River Tawe Barrage Hydrogenerator

Feasibility Study

City and County of Swansea

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Plan Design Enable

Notice

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1. Introduction

Atkins Limited have been commissioned by the City and County of Swansea (CCS) to assess the feasibility and costs involved in installing a new hydrogenerator at the Tawe Barrage at Swansea.

The Tawe Barrage was originally designed to incorporate a back pumping facility to offset water losses through the lock and fish pass. During the barrage design process, a decision was made to modify the design of the back pumping facility to allow it to be used for the dual purposes of back pumping and electricity generation.

The original turbine / pump unit was a modified Flygt pump and was operational for a few years after the construction of the Barrage. The turbine / pump unit was removed from the shaft a few years ago.

The City and County of Swansea (CCS) are interested in re-installing a hydrogenerator unit within the existing construction and assessing whether installing a new unit is financially viable. It is intended that the new unit will only be used for hydrogenation and we understand that pumps will be hired in should back pumping to maintain the water level in the impounded reach be required.

Figure 1.1 – The Tawe Barrage with the inlet to the hydrogenerator shaft in the foreground

2. Potential for Hydro Power Generation

The quantities of water that could be available for power generation will be impacted by a number of factors. These are listed below;

- **Abstraction licence:** Consent issued by the Environment Agency. This imposes daily/yearly limits to the quantity of water that can be abstracted, as well as setting derogation of the abstraction to maintain a minimum flow within the fish pass.
- **Flow in the River Tawe:** A flow/frequency relationship will need to be derived to calculate how much water might be available for abstraction.
- **Tides:** Tidal fluctuations within the Bristol Channel mean that the differential head across the barrage will vary with time. As this is a half tide barrage, tide levels exceed the normal level of the impounded reach, meaning that no power generation will be possible around the peak of the tide.
- **Lock operation (lockage):** Use of the lock will take water from the impounded reach, reducing the quantity available for power generation. The quantity of lockage water will vary with time as levels downstream of the barrage vary with the tide.
- **Potential energy losses:** Constraints within the existing pipe work mean that head losses within the system will reduce the differential levels available for power generation.

The impact of each of the above on the potential for hydropower generation is discussed below.

2.1. Abstraction Licence

The conditions of the abstraction licence have been reviewed. The constraints of the abstraction licence are listed below;

- Not more than 34,000,000 cubic metres a year to be abstracted.
- The rate of abstraction does not exceed 133,000 cubic metres in any one day of 24 hours.
- The hourly rate does not exceed 8,300 cubic metres.
- When the flow in the fish pass falls to one cubic metre per second, the abstraction shall cease.
- During the months of April and May, the abstraction shall not cause the level of water over the primary weir to fall below 150mm. A relaxation of this condition may be sought annually by application to the Area Water Resource Manager who, subject to prevailing conditions, may give written notification of any such relaxation.

2.2. Hydrology

In order to determine the quantity of water that would be available for abstraction, use has been made of the Environment Agency stream flow gauge at Ynystanglwys. Ynystanglwys is located on the outskirts of Swansea, some 8.5km upstream of the Tawe Barrage.

The flow records for the last 10 years at the Ynystanglws gauge were requested from the Environment Agency.

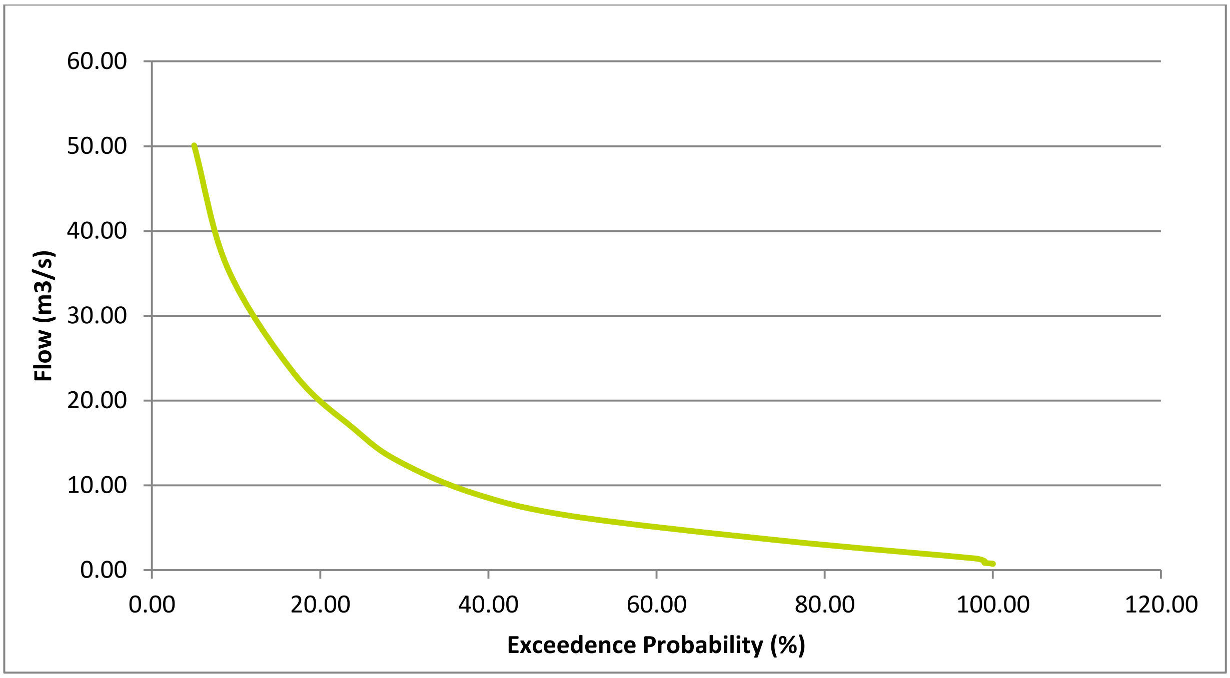
The catchment area located to the south of the gauge has been included within the assessment by using a ratio factor calculated from the recent hydraulic modelling work Atkins have undertaken on the River Tawe for the Environment Agency and the City and County of Swansea. Once the flows were adjusted to take account of the additional catchment area between the gauge and the barrage, the flow characteristics were computed from the daily river flow data recorded at the gauge. The data was then used to provide flow exceedence values for the different probability events.

The results provided below are shown as flow exceedences, i.e. the Q95 is the flow that is exceeded 95% of the time.

Table 2-1 – Exceedence flow values at Ynystanglwys Gauge and Tawe Barrage

	Exceedence Flow (m^3/s) for different percentiles										
	Q5	**Q10**	**Q20**	**Q30**	**Q40**	**Q50**	**Q60**	**Q70**	**Q80**	**Q90**	**Q95**
Ynystanglwys Gauge	46.7	30.6	17.8	11.2	7.7	5.7	4.4	3.4	2.8	2.0	1.6
Tawe Barrage	53.2	34.9	20.3	12.8	8.8	6.5	5.0	3.9	3.1	2.2	1.8

Figure 2.1 Flow Exceedence at the Tawe Barrage



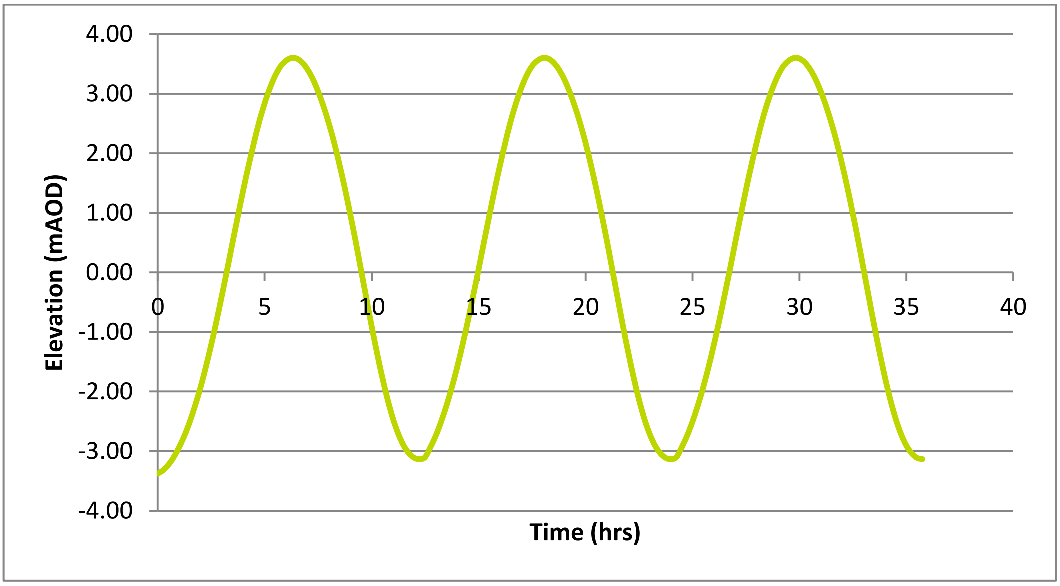
2.3. Tides

The tide tables for 2011 were analysed and for the purpose of these calculations an average tide was assumed. After calculating an average high and low tide from the 2011 data (Table 2-2), a tidal curve was generated using these average values ().

Table 2-2 – Average 2011 tide levels at Swansea.

Chart Datum (m)		Ordnance Datum (mAOD)	
Average Low Tide	Average High Tide	Average Low Tide	Average High Tide
1.9	8.6	-3.1	3.6

Figure 2.2 – Tidal curve produced from 2011 tide tables.



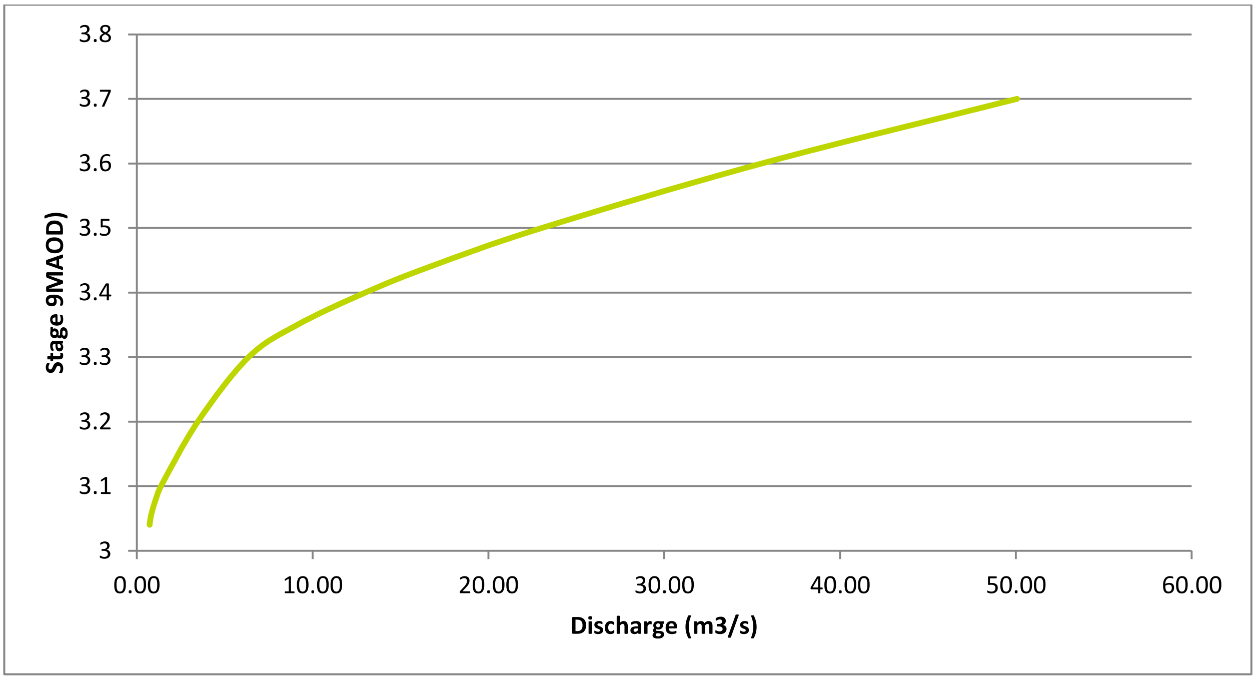
3. Hydraulic Analysis

3.1. Hydraulic Calculations

The barrage design and as built drawings were obtained from the Atkins internal achieve. These drawings were used to base all of the hydraulic calculations to determine the flow available for the hydrogenerator. The hydraulics of the barrage needs to consider the fish pass, as well as the primary and secondary weirs.

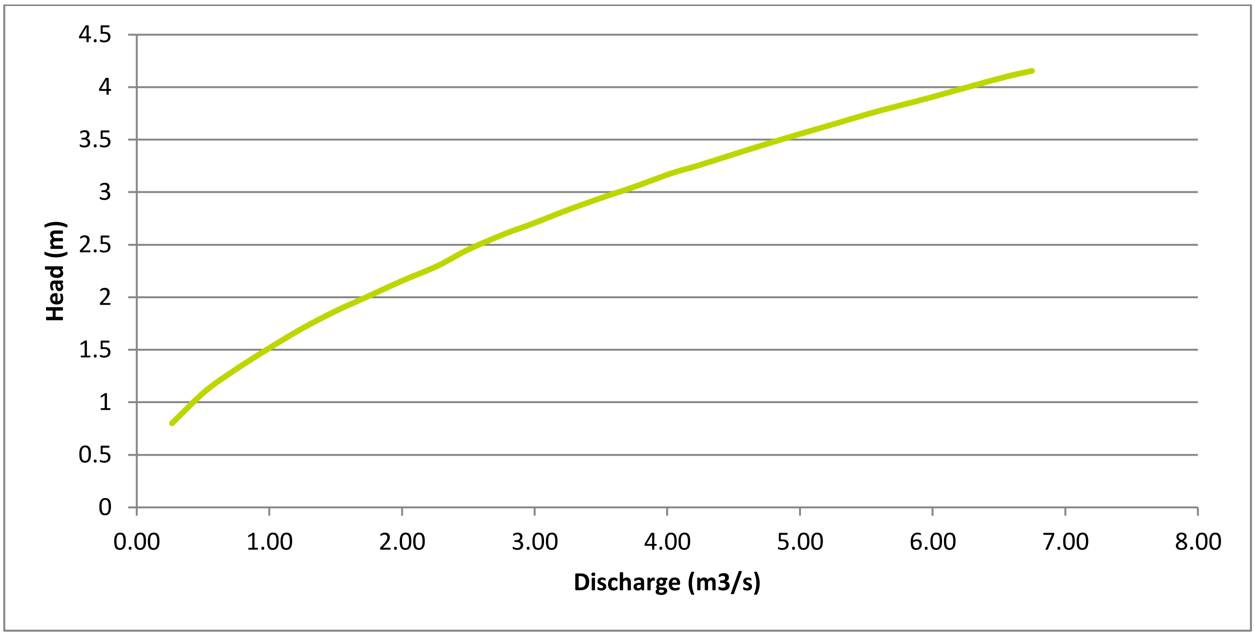
The total flow overtopping the barrage structure was calculated. This was achieved by developing a rating equation for the barrage from the as-built drawings. The relationship is shown in Figure 3.1 below.

Figure 3.1 – Stage Discharge Relationship for the Tawe Barrage



Similarly, an additional rating equation was developed for the hydrogenerator shaft. This again was developed from the barrage as built drawings. The relationship developed for the hydrogenerator shaft is shown in Figure 3.2 below.

Figure 3.2 – Stage Discharge Relationship for the Hydrogenerator Shaft



In addition to the flow overtopping the barrage, the volume of water removed from the upstream impounded area during a lockage scenario needs to be included within the overall calculations. Logs for the operation of the lock during 2009 and 2010 were provided by CCS. These were reviewed to assess the frequency of operation that could be expected.

The total number of lockages in the winter and summer were both averaged. The total number of daily lockages in the winter months was 8 in 2009 and 9 in 2010 whilst the total number of daily lockages in the summer of 2009 and 2010 was 23. It was assumed that the lock did not operate during night time hours. In addition to the number of lockages that occurred during 2009 and 2010, the differential head across the lock during each lockage was also supplied. The average differential head across the lock in 2009 was 2.98m and 2.94m in 2010. This average differential head was then used to calculate the average volume of water required to operate the lock.

3.2. Power Output

The mechanical power produced at the turbine shaft was calculated from the rating curve developed for the hydrogenerator shaft. The equation was calculated utilising a unit efficiency of 60%, 70% and 80%. These are the typical efficiencies that can be expected from a low head hydrogenerator.

The power output from a unit similar to the original Flygt turbine was calculated in order to provide a comparison in case a similar unit is refitted.

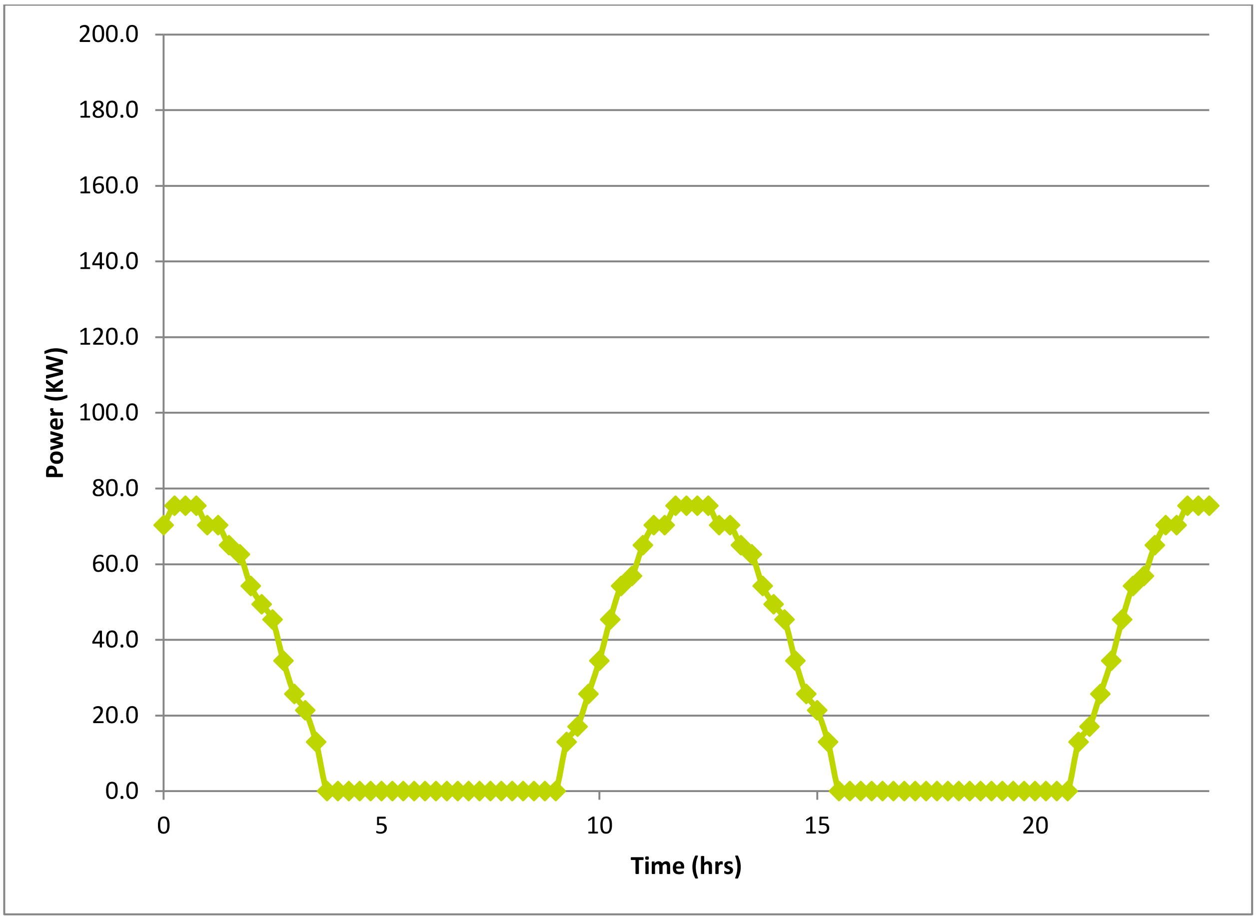
4. Hydraulic Results

4.1. Original Flygt Unit

The original Flygt unit provided a dual purpose of operations as a backflow pump and a hydro-generator. To perform this function it was installed within the main hydrogenerator shaft, and as a result induced relatively high losses which thus reduced the generating potential of the system.

The original generator was an 85kW unit. The power output over a typical tidal cycle with the stage in the impounded area at 3.3mAOD is shown in Figure 4.1 below. The Flygt unit required a differential head of 2.5m before the unit started to generate power. The restrictions stipulated within the abstraction licence have been taken into account during the calculations and it appears that the operation of the previous system would have complied with those abstraction constraints.

Figure 4.1 – Predicted Power Output of Original Flygt Generator



4.2. Proposed Unit

To reduce the head losses associated with the hydro generator shaft, it is suggested that the new unit would be set-up differently to the original Flygt hydro generator. It is suggested that only the propeller should be positioned within the shaft with all the associated switchgear located above the shaft (this is now possible as the unit does not have to operate as a pump). In addition to reducing the losses within the shaft, this would provide easy access for servicing/maintenance requirements.

We have engaged with numerous manufactures in an effort to obtain technical data and outline cost. Unfortunately we have found little interest from any of the suppliers in getting involved in this feasibility study. Across the board there has been a reluctance to supply any data. In order to progress the feasibility we have made assumptions based on the shaft propeller imposing a loss which is equivalent to 25% of the loss through the original hydrogenerator. If additional data and 'in house' losses become available this can easily be incorporated into the calculation to determine estimates of the power output of the system. Based on the reduced losses through the system, there is the potential to utilise a slightly larger 100kW unit, thus providing the capacity to generate more power.

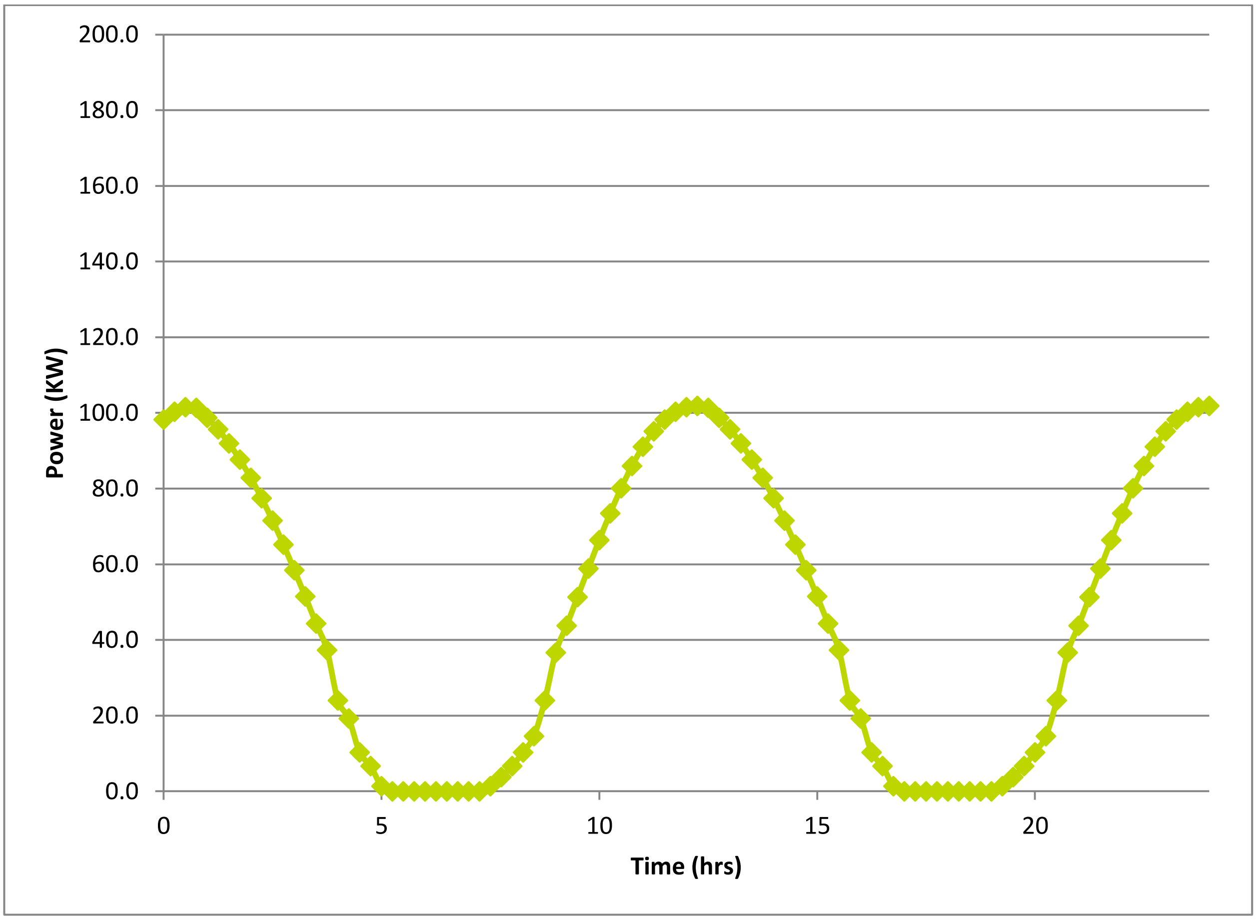
Impact of Abstraction Licence

If the conditions listed in the abstraction licence are taken into account, the flow passing via the hydrogenerator would need to be reduced (limited) significantly during the periods of highest available heads within a tidal cycle. This has the effect of reducing the potential power being generated within the shaft.

In order to meet the conditions of the abstraction licence, an automated sluice would be required to control the flow through the hydrogenerator shaft. It would be required that a level sensor identifies when the flow in the barrage fish pass drops below one cubic metre per second and consequently the abstraction would cease. Additionally, level sensors would be required to measure the differential head across the structure. Once the differential head increases above 2.25m, the automated sluice would need to restrict the amount of flow being passed into the shaft in order to meet the conditions within the abstraction licence.

The power output over a typical tidal cycle with the stage in the impounded area at 3.3mAOD, is shown below. Allowance has been made for a minimum differential head of 0.25m prior to the system being able to generate any power. The efficiency conversion has been applied following discussions with a turbine manufacturer who suggested that a unit with a 70% efficiency would be appropriate for this site.

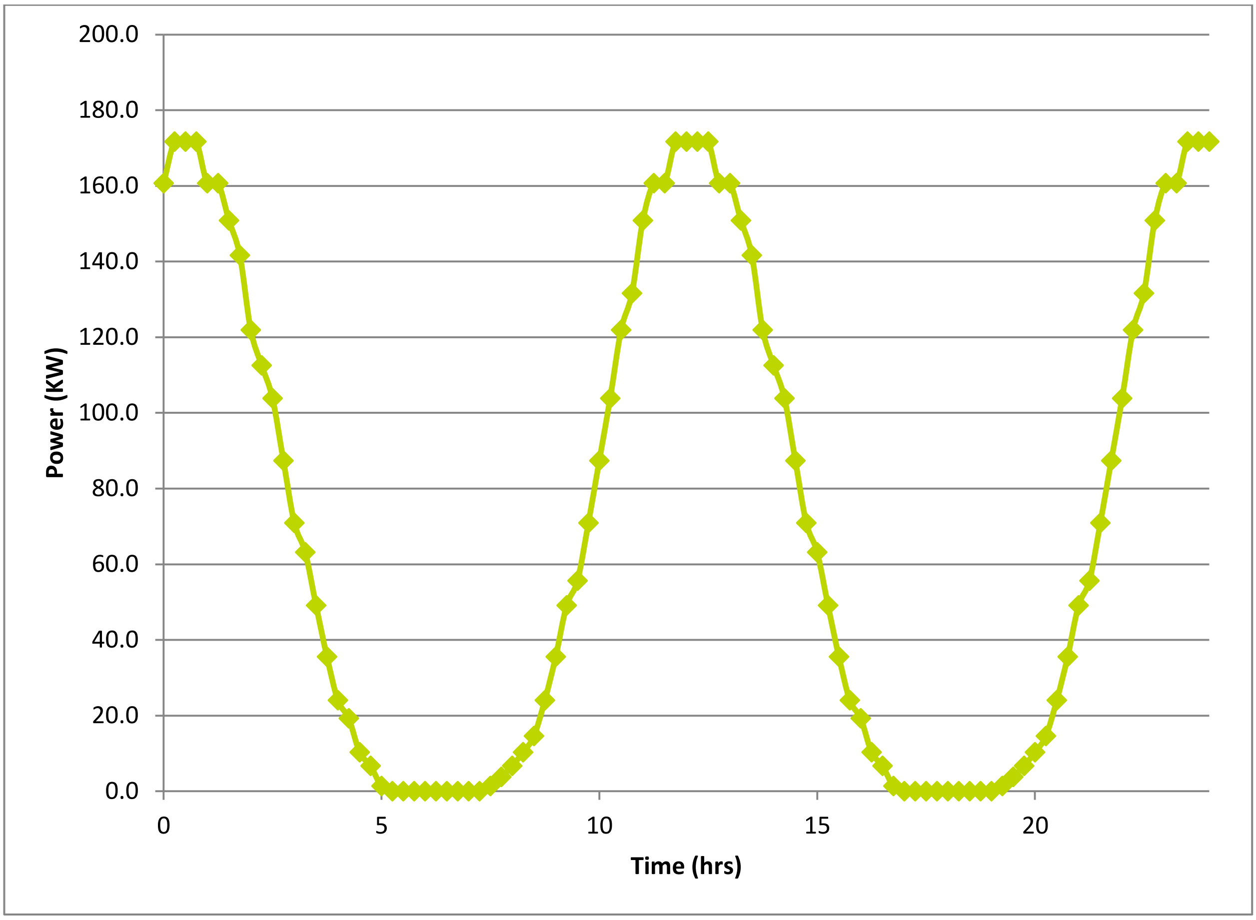
Figure 4.2 – Predicted Power Output of Proposed Generator with implications of Abstraction Licence



4.3. Unrestricted Output

The results indicate that if the flow is free to pass through the generator shaft across a typical tidal cycle without the flow implications of the abstraction licence (except for the fish pass control), it is probable that a unit with a capacity of between 150kW and 170kW would be viable. The power output over a typical tidal cycle (with an operating efficiency of 70%), with the stage in the impounded area at 3.3mAOD is shown below.

Figure 4.3 – Predicted Power Output of Proposed Generator without implications of Abstraction Licence



4.4. Implications of Restrictions

The abstraction licence imposes restrictions on the quantity of water passing through the hydrogenerator as well as the restrictions imposed to maintain a minimum flow within the fish pass. We have estimated that the biggest restriction to power generation is the limit imposed on the total quantity of water that can be abstracted from upstream of the barrage.

The power output has been calculated for the night (no lockages) and typical summer and winter days to allow for the different frequency of lockage to be taken into account. The calculations assume derogation of the abstraction when flows of less than one cubic metre per second (cumec) are recorded within the fish pass. Until the total flow in the fish pass is greater than one cumec, no flow can be abstracted for hydrogenation. Flows of less than one cumec in the fish pass occur when levels within the impounded reach drop below 3.1mAOD.

4.5. Potential revenue

Using the available information, and an assumption that a unit will provide a 70% power efficiency we have assessed the potential generating revenue that the potential system may provide based on published fee-in-tariffs.

The figures calculated in Table 4-1 are based on a level in the impounded area of 3.2mAOD which is exceeded 75% of the time. For units with a capacity of less than a 100kW, the feed in tariff is 18.7p/kWh, whilst for units with capacities of more than 100kW, the 11.5p/kWh feed in tariff applies.

Table 4-1 – Annual revenue assuming an upstream water level of 3.2mAOD.

5.	**Allowing for abstraction licence (100kW Unit)***		**Not allowing for abstraction licence (170kW Unit)****	
	Day (Summer)	**Day (Winter)**	**Day (Summer)**	**Day (Winter)**
Average Daily (kW)	823	858	1122	1162
Total Daily Revenue (£)	£103*	£107*	£129**	£134**
Total Annual Revenue (£)	£26,836*		£47,944**	

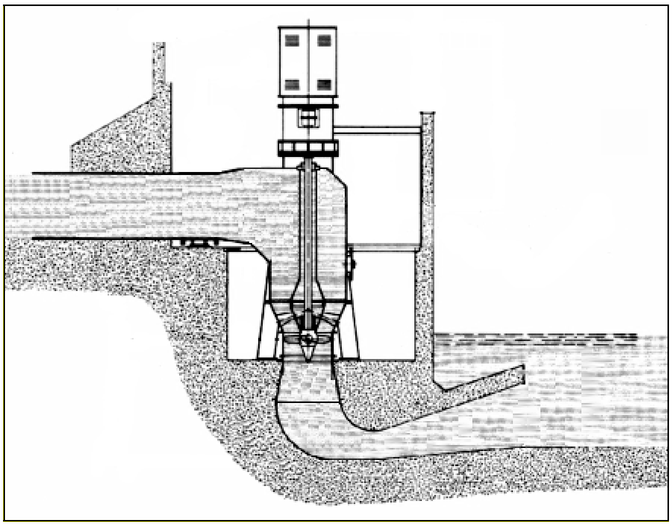
*Revenue based on 18.7p/kWh feed in tariff.
**Revenue based on 11.5p/kWh feed in tariff.

To meet the hourly restriction within the abstraction licence, the maximum flow would need to be limited to $2.3m^3/s$. By implementing this, the generator would be able to operate for 16hrs every day, and for 256 days a year. If the abstraction licence was re-negotiated, the new unit would potentially be able to operate for 19hrs every day (no power output available when the tide exceeds the normal barrage impounded level), and for the full 365 days a year.

5. Proposed Hydrogenerator

It is recommended that a Kaplan turbine is installed at the site as it will utilise the existing infrastructure with limited additional works required. One of the main advantages of the unit is that it features adjustable rotor blades and inlet guide-vanes. The benefit of this adjustability of the rotors and guide vanes is that it provides a wide flow operating range with a high turbine efficiency which is ideally suited for the Tawe Barrage.

Figure 5.1 – A typical Kaplan turbine



Costs for a 100kW unit designed to operate within the differential heads and the flows associated with the Tawe Barrage have been estimated to be approximately £285,000. If the abstraction licence was renegotiated, a unit with a 170kW unit would cost approximately £375,000.

The installation costs associated with both units would be in the region of £30,000-£50,000. These figures have been estimated from previous installations with similar power outputs and operating heads to that of the Tawe Barrage.

6. Electrical Works

6.1. Existing Electrical Works

A control panel is currently installed within the East side pump house which did provide power to the removed combined pump/generator unit, and in turn is fed via 2x armoured cables routed back through the barrage's service tunnel back onto a Western Power Distribution (WPD) import / export meter within the ground floor switchroom of the Lock Control house at the West side of the barrage.

This control panel is now partially redundant and cannot be utilised for any new proposed hydro generator, however the same panel provides small power and lighting sub-circuits within the pumphouse building together with the local penstock actuator and river aerators.

At the time of removal of the old pump/generator unit from within the turbine shaft, it is unknown how the existing cables were disconnected. The exact condition of these terminations will have to be determined prior to any new works being undertaken.

The existing import/export metering unit will have to be replaced due to current legislation for paralleling with the incoming mains WPD power supply, and also WPD have confirmed that there is no current "feed in tariff" arrangement for the Barrage site.

It is also worth noting that the City & County of Swansea are likely to be incurring a substantial standing charge to cover the electrical load that was once requested for the back pumping facility.

Because the original pump/generator unit was designed to operate as a pump for a proportion of its time, it actually was positioned within the river water, which became very prone to breakdowns and limitations of use as a result of debris blocking its inlets.

6.2. Proposed Electrical Installations

Should a new generator be installed, and the fact that the back pumping facility is no longer required, the existing switch and control panels installed at the East side, should be disconnected and removed, with the provision of a smaller panel that will provide power to the local lighting, sockets, penstock and aerators. These could be facilitated utilising one of the existing armoured cables already routed over to the pump house together with a new MCB distribution board.

The other armoured cable could then be used solely to back feed the generator output back onto the WPD's grid.

To enable a new unit to be installed and operate to its maximum efficiency apart from the civil/structural requirements there are various permutations of connection onto the WPD grid that could be considered, and are summarized together with budget costs (not including the generator or civil costs) within the following table.

As the existing generator has now been removed for some time, a new feed in generator tariff will have to be procured with WPD, particularly now as the exact arrangement of connection will change.

Table 6-1 – Electrical connection options

Options	WPD Connection	Works Required	Budget Costs (WPD & Elec. Works)
6.4.	Use existing cabling through service tunnel, to back feed onto the WPD grid via a new export meter located at the Lockhouse's ground floor switch room.	New meter unit, 2x new MCCBs within panel. 1x existing cable used to feed lighting and power within East pumphouse, other cable to be used for export from generator. New dist board and sub-circuit mods within pumphouse. Review standing charge for existing supply, as back wash pump no longer required.	£10,000
2	WPD to provide an export connection at the East side pumphouse.	New export meter, new additional incoming supply to pick up lighting and small power sub-circuits. Existing cables routed through service tunnel and existing meter becomes redundant.	£45,000
3	WPD to provide an export connection at the East side pumphouse, via a new HV substation, should there be limitations within the WPD's LV network.	New export meter, new additional incoming supply to pick up lighting and small power sub-circuits. Existing cables routed through service tunnel and existing meter becomes redundant.	£65,000

If the capacity of the proposed unit was increased to between 150kW and 170kW, an additional cable would be required to export from the generator. This would have an additional cost of £5,000.

Further detailed calculations will have to be undertaken once a final generator unit is proposed, to ensure that the voltage drop of the existing cables (if reutilised as summarised within Option 1) are within the permissible limitations for the actual maximum load that may be exported by the new hydro generator unit.

7. Hydrogenerator Suppliers

We have researched many specialist companies from around the world who could provide a hydro generator suitable for the River Tawe Barrage, these include:-

- Ampair
- Ecowave
- Enocean
- Exmork
- Globalll Hydro Services
- Hydroscrew
- Mahler
- Micro Hydro
- Micro Hydro Power
- Noutage
- Renewables First
- Reuk
- Turbine Services
- Water Turbines

Only one company: Renewables First, has confirmed that they would be interested and be able to provide such a Hydro Generator that is suitable for the Barrage.

8. Conclusions

An assessment has been undertaken on the feasibility of retro fitting a new hydrogenerator within the existing infrastructure at the Tawe Barrage, Swansea.

Calculations have been undertaken on the potential power generation taking into account;

- Variation in flow in the River Tawe
- Seasonal variations in the number of lockages
- Tidal variations across the barrage
- Losses through the existing pipe work infrastructure
- Restrictions of abstraction imposed by the existing abstraction licence.

It is concluded that the most appropriate unit would comprise of a Kaplan turbine. Based on the current restrictions imposed by the abstraction licence, estimated power outputs amount to 100kW. The 100kW unit would allow for the higher feed in tariff of 18.7p/kWh to be utilised rather than the 11.5p/kWh which is the rate associated with turbines with a capacity greater than 100kW.

It would be possible to maximise the potential power generation through the renegotiation of the abstraction licence and the fitting of a higher capacity unit. This could result in the revenue doubling over an annual period.

It is recommended that an approach be made to Renewable First so that more detailed technical data and costs be obtained on a specific hydrogenerating unit.

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