Department of Mechanical and Aerospace Engineering

An Investigation into the Feasibility of a Micro-hydro Installation for the Guardbridge Energy Centre as Part of a Brownfield Redevelopment

Author: Ruth Prophet

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Abstract

The focus of this thesis is on hydro power and the opportunity to develop an installation as part of a brownfield redevelopment.

The current legislation surrounding sustainable development is discussed in regard to its significance to brownfield redevelopment. The theory behind hydro power generation is also discussed along with the various configurations of hydro power systems and the different types of turbines available for harnessing power depending on site characteristics. Power calculations are also defined for the output power associated with hydro developments.

This thesis presents the results of an experimental analysis of the feasibility of a micro hydropower development for the Guardbridge Energy Centre.

The analysis and experimental results are based on harnessing power from an existing system of sluice gates and pipe network, originally developed for the Guardbridge site when it operated as a paper mill. As the existing network is now redundant due to the closure of the mill and the proceeding takeover by the University of St. Andrews, the project aims to determine the feasibility of utilising this infrastructure, redeveloping it and giving it a new purpose as a source of hydro power. A full analysis was conducted to estimate frictional and pressure losses in the pipe network in order to calculate the potential power output from the system. Additionally, an economic and environmental assessment of the project was also conducted.

It was found that developing the site in its current configuration could produce 18% of the Guardbridge sites current energy demand with a payback period 6.2 years for the scheme. Further analysis also found that substituting and replacing some components of the existing system could yield as much as 34% of the sites energy demand.

Acknowledgements

I'd like to dedicate this dissertation to my parents for all their love, encouragement and continuous support throughout my studies.

I'd like to give a special thanks to Kenneth Tindal at the Guardbridge site for his time, patience and invaluable knowledge which he was kind enough to share with me.

A special thanks to all the lecturers of this masters course and especially to the MSc course director Dr. Paul Strachan

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1. Introduction

Throughout the world there is rising concern over exhaustible natural resources such as fossil fuels and the environmental impacts associated with them. These concerns are not limited merely to energy resources but also include greenfield land which is diminishing as our populations continue to expand outwards and more and more of this land disappears for new housing developments. In light of this, we are beginning to see a rise in brownfield redevelopment around the country where previously developed land, commonly used for industrial purposes, is being regenerated and used once again in order to protect greenfield land.

Energy demand is increasing on a global scale. With emissions continuing to rise, reducing these emissions and meeting this energy demand through increased use of renewable is at the forefront of the international energy arena. The shift towards carbon free energy production has been encouraged by national and international targets and incentives outlined by international committees and governments. Renewable generation can make a significant contribution towards tackling climate change by providing a sustainable source of low carbon energy to reduce carbon emissions from domestic households, small commercial buildings and community buildings.

The basis of this project is to combine the two concepts; generate renewable energy as a consequence of systems left behind from the sites industrial days. By using systems and infrastructure that were already in place from when the site was used for industrial processes and altering these to generate low carbon energy the site can contribute towards sustainable development, renewable energy generation and reduced carbon emissions

Scotland has an abundance of renewable energy sources which can be used to meet both the British and European targets set for the future. In previous years we have seen many large scale hydro developments, particularly in Scotland, but as undeveloped large scale potential hydro sites become scarce, the focus has shifted to small scale hydro developments. The overall aim of the project is therefore to explore the possibility of modifying existing infrastructure on a brownfield site to generate hydro power as part of the sites redevelopment.

1.1. The Project

Guardbridge

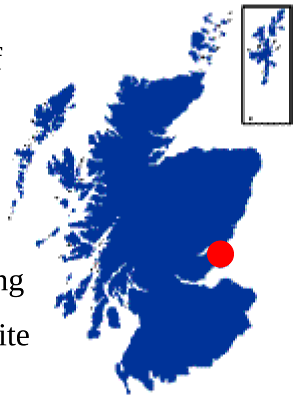

Figure 1

Guardbridge is a small village in the north-east of Fife, on the East coast of Scotland. It is situated approximately 3 miles north-west of St. Andrews and the village itself is situated on the estuary of the River Eden.

The site at Guardbridge is located on a former paper mill and has a long history of industrial use. Originally built as a distillery around 1810[1] the site was then redeveloped as a paper mill in 1873[2] and continued to operate as such until 2008 when Curtis Fine Papers went into administration. The site was vacant until November 2010 when the University of St. Andrews purchased the site with the primary intention of developing the site into an energy centre.

The University is in the process of installing a biomass boiler on site which will meet the universities heating and hot water needs. In October 2013, the university also had plans approved to build a 6 turbine wind farm at Kenly (located to the East of St. Andrews) which together are a key element of St. Andrews target towards becoming the UK's first carbon neutral university.

As part of the Universities Sustainable Power and Research Campus (SPARC) they plan to provide a platform for industrial, storage, distribution and office uses associated with research and development[3]. It is hoped that by utilizing the site in such a way it will unlock opportunities for renewable energy production, research, education, community and industry engagement surrounding low carbon and sustainable technologies.

As well as striving towards being the UK's first carbon neutral university, they are also keen to generate their own energy in order to manage the rising cost of energy use within the university. A recent study shows that the energy forecast over the next several years shows an almost exponential rise in energy costs (figure 2) and in order to tackle this issue the university is keen to look into various renewable energy sources which can contribute towards cleaner and cheaper energy.

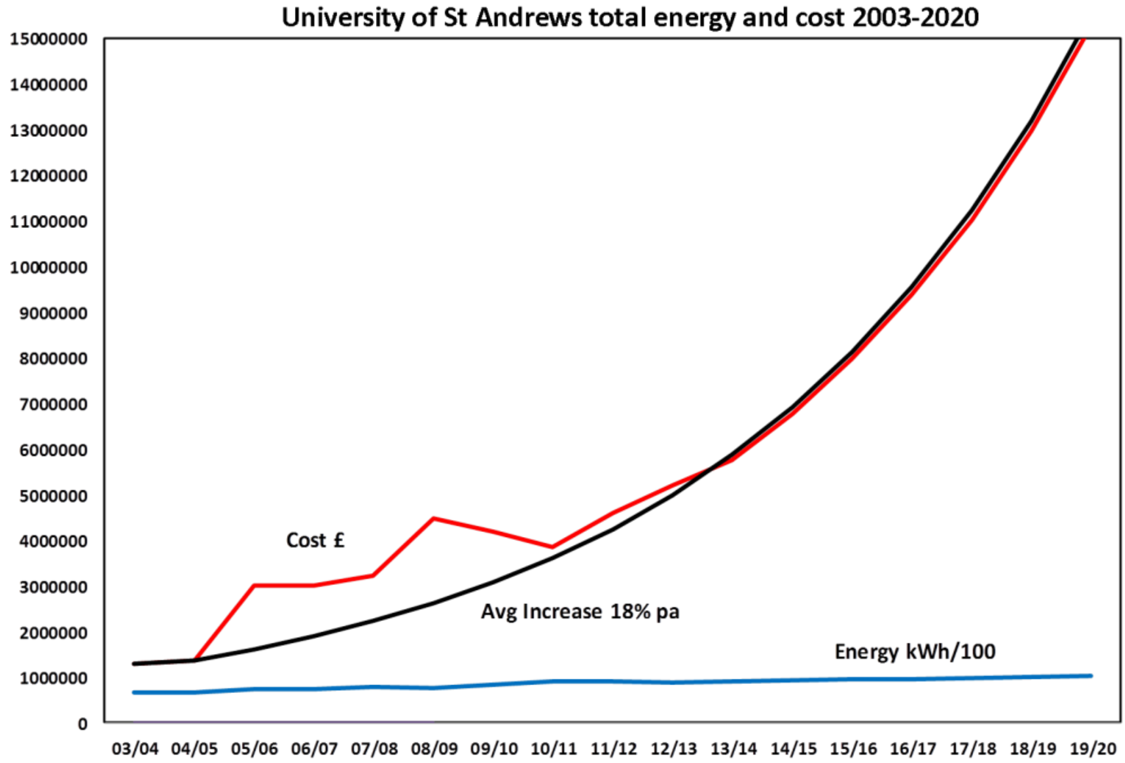

Figure 2

Source: http://guardbridgeenergycentre.wp.st-andrews.ac.uk/energy-forecast/

In order to supply their own energy through renewable generation the university will require a diverse and varied set of renewable energy systems to be employed wherever they are deemed economically feasible. The university has already explored both biomass and wind ventures which it is now commissioning but the site may also have the potential for hydro/marine energy development. Given the Guardbridge sites location on the Eden estuary, it has two rivers the Eden and the Motray water, which each may have the potential for hydroelectric developments and the Eden estuary itself is exposed to the tidal regime several times a day and so there may indeed be potential to harness marine energy within the estuary.

1.2. Project Objectives

In this study, the possibility of developing a micro hydro system as part of a brownfield redevelopment for the Guardbridge Energy Centre was explored.

Within the scope of the project there were several objectives and deliverables highlighted which were as follows:

Objectives

- Assess the Guardbridge site to determine suitable hydro power resources
- Research technology for the selection of an appropriate turbine
- Conduct a literature review to research the current British, European and international policy and legislation surrounding sustainable development and the measures in place to encourage renewable energy generation.

Deliverables

- Determine the potential power output available from a hydro development on the Guardbridge site and the annual energy produced.
- Explore the effect that varying the penstock pipe diameter has on the power output.
- Determine the financial saving and cost benefit analysis including the associated payback period for a micro hydro development on the site.
- Conduct an economic, environmental and social assessment of the project.

1.3. Project Overview

The project is composed of eight sections which are outlined below

Section 1: General, Introduces the project, the subject of study and the scope of the thesis. The aims and objectives of the project are discussed.

Section 2: Literature Review, Explores current legislation on sustainable development and the current targets set forth by British and European governments to reduce carbon emission and increase renewable energy generation. The concept of energy production from water is explored and hydro technology reviewed and discussed in detail.

Section 3: Feasibility Study/Site Survey, The Guardbridge site is analysed for hydro resources and the site layout detailed. Details of the site characteristics are detailed such as flor rate and available head

Section 4: Technical Analysis, A technical analysis is carried out to calculate pressure losses in the pipe and estimate the resultant head loss. The concept of varying the penstock pipe diameter was also explored to analyse how this affects the power output

Section 5: Analysis of Potential Energy and Annual Revenue, The potential power output and annual energy generation is calculated and the annual revenue calculated based on energy saving costs and feed in tariffs

Section 6: Economic Analysis & Financial Viability, Capital Costs of the project, operating costs and the payback period estimated. Potential sources of project funding are also discussed.

Section 7: Environmental Impact Assessment, The possible environmental impacts of the project are discussed and where appropriate mitigation measures suggested.

Section 8: Conclusions, Recommendations & Future Work, Conclusions from the experimental work are detailed and recommendations made based on the findings of the project. Recommendations are also made for possible future experimental work on the site.

2. Literature Review

2.1. Brownfield Redevelopment

As the population continues to grow and our cities rapidly expand there is a growing strain on our natural resources to be able to accommodate our growing numbers. Available land is a precious resource and as the land within cities and towns is, in most cases, developed to its full potential with very little space available for new development, cities are growing outwards creating urban sprawl and continually diminishing our greenbelt. The lack of available green spaces for development purposes has meant that the concept of redeveloping previously used or derelict sites is becoming increasingly popular. These previously used sites are known as 'brownfield sites' though there are numerous different definitions and understandings of the term. In the UK a brownfield site is defined as previously developed land that has the potential to be redeveloped. It is often land that has been used for industrial and commercial purposes and is now derelict and possibly contaminated.[4]" Perhaps the most widely accepted definition of the term 'brownfield' was coined by Paul Syms in a 1993 conference and then later in his 1994 book describing them as:

"any areas of land which previously have been the subject of a man-made or non-agricultural use of any type. This would include industrial uses such as chemical works, heavy engineering, shipbuilding and textile processing, together with unfit housing clearance sites and docklands as well as (former) mineral extraction sites and those used for landfill purposes[5]"

Brownfield association with industry has led to the term being negatively portrayed in the past and in some cases used interchangeably with the term contaminated land. It should be noted that in the UK brownfield is not necessarily contaminated and that the concept brownfield emerged as the opposite of greenfield[6].

It is widely agreed that brownfield redevelopment has many potential benefits including cleaning up environmental health hazards, reducing the visual impact of derelict buildings which may be deemed as 'eyesores' and providing the catalyst for community regeneration. The reuse and redevelopment of brownfield sites is now a core component of the UK Sustainable Development Strategy. It is estimated that there is currently 66,000 hectares of brownfield sites in England with a large percentage of these being in high growth areas such as London and so the government has set targets which aim to build over 60% of new houses on brownfield sites over the next decade.

2.2. Sustainable Development

In the UK, and indeed throughout the world, various different legislation surrounds sustainable development and provides a regulatory framework for decision making centred on five key principles: living within environmental limits, promoting good governance, ensuring a healthy and just society , achieving a sustainable economy and using sound science responsibly[7].

The current and future state of the built environment represents the best and worst opportunities for societies to survive and prosper in a protected and sustainable environment. Legislation can place restrictions on development or ensure they comply with environmentally sound guidelines. National and international strategies can ensure best practice is being implemented while scientists and engineers throughout the world develop and apply their knowledge to provide the best possible quality of life while not compromising the environment or restricting this to have minimal impact. It is recognised by many that there needs to be a comprehensive understanding of the issues surrounding the built environment to ensure measures are taken to allow the long term delivery of sustainable development[8].

The rate at which materials, resources, energy and space are being consumed must be drastically reduced so that building and transport systems make fewer demands on the planets finite resources and produce lest waste. The lack of cross-disciplinary approach and planning needs to be addressed in order to ensure that the built environment utilises the best possible environmental practices to achieve sustainability. Tolerance of buildings considered ‘eyesores’ and failure to recognised potential for redevelopment has led to an increased demand on Greenland, but if we are to achieve sustainability within the built environment we must exploit the potential for brownfield redevelopment .

Redeveloping brownfield land is considered to have many advantages[9] including:

- Reducing pressure on undeveloped land including greenfield sites
- It raises densities making better use of the existing infrastructure and improving the viability of public transport systems
- Assists social and economic regeneration
- It enhances the appearance of the landscape surrounding towns or villages.

As the need for sustainable practices and development come to the foreground of environmental and sustainability issues, there is various different legislation and policies being developed and put into practice at local, national and international levels.

2.3. Sustainable Development Strategies and Policies

Climate Change Act Scotland 2009

The climate change act Scotland details the statutory framework for reductions in greenhouse gas emissions in Scotland. A target of 80% reduction in greenhouse gas emissions by 2050 has been set with an interim target of 42% for the year 2020[10]. The targets set in the climate change act are compared to 1990 levels. The legislation also allows Scottish ministers to impose climate change duties on public bodies to make further provision about mitigation and adaption to climate change.

Policies such as this have been vital to the development and continued growth of renewable energy sources in Scotland and there have been many incentives and subsidies set up in order to make renewable energy generation accessible for both domestic and large scale developers.

In Scotland, the government’s independent advisor on sustainable development is the ‘Sustainable Development Commission Scotland’ (SDCS). Their key role is to conduct an annual assessment to scrutinize the government’s delivery of sustainable development policies. While the SDCS acknowledge that emissions in Scotland continue to fall they have stated that the average annual reduction in the last decade has been just 1%, when in the future a rate of 3% annual reductions will be required in order to ensure Scotland's targets are met[11].

UK Sustainable Development Strategy

After the Rio Earth Summit in 1992 the UK was one of the first nations to adopt the principles of the Earth Summit and Agenda 21 publishing the first UK Sustainable Development Strategy in January 1994[12].

Within the strategy the UK highlighted four priorities; sustainable consumption and production, climate change, natural resource protection and sustainable communities.

It can be argued that each of these four priorities fit with the concept of brownfield redevelopment. For example, sustainable consumption and production would fit with the concept of on site energy generation through renewables which will help offset the second of the priorities, climate change. By producing renewable energy on site this will help reduce carbon emissions. As well as protecting natural resources by using renewable energy sources instead of coal, oil and gas, redeveloping 'used' land will also help to protect natural resources such as the green belt by reusing developed land rather than using green land to develop on. Brownfield development may also help support sustainable communities, the fourth and final of the priorities agreed in the strategy, by giving local economies a boost, bringing in new businesses to the area and creating more jobs.

Agenda 21

Agenda 21 is a product of the Rio Earth Summit (UN Conference on Environment and Development) held in Brazil in 1992. It is a non-binding, voluntarily implemented action plan regarding sustainable development which can be implemented at local, national and international levels. The 21 in Agenda 21 is a reference to the 21st century.

The agenda recognises the need to review and develop policies to support the best possible use of land and the sustainable management of land resources. It also seeks to improve and strengthen planning, management and evaluation systems for land and land resources. It states:

"Support the promotion of less polluting and more efficient technologies and processes in industries taking into account area-specific accessible potentials for energy, particularly safe and responsible sources of energy, with a view to limiting industrial pollution.

Expanding human requirements and economic activities are placing ever increasing pressures on land resources, creating competition and conflicts and resulting in suboptimal use both of land and land resources. If, in the future, human requirements are to be met in a sustainable manner it is essential now to resolve these conflicts and move towards more effective and efficient use of land and its natural resources[13]"

From the above, it is clear that Agenda 21 recognises the importance of treating land as a finite resource and of making preparations to ensure it is used in a sustainable manner both in the present and in the future. Again, brownfield redevelopment may be a major component of easing pressure on land resources to ensure that land is used effectively and developed to its full potential without encroaching on greenspace.

It is also stated above that Agenda 21 supports the promotion of less polluting technologies and wishes to exploit area specific potentials for energy and this may be in the form of site specific renewables such as wind, solar, hydro and tidal resources. By regenerating brownfield sites into cleaner, greener, more environmentally sound developments while incorporating renewable energy generation this will help to meet many of the aims and objectives set out in the national and international sustainable development policies.

2.4. Renewable Energy Generation Strategies and Policies

EU Renewable Energy Directive

The EU Renewable Energy Directive is the governing policy within the EU for the production and promotion of renewable energy generation. The policy details actions required by member states to meet the target of achieving 20% of its overall energy needs through renewable sources by 2020. The policy outlines individual national targets which must be met in order to achieve 20% renewable energy generation throughout Europe and these targets range from as little as 10% in countries such as Malta up to 49% in Sweden. These targets have been set taking into account the countries starting point in terms of renewable energy generation already in place and the countries overall potential for renewables.

In order to meet the targets set to each country, the Directive required the member states to notify the European Commission of a National Renewable Energy Action plan which would set out a national strategy for achieving their renewable generation.

The overall aims of the policy are to promote increased use of renewable energy sources while increasing energy efficiency and creating energy savings where possible. Each of these aims constitutes and important part of the overall process to achieving the reduction in greenhouse gas emissions laid out by the Kyoto Protocol. The Directive also recognised the important role small scale generation will play in achieving these targets and contributing to improving the security of energy supply, promoting technical innovation and development and providing localised employment and income opportunities by stating:

"It is appropriate to support the demonstration and commercialisation phase of decentralised renewable energy technologies. The move towards decentralised energy production has many benefits, including the utilisation of local energy sources, increased local security of energy supply, shorter transport distances and reduced energy transmission

losses. Such decentralisation also fosters community development and cohesion by providing some income sources and creating jobs[14]".

The UK Renewables Policy

The UK's current renewables target is to achieve 15% of their energy consumption needs from renewable sources by 2020. According to some, in order to achieve this target will require a four-fold increase in our renewable energy consumption if this goal is to be realised[15].

The UK government's current international and domestic strategy on renewable energy generation is detailed in the 2007 White Paper which states their strategy is to deliver energy security and accelerate the transition to a low carbon economy which requires urgent and ambitious action at home and abroad. It recognises the need to save energy, develop cleaner energy supplies and secure reliable energy supplies at prices set in competitive markets.

An Energy Review Report identified several key areas where the UK policy and regulatory framework governing the energy markets needed strengthened, and highlighted the key elements of the strategy which are to[16]:

- Establish an international framework to tackle climate change
- Provide legally binding carbon targets for the whole UK economy progressively reducing emissions
- Make further progress in achieving fully competitive and transparent international markets
- Encourage more energy saving through better information, incentives and regulation
- Provide more support for low carbon technologies
- Ensure the right conditions for investment.

In order to achieve the key elements set out above, the UK government has developed further policy and incentives in order to encourage nation wide compliance and participation. Among these policies the UK Renewables Obligation as well as the Feed-In-Tariff scheme have been developed in order to encourage renewable energy generation at both small domestic scale and large commercial scale while providing incentives to make such investments financially viable.

Renewable Obligation

The Renewables Obligation (RO) is the governments key policy for encouraging renewable electricity generation within the UK. The RO requires licensed electricity suppliers in the UK to source a specified, annually increasing percentage of the electricity they supply from renewable sources[17].

In order to manage the RO and ensure electricity suppliers are complying with the obligation, the suppliers are presented with Renewable Obligation Certificates (ROCs), as evidence of renewable generation. ROCs are issued to accredited renewable energy generating stations for the eligible renewable electricity they supply. ROCs are tradeable commodities and can be traded with other parties and suppliers.

Ultimately, ROCs are used to demonstrate that suppliers have met their obligation and where insufficient ROCs are presented to meet the RO, the supplier must pay an equivalent amount to a buyout fund. The administration costs of the scheme are covered from this fund and the remaining funds are redistributed back to the suppliers in proportion to the number of ROCs produced in respect of their obligation[18].

ROCs are issued per megawatt hour (MWh) of renewable electricity output by the supplier. The buyout price has increased annually (table 1) and the current buyout price (for 2015-16 obligation period) is £44.33 per ROC[19]. This is the amount that must be paid for each ROC that the supplier falls short of meeting their obligation.

Obligation period (1 April - 31 March)	Buy-out price	Obligation for England & Wales and Scotland (ROCs/MWh)
2009-2010	£37.19	0.097
2010-2011	£36.99	0.111
2011-2012	£38.69	0.124
2012-2013	£40.71	0.158
2013-2014	£42.02	0.206
2014-2015	£43.30	0.244
2015-2016	£44.33	0.290

Table 1

When the ROCs scheme was first introduced all forms of renewable technology were eligible for the same level of support i.e. 1 ROC/MWh. Though this meant all technologies were treated equally, it transpired that the scheme actually encouraged the use of more established technologies such as onshore wind or landfill gas as they were more economically viable, while less well developed technologies were not as attractive a proposition to electricity suppliers as they were not commercially viable yet. This led to the introduction of scheme banding meaning certain types of renewable technologies are eligible for more ROCS than others, for the same amount of electricity. For example, during the period 2013-17 support for onshore wind will be reduced to 0.9 ROCs/MWh while marine technologies will increase to 5ROCs/MWh, up to a limit of 30 MWhs per generating station.

It is hoped that by restructuring the scheme with a banding system, it will allow the government to steer the industry towards supporting less well developed forms of renewable energy technology. It has been recognised by the government that the market would not deliver the required mix of renewables needed to meet its targets previously, but by making the technologies in the early stages of development more attractive to suppliers by increasing the incentive to develop them, it is hoped that these younger technologies can contribute to the long term goals rather than focusing on renewable options which are financially appealing in the short-term[20].

Feed In Tariffs (FITs)

The Feed in Tariff scheme was introduced on 1st April 2010 and is the primary support mechanism for small scale renewable electricity generation.   The FITs scheme supports organisations, businesses, communities and individuals to generate electricity through small-scale, low-carbon schemes with an installed capacity of 5MW s or less.

There are several stages to the FITS scheme. Firstly, an organisation, community etc. installs a small-scale renewable electricity generation system (such as wind, hydro, micro CHP, solar PV etc.) and registers the installation with a licensed electricity supplier. Ofgem will then check the generator is eligible for the FITS scheme and processes the generation data. The generator will then receive a generation tariff from the supplier for any electricity generated through the scheme, and if any excess electricity is exported to the grid, the generator will also receive an export tariff.

The amount of electricity (as a percentage) assumed to be exported by an eligible FIT installation which does not have an export meter is dependent on the type of renewable technology in question. The installation must be registered under the Balancing and Settlement Code and for F IT year 6 (1st April 2015-31st March 2016) is assumed to be 50% of generation exported for micro CHP, anaerobic digestion, solar PV and wind, and 75% of the generation meter reading for an accredited FIT installation which is a hydro generating station[21]. The FITs determination is reviewed annually and is set by the Secretary of State for Energy and Climate Change.

2.5. Hydro Power

The term hydro comes from the Greek word for 'water', and so 'hydro power' is the process of harnessing energy from running water. All streams and rivers flow down-hill towards the sea. Before running down the hill the water has potential energy due to its height. Hydro power systems convert this potential energy into useable kinetic energy. The amount of energy generated is dependent on two primary factors which are the height the water is falling and the volume of water flowing per second. The greater these factors, the greater energy potential there will be.

The primary energy sources for hydropower are solar and gravitational. The complete process is a result of the natural hydrologic cycle of evaporation and condensation[22]. Water is evaporated from the seas and oceans transporting it from lower ground to higher ground. When it reaches the upper atmosphere it condenses into the form of cloud and can be carried by the Earth's natural forces over higher ground where it is then released in the form of rain. This cycle increases the potential energy of the water which then flows back to the seas and oceans under the influence of gravity and it is this stage that provides the opportunity for a portion of energy to be converted into kinetic energy.

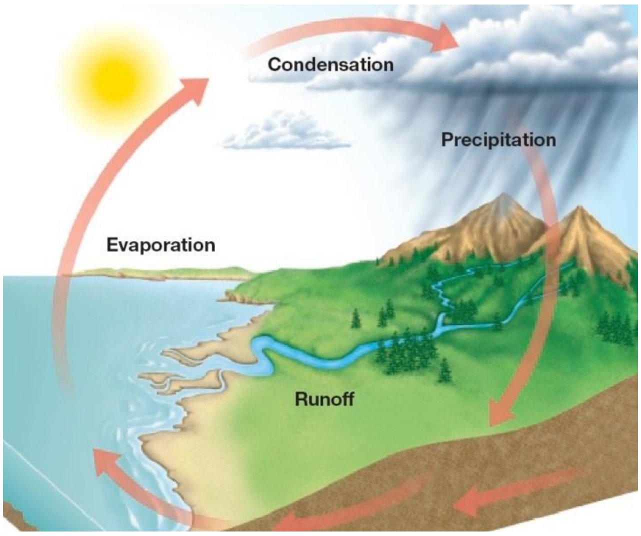

Figure 3: https://gracegreaterthanoursin.wordpress.com/tag/water-cycle/

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2.6. A Brief History of Hydro Power

Hydro power is perhaps the form of renewable energy we have been harnessing the longest. Indeed there is evidence that humans have been extracting power from water for over 2000 years. Key developments in hydro power technology during the early half of the 19th century birthed the era of hydroelectricity.

- 202 B.C-9A.D. Han Dynasty in China used trip hammers powered by vertical set water wheels to pound hull grain and break ore
- Nearly 2000 years ago the Greeks and imperial Rome used the power of water to grind wheat into flour
- 1700's. Hydropower was most commonly used to mill lumber and grain and for pumping irrigation water
- 1827. The earliest known version of the Fourneyron reaction turbine was invented by French engineer Benoit Fourneyron.
- 1831. The first electric generator was created by Michael Faraday which paved the way for electricity to be generated from hydropower almost 50 years later in 1878.
- 1870's. Lester Allan Pelton develops the Pelton water wheel.
- 1878. The world's first hydroelectric endeavour was used to power a single lamp in the Cragside country house in Northumberland, England.
- 1882. The first hydroelectric power plant began to generate electricity and was located in Appleton, Wisconsin[23]. It served both private and commercial customers. Over the following 10 years there were hundreds of similar hydropower plants commissioned and put into operation in locations such as grand rapids, Michigan, Dolgeville, New York and Niagara Falls.
- 1891. Germany produces the first three phase electric system.
- The early half of the 20th century saw Canada and USA become world leaders in terms of hydropower engineering with the 1345 MW Hoover dam being built on the Colorado river.
- 1942. Grand Coulee Dam in Washington becomes the world's largest hydro-electric power plant capable of generating 1974MW (later upgraded to generate 6809MW)
- 1960s-1980s. Large hydroelectric plants were constructed throughout Canada, Latin America and the USSR.

- 1980's-present. In recent years projects in Brazil and China have seen them become world leaders in hydropower. The biggest hydropower plant in the world, Three Gorges Dam opened in China in 2008 and is capable of generating 22,500 MW[24].

2.7. Hydropower Resource and Potential in the UK

In the UK, renewable energy generation currently accounts for 19.1% of the total electricity generated. The total electricity generation from renewables in 2014 was some 64,654 GWh , an increase of 21% compared to the statistics for 2013. The chart below gives a breakdown of the percentage contributions from each type of renewable energy source to the total renewable energy generation in 2014.

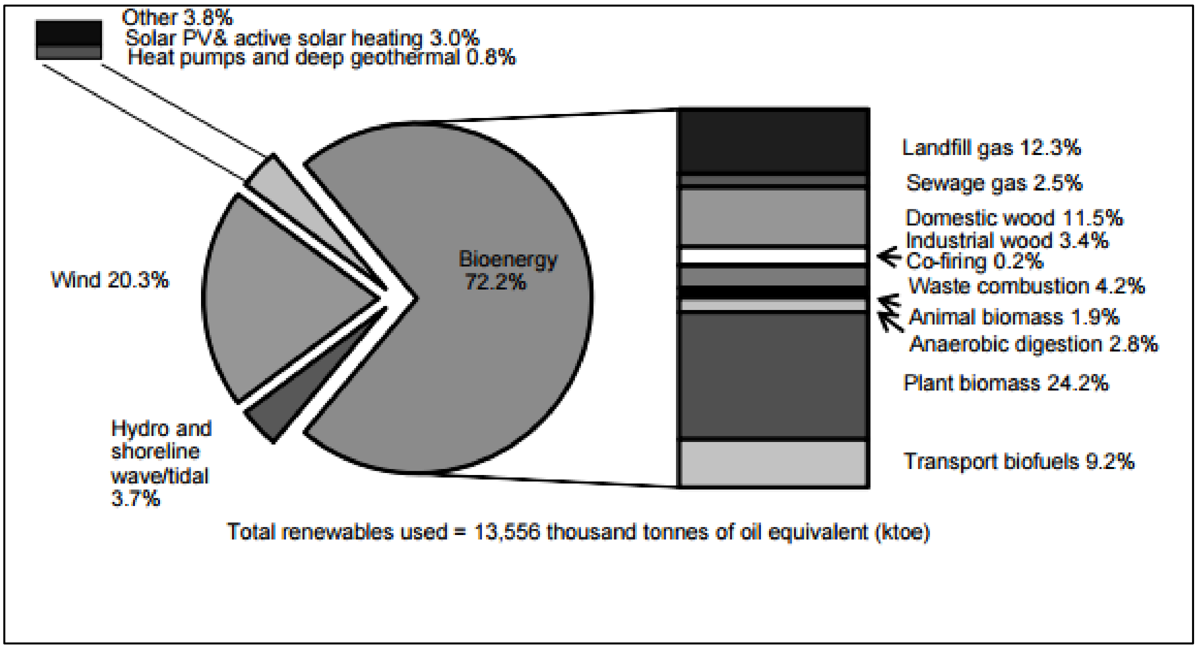

Figure 4

Sourced:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/450298/DUKES_2015_Chapter_6.pdf

According to figure 4, the total contribution of hydroelectric accounts for a mere 3.7% of renewable electricity generation in the UK, though a significant portion of this hydro is produced in Scotland. Figure 5 below shows the contribution from various renewable energy sources in Scotland and it can be seen that hydro accounts for as much as 25% renewable electricity generation north of the border.

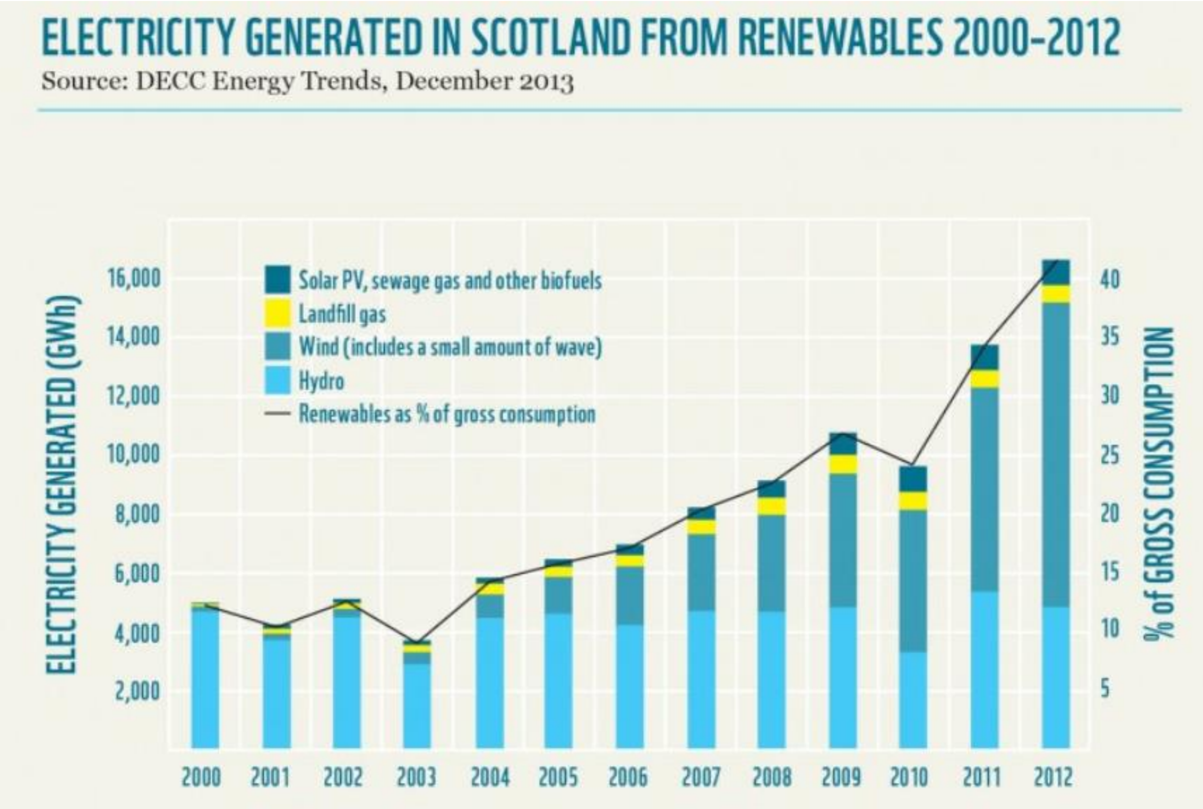

Figure 5

It can also be noted from figure 5 that while hydro was once the biggest source of renewable energy generation, new developments in this sector have slowed down in favour of newer and cheaper alternatives such as onshore wind and solar PV. There are several reasons for this such as government subsides making these developments more economically feasible, and improvements in technology means it is now more economically viable to install domestic solarPV systems in households around the country. This means that small scale generation now accounts for a significant portion of these newer forms of renewable generation. Another reason though for the lack of new hydro developments is that most of the sites with the potential for large scale hydro systems have already been developed and exploited to their full potential, and there are very few large scale sites with the potential for hydroelectric left untapped . Instead, the remainder of untapped potential lies in small scale and in micro hydro sites around the country and table 2 below outlines the number of potential hydro sites in different areas of Scotland along with the total power potential available from these sites.

	Region	Number	Total power (MW)
1	Strathclyde	2,090	280
2	Dumfries & Galloway	282	47
3	Borders	158	33
4	Lothian	54	4
5	Central	176	33
6	Fife	29	2
7	Tayside	893	154
8	Grampian	199	43
9	Highland	3,008	594
10	Western Isles	136	12
11	Shetland	10	1
12	Orkney	8	0.4

Table 2: Breakdown of hydro potential by region

Sourced: Forum of Renewable Energy Development in Scotland (FREDS)

Available at: http://www.british-hydro.org/UK%20Hydro%20Resource/Employment%20Potential%20of%20Scotland's%20Hydro%20Resource%20(Sep%202009).pdf

As mentioned previously the majority of undeveloped sites will be micro-hydro systems. Hydro developments can be split into categories according to their size i.e. Installed capacity. These subcategories and their associated sizes are summarised in table 3.

Classification of Hydroelectric Schemes	
Large	Greater than 5MW
Small	Less than 5MW
Micro	5-100kW
Pico	Less than 5kW

Table 3

2.8. Types of Hydro Scheme

Hydropower schemes can be categorised into 3 different groups depending on their principals of operation; impoundment, diversion and pumped storage. Impoundment type schemes involve structures such as dams to store river water in a reservoir while diversion schemes (often referred to as run of the river) divert a portion of the river water through a penstock to produce electricity. Pumped storage schemes on the other hand work like a battery to store energy when demand is low. Each of these schemes is discussed in further detail below.

Dam-based Hydro-electric Schemes

Dams are man-made structures that are built across rivers , estuaries or streams to retain water. They are typically built where there is a large drop in elevation and can be anything from small earth embankments to large concrete structure hundreds of meters high. Hydroelectric power is produced as water passes through a dam and into the river below. Where dams are built man-made reservoirs are formed behind it to store water. At the bottom of a dam there is a water intake. The weight of the water in the deep reservoir and the drop in height from the dam forces the water from the intake through the penstock inside the dam under high pressure[25]. The high pressure water is then used to turn a turbine and the shaft from the turbine is connected to a generator which converts the rotational energy into electricity.

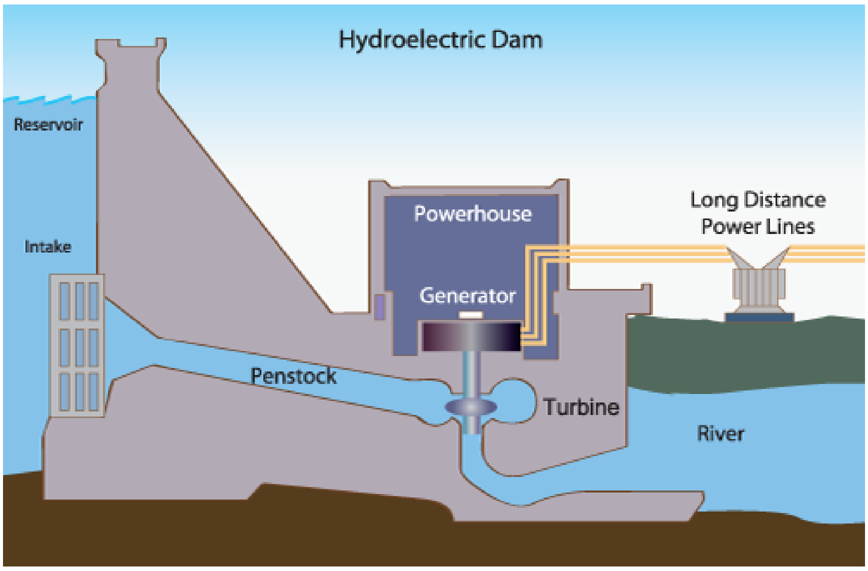

Figure 6: Operation of a hydroelectric dam

http://www.energyland.emsd.gov.hk/filemanager/template/en/images/hydro_1.png

Run-of-the-River Schemes

Run-of-the-river projects can be subdivided into two categories; upland and lowland. Upland projects typically use the natural fall of the river to provide a suitable head which is then channelled through a tunnel, canal or pipe, and these type of schemes are typically high-head, low-flow systems. Lowland projects however are generally low-head, high-flow schemes and are typically situated at barrages on the more mature, lower reaches of the river where they rely solely on the head created by the barrage[26].

In run-of-the-river schemes some sort of diversion structure is used to direct some of the river water through a channel called the headrace in order to transport the water to a spot above the powerhouse which will employ the sites topology to achieve minimum drop in elevation. At this point the water will be directed through a steep pipe called the penstock and will then flow through the turbines located at the bottom of the penstock. The difference in elevation between the penstock intake and the turbines represents the head of water available for generating power. The pressure at the bottom of the head provides the force to drive the turbines. After passing through the turbines the water is then returned to the river downstream of the diversion structure[27].

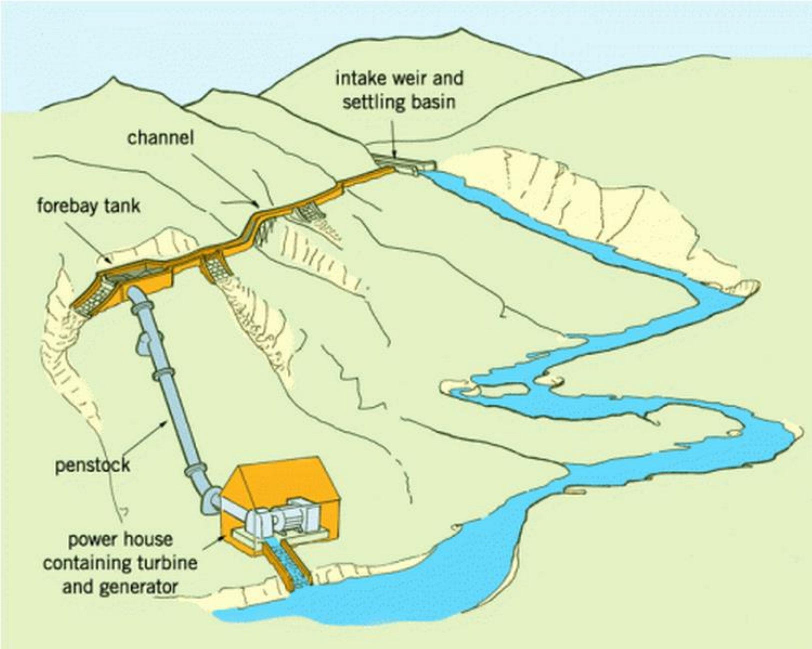

Figure 7:http://www.sswm.info/content/hydropower-small-scale

Most run-of the-river schemes have little or no storage in the head pond upstream of the intake to conserve water and so power production is determined exclusively by the flow of the river. As this fluctuates so will the power produced. In some cases there is enough storage to provide hourly or daily regulation but generally the output of the scheme will match river flows.

Pumped Storage Hydro Schemes

Pumped storage hydro is a method of storing energy and is the oldest type of large scale energy storage. In this type of scheme there are two reservoirs, one at a higher elevation and a second at lower elevation. When energy demand is low (such as during the night) but production is high, excess energy can be used to pump water from the lower reservoir to the higher reservoir. When demand is once again high the water from the upper reservoir can be released and allowed to flow back through to the lower reservoir to produce electricity. Though this type of system is a net user of power it provides a dynamic and rapid response when a heavy load is

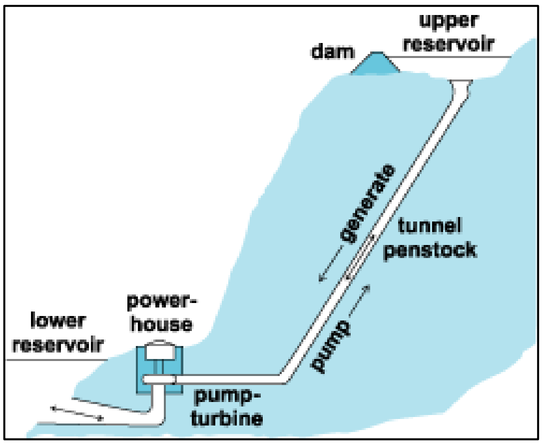

Figure8 http://www.snipview.com/q/Pumped_storage_power_stations placed on the system and/or to maintain grid stability. This type of hydroelectric generating plant can start up quickly and make rapid adjustments in output.[28]

2.9. Turbine Types

One of the key decisions when developing a hydro site is which type of turbine to use. The selection of the turbine depends upon the site characteristics, namely available head and flow. The desired running speed of the generator and whether the turbine will be required to operate in reduced flow condition should also be taken into account.

Various turbines can be subdivided by their principals of operation into three categories; impulse turbines, reaction turbines and finally, gravity turbines.

Impulse Turbines

Impulse turbines are driven by high velocity jets of water. Fast moving water is fired through a narrow nozzle at the turbine blades which causes them to spin. The blades of an impulse turbine are normally bucket shaped which allows them to capture the water. The moving blades or buckets absorb the kinetic energy of the jets of water and convert it into mechanical work . As the water strikes the moving blades it suffers a change in direction and therefore a change in momentum which causes an impulse on the blades[29].

The water will be directed off at an angle and in some cases it will even be directed back the way it came which will provide the most efficient transfer of energy from the water to the turbine. The mechanical work done on the turbines by the jets of water will then be converted to electricity via a generator.

In order for an impulse turbine to operate it must rotate in the air. If it becomes submerged its rotation may be impaired. This is contrary to the second type of turbine, the reaction turbine, whose submersion in water is critical to its efficient operation[30].

Pelton Turbine

The Pelton turbine was developed by Lester Pelton in the USA in 1889. Pelton turbines closely resemble the traditional water wheels used in the past. It is an axial flow turbine which is commonly mounted on a horizontal shaft with a number of buckets round the periphery of the wheel. The flow is directed towards the wheel through a nozzle where it completely expands to atmospheric pressure[31]. The resulting jet of water impacts on the turbine blades producing the required torque and power output.

Pelton turbines are useful for high head schemes in the range of 200m-2000m and a low volume flow of up to 40m³/s. They typically have a hydro-electric efficiency of 85-95% [32].


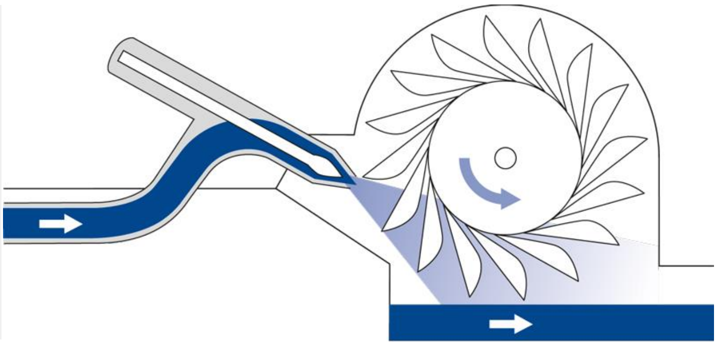

Figure 9:Pelton turbine and its operation

Source: http://www.green-mechanic.com/ and http://www.renewables-made-in-germany.com/

Turgo Wheel

The Turgo wheel is a variant of the Pelton turbine. Originally developed in 1919 the Turgo wheel has undergone many changes and design alterations and is now recognised for use within a specific head and flow range. The Turgo wheel is commonly used for heads ranging from 50m-250m as it is considerably smaller than its Pelton counterpart. The Turgo looks similar to the Pelton wheel but looks as if it has been split into two along the splitters with the blades being shallow bowl shaped units

Figure 10

Source: http://www.southerncross.pentair.com/

onto which the water from the jets strike them at an angle of about 20° and passes across the cup before exiting on the opposite side[33]. The Turgo wheel can be mounted either horizontally or vertically and has a maximum efficiency of approximately 85%.

Crossflow Turbine

Sometimes referred to as 'mixed flow', crossflow turbines show characteristics of both reaction and impulse turbines but ultimately use impulse to extract power. The turbine has curved blades around its peripheral edge. Water is then released from the pressure pipe onto the runner and fires through deflecting off the blades as it runs to the centre of the runner. The water is slowed and changed in direction, finally passing through the other side at a low velocity[34].

This type of turbine is suitable for a head of range of about 2m-200m and rating up to approximately 1MW[35]. This type of turbine is generally suitable for the smaller end of the micro hydro range due to its versatility and relatively low cost.

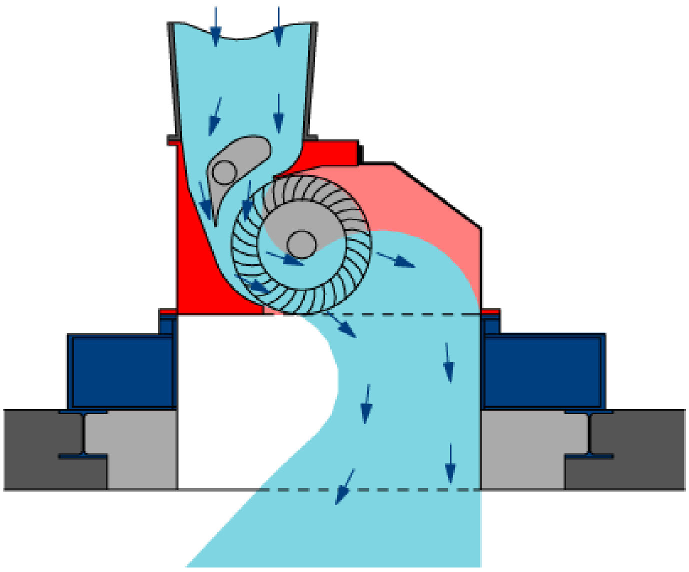

Figure 11: Crossflow Turbine

Source: http://cink-hydro-energy.com/

Reaction Turbines

Reaction turbines differ from impulse turbines in many ways. For example, large power cannot be developed in an impulse turbine but can be developed in a reaction turbine. The efficiency of reaction turbines is also much greater than for impulse turbines. Reaction turbines are typically used for sites with smaller heads and higher flow rates than compared with impulse turbines[36].

The operation of a reaction turbine is based on Newton's third law; for every action there is an equal and opposite reaction. The blades of the turbine sit in a much greater volume of water and turn around as the water flows past them. The power is developed from the combined action of pressure and moving flow path while it passes along the rotor blades. This causes a change in velocity which causes a reaction on the turbine blades[37]. When the flow   goes through the turbine   the weight of the water gives a push to the blades of the runner with shaft rotation as the reaction[38], which can then be converted into electricity. Perhaps the most familiar examples of reaction turbines are wind turbines[39].

Propeller Turbine (with Kaplan Varient)

Propeller and Kaplan turbines make use of large volumes of available water and are designed to provide a very large flow area while allowing the turbine machine to run at low speeds. They are axial flow turbines suitable for medium head application of approximately 5m-70m with specific speeds of 300-1000rpm[40]. The Kaplan turbine was named after German engineer Dr.V.Kaplan. In this type of turbine the water enters the blades in axial direction from one side and leaves through the other side so that large volumes of water are passing through the runner[41].

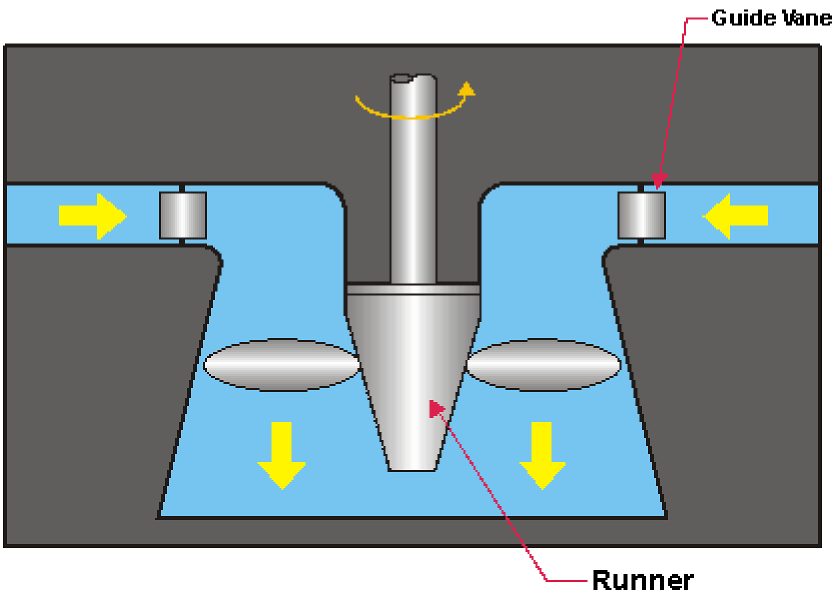

Figure 12: Propeller Turbine

Source: http://re.emsd.gov.hk/english/other/hydroelectric/images/image008.gif

Propeller and Kaplan turbines are very similar but differ in the fact that the Kaplan variant has adjustable blades. The Kaplan turbine is more advanced than its predecessor, the propeller turbine, as its blades can be adjusted during operation depending on the flow rate thus maximising its efficiency[42]. On the other hand the blades of the propeller turbine can only be adjusted by hand when the turbine is drained.

Francis Turbine

The Francis turbine is named after the American engineer J.B. Francis who designed inward radial flow reaction type turbines. Francis turbines are mixed flow type turbines[43] and are the most common turbine used around the world in medium and large scale power plants.

The turbine operates by channelling water through a volute, a small scroll shaped tube that diminished in size while at the same time coiling inwards. The snail-like design forces the water inwards towards the runner. Guide vanes will be set on the turbines inner surface to help guide the water towards the runner, and as the water crosses the curved runner blades it will be deflected sideways. The force of the water being deflected pushes the runner blades in the direction they are travelling sending energy to the runner and keeping the rotation going[44].

Figure 13: Francis Turbine

Source: http://www.alibaba.com/

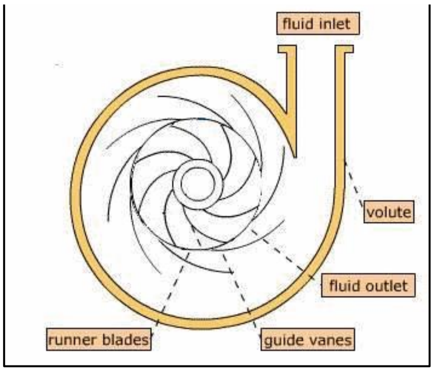

Figure 14 Francis Turbine Schematic

Source: http://www.jfccivilengineer.com/

As mentioned previously Francis turbines can be used for both medium and high head systems with heads of anywhere between 15m-500m.

Gravity Turbines

Gravity turbines are simply driven by the weight of water entering the top of a turbine and falling to the bottom where it is then released. They are typically slow running machines with examples of gravity turbines being the overshot waterwheel and the reverse Archimedes screw.

Overshot Waterwheel

This type of turbine is the oldest type of waterwheel. The wheel consists of many curved buckets which fill with water as the water falls on them. Gravity then acts on the buckets causing the weight of the water to rotate the wheel. The buckets then empty the water into the tailrace[45].

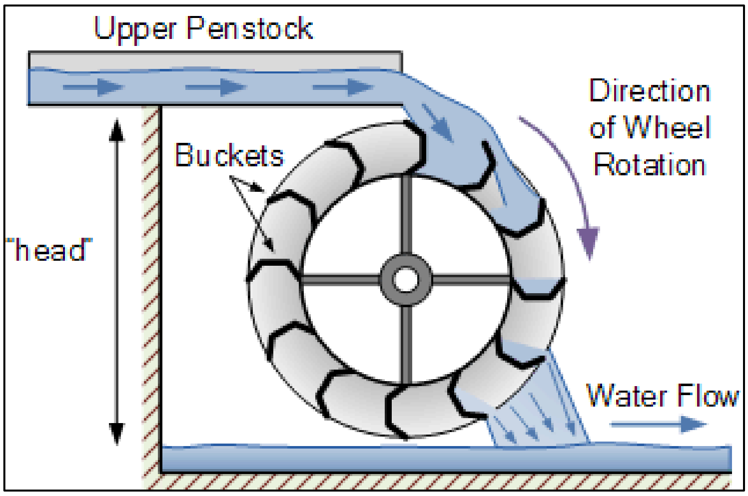

Figure 15: Overshot Waterwheel Operation

Source: http://www.alternative-energy-tutorials.com/

Reverse Archimedes Screw

The concept of the Archimedes screw was traditionally to transfer water from a low-lying body of water to a high elevation (such as to irrigation ditches). This would be achieved by turning the handle in an anti-clockwise direction to draw the water up from a lower elevation to a higher elevation. The theory of using the Archimedes screw as a hydro turbine uses the same principal of operation but acts in reverse. The water instead enters the screw at the top and the weight of the water pushes on the helical flights, allowing the water to fall through the system to the lower level causing the screw to rotate. This rotational energy can then be extracted and converted into electrical energy by an electrical generator connected to the main shaft of the Archimedes screw. This type of device can work efficiently on heads as low as one meter[46].

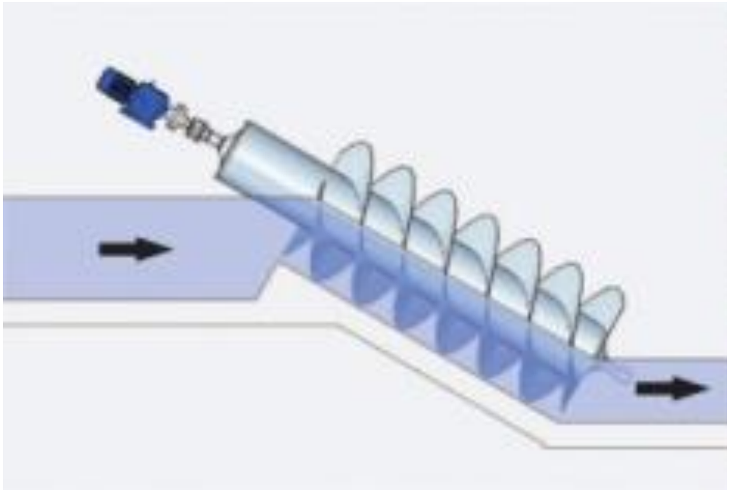

Figure 16: Reverse Archimedes Screw

Source: http://www.energysavingadvisor.co.uk/

The different categories of turbine types and their associated application for various head heights can be summarised as follows in table 4.

	HEAD CLASIFICATION		
TURBINE TYPES	HIGH (>50M)	MEDIUM (10-50M)	LOW (<10M)
IMPULSE	Pelton Turgo	Crossflow Turgo Multi-jet Pelton	Crossflow Under-shot Waterwheel
REACTION		Francis (spiral-case)	Francis (open-flume) Propeller Kaplan
GRAVITY			Over-shot Waterwheel Archimedes Screw

Table 4

2.10. Turbine Efficiency

Figure 17 shows how the efficiency of selected turbines varies with the percentage of turbine flow.

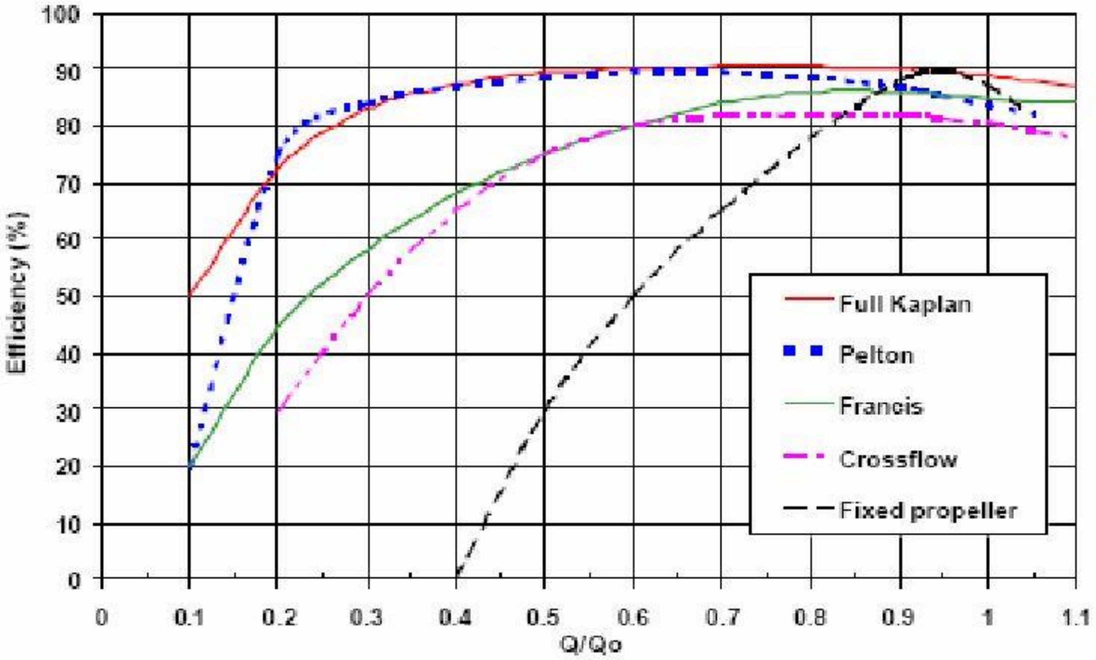

Figure 17

Source: http://waterturbines.wikidot.com/system:join

It can be observed from the efficiencies comparison chart in figure 17 that for Kaplan turbines a maximum efficiency of 90% is achieved when the percentage of turbine flow is between 50 and 90%. It can also be seen that when the percentage flow drops below 30% the efficiency quickly deteriorates. The same is also true for Pelton turbines as when the percentage flow is below 20% the efficiency drops away rapidly though this turbine is capable of reaching efficiencies of 90% when the percentage flow is 60-70%. Therefore it can be concluded that Pelton and Kaplan turbines retain high efficiencies when running below their design flow. Though the Francis turbine can be observed to have a lesser maximum efficiency they have the widest range of application among the various turbines in terms of size and operating heads though it can be noted that when the turbines flow rate drops below 80% the efficiency of the turbine drops off rapidly. Both in the case of the crossflow turbine and the Francis turbine the efficiency falls away rapidly as they are operated below half their design flow.

Turbines must be selected according to the site specifications and changing flow rate to ensure that the turbine is producing the maximum power possible. Turbines that can work with a wide range of flow rates and maintain a high efficiency are desirable in order to maximise power production.

2.11. Turbine Selection Chart

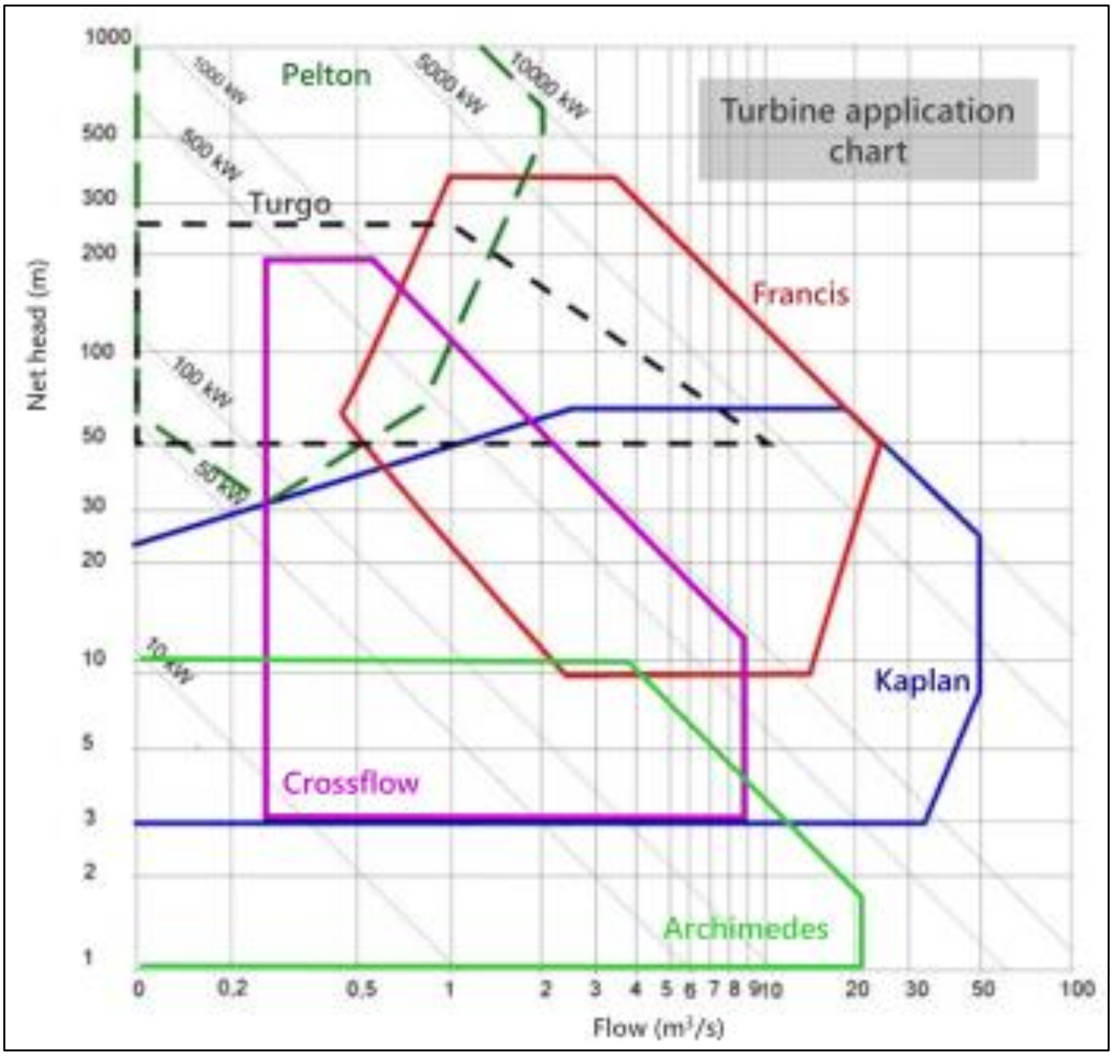

Figure 18: Turbine Selection Chart

Sourced: http://www.energysavingadvisor.co.uk/hydro-power/hydro-power-technical-stuff-further-reading-references

The green dashed line represents the domain of a Pelton turbine.

The black dashed line represents the domain of a Turgo turbine.

The red line represents the domain of a Francis turbine.

The purple line represents the domain of a crossflow turbine.

The blue line represents the domain of a Kaplan turbine.

The solid green line represents the domain of a reverse Archimedes screw turbine.

2.12. Turbine Governors

The purpose of a governor is to ensure that the generator spins at the correct speed. Governors used in small hydro systems commonly achieve this by managing the load on the generator. Maintaining the correct load on the generator may be possible manually by switching the device on and off but a governor can do this accurately and automatically.

The key function of a governor is to automatically adjust the rotating speed of the hydroelectric generator, ensuring that they are constantly running within the acceptable deviation rated speed in order to meet the requirements of the power grid frequency quality.

The working principle of a hydro turbine governor is by comparing the rotational speed signal (frequency unit) to the power grid frequency, based on the difference between the two, it can give the hydro-electric converter an operating signal relay device an on off command to control the turbine water flow and in this way achieves the regulation of turbine speed[47].

2.13. The Generator

The generator, along with the turbine, is the key component of a hydropower system and together are the heart of the system. These key components are responsible for the conversion of potential energy contained within the water to other forms. Firstly, the turbine converts the potential or kinetic energy within the water to mechanical movement (rotational energy) and the generator then converts the mechanical movement into electrical energy[48].

The generator must ensure that there is a balance between the power going in from the turbine and the power coming out (plus losses). If the power going out is reduced the turbine will run faster and become more inefficient until a new balance of power is met. If the power going out is increased the turbine will slow down until the generator power output is reduced[49].

For hydroelectric installations both synchronous and induction generators may be used based on the system design and requirements

Synchronous Generators

Turbines provide mechanical input to synchronous generators that convert mechanical input to 3-phase electrical power output. In small hydro-power installations where the scheme is operated free of a grid connection synchronous generators are typically used to meet the requirements of the energy consumers[50]. This is due to the fact that the output frequency of this type of generator can be more easily regulated to remain at a constant value which can more easily accommodate load power factor variations. In hydropower installations where the synchronous generator is connected to the grid speed variation is are not possible which makes the system more inefficient as the generator cannot adapt to a partial load. Typically, salient pole 3-phase generators are used because the hydraulic turbines in hydroelectric systems operate a slow speeds and so require a large number of field poles to produce the rated frequency.

Induction Generators

Induction generators are also known as asynchronous generators and generate electrical power when its rotor spins faster than the synchronous speed. Induction generators draw their excitation power from an outside power source such as the national grid meaning that the magnetic field that is created by the stator windings is powered by the grid. This is advantageous as it means that the electricity generated is perfectly synchronised with the grid as it is the grid that is providing the excitation. However this also means that if there is a power cut the excitation will stop causing the generator to cease operation and so the hydro system with be non-operational[51]. Induction generators may also produce power if connected to a significant source of capacitance reactance such as capacitors, though this may be hazardous to the equipment due to the high voltages produced.

2.14. Power Derivations and Calculations for Hydro Power

The energy released by a flow of water through a vertical height can be described as:

$$E = mgh$$

Where,

E= Energy released in Joules

m= Mass of water in kg

g= Acceleration due to gravity in m/s^2 (typically $9.81 m/s^2$)

h= Vertical distance or gross head in meters

As mass is equal to the product of density and volume, the energy released now becomes:

$$E = \rho V g h$$

Where,

ρ= density in kg/m^3 (typically $1000 kg/m^3$ for water)

V=volume in m^3

If we consider substituting volume with volume per second, or flow rate, then the equation changes energy released per second, or power, thereby giving:

$$P_g = \rho Q g h$$

Where,

P_g = gross power in W

Q = Volumetric flow rate in m^3/s

Gross power, however, is an ideal situation that ignores various losses experienced in a working system such as pipe work friction and mechanical losses associated with turbines and generators. To take account of these losses, an efficiency factor can be included to give the net power:

$$P_n = \eta\rho Qgh$$

Where,

P_n = net power in W

$\eta = hydraulic\ efficiency\ in$ %

Using this equation to convert flow rate exceedance curve to an equivalent power curve then allows the total energy generated to be calculated in the same way as for a wind turbine.

Pressure losses in the pipes are a result of frictional drag and turbulence as the water flows through the pipe. These flow losses contribute towards energy losses in the pipe. The CIBSE GUIDE VOLUME C SECTION C4 FLOW OF FLUIDS IN PIPES can be used to calculate pressure losses for a range of given flow rates

Calculating Frictional Losses

One of the accepted methods to calculate frictional losses resulting from fluid motion in pipes is by the Darcy-Weisbach equation, named after Henry Darcy and Julius Weisbach. For a circular pipe:

$$h_l = f_D\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

h_l =Head loss due to friction given in units of length

f_D =Darcy friction factor (obtain from Moody diagrams)

L =Pipe Length

D =Pipe Diameter

V =Flow velocity

g = Gravitational acceleration

3. Feasibility Study

3.1. Methodology

According to the British Hydropower Association (BHA), there are several critical steps which must be carried out when assessing the feasibility of a hydropower site. The feasibility study should incorporate accurate data in order to develop design and site layout while taking into consideration the financial viability of the project. The following 4 steps are essential components of a hydropower feasibility study.

1. Hydrological Survey. The hydrological survey should produce a flow duration curve based on long term records of rainfall and/or flow data. The long term information may be backed up by short term flow measurements. The BHA also recommend s that the hydrological survey include a recommendation for the required compensation flow.

2. System Design. This section should include a description of the overall layout of the project, including a drawing showing the general arrangement of the site. The significant aspects of the project should be described in detail with appropriate cover drawings and supporting diagrams, etc. These significant aspects should include civil works (such as intake and weir, penstock, turbine house, tailrace channel, site access and construction details.), detail of the generating equipment (turbine selection, gearbox, generator, control system) and machinery layout plus details of the grid connection.

3. Estimation of system cost. A breakdown of the financial aspects of the must be detailed which should include estimations of capital cost broken down into subcategories of civil costs, the cost of grid connection, the cost of electro-mechanical equipment and engineering and project maintenance fees.

4. Estimation of annual energy output and annual revenue. This should include a technical analysis and summary of the source data including river flows, hydraulic losses, operating head, turbine efficiencies and methods of calculation for the output of the scheme in terms of maximum potential power

in (kW) and the average annual energy yield (kWh/year) and the equivalent annual revenue(£/year)this may generate.

5. Environmental Impact Assessment. This is an additional task which may for part of the feasibility study and can be carried out in order to assess the environmental consequences of developing the scheme.

3.2. Legal Considerations

Ownership and Management of the scheme

The University of St. Andrews will own and operate the scheme, though it will be managed from their site at the Guardbridge Energy Centre. The safety and operation of the hydro-generator unit will be the responsibility of the contractor.

3.3. Planning Considerations, Licences & Guidance

SEPA

SEPA are Scotland's principal environmental regulators and responsible for the management of all Scotland's waterways. All hydro power development must obtain a Water Environment (Controlled Activities) (Scotland) Regulations 2011 licence (CARS licence)from SEPA. They also offer developers guidance on run-of-river hydropower schemes. SEPA aim to achieve the right balance between protection of the water environment and renewable energy generation according to the Scottish ministers policy statement. It is the responsibility of the local authority to consult them on proposals which have the capacity to generate 50MW or less.

Local Authority

The local authority should be contacted for specialist advice at the earliest stage before undertaking a feasibility study. In the case of the Guardbridge Energy Centre the local authority if Fife Council. Planning permission must be obtained from the local authority prior to the commencement of the development and throughout the planning process the local authority will control the development.

Scottish Natural Heritage

SNH offers special guidance to the competent authorities in order to help them identify, assess and where necessary mitigate against impacts on the natural heritage. This advice mainly focuses on run-of-river schemes but will be relevant for this project being so close to the Eden estuary conservation area.

4. Hydrological Survey

The data for the hydrological survey was taken from the National River Flow Archive which is operated by the Centre for Ecology and Hydrology. The data was measured at the St. Michaels gauging station (station number 14005) which is upstream of Guardbridge. The measuring authority for the station is the Scottish Environmental Protection Agency (SEPA) and the data for this station has been recorded over the last two decades from 1984-2014.

Figure 19 depicts the annual hydrograph for the Motray Water. A hydrograph is a graph showing the rate of flow past a specific point on the river per unit of time. The rate of flow is typically expressed in cubic meters per second. The water carried by the river will vary from month-to month, and so the annual hydrograph will depict this variation in the rivers discharge throughout the year and the pattern of flow is known as the river regime.

Shown in figure 20 is the flow duration curve for the Motray water. A flow duration curve is a graph which shows the percentage of time that the flow in a stream or river is likely to equal or exceed a specified value. The area under the flow duration curve gives the average daily flow and the median daily flow is the 50% value.

The shape of the flow duration curve is of particular significance as it can help determine important characteristics of the stream. The shape of the curve in the high-flow region will give information on the rivers flood regime whereas the shape of the curve in the low-flow region will determine the rivers ability to sustain low flows during the dry seasons[52]. A flat curve indicates a river that has a few floods with large groundwater contribution and also indicates that moderate flows are sustained throughout the year due to natural or artificial streamflow regulation which will sustain the base flow of the stream. A steep curve on the other hand would suggest frequent floods and dry periods with little groundwater contribution[53].

The flow duration curve is extremely useful for the planning and design phase of water resource projects such as hydropower installations as it determines the potential for firm power generation. For run of the river type plants where there is no storage potential the firm power is usually computed on the basis of the flow available 90-97% of the time[54].

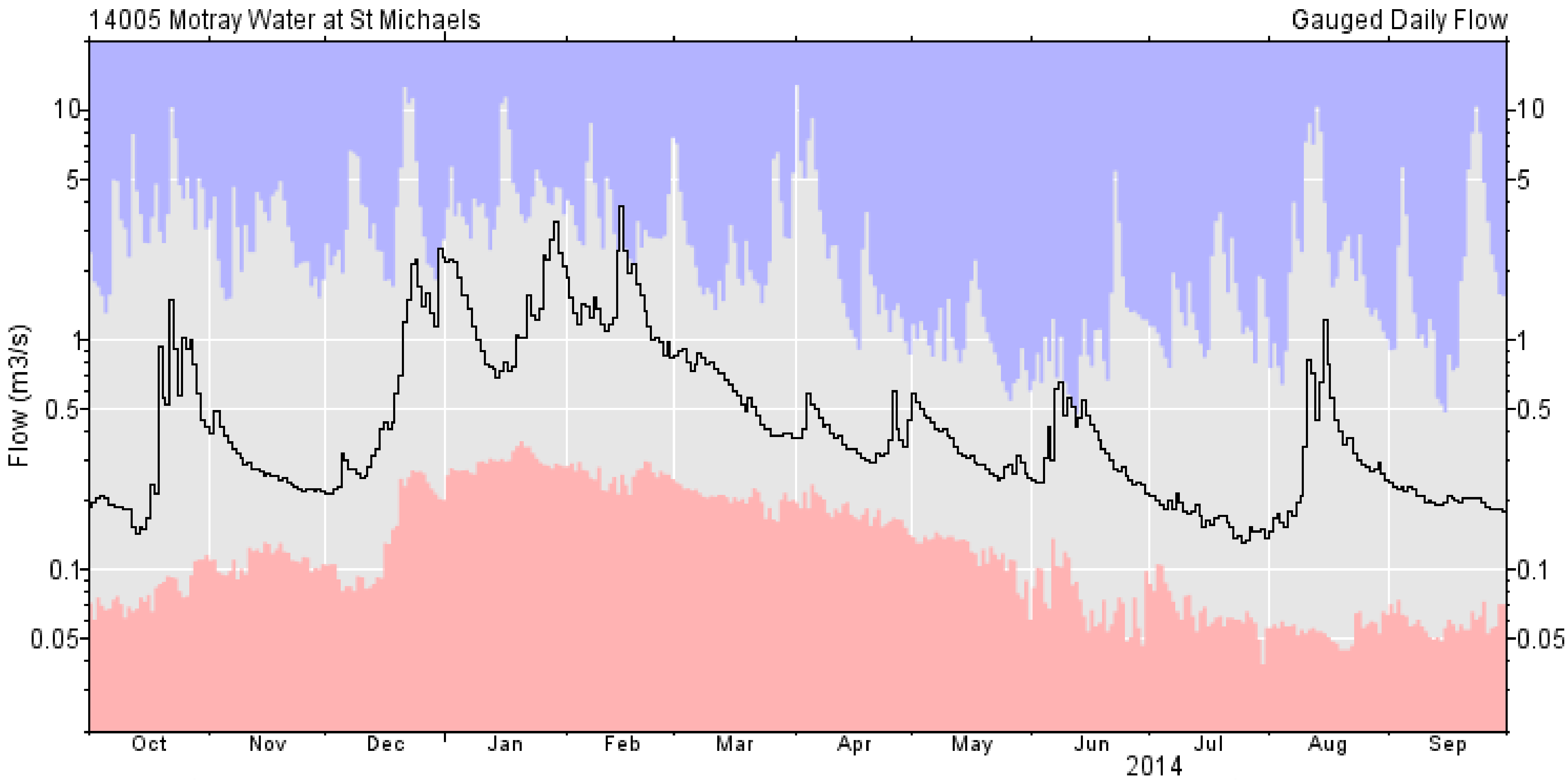

Figure 19: Annual Hydrograph for the Motray Water (2014)

Key: Red and blue envelopes represent lowest and highest flows on each day over the period of record.

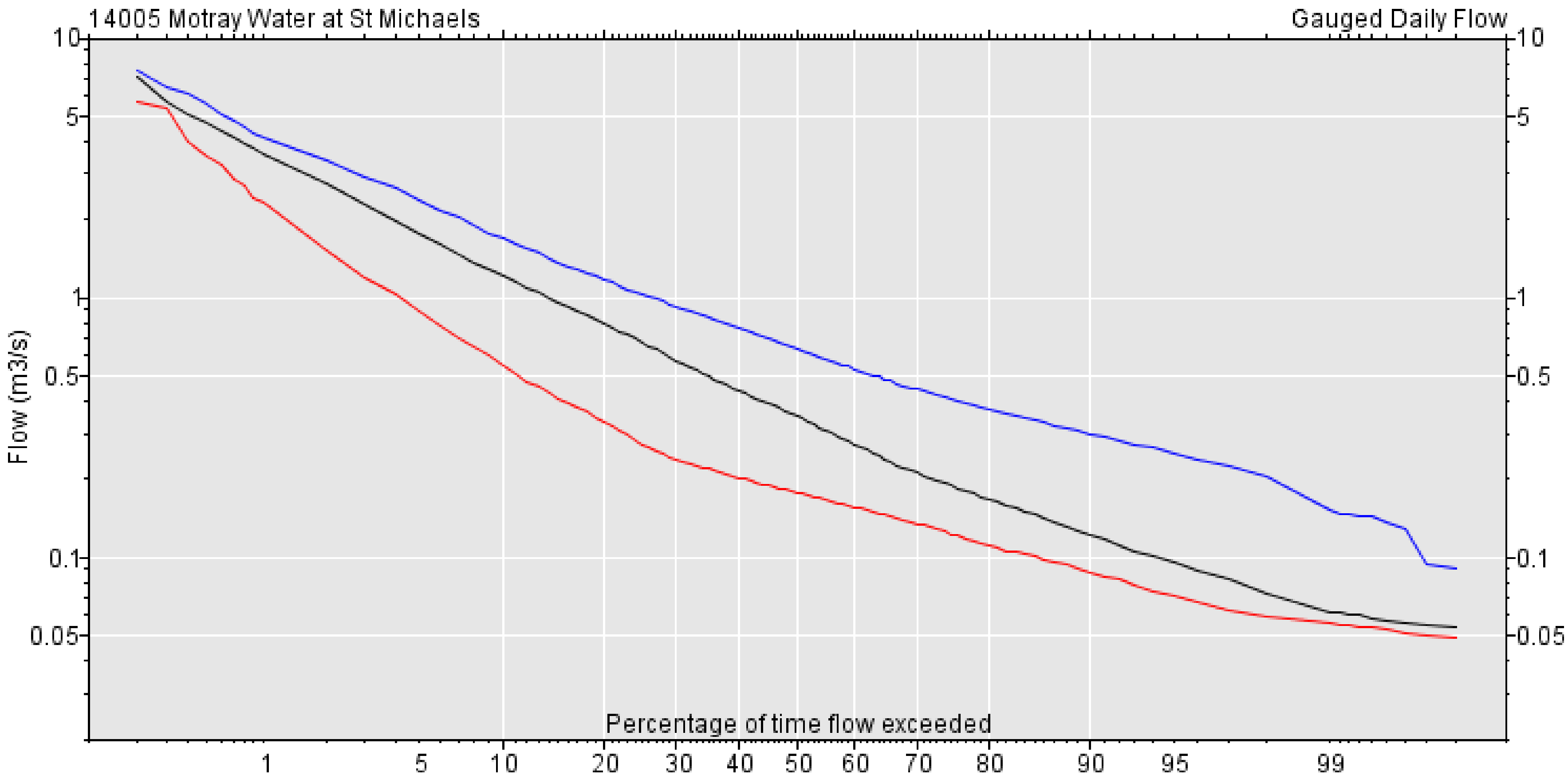

Figure 20: Flow Duration Curve for the Motray Water (2014)

Key: Black line - annual; blue line - December to March; red line - June to September.

From the annual hydrograph and the flow duration curve the following statistics can be obtained:

Time Series Statistics	
Period of Record	1984-2014
Base Flow Index	0.58
Mean Flow	$0.575m^3/s$
95% Exceedance (Q95)	$0.096m^3/s$
70% Exceedance (Q70)	$0.212m^3/s$
50% Exceedance (Q50)	$0.35m^3/s$
10% Exceedance (Q10)	$1.217m^3/s$

Table 5

As this would be a micro hydro project there is no need to set a compensation flow as recommended by the British Hydro Association. Compensation flows tend to be set in large scale plants where water is released from a dam to maintain the water level downstream preventing the river from dropping below its natural minimum level. As this project would be utilising an existing portion of the water which is already being diverted away from the river it will not put any further demand on the rivers water resource.

5. System Design

5.1. Site Layout

The map below, along with the associated photographs, shows the overall site layout and the map location references are detailed on page 60.

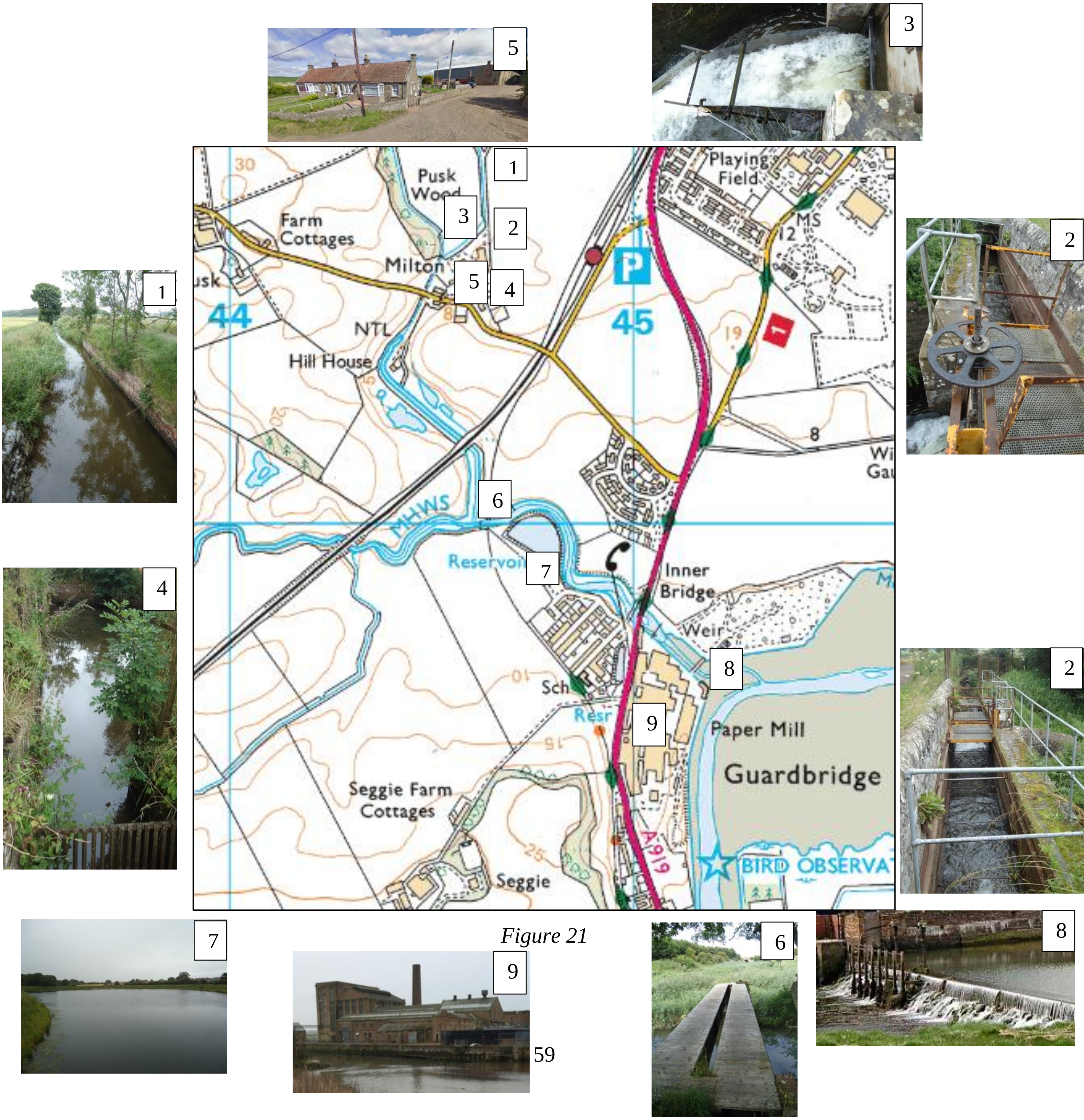

Figure 21

5.2. Map Location References

1. Water diversion channelled from the Motray Water
2. Sluice Gate
3. Unused water which is not used to feed the reservoir pipes channelled back into the Motray Water. (One of the potential hydro installation sites identified)
4. Holding pond where pipe inlets are located
5. Milton Farm
6. Aqueduct
7. Reservoir
8. Weir on the Motray Water (Another of the potential hydro installation sites which were identified)
9. Site of the former Guardbridge paper mill and future energy centre

5.3. Site Survey

The purpose of the initial site survey was to assess the site for possible hydro power sources and, of these, decide which had the most potential to be developed.
Initially 3 potential sites were identified along the Motray Water . The first of these was at Milton Farm where there is considerable flow and several meters of height to generate power. Secondly at the point where the pipes feeding the reservoir cross over the Motray Water , there is considerable height within the aqueduct. The reservoir is now redundant as its original purpose was to feed the paper mill with freshwater for the industrial process. It has been suggested that if the water was released at this point to be fed back into the Motray Water this would provide considerable head height in order for power to be generated. Lastly there is an existing weir over the Motray Water before it reaches the Eden estuary. The weir itself spans the water and has two sluice gates. This portion of the Motray is tidal and so fills and discharges with water due to the tides twice a day. The idea for this potential hydro source is to operate the weir as some sort of tidal barrage device as it provides a predictable and consistent source of power.

It was decided that the feasibility of generating power from the aqueduct would be investigated as some of the infrastructure for generating hydro power was already in place. Currently, a portion of water from the Motray Water is channelled through a sluice gate down a lade to Milton Farm where it reaches a holding pond. From this pond there are two pipes of different diameters fed with water and it is these pipes which traverse the aqueduct and feed the reservoir. The route of the water channel as it is directed away from the Motray water to Milton farm can be seen in red in figure 22, the blue line represents the path of the Motray Water.

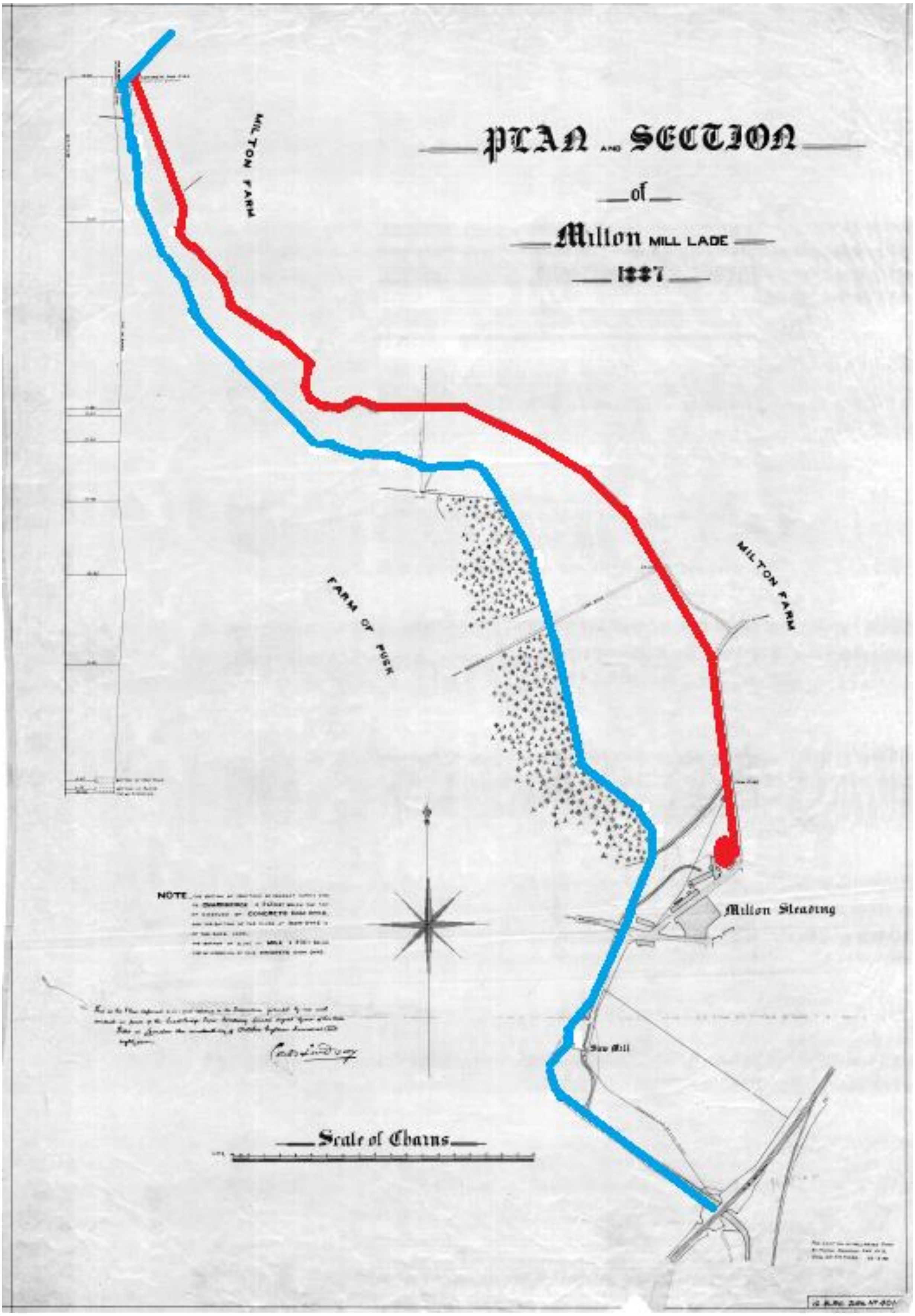
PLAN AND SECTION
of
Milton MILL LADE
1887
MILTON FARM
FARM OF FUSK
MILTON FARM
Milton Steading
Saw Mill
Scale of Chains

Figure 22

Having determined where to site the project there were several other factors to be determined. Firstly the site had to be assessed to determine the available head, and the flow rate of the water through the pipes defined.

5.4. Flow Rate Through Pipes

The reservoir is fed by two pipes of different diameters, a 365mm and a 305mm pipe. These pipes convey water from Southfield weir on a lade fed by the Motray water North of Milton Farm. The maximum flow is $0.18m^3/s$ [55].

5.5. Available and Effective Head

The available head was determined by carrying out a site visit and measuring this manually. The head was measured to be approximately 4m from the top of the aqueduct to the water level. This is an average measurement and it should be noted that the actual head varies between 3.5 and 4.5m due to tidal variations in the water level.

There is also an additional head of 5.5meteres available as this is the elevation difference between the pipe inlet at Milton farm and the proposed outlet at the aqueduct, therefore the total available head would be 9.5 meters.

As mentioned previously, pressure losses occur within pipes due to friction. These frictional losses can be represented as head loss and so the effective head will be smaller than the figure stated above. There are a number of factors which affect the frictional losses in the pipe including the viscosity of the fluid, the roughness of the internal surface of the pipe, the change in elevation between the ends of the pipe, the length of the pipe through which the fluid travels and the size of the internal pipe diameter.

Over the years there have been a number of different methods developed for calculating the frictional losses in pipes but the Darcy-Weisbach formula is now considered the most accurate pipe friction loss formula[56]. As outlined previously the Darcy-Weisbach formula is as follows:

$$h_l = f_D \left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

h_l =Head loss due to friction given in units of length
f_D =Darcy friction factor (obtain from Moody diagrams)
L =Pipe Length
D =Pipe Diameter
V =Flow velocity
g = Gravitational acceleration

The equation contains a dimensionless friction factor known as the Darcy friction factor. This is not a constant value and is system specific. It is dependent on the parameters of the pipe and the properties of the fluid flowing through it but is known to an extremely high accuracy for certain flow regimes. This friction factor can be obtained through various imperial or theoretical calculations or can be acquired from various published charts. The most commonly utilised of these charts are known as Moody diagrams, named after L.F.Moody and so the factor is sometimes called the Moody friction factor[57].

Moody charts link several key factors which contribute to the overall frictional losses in the system and these are the Reynolds number and the relative roughness.

The Moody chart can be split into two flow regimes; laminar and turbulent. Laminar flows occur for values of Reynolds number less than 2000 and this is unlikely to occur for water flow. Laminar flow tends to occur in more viscous fluids such as oil. Instead water flow is most likely to be turbulent and this occurs for values of Reynolds number in excess of 3000.

The group of curves on the Moody chart can be generated using the following equation developed by Colbrook-White, and this equation may also be used directly instead of using the chart:

$$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{2.51}{Re\sqrt{\lambda}} + \frac{\frac{k}{d}}{3.7}\right)$$

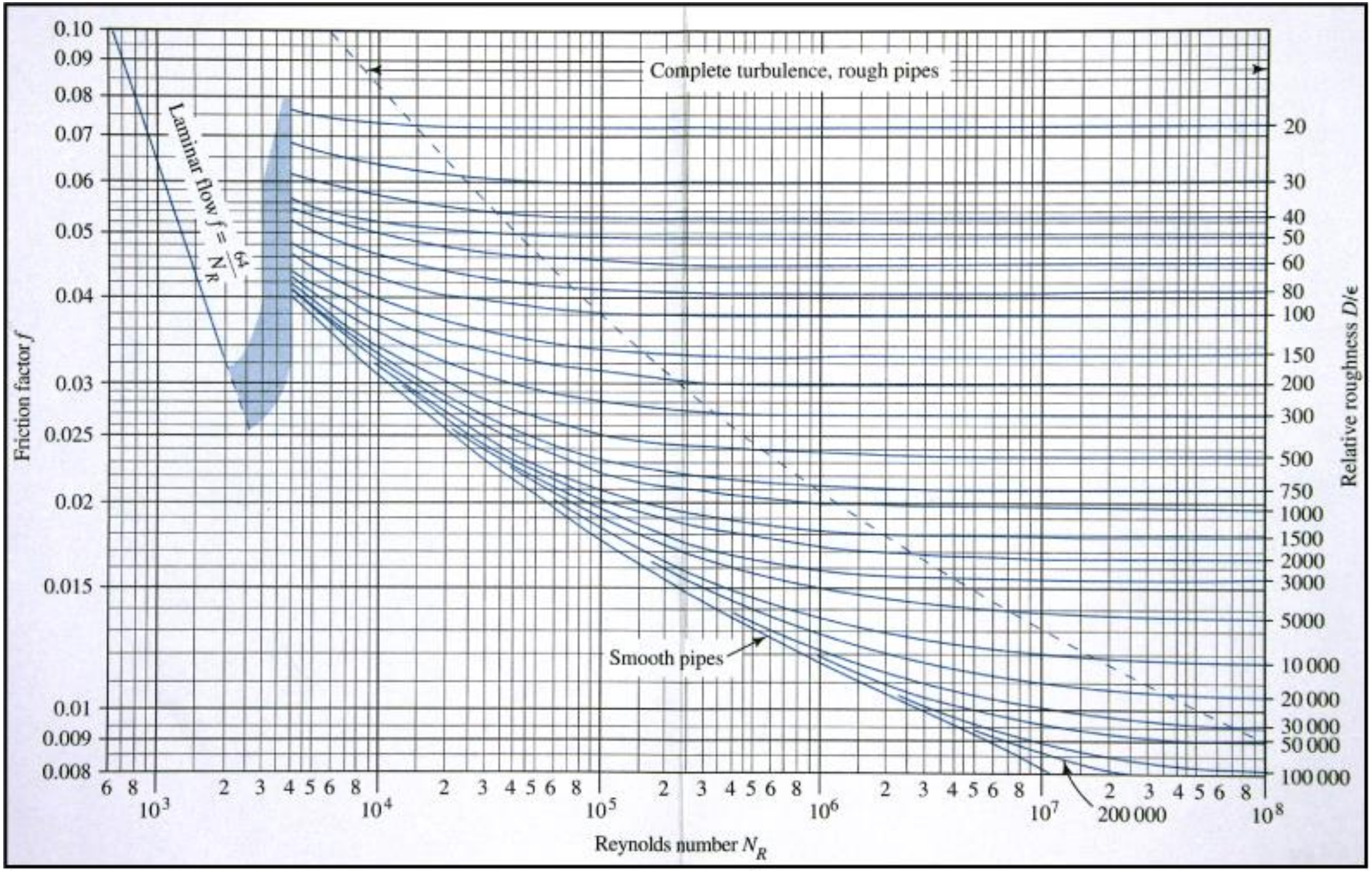

Figure 23: Moody chart[58]

The Darcy equation must be calculated twice i.e. once for each pipe (the 365mm and 305mm pipes). The values for the 365mm pipe will be calculated first followed by the 305mm. Assume the total flow rate is divided equally between the two pipes i.e $0.09m^3/s$ flowing through each pipe.

The internal diameter of the pipes will be somewhat smaller than the external diameter stated. The pipes are assumed to be class C and so the internal diameters for each pipe is considered to be:

365mm external diameter= 330 mm internal diameter
305mm external diameter= 270 mm internal diameter

These values were obtained from table found in appendix A

In order to calculate the Reynolds number for reference with the Moody diagram the following equation can be used:

$$Re = \frac{QD_H}{vA}$$

Where
Re=Reynolds number
Q= volumetric flow rate m^3/s=$0.09m^3/s$
D_H =The hydraulic diameter of the pipe(characteristic travelled length)=500m
v =Kinematic viscosity=1.307x 10^{-6} (m^2/s)
A =Is the pipe cross-sectional area (πr^2) =$0.09m^2$

Using the above values gives a Reynolds number of 3.83 x10^8. This can then be used along with the value for relative roughness to find the Darcy friction factor (f_D) from the Moody diagram. For the purpose of this calculation the pipes are considered to be corroded as they have been there a long time. Corroded cast iron has a roughness, k ,(mm) of 1.00-1.25m (obtained from CIBSE guide C)[59]. For this calculation the roughness will be assumed to be 1.00mm.

Relative roughness (k/d)=1.00mm/330mm=0.003. From the Moody diagram the friction factor (f_D) can be found to be approximately 0.026.

The Darcy-Weisbach formula can then be used to find the effective head loss and the inputs for the equation are as follows.

$f_D = 0.026$
L =500m
D =0.33m
V =flow velocity for a circular pipe can be given by

$$v = \frac{1.273q}{d^2}$$

$$v = 1.05ms^{-1}$$

$g = 9.81ms^{-1}$

Using these values gives a head loss of 2.21 meters for the 365mm pipe.

The procedure must then be repeated for the 305mm pipe.
The cross sectional area (πr^2) for the 305mm (internal diameter 270mm) pipe is $0.06m^2$. Substituting this value into the Reynolds equation along with the other values detailed above gives a Reynolds value of 5.74x10^8. The relative roughness (k/d)= 1.00mm/270mm=0.0037. From the Moody diagram the friction factor (f_D) can be found to be approximately 0.026.
The Darcy-Weisbach formula can then be used to find the effective head loss and the inputs for the equation are as follows.

$f_D = 0.026$
L =500m
D =0.27m
V =flow velocity for a circular pipe can be given by

$$v = \frac{1.273q}{d^2}$$

$$v = 1.57ms^{-1}$$

$g = 9.81\text{ms}^{-1}$

Using these values gives a head loss of 6 meters for the 305mm pipe.

This means that between the two pipes there is an average head loss of 4.1meters. Subtracting this from the available head gives a net head of 5.4 meters. These value can be used along with the flow rate to calculate the output power of the system.

5.6. Turbine Selection

According to the turbine selection chart (figure 18) either a reverse Archimedes screw or a Kaplan turbine could be used for this development. It would be recommended that a Kaplan turbine is utilised as the site layout and characteristics suit this type of technology and additionally this type of technology is more efficient.

5.7. Location of the Hydro-Generator

In order to make the most of the available head the hydro generator would ideally be situated on the North bank of the Motray water with the turbine located at the base of the aqueduct in order to maximise the head.

5.8. Electrical Inter connection

The hydro generator would be connected for parallel operation with the national grid system. The generator would be of the asynchronous type and would require a load control governor to monitor the voltage of the system and ensure the generator is correctly loaded. The energy requirements of the Guardbridge site are high enough that most, and potentially all, of the energy generated will be used on site. Electrical interconnection with the main grid will be used to meet the rest of the sites energy demand. An underground cable would be run from the hydro-generator house to the Guardbridge site and the electrical interconnection and hydro generator would include protection equipment.

6. Estimation of Annual Energy Output and Annual Revenue

6.1. Potential Energy Resource

The potential energy resource for the system can be calculated from the following equation as outlined I n section 2.14:

$$P_n = \eta \rho Q g h$$

For the calculation the mechanical efficiency, η , is assumed to be 90% based on a Kaplan turbine hydro generator system.. The calculation must be done twice, once for each pipe and the power output combined to give the total power output for the system. Once again the total flow rate 0.18m³/s is considered to be split equally between the two pipes. i.e. 0.09m³/s flowing through each.

6.2. Power output from the 365mm pipe

The head loss for the 365mm pipe was calculated to be 2.21 meters which gives an effective head of 7.29m. Therefore the power output from the 365mm pipe will be:

$$P_n = 0.9 * 1000 * 0.09 * 9.81 * 7.29$$
$$P_n = 5793W$$
$$P_n = 5.8kW$$

6.3. Power output from the 305mm pipe

The head loss for the 305mm pipe was calculated to be 6 meters which gives an effective head of 3.5m. Therefore the power output from the 305mm pipe will be:

$$P_n = 0.9 * 1000 * 0.09 * 9.81 * 3.5$$
$$P_n = 2781W$$
$$P_n = 2.8kW$$

6.4. Total Power Output

Combining the power outputs for both pipes gives a total power output of 8.6kW.

6.5. Annual Energy Production

In order to accurately quantify the annual energy production from a hydro system requires the use of specialist software, but a good estimation can be made using a capacity factor. A capacity factor is essentially the ratio of actual power output over a period of time compared to the theoretical maximum potential power output if it was operating at maximum capacity over the same time period. For a typical UK site with good quality turbine and a maximum flow rate of Q_{mean} and exceedance of Q_{95} , it can be shown that the capacity factor is approximately 0.5[60]. The annual energy production from the system can then be calculated as follows:

Annual Energy Production (kWh) =Maximum Power Output (kW) x No of hours in a year x Capacity Factor

$$Annual\ Energy\ Production = 8.6 * 8760 * 0.5$$

$$Annual\ Energy\ Production = 37668kWh$$

The annual energy production from the system is calculated to be 37668kWh

6.6. Electricity Consumers

There are currently only a handful of buildings on the Guardbridge site using electricity. These are a brewery, a distillery, a food growing business and the Guardbridge site office. Over the coming years, as the site attracts more businesses to utilise the space, the site energy requirement is expected to increase and this energy forecast is not yet clear. The energy requirements for the past four years for the businesses already based there are outlined below.

6.7. Guardbridge Site Electricity Demand

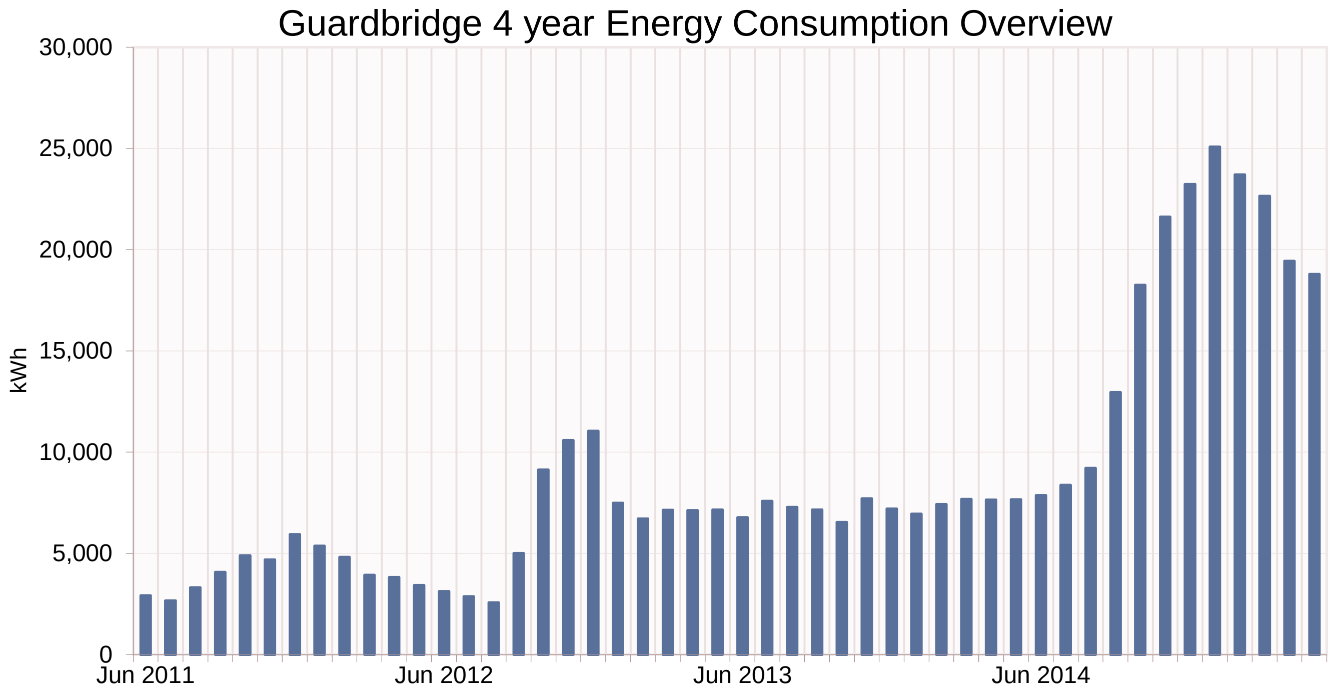

Figure 24

As figure 24 above shows the energy requirements of the site have steadily increased over the last four years and this is a trend that is expected to continue. Table 6 also shows that the total energy used has risen from almost 50kWh to 211000kWh. This means that were the energy generated from the hydro scheme to be completely utilised on site that in 2011 it could have produce 75% of the sites energy requirements. This figure is less significant now in the 2014-15 requirements but would still account for approximately 18% of the site energy requirements and this would equate to a significant monetary saving as discussed below.

Month	2011 - 12	2012 - 13	2013 - 14	2014 - 15
	kWh	kWh	kWh	kWh
Jun	2,921	3,120	6,777	7,865
Jul	2,675	2,867	7,590	8,373
Aug	3,325	2,577	7,278	9,219
Sep	4,074	5,013	7,162	12,954
Oct	4,896	9,129	6,538	18,248
Nov	4,695	10,586	7,708	21,621
Dec	5,933	11,043	7,212	23,233
Jan	5,367	7,483	6,957	25,086
Feb	4,826	6,715	7,427	23,707
Mar	3,937	7,144	7,684	22,652
Apr	3,818	7,130	7,647	19,440
May	3,421	7,154	7,668	18,796
Total	49,888	79,961	87,648	211,194

Table 6: Guardbridge 4 year Energy Overview

6.8. Annual Revenue/Cost Saving Generated from the Scheme

The annual revenue generated from the scheme is calculated based on two components. Firstly, the cost saving associated with not using electricity bought from the grid constitutes a saving of 14p/kWh[61]. This saving multiplied by the annual energy generation equates to a saving of £5270. The second part of the annual revenue generated from the scheme comes from the feed in tariffs. The associated FITs for micro-hydro installations are detailed below in table 7.

Description	Period in which Tariff Date falls	Tariff (p/kWh)
Hydro generating station with total installed capacity of 15kW or less	1 April 2010 to 30 November 2012	23.56
	1 December 2012 to 31 March 2014	22.59
	1 April 2014 to 30 September 2014	21.46
	1 October 2014 to 31 March 2015	19.31
	1 April 2015 to 30 September 2015	17.17
	1 October 2015 to 31 March 2016	15.45
Hydro generating station with total installed capacity greater than 15kW but not exceeding 100kW	1 April 2010 to 31 March 2014	21.09
	1 April 2014 to 30 September 2014	20.04
	1 October 2014 to 31 March 2015	18.03
	1 April 2015 to 30 September 2015	16.03
	1 October 2015 to 31 March 2016	14.43
Hydro generating station with total installed capacity greater than 100kW but not exceeding 500kW	1 April 2010 to 14 March 2013	13.03
	15 March 2013 to 31 March 2014	16.67
	1 April 2014 to 30 September 2014	15.84
	1 October 2014 to 31 March 2015	14.25
	1 April 2015 to 30 September 2015	12.67
	1 October 2015 to 31 March 2016	11.40

Table 7: Feed in Tariffs for hydro installations

Source: Ofgem

The hydro development on the Guardbridge site would fall under the 15kW or less installed capacity range and assuming current feed in tariff rates (1 April 2015 to 30 September 2015) the system would generate 17.17 p/kWh for any electricity produced. The feed-in-tariff multiplied by the annual energy generation would produce an income of £6470. These two components when combined constitute a total annual revenue of £11740.

7. Estimation of System Cost

In order to analyse the total estimated cost of the system, the project must be broken down into different components. The overall cost of the project can be divided into 2 categories; capital cost of the project and ongoing annual and maintenance costs.

7.1. Capital Cost of Project

The capital cost of the projects can be further broken down into different financial aspects which are as follows:

- Civil, mechanical & electrical costs
- Cost of electro-mechanical equipment.
- Engineering fees (installation, connection, testing of equipment)
- Cost of grid connection
- Planning costs and other statutory fees

Other factors affecting the capital cost of the project are system location and whether the existing infrastructure of the site can be adapted to make use of the civil structures already in place.
As this site is being developed as part of brownfield regeneration some of the components required for the hydro power installation are already in place and so will reduce capital cost significantly.

It has been reported that upgrading existing infrastructure can reduce the cost to half of what it would be for a completely new development and refurbishing or upgrading an existing plant can reduce the cost to a third. Not only can using the existing infrastructure reduce the cost of the project but it can also mean fewer environmental impacts.

The capital costs of the project have been estimated according to the formulae set out by Aggidis, G.A. et al (2010)[62] . The formulae estimates the cost of a hydro development by using site data such as hydraulic head, installed capacity and estimated cost per kW. The cost estimating formula was developed based on the statistical analysis of the cost data for various hydro projects discussed in the Salford Report. The Salford Report cost data estimates are the most accurate in the UK. A further formula detailed in the report allows the cost of the electromechanical equipment (turbine, gearbox and generator) to be estimated using the hydraulic characteristics of the site such as head and flow.

The results from the formulae allows the capital cost of the project to be estimated.. A more detailed set of the capital cost calculations can be found in Appendix B. A breakdown of the initial costs involved for the project are outlined in table 8 below.

	Capital Costs
Civil, Mechanical &Electrical costs (Including Engineering Fees)	36000
Cost of hydro plant equipment	33000
Planning Permission	3850
TOTAL	**72850**

Table 8

Total Estimated Capital Cost of the Project: £72850

7.2. Ongoing Annual Costs and Project Maintenance Costs

Ongoing annual costs are considered to be

- Operation and Maintenance of the hydro-generator
- Insurance

Ongoing Annual and Maintenance Costs: £2900

7.3. Project Financing

There are currently several grants, loans and financial incentives available for sustainable energy projects in the UK that the project may potentially benefit from if deemed eligible, and these include:

- Community Sustainable Energy Programme (CSEP): Run by BRE as an award partner of the BIG lottery fund. Up to £5,000 or 50% of project costs for feasibility studies and microgeneration for community based organisations.
- EDF Green Fund: Grants for feasibility studies (Up to £5,000), small scale energy projects (up to £30,000) for local authorities and community groups.
- Community Energy Saving Programme (CESP): Supports microgeneration on a street or neighbourhood basis, and this grant is available to community groups, housing associations and local authorities
- Carbon Trust: Offers grants to organisations for energy advice, feasibility studies and low carbon based projects. The carbon trust also offer interest free loans from £3,000 to £100,000 for low carbon energy projects.
- Green Investment Bank : The government launched a £1bn seed funding programme available to developers to provide a source of capital funding for sustainable energy projects. Eligible borrowers for the fund can be local authorities, energy utilities, energy service companies, public or private corporate investors.
- As mentioned previously the project may also benefit from financial incentives such as the feed in tariff or renewables obligation (RO).

7.4. Payback Period

The payback period is site specific and may be subject to change depending on the FITs payments and how they vary.

It should be noted that a better return of investment will be achieved if all the energy generated is used on site rather than exporting energy to the national grid as the price of exported energy is less than the price of purchased energy. For the purpose of this calculation, it is assumed that all energy is used on site.

For the hydropower installation the associated payback period is outlined below. For the current Feed In Tariffs (17.17p per KWh for hydro) the payback period would be 6.2 years.

Size of Hydropower plant	8.6kW
Amount of electricity generated annually	37668kWh
Capital Costs	£72850
Annual Feed-In Tariffs (FITs) income ➢ 17.17p for every kWh generated ➢ 4.85p for every kWh exported to the grid	£6470 - -
Annual savings from not using grid electricity, assuming 14p/kWh (This is the amount saved if some or all of the electricity generated is used on site)	£5270
Annual net income from the hydropower plant	£11740
Simple Payback	6.2 years

Table 9

8. Sensitivity Analysis

As discussed previously, pressure losses in the pipe are the result of frictional forces and turbulence as the water flows through the pipes, and these losses result in energy losses within the system. A sensitivity test was carried out in order to explore the relationship between varying the diameter of the pipes for a range of different flow rates to see how this affects the power output and effective head of the system. The CIBSE Volume C Flow of Fluids in Pipes tables were used to calculate the pressure losses for a range of flow rates. The calculations were based on a Kaplan turbine hydro generator with an efficiency of 90% where the available head is 9.5m and the pipe length 500m. Various flow rates were used up to a maximum of $0.18m^3/s$ as this is the maximum flow rate available to the system. Entry and exit losses are negligible for pipe diameters of these sizes and so were omitted from the calculations. For each pipe diameter, the pressure losses were taken away from the available head to give the effective head for various flow rates. The power output was then calculated from the effective head and corresponding flow rate. Line graphs of power output and flow rate vs effective head were produced for each diameter and are discussed in detail below.

Figure 25 below shows the power output from a pipe with 500mm diameter. Compared with the other pipe diameters tested, the effective head is increased with the 500mm pipe as the pressure losses are reduced. As expected, as the effective head increases so does the power ou put. The 500mm pipe also had the largest maximum potential power output with a peak of 14kW.

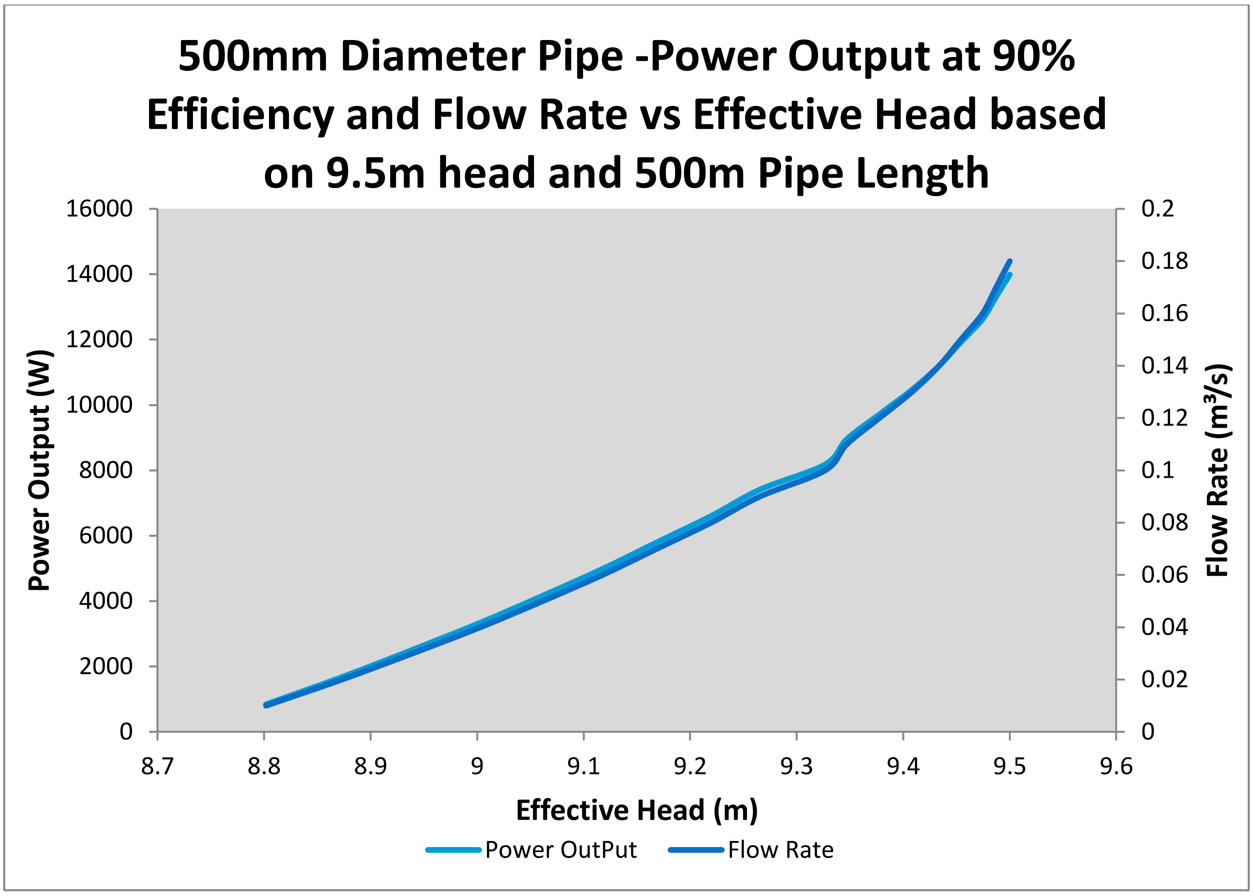

Figure 25

The power output and associated flow rates for the 400mm diameter pipe are outlined below in figure 26. Compared with the 500mm pipe, the 400mm pipe has smaller values of effective head as there are greater pressure losses within the system. The maximum potential power output is also decreased by approximately 2.5 kW with a maximum potential output of 11.6kW.

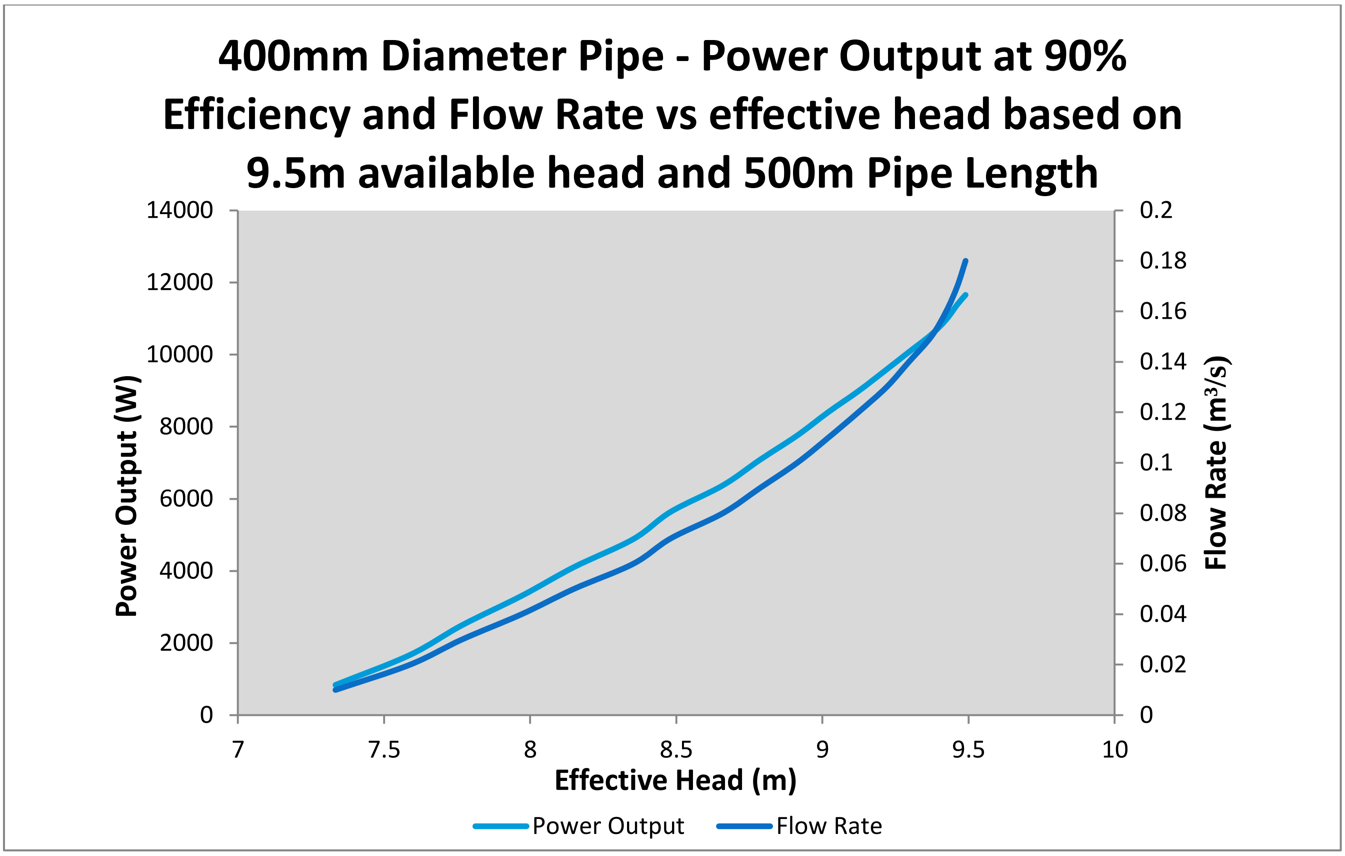

Figure 26

The power out put and associated flow rates for the 300mm diameter pipe are outlined below in figure 27. Compared with the 500mm and 400mm pipes ,the 300mm pipe has significantly smaller values of effective head as there are far greater pressure losses within the system for these dimensions. The maximum potential power output is once again decreased with a maximum potential output of 6.7kW. This is less than half of the potential power output for the 500mm pipes.

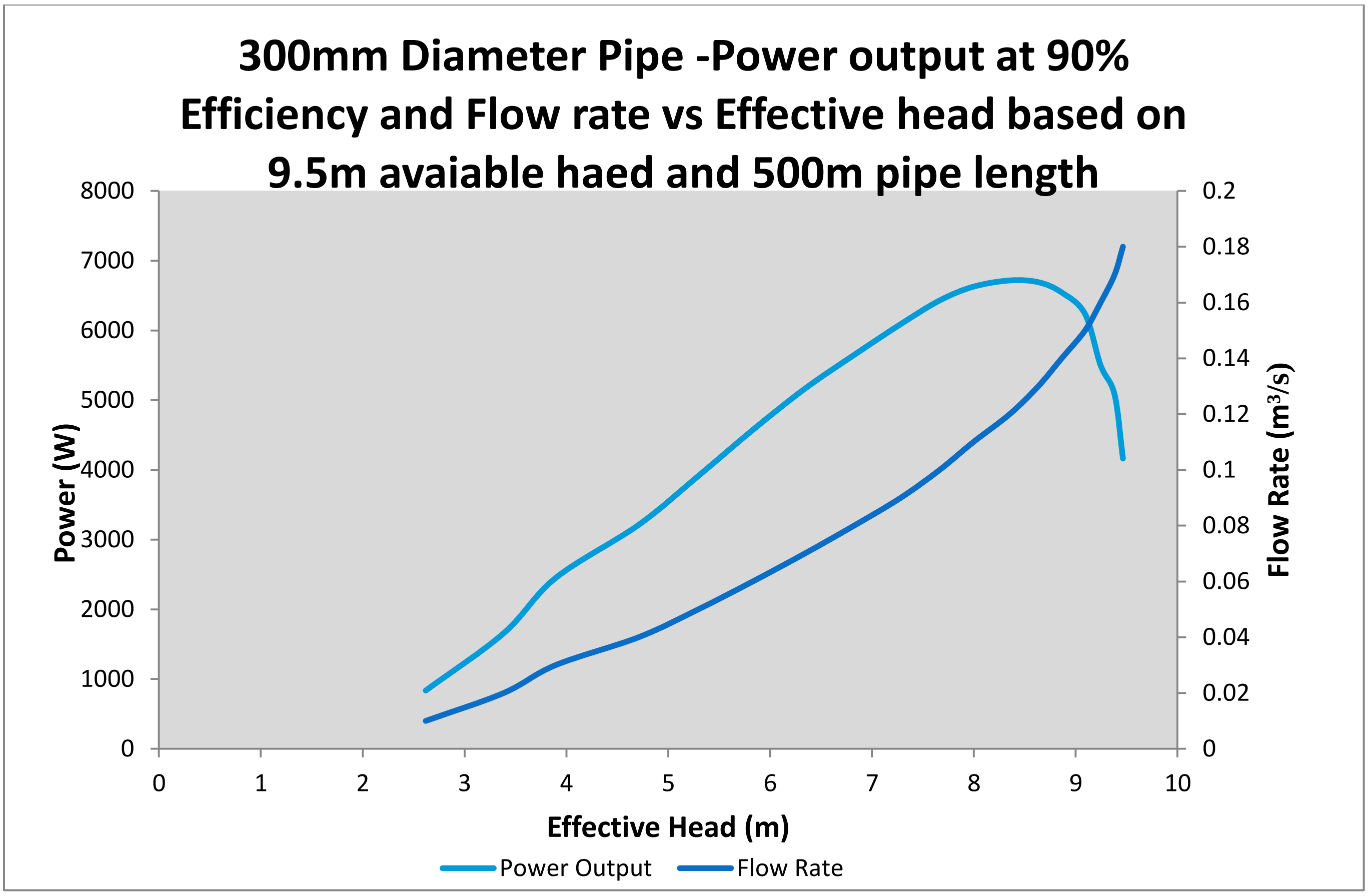

Figure 27

Although the pipes in the Guardbridge system are closest in size to the 300mm pipes which have the greatest losses, the sensitivity test shows that if the existing pipes were to be replaced with those of a larger dimension there would be a greater amount of power produced from the system, though this would significantly increase the cost of the project and so analysis of additional cost would need to be carried out against potential additional saving to determine whether or not this is feasible. The project costs, annual revenue and payback period were calculated for the 500mm pipe (table 10), which produced the greatest amount of power. It was found that by replacing the existing pipe for a pipe of this diameter the system could provide 34% of the sites current energy needs. It would also produce higher annual revenue with a shorter payback period of only 4.3years compared with using the existing pipes 6.2 years payback period. It should however be noted that the equation used to estimate total cost of the project is a best case scenario and it is stated in the report from which the equation was obtained that the cost estimations obtained are a best case scenario and will be at the lower end of the cost estimate. Using the existing pipe structure means this estimate is reasonably more accurate than if the pipe had to be replaced as there would be an additional cost to take away the old pipes and so the actual payback period will be somewhat higher. It should also be noted that by taking away the old and installing new pipes will also have a considerabley greater impact on the environment.

Size of Hydropower plant	14kW
Amount of electricity generated annually	61320kWh
Capital Costs	£83270
Annual Feed-In Tariffs (FITs) income ➢ 17.17p for every kWh generated ➢ 4.85p for every kWh exported to the grid	£10854 -
Annual savings from not using grid electricity, assuming 14p/kWh (This is the amount saved if some or all of the electricity generated is used on site)	£8585
Annual net income from the hydropower plant	£19439
Simple Payback	4.3 years

Table 10

9. Environmental Impact Assessment

An environmental impact assessment (EIA) is the process used to predict he environmental impacts, both positive and negative, that a proposed plan, policy, program, project or development may have before the decision to proceed with the project is made. The UK Department of Energy operational definition is as follows:

"The term 'environmental assessment' describes a technique and a process by which information about the environmental effects of a project is collected, both by the developer and from other sources, and taken into account by the planning authority in forming their judgements on whether development should go ahead[63]"

The framework for carrying out an EIA is set under the European Directive: 85/337/EEC. In Scotland however, the process of EIA is governed by the Environmental Impact Assessment (Scotland) Regulations 1999, and these regulations implement the provision set down by the European Directive almost to the letter for those projects subject to planning control[64]. Although the ecological impact of micro hydro projects is often considered minimal, the low level environmental effects must be taken into consideration before construction begins in order to reduce or avoid any negative impacts which may be caused by the development of the project. Additionally all developments listed in schedule 2 that may be located in sensitive areas such as those listed in Regulation 2(1) must be screened for the need for an EIA and these sensitive areas include:

-Sites of Special Scientific Interest
-Land to which Nature Conservation Orders Apply
-Internationally designated conservation sites
-National Scenic Areas World Heritage Sites
-National Parks

Although the development on the Motray Water does not directly fall into one of these categories, the water from the river discharges into the Eden Estuary which is a local nature reserve and so indirect environmental effects which may be caused by the project must be considered. Whether or not the project will require an EIA will be subject to the specifications outlined in schedule 3.

Schedule 3 selection criteria for screening the schedule 2 developments outlined above are dependent on two different factors; the characteristics of the development and the location of the development. The characteristics of the development concerns factors such as the size of the development, the use of natural resources, the production of waste and/or pollution, and the risk of accidents due to technologies or substances used. As the project in question is a small development which produces no waste or pollution and does not use up natural resources (the water is returned to the river after it has been put through the generator) it would not be subject to and EIA under these condition. However, it is with the location of the development that may be cause for an EIA. The environmental sensitivity of geographical areas likely to be affected by the development must be considered and this elates to existing land use, the abundance, quality and regenerative capacity of the area's natural resources and the absorption capacity of the natural environment and there are a number of listed areas which his is of particular concern to and among these are wetlands and coastal zones, and under these condition the project would indeed require an EIA.

EIAs will result in an environmental statement being developed. The environmental statement will include a description of the development, a description of the physical characteristics and the land use requirements during construction and operation, a description of the production process, estimates of expected residues and emissions (such as water, soil, noise, vibration light, heat etc.) of the development and it will also contain a section of the measures being employed to avoid, reduce, mitigate or offset any significant negative effects to the environment[65].

The environmental consequences of a project can be rated according to their significance. There are various different techniques for determining impact significance which can be done by comparison on likely impacts with legal requirements and standards, or by using professional judgement. Professional judgement involves interpretations and application of judgement which can be rationalised in different ways but are all subject. One way of doing this is to attribute weights to different impacts considered in relation to several different factors which include[66]:

-Spatial incidence

-Duration

-Periodicity

-Reversibility

-Probabilities

-Sensitivity of receiving environment

-Number of people affected

-Designated sites

-Carrying Capacity and Sustainability

-Public Opinion

-Regulations

Although small, localised renewable energy sources are environmentally friendly from a global perspective all of the have the potential to have negative local impacts if not properly considered at the planning phase. Even small hydropower installations can cause severe environmental impacts during the construction and operational phases with the potential to affect water resources, biological communities and resources.

Many micro hydro projects are considered run-of-the-river as the water passing through the generators are directed back into the stream with little impact to the surrounding ecology, and thanks to the absence of a storage basin they have little impact on the hydrological regime of the river. Careful design and operation can avoid these effects and ensure integration of the plant within its natural surrounding environment. However, there are still a number of issues which must be addressed at the EIA stage in order to incorporate them into the design of the project and these are outlined below.

Visual Impact

Even small hydro power developments can alter the landscape, particularly when located in the middle of the countryside, such as this development would be. Each component of a hydro system has the potential to create a change in the visuals of the landscape and this is of increasing concern to the public who are less and less willing to tolerate changes to their visual environment.

It is the job of the designer to integrate the powerhouse into the surrounding environment as much as possible. In order to disguise the powerhouse from its industrial process it could be built from materials to help it blend in with the nearby farm houses characterised by limestone walls, old roof tiles and heavy wooden windows. The natural features of the area such as local stones and vegetation could be used to veil the building but if this is not an option then the building could be painted with non-contrasting colours and textures which reduce the contrast with the surroundings allowing it to be camouflaged to an extent with the landscape. This would allow it to blend in with the surrounding countryside with minimal visual impact.

Aside from the powerhouse, the penstock is usually the main cause of visual significance and can also cause a barrier for wildlife. Improvements in technology means that interred penstocks requires little or no maintenance for several decades meaning there will be little disruption after it has been installed for the foreseeable future. Choosing glass reinforced plastic pipes can also control corrosion and frequently reduces maintenance.

It should be noted that it has been recommended by some that hydro power developments contain some element of recognition as a hydro installation. In this way it would allow the idea of renewable energy systems to be associated with beauty and conserving the landscape while producing power in much the same way as waterwheels of the past were providing a valuable opportunity to demonstrate to the community and public the positive contributions the plant can make.

<u>Noise</u>

Noise and vibrations within a small hydroelectric unit are caused by the generator, the gearbox, the turbine, transformer, the hydroelectric unit and the speed increaser. If the powerhouse is located near houses or perhaps farms which have livestock, or is on a protected natural site then his sort of noise can be unacceptable. However, careful design and the incorporation of mitigation measures can reduce noise levels to be minimalistic and strongly mitigate the acoustic impact o he plant. Some technologies that can be employed to achieve this are small tolerances in gear manufacturing, sound insulating blankets over the turbine casing, water cooling instead of air cooling for the generator and acoustic insulation of the building[67].

Power cable

The power cable could be buried in order to transport the power generated the short distance from the powerhouse to the Guardbridge site. This would help protect the local wildlife as it passes through their habitat, including some rare bird species which may nest in the nearby Eden estuary.

Reserved Flow

Channelling a portion of river water, such as for a hydro development, can deprive a portion of the river of its natural flow and this is a key issue concerning the environmental impact of the development. In order to be as uninstructive as possible, a minimum flow must be released so as to ensure the continuity of the hydrology of the river and ultimately the conservation of the river habitat and ecological life. For this particular project the reserved flow is not deemed to be an issue as it is not going to have any further effect on the environment. The project will utilise a portion of the water that has been diverted away from the river for decades and so will no put any further demand on the flow of the river. No more and no less water will be taken from the Moray Water and so from this point of view will have zero impact. Moreover, the hydrograph shown in figure 19 shows that there is adequate supply in the river to channel the portion needed for the hydro power development.

Loss of Habitat

Going forward, the biggest concern with the project would be the potential loss of habitat concerning the reservoir. If the water inflow to the reservoir is to be utilised elsewhere then there will be no flow to maintain the water level there and it would becoming redundant, potentially drying up. It would be suggested that the reservoir remain, perhaps being turned into a large pond with the water in it being maintained by rain water alone. If the worst case scenario were to be realised and the reservoir did indeed dry out the animals such as birds which currently bath here would have access to the Motray Water which provides an alternative freshwater source for local animal etc. It may also be argued that by the reservoir being dried out and filled in that the land is being returned to its original natural state. The reservoir was originally developed to be used for industrial purposes but is no longer required and so potentially this is the cycle being completed, and the loop closed by returning the land to its original layout.

Vehicular Access and Plant Equipment

There is a main road which leads to the edge of the reservoir. From here it is a short distance to the aqueduct but is a narrow track and so the size of equipment which can be taken onto the site will be limited.

10. Conclusions and Recommendations

10.1. Report Summary

The method used to assess the feasibility of installing a micro hydro system as part of the Guardbridge project regeneration was based on the procedures outlined by the British Hydro Association. The study was carried out in various stages outlined below.

Stage 1: Critical Literature Review

Before any site specific work was carried out a critical literature review was conducted in order to highlight the importance of brownfield redevelopment as part of the effort to meet the current sustainable development targets. British, European and International legislation and policy were reviewed in order to address the present targets in place and the measures and incentives currently in place to implement sustainable practices and technologies and encourage renewable energy generation. Current hydro technology was researched and hydro power calculations outlined in order to be able to assess the energy available from hydro power on the site.

Stage 2: Site Survey

The Guardbridge site was then assessed to identify possible hydro power sources and a suitable source selected for a full feasibility study to be conducted. The source chosen to be analysed uses an existing channel of water diverted from the Motray Water to Milton farm where it then feeds two pipes. The pipes then channel the water to a now redundant reservoir. The proposal for the project is to release the water as it crosses the aqueduct where it has an available head of 9.5 meteres .

Data was obtained for the Motray water with associated annual hydrograph and flow duration curve obtained.

Stage 3: Estimation of annual energy output and annual revenue

Pressure losses in the pipe were calculated using the Darcy-Weisbach method and the potential power output available from the pipes estimated.. The annual energy production from the scheme was also calculated and the financial saving, annual revenue and payback period associated with the development estimated. Calculations and graphs were also produced to explore the effect of varying the pipe diameter size to define how this affects the effective head and hence the power output of the system.

Stage 4: Estimation of System Cost

The capital cost of the development was estimated including electro-mechanical equipment, civil works and planning costs.

Stage 5: Environmental Assessment

Finally an environmental impact assessment of the development was conducted.

10.2. Conclusions

The feasibility study found that this development could potentially provide 18% of the Guardbridge sites current energy demand, though 4 years ago the energy produced would have equated to 75% of the sites energy needs. As the site grows and develops this percentage match may continue to diminish but at the moment this is a significant portion of the sites energy demand being met through renewable sources. Developing the hydro project utilising the existing pipes in place could potentially produce a power output of 8.6kW with an annual energy generation of 37668kWh. The annual net income from the development would be £11740 including savings and feed-in tariffs which at their current levels would have a payback period of just 6.2 years. This payback period is relatively small and so the development would be highly recommended . Additional benefits of the scheme would be localised energy generation which will reduce transmission losses and maximise the use of low or zero carbon technology.

While the main basis of the project is to utilise the existing civil works and infrastructure already in place as part of a brownfield redevelopment it was found that be replacing the existing pipes with ones of a larger diameter it would reduce pressure losses in the pipes and increase the power output from them. Though this system would have a higher capital cost the larger amounts of energy generated (61320 kWh annually) means it would actually overcompensate for this resulting in a smaller payback period than using the current pipes with annual net income of £19439 and a payback period of only 4.3 years. This setup would also yield 34% of current energy demands which is a more significant figure than the existing pipes. The disadvantage to this is that it would mean lifting the old pipes and putting in new ones causing a far greater disruption to the local environment. If the main objective is to developed the hydro project as a brownfield development then ultimately the existing pipes with smaller energy production would be used. But if the aim of the project is to maximise energy production and cost saving (which was originally outlined as the primary need for the project) then it would be recommended to retrofit the system with new pipes of a larger diameter in order to ensure a greater renewable energy resource for the future.

Small localised renewable energy generation is typically considered environmentally friendly as in the case of this development the environmental impacts are relatively minor. The main concerns such as visual impact and noise vibrations can be mitigated against in order to reduce the impacts to have minimal effect. The primary concern would be loss of habitat due to the possibility of the reservoir drying up though there is alternative similar habitat in close proximity of the site at the Eden estuary which is a conservation and specially protected area for many species.

The redevelopment of the site has many social benefits and aims to achieve community engagement and educational outreach to promote renewable energy sources. In addition to the sites potential for research and development opportunities the redevelopment of the site will create jobs within the university and for the local community.

The project will ultimately benefit the local community and energy consumers who can enjoy zero net carbon energy and can generate additional interest in the Guardbridge site as a showcase for sustainable energy and as an educational energy centre.

11. Future Work

Initially there were three sources of hydro/marine power highlighted as possible renewable energy sources as part of the Guardbridge project. One of these was to utilise an existing weir on the Motray Water located at the edge of the Guardbridge site as a mini tidal barrage system (location 8 in figure 21). There is considerable potential energy available from the tidal flow. Data was analysed from a six month period and it is assumed that this variation would be similar to the tidal variations throughout the rest of the year. Further analysis of this data showed that the mean tidal range was 3.74m with a mean spring tide of 4.77m and a mean neap tide of 1.3 m.

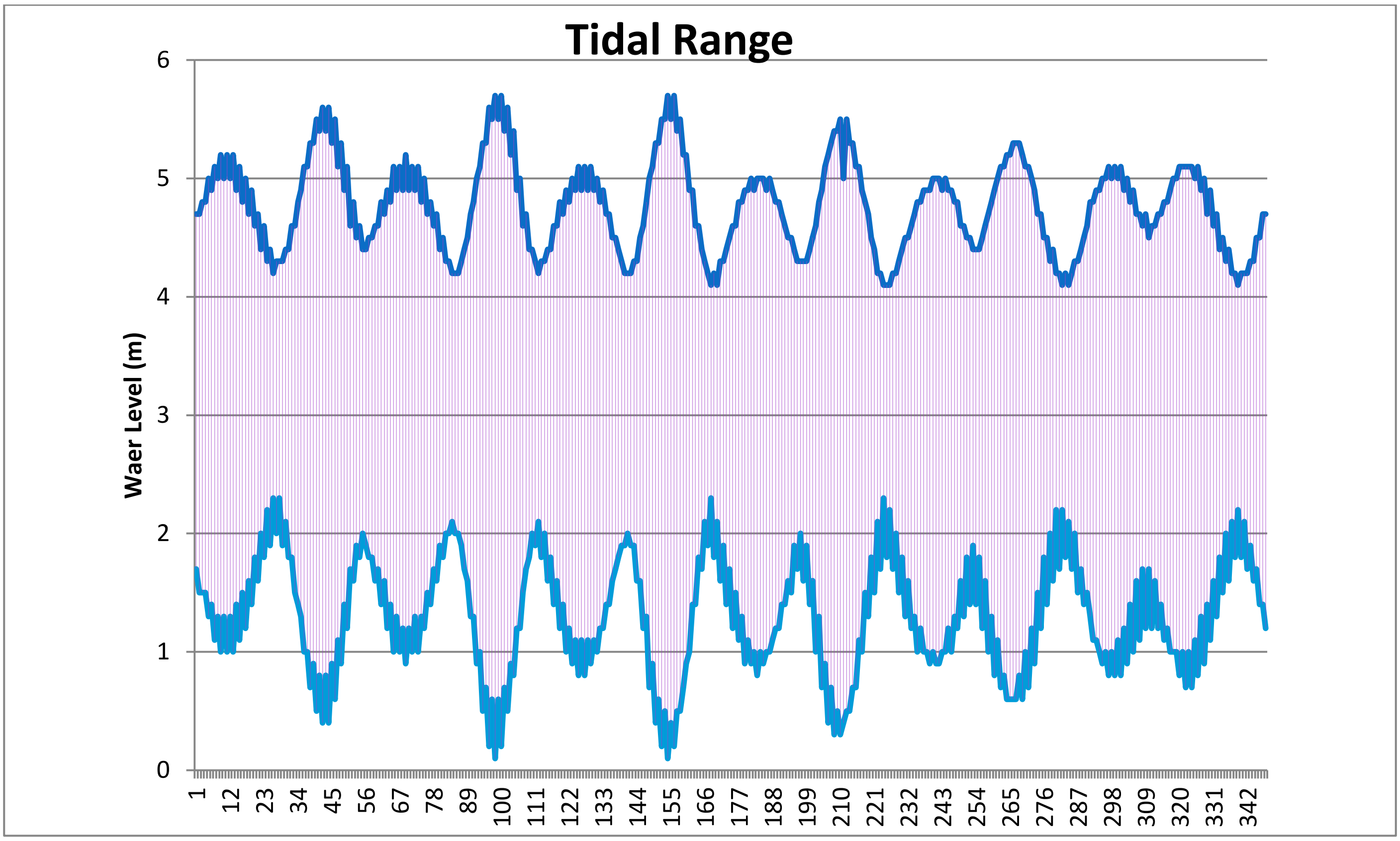

Figure 28

This data could be used to estimate the potential power produced per cycle from having a tidal barrage system in place. As tidal energy is extremely reliable this could also be used to provide a 'base load' or as an additional energy resource.

It would be highly recommended to consider utilising the tidal resource in addition to the hydro resource explored in this study or to conduct a full feasibility study and weigh up the cost benefit against the capital cost of installing the system. From these results the two developments could be weighed against each other to see which has the most potential energy resource and has the best return of investment to be developed as part of the project. Perhaps both could be developed in order to incorporate a wide and varied set of renewable technologies to be showcased as part of the energy centre.

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Appendices

Appendix A

Nominal size	Class									
	A & B	A		B		C & D	C		D	
	Outer diameter [in (mm)]	Wall thickness [in (mm)]	Internal diameter [in (mm)]	Wall thickness [in (mm)]	Internal diameter [in (mm)]	Outer diameter [in (mm)]	Wall thickness [in (mm)]	Internal diameter [in (mm)]	Wall thickness [in (mm)]	Internal diameter [in (mm)]
3	3.76 (95.504)	0.38 (9.652)	3.00 (76.200)	0.38 (9.652)	3.00 (76.200)	3.76 (95.504)	0.38 (9.652)	3.00 (76.200)	0.40 (10.160)	2.96 (75.184)
4	4.80 (121.920)	0.39 (9.906)	4.02 (102.108)	0.39 (9.906)	4.02 (102.108)	4.80 (121.920)	0.40 (10.160)	4.00 (101.600)	0.46 (11.684)	3.88 (98.552)
5	5.90 (149.860)	0.41 (10.414)	5.08 (129.032)	0.41 (10.414)	5.08 (129.032)	5.90 (149.860)	0.45 (11.430)	5.00 (127.000)	0.52 (13.208)	4.86 (123.444)
6	6.98 (177.292)	0.43 (10.922)	6.12 (155.448)	0.43 (10.922)	6.12 (155.448)	6.98 (177.292)	0.49 (12.446)	6.00 (152.400)	0.57 (14.478)	5.84 (148.336)
7	8.06 (204.724)	0.45 (11.430)	7.16 (181.864)	0.45 (11.430)	7.16 (181.864)	8.06 (204.724)	0.53 (13.462)	7.00 (177.800)	0.61 (15.494)	6.84 (173.736)
8	9.14 (232.156)	0.47 (11.938)	8.20 (208.280)	0.47 (11.938)	8.20 (208.280)	9.14 (232.156)	0.57 (14.478)	8.00 (203.200)	0.65 (16.510)	7.84 (199.136)
9	10.20 (259.080)	0.48 (12.192)	9.22 (234.188)	0.49 (12.446)	9.22 (234.188)	10.20 (259.080)	0.60 (15.240)	9.00 (228.600)	0.69 (17.526)	8.82 (224.028)
10	11.26 (286.004)	0.52 (13.208)	10.22 (259.588)	0.52 (13.208)	10.22 (259.588)	11.26 (286.004)	0.63 (16.002)	10.00 (254.000)	0.73 (18.542)	9.80 (248.920)
12	13.14 (333.756)	0.55 (13.970)	12.04 (305.816)	0.57 (14.478)	12.00 (304.800)	13.60 (345.440)	0.69 (17.526)	12.22 (310.388)	0.80 (20.320)	12.00 (304.800)
14	15.22 (386.588)	0.57 (14.478)	14.08 (357.632)	0.61 (15.494)	14.00 (355.600)	15.72 (399.288)	0.75 (19.050)	14.22 (361.188)	0.86 (21.844)	14.00 (355.600)
15	16.26 (413.004)	0.59 (14.986)	15.08 (383.032)	0.63 (16.002)	15.00 (381.000)	16.78 (426.212)	0.77 (19.558)	15.24 (387.096)	0.89 (22.606)	15.00 (381.000)
16	17.30 (439.420)	0.60 (15.240)	16.10 (408.940)	0.65 (16.510)	16.00 (406.400)	17.84 (453.136)	0.80 (20.320)	16.24 (412.496)	0.92 (23.368)	16.00 (406.400)
18	19.38 (492.252)	0.63 (16.002)	18.12 (460.248)	0.69 (17.526)	18.00 (457.200)	19.96 (506.984)	0.85 (21.590)	18.26 (463.804)	0.98 (24.892)	18.00 (457.200)
20	21.46 (545.084)	0.65 (16.510)	20.16 (512.064)	0.73 (18.542)	20.00 (508.000)	22.06 (560.324)	0.89 (22.606)	20.28 (515.112)	1.03 (26.162)	20.00 (508.000)
21	22.50 (571.500)	0.67 (17.018)	21.16 (537.464)	0.75 (19.050)	21.00 (533.400)	23.12 (587.248)	0.92 (23.368)	21.28 (540.512)	1.03 (26.162)	21.00 (533.400)
24	25.60 (650.240)	0.71 (18.034)	24.18 (614.172)	0.80 (20.320)	24.00 (609.600)	26.26 (667.004)	0.98 (24.892)	24.30 (617.220)	1.13 (28.702)	24.00 (609.600)
27	28.70 (728.980)	0.75 (19.050)	27.20 (690.880)	0.85 (21.590)	27.00 (685.800)	29.40 (746.760)	1.04 (26.416)	27.32 (693.928)	1.20 (30.480)	27.00 (685.800)
30	32.52 (826.008)	0.79 (20.066)	30.94 (785.876)	0.89 (22.606)	30.74 (780.796)	32.52 (826.008)	1.09 (27.686)	30.34 (770.636)	1.26 (32.004)	30.00 (762.000)
33	35.66 (905.764)	0.83 (21.082)	34.00 (863.600)	0.94 (23.876)	33.78 (858.012)	35.66 (905.764)	1.15 (29.210)	33.36 (847.344)	1.33 (33.782)	33.00 (838.200)
36	38.76 (984.504)	0.87 (22.098)	37.02 (940.308)	0.98 (24.892)	36.80 (934.720)	38.76 (984.504)	1.20 (30.480)	36.36 (923.544)	1.38 (35.052)	36.00 (914.400)
40	42.92 (1,090.168)	0.92 (23.368)	41.08 (1,043.432)	1.03 (26.162)	40.86 (1,037.844)	42.92 (1,090.168)	1.26 (32.004)	40.40 (1,026.160)	1.46 (37.084)	40.00 (1,016.000)
42	45.00 (1,143.000)	0.95 (24.130)	43.10 (1,094.740)	1.06 (26.924)	42.88 (1,089.152)	45.00 (1,143.000)	1.30 (33.020)	42.40 (1,076.960)	1.50 (38.100)	42.00 (1,066.800)
45	48.10 (1,221.740)	0.99 (25.146)	46.12 (1,171.448)	1.09 (27.686)	45.92 (1,166.368)	48.10 (1,221.740)	1.35 (34.290)	45.40 (1,153.160)	1.55 (39.370)	45.00 (1,143.000)
48	51.20 (1,300.480)	1.03 (26.162)	49.14 (1,248.156)	1.13 (28.702)	48.94 (1,243.076)	51.20 (1,300.480)	1.38 (35.052)	48.44 (1,230.376)	1.68 (42.672)	47.84 (1,215.136)

BS 78 was finally superseded when the U.K. harmonised with incompatible European standards, however, the specified outer dimensions continue to remain in effect (albeit in metric form) as the standard pipe outer

Appendix B

Calculation of Capital Costs

In order to conduct a comprehensive assessment of the economic feasibility of small scale hydro developments in the UK, the Department of Energy commissioned the Salford Report. The report was commissioned in 1989 and was conducted by the civil engineering department at Salford University. The report focused on both sites within the water industry and run of the river type schemes with head ranges starting from 2 meters. Detailed analysis was carried out for many different sites which assessed scheme layouts, scheme costing and economic evaluations. The results from the study were used to develop a sophisticated computer based costing package and a cost estimating formula for small scale hydro developments based on the statistical analysis of the cost data analysed in the Salford report.

The formula derived from the original report has been adjusted to reflect inflation over the past 20 year period, which gives the following cost estimation formula for heads of between 2-30m:

$$C_{pr} = 25{,}000 \times \left(\frac{kW}{H^{0.35}}\right)^{0.65}$$

Previously to the Salford report, Gordon and Penman (1979), had developed a formula to estimate the cost of electromechanical equipment based on the hydro plant capacity and hydraulic head. Later this formula was updated as the data on which the formula was based was out of date and there have been many more hydro sites developed since that time. Recent data was obtained from global manufacturing companies such as *Alstom*, *Andritz, Gilbert Gilkes & Gordon Ltd* and *Voith Siemens*. Based on the feedback from these companies a new formula was developed to estimate the cost of electromechanical equipment for small scale hydro which resulted in the following formula being derived:

$$C_{EM} = 12{,}000 \times \left(\frac{kW}{H^{0.2}}\right)^{0.56}$$

Where,
kW=hydro plant capacity
H=effective head (m)

From the analysis the hydro plant capacity was calculated to be 8.6kW and the effective head was taken to be the mean effective head of the 305mm and 365mm pipes which was 5.4 meters. These were the values used in the equation to calculate capital costs.

Calculation of Planning Fees

The cost of planning permission was calculated using an online tool provided by the UK government. The tool calculates the cost of planning permission based on several key aspects which are:

I. The type of development
II. What its purpose is
III. The amount of land that the development will utilise

The tool can be accessed at:
http://www.planningportal.gov.uk/PpApplications/genpub/en/StandaloneFeeCalculator