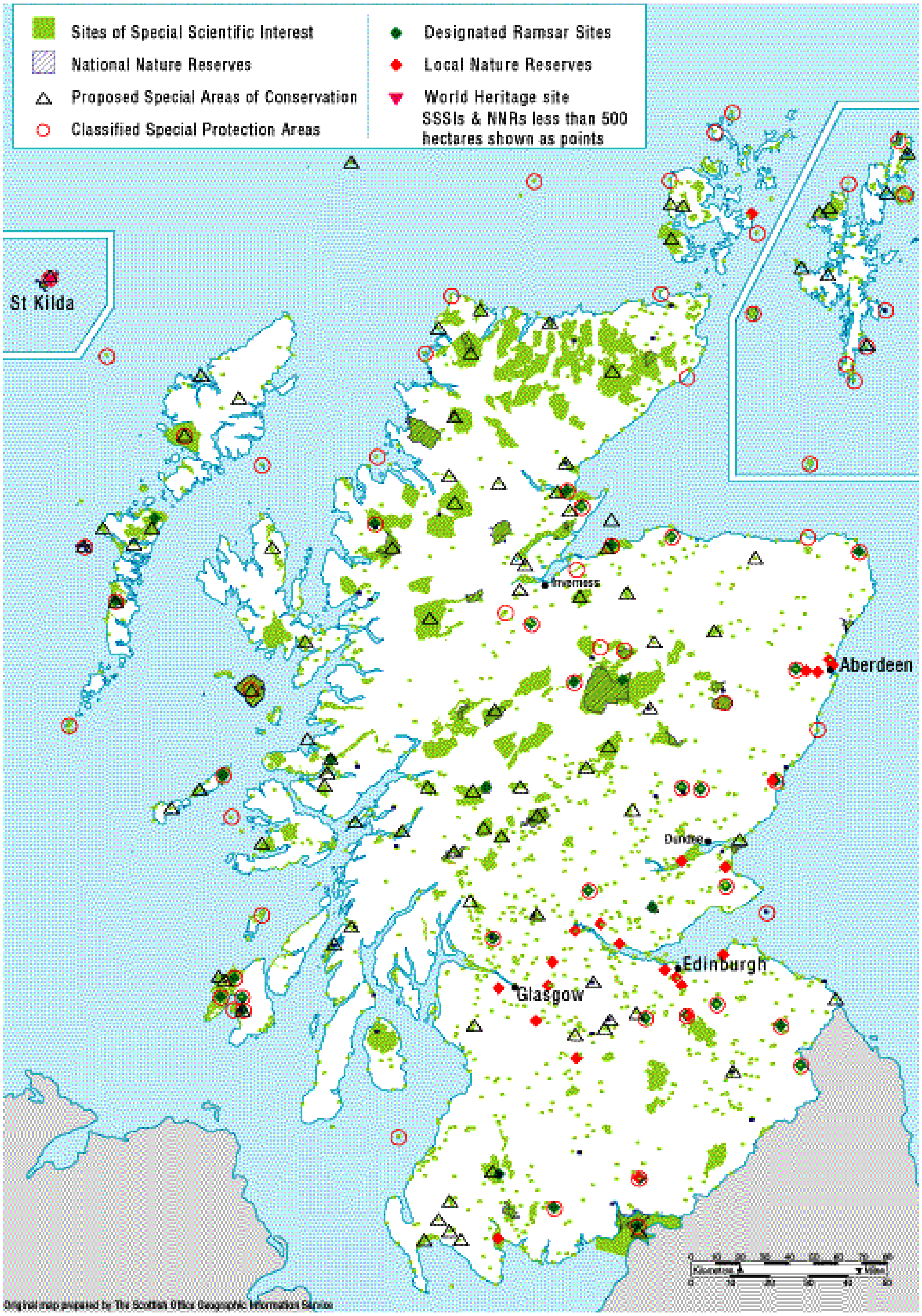
Black circled area indicates the area of the corrie.

Appendix 5.



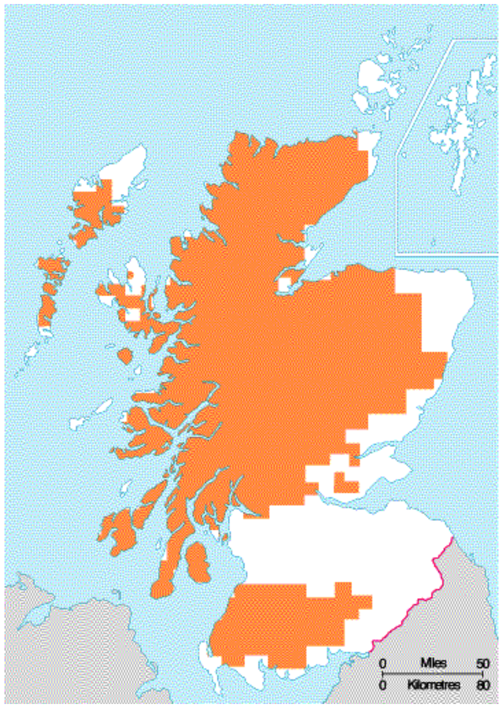
Landscape conservation, designated areas 1997

Appendix 6.

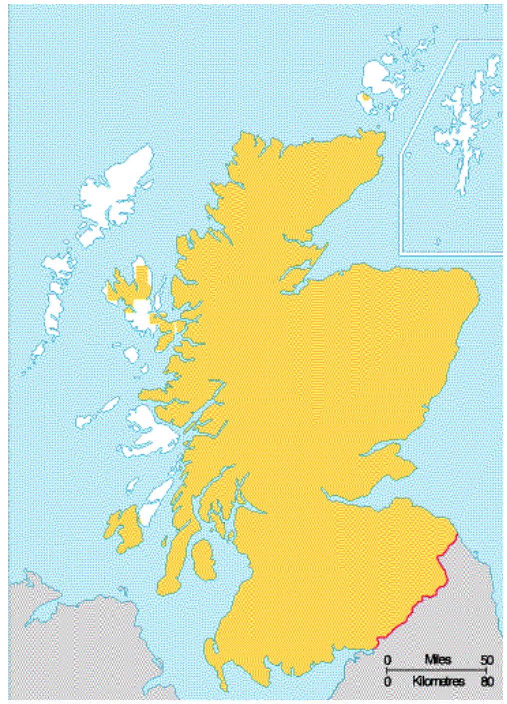


Nature conservation, statutory protected areas 1997

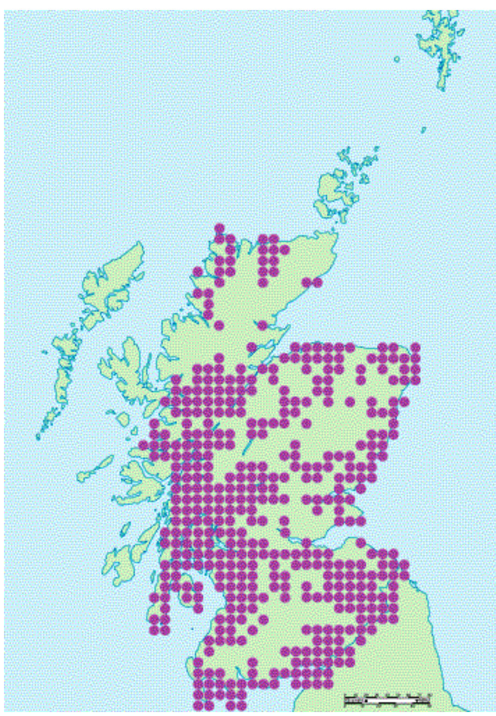
Appendix 7.



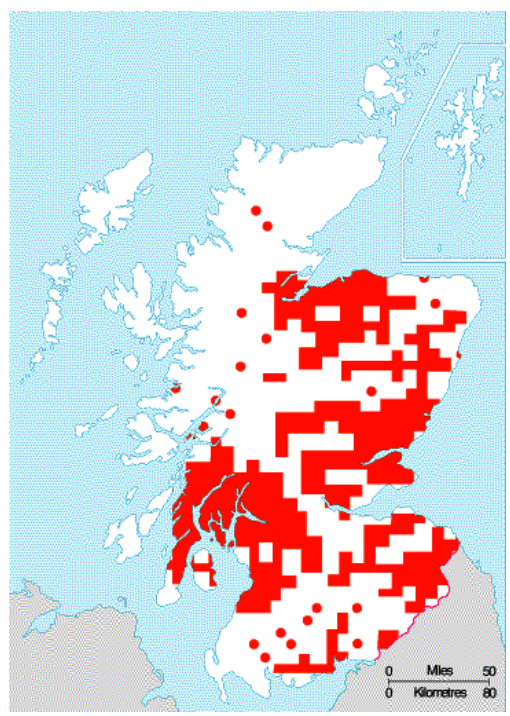
Distribution of red deer



Distribution of roe deer



Distribution of badgers



Distribution of red squirrel