RETScreen® International

Clean Energy Decision Support Centre

e-Learning

Training Module

SPEAKER'S NOTES

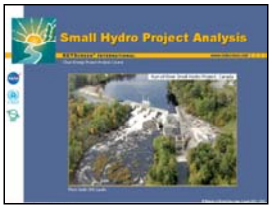
SMALL HYDRO PROJECT ANALYSIS

CLEAN ENERGY PROJECT ANALYSIS COURSE

This document provides a transcription of the oral presentation (Voice & Slides) for this training module and it can be used as speaker's notes. The oral presentation includes a background of the technology and provides an overview of the algorithms found in the RETScreen Model. The training material is available free-of-charge at the RETScreen® International Clean Energy Decision Support Centre Website: www.retscreen.net.

SLIDE 1: **Small Hydro Project Analysis**

This is the Small Hydro Project Analysis Training Module of the RETScreen International Clean Energy Project Analysis Course. Here, we examine the generation of electricity by small hydro projects, such as this plant located in Eastern Canada.



Small Hydro Project Analysis

Slide 1

SLIDE 2: **Objectives**

This module has three objectives. These are first, to review the basics of small hydro systems; second, to illustrate key considerations in small hydro project analysis; and third, to introduce the RETScreen Small Hydro Project Model.

Objectives

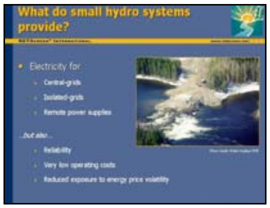
- Review basics of Small Hydro systems
- Illustrate key considerations for Small Hydro project analysis
- Introduce RETScreen® Small Hydro Project Model

Slide 2

SLIDE 3: **What do small hydro systems provide?**

Small hydro systems harness the power of falling water to provide electricity. This electricity can be sold onto a grid or used at remote locations where there is no grid power.

A grid is an interconnected web of generating stations and transmission facilities that provides electric power to a number of distributed consumers. Small hydro projects can be integrated onto central or isolated grids. A central grid is one that covers a vast geographical area, with many generators and millions of consumers. The North American electricity grid is one example. An isolated grid is a smaller network of generation and distribution facilities, not interconnected with the central grid, that supplies electricity to a limited area, such as a remote community or the communities on an island.



What do small hydro systems provide?

- Electricity for
  - Central-grids
  - Isolated-grids
  - Remote power supplies

…but also…

  - Reliability
  - Very low operating costs
  - Reduced exposure to energy price volatility

Slide 3

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Canada

SLIDE 3: **What do small hydro systems provide? (cont.)**

Small hydro systems are used to power remote communities, mines, and camps that are not served by the grid. Very small hydro systems can even be used to provide electricity to individual off-grid homes.

Beyond their ability to provide electricity, small hydro projects have a number of attributes that make them attractive.

First, they are a very reliable and well-understood power source. Hydroelectricity is the most mature of the renewable energy technologies, having been in use for over one hundred years. Over 19% of the world's electricity is generated by hydro projects, with countries as diverse as Brazil, Canada, China, Norway, and the USA having significant hydroelectric developments. While most of the world's hydroelectricity comes from large hydro projects, small hydro projects benefit from the knowledge and experience associated with the large hydro projects.

Second, they can generate large amounts of electricity with very low operating costs. The majority of the costs of a small hydro project stem from up front expenses in construction and equipment purchase. Once the development is in place, the project can provide electricity with modest operation and maintenance expenditures for 50 years or longer.

Third, the cost of generating hydroelectric power is not affected by the price of fossil fuels, which can rise drastically and unexpectedly. This reduces the financial risk associated with producing power.

Fourth, because the flow of water through the system can be controlled, on a short time scale, hydroelectricity can reliably meet a varying load.

SLIDE 4: **Small Hydro System Description**


Small Hydro System Description

Power in kW = 7 x Head x Flow

Slide 4

When water flows from a higher to a lower elevation, it converts potential energy into other forms of energy, such as kinetic energy, or the energy associated with a moving mass. Some of this potential energy can be transferred to a turbine, making it spin. This rotational motion can be converted into electrical energy through a generator.

The amount of electrical energy that can be generated is directly related to the *head* and the *flow*. The head is the difference in height between the turbine and the surface of the water upstream of the project. The change in the potential energy of a unit mass of water as it flows through the system is proportional to the head. The flow is the volume of water passing through the turbine per unit of time. Obviously, for a given level of head more water flow results in more power. As a conservative rule of thumb, the power output of a hydro project, expressed in kilowatts, is equal to seven times the head, expressed in meters, multiplied by the flow, expressed in cubic meters per second.

Let's examine in more detail the components of a small hydro project involved in this transformation of potential energy to electricity.

A small hydro project can be divided into its civil works and its electrical and mechanical equipment.

SLIDE 4: **Small Hydro System Description (cont.)**

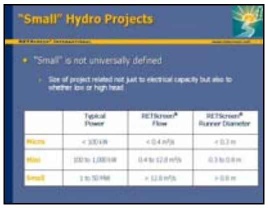
The civil works are structures that service the electrical and mechanical equipment: they collect the water and transport it to and from the electrical and mechanical equipment. They also include the powerhouse, the building in which the electrical and mechanical equipment are housed.

The most significant part of the civil works is the dam or diversion weir. This is an obstruction extending into or across the path of a watercourse. At least part of the flow is diverted to the powerhouse by the dam; it prevents the flow from simply bypassing the electrical and mechanical equipment. The body of water just upstream of the dam is known as the headpond or forebay.

An intake in the dam or diversion weir directs the flow towards a water passage. A sieve-like structure called a trashrack prevents leaves, wood, and other detritus from entering the intake; a gate of wood or steel turns the flow on and off. The passage transports the water into the powerhouse and to the turbine. Water exiting the turbine passes through a draft tube and then back to the river by an excavated channel known as a tailrace.

The electrical and mechanical equipment includes the turbine, which spins under the force of the moving water, and the generator, which is rotated by the turbine and converts the energy of the water into electrical energy. The operation of the generator is regulated by electrical controls. The electrical energy is transported away from the powerhouse by power lines connected to the grid or the load at a switchyard.

SLIDE 5: **“Small” Hydro Projects**



"Small" Hydro Projects

- "Small" is not universally defined
  - Size of project related not just to electrical capacity but also to whether low or high head

	Typical Power	RETScreen® Flow	RETScreen® Runner Diameter
Micro	< 100 kW	< 0.4 m³/s	< 0.3 m
Mini	100 to 1,000 kW	0.4 to 12.8 m³/s	0.3 to 0.8 m
Small	1 to 50 MW	> 12.8 m³/s	> 0.8 m

Slide 5

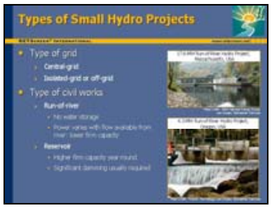
When we talk about “small” hydro projects, what size do we actually mean? Unfortunately, there is no universally accepted definition of this. Furthermore, small hydro projects include so-called mini and micro hydro projects.

Small hydro projects can be classified according to a number of criteria, including the rated power output of the project, the flow through the project, and the diameter of the runner, that is, the spinning wheel within the turbine. The problem with using the power capacity is that a diminutive high head project can generate with a small flow the same power as an enormous low head project requiring a huge flow. Using the runner diameter, which is closely related to the flow through the turbine, is a more logical choice.

In RETScreen, micro hydro refers to projects using turbines with a runner diameter less than 0.3 m; this corresponds to a maximum flow rate of 0.4 m^3/s. Mini hydro projects have turbines with runners 0.3 to 0.8 m in diameter and have maximum flow rates of 0.4 m^3/s to 12.8 m^3/s. This upper limit is the flow permitted by four turbines operating in parallel, each operating with 0.8 m runner diameter. Turbines with runners greater than 0.8 m cannot be shipped easily by truck to an isolated site. The use of more than four mini turbines is not economical compared with a single larger turbine so projects with maximum flow rates above 12.8 m^3/s make use of turbines with runner diameters greater than 0.8 m and are therefore not considered mini hydro projects. They are simply known as small hydro projects.

In general, micro hydro designates projects with power output of less than 100 kW; mini hydro is used for projects of 100 kW to 1 MW, and small hydro describes projects of 1 to 50 MW.

SLIDE 6: **Types of Small Hydro Projects**



Types of Small Hydro Projects

- Type of grid
  - Central-grid
  - Isolated-grid or off-grid
- Type of civil works
  - Run-of-river
    - No water storage
    - Power varies with flow available from river: lower firm capacity
  - Reservoir
    - Higher firm capacity year round
    - Significant damming usually required

Slide 6

Small hydro projects can be classified according to characteristics other than the size of the turbine runner or the power output. Two important characteristics that are often used are the type of grid the project is connected to and the nature of its civil works.

Small hydro projects can be connected to a central grid, to an isolated grid or they can be off-grid. A small hydro project connected to a grid supplies its power either to a utility, to a power pool, or to a particular customer or group of customers also connected to the grid. Off-grid small hydro systems power loads at mines, isolated residences, lodges, and remote industries.

The type of civil works can also be used to classify hydro projects. Specifically, the civil structures may result in a run-of-river system or include a water storage reservoir.

In a run-of-river system, there is no water storage, the plant can make use of only the natural flow in the river at a given point in time, and as a consequence, the plant's power output can vary over time. The plant may not offer firm generation capacity – that is, the power output it can be counted on to produce – since the flow in most rivers declines significantly during certain seasons. Because of this, run-of-river systems are most appropriate for operation on a central grid or large isolated grid, in which other generators can compensate for variation in the hydro plant's output. In small isolated grid or off-grid applications, either the minimum usable flow in the river must be sufficient to power the peak load or supplemental power generators will be required.

When there is water stored upstream of the plant, the output of the plant is not limited to the flow in the river at a given time, and can fluctuate to meet the electric load. Water stored in the reservoir acts like a battery that can be discharged when the load – or the price paid for electricity – is high. Unfortunately, the creation of a reservoir generally requires damming and the creation of a new lake. This is costly, has significant environmental impacts, and is often subject to an involved approvals process. The construction of such a dam is rarely justified for small projects, except if the value of the electricity is very high: this is sometimes the case at isolated locations where there are few competing power options. Therefore, unless a lake upstream of a pre-existing dam can be used, storage in small hydro projects, if any, tends to be limited to the small quantity of water, called pondage, available from the head pond.

The photos on this page show two run-of-river small hydro projects, one in the Eastern USA and the other in the Western USA.

SLIDE 7: **Components: Civil Works**

Components: Civil Works

- Typically account for 60% of plant initial costs
- Diversion dam or weir
  - Low dam of simple construction for run-of-river
  - Concrete, wood, masonry
  - Cost of dam alone can render project unviable
- Water passage
  - Intake with trashrack and gate; tailrace at exit
  - Excavated canal, underground tunnel and/or penstock
  - Valves/gates at turbine entrance/exit, for maintenance
- Power house
  - Houses turbine, mechanical, and electrical equipment

Slide 7

In terms of a feasibility analysis of a small hydro project, the civil works constitute the most important part of the project. They typically account for 60% of initial plant costs, and if planned poorly can be subject to significant cost overruns.

The cost of a dam capable of significantly raising the level of a river or pond to create a storage reservoir is usually prohibitive for small hydro projects, so dams and diversion weirs tend to be low, simple structures built of concrete, wood, or masonry. They serve to direct flow into the water passage, often permitting a portion of the river's flow to bypass the powerhouse by flowing down a spillway. The spillway may include a fish ladder so that fish can move upstream past the dam. If site conditions are difficult, the cost of the dam alone may render a small hydro project financially unattractive.

SLIDE 7: **Components: Civil Works (cont.)**

The nature of the water passage will depend on the proximity of the intake and the powerhouse and what is found between them. It may be an excavated open canal, a tunnel blasted or bored through the ground, and/or a penstock, a pipe capable of conveying water under pressure. The path of the water passage may deviate significantly from that of the river, especially when this increases the head of the project. Sometimes the powerhouse is located right below the intake and no passage is necessary. Valves and steel or iron gates at the entrance and exit of the turbine make it possible to shut off flow for maintenance or shutdown.

The powerhouse, containing the turbine, generator, and other electrical and mechanical equipment, is also a part of the civil works. For small hydro projects, the powerhouse tends to be a fairly small, simple structure; it must, however, provide a solid foundation for the turbine and generator and permit safe access to the equipment.

The photo on this slide shows a small hydro dam in Eastern Canada.

SLIDE 8: **Components: Turbine**

Components: Turbine

- Scaled-down versions of large-hydro turbines
- Efficiency of 90% possible
- In run-of-river, flow rate is quite variable
  - Turbine should function well over a range of flow rates or multiple turbines should be used
- Reaction: Francis, fixed pitch propeller, Kaplan
  - For low to medium head applications
  - Submerged turbine uses water pressure and kinetic energy
- Impulse: Pelton, Turgo, crossflow
  - For high head applications
  - Uses kinetic energy of a high speed jet of water

Slide 8

The turbines used in small hydro projects are scaled-down versions of the designs found in large hydro projects, and thus benefit from well over a century of development and engineering improvements. As a result, small hydro turbines can attain efficiencies of around 90% if operated under the conditions for which they were designed. Because the flow rate in a run-of-river project tends to be highly variable, attention must be paid to matching the turbine to the range of flow rates that will occur. Alternatively, multiple turbines with limited flow ranges can be used, such that the water flow determines how many turbines are used at a given time.

Turbines can be divided into two classes, reaction and impulse, based on the manner of head conversion. In a reaction turbine, the runner, or spinning wheel, is completely immersed in the flow. The pressure of the water makes it flow into the turbine, force its way past the blades of the turbine, and then exit the turbine. The blades partially block the flow, and exert a force on the flow causing it to be diverted around them. But, according to Newton’s third law, this force on the water has an equal and opposite *reaction* force on the turbine blades, causing the runner to spin.

Reaction turbines are appropriate for low to medium head applications. One common type is the *Francis* turbine, named after the engineer James B. Francis, who built the first efficient inward flow reaction turbine in 1849. In Francis turbines, the flow has a significant radial component: it enters the turbine from a ring at the perimeter of the turbine and, moving inward, exits at the center, or eye, of the turbine. The photo on this slide shows a Francis turbine: the water is admitted radially to the blue bulbous ring from the tube in the background on the right; it exits at the center of the turbine, through the tube in the foreground with the downward elbow. The shaft to the generator is at the rear of the turbine, on the left of the photo.

When head is low, a reaction turbine that utilizes purely axial flow may be preferable: the flow, moving parallel to the axis of the turbine, passes through a propeller. Such propeller turbines may have fixed or adjustable pitch. Adjustable pitch propeller turbines are also called Kaplan turbines, and, while more mechanically complicated than fixed pitch designs, function more efficiently at low power settings.

SLIDE 8: **Components: Turbine (cont.)**

As head increases, the runner of a reaction turbine must spin more quickly and the casing must withstand higher pressures. At some point, the reaction design becomes impractical and impulse turbines, which include the Pelton and Turgo designs, are used instead. The cross-flow turbine is a special type of impulse turbine that recovers some of the head in the draft tube.

In impulse turbines, the high pressure flow passes through a nozzle that converts it into a jet of water at atmospheric pressure but with high velocity and high kinetic energy. The runner itself is a wheel with buckets around its perimeter; it spins in air and is not immersed in the flow. The jet is fired through the air at the buckets of the turbine, which, due to their shape, cause the flow to be deflected backwards. Since momentum is conserved, the radical change in the momentum of the jet exerts an *impulsive* force on the runner, causing it to spin.

SLIDE 9: **Components: Electrical and Other Equipment**

Components: Electrical and Other Equipment

- Generator
  - Induction
    - Must be tied to other generators
    - Use to feed electricity onto large grid
  - Synchronous
    - Can function in isolation from other generators
    - For stand-alone and isolated-grid applications
- Other equipment
  - Speed increaser to match turbine to generator
  - Valves, electronic controls, protection devices
  - Transformer

Slide 9

The principal electrical component in a small hydro project is the generator. Two different types are used: induction and synchronous generators.

The induction generator, also known as an asynchronous generator, is common in small hydro projects that are connected to the central grid. For an induction generator to function, alternating current must be present to energize electromagnets arranged in a ring around a circular cage that is free to turn. The alternating current sets up a rotating magnetic field. Unless the cage spins at exactly the same rotational speed as the field, the field will *induce* a circulating current in the cage. The circulating current in the cage results in a second magnetic field, which opposes that of the electromagnets.

In practice, this means that if a turbine is attached to the cage and exerts a torque on it, the cage will spin slightly faster than the rotation of the magnetic field, generating an opposing magnetic field. This opposing magnetic field will be seen at the electromagnets as an electromotive force that adds energy to the grid.

Induction generators are fairly uncommon, being used mainly in wind turbines and small hydro generators. They are readily available, however, in the form of induction motors. An induction motor – the most common type of motor – operates as an induction generator when a driving torque is substituted for a load. Thus, the induction generator is a well-understood and relatively inexpensive technology.

Note that there must be alternating current already present at the electromagnets for the induction generator to operate. While it is possible to use auxiliary circuitry or generation equipment to furnish this current, this type of generator is normally used only when it is connected to the central grid or a grid containing synchronous generators.

In synchronous generators, the rotating cage is replaced by a rotating electromagnet that generates a spinning magnetic field. Like in the induction generator, this spinning magnetic field is seen at the outer ring of electromagnets as an electromotive force that adds energy to the grid. Unlike in an induction generator, however, the synchronous generator does not need to have an alternating current already present at these electromagnets: it can function in isolation, with the frequency of the electric output being a multiple of the rotational speed of the turbine driving the generator. As a result, it is used for isolated grid and off-grid applications where there are no other generators. It is also used for larger small hydro projects since large induction generators are quite expensive.

SLIDE 9: **Components: Electrical and Other Equipment (cont.)**

Small hydro projects include a number of other components, both electrical and mechanical. Sometimes a speed increaser is required to match the rotational speed of the turbine to the speed at which the generator must turn, as dictated by the grid frequency. Electrical and mechanical controls, such as water flow valves, regulate the operation and protect the equipment from unexpected situations. Often an electrical transformer will raise the voltage of the electricity produced in order to reduce losses in transmission lines.

SLIDE 10: **World Hydro Resource**

World Hydro Resource

- More rain falls on continents than evaporates from them
- For equilibrium, rain must flow to the oceans in rivers

	Technical Potential (TWh/year)	% Developed
Africa	1,150	3
South Asia and Middle East	2,280	8
China	1,920	6
Former Soviet Union	3,830	6
North America	970	55
South America	3,190	11
Central America	350	9
Europe	1,070	45
Australasia	200	19

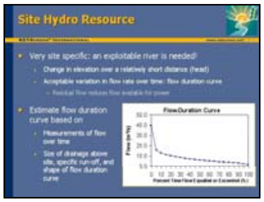
Slide 10

The origins of the hydroelectric resource are quite simple. The sun heats the globe, causing evaporation of surface water. Clouds return this water to the surface as precipitation. On average, the water is returned to a higher level than that from which it evaporated: thus, effectively, solar energy pumps it upwards, generating head that can be harnessed. Over the continental land masses, the amount of water that precipitates exceeds the amount that evaporates. This excess must flow off the continents to the oceans in order to keep the globe in equilibrium. Theoretically, this excess flow can be harnessed for hydroelectric generation. In reality, it is technically feasible to exploit only a fraction of the flow. This technical potential, broken down by geographical area, is shown in the first column of figures in the table on this slide. The former Soviet Union, the rest of Asia, and South America have the largest technical potential.

The rightmost column of this slide shows the fraction of this technical potential that is actually being used. In Europe, Japan, and North America, 45 to 55% of the technical potential has been exploited, and this appears to approach the limit of what can be economically exploited. The other areas show enormous potential for further development.

Much of this potential is suitable only for large hydro projects. Nevertheless, the total potential is so huge that the remaining portion that *is* suitable for small hydro development is still very significant.

SLIDE 11: **Site Hydro Resource**



Site Hydro Resource

- Very site specific: an exploitable river is needed!
  - Change in elevation over a relatively short distance (head)
  - Acceptable variation in flow rate over time: flow duration curve
    - Residual flow reduces flow available for power
- Estimate flow duration curve based on
  - Measurements of flow over time
  - Size of drainage above site, specific run-off, and shape of flow duration curve

Slide 11

The hydro resource varies greatly from one location to the next. At a site with an exploitable river having reasonable head and flow, the resource can be enormous. At sites without a river, the resource is zero. Few renewable energy resources are so site-dependent.

Given that a site has an exploitable river, the hydro resource will be related to the head and the flow. Stretches of river that lose significant elevation over a short distance offer good head. The flow – and therefore the resource – will vary with the time of year and even the time of the day. During wet seasons or when snow is melting, the flow will be high; during dry seasons or when precipitation takes the form of snow, the flow will be low.

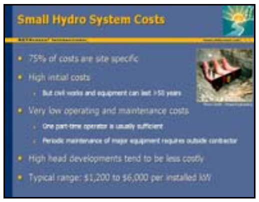
SLIDE 11: **Site Hydro Resource (cont.)**

This temporal variation in the flow is represented in a flow duration curve. An example is shown on this slide. The vertical axis shows flow rate, in m^3/s. The horizontal axis shows the fraction of the time that the flow rate is exceeded. Thus, the minimum flow rate in the river over the course of an average year is exceeded virtually 100% of the time, and is about 3 m^3/s in this example. The peak flow rate is never exceeded, and is 40 m^3/s.

Environmental regulations generally prohibit the use of the entire flow in the river: a certain minimum flow must always bypass the hydro project to maintain aquatic habitat. This residual flow effectively shifts the flow duration curve downwards, at least from the point of view of the flow that is available for use.

While the head at a given site is relatively easy to estimate, determination of the flow duration curve either requires measurements of the flow in the river over the course of a number of representative years, or estimation based on data from various sources. In the latter case, the size of the area that is draining into the river above the site must be estimated from topographical maps or previous studies. Then the specific run-off, or mean water flow off a unit area of land, must be found for that drainage area. This can be determined from maps that classify geographical areas according to their run-off. The product of the drainage area and the specific run-off gives the mean flow. Finally, the shape of the flow duration curve must be found. Maps and databases classify areas and even specific rivers according to the shape of their flow duration curve; alternatively, this can be estimated on the basis of the flow duration curve for similar rivers in the area.

SLIDE 12: **Small Hydro System Costs**



Small Hydro System Costs

- 75% of costs are site specific
- High initial costs
  - But civil works and equipment can last >50 years
- Very low operating and maintenance costs
  - One part-time operator is usually sufficient
  - Periodic maintenance of major equipment requires outside contractor
- High head developments tend to be less costly
- Typical range: $1,200 to $6,000 per installed kW

Slide 12

Just as the hydro resource is very site-dependent, the initial costs of a small hydro project vary greatly from location to location. On average, site-dependent costs account for 75% of the initial costs, the majority of this being for civil structures. The remaining 25% is for equipment, such as turbines and generators, whose costs are more closely related to the size of the project than its location.

As with most renewable energy projects, small hydro projects have high initial costs and low operating costs. Once built, a project’s civil works and equipment can have a useful life of 50 years or more. One part-time operator is usually sufficient for most small hydro projects, with periodic maintenance of larger components conducted by specialized contractors. Some automated small hydro projects now operate without an on-site operator, only requiring periodic visits for routine preventative maintenance.

The size of the turbine varies with the flow that it must accommodate. As a result, higher head projects, which require less flow to generate a unit of electricity, can use smaller turbines than low head projects. The smaller turbines are less expensive, so high head tend to have lower equipment costs. The civil works, however, are not necessarily less expensive for high head projects.

With so much of the cost of the project being site-dependent, the range of project costs is very wide. Many projects fall within the range of $1,200 to $6,000 per kW of capacity installed.

SLIDE 13: **Small Hydro Project Considerations**

Small Hydro Project Considerations

- Keep costs down with simple design and practical, easily-constructed civil structures
- Existing dams and civil structures can be used
- Development time of 2 to 5 years
  - Resource and environmental studies: approvals
- Four phases for engineering work:
  - Reconnaissance surveys/hydraulic studies
  - Pre-feasibility study
  - Feasibility study
  - System planning and project engineering

Slide 13

With civil works typically accounting for 60% of the initial costs of a small hydro project, and with these initial costs being very high in general, the design and construction of the civil works merit special attention. Existing dams and civil structures, even those not originally built for power generation, may be reused, and this will reduce costs. Where this is not possible, past experiences have shown that simple designs and practical, easily-constructed civil structures help keep initial costs down.

The development of a small hydro project will typically take two to five years from conception to final commissioning. This time is required to conduct studies of the resource, site conditions, and environmental impacts, for design and engineering, to obtain necessary approvals, and for construction.

Engineering work consists of four phases, although the first and second phases are often combined. First, reconnaissance surveys and hydraulic studies are used to identify promising sites and to rank their power potential and probable costs. Second, a pre-feasibility study for each promising site is conducted; this involves site mapping, geological investigations, reconnaissance of places where sand and gravel needed in construction could be taken from, a preliminary layout and selection of project characteristics, a preliminary cost estimate, and identification of possible environmental impacts. Third, an in-depth feasibility study must report on foundations, probabilities of floods and earthquakes, design of major structures and selection of components, detailed cost estimates, utility interconnection, impacts on the grid, and financial feasibility. Fourth, in the system planning and project engineering phase, the electrical transmission system must be designed, tender drawings and specifications produced, bids and detailed design analysed, and detailed construction drawings made.

SLIDE 14: **Small Hydro Environmental Considerations**

Small Hydro Environmental Considerations

- Small hydro development can change
  - Fish habitat
  - Site aesthetics
  - Recreational/navigational uses
- Impacts and environmental assessment requirements depend on site & type of project:
  - Run-of-river at existing dam: relatively minor
  - Run-of-river at undeveloped site: dam/weir/diversion construction
  - Water storage developments: larger impacts that increase with scale of project

Slide 14

A small hydro development will impact its environment in various ways; the extent and nature of these impacts will vary depending on the type of development, the species present, and the site. Many of the potential negative impacts can be mitigated through careful planning, construction, and operation of the project.

The most significant environmental impacts of a hydro project are usually associated with the flooding of land to create a reservoir. This can result in the loss of agricultural land, the flooding of dwellings and archeological sites, loss of fish habitat and spawning areas, and drowned forest. In places where the land is acidic rock with soft acidic water, such as the Canadian Shield, the creation of new lakes and reservoirs can permit submerged vegetation to release mercury compounds – dangerous pollutants – into the water. The decomposition of submerged vegetation also releases methane and carbon dioxide, both greenhouse gases. Clearing the forest in the area to be flooded can partially mitigate these problems.

SLIDE 14: **Small Hydro Environmental Considerations (cont.)**

Fortunately, most *small* hydro systems are run-of-river plants that do not cause significant flooding; the creation of new reservoirs is rarely financially feasible for projects of this scale. The creation of a head pond or small reservoir meant to smooth flows may cause minor flooding, but this will generally be limited to rapids just upstream of the dam. Sometimes small hydro projects make use of an existing lake or reservoir for water storage. While flooding is avoided, in projects meant to operate primarily during the times of peak electrical load, the water level upstream of the dam and the flow through the tailrace and downstream of the project may fluctuate. In a large storage reservoir, this fluctuation is usually slow, and not a problem. Downstream of the turbine, these fluctuations may be rapid, and more objectionable.

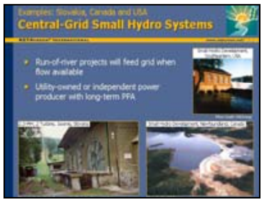
Dam or diversion weir construction has negative environmental consequences beyond flooding. The dam presents a barrier to anadromous fish, which migrate up rivers from the sea in order to breed in fresh water. Fish passages and fish diversion structures are used to address this problem. Similarly, the dam may be a barrier to navigation in the watercourse, and will affect canoeists and kayakers who use the river for recreational purposes. Sedimentation of the watercourse can occur during construction if the construction is not done with sufficient care. River diversion tends to result in a loss of fish habitat between intake and tailrace, where channels may dry up, although maintaining a reasonable residual flow can mitigate this.

On the other hand, falls and rapids are generally considered as sites of natural beauty, and their loss may be strongly felt by many people acquainted with the river. Other aesthetic impacts include the presence of the civil structures in the landscape and transmission lines between the project and the load or the existing grid.

The level of environmental impact and impact assessment requirements therefore tend to vary with the type of project, the species presents, and its location. A run-of-river project at an existing dam has very minor impacts. A run-of-river project at an undeveloped site will have impacts associated with the construction of the dam or weir. A water storage project involves a much larger dam, causes flooding, and will be subject to a much more rigorous environmental impact assessment.

SLIDE 15: **Central-Grid Small Hydro Systems**
Examples: Slovakia, Canada, and USA

Most small hydro projects are run-of-river developments connected to the grid. Because there are a multitude of generators on the grid, the fluctuations in the system's power output are not problematic, and all electricity that can be generated can be made use of. These projects may be owned by a utility, or may be owned by independent power producers. Independent power producers strive for long-term power purchase agreements with a utility or major consumer to ensure that the power is sold at a rate that will service the debt incurred during project construction.



Examples: Slovakia, Canada and USA

Central-Grid Small Hydro Systems

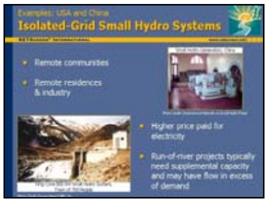
- Run-of-river projects will feed grid when flow available
- Utility-owned or independent power producer with long-term PPA

Slide 15

SLIDE 15: Central-Grid Small Hydro Systems
Examples: Slovakia, Canada, and USA (cont.)

The photo at the bottom left shows the powerhouse of a 2.3 MW, two-turbine project in Slovakia; the penstock is seen descending the hill in the background. The original plant was built in 1924, and serves as a testament to the longevity of the civil structures associated with small hydro projects. The bottom right photo provides an aerial view of the recently constructed Star Lake development in Newfoundland, Canada. Downstream of the dam, where the rapids are, we can see the shape of the river bed, showing that virtually no flooding occurred. The top right photo shows a small hydro development in the Southeastern USA. The brick powerhouse demonstrates that the civil structures for small hydro projects need not be ugly.

SLIDE 16: Isolated-Grid Small Hydro Systems
Examples: USA and China



Examples: USA and China

Isolated-Grid Small Hydro Systems

- Remote communities
- Remote residences & industry
- Higher price paid for electricity
- Run-of-river projects typically need supplemental capacity and may have flow in excess of demand

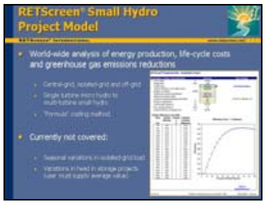
Slide 16

Small hydro systems are also used in areas where the central grid is not present. These include remote communities or clusters of remote communities that operate an isolated grid as well as remote industries such as mines and forestry operations. Off-grid residences, though typically not on an isolated grid, can also meet their electrical needs through very small-scale hydro projects.

Because cheap electricity is not available from the central grid, the value of electricity at these locations tends to be high. This makes the output of the small hydro development more valuable, and the project more financially attractive. On the other hand, accommodating the fluctuating power output of a run-of-river project presents a challenge that does not usually exist for central grid-tied systems. Unless the firm capacity of the plant is sufficient to meet the peak load, supplemental generation capacity, such as diesel-fired generators, will be required. There is also the likelihood that during times of strong flow in the river, electricity load will require only a fraction of the plant's potential output, and the rest will not generate any benefit.

The top photo shows generators inside a powerhouse in China. China has 45,000 small hydro facilities with a combined capacity of 19,000 MW. The bottom photo shows the small hydro plant of the remote community of King Cove, Alaska. The 800 kW facility supplies the town of 700 with electricity.

SLIDE 17: RETScreen® Small Hydro Project Model



RETScreen® Small Hydro Project Model

- World-wide analysis of energy production, life-cycle costs and greenhouse gas emissions reductions
  - Central-grid, isolated-grid and off-grid
  - Single turbine micro hydro to multi-turbine small hydro
  - "Formula" costing method
- Currently not covered:
  - Seasonal variations in isolated-grid load
  - Variations in head in storage projects (user must supply average value)

Slide 17

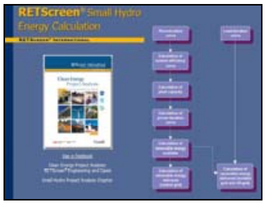
The RETScreen Small Hydro Project Model is a simple but very useful tool for the preliminary investigation of the technical and financial feasibility of small hydro projects. For an installation anywhere in the world, it can provide an analysis of the energy production, life-cycle costs, and greenhouse gas emissions reductions. The development can be on a central grid or an isolated grid, can be run-of-river or incorporate storage, and can range in scale from a single turbine micro-hydro system to a multi-turbine small hydro project.

A very powerful feature of the tool is a "formula" costing method that helps estimate project costs based on the characteristics of the site and the project configuration. Of course, the user who so prefers can use a detailed costing method based on quantities and unit costs.

SLIDE 17: **RETScreen® Small Hydro Project Model (cont.)**

In terms of pre-feasibility analysis, the limitations of the RETScreen small hydro project model are relatively minor. The model assumes that all variation in the load on an isolated grid occurs on a daily basis, and that there are no seasonal variations in load. It also cannot account for variation in the head of systems incorporating water storage; rather, calculations are based on an average value of head supplied by the user.

SLIDE 18: **RETScreen® Small Hydro Energy Calculation**



Slide 18

The RETScreen Small Hydro Energy calculation determines the energy delivered by a hydro project over the period of a year. The data used for this calculation are the head, various component efficiencies, a flow duration curve representative of the flow over the year and, for isolated grids, a load duration curve. A load duration curve describes annual variation in the load on an isolated grid: like a flow duration curve, it is expressed in terms of the load that is exceeded for a specified fraction of the year. Here we provide a step-by-step overview of this calculation; for more information, see the *RETScreen Engineering and Cases Textbook*, available on-line and free-of-charge.

The first step is the calculation of turbine efficiency as a function of flow rate. A number of empirical relations are used to do this; these relations are specific to the type of turbine employed. The user is also free to bypass this calculation and enter data describing the turbine efficiency as a function of flow.

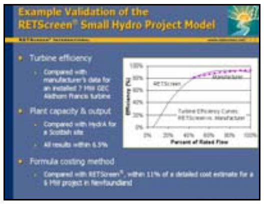
The second step is the calculation of the plant capacity. This is based on an equation for the power output as a function of flow. The power output is the product of the mass flow rate, the acceleration due to gravity, the head, the turbine efficiency at the given flow rate, the generator efficiency, and the transmission system efficiency, all reduced by the parasitic losses. This calculation uses the net head; that is, the difference in elevation between the surface of the water above the intake and the turbine minus hydraulic losses caused by resistance to water flow in the passages between the intake and the turbine. The plant capacity is simply the power output, as found from this equation, with the flow rate set to the design flow rate.

The third step is the calculation of the power duration curve. This is constructed from the flow duration curve: for each point on the flow duration curve, the corresponding plant output is calculated from the aforementioned equation for power as a function of flow. When the available flow exceeds the design flow, the design flow is used as the independent variable in the equation.

The fourth step is the calculation of available energy. This consists simply of integrating the power duration curve to find the area underneath it.

The fifth step is the calculation of the energy delivered. It is assumed that central grids can absorb all the energy produced by the plant, so for them, the energy delivered is equal to the available energy. For isolated grid plants, output of the plant in excess of the load is not used, so the power duration curve must be compared with the load duration curve to determine which is the limiting consideration. The power duration curve is broken into 20 segments, each representing the power output during 5% of the year. Then the area under the load duration curve that lies below this power level is used to determine the energy delivered during that 5% of the year. The annual energy delivered is the sum of the energy delivered in all of the 20 segments.

SLIDE 19: **Example Validation of the RETScreen® Small Hydro Project Model**


Example Validation of the RETScreen® Small Hydro Project Model

- Turbine efficiency
  - Compared with manufacturer's data for an installed 7 MW GEC Alsthom Francis turbine
- Plant capacity & output
  - Compared with HydrA for a Scottish site
  - All results within 6.5%
- Formula costing method
  - Compared with RETScreen®, within 11% of a detailed cost estimate for a 6 MW project in Newfoundland

Slide 19

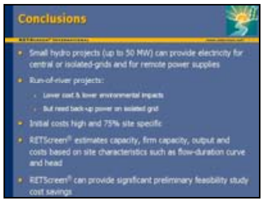
The RETScreen software has been validated in a number of ways. Here we discuss several aspects of the software that have been validated, namely the calculation of turbine efficiency curves, the determination of plant capacity and available energy, and the formula costing method.

The efficiency curve calculated by RETScreen was compared with manufacturer's data for a number of turbines, including a 7 MW Francis turbine, manufactured by GEC Alsthom and installed at a site with 105 m of head, near Prince Rupert, British Columbia, Canada. The results, shown in the figure on this slide, demonstrate a good correspondence between the manufacturer's data and RETScreen's predictions.

RETScreen's calculation of the plant capacity and available energy were compared with those of HydrA, a small hydro software tool used in the United Kingdom and Spain; the results of the comparison were published in an International Energy Agency document. A Scottish site having 65 m of head and a flow of 1.6 m^3/s was used for this comparison. The estimated power output from the site was in the range of 700 to 825 kW. For Francis, Crossflow, and Turgo turbines, the report concluded that "there is little difference in the energy calculations"; at most, the estimates of plant capacity and available energy differed by 6.5 and 3.5%, respectively.

The formula costing method was compared to costs estimated by the RETScreen detailed costing method for a recently commissioned 6 MW small hydro project in Newfoundland, Canada. The project had a head of 114 m, a design flow of 6.1 m^3/s, a small dam with minimal storage, two Francis turbines, a single generator, a 1300 m penstock, and a 3 km transmission line. While the estimates for individual items differed quite significantly, the overall estimate of costs made by the formula method was only 11% larger than the detailed cost accounting. This level of accuracy is adequate for pre-feasibility purposes.

SLIDE 20: **Conclusions**


Conclusions

- Small hydro projects (up to 50 MW) can provide electricity for central or isolated-grids and for remote power supplies
- Run-of-river projects:
  - Lower cost & lower environmental impacts
  - But need back-up power on isolated grid
- Initial costs high and 75% site specific
- RETScreen® estimates capacity, firm capacity, output and costs based on site characteristics such as flow-duration curve and head
- RETScreen® can provide significant preliminary feasibility study cost savings

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Small hydro power – that is, projects less than about 50 MW – can cost-effectively provide electricity to central grids, to isolated grids, or to remote loads. It is a proven technology that benefits from over a century of experience with large and small hydro systems.

Most small hydro power plants are of the run-of-river configuration and therefore do not incorporate water storage reservoirs. This minimizes costs and environmental impacts associated with flooding. The power output of such plants varies with the fluctuations in the river's flow, but central grids can accommodate this variation. On isolated grids, supplemental generating capacity may be required, but the value of the electricity produced by the hydro plant will probably be higher than on a central grid.

As with most renewable energy technologies, small hydro plants have high initial costs but very low operating and maintenance costs. Most of the initial costs are accounted for by the civil structures, and as a result are 75% site-specific. Small hydro plants have useful lifetimes of 50 years or more.

Based on site characteristics such as flow duration curve and head, the RETScreen software calculates plant capacity, firm capacity, annual output and estimates costs. RETScreen can significantly reduce the cost of conducting preliminary feasibility studies of small hydro projects.

SLIDE 21: **Questions?**

This is the end of the Small Hydro Project Analysis Training Module in the RETScreen International Clean Energy Analysis Course.

Questions?

Small Hydro Project Analysis Module
RETScreen® International Clean Energy Project Analysis Course

For further information please visit the RETScreen Website at
www.retscreen.net

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