GREAT WESTERN POWER BARRAGE

Energy security through tried and tested technology

May 2021

LESSONS LEARNT EDITION

SUMMARY

The case for tidal power is compelling. Without it, the UK's increasing reliance on wind and solar for its renewable power will lead to failures in the energy supply due to the great variability of the weather. Winter, when the sun is often blocked out by heavy clouds and wind turbines have to be secured to prevent them being broken in the storms, is also a time of peak demand. This combination can lead to a complete electricity supply system closure. This has already occurred in South Australia and Texas which, in both cases, led to a week-long, state-wide, interruption of supply.

Yet a secure electricity supply is essential considering our increasing dependence on computers in every part of our modern world for looking after our homes, commerce, industry and health for many years.

The demand for electricity will grow as the present Government's plans are realised, including the phasing out of gas and oil-fired domestic heating from 2025 and petrol and diesel cars from 2030.

Tidal power has the advantage of being 100% reliable and predictable; the movement of the tides is known far into the future and hence how much supply will be available. Unlike with nuclear generation, there is no long-term danger of radioactive areas and spent fuel. Unlike wind and solar generations, there are no times when the weather prevents its operation.

Power barrages elsewhere in the world have been in operation for many decades without any environmental concerns or other problems. This document outlines features of two working examples of similar tidal power projects with lessons learnt for creating a successful Great Western Power Barrage. There are three other projects which are also discussed briefly for completeness.

In addition, the situation on power generation has been transformed by the international climate change agenda. The proposed Great Western Power Barrage will provide long-term economic benefits for the country. It will generate an environmentally beneficial 7% of the nation's power and will uniquely do so reliably and in all weathers for many decades. It will also enable the UK Government to prove their international leadership in the climate change debate.

This barrage is a major environmentally friendly scheme based on proven technology. It will make a great contribution to fighting climate change by providing renewable and totally reliable tidal energy. It will also prevent flooding of Bristol and the Somerset Levels.

1. INTRODUCTION

This Paper complements two earlier ones for the Great Western Power Barrage (GWPB) 'Centuries of Secure Carbon-Free Electricity' and 'Opening up the Economy of the West and Wales'. Together, these earlier Papers describe the main features of the proposed development of the GWPB and how it should be the cornerstone for the UK's renewables electricity supply.

GWPB requires substantial investment in time and money and so, in addition to modelling having shown it to be viable, this is strongly supported by two schemes which have been operating successfully for many years.

The two reference schemes that operate on the same principles as proposed for the GWPB are La Rance tidal power plant (La Rance) near Dinard on the north side of Brittany, France and Lake Sihwa tidal barrage power plant (Sihwa) in South Korea, which produce around 240 and 250GWh/annum respectively and have similar generating profiles to that planned for GWPB.

Figure 1: Location of La Rance Tidal Power Plant

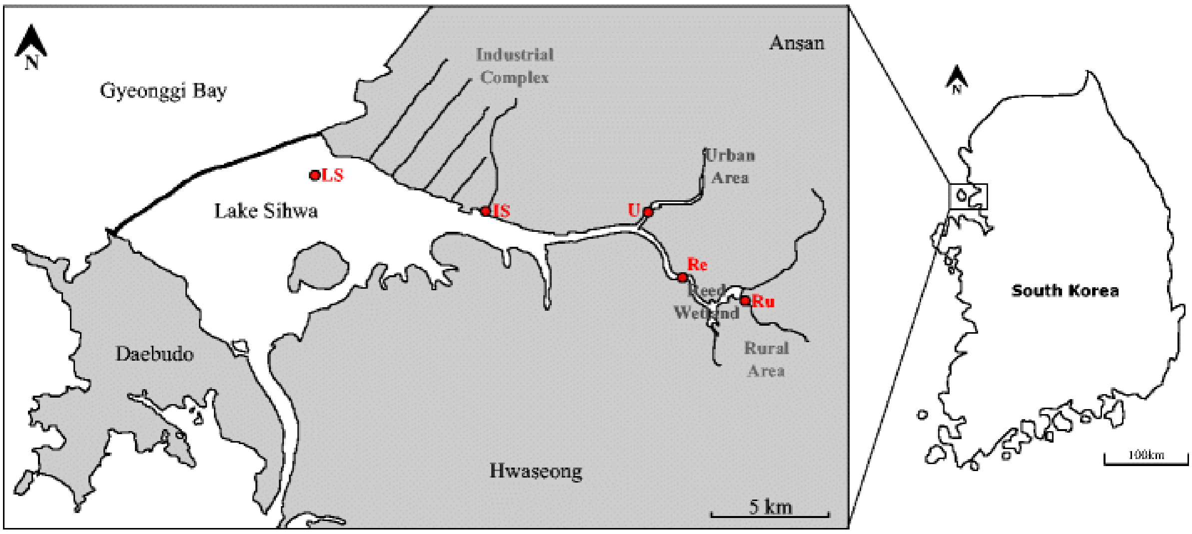

Figure 2: Location of Sihwa Tidal Barrage Power Plant

2. COMPARISON WITH EXISTING TIDAL SCHEMES

The main features of the La Rance and Sihwa projects are compared in the table which follows to those proposed for the barrage across the River Severn. For ease of assembling the information for the Severn, the figures given are those published for the Hafren Power barrage between Lavernock Point (Vale of Glamorgan) and Brean Down (Somerset).

The GWPB proposal is for an alignment from Lavernock Point to the area of the Stert Flats, near Hinckley Point (Somerset). This will increase the reservoir size, the number of turbines and the power generated by approximately 20% from the figures for the Hafren Power Barrage in the comparison in Table 1.

This longer alignment has been selected to protect both Bristol and the Somerset Levels against repeat flooding.

	La Rance	Sihwa	GWPB
Length	750m	12,700m	18,100m
Reservoir size			
- Area	22km^2	56.5km^2	573km^2
- Volume	184,000,000m^3	320,000,000m^3	2,500,000,000m^3
Tides			
- Average	8.2m	5.6m	8.5m
- Maximum	13.5m	7.8m	14.0m
Turbines			
- Type	Bulb	Bulb	VLH (1)
- Size	10MW	25MW	6.3MW
- Number	24	10	1,026
- Installed capacity	240MW	250MW	6,464MW
Annual generation	540GWh	553GWh	17,000GWh (2)
Generation profile	Ebb-flow plus pumping	Flow only	Ebb-flow

Table 1: Tidal Barrage Precedent Comparison

Notes:

(1) VLH turbines are bi-directional and far more efficient at generating energy on the flood tide than traditional bulb turbines. These turbines are lighter, easier to maintain (through a plug-and-play approach) and offer more flexibility in terms of power production and environmental mitigation.

(2) Preliminary estimate for annual generation; more recent modelling indicates that this will be greater.

3. CONSTRUCTION

3.1 LA RANCE TIDAL POWER PLANT

Figure 3: La Rance Tidal Power Plant

This is the oldest tidal range generating plant in the world. Initial studies began in 1943 but it took up until the early 1960s before construction commenced. The barrage then took just over six years to complete and it was commissioned between August 1966 and December 1967.

The structure also includes a lock for boats to pass upstream, as well as sluices. The whole structure was cast in-situ in cofferdams as shown in Figures 4 and 5. The net effect of this method and sequence of construction was that much of the upstream estuary was drained during the construction of the generating part of the barrage.

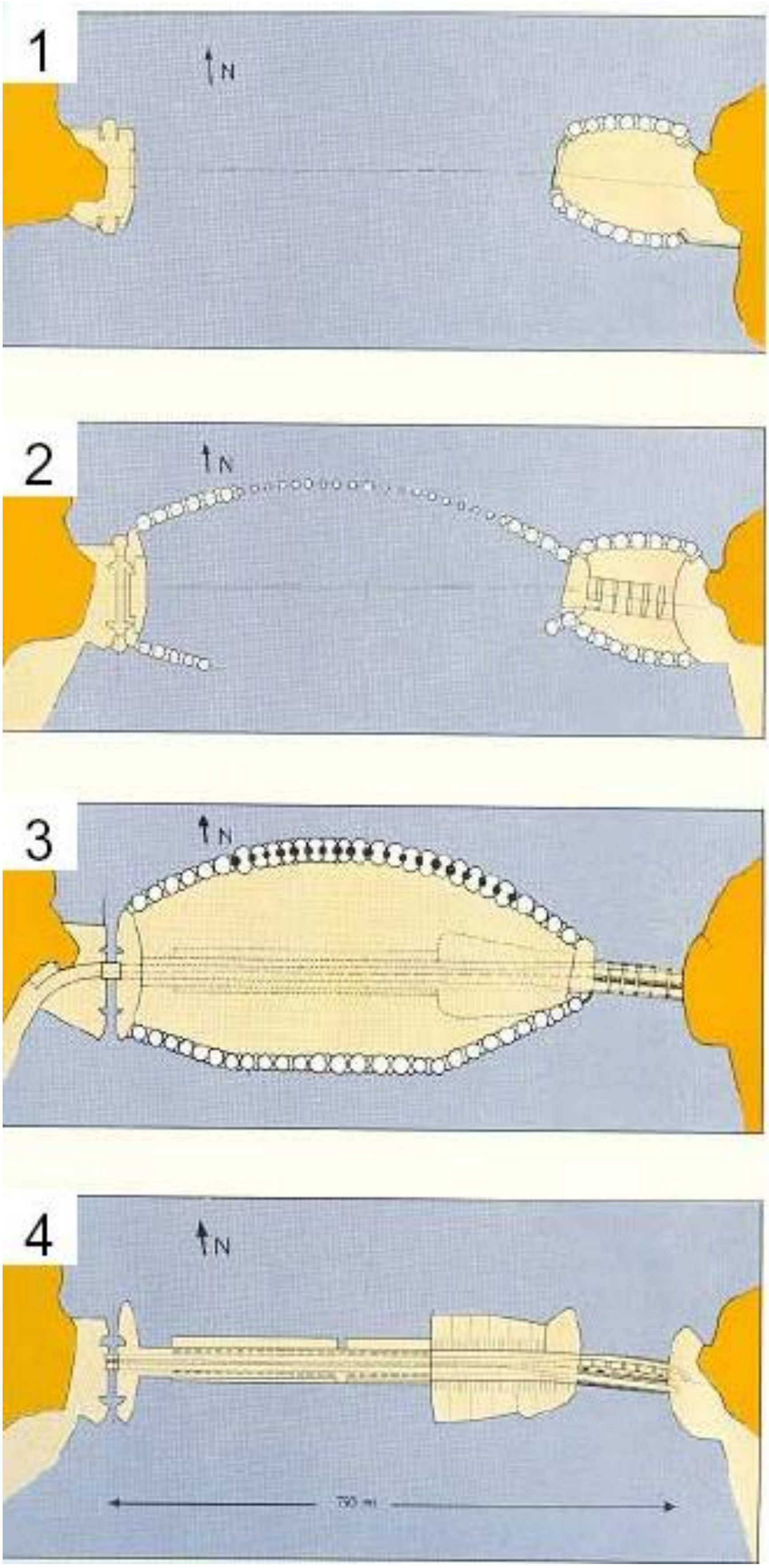

Figure 4: Construction of La Rance using cofferdams

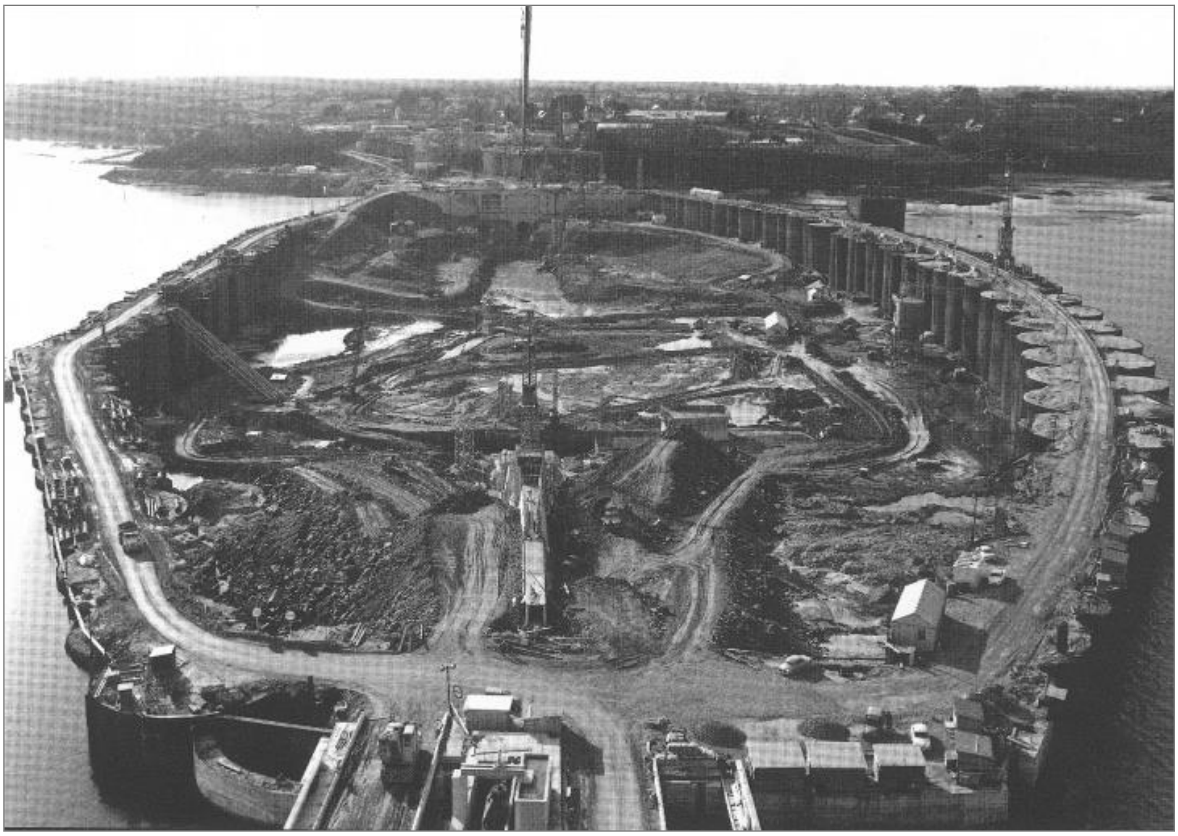

Figure 5: Main barrage cofferdam for La Rance

The following list gives the most important stages of its construction:

Date	Activity
January 1961	Commencement of construction
19 November 1962	Commissioning of the lock (on the west side)
24 March 1963	Commissioning of the six sluices section (on the east side)
20 July 1963	Final closure of the barrage across the estuary
19 August 1966	On-line connection of the first power set
1 July 1967	Inauguration of the road across the dam
4 September 1967	Commissioning of the twenty-fourth power set

Table 2: Key dates for the construction of La Rance Tidal Power Plant

One early decision was to provide cathodic protection against the corrosive effects of seawater on the turbines and sluice gates. This protection was installed, and there has not been any corrosion for over 40 years. The ship lock was refurbished in 2009.

Electricity generation started from August 1966 after the first generating set had been installed. The barrage supports ebb-flow generation albeit that since these are early bi-directional turbines, the efficiency of the ebb-generation is better than for flow-generation and it can also be enhanced by additional pumping from the sea to the upstream reservoir.

The overall barrage comprising the lock, the generating part of the barrage and the sluiceways cost $115m (1966 prices) and this gave an installed cost of US$382 per kWh. The construction cost has now been repaid and the present cost of generating electricity is US$0.2 per kWh.

No breakdowns have been reported and the current turbines are still the original ones even after 54 years of operation. The lock allows for the passage of 16,000 boats each year and the barrage attracts around 70,000 visitors annually. It also provides a road link between Dinard and St Malo which is used by between 20,000 and 60,000 vehicles/day.

The conclusion is that after completion of commissioning, the La Rance tidal power plant including the bulb turbines have performed fully up to expectations for over 54 years.

3.2 SIHWA LAKE TIDAL BARRAGE POWER PLANT

Figure 6: Lake Sihwa Tidal Barrage Power Plant

This project was completed in 2011 and it started operation in August of that year.

The power plant was added to an earlier seawall, providing not only power, but also additional water circulation in the enclosed lake.

The plant is housed in a small island along the earlier seawall. One half is taken up by the ten generating units and the other half by eight culvert-type sluice gates. Generation exploits the head difference between the water level in the sea and Lake Sihwa. As the tide rises, saltwater flows through the turbines to generate electricity. However, at low tide, the sluice gates are raised and the turbines revert to sluicing mode to allow the lake to be emptied.

The turbine and gate housings were cast in-situ in a drained albeit localised cofferdam. Thereafter, a gantry crane was erected and the turbines and sluices installed. New roads were then built over the sluice gates and the temporary diversion roads and cofferdam were removed.

The resulting Sihwa Tidal Barrage Power Plant became the largest and most expensive tidal installation in the world, with an installed capacity of 254MW. According to IRENA (International Renewable Energy Agency), the site cost US$298m to build in 2011 with an estimated cost of US$117 per kWh. It produces over 550GWh electricity annually at US$0.02 per kWh.

Note:

None of these figures can be ‘true’ costs for the development of the scheme—the tidal power was retrofitted to an earlier seawall which does not appear to have been included in the capital cost of the scheme. In addition, the US$0.02 per kWh cannot be allowing for any capital repayment.

4. ENVIRONMENTAL CONSIDERATIONS

4.1 LA RANCE TIDAL BARRAGE

The main build period for this scheme affecting the environment was between the start of construction in January 1961 and July 1963 when there was final closure of the dam across the estuary.

The impact on the wildlife in the estuary was significant during this period largely because the upstream basin was drained of all water to allow the use of a cofferdam so that the concrete for the main parts of the barrage could be cast in situ.

A new ecological equilibrium took about 10 years to re-establish. The operator, EDF Energy, considered the estuary to be richly diversified again by around 1976. A survey in 1980 reported the basin to be home to 110 warm-blooded, 47 crustacean and 70 fish species.

The operation of this barrage has resulted in a 2.5m rise in the mean water level. In addition, there has been a reduction in the hydrodynamic regime, including reduced velocities in the water within the upstream estuary, where the slack period is also longer.

The general flora and fauna distribution became increasingly diverse post-construction. The patterns of distribution, their grouping into ecological units and the nature of their inter-relationships indicate some biological adjustment to the new environmental conditions.

However, the bird varieties visiting the estuary are the same as before the construction of the barrage – around 120 species. The operator reports well developed communities of fish-eating birds including gulls, guillemots and shags. However, some numbers may have altered because of the decrease in the intertidal area – from the 2.5m rise in mean water level. Birds can also find food in other bays (mudflats).

Seabass and cuttlefish have returned to the estuary and there are new fishery activities; scallops and belon oysters are now harvested.

There have also been some changes to the patterns of sedimentation. Even with the slackening of water currents, it appears that the distribution and composition of the estuary sediments is comparable with what is observed in neighbouring natural estuaries. However, one study suggested that the modification of the tidal stream in the estuary, in particular during ebb tides, has provoked more silt deposit in the lower intertidal zone.

4.2 SIHWA TIDAL BARRAGE POWER PLANT

In 1994, South Korea created a 56.5km^2 freshwater lake at Sihwa by constructing a 12.7km dyke between Oido Island in Sikeung City and Daebudo Island in Ansan City. The purpose of this lake was to secure agricultural and irrigation water and to reclaim 173km^2 of land near the local metropolitan areas comprising the three cities around the lake.

However, within a few short years after the completion of the embankment, it became apparent that without seawater circulation, Lake Sihwa was experiencing an inordinate inflow of polluted wastewater from a nearby industrial complex severely contaminating the basin and making it unusable as a freshwater reservoir.

By 1997 and partly driven by the scandal of the pollution, officials had to reformulate their plans by retrofitting a tidal power barrage to circulate seawater for regular flushing as well as for generating power.

This tidal power barrage only generates as the tide in the Yellow Sea outside of the lake rises. During the ebb tide when the tide falls the lake is emptied by opening sluice gates. The reason for this unusual regime is that several buildings had been erected on the lake shores after the building of the original seawall and, as a consequence, the level of the water in the lake had to be reduced by 1.0m relative to the sea level outside. This meant that it was not possible to design turbines which could generate satisfactorily in both directions.

The tidal power plant has effectively dispersed the accumulating pollution in the lake. There is not much other information on what the coast was like before constructing the original dyke and the tidal power plant was an ‘add-on’ to deal with the unexpected pollution problems.

The most remarkable impact has been the recovery of water quality and ecosystems. Approximately 60 billion tonnes of sea water flows in and out of the turbines and the floodgates annually, which equates to a change of about half of the total water in Sihwa Lake every day. This continuous circulation of water between the lake and the outer sea during the power generation process has improved the water quality.

In 1988, the chemical oxygen level in Sihwa Lake was 17ppm, but has since been reduced to 2ppm, resulting in an improved habitat for all fish species.

This site attracts interest for learning about live ecosystems, with over 146 bird species including stork and mallard, and some 23 million birds living in and around the lake.

The Sihwa seawall is a popular spot for leisure activities and sports. Since the addition of a 75m tall observatory in 2014, this project and surrounding area now attracts some 1.5 million people annually.

LESSONS LEARNT

Most importantly, GWPB will be purpose-designed and built as a tidal power station and will have a thorough Environmental Impact Assessment. It will also be brought before Parliament for a Hybrid Bill to be scrutinised and passed to allow it to be built.

Notwithstanding, there are important lessons to learn from these two examples including:

a) The barrage will be constructed from caissons which will be precast in a dry dock and towed into location. Accordingly, there will be no need for a cofferdam and, as the barrage nears completion, water will be able to pass through the turbines already installed and/or the openings for the turbines along with the other sluice gates required for the permanent construction.

b) The design and consultation process will seek to optimise the line of the barrage to minimise disruption to known ecological features.

c) Neither of the other schemes had a baseline assessment prior to the start of construction. This was not uncommon at the time La Rance was constructed and it is not known when and how the assessment of habitat change was carried out post-construction for this scheme. This will be addressed methodically for GWPB.

d) If the tidal waters to and from upstream of the proposed barrage are through the turbines only, the upstream tidal range will be reduced because of head losses. Consideration will be given to maintaining a similar range of tidal movements upstream either through providing sluice gates for water to pass through the barrage at high and low tides or by over-pumping or even a combination of both.

5. OTHER SCHEMES

For further comparison, there are three other schemes that are often cited as examples of tidal power projects. They are relatively small but are included for completeness.

5.1 EASTERN SCHELDT (NETHERLANDS)

Figure 7: Turbines installed as part of the Eastern Scheldt Tidal Surge Barrier

The Eastern Scheldt (Dutch: Oosterschelde) is a former estuary in the province of Zeeland, Netherlands, between Schouwen-Duiveland and Tholen in the north and Noord-Beveland and Zuid-Beveland in the south.

This scheme is included because it is within a similar silt laden delta even though it uses tidal stream generation. In other words, the turbines are turned by the velocity of moving water rather than head differences as in other schemes.

After the North Sea flood of 1953, it was decided to close off the Oosterschelde by means of a dam and barrier. The Oosterscheldekering (Eastern Scheldt Storm Surge Barrier), between Schouwen-Duiveland and Noord-Beveland, is the largest of 13 ambitious Delta Works designed to protect a large part of the Netherlands from flooding.

A 40m length of the barrier contains five parallel Tocardo turbines which generate up to 1.2MW from the current velocities in the tidal movements. Generation commenced when the barrier was completed in 1986 and has operated successfully since.

This scheme is included for its example of inadvertent erosion leading to a change in the character of the coastline. When the barrier was completed in 1986, the flow of water decreased and the tidal height differential reduced from 3.40m to 3.25m. As a result, no new sand is now being deposited on the sand bars and they are slowly eroding, which is changing the character of the coast.

LESSONS LEARNT

As a general statement for GWPB, the currents upstream of the proposed barrage will reduce. The present erosion of the salt marshes around the edges of the estuary continues at a rate of around 1m/annum as it has over at least the past 150 years. This erosion has resulted in sediment loss and coastal squeeze, leading to loss of habitat area and a steepening of the foreshore. These effects will be halted if not reversed. This will likely give a net environmental gain through the re-establishment of salt marshes and thus areas for bird foraging particularly around the Wentloog and Caldicot Levels.

Currents downstream of the barrage are not expected to vary significantly although this will need careful examination when the final hydrodynamic model is established.

5.2 ANNAPOLIS ROYAL TIDAL STATION (CANADA)

Figure 8: Annapolis Royal Tidal Station

The Annapolis Royal Tidal Station is in the Annapolis Basin, a sub-basin of the Bay of Fundy in Canada. It has an installed capacity of 20MW, making it the world's third biggest operating tidal power plant. It generates 50GWh electricity annually to power over 4,000 homes.

The plant, operated by Nova Scotia Power, came online in 1984 after four years of construction. It utilises a causeway built in the early 1960s which was originally designed to serve as a transportation link as well as a water control structure to prevent flooding.

The power plant comprises a single four-blade turbine and sluice gates. The gates are closed as the incoming tides create a head pond in the lower reaches of the Annapolis River upstream of the causeway. The gates are opened and the water rushing into the sea drives the turbine to generate power when a head of 1.6m or more is created between the head pond and seaside. This happens with the falling of the tide for about five hours, twice a day.

The decision to build the facility was partly prompted by the promise of federal funding for this energy project. In addition, there was an existing rock-filled causeway which had been built on the Annapolis River in 1960 by the Maritime Marshlands Reclamation Authority which facilitated its construction. Its purpose was to block the Bay of Fundy tides from entering the river by replacing the function of the existing dykes along the riverbanks. The causeway housed the powerhouse and sluice gates. It was thought that the blocking of water flow by the causeway had resulted in increased riverbank erosion on both the upstream and downstream sides. However, this may not be the only cause as the erosion was occurring before in the unregulated course of the Annapolis River as it had meandered during the previous years.

The causeway is also known as a snare for marine life. In 2004, a mature humpback whale swam through the open sluice gate at slack tide, ending up trapped for several days in the upper part of the river before eventually finding its way out.

The station operated successfully for 34 years, mostly with minimal regulatory scrutiny. It was shut down in April 2019, following concerns from the Canadian Science Advisory Secretariat that fish mortality, particularly shad, caused by the turbines did not meet present day expectations.

LESSONS LEARNT

The Annapolis scheme provides another example of tidal generation that has been added to existing infrastructure. However, it would be prudent to investigate further its impact on the shad and whether this issue is likely to transfer to the Severn Estuary with the different and better engineered turbines.

Figure 9: Twaite shad (as found in the Severn Estuary)

Shad are a feature of the Severn Estuary and will be one of the main environmental concerns. The mitigations are likely to be a combination of fish passes associated with the barrage as well as designing the turbines to have lower speeds of rotation and in particular, the tip speeds of the turbine blades. As a guide, the tip speeds are expected to be around 9m/s for the VLH turbines – below the 12 m/s which has been determined as the speed which results in negligible fish mortality.

The type of erosion described for the Annapolis River is unlikely to be relevant for the Severn and GWPB. However, a positive benefit expected will be the slowing of currents upstream of the barrage and a reduction in the present erosion of the salt marshes particularly along the Wentloog and Caldicot Levels.

5.3 KISLOGUBSKAYA TIDAL POWER PLANT

Figure 10: Kislogubskaya Tidal Power Plant, Murmansk, Russia

The Kislogubskaya Tidal Power Plant in the Murmansk Region of Russia was built in 1968. It has operated successfully and almost continuously since that date. It started with an installed capacity of 0.4MW and the plant was upgraded in 2006 to triple the installed capacity to 1.2MW from the same site.

The plant itself uses a Russian-developed low-speed turbine which increases the tidal load factor and hence the annual electricity production. It has proved a successful demonstration for this power block module. It will now be the turbine that will be used for the proposed Tugar Bay tidal barrage nearby at approximately half the size of the GWPB and for the proposed White Sea Mezenskaya tidal barrage at about ten times the size of the GWPB.

Both of these proposed schemes will be designed for Russian electricity for export to Western Europe to supplement their gas exports.

The turbine module was built in a shipyard and floated into its final position as a completed plant reducing the cost of civil engineering works and also the marine risk.

LESSONS LEARNT

The turbine uses flat strip steel which may be obtained directly from rolling mills. This opens opportunities for employment in local fabrication shops during construction and for routine maintenance. These turbines are much lighter than the bulb turbines, used elsewhere. They will be cheaper to construct because of both the lower material costs and the need for heavy construction cranage during construction and maintenance.

A number of ecological optimisation methods were used for the design of this tidal power scheme. These included the adoption and maintenance of an operating regime to prevent the degradation of the marine ecosystem. In addition, there is the need to recognise that the environmental impacts of tidal power schemes are site specific, and not global in character.

6. CONCLUSIONS

(i) Both France and South Korea have considered developing more tidal power projects.

However, despite suggestions that France could overtake the UK as Europe's leader in tidal energy, it has not yet added to the La Rance project preferring to expand its nuclear energy efforts instead. The reason is faster commissioning and being prepared to leave the problems of decommissioning the highly radioactive materials to later generations. In other words, they appear to have decided to pursue a short-term policy, which suits their present government.

The Lake Sihwa project has spawned similar projects in South Korea—they are gearing up to build a 1,320MW tidal power plant on Incheon Bay, some 60km north of Lake Sihwa, and also looking at possibly building a 420MW barrage even further north.

(ii) Examples of tidal energy generation elsewhere have proven the highly successful long-term benefits of tidal power.

(iii) The UK has around 50% of Europe's tidal energy capacity. The tidal industry needs a successful pilot project to realise this untapped potential, especially one that can produce power at a cost in line with offshore wind. This will unlock the tidal power resource to generate the most cost-effective and reliable renewable energy in the UK.

(iv) A stepwise approach to implementing the Great Western Power Barrage may be useful even though there would not appear to be any impediment from the earlier projects. A suitable pathfinder would be to progress an essentially similar barrage on the Wyre Estuary at Fleetwood – it has the same components as are needed for the Severn at around 1% of the size and cost.

(v) Figure 11 shows the location of the examples discussed in this document. The red colour shows those areas of the world where the development of a successful tidal range industry in the UK would lead to the greatest potential for exports.

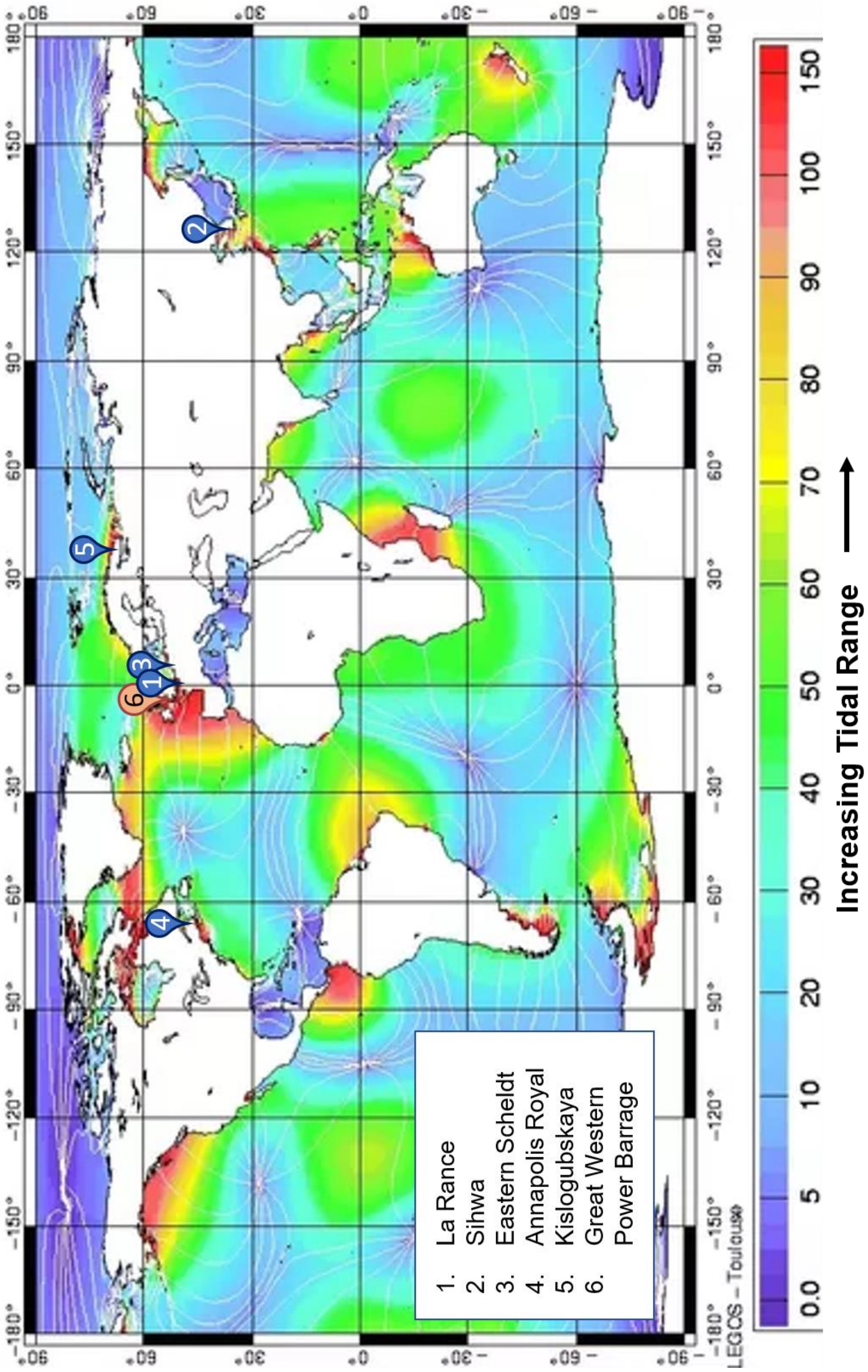

Figure 11: Location of example projects and areas of greatest export potential shown in red

Building the Great Western Power Barrage will make Britain a world leader in environmentally friendly, all-weather power generation, with great benefits to its economy.

GREAT WESTERN POWER BARRAGE

Contact:

David Evans MA(Cantab) MSc CEng FICE MCIWEM

E: david.evans@mailhaven.com

M: +447824 538388