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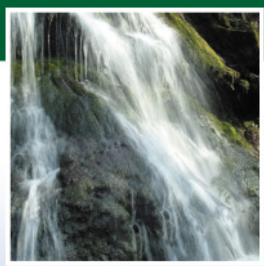

Chapter 8
Hydro Energy

TIPPERARY INSTITUTE

NATIONAL DEVELOPMENT PLAN

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8 Small Scale Hydro

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8.1 Objectives

Having completed this section of the training course and manual, learners should:

- Understand the principles of hydro energy
- Be familiar with the different technologies used for small scale hydro
- Be familiar with the steps involved in developing a hydro project.

8.2 Hydro Energy Technology

8.2.1 Scale

Using water to produce electricity can be done at a wide range of scales. Typically, these are classified into three levels or scales of development (ESHA, 1998)

- Large scale or full scale hydro projects are typically multi-megawatt (>10MW) size developments. The development on the River Shannon in Ireland (Ardnacrusha) is an example with a capacity of 96MW. At the upper end of this scale is the Three Gorges project in China which has a capacity of 18.2 GW at a cost of $1,200bn (Boyle, 2004). These systems always supply electricity to the electricity grid.
- Mini-Hydro systems are generally taken to be between 300kW to 10MW. These systems are also generally connected to the electricity grid.
- Micro-Hydro systems are generally taken as being less that 300kW and may or may not supply electricity to the electricity grid. In many cases, the smaller micro-hydro systems will be independent of the grid and supply electricity to residential or commercial units.

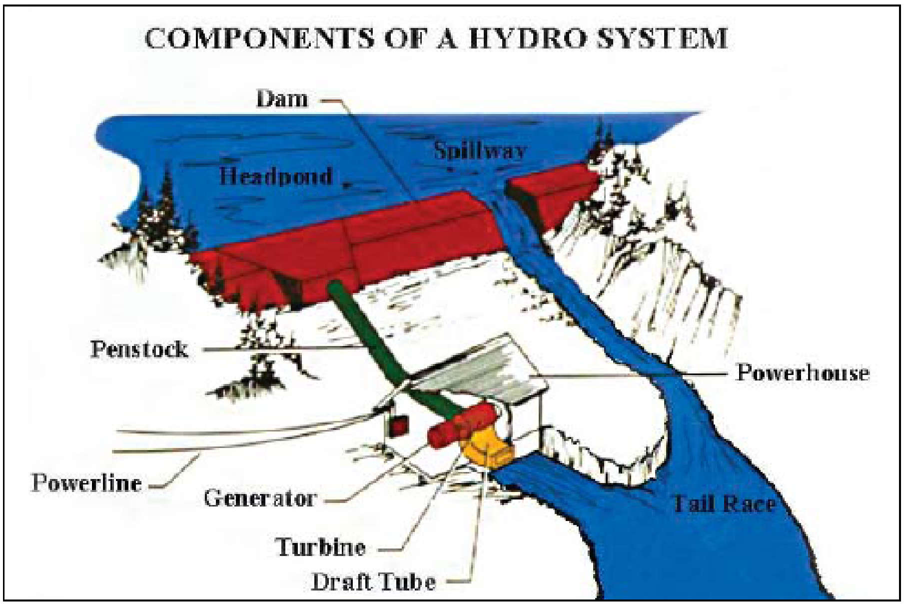

Figure 8.1 Schematic of a hydro system
(Dept of Natural Resources, 2004)

8.2.2 Understanding Energy and Power from Water

The potential energy of a volume of water stored at a particular height can be calculated using the following equation.

Potential energy (kWh) = M x g x H

Formula 8.1 Potential Energy from water

Where:

M = mass of water in kilograms

g = gravitational constant of 9.81 m/s^2 (for most hydro projects it is possible to assume a figure of 10)

H = is the height through which the water will fall – the available head (in metres).

However, for hydro projects it is often more important to first calculate the power available at the site as this will define the technologies which will be used. The power for a particular site can be calculated using the following:

Power (W) = 1000 x Q x g x H

Formula 8.2 Theoretical power from water

Where

1000 = mass of a cubic meter of water (kg)

Q = flow rate of water – (cubic meters per second, m^3/s)

Formula 2 assumes 100% turbine efficiency and perfect operating conditions. This will never be the case so adjustments to the equation are made to take account for turbine inefficiencies. Also, by assuming a value of 10 for g and expressing the power in kilowatts (kW) the equation can be simplified as follows:

$$\text{Power (kW)} = 10 \times ή \times Q \times H$$

Formula 8.3 Power Equation with Turbine Efficiency

Where

ή = turbine efficiency (typically between 80-97%)

A further simplification can be made to take account of all inefficiencies in the system (intake, turbine, generator, transformer etc.) to do an immediate rough calculation for a site. This involves taking an overall system efficiency, $ή_o$, of 50% thereby giving the equation:

$$\text{Power (kW)} = 10 \times 0.5 \times Q \times H$$

Formula 8.4 Power Equation - System Efficiency

The use of this equation can be seen in the following example

You have been given details of a site were the average flow rate is 0.15 m^3/s and the head is 30m. What is the estimated power output at the site?

Power (kW) = 10 x 0.5 x Q x H

P = 10 x 0.5 x 0.15 x 30

P = 22.5 kW

Example 8.1 Use of System Efficiency Power Equation

It is very important that you use the correct units when using the power equation. Flow rate should be in cubic metres per second (m^3/s) and head in metres (m).

8.2.3 Measuring Flow and Head, Flow Duration Curves

To select the appropriate turbine for a particular site it is necessary to know the flow rate and the head available at the site. This can be determined in the number of ways:

- If the site previously had a water turbine/wheel data may be available
- Certain rivers have monitoring stations where data from a nearby location can be taken from e.g. OPW in Ireland (http://www.opw.ie/hydro/home.asp)
- Head can be measured using standard surveying equipment
- Flow rate can be measured using a range of methods. This can range from diverting the flow into a know sized container e.g. barrel and measuring the time to fill the container to using specifically designed weirs e.g. a V notch with related graphs to determine flow.

For a particular site it is typical to produce a Flow Duration Curve (FDC) where possible. A flow-duration curve is a graph of the historical flow at a site ordered from maximum to minimum flow. The flow-duration curve is used to assess the anticipated availability of flow over time, and consequently the power and energy, at a site. A typical FDC is shown in Figure 8.2.

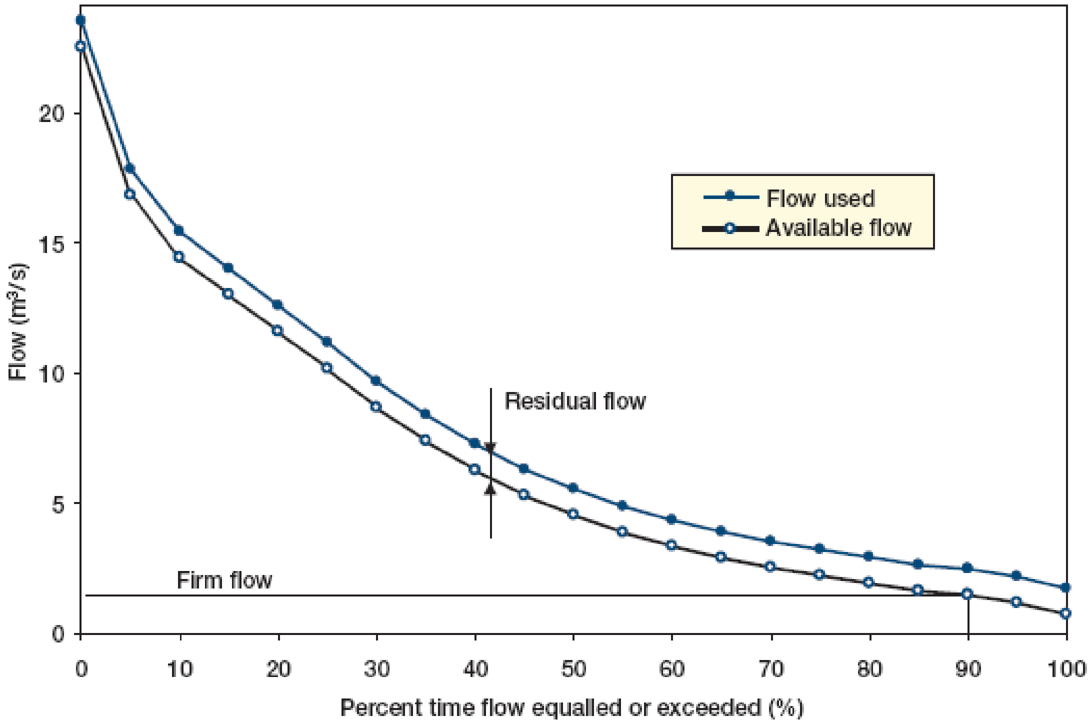

Figure 8.2 Example of Flow Duration Curve (FDC)
(Dept of Natural Resources, 2004)

If a FDC is available for a particular site it is typical to take the mean flow rate as the flow rate at the 30% level for initial calculations.

Once the flow duration curve data is know for a particular site the power output and energy production for each flow rate can be determined using the formula. These can then be summed to calculate the total site annual energy production.

$$\text{Energy Production} = 10 \times \eta \times Q \times H \times T$$

Formula 8.5 Energy Production

Where:

T = length of time of particular flow is available (hours)

It is recommended that once the flow and head conditions for a particular site are known that the project developer seek expert advice to complete the energy output analysis.

8.2.4 A Brief History of Hydro Power

The use of moving water to provide energy dates back many centuries. It is estimated that the earliest systems were used for irrigation but the water wheel developed for use in mills was for grinding grain. Between 1650 and 1800 there emerged a number of different types of water wheel which continue to be used in some cases today. The wheel types are

- Overshot – water feed from the top of the wheel
- Undershoot – water feed into the bottom of the wheel
- Breastshot – water feed at the axel height of the wheel

Developments in the 1800s saw the waterwheel being superseded by new turbine developments which were then combined with generators to allow for electricity production. The late 1800s and early 1900s saw installations of hydro electricity grow at a significant rate. In many cases electricity from hydro was the first electricity to be provided in towns/regions.

Figure 8.3 Undershoot wheel
(Wikipedia, 2006)

8.2.5 System Types

Hydro electricity installations are typically described in a number of ways:

a) By the head of water available

- o Systems can generally be defined as low, medium or high head sites. Low head is typically below 10m and high head above 100m but these are not definitive boundaries.
- o In Ireland the majority of sites with remaining potential for development would be classified as ‘run of the river’ systems. This is where a turbine site would be placed in a part of the river to capture the energy available. These would mostly be systems in the mini or micro scale and would be low to medium head systems.

b) By the capacity of the plant in kilowatts

c) By the type of turbine used

d) By the location and type of dam or reservoir.

Further definition of systems types can be taken from the European Commission (2000):

- *“Run-of-river hydro plants use the river flow as it occurs, the filling period of its reservoir being practically negligible. The majority of small hydropower plants are run-of-river plants because of the high construction cost of a reservoir.*
- *Pondage hydro plants are plants in which the reservoir permits the storage of water over a period of a few weeks at most. In particular, a pondage hydro plant permits water to be stored during periods of low load to enable the turbine to operate during periods of high load on the same or following days. Some small hydropower plants fall into this type, especially high head ones with high installed capacities (> 1.000 kW).*
- *Reservoir hydro plants are plants in which the filling period of the reservoir is longer than several weeks. It generally permits water to be stored during high water periods to enable the turbine to operate during later high load periods. As the operation of these plants requires the construction of very large basins, practically no small or micro hydropower plant is of this type.”*

8.2.6 Turbine Types

The selection of the turbine for a particular site will depend on site characteristics such as head and power required. Also, the speed at which the generator needs to be run and whether the system will need to run at part flow conditions i.e. not to maximum efficiency, will be factors to be considered. Turbine types can generally be divided based on head or the pressure of water above the turbine. These can be sub-divided into Impulse or Reaction Turbines.

Head or Pressure	High	Medium	Low
Impulse	Pelton Turgo Muli-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis Pump-as-turbine	Propeller Kaplan

Table 8.1 Turbine classification by head/pressure
(Harvey, 1993)

Impulse turbines have the following key advantages;

- They are more tolerant of sand and particles
- They are not submerged access and maintenance can be easier
- They are easier to fabricate
- They have more stable efficiency profiles.

Impulse turbines are not suitable for sites which have low head to power ratios.

Reaction Turbines are typically more suitable for medium head sites. In many instances reaction turbines have the advantage of being able to be connected directly to the generator as they run at higher speeds than impulse turbines. They are more expensive to construct as they involve intricately profiled blades and runners.

A number of main turbine types will now be discussed in more detail.

8.2.6.1 Pelton Wheel - Impulse

This consists of a wheel with a set of double cups (buckets) attached around the rim. Water is directed into the cups in a high speed jet and the kinetic energy is transferred forcing the wheel to spin. The size and volume of the jet of water can be adjusted to vary the power output.

Figure 8.4 Pelton Wheel Turbine
Schematic (left) (Dept of Energy, 2006); Installation (right) ESHA, 2006)

A variation of the Pelton Wheel is the Turgo which varies the design and orientation of the cups so that the jet hits three cups at once and rotates faster than the standard Pelton design.

8.2.6.2 Francis Turbine - Reaction

These are one of the most common turbine types for medium to large scale installations. They can operate across medium to high head systems.

The turbine involves a series of profiled runner blades fitted on a central shaft. These are housed in a casing. Water enters through the periphery of the casing, passes through a set of guide vanes and the runners before exiting axially from the centre of the runner. Francis turbines are often called radial flow turbines i.e. the water flow is in the direction of the radius of the turbine.

Figure 8.5 Francis Turbine connected to generator
(Wikipedia, 2006)

The guide vanes are used to regulate the water flow into the runners and these can then be used to regulate power output. However, adjustment of the vanes away from their optimal position will result in reduced efficiencies.

8.2.6.3 Propeller and Kaplan - Reaction

Propeller turbines essentially use a propeller, very similar to a ships propeller and the water flow is axially i.e. in line with the axis of the main shaft. The propeller type turbines are ideal for situations where there is low head but there are very large volumes of water.

Technically, in contrast to the Francis turbine, it is possible to adjust the angle of the blades to maximise energy output for differing power demands and flow rates. Propeller turbines which have this capacity are called Kaplan Turbines.

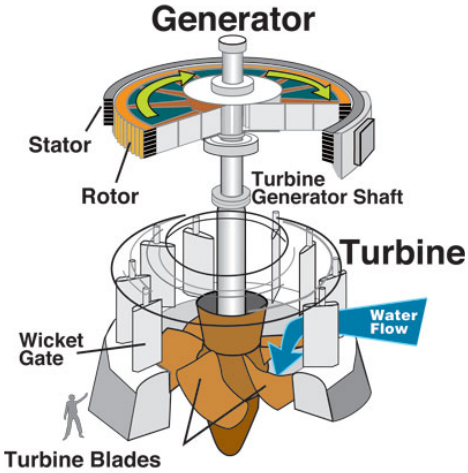

Figure 8.6 Turbine propeller (left) and Kaplan Turbine Schematic (right) (Wikipedia, 2006)

8.2.7 Turbine Selection

Once the parameters of head and flow are know it is typical to use the graph in Figure 8.7 to determine the most appropriate turbine selection. In some instances more than one turbine type would be appropriate for the site in question. The developer will then have to select taking cost, installation and other factors into account.

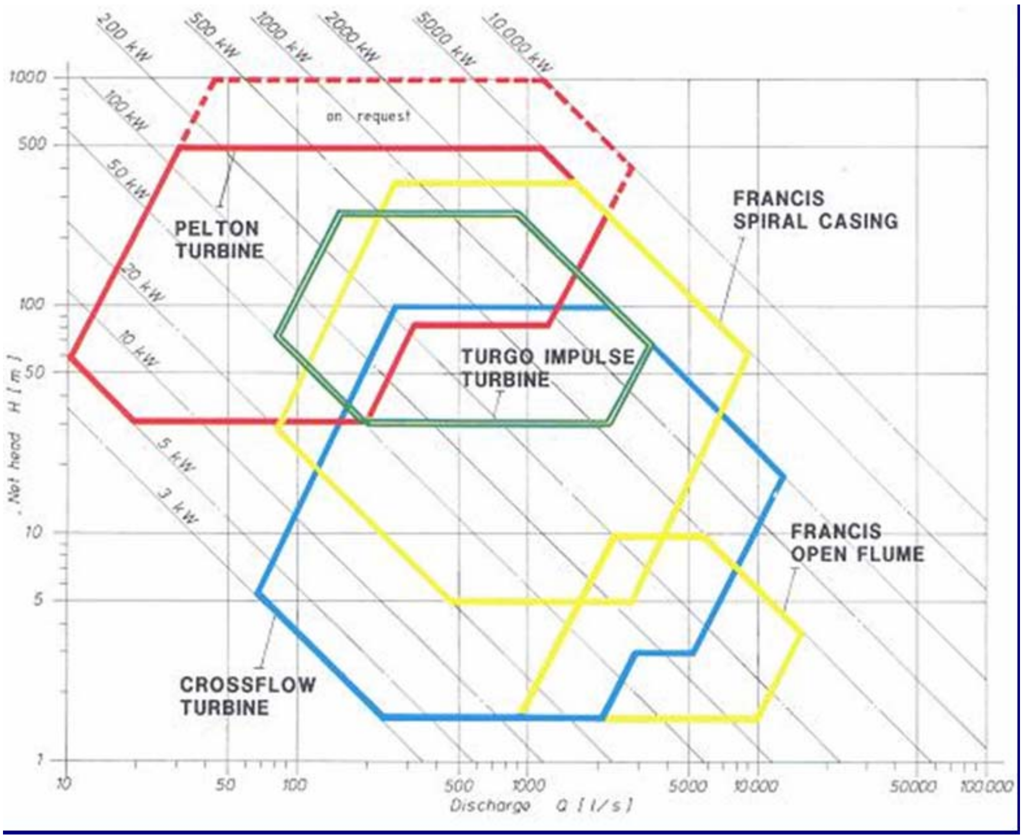

Figure 8.7 Turbine selection graph
(Cork County Council, 2004)

8.2.8 System Components

A typical hydro system will have the following key components

- Water source: - river or reservoir
- Penstock/Headrace: - this is where water is channelled directly into the turbine. This can be a pipe or channel which will deliver the water to the turbine in the most efficient manner possible
- Turbine
- Draft tube/Tailrace: - it is equally important that the water leaves the turbine as smoothly as possible and this requires a suitably designed tube or tailrace to take the water away from the turbine.
- Gearbox – this may be required as the speed of rotation of the turbine can be lower than the speed at which the generator will operate
- Generator – to produce electricity.

Figure 8.8 Headrace for run of the river hydro project
(Tipperary Institute)

8.2.9 Project Development

The development of a small scale hydro project will typically follow the following key steps:

- Site Selection – choosing a suitable site is one of the most important steps. In many cases it may involve looking at a site where hydro power was produced previously e.g. an old mill. From this point analysis of key factors (head, water flow etc.) can start.
- Choice of Technology – according to the configuration of the site, an appropriate type of turbine has to be selected and the system designed/planned.
- Plan Development – based on the technology, site characteristics, and supports available a business plan for the project can then be developed.
- Costs and Financing –The cost of a project is largely dependent on facility size, penstock length, length of transmission lines (if exporting to the grid), site conditions and accessibility. Costs should be broken

down into development, construction, equipment and operating costs, so that the project feasibility can be determined.

- Permit and Licenses Granting Process – there are many different processes involved in obtaining the necessary licences and permits. These will include planning permission for construction, land rights, water rights and licenses. All require careful planning. Particular consideration should be given to permissions and permits required by the relevant Water or Fisheries Authority.

8.3 National Potential

The 1996 study completed by ESB International indicated that there was an additional resource of between 29-38MW which could practically be developed in Ireland. This could yield between 113 and 124 GWh of energy per annum. This report indicated that much of this resource was located in the Counties of Kerry, Cork, Donegal and Mayo (counties with high upland areas) (ESBI, 1997).

In reality the majority of the viable sites for the exploitation of hydro in Ireland have already been developed. Further development is likely to be limited. This is further emphasised in the 2020 Vision for Renewable Energy (DCMNR, 2005) which indicated that total of 1MW might be required from hydro to contribute to Ireland's energy requirements.

8.4 National Installed Capacity

As of 2004 Ireland had a total of 240 MW of hydro electricity plants operating in. 220MW of this would be classified as large scale commercial plants and these are generally operated by the ESB. The remainder are usually operated by private developers, estate owners and small companies. The first major development in Ireland was on the river Shannon in the early 1920s. In addition there is a 292MW pumped storage system at Turlough Hill.

8.5 Barriers to Adoption

The key issues which will restrict the development of hydro power projects will include:

- Availability of suitable sites: in many cases, to reduce environmental impacts, the ideal option is to try and utilise existing sites which can be renovated or refurbished for development. This takes advantage of existing civil works (head races, tail races etc.) and reduces local impact. There is also the benefit of reduced capital costs. However, these sites are difficult to find and most have already been developed – particularly for mini or small scale systems with export of electricity to the grid.
- Permissions and Permits: Depending on the site characteristics and local conditions permits (water access, fisheries etc.) can be difficult to secure. It is therefore important that the project developer seek to engage with the relevant authorities as early as possible in the planning of the site to overcome these issues.
- Grid Connection: where electricity is to be exported to the grid, similar to wind, an agreement with the electricity network operator is required. Depending on distance from the grid and the size of the installation this could have a significant cost which may make the project unviable.

8.6 Relevant Policy and Legislation

There are a number of key policy and legislative issues which are relevant to the hydro energy sector in Ireland. In the policy area these include:

- Green Paper on Sustainable Energy (1999): set a target an additional 500MW of renewable energy by 2005
- Green Paper on Energy – Towards a Sustainable Energy Future for Ireland (2006): proposes targets of 30% electricity consumption from renewables by 2020
- National Climate Change Strategy (2000 and review in 2007): Highlights the impact renewables can make in terms of emission reductions

- All-Island Energy Market: Renewable Electricity – A '2020 Vision': Identifies the need for additional capacity in the Republic and Northern Ireland.

Key legislation relevant to the hydro sector is primarily related to the electricity network and its regulation. This is related primarily to the establishment of the Commission for Energy Regulation and liberalisation of the electricity network. Further details are available at www.cer.ie.

8.7 Government Supports

8.7.1 AER and ReFIT

Ireland used a programme called the Alternative Energy Requirement (AER) Programme to support wind, and other renewables, since 1993. The AER was a competition based programme where project developers applied to secure a PPA with the ESB, through the Government. While this delivered projects at least cost it was delivered in a stop/start fashion and provided no certainty within the sector. In addition, some projects which secured contracts were never built as the bid price was too low to ensure project viability. The AER VI programme provided support for hydro projects at a level of 7.018 cent per kWh.

In 2005, the Government changed to a fixed feed in price system called REFIT. The initial capacity which will be offered contracts under the current REFIT has been limited to 400MW. The support for hydro energy projects under the REFIT programme is 7.2 cent per kWh.

8.7.2 SEI Renewable Energy RD&D Programme

The programme is primarily focused on stimulating the deployment of renewable energy technologies that are close to market, and on assessing the development of technologies that have prospects for the future. Financial support is available in three categories:

- Category 1: Shared-cost Demonstration (grant support of up to 25% of eligible costs)
- Category 2: Shared-cost R&D (grant support of up to 45% of eligible costs)
- Category 3: Commissioned Public Good Activities (grant support of up to 100%).

As of mid-2004 the status of support provided for hydro under this programme was as follows:

- Tarmonbarry Hydroelectric Ltd - An Environmentally Friendly Low Head Small Hydro Implementation Solution
- Dr Martin J Leahy - Case Study of a modern small hydro generating station
- Water Power Services - Annagh Lodge Hydroelectric.

The priority for the end of the programme up to the end of 2006 was to support an industrial-scale auto-production hydro power project to illustrate the cost benefit of using auto-production.

8.8 Financial Viability

The capital costs for hydro projects are particularly related to the civil and site development costs. A number of studies have indicated that typical development costs for small hydro projects are between €1,570 to €3,150 per kW (Hall *et al,* 2003 and ETSU, 1999).

Hall *et al* in particular highlighted the fact that the development costs for hydro projects are dominated by the initial costs related to civil engineering and meeting environmental requirements. It was noted that civil costs account for 65-75% of total costs with environmental/licensing costs accounting for 15-20%. The balance was made up of turbine and other equipment costs.

The viability of a project can be checked by calculating the average cost per unit generated at the site and comparing this to the contract price that might be available for sale of the electricity. This can be done using the formula;

$$\text{Unit price of electricity cost} = ((C \times R) + M)/(E)$$

Formula 8.6 Unit price calculation for hydro energy project

Where

C = Capital Cost of the hydro project

R = Capital Recovery Factor/Annuity Factor

E = Annual electricity production

M = Operation and Maintenance Cost

R is calculated by using the following formula

$$R = x /(1- (1+x)^{-n})$$

Formula 8.7 Annuity Factor calculation

Where

X = required annual rate of return

N = number of years over which investment is to be recovered

This is just one of many methodologies which can be used. The RETScreen Model (www.retscreen.net) provides a more comprehensive method for producing a comprehensive feasibility study of the costs and financial viability of a hydro project.

Investors will have their own methodologies for checking both financial and project viability.

8.9 *Case Studies*

8.9.1 Feasibility Study

A study was completed to determine the viability of installing a hydro power station at a site in Co. Sligo. The study was completed by R.G. Parkins & Partners for Curry Water Mill Restoration Group (RG Parkins, 1998).

The site had existing infrastructure in place and water power was used at a mill. Analysis of existing data and information for the site indicated the following key data:

- Mean flow rate: 2.1 m^3/s
- Head: 2.7 m

Reviewing Figure 8.7 and Table 8.1 it was determined that a Cross Flow or Kaplan turbine would appear to be the most appropriate.

Energy production assessments indicated that total annual production would be in the region 190,800 kWh per annum.

Total investment costs where determined to be €150,000 with O&M estimated to be €2,160. Economic analysis, using Formula 6, was done to determine the annual unit cost based on an 8% discount rate and 15 year period. This gave an average unit production cost of €0.103/kWh.

This is significantly above the rate that is available under the REFIT programme or AER VI programme and would indicate that the project would be unviable without grant support or reduction of initial costs. Capital grant support in the region of 35% of initial costs would be required to bring the project in line with REFIT support levels.

8.9.2 Existing Project

In 1989 a hydro project was redeveloped on the River Tar in Co. Tipperary. There was a mill at site since 1656. There was an old Armfield turbine at the site initially. A Francis turbine was installed at the site in 1939, with 30 kWe maximum output. This ran for 49 years (until 1988/9). A 100kWe Kaplan turbine was installed at the site in 1989.

A Kaplan turbine type was chosen as it has a better efficiency curve than the Francis turbine, and is more suited to variable flow rates. The Grubb's turbine is 1,180 mm in diameter and has double regulation – it can be turned down to an output of 10 to 15 kW. Generally the turbine can continue to operate in low river flow. Average power output is 65kW.

The system has a 225 volt generator which operates at 1,000 rpm. The system has a vertical shaft. The draught tube is sophisticated and produces very little turbulence. The system includes very sensitive monitoring equipment. Fish are discouraged from swimming up the tail race by an electric barrier (24 volt DC).

Flooding resulted in silt getting into and damaging the thrust bearing, which had to be repaired by the David Brown Company at a cost of €8,000. The normal service interval is 15 years. Silt is removed every three to four years. The tunnel supplying water to the turbine is heavily reinforced. There is a screen on the intake, with debris removed by hand at present – an automatic cleaning system is planned.

In 1989 price terms the total project development cost was €190,000 (£150,000). The turbine cost was €69,840 (£55,000). The project developer noted that a similar turbine would be considerably more expensive at today's prices.

The project negotiated a 10 year contract with the electricity company and currently has average annual sales of €20,000 per annum.

8.9.3 Other Case Studies

Sustainable Energy Ireland also provides information on a number of other hydro projects which are available at www.sei.ie

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8.11 Internet sites:

European Small Scale Hydro Association:	www.esha.be
EU Commission:	www.europa.eu.int
Micro Hydro Web Portal	www.microhydropower.net
Irish Hydro Power Association	http://www.irish-hydro.org/
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