A Practical Guide to Assessment and Implementation of Small Hydropower

Goran Stojmirovic
Group Manager Hydropower & Major Projects
Hydro Tasmania Consulting, Tasmania, Australia
Email: goran.stojmirovic@hydro.com.au

Tammy Chu
Hydropower Engineer
Hydro Tasmania Consulting, Tasmania, Australia
Email: tammy.chu@hydro.com.au

1 INTRODUCTION

Over the many decades Hydro Tasmania has had extensive experience in small hydro, from desktop concept studies through to pre-feasibility and feasibility studies leading to the preparation of business cases. Detailed design, technical specification, contract administration and contract supervision for our own developments, and turnkey design/construct, build own operate and partnership contracts with other developers.

Initial screening on resource availability and utilisation, and then on technical and economic grounds, has led to shortlisting of viable developments and implementation. This paper describes the methodology and assessment capabilities developed for small-hydropower developments in developing countries. It describes key issues pertaining to small hydro development and aims to make developers aware of the opportunities and challenges of energy development, so as to increase the likelihood of a successful project. As such, it is most relevant for projects with installed capacities greater than 1MW, which are not rural electrification.

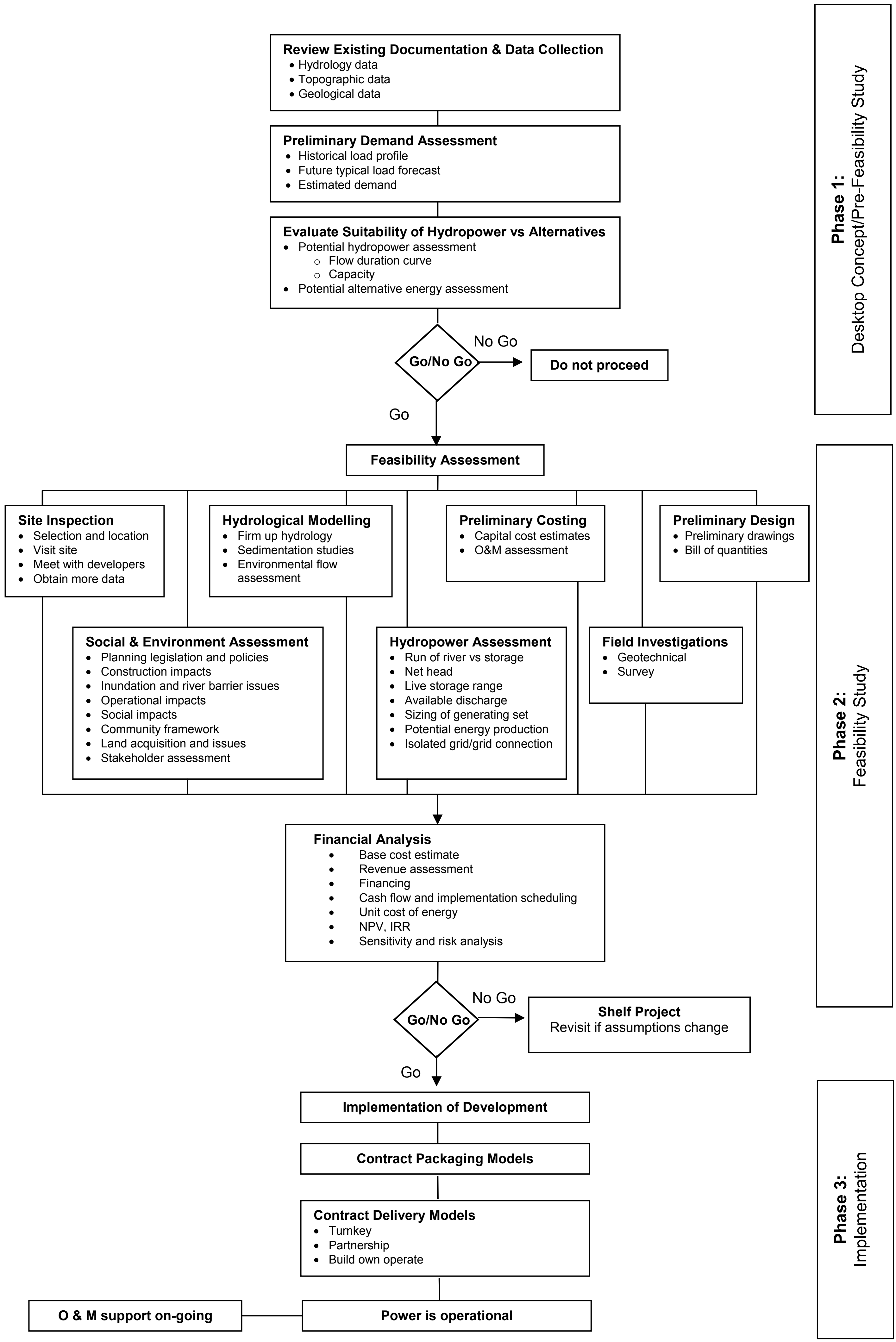
2 SMALL- HYDROPOWER ASSESSMENT

Small hydropower is typically highly customised for the size and scale of the development, as schemes are typically greater than 1MW and less than 10MW. Small hydro opportunities in developed countries have recently been associated with water supply systems and existing water assets for the schemes to be economically viable. The most important aspect of the assessment is the quality of the data required for input and assessment. A subsequent broad-brush analysis of a site considers its location, catchment size, flow and head parameters to perform a potential rated power output. The assessment refines the siting of the scheme, calculates the potential generation and determines the potential cost of the scheme.

Hydro Tasmania has worked successfully with various machine suppliers both within Australia and internationally. Given the small nature of these projects, it is recommended that a streamline approach be adopted, by evaluating a limited number of proven successful suppliers, and keeping the contractual relationship simple, but with a robust framework.

2.1 Assessment Methodology

The following methodology depicted in the flowchart below, demonstrates the activities required from investigation through to implementation.



Review Existing Documentation & Data Collection
Hydrology data
Topographic data
Geological data
Preliminary Demand Assessment
Historical load profile
Future typical load forecast
Estimated demand
Evaluate Suitability of Hydropower vs Alternatives
Potential hydropower assessment
Flow duration curve
Capacity
Potential alternative energy assessment
Go/No Go
No Go
Do not proceed
Go
Feasibility Assessment
Site Inspection
Selection and location
Visit site
Meet with developers
Obtain more data
Hydrological Modelling
Firm up hydrology
Sedimentation studies
Environmental flow assessment
Preliminary Costing
Capital cost estimates
O&M assessment
Preliminary Design
Preliminary drawings
Bill of quantities
Social & Environment Assessment
Planning legislation and policies
Construction impacts
Inundation and river barrier issues
Operational impacts
Social impacts
Community framework
Land acquisition and issues
Stakeholder assessment
Hydropower Assessment
Run of river vs storage
Net head
Live storage range
Available discharge
Sizing of generating set
Potential energy production
Isolated grid/grid connection
Field Investigations
Geotechnical
Survey
Financial Analysis
Base cost estimate
Revenue assessment
Financing
Cash flow and implementation scheduling
Unit cost of energy
NPV, IRR
Sensitivity and risk analysis
Go/No Go
No Go
Shelf Project
Revisit if assumptions change
Go
Implementation of Development
Contract Packaging Models
Contract Delivery Models
Turnkey
Partnership
Build own operate
O & M support on-going
Power is operational
Phase 1:
Desktop Concept/Pre-Feasibility Study
Phase 2:
Feasibility Study
Phase 3:
Implementation

2.1.1 Review of Existing Documentation & Data Collection

As a first step to understanding the issues associated with developing hydropower, a review of relevant documentation is required to be undertaken. To be able to perform a desktop study of the hydropower development all relevant existing information relating to the scheme must be obtained, in particular, hydrological data, topographic data and geological data. Assessing the available water resource is a key part of the project, and the certainty of the energy production potential and price estimates relies on its accuracy.

Hydrological Data Review

Measured hydrological flow data or stream gauging information located on the catchment in question should be utilised. The most accurate data would include the finest time series and the longest period of data. A minimum of 1 years daily flow data is required to make a preliminary assessment. Where no measuring site exists or hydrological data is limited, flow and rainfall information data for an adjacent (or similar) catchment maybe used, and adjusted for catchment area and average rainfall level. Given the similar nature of the topography, mean annual rainfall and catchment areas it would be expected that the flow duration curves for these catchments would be similar. This provides some uncertainty in the results, but will be sufficiently accurate for the purpose of a pre-feasibility assessment. It is advisable to follow this up with site measurement once the project looks likely to be feasible.

Topographic Data Review

In the absence of detailed information, topographic maps should be used for contour information and to determine catchment areas and land use. Contour information or aerial photographic maps with reasonable accuracy (1:25,000) should be obtained for determining levels and distances. Levels or spot height information will need to be verified by a detailed survey at the feasibility stage.

Geological Data Review

An assessment of the regional geology by means of geological maps and review of existing reports should be made to assess the potential location and scheme arrangement. In particular consideration should be given to ground conditions, landslides, regional seismic activity and river sedimentation loads. These features may directly influence the design of penstocks and tunnels; the design of the intake structure to be able to cope with high sediment loads or the height of weirs associated with intake structures.

2.1.2 Preliminary Demand Assessment

It is important to determine the ability of the generated electricity to be used within the region or the need to supply nearby loads (e.g. communities, industry) as this will influence the feasibility of the scheme. Assessment of historical and present electrical demand should be made based on the best available information. This will allow a typical load profile to be determined, which will show energy supplied and the historical trending, system losses and any variance with the expected system losses. Consideration of future maximum demand forecasts should be made by understanding if any firm plans exist to increase loads. (e.g. best knowledge of industrial and commercial developments).

2.1.3 Evaluate suitability of hydropower Vs alternative

It may be necessary to consider alternative energy generation compared to hydropower to determine the most economically and technically viable scheme. By assessing alternative options at a pre-feasibility level, a well-rounded opinion of the power generation available can be made. The energy generation options should be ranked by a project screening exercise, and selection criteria developed to determine the commissioning of a feasibility study. Capacity, demand estimation, community suitability and cost performance issues should be used for the optimisation and selection.

2.1.4 Feasibility Assessment

A feasibility study assesses in detail the technical and economic viability of a small hydropower development, and allows the client to determine whether to proceed with the implementation of the scheme. The approach to this phase should include confirmation of data to be accurate and a detailed assessment and optimisation of the costings. The essential components of a feasibility study are:

Site Inspection

A site inspection should be carried out by a hydropower engineer for familiarisation of the environment and determination of any major impediments to the implementation of the scheme. The engineer should meet with client and operational representatives to obtain the best knowledge available and identify further data input requirements. An assessment of the following should be made while visiting site:

- Existence of a suitable energy resource. i.e. consistent flow of water at a usable head;
- Existing infrastructure and condition, including operational considerations;
- Potential intake and powerhouse location;
- Potential access road routes and suitable construction and equipment installation;
- A nearby demand for electricity, or the prospect of a grid connection at reasonable cost;
- The social and environmental impact/benefits on the local area;
- Land ownership and/or the prospect of land acquisition or lease;

Hydrological Modelling

Confirmation of accurate hydrology and detailed modelling should be made to confirm the flow duration curve. Long-term records of flow data and rainfall, together with an estimation of the compensation/environmental flow (if required) should be assessed. Assessment of seasonal variation and peak and off-peak demands need to be considered. A firm capacity of the scheme should be determined, based upon the 90th percentile flow. The hydrological modelling may need to consider sedimentation studies, especially concentration rates to assist with the design of the intake arrangement and location.

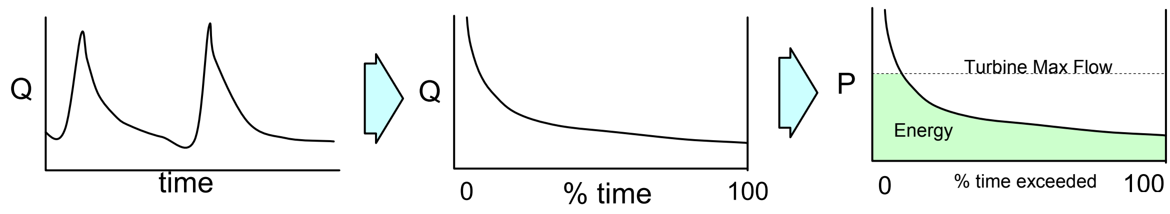


Figure 2 – Resource Assessment leading to flow & power duration curves

Field Investigations

Dependent on the topographic data obtained in the prefeasibility study, it may be necessary to conduct a topographic survey to confirm the net head of the scheme. Survey of the potential location of the intake structure and powerhouse should be conducted, with spot heights recorded. This is particular important for low head schemes when a reasonable amount of confidence is required for the level of accuracy of the net head. Geotechnical boreholes will be required to finalise the location of the intake structure, powerhouse and associated infrastructure and to allow input into the final design drawings.

Hydropower Assessment

Since the flow and head data has now been confirmed the potential annual energy generation can be properly assessed. Firstly the turbine and generator will need to be carefully selected and sized based upon the suitability of the flow and head range. Optimisation of the operating range of the turbine will need to be made, including the capacity factor of the scheme. There is clearly a balance to be stuck between choosing a larger, more expensive turbine which takes a high flow but operates at a low capacity factor, and selecting a smaller turbine which will generate less energy over the year, but will be utilised more of the time. i.e higher capacity factor. The capacity factor for most small hydro schemes would normally fall within the range of 50% to 70% in order to provide a satisfactory return on investment. Most turbines can operate over a range of flows (typically 30-40% of their rated flow) in order to increase their energy capture and sustain a reduced output during the drier months.

The electricity generated by a scheme may be used at the point of generation, in place of electricity supplied by the local electricity company. Alternatively, it may be exported via the local distribution network by agreement with the Distribution Network Operator. It is nearly always financially advantageous to consume as much of the power as possible on site and only export the surplus to the network. If the scheme is to produce power for export to the local network, there should be early discussions with the Distribution Network Operator who will specify the system protection and metering equipment, and will also provide an estimate of the connection costs and best location for feeding into their system.

The hydropower assessment must define the average annual energy output (river flows, hydraulic losses, operating head, turbine efficiencies and methods of calculations) (MWh/year) and the output of the scheme in terms of maximum potential power output (MW).

Social and Environmental

There are a number of environmental and social considerations that need to be investigated as part of the feasibility study. It will include reviews and assessments of likely environmental impacts, broadly considering factors such as:

- Assessment of any planning legislation and policies for the area
- Requirements for clearing native vegetation
- Impacts on stream flow and fish migration
- Inundation or river barrier issues
    - Threatened terrestrial species in inundation zone
    - Fish migration barriers – migratory species can be an issue if they are regarded as a threatened species, or locally important food source
- Operational impacts
    - Community water supply
    - Aquatic ecology health – environmental flows
    - Hydropeaking issues – community safety, erosion potential
    - Flood warning (gate operation if relevant etc.)
    - Water quality in the reservoir
    - Sedimentation of the reservoir and downstream
- Construction impacts
    - Traffic – road safety, noise, fuel spills
    - Site runoff issues – siltation, construction noise, water quality
    - Chemical/fuel spills
    - Materials sourcing
    - Water diversion issues
- Social Impacts
    - Potential for resettlement and relocation (to be avoided where possible)
    - Inundation of arable land
    - Public safety
    - Inundation of sacred sites/areas of cultural or historical value
    - Stakeholder management

Land issues and land compensation can be a major issue and will need to be carefully considered during the study and could be a deciding factor in a recommendation.

Preliminary Design

The design of the scheme should be completed at a level adequate for costing and a bill of quantities to be determined. Hence, the design should be adequate for tendering purposes, and would include general arrangement and layout drawings. Prominent aspects of the works can be categorised into:

- Civil works (intake and weir, intake channel, penstock, powerhouse, tailrace channel, site access, construction details)
- Generating equipment (turbine, generator, control system)
- Network connection design to allow assessment of the local power distribution and the community demand requirements

Optimisation and design of the civil components (intake weir sizing; penstock sizing and lining; minimising access routes and penstock lengths) will need to be finalised. In any small hydro scheme, the electrical and mechanical components (ie. turbine, generator, control systems) determine the physical arrangement of the powerhouse. The floor levels, roof clearance, building footprint, substructure arrangement, pipework alignment and discharge arrangement are all dependent on the specific characteristics of the selected equipment. If possible, the designers will therefore need to work closely with the machinery suppliers, so that specific equipment parameters can be considered as the basis of the design.

Costing

The costing of the scheme should include the costs to implement the project and the operation and maintenance costs to allow its on-going operation. The capital cost estimate must be determined from drawings and a bill of quantities as determined during the design phase. It should be at an accuracy in the order of +/- 10%. Key capital cost items can be subdivided into:

- Cost of civil works;
- Cost of hydro-mechanical and electro-mechanical equipment;
- Cost of grid connection;
- Engineering and project management costs

Capital Costs

Based on Hydro Tasmania's experience in developed countries, costs can range from as little as AU$750/kW installed to over AU$3,500/kW installed for economically viable projects. Generally most potential installations that warrant a closer look will fit below AU$2,500/kW installed. However, installed costs ($/kW) are only part of the overall life cycle costs, and the generating profile (i.e. what proportion of time the turbine will operate for at full output and when) as well as the ongoing maintenance, communications and electrical connections costs are core to the economics of small hydro projects.

The civil costs may include the intake, forebay tank and screen, the penstock or channel to carry the water to the turbine, the powerhouse and machinery foundations, the tailrace channel to return the water to the river, and access roads. The civil works are largely site specific. On high head site the major cost will be the penstock, on low head sites probably the water intake, screens and channel. The cost of penstocks or tunnels has a significant impact on the overall cost of the scheme. Therefore penstock and tunnel lengths should be kept as short as possible.

The size of the powerhouse is generally proportional to the machine diameter, which is related to the square root of the flow volume. Therefore, powerhouse costs may be calculated according to an empirical formula:

$$\text{Cost} = \text{AU\$50,000} + \text{AU\$100,000} \times \text{sqrt(flow)}$$

Based on Hydro Tasmania's experience in developed countries the following table is provided as a guide to providing some assistance in the cost of the supply of turbine, generator and all peripheral mechanical and electrical equipment.

	0-30m	30m-150m	150m+
	Low head	Medium head	High head
Size	AU$/kW	AU$/kW	AU$/kW
1000kW	$1,200	$1,000	$800
2000kW	$1,000	$800	$600
5000kW+	$800	$600	$500

Generally speaking, machinery costs for high head schemes are lower than for low head schemes of similar power. High head machines have to pass less water than low head machines for the same power output and are therefore smaller. They also run faster and thus can be connected directly to the generator without the complication of gearbox or belts.

The electrical system will involve the control panel and system, the wiring within the powerhouse, and a transformer if required, plus the cost of connection to the electricity. These costs are largely dependent on the maximum power output of the installation. The connection cost is set by the local electrical distribution company.

A contingency of 20% of the construction cost was included in the final capital estimates for each project.

Engineering and Project Management Costs
These costs encompass the engineering services to design and manage the installation, plus supervision costs for the project. This is likely to equate to approximate 10 to 15% of the total capital amount.

Land acquisition costs must be considered and should be provided by the client where possible.

Operation & Maintenance Costs
Operation and maintenance costs for small hydro turbines are low. Generally, in developed countries, the stations are unmanned and automatically controlled by water levels or from a central control room. Routine inspections are then required on a regular basis, and generally in conjunction with other routine inspections. In undeveloped countries, stations are generally manned by an operator and/or security guards. Due to low cost of labour, this is generally an insignificant expense. Generally, operation and maintenance costs for a scheme may be in the region of AUD$5/MWh or up to 2% of the project capital cost.

Financial Assessment

A financial analysis will allow the economic viability of the project to be assessed. The analysis must consider the following parameters as part of its economic modelling:

- Base cost estimate;
- Revenue assessment – the value of energy based upon market analysis or demand capability. Include seasonal variation and peak/off-peak pricing;
- Financing strategy;
- Cash flow analysis and implementation schedule;
- Economic life – typically 40 years used.

The economic viability should be presented by means of the unit cost of energy ($/kWh), net present value and the internal rate of return. It is therefore likely that the client will have their own hurdle rate in which the project must provide a minimum return for it to be considered eligible for implementation.

A sensitivity and risk analysis should be performed to test against the base case for various changes in capital cost, revenue price and annual energy production. The risk assessment should consider the project holistically including construction and operational considerations.

Criteria for decision

The feasibility study allows a detailed assessment of the technical and commercial viability of a scheme to be made. However the decision whether to implement the scheme will be up to the owner, especially if the scheme is economically marginal. The owner must fully understand their project and business drivers, as the decision to implement may consider intangible benefits.

Based upon Hydro Tasmania's experience and learnings in developed countries an appropriate criterion for selection should consider;

- The scheme would need to be technically feasible, but of simple arrangement with appropriate risk mitigation and containment in place;
- Easy to implement;
- Robust;
- Cost effective/cheap;
- Environmentally and socially sound and sustainable;

2.1.5 Implementation of Development

Small hydropower development is of relatively complex nature that requires careful consideration of the implementation process to ensure the development risk is effectively managed. Based on Hydro Tasmania's experience as an owner/developer and consultant/contractor, Hydro Tasmania recognises that the plant may be embedded within local communities, which will require appropriate operational considerations and constraints. Small hydro can often expose owners and developers to risks that far exceed the project's direct commercial indices due to the scale of the projects and their interaction with existing water assets, electricity networks and control systems. While some schemes incorporate a degree of classic design, most are born out of reinvested experience in the design and construction of similar schemes. Often the adoption of arrangements to make use of existing structures and the careful consideration of operational flexibilities within the owner's constraints can make the difference to commercial and technical viability.

There are a number of development options, by means of contract packaging and delivery models which can be adopted for the implementation of small hydropower. Each model has its own level of risk and reward, which requires the developer to carefully consider the cost risk benefit of the development. Design and construction risks must therefore for carefully managed to ensure risks are understood and fully considered during construction and long-term operation.

Contract packaging models

The contract and commercial packaging for small hydro developments can be considered in a number of ways. Given the need to manage the commercial conditions and the implementation timeframes, it is important that the construction activities and procurement lead-times of equipment are fully understood. Typically the critical path items are the procurement of the turbine and generator.
The contract can be packaged into a number of broad categories, such as:

- Civil package
- Civil and hydromechanical package
- Electrical and mechanical package
- Grid connection package

The interface or separation points need to be clearly defined to ensure appropriate delivery of design and construction.

Hydro Tasmania has had successful experience in both open tender and direct quotation processes. The open tender process can involve extensive up-front engineering design and specification works to allow all tenderer's to compete on an equal basis, for a defined arrangement and scope of work. Innovation in design would be offered through an alternative or nonconforming tender, and in many cases this would prove successful in reducing the contract cost to allow the project to remain economically viable. Pre-tender consultancies can cost in the order of 10-20% of the value of the contract works for the smaller schemes, and while necessary to determine the feasibility of the scheme, may add limited value to the tender process in achieving the most economical arrangement.

Often, the most economical schemes will be one where the supplier nominates their preferred equipment and standards, and client requirements are then negotiated in. The supplier is in the best position to know the level and standard of equipment required to perform the task, and often tender specifications will only add to the expense of the equipment by specifying standards that may not be warranted by the size of the installation. Some level of specification is always required to define what will finally be delivered, performance criteria and standard of workmanship.

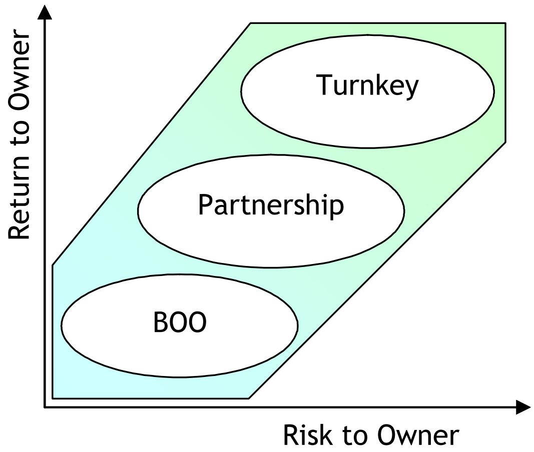
A more streamlined process for the procurement would be to obtain direct quotations from reputable machine suppliers. Usually a maximum of three quotations would be sought, in order to select the most suitable equipment supplier for the works, and that the intention of the design criteria is met. This would also include an interview process of the preferred supplier. Final tender pricing will be prepared based on the final design and outputs, including machine selection and pricing.

Contract delivery models

Since any hydro scheme requires a substantial upfront investment, it is clearly essential that the project is implemented correctly and with robust engineering and equipment. Generally, the delivery models for the implementation can be categorised into:

- Turnkey (engineer, procure, construct)
- Partnership (joint venture/alliance)

- Build own operate



Turnkey

The most common approach for implementing small hydro projects is the turnkey contract in which a single contractor takes the entire scheme from design to construction, which allows simplification of the management of the project. The contractor, who might be a civil engineering company or the turbine supplier, brings together a team of subcontractors and suppliers under a single contract, typically following a competitive tendering process. Since the main contractor takes the full risk, they have the opportunity to maximise the benefits and revenues.

Partnership

Typically the owner enters into a partnership (alliance) arrangement with another developer and the two parties combine their capabilities to best suit the project. This model ensures that the project is delivered with shared risk and shared benefit.

Build own operate

Under this model the owner sells all rights to the project, and a developer pays for the rights and usually pays an annual royalty for its ownership. Hence, the developer takes the responsibility of the full risk and benefits, in which the owner minimises their risk and benefit.

2.2 LESSONS LEARNT

Based on Hydro Tasmania's experience in developed countries, as an owner/developer and consultant/contractor, a number of lessons have been learnt which add value to the commercial and technical viability of small hydropower developments. These include:

- Innovative designs can make the commercial difference. Small hydro are typically highly customised for their scale, and are seldom a standard design;
- Fit for business, the contractor or developer must understand the owner's core business. This is extremely important for installations upon irrigation and water supply systems, where the small hydro may not necessarily be the primary function;

- Know your suppliers – since a large component of small hydro is machinery, experienced machinery suppliers and manufacturers can eliminate risk;
- Understand any competing requirements and who else needs the water. This may influence the energy production if water rights are not achievable or environmental flows have not been fully quantified.
- Guaranteeing revenue– ensure that any eligibility for any subsidies or government grants have been secured prior to implementation. Ensure that a power purchase agreement is in place for the purchase of electricity if connected to the grid;
- Appropriate technology – ensure that the technology is appropriate to the location and maintenance is fully understood;
- Understand the process and manage key stakeholders. The developer needs to be aware of external influences that may affect the process, in particular with changing government and legislation.
- Network connections appear to be easy, but can be complex in achieving appropriate commercial arrangements and technical requirements.
- Local support – inevitably domestic labour and community support are required.

The following principles and studies could assist reducing risks to owners during development and operation of hydropower opportunities:

Studies during design

- Confirmation of inflows and output;
- Sensitivity analysis on technical and economic parameters;
- Hydraulic transient analysis to ensure operational timings are not unacceptable to system integrity and operation;

Minimising outages during Construction

- Schedule construction work to low flow periods;
- Construct temporary bypasses where continuous flows required;
- Reduce cut-over times by construction of separated hydro and water supply assets;
- Optimise storages prior to construction to improve construction scheduling;
- Allow appropriate lead-times for procurement of major equipment;

Redundancy

- Provide bypasses where required to maintain flow in case of power station shutdown;
- Maintaining existing dissipating devices and systems as backups for water releases;
- Additional pressure reducing capacity where required;

Operation

- Water releases take precedence over energy production;
- Optimised operating rules where possible and within constraints to maximise revenues;
- Water quality and security is maintained;
- Ensure appropriate performance testing and commissioning is fully tested over all operating conditions;

2.3 CONCLUSIONS

The following conclusions are made for small hydropower assessments:

- Three distinct phases exist for the assessment of small hydro which includes a desktop pre-feasibility assessment; feasibility study; and an implementation phase.
- The pre-feasibility phase is the concept stage which defines at a high-level the capacity, demand estimation and community suitability. Assessing the water resource and obtaining all available existing data and information is critical in assessing the certainty of the energy production potential.
- Hydrological data is one of the most important parameters in determining the feasibility of a site. Hydrology at some sites is questionable, and where monitoring at a particular site does not exist, adjacent catchment data may be used. Further feasibility studies will need to refine the hydrological data.
- A demand assessment must be made to determine the ability of the generated load to be used.
- The feasibility assessment is a technical and commercial analysis which will allow the owner to decide whether to proceed with implementation of the scheme. The feasibility study assessment should consider as a minimum, a site inspection; hydrological modelling; field investigations; hydropower assessment; social and environmental issues; preliminary design; costing and financial analysis.
- The hydropower assessment must include selection and optimisation of the operating range of the turbine and the capacity factor of the scheme. The capacity factor for most small hydro schemes would normally fall within the range of 50% to 70% in order to provide a satisfactory return on investment.
- Social and environmental impact assessment must be made, including consideration of land acquisition.
- Preliminary design and scheme arrangements need to be made, and where possible designers should work closely with the machinery suppliers, so that specific equipment parameters can be considered as the basis of design.
- Costing should be assessed to an accuracy of +/- 10%, and a 20% contingency should be applied to the capital costs. Engineering and project management costs are likely to equate to approximately 10-15% of the total capital cost.
- Selection criteria developed for commissioning the implementation of a scheme should consider the technical feasibility; ease of implementation; robustness; cost effectiveness; and environmentally and social sustainability.
- Small hydro may be implemented under a number of development options, in which the owner must carefully consider the cost risk benefit of the development. This may be delivered by an open or selected tender process, and numerous contract delivery models: turnkey; partnership; or build own operate.
- Small hydro requires specialised engineering and Hydro Tasmania has extensive experience and learnings which have added value to the technical and commercial viability of many developments throughout Australia and internationally.