Sustainable Energy Development Office
Government of **Western Australia**

Study of Tidal Energy Technologies for Derby

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Report No.: WA – 107384 - CR-01
Rev. Status: REVISION 0
Date Issued: December 2001

Executive Summary

Introduction

This study investigates tidal energy technologies and options to offset or replace the existing diesel generation facilities at Derby, Western Australia. The objectives of the study were:

- To assess the technical feasibility of developing a tidal power station and the likely environmental and social impact of such a development.
- To determine the economic viability of a tidal power development for the supply of power in the Derby region.
- To determine the preferred location and layout of the tidal power development.
- To evaluate the Turnkey and Build Own Operate (BOO) development options for the construction and operation of a tidal power development and advise on the scope of the tender process to deliver potentially feasible options.

The above objectives are covered in detail in this conceptual study. The findings of the study can be summarised as follows.

Study Limitations

Limitations of the current study are:

A. No detailed survey information is available and this limits the accuracy of the estimates of quantities and reservoir volumes;
B. No geotechnical investigation of the potential sites has been undertaken and the conditions may have a major impact on the civil construction costs;
C. No information is available on the sediment dynamics in the estuary. Sediment dynamics has significant environmental and technical implications to the project;
D. Only a preliminary assessment of the potential environmental effects has been undertaken to date.

Tidal Energy Technologies

Tidal technologies were investigated, including those under development and existing tidal plants. Information has been sought from documents on renewable energy, from the internet and from correspondence with technology developers worldwide. A reference list of documents, textbooks and internet sites has been included at the end of this report. Further information was requested from the tidal energy companies regarding many key issues including: costs, applicability, history of development/operating sites, O & M requirements and environmental impacts.

The main findings are:

1. Many tidal energy schemes have been investigated over the past 40 years but very few have actually been built, with very high capital cost and environmental impact the main deterrents.
2. Tidal barrage systems are technically feasible, utilising conventional low head hydro turbines and dams/barrages.
3. Tidal current schemes are primarily in the research and development phase with a few small prototypes being tested at present.
4. The tidal energy technology that is most appropriate for a small-medium scale (<10 MW) tidal plant at Derby is a tidal barrage scheme using conventional low-head hydro turbines.

Tidal Energy Generation

A series of tidal system simulation models was developed to determine the relative merits of different tidal power configurations and the available generation. Evaluation was carried out utilising five-minute simulation of a range of storage curves and tidal system capacities. At each time step the model assessed system load, available tidal power and storage.

The major limitations on tidal generation are posed by the storage volume and head (differential in level between tidal and pond levels) relationships and tidal characteristics of phase and amplitude. A tidal system poses additional limitations to the standard hydro system in that the available head does not increase with storage, it is determined by tidal amplitude, and the available storage and head are dictated by tidal phase.

The system modelling was carried out over a period of 1 year. The modelling was based on historical load patterns for the 2000/2001 financial year and assumes the tidal plant meets 100% of the load when there is sufficient tidal power generated (100% system penetration). The following tables summarise the findings of the system modelling.

Storage	Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
7.4 Mm^3 at 11.5m						
	15	13%	35,700	17,300	9,400	18,300
	12.5	16%	34,500	17,300	9,400	17,300
	10	**20%**	**31,400**	**17,300**	**9,400**	**14,000**
4.35 Mm^3 at 11.5m						
	10	16%	17,500	13,900	12,800	3,600
	7.5	21%	17,400	13,900	12,900	3,600
	5	**32%**	**17,100**	**14,000**	**12,600**	**3,100**
	2	**53%**	**9,500**	**9,300**	**17,400**	**200**
2.5 Mm^3 at 11.5m						
	7.5	21%	17,400	14,300	12,300	3,000
	5	**33%**	**16,700**	**14,300**	**12,400**	**2,300**
	2	**50%**	**8,700**	**8,600**	**18,000**	**80**
1.6 Mm^3 at 11.5m						
	7.5	11%	7,300	7,200	19,400	100
	5	16%	7,300	7,200	19,400	100
	2	**40%**	**7,000**	**7,000**	**19,700**	**20**
0.8 Mm^3 at 11.5m						
	2	21%	3,600	3,600	23,000	0
	1	**40%**	**3,445**	**3,445**	**23,236**	**0**

The main conclusions of the modelling are:

- The modelling showed that single basin tidal plants of 7.5 MW or more will have an uneconomic amount of surplus generation, leading to low utilisation of the plant.
- The optimum sized options in terms of maximising utilisation are of 1-5 MW.
- The small amount of surplus generation from these options will be absorbed by load growth
- For a single basin design, there are hours during the day when the tidal plant will not be generating power. These hours will change from day to day due to tidal cycles.
- The diesel generation system must be able to supply 100% of the load.

Environmental Assessment

There are several significant environmental constraints to the development of tidal power options in the Derby area. The majority of issues relate to changes in the tidal flow patterns in the immediate vicinity of the plant, resulting in altered geomorphological processes, disturbance of riparian communities and potential changes in water quality.

Of greatest concern is the potential for excessive sedimentation of the channels upstream and downstream of the plant and hence the need for ongoing dredging. It is likely that mangrove ecosystems will be modified or destroyed, with losses upstream and possible expansion downstream.

There is a high risk of acid sulphate soils being present, which could lead to corrosion issues with infrastructure, water quality problems and fish kills. Corrosion from seawater, abrasion erosion from silt and sand and biofouling are all major concerns. Preliminary discussions with the Kimberley Land Council did not identify any significant aboriginal heritage issues.

It is concluded that there are three broad sites in the immediate vicinity of Derby for which there do not appear to be overwhelming environmental constraints and therefore should be assessed in terms of technical and economic feasibility for tidal power development. These sites are Airport Creek and various locations along Doctors Creek, particularly the western branch. In addition, it should be noted that there appears to be significant potential for tidal power development in the Buccaneer Archipelago with less environmental impact for much greater available power – the tradeoff being poor existing access and long transmission requirements.

While the environmental assessment did not identify any issues that would preclude tidal power development, proper management of environmental issues could impose significant economic constraints.

Development Options

Three development options were identified around the Derby area – tidal barrages at Airport and Doctors Creek, and the construction of a new reservoir. The installed capacity of the tidal plants investigated range from 1 MW to 5 MW. Multiple basin designs for small systems were not viable due to greatly increased barrage lengths, and therefore no preliminary cost estimates were made.

Conceptual designs and cost estimates were made for the four most economic options based on following assumptions:

- The powerhouse structure would consist of mass concrete foundations to resist buoyancy, and be supported by driven piles to prevent subsidence, rotation and lateral displacement. The walls would be heavily reinforced and the roof would consist of removeable panels.
- Construction of the access road would most likely be achieved by displacement of the upper level of tidal mud with rock.
- Slope and bed protection will be required for protection against erosion.
- Low head bulb or Kaplan turbines would be used, and the warm, saline environment may limit the options significantly.
- The power station will require both upstream and downstream bulkheads, inlet and outlet gates to seal off turbines during maintenance periods, and radial sluice bypass gates.
- Spinning reserve and demand peaks will be major factors in meeting performance standards.
- To maintain a speed and frequency, either a governor or controllable load will be required. A hydrogen production cell could be used for energy storage, or pumping and heating loads.
- Conventional high voltage transmission lines can be used, with an expansion of the existing SCADA system to incorporate the new plant.

Preliminary cost estimates were made for the four most promising options. The cost per kW ranged from $6,770 to $12,800. Capital costs ranged from $12.8 million to $33.9 million for 1

MW and 5 MW options respectively. Capital costs had high fixed components, resulting in larger plants being more cost effective. The cost estimates are very approximate, as they were based on very limited information.

Economic Analysis

The most cost effective option was found to be a 5 MW tidal plant at Doctors Creek with a 2.5 Mm^3 volume of water storage. The proposed development can be constructed for an estimated capital cost of $33.9 million and is expected to generate approximately 16.7 GWh of energy annually including a surplus generation of 2.3 GWh. The tidal plant would meet 50% of the annual demand, with the existing diesel generators meeting the remaining load.

The cost of unsubsidized tidal energy was estimated at $0.41/kWh.

Including the cost of diesel generation, the discounted weighted average tariff for this option was estimated at $0.30/kWh given a 50% capital cost grant of $16.9 million and a nominal discount rate of 15%.

The project is very sensitive to variations in diesel fuel costs, installed capital cost, the grant received, power output and the discount rate used (and therefore inflation).

Social Issues

Tidal power development at Derby is likely to be positive for the social and economic climate of Derby and the greater Kimberley region. There is a high level of support within the township for such development and although the issues need to be investigated in more detail, there do not appear to be any significant social constraints on tidal power development for the township of Derby.

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1 Introduction

1.1 BACKGROUND

The Western Power Corporation is responsible for operating 29 small isolated power systems including Derby area. Demand for electricity in the Derby area is currently met by a 6 MW diesel power station. The Western Australia State Government has a uniform tariff policy across the state with the results that the remote isolated energy systems typically operate at a loss due to high cost of the diesel fuel.

In 1998, the State Government established the Regional Power Policy to encourage private generators to supply power in remote areas and to reduce losses to Western Power in its Regional Systems.

As a part of the Regional Power Procurement Process, Western Power Corporation signed a Power Purchase Agreement in December 2000 with EEC/WEL to supply electricity to Western Power in the West Kimberley. The PPA excluded Derby area to provide opportunity for possible tidal power development.

It was proposed that a tender be called for the supply of electricity to Derby from a tidal power development. In order to asses potential tidal power alternatives which have not been previously identified the Office of Energy engaged Hydro Tasmania to prepare a Study of Tidal Energy Technologies for Derby.

1.2 OBJECTIVES OF STUDY AND METHODOLOGY

Based on a Consultancy Brief the comprehensive investigations have been undertaken with the following objectives:

- To investigate tidal power technologies and options for Derby that would replace existing diesel power generation facilities.
- To assess the technical feasibility of developing tidal power station and the likely environmental and social impact of such a development.
- To determine the economic viability of a tidal power development for the supply in Derby region.
- To determine the preferred location and layout of the tidal power development.
- To evaluate the Semi-Turnkey and Build Own Operate (BOO) development options for the construction and operation of a tidal power development.
- Provide advice as to the scope of a tender process to deliver potentially feasible options for a tidal power development.

The adopted methodology is shown in
Figure 1-1.

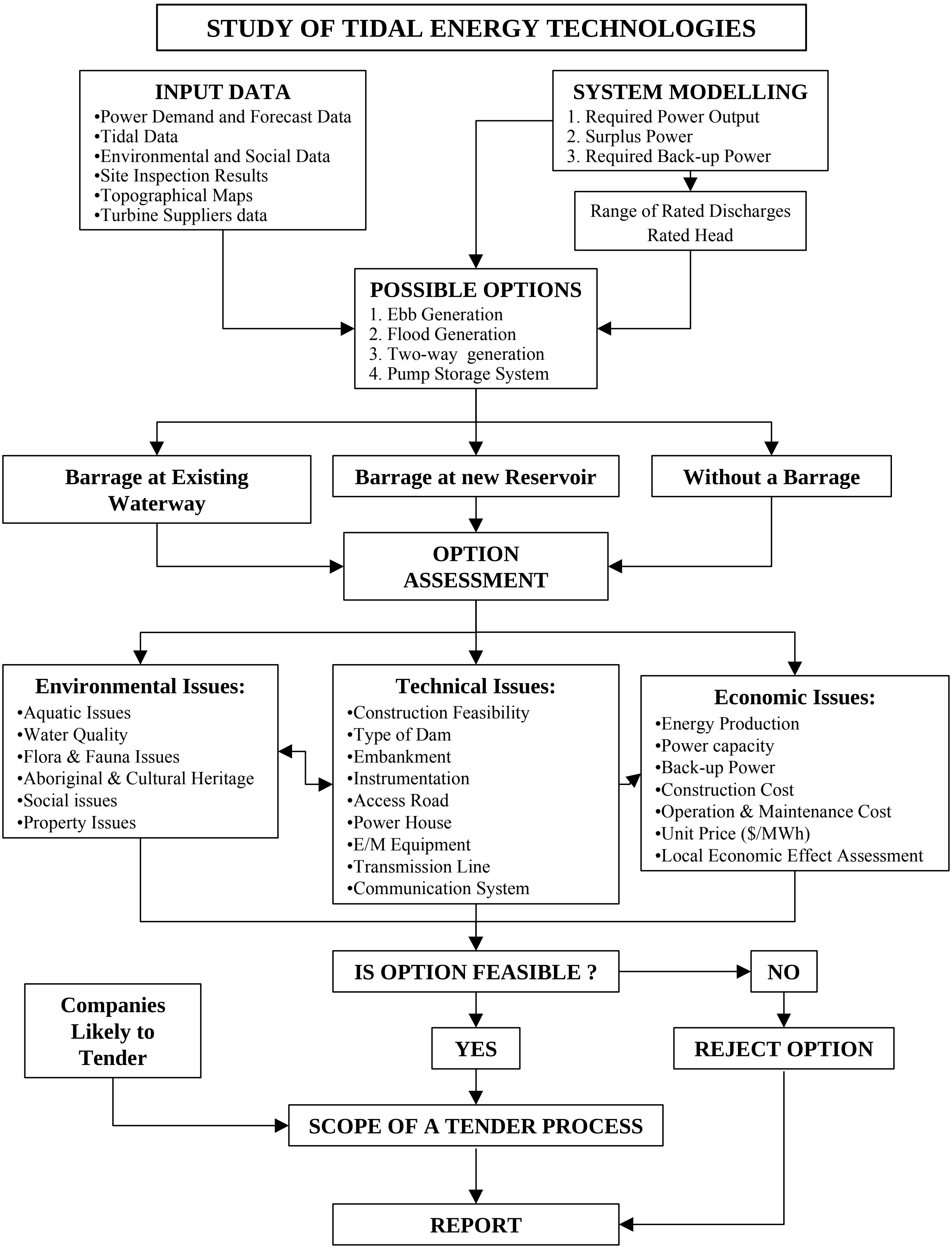

Figure 1-1 Methodology Chart

2 Tidal Energy Potential Assessment

2.1 TIDAL OPERATIONAL PATTERNS

Tidal energy is the result of the interaction of the gravitational pull of the moon and, to a lesser extent, of the sun. In general, there are two tidal cycles per day. Tidal energy is significantly different to hydropower, which derives energy from hydrological climate cycles. Tidal energy is also different to wave energy, where energy is derived from short-term wave action rather than tidal action.

There are two main classes of tidal power generation systems: tidal barrage systems and tidal current systems. Tidal barrages act in a similar way to hydropower schemes by trapping water behind a barrage across the mouth of an estuary or artificial storage and using the head difference as the tide changes to produce energy. Tidal current systems use the velocity of tidal currents to generate energy. All tidal schemes require turbines that can produce power efficiently at variable head levels. This is unlike conventional hydro, which is designed for a relatively fixed head, particularly in low head applications.

Hydro Tasmania has conducted a review of the tidal energy technologies that are currently in use, or under development, around the world. Information has been sought from documents on renewable energy, from the internet and from correspondence with technology developers worldwide. A reference list of documents, textbooks and internet sites has been included at the end of this report. Further information was requested from the tidal energy companies regarding many key issues including: costs, applicability, history of development/operating sites, O & M requirements and environmental impacts.

2.1.1 Tidal Barrage Systems

2.1.1.1 Ebb Generation

As the tide comes in, water passes through sluice gates behind a dam wall (#1), filling the basin as shown in Figure 2-1. As the tide turns, the gates are shut and the water is trapped behind a barrage (#2). After a few hours, power can be generated as the water is released through low head turbines located in the barrage wall. This continues until all the water has been released (#3), and the sluice gates are opened once more to refill the basin. This system has a similar outgoing flow direction during power generation as the ebb tide.

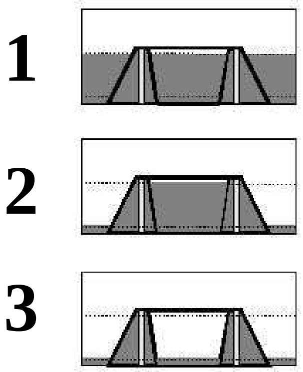

Figure 2-1 Schematic of Ebb Generation (www.tidalelectric.com)

As large volumes of water have to be passed during a fairly short time period, large numbers of turbines are required. Three large scale projects exist in the world, as well as several other experimental ones. Extensive desk studies have also been undertaken in the UK on tidal projects, but none have been implemented due to environmental impacts and very high capital costs. The largest existing projects are:

1) La Rance, France, 240 MW_p[*]
2) Annapolis Royal, Canada, 18 MW_p
3) Murmansk, Russia, 0.4 MW_p

There are a number of different turbines that can be used in an ebb generation scheme. HydroMATRIX is a technology that can also be used for ebb generation, consisting of submersible generators mounted in a gate structure. Information was received from VATECH on the Sulzer Esher Yss STRAFLO® turbines, as well as from EAML Engineering Co. Ltd. and ALSTOM on their low head hydro products.

2.1.1.2 La Rance Tidal Scheme

History of development

The only existing large-scale tidal plants are essentially ebb generation plants. La Rance (Figure 2-2) in France is the largest (240 MW_p), and also incorporates pumping and two-way generation. However, most of the energy comes from ebb generation. At La Rance, both the turbine and generator are mounted within the flow of water. Two-way generation has stopped due to mechanical problems in 1975.

Figure 2-2 La Rance Tidal Scheme (www.greenhouse.gov.au)

Current status of technology

While many proposals have been put forth for more ebb generation projects, which are technically similar to conventional low head hydro technology use at La Rance, there have been few advances in ebb generation technology. Most projects have been planned for estuaries and have not been constructed due to high environmental impacts and irregular generation patterns.

Operating characteristics

Power is generated twice a day, up to 3 hours after the ebb tides begins. Power generation occurs for 3-6 hours in each tidal cycle, giving short bursts of power which may not meet

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[*] MW_p = peak output in MW

demand, especially in an isolated system like Derby. For maximum power generation the turbines do not start to release the water until well after the sea has started to ebb, approximately 3 hours after. Otherwise, there is insufficient head difference between the water inside the barrage and the outside sea level.

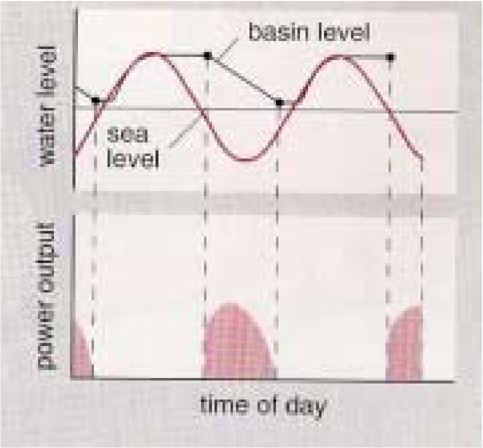


Figure 2-3 Operating characteristics of an ebb generation tidal plant (1)

<u>Deliverability</u>

Ebb generation has a better level of deliverability than most other tidal energy systems investigated. Ebb generation plants have been built in the past, although not in areas like Derby, which has much higher turbidity (16). The technology involved is similar to that required for low head hydropower plants, and mature dam design techniques may be used to assess the design of the barrage. However, the deliverability is still not "off-the-shelf" like other renewable technologies (wind, solar), and considerable time would be required to properly assess a small scale project, for system modelling, engineering design and environmental studies.

2.1.1.3 *Annapolis Royal, Canada, 18 MW*

<u>History of development</u>

At Annapolis Royal, in Nova Scotia, Canada (18 MW), Straflo turbines are used instead of in-stream "bulb" generators used at La Rance. The generator is mounted radially around the rim, with only the turbine blades in the flow of water, allowing access without having to stop the flow. The intake and the draft tube are both divided by centre piers, and the intake pier supports the upstream turbine bearing. The intake pier replaced the bulb, reducing material costs and improved rigidity and hydraulic design. The aim of this project was to highlight difficulties that could occur in much larger tidal plant at the Bay of Fundy, and in this regard, it was considered very successful.

<u>Operating characteristics</u>

Initial plant availability was over 99%. In the first year, 25% of the generation runs were interrupted for short periods due to mechanical problems, but this decreased to 4% in the following year. However, difficulties have been encountered regulating the performance of the Straflo turbine, and in using it for pumping. The Annapolis tidal plant has been operating since 1984, and environmental problems experienced include an increase in sedimentation and turbidity, a decrease in primary production of surrounding salt marshes and micro algae and an increase in phytoplankton in the head pond (16).

Figure 2-4 Annapolis Royal tidal plant (Sulzer Technical Review, 1987)

2.1.1.4 *Feasibility studies, UK*

Costs

In general, there is a very large increase in the cost of low head hydro turbines as the head drops from 5m to 2m, so very low heads may lead to increased costs. The House of Commons Select Committee on Energy, UK compared three tidal plants, and estimated the price of power as shown in Table 2-1 (1).

Project name	**Peak capacity**	**Capital cost**	**Running costs p.a.**	**Electricity price**
Severn, 17.0 TWh/yr	17 000 MW	£ 10,200,000,000	£ 86,000,000	5-6 p/kWh
Mersey, 1.4 TWh/yr	620 MW	£ 966,000,000	£ 17,600,000	6-7 p/kWh
Conwy	33 MW	£ 72,500,000	£ 600,000	8-9 p/kWh

Table 2-1 House of Commons (UK) Select Committee on Energy – Tidal Energy Cost Estimates (1991)

The feasibility study used discount rates of 6-8%, and lifespans of the projects were as high as 120 years. The private sector is more likely to use higher discount rates and lifespans of 20 years or less, resulting in higher energy costs during that period (10-14p/kWh for 15% discount rate). Estimates of small, medium and large scale tidal sites in the UK (1983) resulted in power prices ranging from 3.5p/kWh to 13.9p/kWh. The energy costs are now outdated, but this study did show that tidal energy costs were very site specific.

2.1.1.5 *Sulzer Esher Wyss STRAFLO® turbines*

Operating characteristics

The diameter of the runner at Annapolis is 7.6m, with a rated operating head of 5.5m and a maximum operating head of 7.1m. Each turbine is rated at 20 MW and 378 m3/s, with an efficiency of 89.1%. The generator has 144 poles and an efficiency of 96.5%. Straflo turbines have been used in other projects as well, with a 3m diameter 1.5 MW unit being used in Hoengg, Switzerland, and 3.7m diameter 8.4 MW units being installed in Weinzodl, Austria.

Figure 2-5 Straflo turbine from Annapolis (SULZER Technical Review, 1987)

Costs

No costs were given for the Straflo turbine.

Deliverability

The deliverability for the Straflo turbine is high, as it is commercially available.

2.1.1.6 HydroMATRIX

Operating characteristics

A technology that could be used in an ebb generation scheme has been developed by Obermeyer Machinery Corporation and VA Tech Voest MCE Corporation, and is called the HYDROMATRIX™. This is a factory assembled "grid" of submersible small propeller turbine-generator units that is installed in an existing gate slot (Figure 2-6). As it is designed to be retrofitted into existing dam and gate structures, very little additional construction is required, with no powerhouse or diversions required. The gate can still be lifted out during periods of excessive river flow. Installations can be achieved in less than 12 months. While it is not a tidal plant, it operates on a similar principle, and can be used for ebb generation.

Figure 2-6 HYDROMATRIX™ grid of submersible turbines

Existing projects

A 5 MW plant has been installed in Vienna, Austria, and another 30 MW system has been installed in an irrigation dam (Jebel Aulia) in Sudan. Over 150 MW of contracts have recently been won, indicating that the technology is economic and commercially applicable. Net heads are as low as 5.5m.

Costs

The first installation occurred at a flood control dam in Connecticut in 1988, with this scheme generating 7,000-13,000 MWh per year. The peak capacity is 3 MW, with flow averaging 7 m^3/s. The cost in 1987 was approximately US$4 million. Two modules were supplied, each with three variable pitch semi-Kaplan turbines. Each module was 4m long, 1.5m wide and 4m high.

Deliverability

Due to a large increase in demand for HYDROMATRIX™, the deliverability of the grid of turbines is very high. However, a dam or barrage structure would have to be constructed, and it is unlikely that the efficiency of many small, turbines would be greater than a series of larger low-head hydro turbines.

2.1.1.7 *EAML Engineering Co.*

Operating characteristics

Information was received on a submersible hydro turbine from EAML Engineering Co. Ltd. This company supplies mini hydro propeller turbines, with a power range of 40-700 kW. These are designed for heads of 2.5 – 20m and flows of 0.7 – 12 m^3/s.

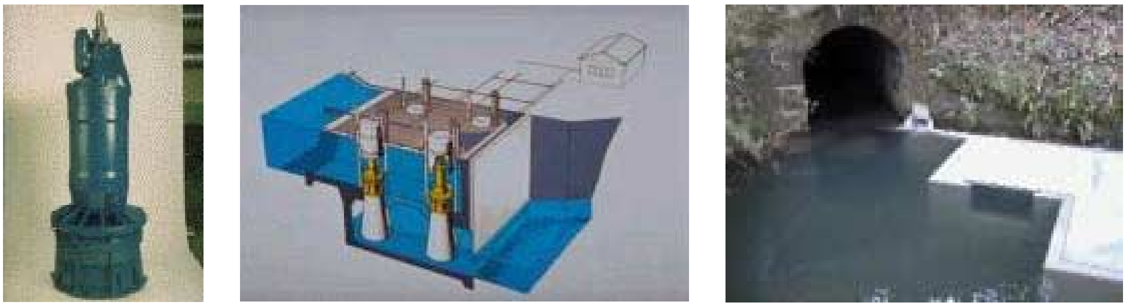


Figure 2-7 EAML submersible turbines (www.eaml.co.jp)

Existing projects

No information was received from the company on existing projects. From the pictures on the website, only mini hydro freshwater projects have been installed to date.

Costs

Being submersible, costs savings can be achieved by not building a powerhouse for the generator. No detailed costs were supplied by the manufacturer

Deliverability

The turbines are commercially available, so deliverability for the turbine is high, although it is not known if these turbines are suitable for marine environments.

2.1.1.8 ALSTOM

Operating characteristics

Information was also received from ALSTOM on their range of very low head Fronto-spiral Kaplan turbines and open pit bulb turbines. These are designed for heads of 2-12m and flows of 5-200 m^3/s, giving power outputs of 0.5-15 MW.

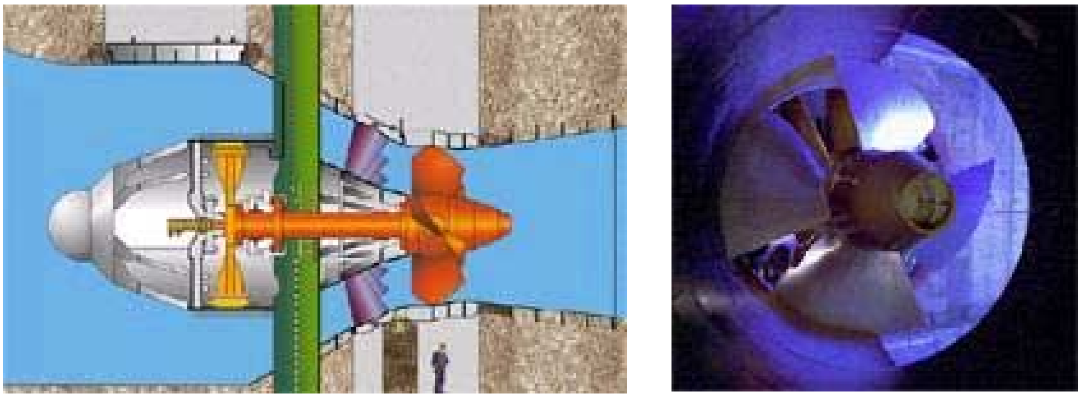


Figure 2-8 ALSTOM bulb turbine (www.alstom.com)

Existing projects

No information was received from ALSTOM on existing projects, although La Rance tidal plant is referred to on their website.

Costs

No costs were supplied by ALSTOM.

Deliverability

The turbines are commercially available, and ALSTOM has a great deal of experience in installing low head hydro systems.

2.1.1.9 Flood generation

Description

Flood generation (Figure 2-9) works by using a barrage to hold back the incoming (flood) tide. As the tide rises (comes in), a head difference is created across the barrage. After a few hours, water passes through the turbines to generate power, at a similar rate to the flow of the incoming tide. Generation continues up to high tide and ends a few hours after high tide. During generation, the water level outside the barrage is always higher than inside the barrage. Therefore, the water inside the barrage never reaches the peak high tide water level – only the water outside the barrage does. Therefore, the peak high tide reached by the water inside the barrage is substantially reduced, and remains at a fairly constant level during power generation. At low tide, the water flows back through the idle turbines. As with ebb generation, low head hydro turbines are used to generate the power.

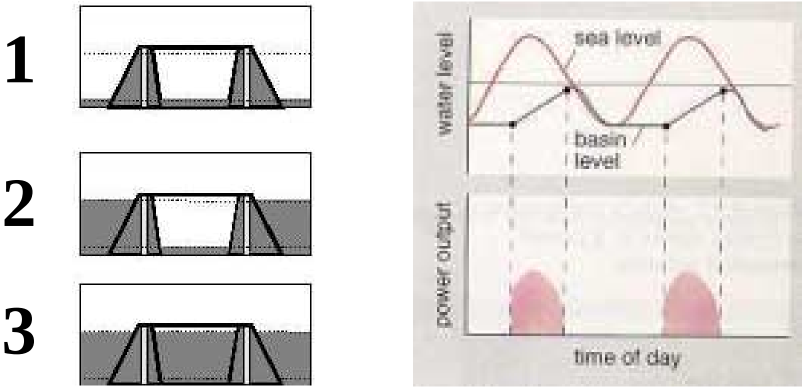


Figure 2-9 Schematic of Flood Generation (www.tidalelectric.com) and operation characteristics (1)

History of development

Flood generation is less popular than ebb generation, as mud flats would be exposed for longer periods, and no projects have been built to date using this concept. Therefore, the technology can be summarized briefly (Table 2-2).

Current status of technology	No projects exist, and no evidence of prototype design were found for flood generation
Operating characteristics	The operating characteristics would be very similar to the peaky production found with ebb generation, although obviously production would occur as the tide comes in, rather than as the tide goes out.
Costs	Costs can only be estimated as being similar to the cost of ebb generation systems
Deliverability	As there are no examples of flood generation plants, deliverability is very limited.

Table 2-2 Characteristics of flood generation

2.1.1.10 Ebb generation plus pumping at high tide

Description

This system is simply a variation on the ebb generation. During or very soon after high tide, the sluice gate are closed and the turbines are reversed in order to act as a pump, forcing more water into the basin. The pumping stops when the sea has fallen to a level where it is no longer economical to pump the required head. The result of pumping at high tide is that there is a larger volume of water and a higher head inside the barrage. This allows generation to start earlier and to continue for a longer time period. The additional water pumped into the basin is released through the turbines at a much greater head than the head during pumping, resulting in a net gain in energy.

The turbine blades are often curved for maximum efficiency in the direction of generating power and so when they are used in reverse as a pump the efficiency is significantly reduced. This must be taken into account when determining at what point should the turbines stop pumping to enable maximum energy gain. Turbines that have variable blades to improve efficiency while pumping can be used, however they are more expensive and require greater maintenance.

History of development

La Rance uses pumping during neap tides (low high tides) to top up the water level behind the barrage. This has resulted in significant gains in net production and therefore profitability, so La Rance offers one proven example that pumping at high tide can be viable.

Current status of technology

Pumping at high tide is similar to pumped hydro technology, with a wide range of marine pumps are available for this purpose. The applicability of pumping at high tide is a function of the tidal range at a particular site. No details of new prototypes or trial projects have been found during this study.

Operating characteristics

Ebb generation with pumping at high tide requires a source of power for the pumps. It is therefore similar to a conventional pumped hydro scheme, that is used to deliver peak power during periods of high load. However, this system can only deliver peak power as the tide recedes, the timing of which changes from day to day. The result is that load is added during incoming tides and peak generation occurs at low tide, and thus in a much peakier profile than straight ebb generation. This system is only suitable as a small scheme connected to a relatively large grid, or where energy storage is possible, so that these fluctuations are not important.

Costs

While there is the added cost of pumps, power costs to run them and additional maintenance, there is evidence to suggest that the additional generation can be economically viable. This is particular the case if there are different power prices at different times of the day. Off-peak pumping and on-peak generation strengthen the case for adding pumps to a tidal plant. Pumps also help maintain a more level and constant head, which leads to more efficient performance of the low-head turbines.

Deliverability

The addition of pumps to a tidal plant is highly deliverable. Marine pumps of many descriptions can be found on the market, and pumped hydro is a mature technology.

2.1.1.11 Two-way generation

Description

In a two-way generation scheme, the power is generated from both the ebb and flood tides. At high tide, the basin is full (Figure 2-10, #1). As the tide recedes, ebb generation begins (#2). Ebb generation must finish at low tide. The gates and turbines are then all closed to prepare for flood generation (#3). Flood generation takes place as the tide comes in, finishing at high tide (#4). At high tide and at the end of the flood generation cycle, the basin is once again full, and the cycle begins once more (#5).

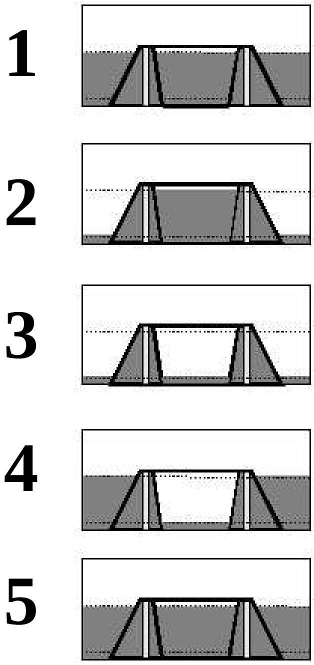


Figure 2-10 Schematic of Two-way Generation (www.tidalelectric.com)

Two way generation requires reversible pitch turbines, or pumps as turbines, which are usually more complex and expensive. Two-way generation produces less energy compared to straight ebb or flood generation, as neither the ebb or flow generation phases can continue as long as they would in a pure ebb or flood generation scheme. Each phase must be stopped short in order to prepare for the following cycle. As blade design cannot be optimised for flow in both directions, one direction will have a lower efficiency than the other, resulting in an overall lower efficiency for the system, compared to straight ebb or flood generation.

The advantage of two-way generation is that generation can occur for more hours every day, resulting in more uniform power generation. This would be very important for an isolated system such as Derby.

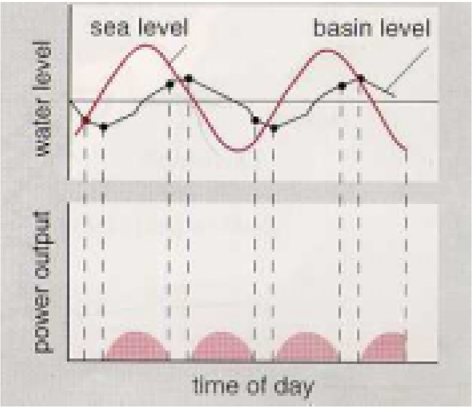


Figure 2-11 Operating characteristics of two-way generation

<u>History of development</u>

La Rance is the largest tidal plant in the world, and was based on two-way generation. La Rance has 24 two-way 10 MW pump-turbines, with a maximum generation capacity of 240 MW, annual net generation averaging 480 GWh/year (capacity factor of 28%) and availability of over 90%. The tidal range can exceed 12m, but a typical head is only 5m. Straight ebb generation would result in a higher head. Two-way generation ceased after 8 years due to mechanical problems in 1975.

During construction of the 740m long barrage, the estuary was completely closed, leading to the complete collapse of the estuarine ecosystem. As there was no baseline monitoring, it is difficult to know if the ecological recovery has been complete.

Current status of technology

No evidence has been found on significant advances in two-way generation, but this is largely a result of very few tidal projects eventuating.

Operating characteristics

Generation occurs twice as often each day, and at a lower peak than for straight ebb or flood generation.

Costs

Reversible pitch turbines are expensive, and less efficient than uni-directional turbines. Energy costs are therefore likely to be slightly higher than for ebb or flood generation, due to the lower overall efficiency, more expensive turbines and lower heads.

Deliverability

Two-way generation uses mature turbine technology and construction techniques, so deliverability is similar to flood or ebb generation. However, as only one or two two-way generation plants of MW scale have ever been built, it will still be difficult to deliver a cost-effective project.

2.1.1.12 Multiple basin systems

Description

Multiple-basin schemes involve two or three basins formed adjacent to each other, equipped with sluice gates in between them. The simplest configuration is to have the turbines in the dividing wall between basin A and basin B. Basin A is the high level basin, filled through its sluices at high tide and emptied through the turbines into basin B. Basin B is empty, so power generation can start without having to wait 3 hours for the tide to recede. The storage available in each basin generally allows the turbines to operate longer than the case of a single basin system. In some cases it is possible for the turbines to run continuously, particularly if water is pumped into Basin A from the sea at high tide, or from Basin B to the sea at low tide, and the peak output is reduced.

There are only three conceptual multi-basin developers:

1) Tidal Electric

2) UK feasibility studies

3) Derby Hydro Power / Tidal Energy Australia

The multiple basin scheme proposed by Derby Hydro Power and Tidal Energy Australia is discussed in section 2.2.

2.1.1.13 Tidal Electric

Tidal Electric's tidal generating plant is an example of a multiple basin system, consisting of three chamber enclosures (Figure 2-12). To generate maximum power, all three basins are operated as ebb generation schemes. However, one basin can be emptied at a time, giving lower power but continuous generation, as full basins are emptied into neighbouring basins. The main feature of Tidal Electric's plant is that it is designed to stand alone on the ocean floor and thus can be placed a distance from the coast. As an existing estuary is not required, the environmental impacts may be greatly reduced. This scheme can also incorporate pumping if required.

Figure 2-12 Tidal Electric multi basin system (www.tidalelectric.com)

Costs

Tidal Electric estimates a 100 MW system would cost US$1200-1500 per kW, but no projects have yet been built for commercial demonstration.

Review of correspondence

A letter was received from Tidal Electric, who indicated a long-standing interest in the tidal resource at Derby. Tidal Electric did not, however, provide detailed operational, financial or environmental information about their technology. The company is currently investigating the construction of two 30 MW and one 430 MW projects in Wales.

2.1.1.14 UK feasibility studies

Double barrage and multiple basin designs have been considered in the UK, but none have ever been implemented. Preliminary feasibility studies have been undertaken for over 100 projects, with power outputs ranging from 20 to 20,000 MW. Detailed feasibility studies have been carried out on the Loughor (8 MW), Conwy (33MW), Wyre (64 MW) and Duddon (100 MW). These studies were carried out between 1983 and 1991, but no systems have been built.

Operating characteristics

A major finding of the studies was the impact of barrages on the water level within the basin and the subsequent environmental impacts. The storage ability of multi-basin schemes allows greater peak generation during peak demand hours. This results in high water levels during periods of low demand, which are usually overnight. High water levels in the basin are important for the passage of small vessels and help prevent mud flats from being uncovered for long periods of time. In contrast, water levels in the basin of a two-way generation system would be closer to the mean sea level, resulting in a reduction in the high tide water level. This applies even more to flood generation, and is one of the reasons a flood generation scheme has never been built.

2.1.2 Tidal current systems

2.1.2.1 *Tidal fences*

Description

Tidal fences consist of a series of long blades rather than the wind-turbine type rotors, mounted within a structure that blocks and guides the flow towards the blades. The structure occupies a large proportion of the space in which they are constructed, and therefore they have similar environmental impacts to tidal barrage systems.

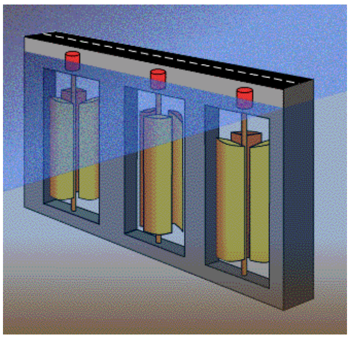


Figure 2-13 Tidal fence system (acre.murdoch.edu.au/ago/ocean/tidal)

By partially blocking the passage of water, the speed is increased, and therefore the energy extracted by the scheme is also increased, making the design feasible. If deployed in the mouth of an estuary, tidal fences cause significant environmental damage. Whilst the slowly turning turbine blades do not normally cause problems with small fish, larger sea animals would have to be steered clear of the system. Generating equipment is located above the normal water level, and can be utilized as a bridge, utility piping to an island or even as a platform for offshore wind farms. Tidal stream speeds need to exceed 2 m/s for the system to be economically feasible. Boats cannot travel through the area once the fence is constructed.

List of companies

Blue Energy is a Canadian company that aims to build large scale commercially viable tidal fence schemes, using its patented Davis Turbine design. Blue Energy is the only company actively developing a tidal fence scheme.

2.1.2.2 *Davis Turbine – Blue Energy*

History of development

The Davis Hydro turbine is an example of a tidal fence. A prototype is shown in Figure 2-14, which was tested in Canada in 1984. The 100 kW prototype turbine is the largest to have been installed to date and was connected to the Novia Scotia grid in 1984. It uses a similar principle to a hydrofoil, which creates enough power from moving water to raise a ship out of the water (at higher water velocities). The US Army Corp of Engineers has assessed proposals for two turbines, up to 100 kW in size, in 1991 and 1994, and found the technology to be technically sound. However, no prototypes have been built since 1984, although applications for funding are currently being assessed.

Current status of technology

Blue Energy's website states that it is negotiating with the Phillipines government to build a 2200 MW scheme across the Dalupiri Passage. The proposal appears to be very ambitious. The proposal is for up to 274 turbines, each generating 7-14 MW in a 4 km long structure up to 41m deep. As there are no tidal fence systems larger than 100 kW currently operating anywhere in the world, and there is very little development in the technology, compared to other renewable energy resources, Blue Energy is hoping to develop a 6 MW base – 50MW peak tidal plant.

Figure 2-14 Prototype Davis turbine (www.bluenergy.com)

Operating characteristics

The power output of a tidal fence system would provide 24 hour power to meet baseload requirements, at 50% of the peak installed capacity. The peak power periods would vary with the tidal current speeds.

Costs

Blue Energy estimates costs of US$1200-2000/kW, depending on the site conditions and scale of the project. No actual construction costs are available as no projects have been constructed. The estimates for the 15 MW_p tidal plant are $33 million (4) and $136 million for the 30 MW_p tidal plant (5).

Deliverability

Considering the lack of manufacturing expertise and pilot nature of any tidal fence project, deliverability is considered very low.

Review of correspondence

A good deal of additional information on tidal fence benefits can be found on the Blue Energy website (2). No replies were received from Blue Energy after sending a letter of interest.

Review of Davis Turbine (tidal fence)

A consultants report (6) on the Davis turbine has been reviewed for this study. The report was conducted by a consultant for the Ministry of Employment and Investment in British Columbia in 1994. The consultant found that the technology is basically sound and believed it to be environmentally benign, but further work is required to determine its financial viability, as it has not yet been proven to be cost effective. Deep, fast currents are required to best utilize the turbine, with current speeds above 2 m/s.

2.1.2.3 Tidal turbines

Description

The main competitor to tidal fences in the category of tidal current schemes is the tidal turbine. Tidal turbines were first proposed after the oil crises of the 1970s, but have only become a reality in the last five years. Tidal turbines have lower environmental effects than tidal fences, and require less material to build per unit of energy, which may lead to lower capital costs. However, the do not have the multiple uses that tidal fences can provide.

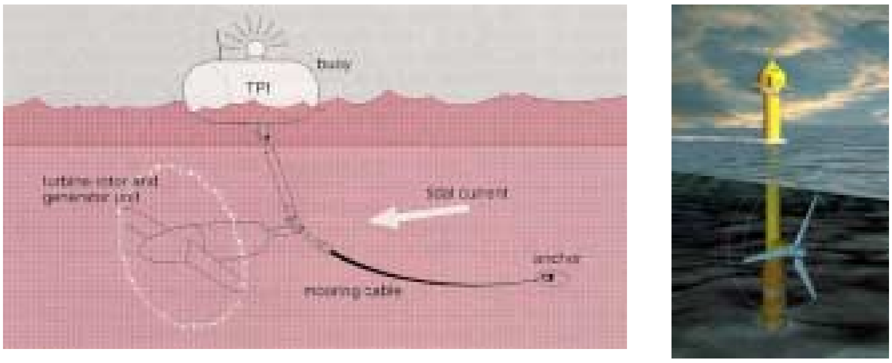


Figure 2-15 Tidal turbine options

A tidal turbine may be tethered to the seabed with a mooring cable and suspended clear of the seabed using a flotation buoy, or mounted on piles (Figure 2-15). A tidal turbine is free to orientate itself into the direction of the tidal flow, and can be rotated 90 degrees to the current during rough conditions, similar to most wind turbines. As water is more dense than air, and tidal currents are generally bi-directional rather than multi-directional, current turbines can be smaller and more densely packed than a similarly sized offshore wind farm. This reduces cable costs. Average load factors are estimated at 35-45%, about 5% higher than an average wind farm.

List of companies

There are several organizations developing marine current turbines. These include:

1) Marine Current Technologies
2) Tyson Turbine
3) GCK Technology – helical turbine
4) Northern Territory University

2.1.2.4 *Marine Current Technologies*

History of development

A 15 kW proof of concept turbine was operated on Loch Linnhe in 1994. Several other prototypes have also been developed. Marine Current Technologies is a leader in the development of the technology, and hopes to be building the world's first grid-connected system. This will be a 300 kW prototype in North Devon, UK. Funding has already been secured from the European Commission for this project.

Current status of technology

A study by the ETSU (Energy Technology Support Unit) found that the United Kingdom may obtain up to 20 percent of its total electricity by using these devices to collect energy from fast moving tidal currents that exist in channels and offshore areas. Similar resources have been noted to exist elsewhere such as in the Straits of Messina, between Sicily and mainland Italy. Commercial scale demonstration projects, however, are not likely before 2010 (10).

Figure 2-16 Artist's impression of a marine current generation system (www.itpower.co.uk)

Operating characteristics

In general, tidal turbines can provide continuous power, but well below the peak installed capacity. Capacity factors are estimated at 25-40%. The power produced is proportional to the speed of the water, with water speeds of 12 knots being required for helical turbines. Turbine efficiency is approximately 35%.

For a commercial scale scheme, Marine Current Turbines (MCT) estimate a plant factor of around 30-35% in a semi-diurnal tide with mean spring current of 2-3 m/s.

Costs

MCT desk studies are the only cost estimates available to date. The cost of energy is estimated at AU$0.10-0.20 per kWh for a large project using mass-produced turbines. The technology is only at the prototype stage, these estimates are only indicative.

Deliverability

This technology can not be delivered for a project the size of the Derby tidal scheme, as no suitably sized power generation units exist yet.

Review of correspondence

In response to our letter of interest, some information was supplied by Marine Current Technologies. MCT did not, however, provide any detailed cost or operational data as they are still conducting prototype development and testing.

Technology Status Report, Tidal Streams

A report (10) on tidal stream technology was undertaken by the Energy Technology Support Unit (ETSU) from the UK, as part of the Department of Trade and Industry's (DTI) renewable energy program. The ETSU report stated that other independent studies on the Marine Current Turbine concept have shown that predicted energy costs could be between AU$0.10-20/kWh, and that the UK possesses some of the best tidal stream resources in Europe.

The technology status was described as "…*No meaningful scale systems have yet been constructed and there is presently no realistic operating experience to verify the concepts and to demonstrate long-term performance and reliability, for us to be confident about their prospects. The most advanced tidal stream generator concept is that proposed by Marine Current Turbines Ltd.*" This report shows the current immaturity of the technology.

The ETSU report goes on to identify the primary market for tidal stream generators, the benefits of developing the technology, targets for commercial competitiveness and R&D issues. Environmental reports to date indicate "….providing schemes are deployed with some care, they should not have any significant adverse effect on the environment…". The report suggests testing and development of designs of around 300 kW in size and to evaluate the operation of these prototypes until 2004. Then in 2010, steps could be taken to commercialise the development of the most promising technologies, and commercial scale demonstrations could then begin.

The ETSU report clearly shows that tidal stream technology is not yet suitable for commercial scale operation. Please note that this report did not cover tidal barrage systems.

UK House of Commons Select Committee on Science and Technology, Seventh Report - Wave and Tidal energy – 8th May, 2001

Wave and tidal energy was reviewed by the Select Committee on Science and Technology (12). The report summarised the tidal resource available within the UK, the technical and commercial viability, environmental aspects, research, development, demonstration, international comparisons and finally recommended a strategy to pursue. In particular reference to tidal energy technologies, there was very strong support for the development of tidal stream turbines and wave energy converters, but less support for barrage schemes. A recommendation was included to establish an offshore wave and tidal test centre. Despite these encouraging signs, it is clear the technology is in its infancy and will require at least 5 years of well-funded development to reach the stage of commercial demonstration.

2.1.2.5 *Tyson Turbine*

History of development

The alternative to a pile-mounted rotor design like MCT's design is a tethered buoy system (7). With this system, the rotor is suspended from a buoy that floats on the water surface, and is also tethered from below to the sea or river bed. This system is likely to be most appropriate for small scale systems (<100 kW). An example of a tethered buoy system is the Tyson Turbine, which provides not just power but also the ability to pump water. The propeller type turbine is supported below water level by two pontoons, which also supports the pump and generator above water.

Figure 2-17 Tyson turbine, installed in the Murray River (members.ozemail.com/~tysonturbine)

Deliverability

The Tyson Turbine is a commercially available Australian product, only available up to 3 kW, and is intended for use in isolated areas (7).

2.1.2.6 GCK Technology – helical turbine

History of development

A variation to the standard turbine rotor design is a recent invention of a helical reaction turbine which has been developed by Dr Alexander Gorlov and GCK Technolgies. Only very small prototypes have been constructed to data by Dr Alexander Gorlov at Northeastern University, Boston, USA (8), although GCK Technology Inc is currently developing a power generating module suitable micro applications in remote areas. A 1 meter diameter unit can provide up to 80 kW of power. Demonstration sites can be found in Maine, USA and the Amazon River, Brazil. It is estimated that it will be at least 10 years before the idea is fully commercialized (9).

Figure 2-18 Helical turbine (picture from GCK Technology information pack)

Current status of technology

South Korea has shown interest in developing larger applications for the helical turbine. Hoewever, GCK's current target market is small, remote projects, as their largest size turbine is 80 kW.

Costs

A 1m diameter aluminium helical turbine can produce 80 kW in currents of 11 knots and 10 kW in a current of 5.5 knots, and would cost about US$3,000. The proponents believe that the cost of power generated by a helical turbine will be comparable to conventional hydropower once mass production begins, but no formal studies have been made to verify this. No information was supplied for the installed cost of a complete system.

Deliverability

80 kW helical turbines can be delivered in 4-10 weeks, depending on the quantity.

Review of correspondence

Alexander Gorlov and GCK Technology sent a detailed package of information, including publications, pictures, drawings and efficiencies.

2.1.2.7 Northern Territory University / NT Power and Water Authority

History of development

The Northern Territory's Power and Water Authority, together with the Northern Territory University, have moored a prototype turbine with four blades between Bathurst and Melville Islands, which produces a few kilowatts (13).

Figure 2-19 Prototype current turbine from NTU (ee.ntu.edu.au/ntcer/projects/tidalpower/main.html)

2.1.3 Summary and conclusions

A summary of tidal technologies is presented in Table 2-3.

Type	***Company***	***Development Status***	***Costs***	***Deliver-ability***	***Environmental impact***
Tidal current					
Turbines	Marine Current Technologies	100 kW prototype	AU$0.10-0.20/kWh (2001, P)	Low	Low
	Helical turbine, GCK Tech.	80 kW, small commercial	US$3000 for 80 kWp, turbine only	Medium	Low
	Tyson Turbine	3 kW, small commercial	N/A	Medium	Low
	Northern Territory University	10 kW, prototype	N/A	Low	Low
Fences	Davis turbine, Blue Energy	100 kW prototype	US$1200-2000/kW (2001, P)	Low	Medium
Tidal barrage					
Ebb generation	La Rance	240 MW_p, commercial	N/A	Medium	High
	Annapolis Royal	18 MW_p, commercial	N/A	High	High
	Murmansk	0.4 MW_p, commercial	N/A	High	High
	UK desk studies	20-12000 MW_p	AU$0.10-0.42/kWh (1983, P)	High	High
Flood generation	None	N/A	N/A	Low	High
Ebb + pumping	La Rance	240 MW_p, commercial	N/A	Medium	High
Two-way generation	La Rance	240 MW_p, commercial	N/A	Medium	High
Multi-basin generation	Tidal Electric	No prototype built	US$1200-1500/kW (P)	Low	Medium

Note: costs have a date included, and are either predicted costs (P) or actual constructed costs (C)

N/A – no information available

Table 2-3 Summary of tidal technologies

As a result of our study into operational tidal schemes, feasibility studies of tidal schemes and tidal energy technologies, Hydro Tasmania has made the following conclusions:

Tidal Barrage Schemes

- Only 2-3 schemes have been built worldwide with peak capacities greater than 1 MW.
- The schemes that have been built have all had significant environmental impacts on estuaries in which they are sited.
- The capital costs for tidal barrage systems are very site specific.
- The deliverability for barrage schemes is generally good as conventional low head hydro technology and dam design can be used.
- Existing barrage schemes primarily use ebb generation and a single basin design.
- Multi-basin designs, such as the double-basin design proposed by the Derby Hydro Power Company, offer important benefits by providing continuous power, which is highly valuable in an isolated grid system.
- After 35 years of operation, La Rance now generates power at 25% less cost than all the nuclear plants in France, indicating that it is a cost-effective means of generating power.

Tidal Current Schemes

- Tidal fence technologies have been tested on a small scale in the past but have so far failed to receive the support required for commercial installation.
- The cost and environmental impact of tidal fence schemes is unknown at this stage.
- Tidal current turbines are being developed by a number of different companies but are still in the small prototype stage.
- The environmental impact of tidal & marine current turbines could be the lowest of any tidal energy technology.
- The true cost of tidal current systems will probably not be known for 10 years, after the first commercial demonstration plants are installed.

2.2 SUMMARY OF RECENT TIDAL ENERGY INVESTIGATIONS

2.2.1 Derby Hydropower / Tidal Energy Australia

Tidal Energy Australia Pty Ltd and Leighton Contractors Pty Ltd (collectively referred to as "TEA", submitted a proposal to Western Power Corporation ("WPC") in response to a call for Expressions of Interest to provide power in the West Kimberley region of Western Australia. KPMG and the Snowy Mountains Engineering Corporation ("SMEC") reviewed the TEA proposal for the Australian Greenhouse Office ("AGO") in June 2000. The TEA proposal was to meet the entire load in the Kimberley region using a large twin-basin tidal scheme (see Figure 2-20), backed up by the existing diesel power stations. The diesel power stations were to supplemented by LPG over the course of the project.

Briefly the TEA proposal involved:

- The construction of a twin-basin tidal energy scheme in Doctors Creek north of Derby,
- The installation of 5 x 8MW generator sets with conventional double regulated Kaplan type turbines initially, with a 6th generator set and turbine installed at a later date to meet rising electrical demand.
- The installation of 524 km of 132 kV transmission line linking Derby to Broome and Pillara (including switching stations substations), and
- The installation of 51 km of 33 kV transmission line linking the tidal power station to Derby and Pillara to Fitzroy Crossing.

Figure 2-20 Proposed Derby double basin tidal plant (www.gannonmedia.com.au)

The contractual requirements that TEA sought from WPC were a 25 year take or pay contract at 15.5c/kWh + CPI, and minimum guaranteed load. TEA assumed a renewable energy credit (REC) price of $20/MWh initially, rising to $40/MWh by 2020, and an emission credit value of $13 - $20/MWh. The total cost for the project was approximately $350 M and TEA sought $75 M in funding from the AGO for the project. Based on these assumptions, KPMG calculated the IRR of the project to be 17.4%.

Hydro Tasmania has not undertaken a further review of the TEA proposal, rather we have relied upon the KPMG and SMEC assessment. SMEC concluded that in regard to the technical and engineering viability of the project:

> *"Subject to the issues noted, proposed design and plant are generally considered to be sound and based on proven technology. The issues requiring further attention are:*
>
> - *The operation of the tidal gates under all conditions; and*

- *The build up of sediment and the need for additional dredging."*

In regard to the environmental factors and approvals, SMEC found:

> *"No environmental impediments to the project presently exist. However, there is the potential for the project to be delayed pending finalisation of environmental requirements relating to mangroves. Further, the assumption as to the value of emission trading may be questionable."*

Therefore based on the independent review by KPMG and SMEC, the construction of a twin-basin tidal scheme at Derby is technically and environmentally feasible.

2.3 HISTORICAL TIDAL DATA

Hydro Tasmania has obtained 5 years of 5-minute tidal data recorded at the Derby Wharf, from the Coastal Data Centre. The maximum tide recorded was approximately 12m, with a minimum tide of approximately 1.5m. The maximum tidal range at the wharf is therefore 10.5m (spring tide). The minimum tidal range was approximately 4m (neap tide).

2.4 HISTORICAL CURRENT DATA

No recorded data was available relating to the strength of the tidal currents at Derby or within Doctors Creek.

2.5 RELIABILITY OF SUPPLY

As tidal energy is derived from the movements of the moon around the Earth and the Earth around the Sun, it is very predictable and reliable. The predicability and reliability of the tidal resource should result in a smooth integration between a tidal energy plant and back-up fossil fuel generation at Derby.

2.6 CONCLUSION

- Many tidal energy schemes have been investigated over the past 40 years but very few have actually been built, with very high capital cost and environmental impact the main deterrents.
- Tidal barrage systems are technically feasible, utilising conventional low head hydro turbines and dams/barrages.
- Tidal current schemes are primarily in the research and development phase with a few small prototypes being tested at present.
- **The tidal energy technology that is most appropriate for a small-medium scale (<10 MW) tidal plant at Derby is a tidal barrage scheme using conventional low-head hydro turbines.**

3 Tidal Energy Modelling

3.1 ASSUMPTIONS AND METHODOLOGY

A series of tidal system simulation models was developed to determine the relative merits of different tidal power configurations and the available generation. Evaluation was carried out utilising five-minutely simulation of a range of storage curves and tidal system capacities. At each time step the model assessed system load, available tidal power and storage.

Optimum generation was available from a system generating on both the rising and falling tide. A single pond system was assumed due to practical limitations as outlined in other sections of this report. As a single pond system was assumed, full diesel backup will be required.

The major limitations on tidal generation are posed by the storage volume and head relationships (differential in level between tidal and pond levels) and tidal characteristics of phase and amplitude. A tidal system poses additional limitations to the standard hydro system in that the available head does not increase with storage, it is determined by tidal amplitude, and the available storage and head is dictated by tidal phase.

The main factors influencing generation are pond head and flow in and out of the storage. Considering a simplified system without a bypass, flow in and out of the pond is determined by head, tide phase timing and machine characteristics. Given that a tidal system has limited storage and time dependency of head, generation for a particular installed capacity is strongly dependent on the storage curve (volume v's water level relationship) for a particular pond. Therefore, to determine the possible system outputs tidal modelling was carried out based on a series of storage curves.

For a given system generating capacity and storage curve, load met was optimised by varying:

- θ_1 and θ_3	Bypass timing. The time into a tidal cycle at which the bypass gates are opened to allow the pond level to equal that of the natural tide thus creating optimum head for generation on the following tide phase.
- θ_2 and θ_4	Machine start up lag periods. The time lag between the minimum operating head being reached and the machines starting to generate.
- Q_{Bypass}	Bypass Flow.
- N_{Machine}	The number of machines operating at a given head and time relative to the tidal phase. Varying the number of machines effectively varies the head at which the machines operate.

Figure 3-1 shows these variables in relation to tidal period, pond level and system generation. The operation of multiple generators is evident through the irregularity in the generation curves. Our system model was optimized based on maximum load met. This was achieved by regulating the number of turbines generating at a given point in time in accordance with tidal phase (time taken for tide to pass from minimum to maximum level), total tidal amplitude for a given tidal phase and head (difference in pond and sea level). This operation regime is most evident during flood generation in Figure 3-1 (tide coming in), where the stepping in of additional machines is clearly marked by a sharp increase in generation.

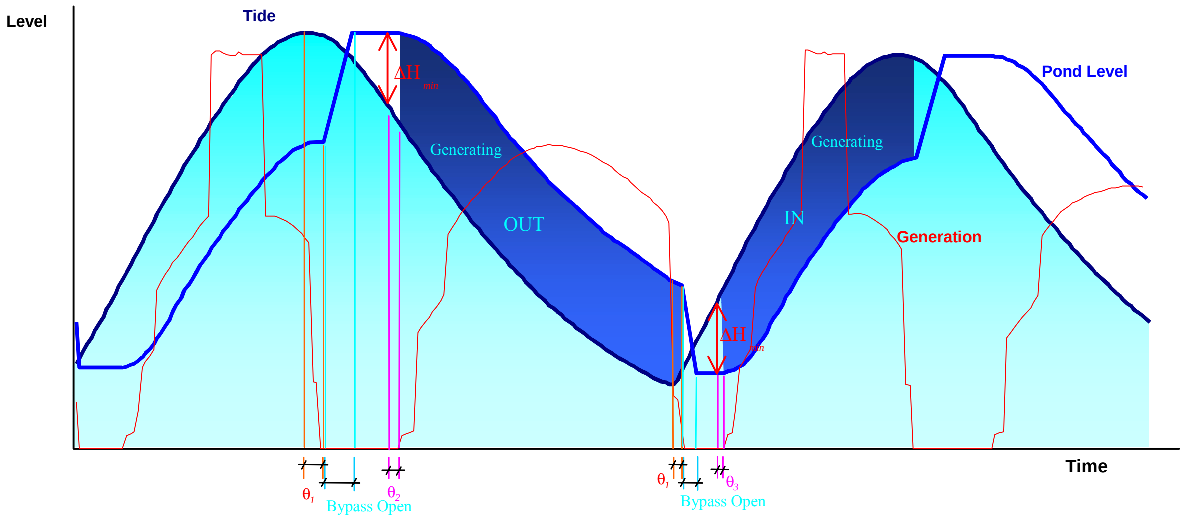


Figure 3-1 Tidal Modelling Characteristics

Model Variables:

ΔH_{min}	= set value for given machine	Minimum operating head
θ_1 and θ_3	= fn (Q_{Bypass} Tide Amplitude $Q_{\text{Power Station}}$)	Bypass timing
θ_2 and θ_4	= fn (Tide Amplitude $Q_{\text{Power Station}}$ φ_{Tide})	Machine start up lag period
Q_{Bypass}	= fn (ΔH_{bypass} $\text{Height}_{\text{bypass}}$ $\text{Width}_{\text{bypass}}$)	Bypass Flow
$Q_{\text{Power Station}}$	= fn (ΔH No. of Machines Installed Capacity)	Power Station Flow
L_{Pond}	= fn (Volume)	Pond Level
φ_{Tide}	= fn (Date)	Time taken for each tidal phase
P	= fn (ΔH No. of Machines Installed Capacity)	Power
E	= fn (P Time)	Energy
κ	= set penetration for system operation	Tidal System Penetration
V_{Pond}	= fn (Storage Available)	Pond Volume
N_{Machine}	= fn (Head)	Number of machines

Five different storage curves were used in the analyses representing storages of:

- 7.4 Mm^3 at 11.5m
- 4.35 Mm^3 at 11.5m
- 2.5 Mm^3 at 11.5m
- 1.6 Mm^3 at 11.5m Airport Creek
- 0.8 Mm^3 at 11.5m Possible constructed scenario

A range of installed capacities was analysed for each storage curve as presented in the following section of this report. The system modelling was carried out of a period of 1 year minus 8 hours and five minutes to allow for tidal phase. The modelling was based on historical load patterns for the 2000/2001 financial year and assumes 100% system penetration. The following tables summarise the findings of the system modelling.

3.1.1 Available Tidal Power

Storage	Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
7.4 Mm^3 at 11.5m	15	13%	35,700	17,300	9,400	18,300
	12.5	16%	34,500	17,300	9,400	17,300
	10	**20%**	**31,400**	**17,300**	**9,400**	**14,000**
4.35 Mm^3 at 11.5m	10	16%	17,500	13,900	12,800	3,600
	7.5	21%	17,400	13,900	12,900	3,600
	5	**32%**	**17,100**	**14,000**	**12,600**	**3,100**
	2	**53%**	**9,500**	**9,300**	**17,400**	**200**
2.5 Mm^3 at 11.5m	7.5	21%	17,400	14,300	12,300	3,000
	5	**33%**	**16,700**	**14,300**	**12,400**	**2,300**
	2	**50%**	**8,700**	**8,600**	**18,000**	**80**
1.6 Mm^3 at 11.5m	7.5	11%	7,300	7,200	19,400	100
	5	16%	7,300	7,200	19,400	100
	2	**40%**	**7,000**	**7,000**	**19,700**	**20**
0.8 Mm^3 at 11.5m	2	21%	3,600	3,600	23,000	0
	1	**40%**	**3,445**	**3,445**	**23,236**	**0**

Table 3-1 Summary of Annual System Generation by Storage

As shown in the table above increasing generation capacity for a given storage curve does not necessarily result in an increase in the percentage utilisation, nor does it necessarily generate an increase in total tidal power generation. This occurs due to the head / storage / time relationship. Increased system generation capacity results in increased flow and a consequent rise in the rate of storage volume increase or decrease. If the storage volume and therefore level increases quickly then the system head remains low. That is, a high flow in a limited storage results in low head, and a low flow results in high head. However, due to the time limitations created by tidal phase, generating at high head may not be optimal. There is a need to wait until high head limits are reached and thus there is a reduction in the time available for generation. As generation is not stored, the tidal generation system needs to be optimised to meet system load. Generation is also limited by total available head as set by the amplitude limits of the tide. The maximum tide over the period of simulation was 11.95m and the minimum tide 1.49m. Therefore, for a given storage curve increasing the system generating capacity and therefore flow in and out of the pond, can result in no increase in the total generation.

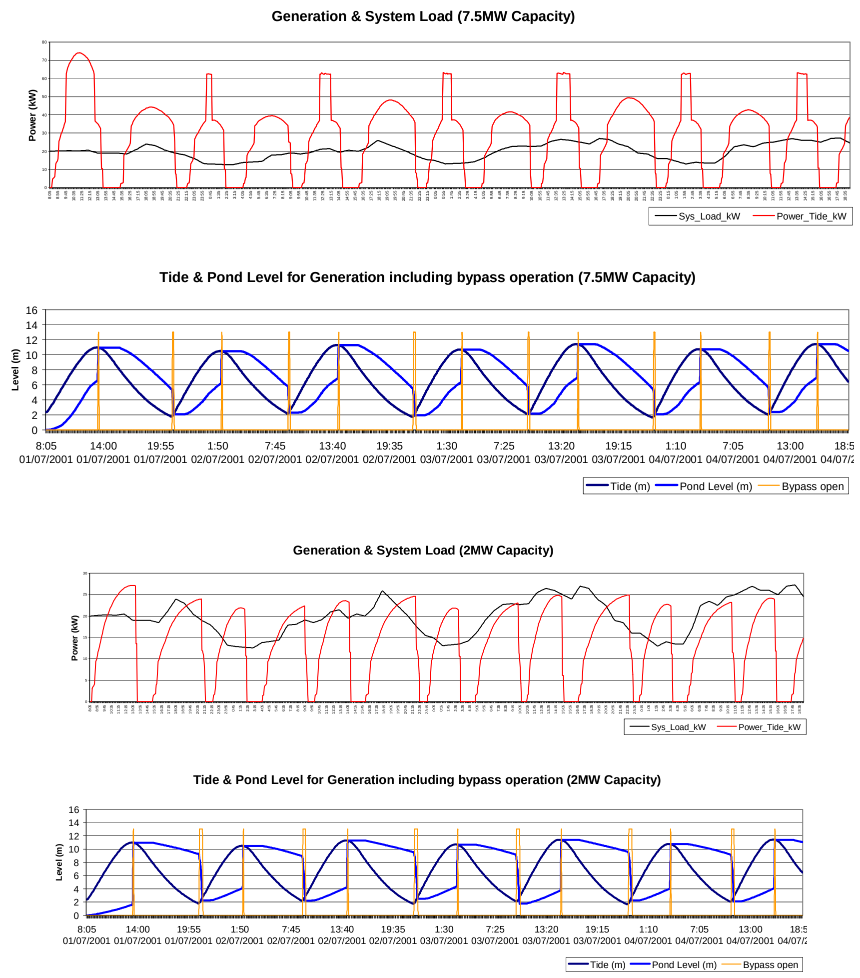


Figure 3-2 Examples of tidal generation

The total system load met by tidal generation is also limited. As shown in the figure above increasing capacity can result in higher peak generation which is above the system load and therefore lost to the system unless energy storage is developed. As fuel cell technology becomes more readily available this surplus generation could potentially be stored using hydrogen cells. However the efficiency of such systems is relatively low. Other options for utilising this power also exist such as pumped storage systems.

The following table presents the same information as Table 3-1 summarised according to installed capacity. Here we see the effect of the different storage curves on generation. The difference in the slopes of the storage curves for the 4.35 Mm^3 storage and the 7.4 Mm^3 is clearly shown in the variation of total load met.

The optimum scenarios for tidal generation in Table 3-1 and Table 3-2 are highlighted in bold blue type.

Installed Capacity (MW)	Storage at 11.5m	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)
15	7.4 Mm^3	13%	35,700	17,300
12.5	7.4 Mm^3	16%	34,500	17,300
10	**7.4 Mm^3**	**20%**	**31,400**	**17,300**
	4.35 Mm^3	16%	17,500	13,900
7.5	4.35 Mm^3	21%	17,400	13,900
	2.5 Mm^3	21%	17,400	14,300
	1.6 Mm^3	11%	7,300	7,200
5	**4.35 Mm^3**	**32%**	**17,100**	**14,000**
	2.5 Mm^3	**33%**	**16,700**	**14,300**
	1.6 Mm^3	16%	7,300	7,200
2	**4.35 Mm^3**	**53%**	**9,500**	**9,300**
	2.5 Mm^3	**50%**	**8,700**	**8,600**
	1.6 Mm^3	**40%**	**7,000**	**7,000**
	0.8 Mm^3	21%	3,600	3,600
1	**0.8 Mm^3**	**40%**	**3,445**	**3,445**

Table 3-2 Summary of Annual System Generation by Capacity

Using the optimised configurations from the initial analysis and assuming load growth of 2% per annum, the model was used to predict 10 year and 20 year figures as shown in Table 2-6.

	Load	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
Storage7.4 Mm^3 at 11.5m ***10 MW Installed capacity***	existing	20%	31,400	17,300	9,400	14,000
	10 years growth	23%	31,400	20,300	12,300	11,200
	20 years growth	26%	31,400	23,200	16,300	8,200
Storage 4.35 Mm^3 at 11.5m ***5 MW Installed Capacity***	existing	32%	17,100	14,000	12,600	3,100
	10 years growth	35%	17,100	15,200	17,400	1,900
	20 years growth	38%	17,100	16,100	23,400	1000
2 MW Installed Capacity	existing	53%	9,500	9,300	17,400	200
	10 years growth	54%	9,500	9,400	23,200	100
	20 years growth	54%	9,500	9,400	30,000	0
Storage 2.5 Mm^3 at 11.5m ***5 MW Installed Capacity***	existing	33%	16,700	14,300	12,400	3,300
	10 years growth	35%	16,700	15,400	17,200	1,300
	20 years growth	37%	16,700	16,000	23,500	600
2 MW Installed Capacity	existing	50%	8,700	8,600	18,000	80
	10 years growth	50%	8,700	8,700	23,900	0
	20 years growth	50%	8,700	8,700	30,800	0
Storage 1.6 Mm^3 at 11.5m ***2 MW Installed Capacity***	existing	40%	7,000	7,000	19,700	20
	10 years growth	40%	7,000	7,000	25,600	0
	20 years growth	40%	7,000	7,000	32,500	
Storage 0.8 Mm^3 at 11.5m ***1 MW Installed Capacity***	existing	40%	3,445	3,445	23,236	0
	10 years growth	40%	3,445	3,445	29,155	0
	20 years growth	40%	3,445	3,445	36,055	0

Table 3-3 Summary of System Data with Load Growth

As shown in Table 3-3 extrapolation of the system load indicates that higher utilisation rates can be achieved with higher system demand. This occurs in systems with large capacities where the generation is not maximised for the existing load. These figures are further discussed in the economic analysis section of this report.

The following section of this report presents detailed information for each of the storage curves analysed.

3.1.2 System Load

The historical system load figures used for the tidal analysis were derived from Western Power's *Power Station Log Sheets* for the period between July 2000 and July 2001. The load pattern varied in magnitude from a minimum load of 460kW to a maximum load of 5260kW, with an average system load of 3050kW. To model load growth a growth rate of 2% per annum was assumed to give a ten and twenty year projected load. Figure 3-3 shows an example of an average load pattern for two days in July.

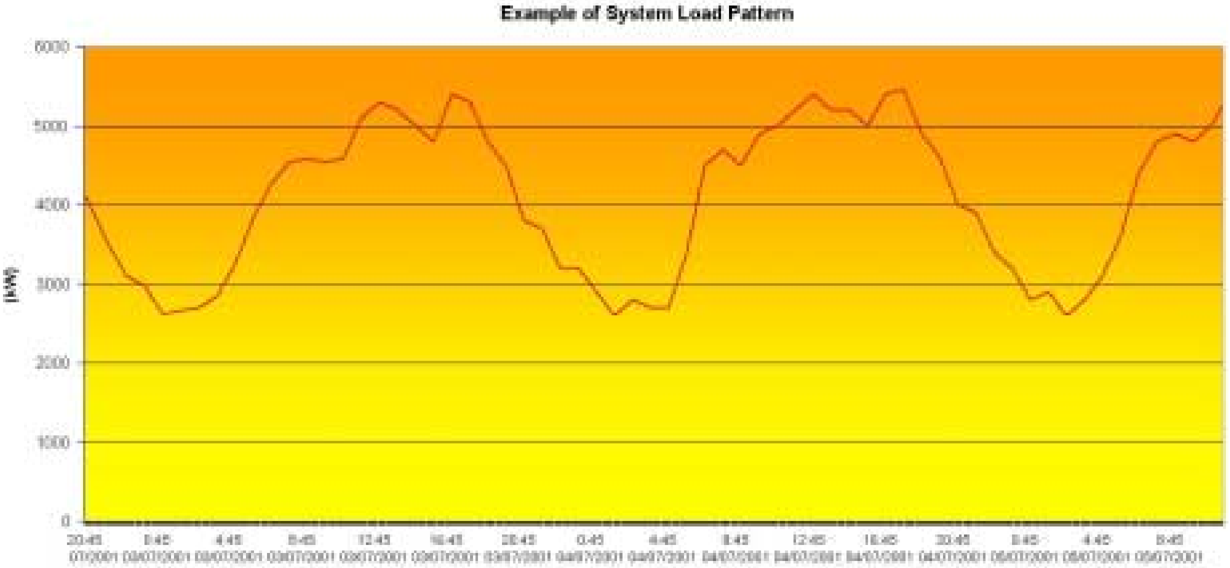


Figure 3-3 System Load Pattern

The average load pattern varied significantly according to day of week and season. Figure 3-4 shows the seasonal variation in the load pattern for Friday. The peaks in the summer months are consistent with air-conditioner loads.

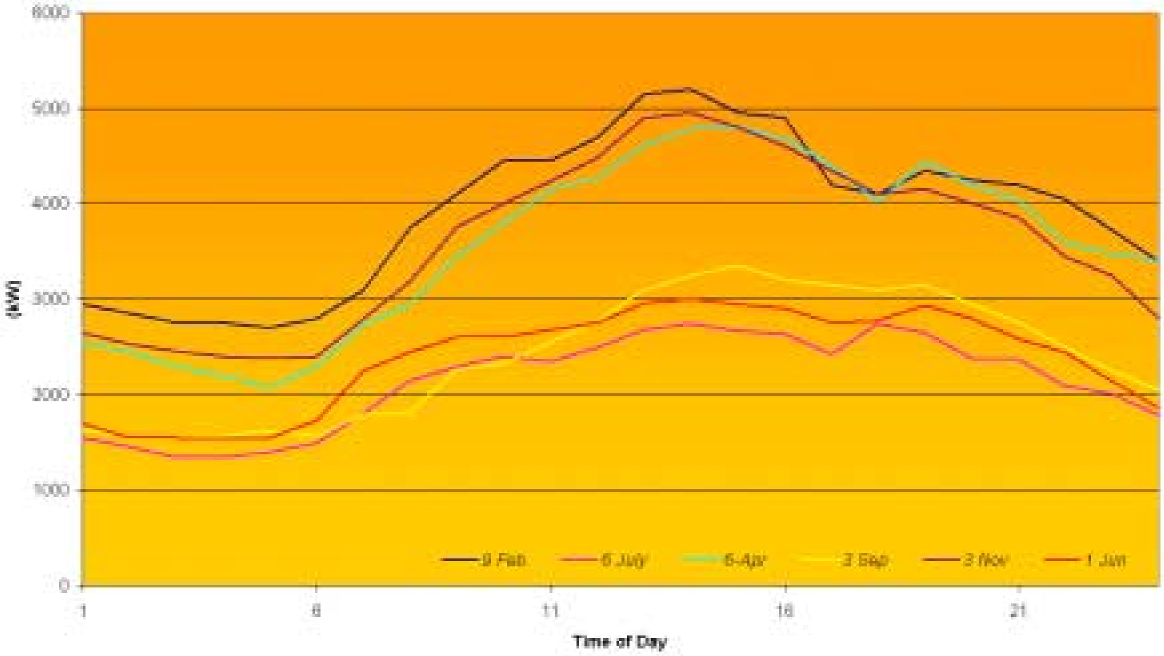


Figure 3-4 Variation of load pattern throughout the 2000/2001 calendar year

3.1.3 Power and Energy Output

3.1.3.1 Storage 7.4 Mm^3 at 11.5m

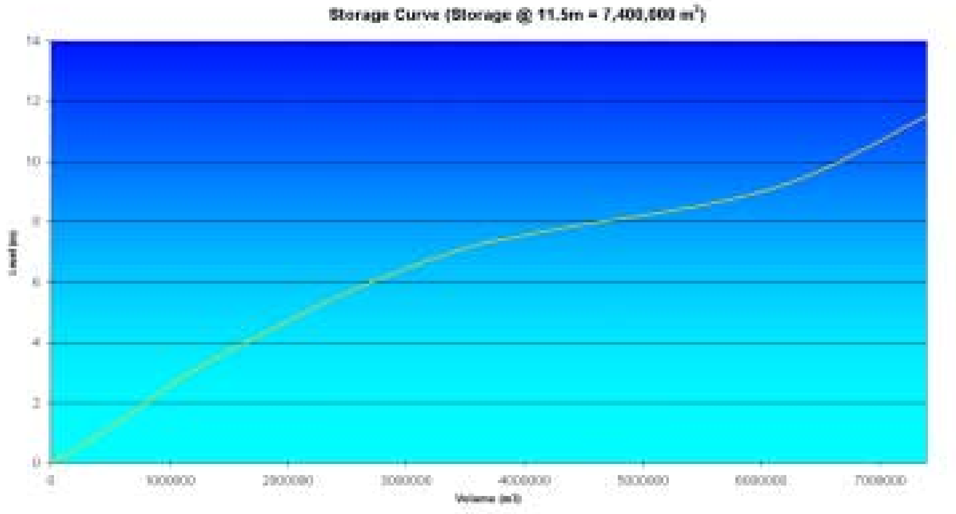


Figure 3-5 Storage Curve for 7.4 Mm^3 Storage

Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
10	20%	31,300	17,300	9,400	14,000
12.5	16%	34,500	17,300	9,400	17,300
15	13%	35,700	17,300	9,400	18,300

Table 3-4 Modelled System Characteristics for 7.4 Mm^3 Storage

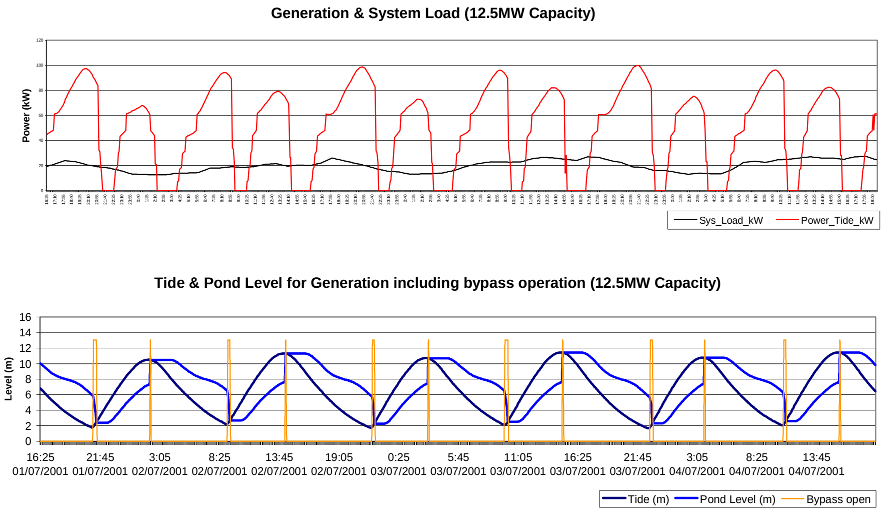


Figure 3-6 System Modelling for 12.5MW Installed Capacity

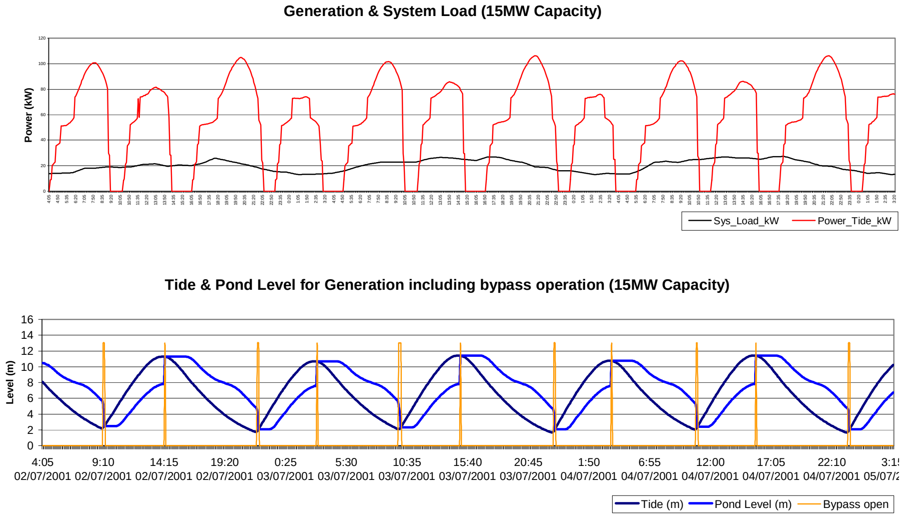


Figure 3-7 System Modelling for 15MW Installed Capacity

3.1.3.2 Storage 4.35 Mm^3 at 11.5m

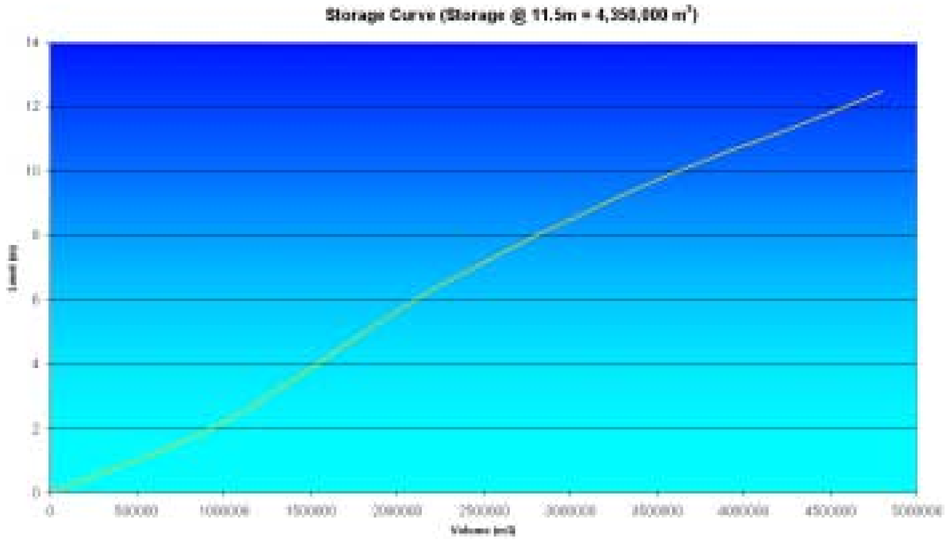


Figure 3-8 Storage Curve for 4.35 Mm^3 Storage

Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
2	53%	9,500	9,300	17,400	200
5	32%	17,100	14,000	12,600	3,100
7.5	21%	17,400	13,900	12,900	3,600
10	16%	17,500	13,900	12,800	3,600

Table 3-5 Modelled System Characteristics for 4.35 Mm^3 Storage

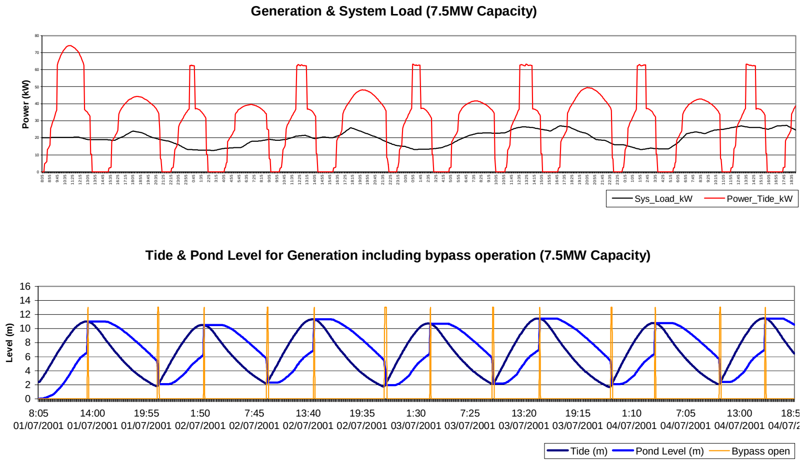


Figure 3-9 System Modelling for 7.5MW Installed Capacity

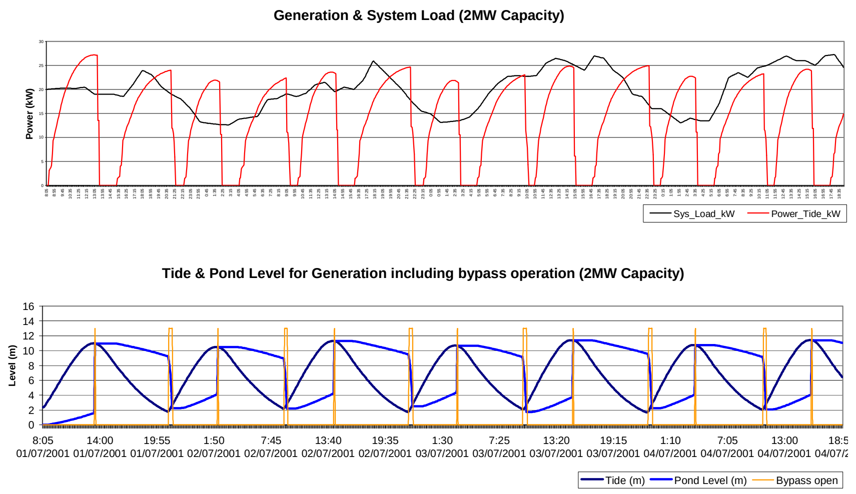


Figure 3-10 System Modelling for 2MW Installed Capacity

3.1.3.3 Storage 2.5 Mm^3 at 11.5m

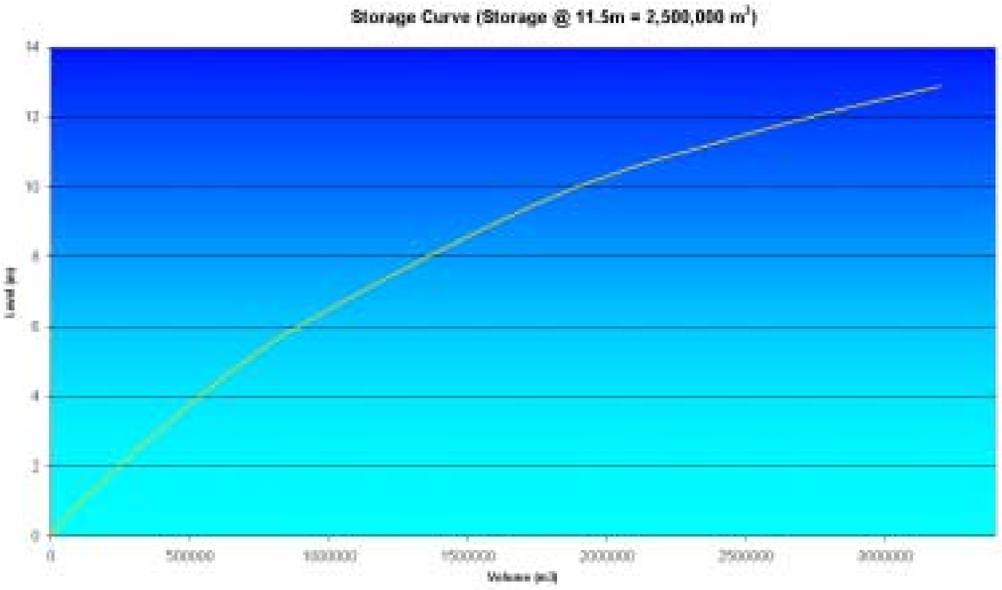
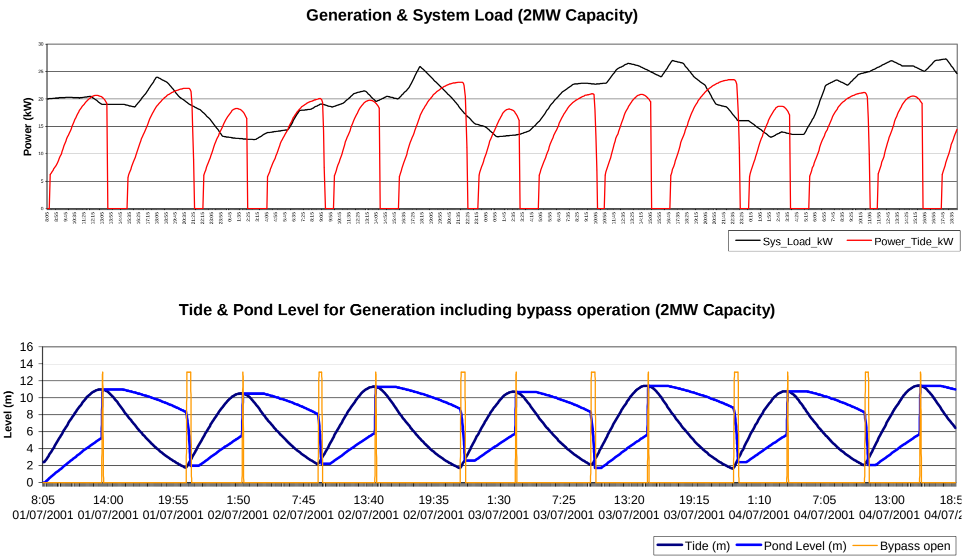


Figure 3-11 Storage Curve for 2.5 Mm^3 Storage

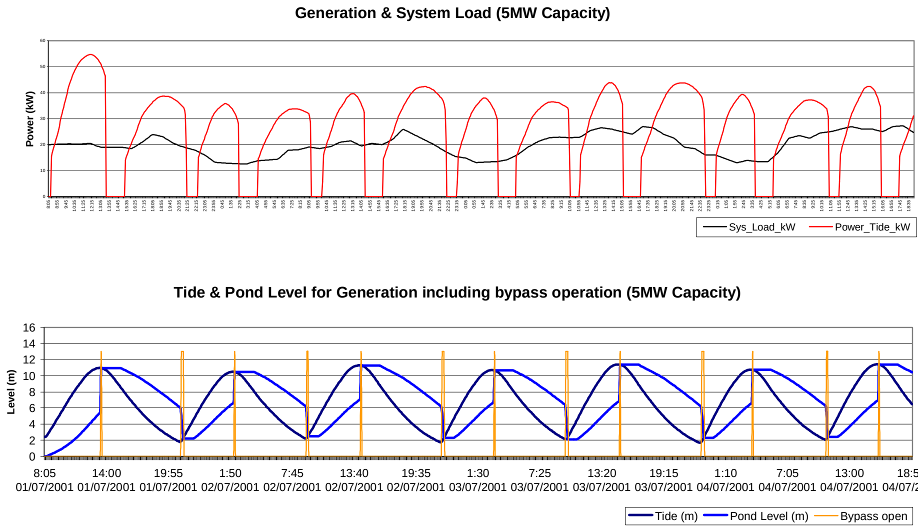
Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
2	50%	8,700	8,600	18,000	80
5	33%	16,700	14,300	12,400	3,300
7.5	21%	17,400	14,300	12,300	3,000

Table 3-6 Modelled System Characteristics for 2.5 Mm^3 Storage


Generation & System Load (2MW Capacity)

Tide & Pond Level for Generation including bypass operation (2MW Capacity)

Figure 3-12 System Modelling for 2MW Installed Capacity


Generation & System Load (5MW Capacity)

Tide & Pond Level for Generation including bypass operation (5MW Capacity)

Figure 3-13 System Modelling for 5MW Installed Capacity

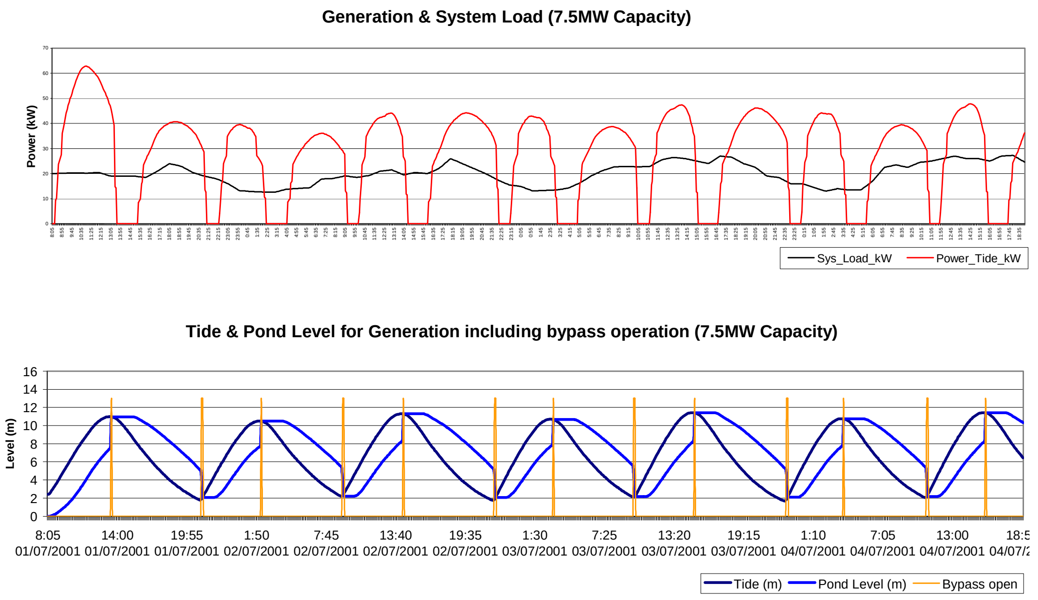


Figure 3-14 System Modelling for 7.5MW Installed Capacity

3.1.3.4 Storage 1.6 Mm^3 at 11.5m

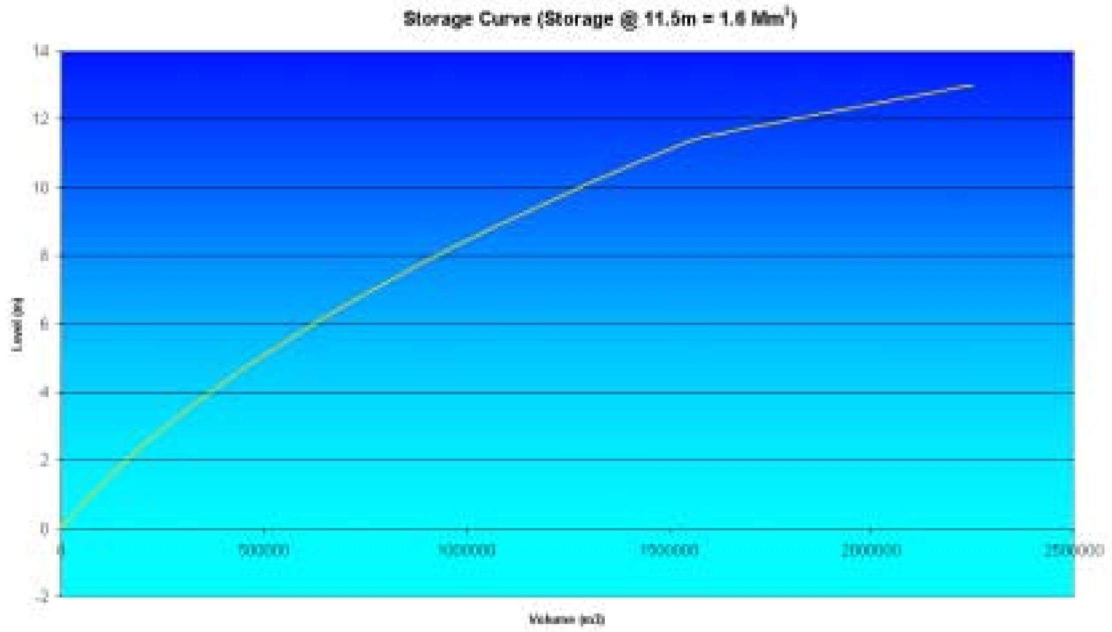


Figure 3-15 Storage Curve for 1.6 Mm^3 Storage

Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
2	40%	7,000	7,000	19,700	20
5	33%	7,300	7,200	19,400	100
7.5	21%	7,300	7,200	19,400	100

Table 3-7 Modelled System Characteristics for 1.6 Mm^3 Storage

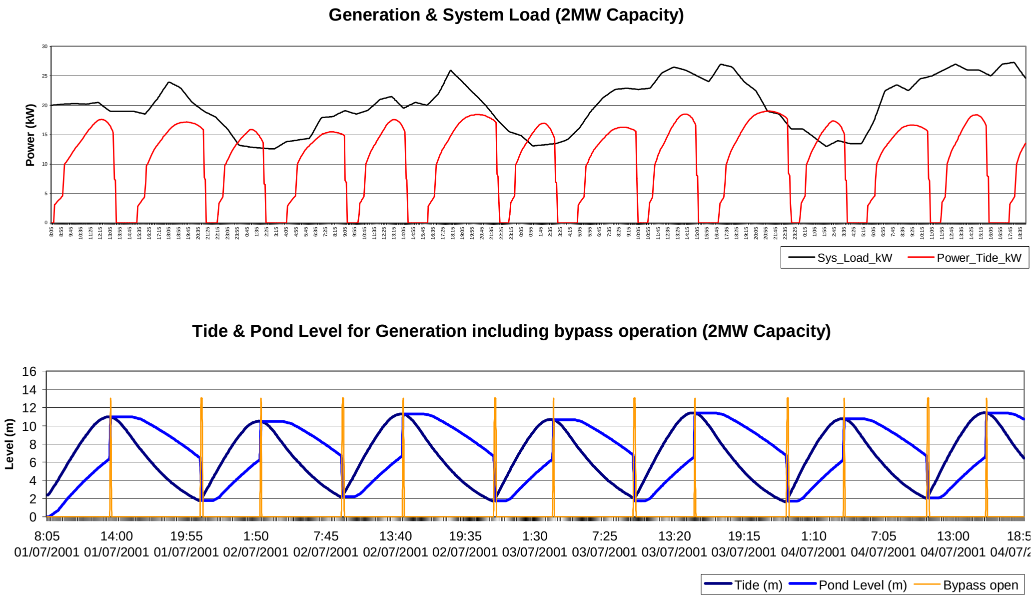


Figure 3-16 System Modelling for 2MW Installed Capacity

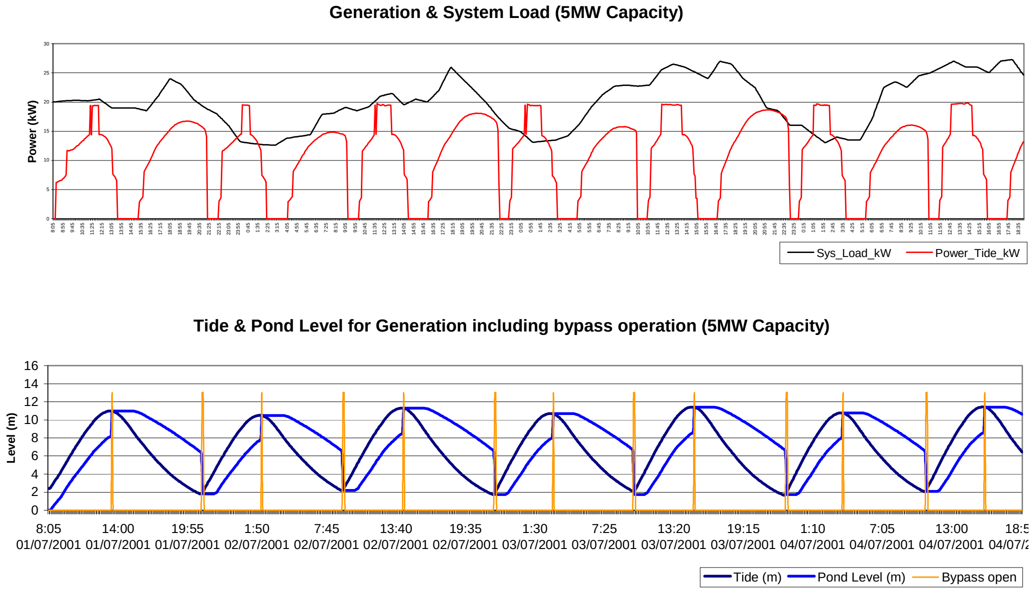


Figure 3-17 System Modelling for 5MW Installed Capacity

3.1.3.5 Storage 0.8 Mm^3 at 11.5m

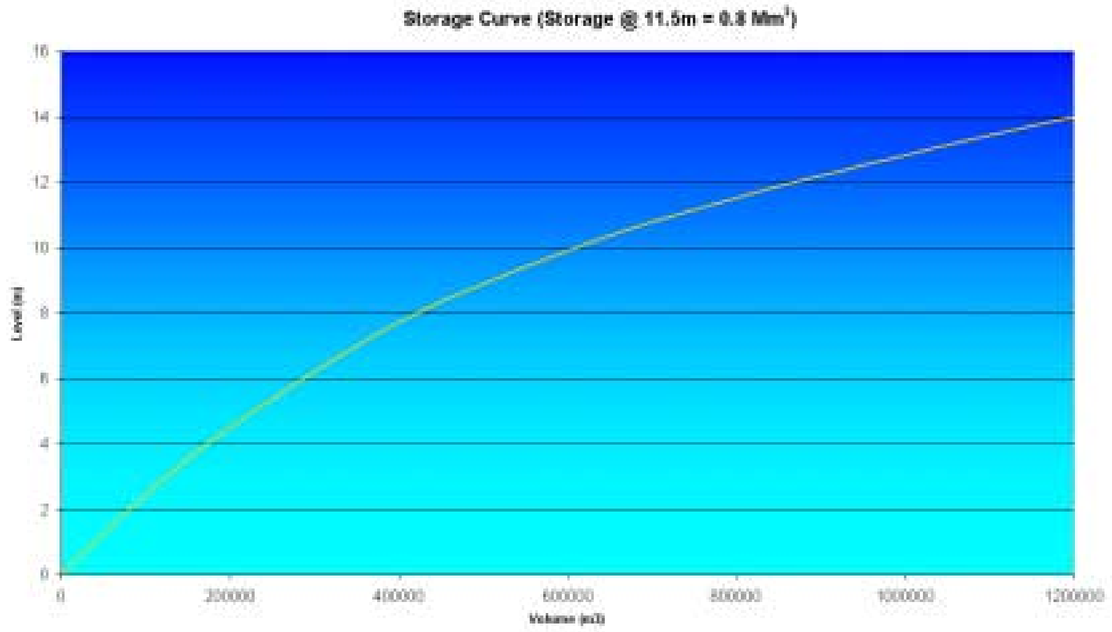


Figure 3-18 Storage Curve for 0.8 Mm^3 Storage

Installed Capacity (MW)	% Utilisation	Total Generation (MWh)	Total Load Met (MWh)	Total Load Not Met (MWh)	Total Surplus Generation (MWh)
1	40%	3,445	3,445	23,236	0
2	21%	3,600	3,600	23,000	0

Table 3-8 Modelled System Characteristics for 0.8 Mm^3 Storage

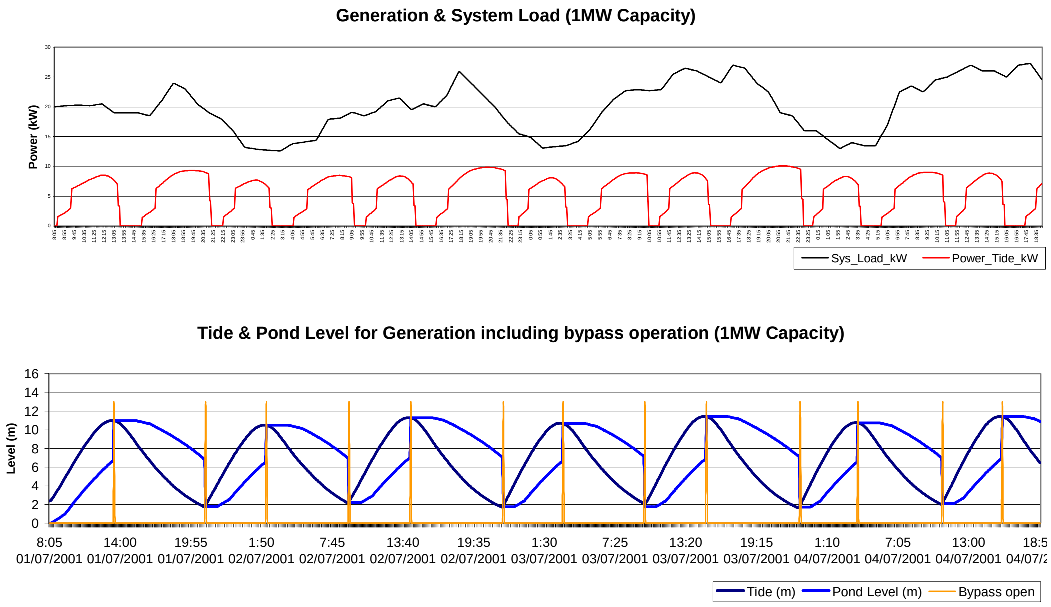


Figure 3-19 System Modelling for 1 MW Installed Capacity

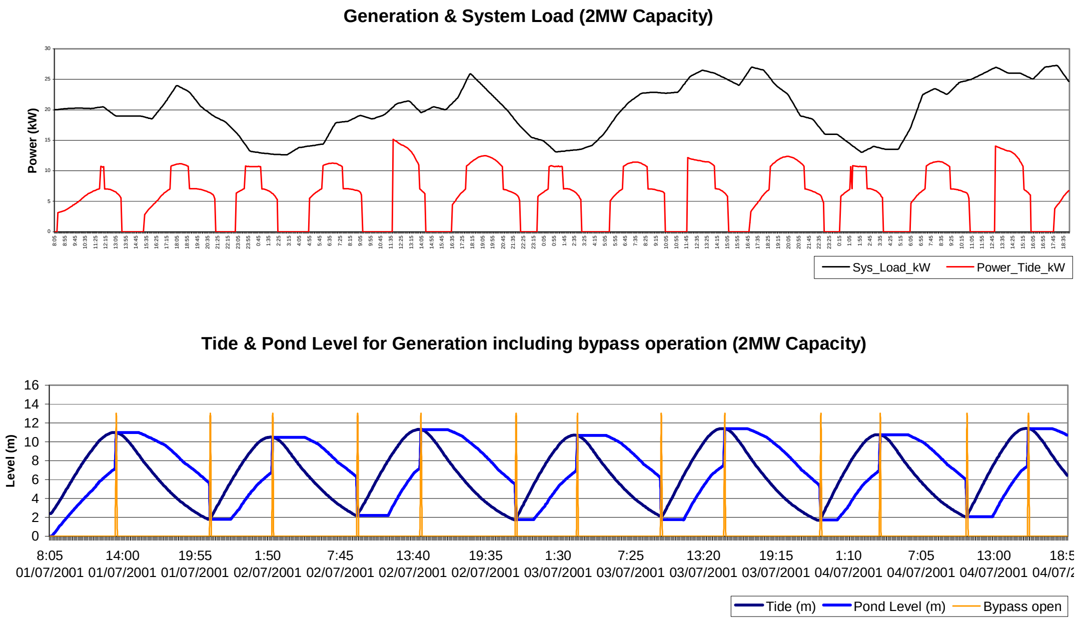


Figure 3-20 System Modelling for 2MW Installed Capacity

3.1.4 Required Back-up Power

As a single pond system was assumed, full diesel backup will be required to meet the time gap where no tidal power can be generated at the peek and trough of the tide. Figure 3-21 shows the gap in tidal power generation which will be met through diesel generation.

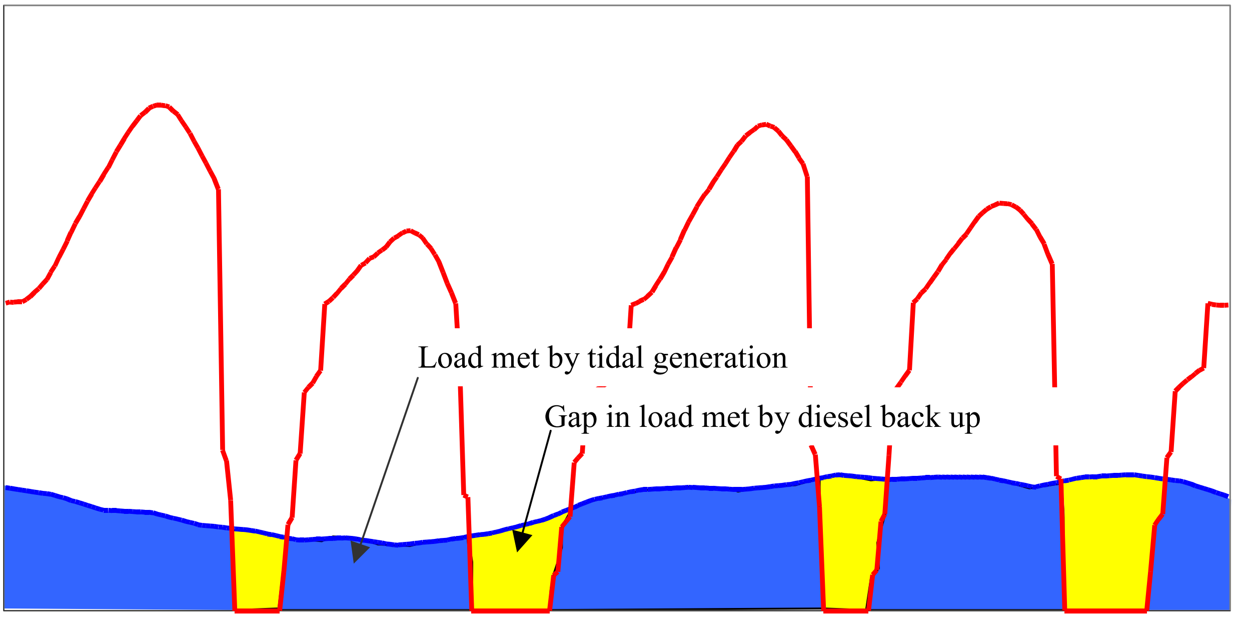


Figure 3-21 Back – Up Power Requirements

4 Potential Constraints for Development

4.1 GEOLOGY AND FOUNDATION

4.1.1 Introduction

Ground conditions pose a challenge for tidal power stations, especially those that require the construction of a barrage. The following is an outline of the anticipated geotechnical issues associated with the construction of these developments in the areas close to Derby.

4.1.2 Regional Geology

Reference to published geological map for the Derby region (Published by the Bureau of Mineral Resources, Geology and Geophysics, Dept. of National Development, in conjunction with the Geological Survey of Western Australia, scale1:250 000) indicate that the coastal areas close to Derby are underlain by superficial layers of Quaternary tidal flat and mangrove swamp deposits comprising silty clay, black organic clay, with minor salt. The publication indicates that the stratum has a thickness in the order of 10 metres.

4.1.3 Geological Implications for Tidal Scheme Construction

4.1.3.1 Tidal Barrage Development

The type of construction to facilitate a coastal site for power development could fall into one of two distinct categories:

1) On-shore Development

For this type of development a physical barrier will have to be constructed encompassing gates to control the passage and release of seawater between high and low tide periods. An embankment-like structure could be designed to act as a two-sided impoundment. Loss of storage due to leakage would not be of a major economic significance as the impounding and the release of storage will take place twice a day. The major issues to consider as far as the geotechnical constraints are concerned would be:

- Channel(s) long-term slope stability.

  This applies to the existing channel slopes as well as the modified (cut or supported by filling. Side slopes could initially be assumed as 1 in 3 to 1 in 2.5.

- Excavation slope stability and dewatering.

  For example excavations needed to construct the powerhouse and the concrete structure for the gates. Side slopes could initially be assumed as 1 in 3 to 1 in 2.5.

- Loose/soft foundation deposits with the associated bearing capacity/settlement/stability issues (for gravity structures as well as levee type structure).

- Upstream and toe superficial erosion.

  This relates to the areas upstream and downstream of the gates, and the power turbines.

- Foundation uplift and internal erosion at the toe.

  This affects all structures with permeable foundations.

- Suitable materials for embankment fill and armour.

Hard sandstone is reported to be available at Point Torment. The main impact of the wet weather in summer would be on excavations and embankment works, specifically with fine-grained soils.

- Excavation waste: Some of the excavation waste could be incorporated in the construction of the levees and transformer platforms.

A levee type structure is considered flexible and tolerates less favourable ground conditions, and provided that suitable materials are within reasonable proximity to the site, then construction of a levee could be cost-effective. The armour material will need to be well chosen to ensure the desired quality for the job. Compaction equipment will be needed for levee construction.

Gravity structures designed to rely on their weight to overcome overturning moments need competent ground conditions, while lighter structures may require piling to competent sub-strata. Toe protection against scour and erosion is important.

Sheet-pile type structure will require anchoring/tiebacks with the increase in height, and also require adequate embedment. Toe protection against scour and erosion is important.

Artificial inland basins carry the merits of requiring relatively economic excavations and less breakwater costs, and having a potential for expansion to meet future demand. Some of the negative aspects are the vulnerability for flooding or sedimentation from upland sources, and silting. Construction of an artificial pond may likely require floor and sides sealing if located in sandy areas, and this adds on costs. Scouring in the vicinity of the power turbines should be properly addressed.

2) Off-shore Development

Construction would take place in an off-shore location without the need to construct a physical barrier. The major issues to consider would be the construction using barges, and anchoring the structures into competent seabed strata. Construction costs are relatively high, with the near shore construction requiring extensive breakwater material.

4.2 ENVIRONMENTAL ISSUES

4.2.1 Background and Environmental Setting

Although several technologies exist that could potentially be applied in the Derby area to harness tidal energy, the technical analysis of civil engineering constraints in the area have shown that only two main strategies are likely to have any promise; barrages across tidal creeks and the use of an artificial tidal storage. The discussion of potential environmental considerations will therefore be focussed primarily on these technologies.

The Tidal Energy Australia (TEA) proposal for a double basin barrage system at the mouth of Doctors Creek and the EPA's assessment of the CER (HGM 1997) documentation provides a comprehensive baseline for the discussion of the potential environmental issues associated with barrage systems in the tidal creek environments areas close to Derby. These documents are particularly relevant to the options that have been identified for West Doctors Creek discussed later in this document.

The environment in the immediate Derby region is characterised by macro-tidal estuarine habitats dominated by soft sediments that are colonised by mangrove, samphire and other salt marsh communities. The tidal range of over 11m is a significant factor in determining the form and distribution of these communities. Further north, the extensive mud flats give way to rocky outcrops, headlands and a multitude of small islands comprising the Buccaneer Archipelago. A more detailed description of the area along with specific comments on environmental constraints pertaining to these sites is given in section 4.2.11.

Climatically, the area is dominated by ‘wet’ and ‘dry’ monsoonal seasons, with the annual average rainfall of 622 mm, the majority of which (86%) falls during the months December to March.

Most environmental studies dealing with the effects of, and mitigation requirements necessary, for tidal energy schemes have been undertaken in temperate regions. Several environmental issues require consideration if all environmental components of any tidal power generation proposals are to be considered feasible. These issues are outlined below, with particular emphasis on the Derby region.

4.2.2 Sedimentation

Issues of sedimentation are likely to comprise the largest potential developmental constraint. King Sound is currently undergoing net sedimentation on a geological time scale (HGM 1997) primarily due to the large catchment associated with the Fitzroy River. In addition, pastoral plains within the region have been made vulnerable to erosion due to overstocking of introduced livestock. It is believed that due to the extensive size of King Sound and the distance from its entrance to the Fitzroy River (~100km) most sediment currently remains within the Sound (HGM 1997). Aerial photographs show that the region has undergone significant erosion and deposition over the last 30 years (HGM 1997).

There is some uncertainty about the sediment concentrations in the water in the Derby area. Figures range from 363 mg/L, a figure given in the Consultative Environmental Report (CER), up to 5500 mg/L, which was found by Analytical Reference Laboratory (WA) Pty Ltd. The sediment concentration will have an effect on the rate of siltation in the area of the development and different areas within King Sound will have different concentrations. It is necessary to understand how sediment will build up around the development, as dredging operations will need to be developed to maintain optimum flow through the barrage.

The mobility of sediments in the region, particularly at the head of King Sound, poses engineering, operational and environmental constraints on any development. In this area, the sediment inputs from the Fitzroy River are at their greatest and the extensive shoals are exposed to tidal, river flow and wave action. The shoals are composed primarily of fine sand and silt and are highly mobile.

Sedimentation poses an environmental risk due to the potential for burial of benthic ecosystems, alteration of tidal current patterns, and the likely necessity for dredging in order to maintain the viability of any tidal power plant. Of these issues, the most significant is the likely need for dredging, the associated geomorphic instability of the surrounding sediments and the environmental issues at the dredge spoil disposal area. For the Doctors Creek barrage proposal (HGM 1997) it was proposed that a small dredge be operated on a permanent basis in the ‘low basin’ in order to offset the anticipated sedimentation. There was minimal discussion of the likely spoil disposal sites, although the most likely and straight forward would be disposal to the areas immediately downstream of the barrage. Sediments disposed of in this manner would be redistributed by the tidal currents in the area and would form part of the large and highly dynamic sediment store within King Sound. Sedimentation would be expected downstream of any creek barrage as noted in the CER (HGM 1997) due to the containment of currents near sluiceways and turbines and subsequent low velocities in other areas. It would be expected that channels would remain in areas corresponding with such openings to allow tidal intrusion to the barrage site, although some lessening of tidal prism would be a certainty.

Amelioration measures proposed by the CER (HGM 1997) to overcome issues arising from sedimentation included occasional sluicing (ie. High volume releases) as well as permanent deployment of a small river dredge. The sluicing would involve periodic flushes that would lead to re-establishment of the downstream channels and short-term shifts in sedimentation patterns near the barrage. Releases of this nature effectively lead to a loss of generation potential proportional to the volume of water released.

The single greatest potential uncertainty for any proposal at present is a lack of qualitative and quantitative sedimentation data. Estimates of rates of sedimentation and associated ecological effects and mitigatory measures have been based on limited data. Biological effects on erosional rates in the region are also poorly understood. Daborn (2001) states that it is not possible to predict the consequences of a change in current velocity associated with a tidal power scheme based on the present lack of information on sediment concentrations in the region. The CER (HGM 1998) states that the Doctors Creek system (and most likely all other systems under consideration) is turbid, stating a range of figures based on data captured on ebb and flood tides during July 1997. According to Daborn (2001) factors not considered would be important considerations in predicting current velocity. These include seasonal variation on ebb and flood tides, wave and turbulence conditions, grain size, organic content, sediment mineralogy or salinity variations. Daborn (2001) expressed concern that these factors can produce orders of magnitude variations in suspended sediment concentrations.

The lack of comprehensive data could result in significant variations to predicted sediment patterns expressed in the CER (HGM 1998), not only for the Doctors Creek proposal, but also for any proposal within the region. Significant variations in sediment loads could have significant impact on tidal scheme infrastructure (increased dredging requirements, infrastructure damage, erosion adjacent to key infrastructure components etc.), power generation and ecological processes (increased sediment deposition and resuspension of sediments, sediment deposition on a large regional scale, etc.). These impacts could occur at a local scale and potentially on a much wider scale.

Dredge spoil disposal permits would likely be required under the *Environment Protection (Sea Dumping) Act 1981* and the *Environment Protection (Sea Dumping) Amendment Act 1986.* Three sites mooted to date as potential areas of disposal include within the deeper reaches of a barrage basin, into King Sound and on to tidal flats. A paucity of data prevents informed predictions on the consequences of these forms of disposal, but it is likely that smothering of substrate and potentially faunal habitat could occur, particularly on mud flats or within King Sound. In addition, sediment plumes would occur in King Sound and the resulting consequences of these plumes are unknown. Further study is required for specific proposals to establish if spoil disposal could be a constraining factor.

Stability of sediment flats has been raised as an issue with regard to engineering structures with the TEA proposal. From an environmental standpoint, increased erosion of sandflats would lead to increased basin sedimentation, potential loss of further mangroves and reduction in water quality.

It is likely that a detailed monitoring program would need to be implemented for any tidal power development to document changes in geomorphological processes and to establish long-term trends in sedimentation and erosion in response to the development.

4.2.3 Water Quality

A number of potential water quality issues could arise from any tidal generation system implemented. Important considerations for proposals likely to impact on mangroves areas are organic debris from inundated mangroves, reduction in tidal and current movements and reduction of flushing of creek and river systems, particularly tidal barrage systems.

A change in tidal patterns will result in the local die-off of mangroves in areas where the tidal regime has become unsuitable. The collapse of mangroves would be likely to result in build up of organic debris in affected tidal creeks or rivers over a period of months. Most mangrove loss would occur at the immediate site of any power station and in those areas subject to changed inundation patterns as a result of tidal power plant operation processes. Tidal drainage of this basin through power generation would flush dissolved and suspended sediments as well as organic matter into King Sound. The short-term nutrient increases associated with such a die-off are likely to be short-term in nature and significant only in the local area. The high volume of water exchange likely for any tidal plant would decrease residence times such that it would be unlikely for large algal blooms to become established with the tidal storage.

Potential risks could arise from large debris, such as floating logs or debris mats, interfering with the facility as a result of flushing, impacting or blocking turbines and supporting structures. Mitigation measures could potentially be needed to minimise damage to infrastructure and reduce maintenance requirements in tidal barrage systems. Aggregation of debris near the facility could also potentially minimise productivity. This would potentially only be a medium-term issue as the majority of debris would decay within two years in a tidal environment.

The reduction in tidal and current movement could potentially lead to a large sediment load dropping out of suspension. A drop in suspended sediments would lead to increased water clarity and a likely increase in primary production in the water column and the benthic community. A possible negative effect would the occurrence of algal blooms, resulting in anoxic conditions within a barraged tidal creek or river, although this is unlikely if sufficient water exchange is maintained.

The water quality of freshwater aquifers around Derby could potentially be affected by tidal power development. This was raised in response to the TEA proposal, where it was thought there was some possibility of prolonged artificially high tidal storage levels may lead to salinisation of the shallow aquifers used in some parts of Derby. Most of the ground water resource utilised by Derby is drawn from a deeper constrained aquifer that is unlikely to be affected by any localised change in tidal regimes.

The potential for acid sulphate soils to impact on water quality is discussed in the next section.

4.2.4 Acid Sulphate Soils

Acid sulphate soils are soil types containing sulphide compounds, most commonly pyrite. They are distributed throughout the north-western coastline of Australia and closely associated with mangrove habitats. Sulphides in the soil are generally stable under anaerobic conditions but if exposed to air or oxygenated water, through dredging, construction or draining of the mangrove habitat, the sulphides oxidise to form sulphuric acid.

The presence of acid sulphate soils present a risk to both the local ecology and the presence of civil engineering structures. The sulphuric acid will cause corrosion of concrete and metallic structures, significantly reducing the life time of these components. Drainage from oxidised acid sulphate soils is often toxic to estuarine organisms not only due to its acidity, but also due to the high concentrations of dissolved metals, in particular aluminium and iron that are dissolved from the clay matrix in which pyrites are found. Consequently, the disturbance of acid sulphate soils either through direct excavation or through lowering the water table in prone areas poses a significant risk to the local ecology. Secondary impacts of acid drainage include altered water clarity, as dissolved iron coming out of solution in contact with seawater will lead to flocculation of iron oxides along with colloidal material from the water column. In rare cases, this may lead to effects of burial of benthic communities in flocculation zones and increased primary productivity due to lower turbidity waters. The presence of acid sulphate soils poses a risk for the colonisation of dredge spoil by mangroves and other plants, as acidic soils will not promote seed germination or continued growth of seedlings.

For any potential development, extensive studies should be carried out to establish acid sulphate soil distribution in potentially affected sites, including all construction sites, areas of altered water table regimes and areas affected by dredging. The presence of such soils would lead to significant constraints on development. Some mitigation can be undertaken through the bunding and lime neutralisation of exposed soils, however, this is a long-term and expensive strategy.

4.2.5 Mangrove Habitat

The loss of mangrove habitat associated with tidal power development in the Derby region is inevitable. Zonation of mangrove forests and associated saltmarsh communities are governed by the tidal regimes of the area. Any change in these regimes, in particular, an alteration in the duration and/or height of inundation during the tidal cycle will affect the vertical extent of mangrove survival – typically leading to a contraction of the extent of mangrove colonisation.

In volume terms, the impacts to mangroves by any proposal are likely to be of low significance at a regional level due to the extensive mangrove habitat (25,535 ha; HGM 1997) present within King Sound.

At a localised level the impacts would be more significant and would justify a mangrove rehabilitation program in newly formed habitats that would offset the original losses. The TEA proposal for Doctors Creek was estimated to result in the loss of 1,500 ha of mangroves, although significantly, it was projected that up to 2,300 ha of new habitat could be available for re-colonisation. The area likely to be occupied by mangrove and other riparian communities is highly predictable based on modelled tidal ranges for any proposal, however, the species composition if left to natural recruitment, is uncertain. Therefore, any destruction of mangroves that was to be offset by colonisation of new areas should be facilitated through a detailed inventory of the communities to be lost and a subsequent mangrove planting and management plan implemented for the re-colonisation area.

It should be noted that new areas potentially available for mangrove colonisation may be hindered by poor soil quality, in particular the presence of acid sulphate soils. This should be taken into account during the development of a mangrove management plan or making predictions on the likely loss/gain in mangrove habitat associated with any proposal.

4.2.6 Aquatic Fauna

There are several potential constraints to development as a result of impacts to aquatic fauna. Most issues can be mitigated against to a large degree, but place an economic burden on a proposal. The term aquatic fauna as discussed here refers to all freshwater, estuarine and marine organisms such as invertebrates, fish, reptiles and cetaceans that may be impacted by any tidal development.

The disruption of ecological processes and potential mangrove habitat loss will impact on fish and invertebrate habitat in any creek or flats system. Of particular concern would be the potential loss of spawning and juvenile rearing grounds. A lack of information at present of the species assemblages and associated ecological processes of the region prevents a comprehensive understanding of the potential impacts of a tidal power station. In particular, cryptic species' life histories are poorly understood. Studies in other parts of the world suggest tidal power technologies do impact on fish populations primarily through direct contact with turbines or through the obstruction of fish passage. The value of estuarine habitats, in particular mangroves, is widely recognised as an important for estuarine and marine fish nursery habitat and therefore has a direct influence of fish recruitment and hence local fish stocks.

Understanding of habitat requirements is confined almost entirely to a limited number of commercial fish species and endangered reptile species. Consequently, it is not possible to adequately model individual species' response to altered tidal regimes although it is likely that the habitats within a tidal storage basin retain much of their value as estuarine habitat and will be colonised by most flora and fauna species of the region.

A potential economic constraint are the costs associated with mitigation strategies that could include the construction of fishways or installation of efficient turbine systems that are required to operate at levels that would allow safe passage of fish. Upstream migration is generally well catered for, as incoming tides are allowed to flow through open gates into the storage basin. Fauna can pass unobstructed through the structure to upstream habitats during flood tides. Although free upstream passage is possible, some species, particularly cetaceans may not move through gate structures due to behavioural constraints. Little is known about predicting responses of such animals to artificial structures.

Downstream passage is more problematic, as ebb flows are generally passed through a turbine in order to generate electricity. Consequently, fish or other organisms undertaking downstream migrations must be either deflected from the turbine intakes and provided with some other means of passage, or must pass through the turbines themselves.

The provision of fish exclusion screens upstream of turbine intakes can lead to excessive fouling and reduced hydraulic efficiency of the plant. Consequently, there is a high likelihood that generation output would be lowered using this process. In addition, fish screens would require constant maintenance due to fouling and debris accumulation. Fish friendly turbines (variants on the Kaplan design) are highly desirable, but may lead to increased capital cost and potentially reduced output efficiency.

Net oxygen deficiency resulting from decomposition of inundated mangroves could result in anoxic conditions in all proposal areas where mangrove habitat are affected. The level of anoxia is likely to be limited by high water exchange rates, but may have localised effects on aquatic macrophytes and fauna (fish and invertebrates).

The issues associated with acid sulphate soils are discussed in other sections of this document.
Sedimentation has the potential to bury sessile invertebrates or to modify habitats such that community structures change significantly from the pre-development environment. Sedimentation is likely to further change tidal flow patterns and will alter the depth profile of local environment. Excessive sedimentation of estuarine areas, will lead to a conversion from an aquatic habitat to a semi-terrestrial one with a consequent change in community species composition.

4.2.7 Terrestrial and avifauna

The alteration of habitat, specifically mangrove and saltmarsh habitats, may impact on terrestrial fauna, including wading and migratory birds protected under international treaties such as JAMBA and CAMBA. No rare or endangered mammal species are likely to be affected by a generation system within the region, although Environment Australia identified a species list under the *Endangered Species Protection Act 1992* (now listed under the *Environmental Protection and Biodiversity Conservation Act 1999*) that could potentially occur in the region. Due to the paucity of data further studies would need to be undertaken to ascertain whether these species do occur in specific areas under any proposal, and then establish any potential effects arising from any generation scheme.

The most likely impacts of tidal power development on terrestrial and avifauna would be due to the increased amount of transmission lines and the ensuring risk of bird strikes and electrocution on exposed conductors. Increases in road development for access to any sites are also likely to result in some road kills. Alteration in tidal regimes will result in changes in mudflat prey availability for wading birds with potentially negative impacts.

4.2.8 Aboriginal and Cultural Heritage

Sites of aboriginal significance are located throughout the Kimberley region, however, no specific sites are known at this time to influence the selection of tidal power developments. It will be necessary to engage the aboriginal community directly, with the assistance of the Kimberley Land Council (KLC) with respect to specific proposals to assess any aboriginal heritage issues. Preliminary discussion with the KLC did not identify any obvious significant problems with the range of sites identified around Derby.

Clearance of any proposal site in the Derby region is required under the *Native Title Act 1993* and the *Heritage Act 1972* (and *Amendment Act 1998*). The proponent will be required to recognise any commitments made during Native Title negotiations with respect to compensation, employment, training opportunities and business development. All contractors will need instruction of their obligations under the *Aboriginal Heritage Act 1972* (and *Amendment Act 1998*) and any other commitments made during Native Title negotiations.

For any proposal construction plans will need to mitigate against potential damage to sites of aboriginal ethnographic and archaeological significance that occur in the vicinity. Within the wider Derby community, there was a very high degree of support for tidal power development in the vicinity of Derby. Consequently, although caution is urged in terms of both environmental and cultural heritage impacts, there appear to be no social barriers to the development of tidal power in the region.

4.2.9 Property Issues

There appear to be no property issues that may affect the development of tidal power options in the immediate vicinity of Derby. Aboriginal reserves are located in the wider region along the western edge of King Sound and among the Buccaneer Archipelago. Parts of the Buccaneer Archipelago and adjoining land are held as Defence Reserve. Any developments proposed for such areas would need the consent of the relevant title holders.

4.2.10 Social issues

Tidal power development in Derby is considered desirable by the majority of its residents (Figure 3-1). The advantages are seen in the form of increased jobs either directly through construction, or indirectly though increased tourism. These are reasonable expectations, and it is likely that the development of a tidal power option at Derby will be an economic benefit. Visual amenity is unlikely to be adversely affected by the tidal plant itself, although the presence of more transmission lines should be considered as a negative. Strategic placement of transmission lines and utilisation of existing easements where possible would mitigate this risk to some degree. The issue of dust has been raised with the TEA proposal. It has been postulated that a decrease in the absolute tidal range upstream of any tidal plant (due to the constriction that it places on incoming tides) will lead to areas of permanently dry saline sediment. Dust storms already occur in Derby, and there is some risk that a tidal plant may increase the volume of dust available for wind suspension. It is unlikely that the degree of change associated with small tidal power developments will add significantly to the dust load in the region.

Figure 4-1 Local support for tidal power is high.

4.2.11 Site inspections and specific constraints

In order to evaluate the potential environmental constraints on tidal power development in the Derby region, an aerial survey was undertaken of the coastline of King Sound between Valentine to the west and Gerald Peninsula to the north. In addition, inspection of the waterways in close proximity to Derby was undertaken by boat and from areas with land access. The areas inspected were divided into 5 broad zones for the purposes of this document (Figure 4-2). The major development constraints relating to environmental issues at these sites within these zones are discussed below:

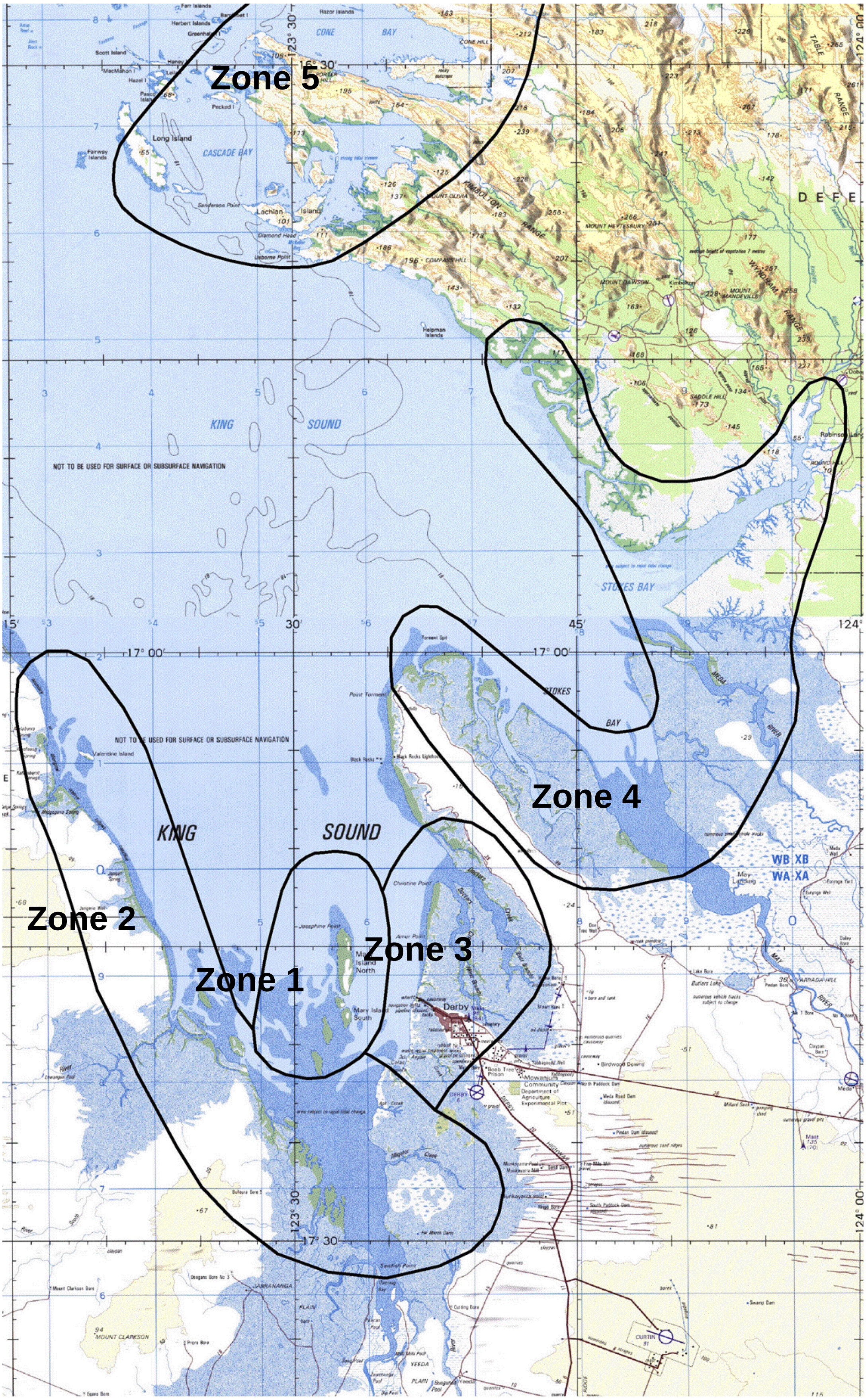


Figure 4-2 Broad environmental feasibility zones discussed in this document.

4.2.11.1 Zone 1 - Mary Islands and other offshore areas

It was initially thought that the Mary Islands immediately offshore from Derby, but still within King Sound, may provide stable sites for the installation of tidal channel generators that could be linked via a subsea power cable to Derby. Aerial inspection of these sites showed that no permanently deep channels exist at this location, and that sand shoals could easily bury any installations in these areas. In addition, the sites were generally shallow and would not be serviceable without extensive dredging. It was concluded therefore that no suitable sites were present offshore from Derby due to the issues of excessive sedimentation.

4.2.11.2 Zone 2 - Valentine Island to Alligator Creek

Many of the creeks entering King Sound at the southern end (eg.

Figure 4-3, and Alligator Creek – Figure 4-4) are isolated at low tide from the main waters of the Sound by bars at their mouths and have restricted tidal exchange due to the extensive shoal development and lack of defined tidal channels within King Sound itself. Consequently, whilst the plan view of the creeks would suggest a high degree of suitability for tidal power development, the shallowness of the creeks, the reduced tidal exchange due to extensive shoals and the highly mobile nature of these sediments greatly reduces the feasibility of these sites. To develop tidal power at such sites, an extensive dredging program would be required to maintain the active volume of the storage basin. In addition, it would be likely that the mouth of the creek would be subject to excessive sedimentation – necessitating an on-going and extensive channel dredging program. The environmental considerations associated with dredging are discussed in Section 4.2.2.

Figure 4-3 Creek inlet near Valentine Island – Zone 2.

Figure 4-4 Alligator Creek Mouth - Zone 2. Note extensive shoal development in the middle of creek mouth.

4.2.11.3 Zone 3 - Airport Creek, Derby wharf and Doctors Creek

Airport Creek (Figure 4-5) to the south of Derby is one of the few small creeks with a reasonable deep mouth and a likelihood of reasonable tidal exchange. This site, although still subject to considerable sediment movement has some potential for tidal power development due to its small catchment (hence limited sediment inflows) and circulation patterns near the mouth of the creek that appear to limit sediment deposition at its mouth. One of the main considerations with Airport Creek is the poor surface drainage around the low-lying airport (Figure 4-6) and any effect that tidal power development may have on it.

Figure 4-5 Airport Creek mouth – Zone 3.

Figure 4-6 Upper reaches of Airport Creek – Zone 3. Note extensive saline flats and low elevation of the airport runway.

The Derby Wharf (Figure 4-7) is a potential site for the installation of tidal turbines, however, sedimentation around such structures is likely to be considerable and would pose a significant issue for the operations of the bulk loading facility. At this location there are significant constraints on ore carriers utilising the wharf due to the shallow depths and limited high tide windows that allow movement without stranding. Any change in sedimentation patterns at the wharf would have significant implications for the operations of the bulk loading facility.

Figure 4-7 The Derby Wharf and bulk loading facility. The mudflats of West Doctors Creek are at the left.

Doctors Creek to the immediate north of Derby has been the subject of a detailed tidal development proposal by Tidal Energy Australia for a double basin tidal power plant. Doctors Creek is made up of two major arms on initial inspection is highly suited to such a proposal. The potential for sedimentation with this proposal was recognised in both the Community Environmental Review for this proposal and subsequent EPA evaluation of these documents. According to the CER (HGM 1997) studies, the Doctors Creek double basin proposal will reduce mean flow velocities up to 30% and will result in net sediment accretion at the creek entrance. It was expected that two channels corresponding to water flows from the sluice gates would remain open through this accretion area. Doctors Creek is currently in an erosional setting, due mainly to limited catchment sediment inputs and a high degree of tidal exchange. This setting has led to the development of extensive creeks draining tidal flats in a highly fractal nature. Excellent examples of this were noted from the air at Doctors Creek (Figure 4-8), Stokes Bay and in the vicinity of the Fraser River.

Figure 4-8 Fractal drainage patterns on the mud flats of East Doctors Creek – Zone 3

4.2.11.4 Zone 4 – Point Torment to Helpman Islands (Stokes Bay)

Several large creeks (Figure 4-9) are present in this zone and have some potential for tidal power development. The constraints discussed for Zone 3, which have been focussed on extensively with the Doctors Creek proposal would also be applicable in this area, with the added constraint of longer transmission line requirements and access issues. There did not appear to be any unique environmental constraints applicable to this zone. Similarly, there were no features in this area that presented better tidal power development options than those in Zone 3.

Figure 4-9 The mouth of the Meda River, Stokes Bay – Zone 4.

4.2.11.5 Zone 5 – Diamond Head and the Buccaneer Archipelago

Significant tidal power potential could be realised at many sites on the landward edge of the Buccaneer Archipelago, of particular note is the unnamed embayment with its entrance at Diamond Head (Figure 4-10). This area is dominated by bedrock outcrops, with deep water and far lower sediment loads than experienced further south. It would be expected that the estuarine environmental issues associated with a development in this region would be relatively minor in comparison, however, the major constraints on these areas are the distance from Derby and hence the length of transmission line required. In addition, this area is currently listed as Defence Reserve and the title of this land would need to be negotiated for any development.

Figure 4-10 Diamond Head, southern end of Zone 5 – note deep water channels in constricted rocky channels.

4.2.12 Consent Procedure

Approval of the any tidal power development project is required under the state legislated *Environmental Protection Act 1986* and potentially also under the Commonwealth legislated *Environment Protection and Biodiversity Conservation Act 1999.* The *EPBC Act 1999* will only require approval if actions have, or are likely to have, a significant impact on a matter of national environmental significance requiring approval from the Commonwealth Environment Minister under the EPBC Act. Approval is also required for actions that are likely to have a significant impact on the environment of Commonwealth land and actions taken by the Commonwealth that will have a significant impact on the environment anywhere in the world.

Six significant impacts of national environmental significance require approval from the Commonwealth. Of these six, listed threatened species and ecological communities and listed migratory species could potentially require approval under the *EPBC Act 1999.* The approval processes under both Acts are stringent and potentially lengthy. Currently there is a paucity of data on listed threatened species and ecological communities or listed migratory species however it is likely that any large scale proposal would need to be submitted for the minister for assessment under the *EPBC Act 1999*.

Requirements under the *Environmental Protection Act 1986* will need to be met. The EPA is the independent statutory authority that provides the advice to the Government based on the ability of the proponent to comply with the requirements outlined by the *Environmental Protection Act 1986.* The EPA has expressed concern over various environmental issues associated with a proposal for a double-basin tidal barrage system in Doctors Creek, having outlined a series of conditions for environmental management. It is likely that other proposals, in particular barrage system proposals, will be subject to the same degree of regulation.

4.2.13 Summary of Environmental Constraints

There are several significant environmental constraints to the development of tidal power options in the Derby area. The majority of the issues relate to changes in the tidal flow patterns in the immediate vicinity of the tidal plant, resulting in altered geomorphological processes, disturbance of riparian communities and potential changes in water quality. Of these, the issue of greatest concern is the potential for excessive sedimentation of the channels leading to the tidal plant and hence the on-going need for dredging. This may occur either upstream or downstream of the tidal plant and may have localised impacts on benthic biological communities, water quality and geomorphological stability. The spoil disposal site may be subject to burial, poor water and/or air quality and visual impact.

The geoheritage value of any geomorphological features or processes need to be assessed for each proposal, however, whilst King Sound offers a unique and complex geomorphological setting, it is unlikely that any one tidal development would compromise the regional significance of this. Depending on the scale and operational patterns of a tidal energy plant, it is still possible for valuable geomorphological processes to be protected to some degree.

Depending on the development proposal, it is likely that mangrove ecosystems will be modified or destroyed through any tidal power development. Mangrove communities are keenly attuned to tidal patterns. For single basin creek barrages, it is likely that there will be a loss of the extent of mangroves upstream of the barrage due to the lessened tidal range with a possible expansion downstream due to sedimentation and increased availability of suitable substrate. For artificial storages, a net decrease in mangrove area would be anticipated although this can be mitigated somewhat by site selection and strategic planting in modified habitats.

The likely extent of issues associated with acid sulphate soils is unknown at this time, primarily due to the lack of information on the local soil structures. There is a high risk of acid sulphate soils being present in the area although none have been confirmed. Disturbance of these soils through dredging and construction work or aeration of the soils through modification of groundwater regimes, could lead to corrosion issues with infrastructure, water quality problems and the potential for fish kills associated with either the acidity or toxic metal load carried by such water. Detailed soil mapping should be undertaken for any areas likely to be subject to direct soil disturbance or groundwater alteration and the risk of such issues evaluated with any proposal.

Passage and survival of fish and other animals at a tidal power plant poses some potential issues. It is likely that the basin upstream of a barrage will still provide substantial estuarine habitat suitable for local fish species, and hence also marine reptiles and some cetaceans. Provision to allow safe passage past a tidal plant will need to be made including the screening of turbine intakes or application of other suitable deterrent devices.

Water quality has the potential to be influenced by numerous processes. For example, surface water quality will be influenced by the degree of exchange through the tidal plant, residence times for nutrients within storages, the degree of sediment settlement in low water velocity areas and turbidity increases around dredging sites. Altered tidal regimes and subsequent adjustment of freshwater reserves may influence ground water. The influence on acid sulphate soils should not be discounted in this regard.

Sites of aboriginal significance a located throughout the Kimberley region, however, no specific sites are known at this time to influence the selection of tidal power developments. It will be necessary to engage the aboriginal community directly, with the assistance of the Kimberley Land Council (KLC) with respect to specific proposals to assess any aboriginal heritage issues. Preliminary discussion with the KLC did not identify any known significant problems. Within the wider Derby community, there was a very high degree of support for tidal power development in the vicinity of Derby. Consequently, although, caution is urged in terms of both environmental and cultural heritage impacts, there appear to be no social barriers to the development of tidal power in the region.

It is apparent that a better benefit to environmental cost ratio can be achieved with larger tidal plants. This is mainly due to the large environmental overhead associated with any development, the relative important of which, on a regional scale, does not significantly alter with the scale of the development. Therefore, recognising the huge tidal resource of the region, it will be important to properly forecast the future power demands that could be met by tidal power and ensure that a minimal number of developments (preferably one) are undertaken to service this demand. Notwithstanding this, it is recognised that transmission of power within this sparsely populated region is not without its own environmental, social and economic constraints.

The broad assessment of the feasibility to harness tidal energy in the region did not identify any environmental or social issues that would preclude the development of tidal power in the region on these issues alone, although the proper management of environmental issues could impose significant economic constraints. Any detailed analysis of tidal power development options in the area should include consideration of the environmental issues discussed in this document, with due reference to the TEA proposal, its CER and the EPA’s assessments of that proposal.

It is concluded that there are three broad sites in the immediate vicinity of Derby for which there do not appear to be overwhelming environmental constraints and therefore should be assessed in terms of technical and economic feasibility for tidal power development. These sites are Airport Creek and various locations with Doctors Creek, particularly the western branch. In addition, it should be noted that there appears to be significant potential for tidal power development in the Buccaneer Archipelago with less environmental impact for much greater available power – the tradeoff being poor existing access and long transmission requirements.

4.3 CORROSION AND ABRASION

Corrosion is a major problem in seawater. Corrosion rates are effected by materials of construction, component design, water velocity, seawater temperature, oxygen content, contaminants, fouling and biological action. Many of these conditions vary, as tidal, seasonal and weather changes occur over a daily, monthly and yearly cycle.

The temperature of the seawater in and around King Sound provides a particularly aggressive seawater environment. The seawater temperatures are commonly above 30 C and nearly always in excess of 25 C. The increased temperature increases oxidation rates and biological growth rates and action, which significantly increase the corrosion rates.

The varying velocity regimes in the system, as the tides move in and out, provide alternating conditions and environments adding to the difficulties of providing corrosion protection.

The presence of oxygen in marine atmospheres, increases the aggressiveness of salt attack. Oxygen is introduced by tidal action and wave action into the seawater in use in the tidal barrage system and provides a highly aggressive oxidising environment.

Seawater is a most efficient electrolyte, and therefore the rates of galvanic corrosion will be high. The quantities of silt, dissolved gases other than DO, and decaying animal and vegetable matter, all effect the fouling and corrosion mechanisms.

4.3.1 Metal Corrosion

Metals and alloys are subject to several forms of corrosion in seawater including general wastage, impingement attack, galvanic action, microbiological effects and localized corrosion, such as pitting, crevice corrosion, stress corrosion cracking and intergranular attack.

Most corrosion resistant metals rely on an oxide film to provide protection against corrosion. Such metals and alloys tend to have low general corrosion rates but can suffer localized corrosion once the film is damaged.

While impossible to eliminate from a complex machine such as a variable pitch, adjustable guide vane turbine, it is important to limit the number of crevices in the turbine for seawater applications. Crevices allow the ingress of water and chlorides but exclude oxygen and rapidly become anodic and acidic and are hidden start points of corrosion. The environmental factors that influence whether crevice corrosion initiates, and at what rate it propagates are many, and include: crevice geometry, surface roughness, metal temperature, seawater velocity, seawater composition, and fouling, both biological and sedimentary. Overall, the tighter the crevice, the greater the propensity for crevice corrosion.

In practice turbines are rarely made just from a single metal or alloy. Modern engineering systems use a wide range of composites and metal alloys, some more, some less resistant to marine corrosion. The more resistant alloys may aggravate the attack an adjacent unprotected less resistant alloys. In the aggressive marine environment even the more resistant alloys may be affected by hydrogen-induced cracking, or by chloride or sulphide stress corrosion cracking. Choosing the right material for corrosion resistance also requires careful attention to component design, selection of manufacturing processes, installation and operation. High levels of stress in service, or residual stress from manufacturing may result in selective corrosion of more highly stressed regions of an otherwise corrosion resistant structure.

4.3.2 Abrasion

The abrasive effects of silt and sand provide direct abrasion erosion of softer materials and erosion corrosion effects on a variety of materials. These effects are obviously increased at higher velocities.

There is some variation in the suspended solids concentrations in King Sound around Derby. Figures range from 363mg/l (CER) up to 5500 mg/l reported by Analytical Reference Laboratory (WA) Pty. Ltd. These levels all indicate higher levels of suspended solids than would normally be encountered for tidal power schemes and this adds to the potential problems for the system. The sediments noted in several previous reports indicates a high level of silt in the suspended solids. The silt is transported into King Sound from the Fitzroy River and composition and levels would vary considerably depending on the season.

Abrasion due to silts can cause significant material degradation. This can be from direct abrasion effects on the materials or from a corrosion/erosion effect of removing the protective oxide layers from materials such as metal alloys. This high abrasion regime limits the choice of construction materials, particularly within the turbine. To resist abrasion harder materials and more resilient protective coatings are required. Softer metals which have otherwise excellent marine corrosion resistance are unable to be utilised, this includes the copper nickel alloys which have excellent antifouling properties combined with good corrosion resistance.

Abrasion also limits alternative non-metallic materials and limits the protective coating systems available. A trade-off may be required in coating systems between abrasion resistance and resistance to biofouling.

4.3.3 Corrosion Prevention

Key factors in prevention of marine corrosion are design, selection of materials and coatings, construction, use and maintenance. Failings in any one of these may lead to a total failure to prevent attack, which once started may cost far more to correct or eliminate than any notional savings on materials achieved at the outset.

Methods for controlling the tendency of metals to corrode in sea water include:
Coating

Coating, linings or painting isolates the metal from the corrosive media. The coating must also be resistant to the marine environment and the application strictly controlled to ensure full and effective coverage. Regular inspection and repair of the coating may be necessary to achieve reliable and lasting protection. A likely conflict exists between antifouling coatings to resist biofouling and the need to resist abrasion from suspended solids.

The coating system may be a ceramic lining as suggested by one turbine supplier for the unit. It is unclear how this is applied in areas such as the blade pivot areas, where close tolerances are required and crevices naturally exist.

Cathodic protection

Sacrificial anodes enable the potential of the system to be changed and will provide temporary protection to steel exposed by wear or damage of the protective coating. Systematic location of the anodes is critical to their overall effectiveness. They must likewise be regularly serviced and replaced when spent.

It is inevitable that within a seawater turbine more than one alloy type will be chosen because of varying strength requirements or even availability in a particular form. Electrical isolation of sections of the system cannot be relied upon in such an environment. It is therefore essential that materials selected for sea water system are galvanically compatible
Protection for the least resistant alloys by anodes, or impressed potential, requires careful control of the system potential to avoid the possibility of hydrogen uptake by the more highly corrosion resistant alloys such as super duplex steel and titanium.

Material Selection
Design factors include the severity of the application and the levels of strength, damage tolerance, reliability, safety and life required. Components and systems can be manufactured from composites, or from stainless steels of increasing resistance, or from copper based alloys such as cupro-nickel or nickel aluminium bronze, nickel alloys or titanium, using these materials exclusively or in conjunction with each other or less resistant alloys.

4.4 MARINE FOULING

Sea water, if not destructive enough on its own, has several powerful allies assisting the breakdown of metals and non metals alike. Fouling in a marine environment can occur from precipitated deposits, suspended solid deposits and biological growth. Fouling from suspended solids and biological growths are the major concerns for tidal power systems in the Derby region.

Bioforms in seawater contribute both to fouling and corrosion. Biofouling refers specifically to fouling caused by marine plants or animals when such organisms attach themselves to materials submerged in the sea. The two basic types of organisms are the "soft" plant like shines, algae and hydroids and the "hard" (shell like) barnacles, mussels, oysters, tube worms and sea squirts. The tendency of such materials to adhere to materials submerged in seawater depends on the nature of the material itself, as do the resultant manifestations of corrosion, scaling, plugging, etc. It is well known that metals and alloys that produce toxic salts (e.g., copper, lead and zinc) resist hard fouling by barnacles and the like, although they may accumulate soft fouling materials under some conditions.

Marine biofouling is most widespread in warm conditions and in low velocity (<<l m/s) sea water. Above l m/s, most fouling organisms have difficulty attaching themselves to surfaces unless already secured.

Microbiological organisms, clusterings of weed, limpets as well as deposits of sand, silt or slime not only exclude oxygen but often create locally corrosive conditions under these deposits which aggravate attack. Coatings and composite structures can experience rapid degradation. Sulphate reducing bacteria, left undisturbed in marine silt or mud deposits, will produce concentrations of hydrogen sulphide which are particularly aggressive to steel alloys.

The silt present in the Derby region of King Sound is mainly derived from the Fitzroy River. Silt from estuary waters contain not only inorganic particles, but also organic matter and possibly metallic oxides. More adherent than sand, silt contributes to fouling, plus adding to corrosion problems, not only by concentration cell effects but also contributing decomposition products. The deposition of sand and silt is generally controlled by maintaining recommended minimum velocities.

In steel, polymers, and concrete marine construction, biofouling can be detrimental, resulting in accelerated corrosion. Other effects can include efficiency losses and imbalance problems for the turbines. Expensive removal by mechanical means is often required. Marine organisms attach themselves to some metals and alloys more readily than they do to others. Steels, titanium and aluminum will foul readily. The environment at Derby, with high suspended solids, limits the use of many of the traditional seawater metals and coatings as they would be damaged by abrasion in a short period. Copper-nickel alloys are an example where they generally exhibit good corrosion resistance to marine environments and limit biofouling, due to the presence of the copper, but are relatively soft and would erode in this environment.

The high suspended solids loads do have some advantages in that the abrasion effects will aid in limiting biofouling and the turbidity created will limit light penetration and thus limit the range and rate of organism attachment to structures.

5 Development Options

5.1 INTRODUCTION

Three options have been assessed to be technically and environmentally feasible in this study of tidal power for the Derby region of Western Australia. Unviable options have been discounted elsewhere in this report, and this section will describe the remaining three options. The proposed development locations are shown in Figure 5-1.

Figure 5-1 Development Locations

5.1.1 Airport Creek

Located approximately 4km southwest of Derby, Airport Creek is an estuary approximately 5km long that ends near Derby Airport. It is a mangrove-lined tidal creek with several short branches. This location would be suited to three types of generation, including; flood generation, ebb generation and two-way generation. This option would involve a powerhouse and barrage across Airport Creek, and a short levee to train the high tide waters into the impounded reservoir.

5.1.2 Doctors Creek

The West Branch of Doctors Creek could be used in the same way as described above. The barrage would be located approximately 8km north of Derby on a narrow section of the creek. The estuary would have a much larger volume in this option, so there would be the option to generate more power through the addition of more turbines.

5.1.3 Wharf Reservoir

The third option for development is to create a new reservoir and place a barrage across its entrance. By creating an artificial estuary, it is possible to avoid many of the environmental issues that could possibly hamper the use of an existing estuary for tidal energy production. It is also possible to choose the most appropriate site in terms of economic, engineering and environmental aspects. The most appropriate site for the new reservoir at this stage appears to be located on the southern side of the causeway that leads to the Derby Wharf. This site has easy access via the causeway. The causeway could also be used as part of the embankment for the reservoir. The major advantage of this site is that there is already a transmission line leading out to the wharf from Derby, which would simply need to be upgraded to carry power from the barrage to the town.

5.1.4 Considerations

In determining the best option for development, several factors need to be taken into account. Possibly the most important consideration is the distance between the development and Derby or the nearest high voltage power line as the cost of building the transmission line is critical to the economic viability of the project. Another consideration is the amount of silt in solution in the water. This will determine the amount of dredging required over the life of the project and is a significant operational cost. The wet season causes the rivers in the Derby area to fill with water with high sediment concentrations so the tidal energy development cannot be located too near, or across one of these rivers. The available storage is another factor in determining the viability of the project. If the storage is too small, then it will fill or empty too quickly, limiting the amount of energy that could be generated.

5.2 CIVIL WORKS - GENERAL ASPECTS

5.2.1 General

The following descriptions of civil works are at this stage only conceptual in nature, due to the scarcity of geotechnical and survey information. Full and extensive feasibility studies would be required to prove the technical and economic viability of the described features.

5.2.2 Powerhouse structure

The powerhouse structure would consist of a mass concrete foundation encasing the turbine and waterway, located below minimum tide level. Since substantial foundations of sufficient bearing capacity would be located a considerable distance below the base of the powerhouse, the entire structure would need to be supported on driven piles to prevent subsidence, rotation and lateral displacement of the entire structure. The entire structure would be required to resist buoyancy loads, by the use of mass concrete ballast.

The powerhouse walls would extend up to above maximum tide level and therefore would need to be heavily reinforced to resist significant hydraulic pressure and soil loads. The roof would consist of a reinforced concrete cover with removable precast panels to allow for machinery and equipment access and removal, or a steel deck type cover with removable panels.
Access to the powerhouse would be through the roof or upper walls and would require a galvanised steel stairway to the lower levels.

A gated bypass of the powerhouse would be required to allow tidal water to enter the reservoir during the rising tide or to leave the reservoir during the falling tide, depending on the preferred option. This would be constructed immediately adjacent and integral with the powerhouse structure. The conceptual design drawings are included in Appendix 1.

5.2.3 Available Construction Services

Due to the difficult construction methods and advanced materials required, most services, equipment, materials and the workforce would need to be sourced from Perth or significant industrial centre.

5.2.4 Access Road

Access to the proposed Derby Power Station will be through a region of tidal mudflats. Foundation investigations have shown that the mud is shallow and located on well compacted clay.

Three different methods of permanent and long term access could be used. These include the following:

- Piles/Pile cap and bridge decking
- Removal and replacement of unsuitable material
- Displacement of unsuitable material.

From these three methods the most appropriate option appears to be the third listed, displacement of unsuitable material.

This can be achieved by displacing the soft and saturated mudflats with either gravel or rock. With this in mind the estimated cost was based using the following assumptions:

- The average depth of the embankment and pavement will be 2.5m.
- The pavement width will be 5m.
- The pavement depth will be approximately 500mm.

Rock will be imported from a distance of 100km on relatively good roads.

5.2.5 Geotechnical, Foundation and Seepage Issues

Seepage issues are not a significant economical concern for the development as filling and emptying will happen twice each day. Of more concern is the erosion of material from underneath the structure by fast flowing water. Adequate protection will need to be provided so as to prevent this erosion. A suitable side slope for excavations will also need to be determined through a site investigation to determine the properties of the soil in the area of the development. This site investigation should also determine the best type of foundation for the structure. The type of foundation used will depend on the depth and engineering properties of the soil profile.

5.2.6 Suitable Construction Material

5.2.6.1 Concrete

The salt-water environment in which the barrage will be constructed is an extreme environment for concrete. Minimum concrete strength will be 50MPa, and minimum cover of 50mm will be required, Additionally, the use of stainless steel or heavily galvanised reinforcement will need to be investigated. It may also be necessary to include additives to the concrete to prevent water seepage and to assist in the protection of reinforcement.

5.2.6.2 Slope and Bed Protection

Due to much of the material to be excavated for construction of the development being easily erodible, it will be necessary to stabilise the slopes so that they will not erode and displace into the stream or fail internally. To prevent the erosion of these materials, side slopes will be covered with riprap stone and a filter cloth to stop the fine clay materials being washed out from under the coarse stone. The bed of the waterway immediately upstream and downstream will also need to be protected to prevent displacement of the bed material that could undermine the structure and possibly result in the failure of the structure. Bed protection materials will be a combination of concrete paving and mattress gabions with a geotextile filter to prevent undermining of the structure.

5.2.7 Construction Methods

Since the powerhouse would be constructed within and below the tidal zone, construction of the powerhouse will be a major component of the project. A possible construction method would be to isolate the site by driving sheet piles in a full ring around the powerhouse. The internal water and soil would be removed by pumping/excavating. Continuous pumping would be required to remove incoming groundwater.

5.3 ELECTROMECHANICAL WORKS - GENERAL ASPECTS

5.3.1 Turbine Types

Tidal systems operate at relatively low generating heads for hydro turbines. When considering low head turbines a number of systems are available however the most common are the bulb type and Kaplan type machines. These types of turbines are in common use in various low head installations around the world and are the most likely to be utilised in any system at Derby.

These machines are complex in nature with control mechanisms to maintain efficiencies, by adjusting blade pitch and guide vane position, as head, flow and machine output power requirements vary. While there are a large number of suppliers with experience in the design and installation of these types of turbines, few have experience in Seawater and none have experience in warm seawater as would be experienced in King Sound. Any supplier would need to draw on experience such as with desalination pumping from the Middle East/Gulf region where seawater temperatures are over 20C, and from thermal Power station cooling systems and offshore oil rigs etc.

This is another limiting factor on many of the “emerging technologies” as the demonstration systems are generally in much cooler and friendlier environments. The experience in varied environmental conditions, of many of suppliers of these systems, is limited.

Suppliers, such as those shortlisted by the Tidal Energy Australia consortium Kvaerner (now GE Hydro) and Sulzer now owned by VA Tech, have significant experience with seawater in other applications, such as pumping. This experience can be utilised for material selection and coating system selection.

Sealing of turbine drives would be an area of considerable design input as the abrasive nature of the suspended solids and salt waters pose significant effect this area. Material selection in the turbine and associated flow equipment would be dictated by the many corrosion problems outlined previously.

5.3.2 Turbine Sizing

Power generation potential is a function of available net head and discharge flow at the site. The relatively low head available in a tidal system dictates that large flows are employed for any given power output. A cost tradeoff exists between machine size and the erosion effects from high flow velocities in the system. Higher rotational speeds are available with the higher flow velocities and these decrease the costs of generating equipment. Another factor effecting this tradeoff equation is where the turbine is required to operate in both directions as this effects blade design and overall efficiencies. These multiple factors would require considerable consultation with suppliers during the concept development and design processes.

There are efficiency gains in the selection of larger output machines over a number of smaller output machines. These gains diminish as the machine size increases. It is likely that a system comprising two or three midsized machines would provide higher operating efficiencies than a system with several small machines, while maintaining machine availability.

The Alstom selection curves for low head Kaplan machines in Appendix B can be used to provide some guide to the flow rates and turbine sizes.

5.3.2.1 2 MW System

A system with 1 machine and an available head of 5 metres, able to generate 2 MW of available power would require a total flow of 50 cumecs (m^3/s). Each turbine would have impellers of approximately 2 metres diameter. The turbine speed would be approximately 250 rpm.

5.3.2.2 5 MW System

To provide generating power of 5 MW a system with 1 machine and an available head of 5 metres would require a total flow of approximately 125 cumecs. Each turbine would have impellers of approximately 2.6 metres diameter and operate at a speed of 175 rpm.

5.3.2.3 10 MW System

To provide power of 10 MW from the generators, a system with two 5 MW machines and an available head of 5 metres was considered. These systems would require a total flow of approximately 250 cumecs. For the 5 MW turbines the impellor diameters would be approximately 3.7 metres diameter and the turbine speed would be approximately 130 rpm. The smaller turbine would be 3 metres in diameter and operate at approximately 150 rpm.

5.3.3 Gates

Gated structures are commonly used in salt water applications, for example tidal barrages and lock gates. Nonetheless, the issues with respect to the high propensity for marine corrosion will apply to the gate design and fabrication and particular attention will be required to design details and selection of materials. Other key issues will be the wear resistance of sealing frames and other steelwork in flow passages, and the effect of marine growth, in particular barnacles and the like on clearances, seals and sealing surfaces. Duplex stainless steels are sometimes used for their high strength and wear resistant properties for sealing frames, in applications where there are high levels of sand and silt.

5.3.3.1 Power station isolation gates

The power station will require both upstream and downstream bulkheads. If an inlet valve is provided for each machine, the bulkheads may be designed as still water bulkheads only. Alternatively if inlet valves are omitted, a wheel gate capable of closure against full power station flow should be provided on the power station inlet. If Kaplan or bulb type turbines are used, the inlet gate will need to close automatically and quickly, as in the event that the machines go to the overspeed condition, these turbines can run up to 250% of normal speed. The turbines are normally only rated to run at this speed for a few minutes.

Both the inlet and outlet gates will be required to seal to allow for maintenance of the turbine.

5.3.3.2 Bypass Gates

If generation is to be one way, a power station bypass gate or gates will need to be provided. This gate would normally only see pressure from one side, while the pond is full and water is being released through the power station, but may, in unusual circumstances be subjected to pressure from the reverse side. A radial sluice gate or gates is proposed. A maximum flow velocity of 2.5 m/s has been assumed for approximation of the gate areas.

5.3.4 Trashracks

A trashrack screen will be required to protect the power station turbines from ingress of debris. Design and fabrication will require attention to bar screen vibration and corrosion. Stainless steel may be used, but has inferior fatigue properties so the screen will require additional support. Screen sizes have been assumed to keep inlet velocities to the normal design velocity for screens of 1m/s.

5.3.5 Electrical Generation and Control

As with all remote area power supplies, there must be multiple generation sources to collectively address all the need of the isolated power system and meet the regulatory quality standards. The standards dictate the allowable voltage and frequency deviations together with system response, harmonics and many other performance requirements. Often these standards are hard to meet due to the cost of maintaining adequate spinning reserve to meet all contingencies.

The power demand is entirely dictated by the customer load and for an isolated power system there must be adequate local generators to respond to the real time demand and meet all the performance requirements.

This requirement can be demanding especially in hot weather when the demand peaks. The current and expected load profile for Derby shows an almost a 2 to 1 variation both within a day and between different months of the year ranging from a low of about 1.5 MW to a high of 6.0 MW.

The reactive loading data has not been specified but for the purposes of this report the power factor will be assumed to be 0.8. This will give a reactive loading range of between 1.125 MVar and 4.5 MVar.

The major concern with tidal power is that the tides are not related to the customer demands and during the extremes of the tide there is no available tidal generation unless a storage system of some type is used. Therefore if no suitable storage scheme can be provided that can provide significant continuous output, a diesel power station of more than 6 MW will be required.

5.3.5.1 Suitable Generators

There are two basic types of AC generators being synchronous and induction generators.

Synchronous generators are the conventional type of generators used for larger generators and considering the proposed size of the tidal generators and that for part of the tidal cycle they are likely to be the only generator operating, the generators must be of the synchronous type.

The generator or generators will require automatic voltage regulators with a reactive droop characteristic to allow stable reactive load operation in parallel with other synchronous generators. The AVRs will be required to have a remote controlled setter to enable the system voltage at the existing power station to be controlled to within the limits set by authorities.

Similarly they will require some form of autosynchroniser to enable the generator to be connected to the power system in a “bumpless” manner.

5.3.5.2 Loading Control

To maintain a constant speed and power system frequency, either the tidal turbine will need to be fitted with a governor or there be large controllable load that will control the speed by fully loading the generator and turbine.

This controllable load could be a Hydrogen production cell or some other form of energy storage in the form of batteries. Alternatively it could be used for some load that did not require continuous power such as water pumping or heat storage. The important requirement for the load is that be able to be easily and quickly controlled to complement the normal customer load and control the power system frequency.

Unless there is significant civil works to store the tidal energy the output of the generators will be cyclic and will frequently exceed the customer load.

The current proposal is to use the turbines for only one tidal direction, thereby restricting the maximum operating time to less than 10 hours per day and the conventional diesel generators or some alternative form of generation will be required for the rest of the daily cycle. Also at the start and end of the tidal cycle there will be a reduced tidal output and the tidal and diesel schemes will need to be operated in parallel.

5.3.5.3 Frequency Control

Varying output systems such as tidal turbines connected into isolated grids can have difficulty maintaining normal system frequency. System frequency can be impacted on by tidal movement and on a smaller scale with wave action, causing the power output to change rapidly. Maintaining normal system frequency is not a major problem, with fluctuating output machines, in low penetration systems.

Where system penetration is high, with a fluctuating generator output the frequency control and stabilisation issues become more critical and complex. System inertia can be used to partially counteract these fluctuations as the inertia acts as a damper to the machines response to the external changes in head or flow.

Modern, variable-speed systems with power electronic control and grid connections, offer the potential to lower the inertia requirements of the system. Lower inertia requirements allows the use of smaller, faster spinning, cheaper turbines. The power electronic system can be controlled to limit output fluctuations and minimise the effects on the system. Variable-speed systems are in the development phase and we cannot provide comment on their cost effectiveness, reliability and suitability for the Derby system.

Battery systems in combination with electronic power supply systems can be utilised to stabilise the frequency. A battery system has the added benefit of accepting load variations from the generation equipment and protect the generation equipment from system load fluctuations, without effecting system voltage or frequency signals.

Commercially available energy storage systems, in the form of lead acid or nickel cadmium battery systems, or emerging battery technology such as the Vanadium Redox battery system, could be utilised for this energy storage and system stabilisation.

5.3.5.4 Spinning (Operating) Reserve

Sufficient operating reserve will have to be maintained to assure adequate system performance and to guard against sudden loss of generation, unexpected load fluctuations, and/or unexpected transmission line outages.

Operating reserve is a combination of spinning and non-spinning reserve. The proportion of spinning reserve to non-spinning reserve depends on the system performance criteria, such as acceptable frequency variation limits and the response of the generator sets connected to the system, including starting time and loading rate.

The maximum amount of spinning reserve required would be approximately equivalent to the largest generator connected to the system, or for an unexpected transmission line outage. However to properly determine the amount of spinning reserve required would require modelling of the power system, and its transient performance.

Battery systems could provide a means of eliminating or minimising the need for additional spinning and operational reserve in the system. Battery draw current limitations are the only limit factor to their response to load changes. This is especially beneficial in systems where the spinning reserve would be provided by off load internal combustion engines running at low efficiencies.

5.3.6 Transmission Line and Connections

The transmission of generated power from the tidal power station to Derby will require the installation of considerable lengths of overhead high voltage transmission lines. This is conventional power supply technology and there are no increased risks due to the tidal energy concept. Transmission lines in this are require special treatment to minimise electrical supply disruptions from severe weather conditions such as cyclones. The option of connecting a second circuit is unlikely to significantly increase reliability as they will both be equally likely to be damaged in severe storm conditions. There are standard designs available to minimise storm damage. System transient studies will be required.

5.3.7 Communications, System Control and Integration

Dual communications would be required in the form of UHF radio and normal telephone lines for backup dial in links. The existing SCADA system at Derby would be expanded to incorporate the new plant. The SCADA would provide operator interface and communication with the local PLC controllers for turbine/generators and for continuing data collection on system components.

5.3.8 Energy Storage (Hydrogen or Other)

As outlined a hydrogen generation system could be utilised as a load control system with all excess produced energy being utilised by an electrolysis unit or some other hydrogen generator or some other form of energy storage system.

Hydrogen generated by electrolysis could be used in a modified engine as fuel replacement. The fuel management system required is quite sophisticated and would possibly require some prototype testing to finalise a design for such a conversion system. Hydrogen used in this way would further replace fossil fuels and could be used in a fuel cell system once these become commercially viable. Efficiencies for electrolysis of pure water are in excess of 80% and some other methods such as steam reformation have even higher efficiencies.

Hydrogen is a high energy fuel and can provide approximately 2.5 times the energy per mass of petroleum fuel. However, the low density of hydrogen (1/700th of petroleum liquid) provides a problem for storage with large storage volumes being required for any substantial fuel load. The storage problem can be overcome by storage at pressure or by freezing, however, the energy required to achieve the compression lowers the overall efficiency of the process. When combined with the low efficiency of an internal combustion engine (typically less than 40%), the efficiency of generating and using hydrogen is lowered substantially (<25%).

Alternatively, forms of energy storage such as zinc air batteries or traditional battery systems are available to store the excess energy and make it available at times of low generation or high energy demand. Zinc air batteries utilise the energy in a similar manner to the electrolysis of water, in that zinc anodes are produced by electroplating, the battery is fitted with these anodes and they are consumed in the battery. A number of other battery systems are possible with recovery efficiencies in excess of 50%. However, the capital costs of these systems are high and the life expectancy quite short giving a high life cycle cost.

These systems are not considered viable at present due to the high capital cost and low conversion efficiencies. However, the technology in these areas is the subject of considerable research and breakthroughs are therefore anticipated in conversion efficiency and in the cost of items such as fuel cells and electrolysis cells. The commercial viability may therefore change in the future.

6 Preliminary Cost Estimate

6.1 GENERAL

The following estimate is based on the general design arrangements included in this report. The data available and the minimal engineering content of this study means the project can only be estimated to a pre-feasibility level. Every effort has been made to obtain the best information but without accurate contour and geological data it is not possible to derive accurate excavation and construction quantities.

6.2 DEVELOPMENT COST

The development cost consists of the following items:

1. Feasibility Study
2. Development Cost
3. Construction – Civil Works
4. Construction – Electromechanical Works
5. Contingencies
6. Operation and Maintenance

6.3 UNIT COSTS

Recent developments by Hydro Tasmania were used as a basis of estimating unit costs. These developments include Butlers Gorge mini hydro (2 MW), Woolnorth wind farm (10 MW), South Australian small hydro projects (2 MW) and Parangana Dam small hydro (0.8 MW). Additional information was also obtained from suppliers and contractors.

6.4 CONTINGENCIES

In this Concept Study stage it is not possible to predict unforseen costs during the feasibility, development and construction stages mainly due to incomplete knowledge of geological conditions but also to multiple other factors. Therefore, the following physical contingencies will be evaluated in construction cost:

✧ For feasibility study:	5% of the feasibility study cost
✧ For development stage:	25% of the development cost
✧ For civil works:	20% of the construction cost
✧ For electrical and mechanical works:	15% of the construction cost

However it has to be noted that this estimate and schedule were prepared at a very preliminary stage. The results shown in this report are indicative and shall not at this stage be considered as a confirmation of the project cost and planning. These activities will need to be studied and detailed more precisely at the feasibility level.

6.5 COST ESTIMATE FOR OPTIONS

The cost estimates for the four options studied are given in Table 6-1. Operation and maintenance costs have been assumed to be $20/MWh.

Table 6-1 Cost estimates of tidal plant options

			Airport Creek - 2MW			Doctors Creek - 2MW			Doctors Creek - 5 MW			Reservoir - 1MW		
		Unit	Quantity	Unit Cost	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Cost	Amount
1	**FEASIBILITY STUDY**				**1,070,000**			**1,410,000**			**1,410,000**			**622,000**
1.1	Site Investigation	hour	200	120	24,000	200	120	24,000	200	120	24,000	100	120	12,000
1.2	Site Survey	item			100,000			150,000			150,000			70,000
1.3	Geotechnical & Sediment Investigation	item			500,000			700,000			700,000			250,000
1.4	Environmental Impact Assessment	item			180,000			250,000			250,000			50,000
1.5	Preliminary Civil Design	hour	700	100	70,000	800	100	80,000	800	100	80,000	600	100	60,000
1.6	Preliminary E/M Design	hour	800	100	80,000	900	100	90,000	900	100	90,000	700	100	70,000
1.7	System Modelling	hour	300	120	36,000	300	120	36,000	300	120	36,000	300	120	36,000
1.8	Economic Analysis	hour	80	120	9,600	80	120	9,600	80	120	9,600	80	120	9,600
1.9	Project Management	hour	200	120	24,000	200	120	24,000	200	120	24,000	150	120	18,000
1.10	Drafting	hour	400	80	32,000	400	80	32,000	400	80	32,000	400	80	32,000
1.11	Report Preparation	hour	120	120	14,400	120	120	14,400	120	120	14,400	120	120	14,400
2	**DEVELOPMENT**				**1,020,000**			**1,310,000**			**1,400,000**			**720,000**
2.1	Detailed Design including drafting	item			400,000			450,000			500,000			300,000
2.2	Development Approval	item			120,000			200,000			200,000			80,000
2.3	Tendering	item			100,000			100,000			100,000			100,000
2.4	Land Acquisition - Easement	item			100,000			200,000			200,000			40,000
2.5	Construction Supervision	year	1.5	100,000	150,000	1.8	100,000	180,000	2	100,000	200,000	1	100,000	100,000
2.6	Project Management	year	1.5	100,000	150,000	1.8	100,000	180,000	2	100,000	200,000	1	100,000	100,000
3	**CONSTRUCTION - CIVIL WORKS**				**9,502,763**			**12,661,688**			**14,567,438**			**5,971,350**
3.1	Site Establishment	10%			863,888			1,151,063			1,324,313			542,850
3.2	Access Road	km	3.5	265,000	927,500	2.5	265,000	662,500	2.5	265,000	662,500	0.2	100,000	20,000
3.3	Levies	m^3	6,000	25	150,000	6,000	25	150,000	6,000	25	150,000	10,000	25	250,000
3.4	Cofferdam (sheet piles)	m^2	4,000	400	1,600,000	6,000	400	2,400,000	7,000	400	2,800,000	0	400	0
3.5	Foundation Excavation & Stabilisation	m^3	16,000	50	800,000	30,000	50	1,500,000	40,000	50	2,000,000	10,000	50	500,000
3.6	Barrage/Reservoir Construction	m^3			0	25,000	60	1,500,000	25,000	60	1,500,000	800,000	3	2,400,000
3.7	Channel Scour Protection	m	200	5,000	1,000,000	200	5,000	1,000,000	200	5,000	1,000,000	100	5,000	500,000
3.8	Powerhouse Construction	m^2	500	7,500	3,750,000	500	7,500	3,750,000	600	7,500	4,500,000	200	7,500	1,500,000
3.9	Site Restoration	5%			411,375			548,125			630,625			258,500
4	**CONSTRUCTION E/M WORKS**				**6,175,000**			**6,225,000**			**11,425,000**			**3,535,000**
4.1	Gates	item			1,000,000			1,000,000			1,300,000			750,000
4.2	Stoplogs	item			300,000			300,000			300,000			200,000
4.3	Trashracks	item			50,000			50,000			50,000			30,000
4.4	Turbine/Generator/Control	kW	2,000	1,800	3,600,000	2,000	1,800	3,600,000	5,000	1,600	8,000,000	1,000	2,000	2,000,000
4.5	Circuit Breaker and Protection	item			350,000			500,000			800,000			150,000
4.7	Transmission Line	km	5	50,000	250,000	2	75,000	150,000	2	100,000	200,000	0.2	100,000	20,000
4.8	Communications, RC Monitoring, Fire and Intruder Alarms	item			75,000			75,000			75,000			75,000
4.9	Monitoring and Control	item			200,000			200,000			200,000			160,000
4.10	Installation and Commissioning	item			350,000			350,000			500,000			150,000
5	**CONTINGENCIES**				**3,135,303**			**3,864,088**			**5,047,738**			**1,935,620**
5.1	Feasibility Study	5%			53,500			70,500			70,500			31,100
5.2	Development	25%			255,000			327,500			350,000			180,000
5.3	Construction - Civil Works	20%			1,900,553			2,532,338			2,913,488			1,194,270
5.4	Construction - E/M Works	15%			926,250			933,750			1,713,750			530,250
6	**Operation and Maintenance**	year			**140,000**			**174,000**			**342,000**			**68,000**
	TOTAL				**20,903,065**			**25,470,775**			**33,850,175**			**12,783,970**

7 Economic and Risk Analysis

7.1 ASSUMPTIONS

The following assumptions have been made for the economic analysis:

Constants

Discount rate (nominal)	15%
Period of analysis	35 years
Construction period	2 years
CAPEX breakdown	50% in 1st year, 50% in 2nd year
Interest during construction	Included
Interest rate on bank loan (nominal)	10%
Period of bank loan	25 years
Capital cost – grants/investment	40% / 60%
Investment – debt/equity	20% / 80%
Taxation rate on grants	0%
Value of renewable energy certificates RECs	$25/MWh
Consumer Price Index (CPI)	3.0 %
O&M costs for tidal plant	$20/MWh
Management costs for tidal plant	$20/MWh
O&M, management cost increase as % of CPI	90%
Diesel fuel price (escalated at CPI of 3 %)	$0.90/L
Fixed costs of running diesel generation	$500,000
Initial load – Derby only	27 GWh/year
Load growth per annum	2 %
Escalation rate of initial power purchase price	3.0 %
Diesel efficiency (kWh/L)	3.6

Variables

Cost per kW installed	As per the options costed
Installed MW	1, 2, 5
Storage volume and load met	Options from Table 2-6

The discounted weighted average tariff (DWAT) has been calculated to compare options independent of the PPA escalation rate. No additional capital expenditure has been assumed for the diesel generation system, although replacement generators will certainly be required in years to come. DWAT discounts future costs and, instead of revenue, generation.

First, the most promising tidal plant options are compared to determine which option will deliver the lowest unit cost of energy. The best tidal plant option is then combined with diesel generation to derive the DWAT of the entire system, and the sensitivity of this system to the assumptions given above.

7.2 ENERGY PRODUCTION

The tidal plant modelled in this study generates no energy for a few hours per day. Therefore, a diesel generation system capable of supporting 100% of the load is required.

The energy production for various sizes of tidal plants has been modelled (Section 3), and has been summarised in Table 3-2. The load met by tidal energy production is not constant if there is surplus generation. As the load increases over time, the load met by the tidal plant will increase and surplus generation will decrease. Table 3-3 gives the load met at 10 and 20 years, assuming 2% load growth. Linear interpolation is used to predict the load met for intermediate loads. Each tidal plant option has its own load met curve, depending on the surplus generation and operating characteristics.

7.3 CAPITAL COST

The capital cost estimates from Section 6 have been used for this analysis. This covers four of the most promising options from the seven options identified in Section 3. The three options not costed are given in Table 7-1.

Option description	***Reason for not costing this option***
10 MW, 7.4 Mm^3 storage at Doctors Ck	Low utilization (20%), much longer barrage required, longer roads and transmission
5 MW, 4.35 Mm^3 storage at Doctors Ck	Utilization and load met is same as the smaller storage of 2.5 Mm3, which has a shorter barrage length, shorter roads and shorter transmission.
2 MW, 4.35 Mm^3 storage at Doctors Ck	Utilization and load met is same as the smaller storage of 2.5 Mm3, which has a shorter barrage length, shorter roads and shorter transmission.

Table 7-1 Options that were not included in the cost estimate

#	*Option description*	*% Utilization*	*Cost per kW*	*Total Load Met (MWh/year)*
1	2 MW, 1.6 Mm^3 storage at Aiport Ck	40.0%	$10,452	7,000
2	2 MW, 2.5 Mm^3 storage at Doctors Ck	49.1%	$12,735	8,600
3	5 MW, 2.5 Mm^3 storage at Doctors Ck	32.6%	$6,770	14,300
4	1 MW, 0.8 Mm^3 storage in new reservoir	39.3%	$12,784	3,445

Table 7-2 Options included in the cost estimate

In this section, utilisation is defined as the total annual load met by the plant divided by the total possible annual production (running at full capacity, 8760 hours/year). As a simple a comparison, the capital cost of the four options was annualized over the life of the project, and the O&M costs added, to estimate the unit cost of tidal energy. This is shown in, as well as other renewable energy options. No grants are included to reduce the capital cost in

Figure 7-1. The graph aims to compare the tidal energy options with other renewable options. The TEA 48 MW proposal estimated cost around $7000/kW and would have initially operated at 40% utilization.

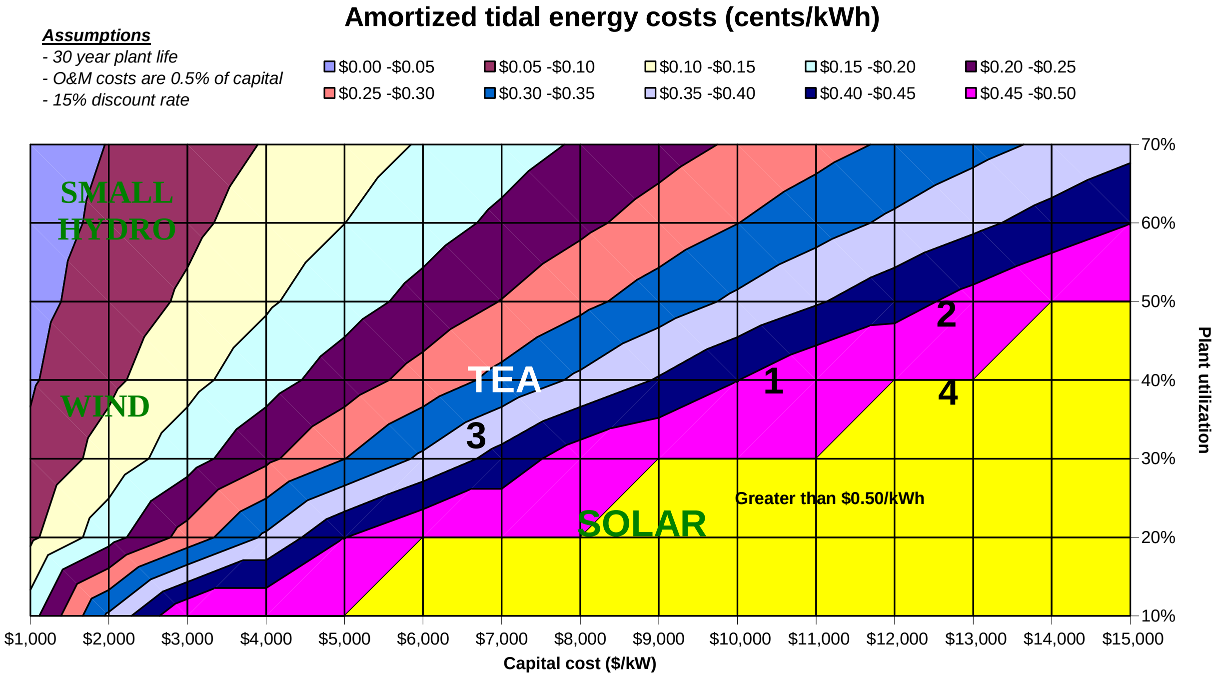


Figure 7-1 Comparison of tidal options against other renewable energy

Tidal energy is clearly a more expensive form of renewable energy than wind or small hydro, particularly for small plants. Option 3 results in an approximate cost of energy of $0.36/kWh for tidal energy, before the inclusion of capital cost grants or green energy benefits such as RECs. The cost of diesel generation is not included in this cost. Options 1, 2 and 4 are smaller projects, and have a high cost per kW. The cost estimates indicate a large fixed cost for items such as the powerhouse, project development and civil works

Figure 7-2). The cost of energy drops dramatically when capital cost grants are included (Table 7-3).

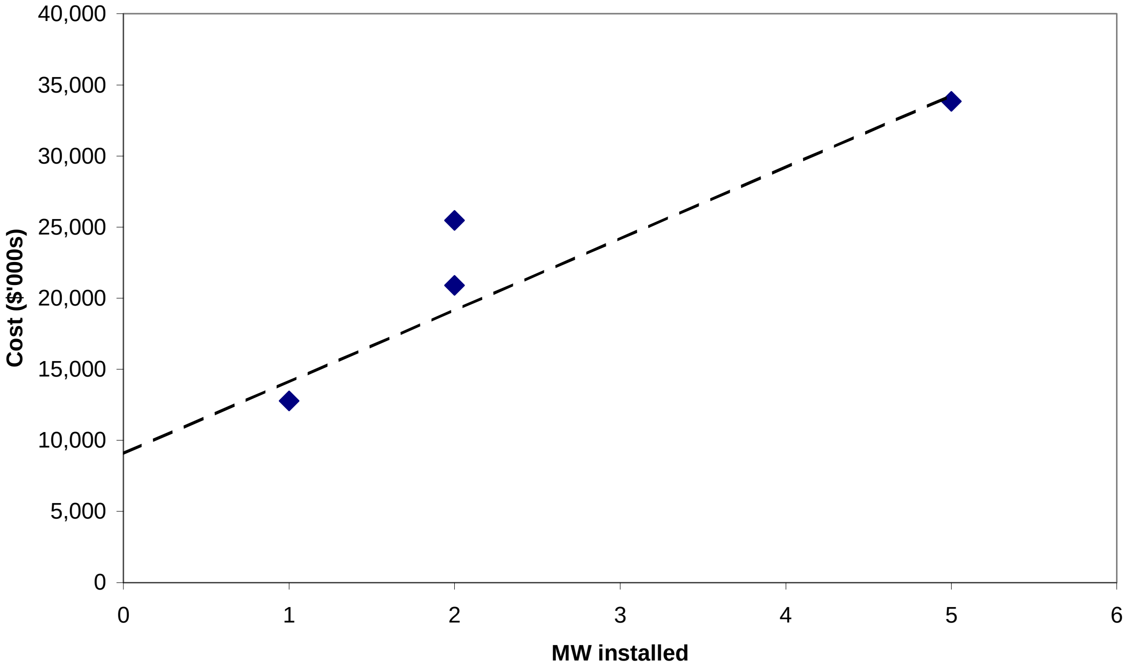


Figure 7-2 Cost trend for tidal options

#	**Option description**	**% Utilization**	**Cost per kW**	**Amortised cost (¢/kWh)**	
				0% grant	*50% grant*
1	2 MW, 1.6 Mm^3 storage at Airport Ck	40.0%	$10,452	48	25
2	2 MW, 2.5 Mm^3 storage at Doctors Ck	49.1%	$12,735	47	24
3	5 MW, 2.5 Mm^3 storage at Doctors Ck	32.6%	$6,770	36	19
4	1 MW, 0.8 Mm^3 storage in new reservoir	39.3%	$12,784	58	30

Table 7-3 Amortised energy costs for tidal plant options

Larger options than option 3 all suffer from low utilization rates. The utilization rate of the 5 MW option will gradually increase to 37% over a 20 year period as the small amount of excess generation is absorbed by growing demand.

The conclusion is that a 5 MW tidal using a 2.5 Mm^3 storage at Doctors Creek is the most cost-effective of the options studied, and is expensive compared to renewable energy options such as wind and small hydro. A 5 MW tidal plant will result in 50% of current load being met by tidal energy, while the remaining 50% will be met by the existing diesel system.

7.4 TOTAL SYSTEM COSTS

Diesel generation costs are required to determine the present value and tariff structure for a generation system that would be attractive to an investor. Costs for diesel generation are given in the assumptions and compromise of fuel costs and annual fixed costs. Both these costs are assumed to increase at the same rate as the CPI. Figure 7-3 clearly shows that diesel fuel costs would still be a major cost of the system, and has a strong impact on the revenue required for the project to be commercially attractive.

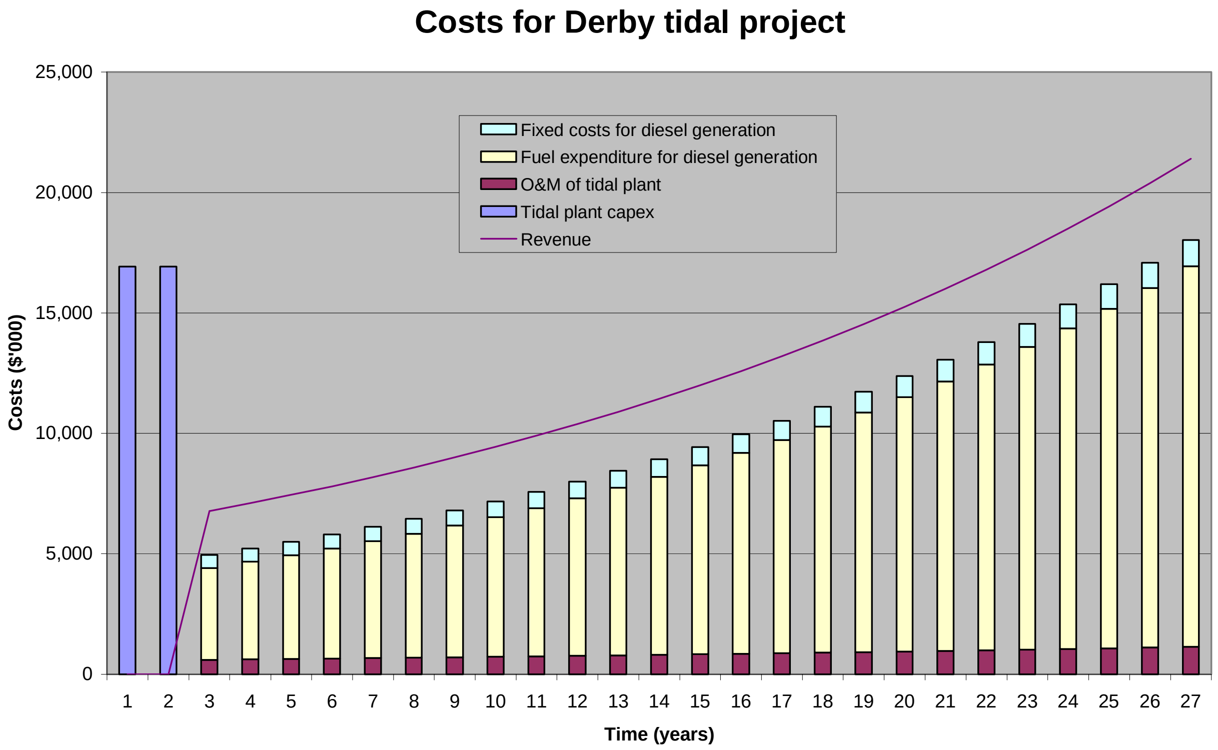


Figure 7-3 Costs and revenue (5 MW tidal plant, $6770/kW, $0.211/kWh)

The return for the project can be assessed in three ways:

1. Return on the project – this is an economic analysis of costs and revenues of the entire system, given the assumptions in section 3.1, but before capital grants are included. This is effectively the return of the project if no grants were given. This is a similar approach to amortising costs, as was done in Table 7-3.

2. Return on investment – this is an economic analysis that includes the capital grant as revenue for the investors in the project. This is effectively the return of the project after grants, but with a debt/equity ratio of 0/100.

3. Return on equity – the original TEA proposal assumed a debt/equity ratio of 80/20, which improves the return on equity, given a lending rate of 10%. This is of most interest to potential investors.

A nominal discount rate of 15% was used for all analyses, and the sensitivity to discount rate is investigated in section 7.5. For each of the "returns" listed above, a "minimum" tariff is calculated for the absolute "minimum" return of NPV=0 and the IRR=15% (the nominal discount rate assumed in Section 7.1). The results are given in Table 7-4.

The aim of this table is to indicate how the financing structure could influence the DWAT. The assumptions include a debt/equity ratio of 80/20 as proposed by TEA and a 50% grant of $16.9 million. All options include the value of RECs as income, at $25/MWh. The table clearly shows that the financing structure of proposals has a very large impact on the DWAT, and that highly leveraged equity combined with a grant can decrease the DWAT by over $0.10/kWh, and that this difference dramatically changes the return on equity. The inclusion of a capital grant for the project reduced the DWAT by 22%, and leveraging reduced the DWAT, although to a lesser extent.

Equity		**Investment**		**Project**		**DWAT**
NPV	*IRR*	*NPV*	*IRR*	*NPV*	*IRR*	*(¢/kWh)*
0	15.0%	-$4.23	11.3%	-$18.0	5.8%	26.8
+$4.23	27.8%	0	15.0%	-$13.8	8.6%	29.3
+$18.0	65.2%	$13.78	24.5%	0	15.0%	37.5

NPV's in $millions

Table 7-4 Economic analysis for 5 MW option at Doctors Creek

7.5 SENSITIVITY ANALYSIS

The sensitivity of the economic results to variations in the assumptions was tested. It is expected that a tidal plant project is likely to receive a grant of 25-50% and involve investment from the private sector. Therefore, the sensitivity analysis is performed on the return on investment, as both equity investors and banks giving a loan will be interested in the results.

The base scenario used for the sensitivity analysis is the "minimum" return on investment – when NPV=0, and there is a 50% capital grant, resulting in a DWAT of 29.3¢/kWh. The parameters varied in the analysis are given in Table 7-5. The results are shown in Figure 7-4 and Figure 7-5, indicating the sensitivity of investment NPV and investment IRR respectively.

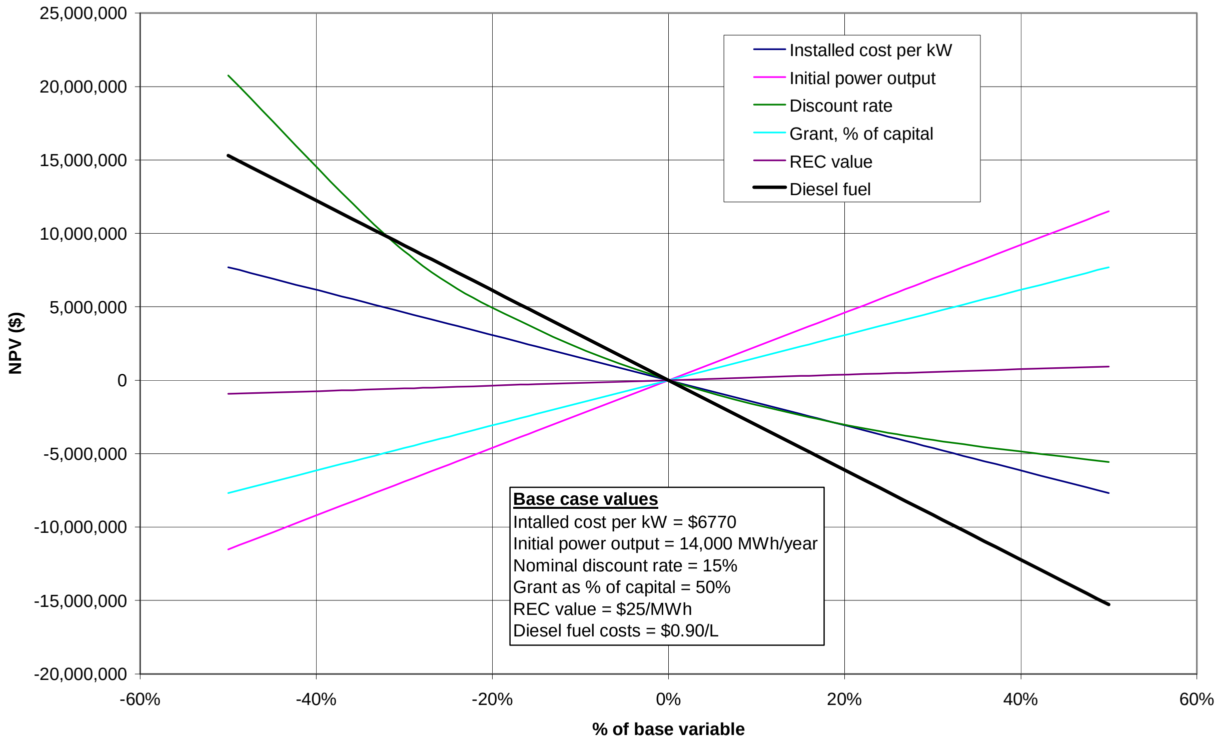


Figure 7-4 Sensitivity analysis of NPV

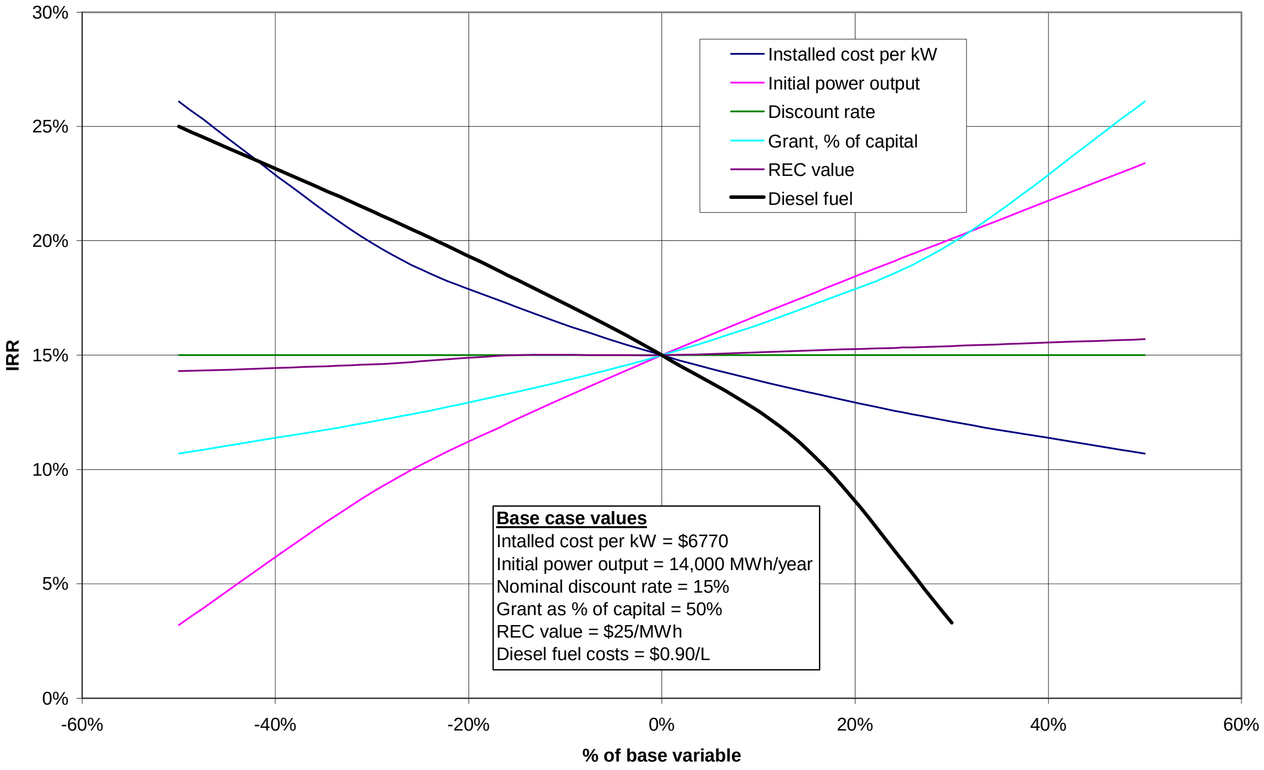


Figure 7-5 Sensitivity analysis of IRR

Assumption	**% Variation**	**Range**
Installed cost per kW	-50% to +50%	$3,385/kW - $10,150/kW
Annual initial power output	-50% to +50%	7,000-21,000 GWh/yr
Discount rate	-50% to +50%	8%-23%
Level of grant received as % of capital cost	-50% to +50%	25%-75%
REC value	-50% to +50%	$12.5/MWh - $37.5/MWh
Cost of diesel fuel	-50% to +50%	$0.45/L - $1.17/L

Table 7-5 Parameters varied for the sensitivity analysis

The economics of the project are still very sensitive to variations in diesel fuel costs and the installed cost per kW. Both of these could vary significantly in the future, and the cost per kW in particular is likely to increase. The project is also sensitive to decreased power production, which may occur due to excessive sedimentation. A decrease in the grant given also has a strong influence on the feasibility of the project. However, the REC values cause little impact, as they only contribute an extra 5% to annual total revenue.

Figure 7-6 shows the impact of assumption variations on the DWAT. For this analysis, the NPV of investment is held constant at zero, again indicating an absolute minimum return to the investor. The previous figures indicate to an investor the sensitivity of the project given a fixed tariff (assumed as a “minimum” tariff an investor could possibly offer, as the NPV would be zero). The aim of this is to show how the various parameters can influence the “minimum” tariff an investor could offer for the PPA, particularly the level of grant offered.

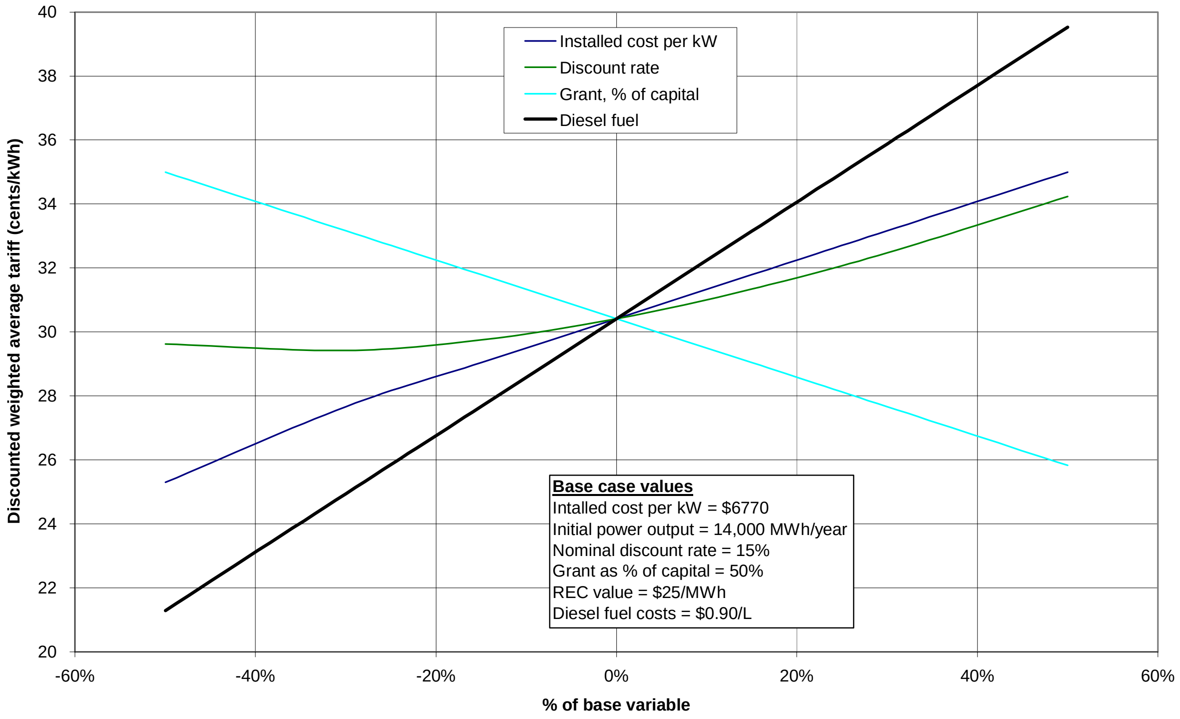


Figure 7-6 Sensitivity of DWAT to analysis assumptions

Again, reducing diesel fuel costs and installed cost per kW are the most effective methods to reduce the tariff for the project. There is little that can be done to reduce the cost per kW, and a reduction in diesel fuel costs indicates that alternative fuels or a continuing subsidy need to be considered. A lower discount rate does little to reduce the DWAT.

shows more explicitly the effect the level of grant has on the 5 MW tidal plant option. If the return on investment is held constant at the “minimum” return (investment IRR=15%, investment NPV=0) and the investor passes on all the benefit of the grant through a reduced tariff, the DWAT decreases linearly with increasing grant levels. Alternatively, the investor may not change the tariff at all (DWAT constant at 29.3¢/kWh) and increases the return on investment (IRR increases exponentially). To what degree the grant results in decreased tariffs or increased profitability needs to be addressed by the State Government and the investors.

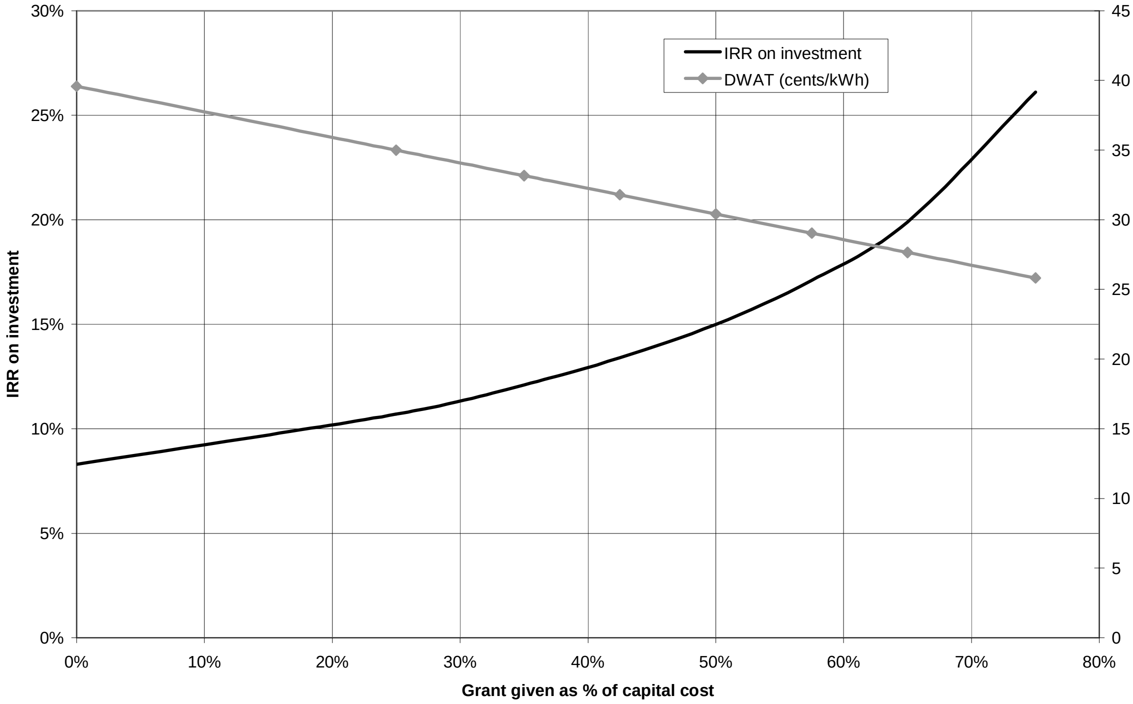


Figure 7-7 Effect of capital grant on project

The total project cost is estimated at $33,850,000, so a 50% grant would total $16,900,000. The discounted total generation from the 5 MW tidal plant is 75 GWh, giving a cost-effectiveness measure of $225/MWh for the tidal plant option, which is 9 times the estimated REC value. This indicates that a subsidizing a tidal plant at Derby may not be the most cost-effective option for reducing greenhouse gas emissions from remote power supplies, or for maximising the stimulation of the renewable energy industry in Western Australia.

7.6 RISK ANALYSIS

7.6.1 Risk Categories, Risk Factors, Likelihood and Impact

The risk analysis consisted of three categories – technical, environmental and commercial. This were separately assessed for feasibility study, construction and operation stages of the tidal project. Many of the risk factors listed can be found in this report, and additional factors were included which were raised in other literature or from communication with stakeholders. The likelihood of a risk factor occurring was rated as high, medium or low, as was the likely impact of the risk factor on the project should it occur.

7.6.2 Risk Management Matrix

The risk management matrix is given in Table 6-5. The major risks include cost escalations, sedimentation levels and associated dredging, acid sulphate soils and rapid deterioration of the turbine and other components in the warm marine environment of Derby.

7.7 CONCLUSIONS

The economic analysis of the Derby tidal project results in the following conclusions

- The tidal energy options are not cost-effective compared to wind or small hydropower, and are approaching the costs of solar PV generation.
- 1 MW and 2 MW options are not as cost effective as larger options due to high fixed costs for the civil works and development.
- A 5 MW tidal plant at Doctors Creek was found to be the most cost-effective option, and is estimated at $33,850,000.
- A tidal plant larger than 5 MW will be uneconomic, due to very low utilization and excessive surplus generation.
- Diesel generation will still supply 50% of annual energy requirements of Derby
- At certain hours of the day, tidal generation will be zero, so full diesel backup is required
- A commercially attractive scenario, even with 50% of capital grants, would result in a discounted average weighted tariff of $0.30/kWh. This is equivalent to an initial tariff of $0.23/kWh, escalating at 3% for 35 years.
- The project is most sensitive to diesel fuel costs, capital cost and the grant available subsidizing the capital cost. RECs add only 5% to total annual income.

Table 7-6 Parameters varied for the sensitivity analysis

REF. NO. (OPTIONAL)					PROJECT TITLE or DEPARTMENT
LOCATION DESIGNTN		PROJECT NUMBER		SUB PROJ /JOB No.	DERBY TIDAL POWER PROJECT CONCEPTUAL STUDY
					SUB PROJECT/JOB TITLE ALL FACTORS

EVENT/RISK FACTORS DESCRIPTION	LIKELIHOOD	IMPACT	CONTAINMENT MEASURES
TECHNICAL			
Feasibility stage			
• Grant/AGO approval of the project	M	L-M	Investigate further with AGO/State Govt.
• Inaccurate modelling of environmental impacts due to lack of information	L	M	Sufficient time and funding to verify models
• Turbine for site conditions cannot be found, or is very expensive	M	H	Detailed market survey during pre-feasibility
Construction stage			
• Site conditions vary from those assumed at feasibility, particularly soils and sediment	M	L	Test drilling during feasibility, geological map
• Weather delays construction – extended wet weather season, storms	L	M	Prepare worst case scenario for weather delay
• Lack of availability of equipment – batch plant, machinery, etc	L	M	Investigate at feasibility, ensure availability
• Construction time underestimated	M	M	Detailed construction schedules, critical path
Operational stage			
• System requires extra maintenance			
Extra dredging required	M	H	Ensure sedimentation models are accurate
Turbine wears excessively due to warm salty water and sedimentation, requires replacing	M	M	Stringent specification for turbine

• System does not achieve predicted energy performance criteria due to;			
low availability and poor reliability	L	H	Criteria in tender, proven equipment, availability history, planned maintenance
technical problem or performance deficiency ie; over estimation of tidal resource	L	H	Sensitivity analysis, check tidal and generation data after commissioning
grid interaction problems	L	L-M	System study, determine possibility and extent
• Storm damage to barrage, especially during cyclone season	L	M	Checked likelihood with Bureau of Meteorology, and wave heights expected
• Corrosion, mainly due to the exposure the elements and salt	H	M	Select equipment with closed circuit cooled generator and good corrosion protection specification
• Spares parts			
Unavailability	L	M	Select large turbine manufacturer
long lead time for delivery	L	L-M	Have suitable supply of parts at Derby, parts supply contract
• Insufficient skills/experience/expertise available for			
Operations	L	M	Training plan
Maintenance	L	M-H	Training plan
• Adverse effect on the diesel motors in areas of maintenance and reliability	L	L-M	Ensure the minimum % scheduled load restrictions are breached
• Lack of routine servicing or preventative maintenance	L	M	Produce or obtain an O&M manual
• Operator/maintenance staff safety			Produce an OHS plan
• Degraded quality of the grid in terms of			
voltage	L	M	switch off tidal generators
frequency	L	M	switch off tidal generators
outage rates of the feeders	L	L	
• Tidal penetration goal of 100% after 1 year not met (affects system quality)	L	H	Contingency plan for possible additional electrical controls
• Fuel cost decreases by using cheaper fuel	L	H	

• Lightning strikes	M	M	Ensure design meets appropriate standards used for similar systems in northern WA
• Selection of a non-performing contractor	L	L-M	Choose a large, established company with a good track record
• Undermining/scour of the barrage foundations	L	M	Erosion protection of all foundations
• Inadequate design of foundations – excessive settling	L	M	Check design and conduct testing of sediments and soils during feasibility
• Tidal resource predicted 10% lower than predicted over project life	L	M	Sensitivity analysis
• Decrease in load demand by 10%	L	L	“
ENVIRONMENTAL			
Feasibility stage			
• Local opposition to development	L	L	Consultation process
• Failure of the land acquisition negotiation			
Goes to court	L	M	Well managed negotiation team
Increased compensation	L	L	“
• Land use, aboriginal or archaeological significance issues	L	L	Have alternative sites possible
• Interferes with communications – microwave, VHF, UHF	L	L	Check during feasibility study
• Environmental measures required make project uneconomic	M	H	Appropriate technical specification
• Environmental approval process delays project	M	M	Appropriate technical specification
Construction stage			
• Construction activities adds to air and noise pollution	M	M	Schedule activities to minimize maximum activity
• Local employment not as great as expected	L	L	Estimate local employment opportunities and assess skills available in Derby
• Decrease in tourism during construction	M	L	

• Visual impact unacceptable	M	L	Construct photomontages for use during consultation processes
• Opposition group formed standing on environmental issues	M	M	Could delay project, especially if overseas interest is raised. Consultation process.
• Lack of adherence to environmental construction guidelines	L	L	Inspection during construction
Operational stage			
• Higher than anticipated impact on mangroves, requiring additional re-colonisation	M	L	Environmental modelling
• Extra sluicing required to flush out sediment, leading to reduce generation	M	H	Sedimentation modelling during feasibilty and verification after operation begins
• High number of road kills on access road	L	L	
• High number of bird kills on transmission line	L	L	
• Exposure of acid sulphate soils through dredging, construction or draining			
Increasing corrosion of concrete and metallic structures	L	M	Identify areas with these soils. Minimize construction in these areas, or replace soil.
Ecological impacts due to increased acidity and dissolved metals	L	L	Lime neutralisation and/or bunding of exposed soils
• Sediment plumes downstream of project result in unexpected impacts	M	L	Modelling and verification
• Sedimentation is same as expected, but leads to severe reduction in fish spawning	M	M	"
• Migration problems and fish kills due to turbines	M	L	Fish friendly turbine design, fish ladders included in the design
• Knock-on effects on local industries – fishing, tourism			
Fishing industry	L	M	
Tourism industry	M	M	Promote project as much as possible to increase tourism

COMMERCIAL			
Feasibility stage			
• Capital costs for lowest tender higher than predicted	M	H	Obtain budget quotes from several sources, not just one, and compare
• Delay in establishment of the BOO development	L	M	Allow at least the same time as BOO contracts of similar sized projects
power agreement	L	M	“
financial and legal entity	L	M	“
agreement on the assignment of the responsibility for risk	L	M	“
• Perception of the project outcome not favourable, project brief or needs not met, brief or needs not communicated, lack of consultation, concerns not addressed	M	M	Devise and manage a communication plan
• Political influence derailing the project	H	H	Stakeholder management plan
Construction stage			
• Contractual dispute during either BOO operation or Turnkey construction	L	M	
• Cost over run by 10% or Time over run	M	M	Suitable checks in preparation of the implementation plan, provide a suitable cost and time contingency, manage expectations of stakeholders
• Industrial relations problems during construction and operation	L	M	Check with union on the construction and operation and maintenance immediately after gaining approval
• Foreign exchange rate less favourable, increasing cost of overseas components (elec/mech)	M	M	“
Operational stage			
• Changes in rural government policies impacting load growth	L	L	
• Increased commercial loads requiring additional generation to be built	M	M	
• Change of State Government	L	M	

• Change of Federal Government	L	M	Next election 3-4 years away, RRPGP is a commitment made by both governments
• Change in the value of Renewable Energy Certificates	M	L	Monitor situation
• Future diesel prices above those estimated	M	H	Monitor situation
• Future diesel prices below those estimated	M	H	Monitor situation
• Financial collapse of the BOO company	L	L	
• Change in ownership of the tidal plant	L	L	Clause/s in the contract
• Buy back required of the tidal plant from the BOO developer	L	L	“
• Changes in owner’s business strategies and corporate policies affect tidal plant in 30 year life	L	M	
• Market or Revenue – change due to change in income (tariff)	L	H	
• O & M increasing above 2% of capital cost allowed	H	M	Warranty from manufacturer for first two years. There will be very little O&M for first 5 to 10 years. Prepare sensitivity analysis for 2 to 4%
• Interest rate increasing or decreasing (hence discount rate)	H	H	Sensitivity study
• Inflation Rate increasing	L	M	Sensitivity study
• Increase in fuel costs to the fuel consumers of Derby	L	L	Consider relationship of volume transported to price
• Tourist benefits not realized	M	L	Promotion after construction is complete
• Power tariff increases for Derby community due to impacts	M	M	Identify and address risks before operation

8 Social Considerations and impact on Local Economy

8.1 SOCIAL CONSIDERATIONS

8.1.1 Background

The town of Derby is isolated by distance, being 2,366 km from Perth by road and over 2 hours drive from Broome. HGM (1997) quote modest growth for the Derby region of around 1.6% by the year 2011 (based on 1996 figures) which is lower than Broome (3.1%) and the historical average for the Kimberley region (2% between 1986 and 1995). It is projected that the town's population will be 9,100 in 2001 (HGM 1997). Around half of the local community is of Aboriginal or Torres Strait Islander origin. It was evident during discussions with Derby residents that growth in the town was less than some other areas, in particular, Broome which has been attracting more of the regional services and tourism trade of the Kimberley region.

Derby does have a sound economic basis founded on local mining and transport activities, tourism, pearling and some regional services. The majority of the local community appear to heavily in favour of tidal power development for the town, due to the impetus this may provide for tourism and industrial growth in the area.

8.1.2 Recreational and commercial utility

Many of the tidal creeks in the area are utilised for recreational fisheries. Sport-fishing for estuarine species such as barramundi and threadfin salmon is popular as is the use of nets and traps for mud crabs. The area has scenic values, typified by largely unspoilt mangrove communities and little residential development. A barrage across any of these creeks will affect the recreational utility of the area by restricting free boat access between upstream and downstream sites, as well as affecting the fishery or scenic values themselves. The presence of electricity transmission lines from the power station site may affect the aesthetic values of some areas. This could be mitigated to a small extent by optimising the placement of these lines, however the landscape is fairly flat, and natural barriers to view fields in the area are limited.

There is some potential for the development of recreational opportunities due to tidal power development. This has been discussed for the double basin TEA proposal (HGM 1997) where the presence of a 'high' basin that had a permanently artificial water level could be utilised for recreational fishing, possibly aquaculture, and had inherent scenic values. With single-basin and other schemes that rely on maximising the tidal range of the storages, it is still likely that a significant recreational fishery can be maintained.

There are likely to be some but possibly unmeasurable negative effects on the commercial fisheries of the immediate area. These impacts arise through either loss of access to fishing grounds by the physical presence of a barrage, or through habitat modification and subsequent loss of nursery areas for commercially important fish species. Any barrage type proposal is likely to increase downstream sedimentation which may lead to an increase in habitat (for instance mangroves) in sites that are currently occupied by tidal channel. The relative change in habitat and the potential affects on commercial and recreational fisheries will need to be assessed in detail for each individual proposal.

8.1.3 Social disturbance and pollution

Construction activities for any of the development options will inevitably lead to temporary increases in dust, noise and road deterioration due to heavy vehicle traffic. This could be offset to some degree by utilising sea transport and barge transfers to construction sites where possible, however some increase in road traffic cannot be avoided. Noise or dust generation at either of the construction sites is unlikely to have a significant effect on residential areas in Derby. Mitigation of these potential impacts can be undertaken through dust minimisation strategies (eg. wetting down of roads) and limitations on noisy work after normal working hours.

Long-term disturbance of the local community is unlikely. There will be limited heavy traffic to the site after construction, with most traffic likely to be of a sight-seeing nature. The operation of the tidal power plant is not likely to generate any significant noise concerns.

Dust increases dues to drying of tidal flats was raised as a concern for the TEA proposal (HGM 1997), but this is unlikely to be significantly higher than the ambient dust loads experienced by the town presently. The scale of potential dust generation is proportional to the size of the scheme and the subsequent constriction of inflowing tides to the tidal flats behind the impoundment.

Electricity transmission lines are traditionally a social concern for both aesthetic and health reasons. It is likely that power lines can be routed such that a minimal number, if any, households are within close proximity to transmission easements. The aesthetic component will be harder to mitigate, but is unlikely to significantly degrade the scenic value of the area. There are widespread health concerns in relation to high voltage transmission lines in other parts of the world. Due to the small distances involved for supply local power to Derby, the voltages to be employed for the Derby tidal power is likely to be a relatively low 11 or 22 KV.

The potential for tidal power to offset a large proportion of diesel generation at the existing Derby power station will reduce local pollution levels, as well as helping Australia to meet its CO_2 emission targets set under the Kyoto Protocol. This should be seen as a major benefit for the community as a whole.

8.1.4 Cultural Heritage

At present, there do not appear to be any major cultural heritage impediments to the development of tidal power in Derby. A high level of consultation will need to be carried out with the aboriginal community for specific proposals should they be the subject of detailed investigation. This would be best facilitated by the Kimberley Land Council. It will be necessary to engage the entire cross-section of the aboriginal community, to ensure that the cultural significant of any sites to be disturbed can be assessed. It is most likely that cultural heritage surveys will need to be conducted at specific sites affected by tidal power proposals, including any new road and transmission line easements. Consultation for the TEA proposal (HGM 1997) appears to be well received with general support from the aboriginal community, pending the results of detailed cultural heritage surveys.

8.2 POTENTIAL IMPACT ON LOCAL ECONOMY

The local economy is likely to benefit significantly from the development of tidal power at Derby. This has been recognised by the local Council who are strong advocates of tidal power generation for the town. The benefits arise through offsetting the costs of diesel fuel which currently is used to generate all of Derby’s electricity. These costs are already subsidised to some extent by Western Power (HGM 1997) and therefore replacement of diesel fuel could be positive for both electricity prices and will ease the financial burden on Western Power.

Construction will lead to many jobs both directly (eg. tradespeople, labours) as well as indirectly (eg. accommodation, services, food). The exact economic benefits cannot be calculated as they vary with the location and scale of the scheme and the technologies employed.

On-going benefits will also be enjoyed by the township of Derby and the greater Kimberley region. It is likely that tourism to the area will be increased and it is likely that tourists will spend additional time in the area to visit the tidal power station. This will have flow-on effects in terms of service provision for these people and may create further jobs in the tourism industry. Depending on the scale of the tidal power development, additional industry may be attracted to the area and this will undoubtedly increase the economic viability of Derby and the Kimberley.

8.3 CONCLUSIONS

Tidal power development at Derby is likely to be positive for the social and economic climate of Derby and the greater Kimberley region. There is a high level of support within the township for such development and although the issues need to be investigated in more detail, there do not appear to be any significant social constraints on tidal power development for the township of Derby.

Socially, there are some drawbacks. For fisheries related issues, the problems arise due to the environmental impact on the tidal areas in the immediate vicinity of the development, yet are relatively minor in relation to the region. Some of these issues can be offset through creation of new fisheries habitats and through increasing accessibility to new fishing areas. Other potential drawbacks are the loss of aesthetic and other landscape values due to either the power plant infrastructure or transmission lines. These issues are likely to be relatively minor at Derby, and can be mitigated against to some degree. It will be necessary to consult extensively with the aboriginal community for any specific development proposals to ensure that cultural values are not significantly compromised.

Economically, the development of tidal power at Derby will be positive for the Derby, in that it will offset expensive diesel power generation and will increase both long and short term employment. It is likely that tidal power will provide another tourism drawcard to the region, with the associated benefits.

9 Funding and Ownership

9.1 TURNKEY

Western Power would call tenders for design and construction of small tidal power development for the scheme previously identified. Western Power would fully fund the scheme, would receive all income from the scheme, and would be responsible for maintenance and operation. The Contractor would be paid for detailed design and construction, and would only be responsible for warranty issues after completion of the project.

Western Power would be required to issue a specification detailing the quality and performance requirements for the proposed scheme, and would need to verify that conformance with the specification was adhered to during design, construction and installation.

Advantages to Western Power:

- Final costs well defined
- Easier to compare and assess competing tenders
- All income goes to Western Power

Disadvantages to Western Power:

- Western Power would need to fully fund the schemes
- Full feasibility study would be required before tendering to determine scheme's viability
- Western Power would need to hire engineering services (or establish a new team) to prepare specifications, tender assessment, construction supervision and performance verification, since small tidal power production is outside Western Power's area of expertise.
- Western Power does not have experience in operating and maintaining small hydro tidal schemes.

Risks to Western Power:

- Western Power takes all risk on energy price fluctuations and potential optimisation of power production
- Anticipated power production may not be achieved.
- Maintenance cost may be too high.

9.2 BUILD/OWN/OPERATE (BOO)

Western Power would call tenders for design and construction of small tidal power development for the scheme previously identified. The Contractor would fully fund the scheme, would receive all income from the scheme, and would be responsible for maintenance and operation.

As the Contractor would own, operate and maintain the schemes, it is in their interest to specify the quality that would provide the best returns, taking into account maximising production and minimising maintenance and downtime.

Advantages to Western Power:

- Minimal involvement required by Western Power in the design and development of the schemes.
- Western Power does not require experience in operating or maintaining the schemes

Disadvantages to Western Power:

- Full feasibility study would be required before tendering to determine scheme’s viability
- Returns to Western Power will not be maximised

Risks to Western Power:

- Projects may not be viable because Developers can not rely on energy output optimisation
- Minimal risk, but minimal return
- No development takers
- Financial collapse of the BOO company and loss of Commonwealth’s and State Government’s granted subsidies.

10 Scope of a Tender Process

10.1 PURPOSE

Tenderers would be required to supply power to Western Power from a Tidal Power Plant at the Project Location with the power to be derived from a “Build, Own and Operate” Derby Tidal Power Plant realised generally in accordance with specified parameters listed as follows:

✧ Project Location	Derby, WA
✧ Type of Development:	Single tidal storage basin
✧ Required Effective Storage Capacity:	2,500,000 m^3 (minimum)
✧ Required Sediment Storage Capacity:	for 20 years (undredged)
✧ Rated Head:	5 m
✧ Rated Discharge:	125 m^3/s
✧ Rated Capacity:	5 MW
✧ Annual Energy Output:	app. 16.7 GWh (to be purchased by Western Power)
✧ Surplus Generation:	app. 2.3 GWh (estimated and not to be purchased by Western Power)
✧ Back-up Supply:	Provided by Western Power

The successful tenderer will be required to enter a power purchase agreement (Agreement) with Western Power for the sale of energy for a period of 20 years from the Nominated Commercial Operation Date which is not to be beyond 1 January 2006.

10.2 PROJECT LOCATION

The work to be carried out by the successful tenderer under this Agreement would be the design, construction, operation and maintenance of a Tidal Power Plant located on Doctor’s Creek West Branch near Derby (Figure 1). There are several locations where the development could be constructed. The successful tenderer should locate the tidal plant at this location or a site that is considered the most advantageous for the success of the project.

10.3 EXTENT OF WORK

The work shall comprise the complete design, manufacture, fabrication, factory testing, delivery to site, the supply of all materials, construction, installation, site testing and commissioning together with the submission of all Contract documentation deliverables necessary for the successful completion of the Derby Tidal Power Plant. All costs associated with the development of the project, ongoing operation and maintenance are to be included in the project and funded by the successful tenderer.

The successful tenderer will be responsible for at least the following list of items:

1. **Funding**
    - All costs associated with the development of the tidal development
    - All costs associated with ongoing operation and maintenance of the tidal development
2. **Detailed Studies and Investigations**
    A. Detailed Contour Survey of the tidal storage basin and adjacent area
    B. Geological and Geotechnical Investigations
    C. Construction Material Investigation
    D. Detailed Modelling of Sediment Behaviour
    E. Environmental Impact Assessment
    F. Energy Production Modelling
    G. Use of Excess Energy
    H. Power Line Connections
    I. Construction Management Plans
3. **Approvals and Licenses**
    a) Federal Government
    b) State Government
    c) Local Government
    d) Road Access
    e) Environmental Approval
    f) Heritage
    g) Native Title
    h) Other
4. **Detailed Design**

The design work to be performed by the successful tenderer under this Agreement includes all design work required to complete the construction of the Derby Tidal Power Plant. The key development items are:

- access road
- levees
- barrage across Doctors Creek
- channel scour protection
- power house
- turbine/generator/control system
- gates and stoplogs
- circuit breaker and protection
- communications, RC monitoring, fire and intruder alarms
- monitoring and control
- transmission line to a specified point of delivery at Derby.

4.1 Design Standards

The design work is to be undertaken according to all relevant Australian Standards. Where no Australian Standard exists the work is to be carried out according to the relevant British Standard.

4.2 Design Life

Materials used, design methods and workmanship standards shall be the best commercially available and have the following targets for design life:

Civil/Structural works	minimum 50 years
M&E plant and equipment	minimum 20 years

4.3 Operation and Maintenance

The Tidal Power Plant shall be designed to:

- Work in accordance with Western Power’s reliability and quality specifications
- Minimise any need for shutdown for maintenance or inspection.
- Restrict any major planned overhaul work to frequencies greater than five years.
- All equipment shall be designed to operate reliably in accordance with the manufacturer’s instructions in the environment in which it is installed.

5. **Construction and Commissioning**
   - Access Road
   - Tidal Power Station
   - Transmission Line
   - Site Testing and Commissioning
6. **Rights**
   - Technology Licences
   - Connection to the Distribution System
   - Renewable Energy Certificates

7. **Operations**
   - The total Derby Tidal Plant and any associated facilities for the Term of the Agreement
   - All required maintenance of the Derby Tidal Plant and any associated facilities
8. **Agreement**
   - Negotiated on the basis of the tender and subject to minimal conditions precedent, all of which to be satisfied prior to the Agreement becoming binding.

10.4 DEVELOPMENT SCHEDULE

It is expected that the development of the Derby Tidal Power Plant will take no more than 36 months as follows:

➢ Tendering Process:	3 months
➢ Detailed Studies and Investigation :	6 months
➢ Detailed design:	4 months
➢ Approvals, Agreements and Licenses	7 months
➢ Construction and Commissioning:	16 months

11 Conclusions and Recommendations

11.1 CONCLUSIONS

A review has been conducted on the tidal energy potential and tidal energy technologies available to tap this potential. The conclusions from this study are as follows.

- Tidal energy technologies can be classified as either tidal current or tidal barrage technologies
- Tidal current turbines are not appropriate for the scale of project required for Derby, as the technology is still in the development phase and is not in commercial production
- Existing tidal barrage designs are technically viable, and have used ebb generation, two-way generation and pumping at ebb tide.
- All existing projects have resulted in major environmental impacts

Limitations of the current study are:

- No detailed survey information is available and this limits the accuracy of the estimates of quantities and reservoir volumes;
- No geotechnical investigation of the potential sites has been undertaken and the conditions may have a major impact on the civil construction costs;
- No information is available on the sediment dynamics in the estuary. Sediment dynamics has significant environmental and technical implications to the project;
- Only a preliminary assessment of the potential environmental effects has been undertaken to date.

Modelling of a single basin tidal scheme was undertaken for 5 storage capacities and 7 sizes of installed capacity, with only Derby connected as a load. The conclusions of the model are:

- The storage ranges from 0.8 Mm^3 to 7.4 Mm^3, all at 11.5m of head.
- Installed capacities modelled varied from 1 MW to 15 MW.
- The modelling showed that single basin tidal plants of 7.5 MW or more will have an uneconomic amount of surplus generation, leading to low utilization of the plant.
- The optimum sized options in terms of maximising utilization are of 1-5 MW.
- The small amount of surplus generation from these options will be absorbed by load growth
- For a single basin design, there are hours during the day when the tidal plant will not be generating power. These hours will change from day to day due to tidal cycles.
- Therefore, the diesel generation system must be able to supply 100% of the load.

A general environmental assessment of a tidal plant at Derby concluded that:

- The majority of issues relate to changes in the tidal flow patterns in the immediate vicinity of the plant, resulting in
    - altered geomorphological processes,
    - disturbance of riparian communities and
    - potential changes in water quality
- Of greatest concern is the potential for excessive sedimentation of the channels upstream and downstream of the plant and hence the need for ongoing dredging.
- It is likely that mangrove ecosystems will be modified or destroyed, with losses upstream and possible expansion downstream.
- There is a high risk of acid sulphate soils being present, which could lead to corrosion issues with infrastructure, water quality problems and fish kills.
- Preliminary discussions with the Kimberley Land Council did not identify any significant aboriginal heritage issues.

- Corrosion from seawater, abrasion erosion from silt and sand and biofouling are all major concerns
- While this assessment did not identify any issues that would preclude tidal power development, proper management of environmental issues could impose significant economic constraints.

A study of development options concluded that:

- Multiple basin designs for small systems were not viable due to greatly increased barrage lengths, and therefore no preliminary cost estimates were made.
- Three locations have been considered as feasible for a single-basin design: Airport Creek, Doctors Creek and the construction of a new reservoir on the southern side of the wharf.
- The powerhouse structure would consist of mass concrete foundations to resist buoyancy, and be supported by driven piles to prevent subsidence, rotation and lateral displacement. The walls would be heavily reinforced and the roof would consist of removeable panels.
- Construction of and access road access would most likely be achieved by displacement of the upper level of tidal mud with rock.
- Slope and bed protection will be required for protection against erosion.
- Low head bulb or Kaplan turbines would be used, and the warm, saline environment may limit the options significantly.
- The power station will require both upstream and downstream bulkheads, inlet and outlet gates to seal of turbines during maintenance periods, and radial sluice bypass gates.
- Spinning reserve and demand peaks will be major factors in meeting performance standards.
- To maintain a speed and frequency, either a governor or controllable load will be required. A hydrogen production cell could be used for energy storage, or pumping and heating loads.
- Conventional high voltage transmission lines can be used, with an expansion of the existing SCADA system to incorporate the new plant.
- Energy storage can be achieved through hydrogen electrolysis, to be used in modified diesel generator as fuel replacement, or a battery system.
- The commercial viability of fuel cells and electrolysis is expected to improve in the future.

Preliminary cost estimates were made for the four most promising options.

- The cost per kW ranged from $6,770 to $12,800. Capital costs ranged from $12.8 million to $33.9 million for 1 MW and 5 MW options respectively.
- Capital costs had high fixed components, resulting in larger plants being more cost effective.
- The cost estimates are very general, as they were based on very limited information.

An economic and risk analysis concluded that:

- The most cost effective option was found to be a 5 MW tidal plant at Doctors Creek with a 2.5 Mm^3 volume of water storage. 1 MW and 2 MW options had higher utilization rates, but much higher costs per kW.
- The tidal plant would meet 50% of the annual demand, with the existing diesel generators meeting the remaining load.
- The cost of unsubsidized tidal energy was estimated at $0.41/kWh for the 5 MW option.
- Including the cost of diesel generation, the discounted weighted average tariff for this option was estimated at $0.304/kWh given a 50% capital cost grant of $16.9 million and a nominal discount rate of 15%.
- Therefore, project remains very sensitive to variations in diesel fuel costs.
- The project is also very sensitive to installed capital cost, the grant received, power output and the discount rate used (and therefore inflation).
- The project is not cost-effective compared to wind or small hydropower, and is approaching the costs of solar PV and fuel cell power generation
- A risk analysis matrix has been included in the report.

Tidal power development at Derby is likely to be positive for the social and economic climate of Derby and the greater Kimberley region. There is a high level of support within the township for such development and although the issues need to be investigated in more detail, there do not appear to be any significant social constraints on tidal power development for the township of Derby.

Two options are presented for construction and ownership.

- Turnkey development gives Western Power well defined costs, allows simple comparisons of competing tenders and results in all income going to Western Power.
- The disadvantages of a turnkey agreement include:
    - Full funding of the project required from Western Power
    - Full feasibility would be required before tendering to determine viability
    - Western Power takes all the risk on energy price fluctuations and maintenance cost variations
- Offering a build/own/operate contract to external companies would give Western Power the advantages of minimal involvement in the design and development of the project.
- However, returns to Wester Power would not be maximised, as the risk has been limited, and the project may not be viable.

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APPENDIX A Derby Tidal Power – General Arrangement Siteworks - Powerhouse

APPENDIX B Alstom selection curves for low head Kaplan

2- Very low head solutions