The Severn Estuary Eco-Barrier

Introduction

The Severn Estuary is threatened on two fronts: it has been subject to severe storm tides in the past, and will be much more so in the future, with global warming, rising sea levels and increasingly severe rainstorms; it is also threatened by successive proposals for tidal barrages designed to extract energy from the extensive estuary basin, but at the expense of severe damage to the finely balanced estuarine ecosystem. Both threats are potentially existential: one to the environment at large, people, places and things; and the other to the biome with its many ecosystems that support a vast array of flora and fauna. There is a potential solution to both of these issues, presented in brief below, in two parts: first, a review of the threats and issues facing the Severn Estuary; second, an examination of a potential solution, with associated project models and costs.

Environment and Ecosystem

The Severn Estuary, in Southwest England, is a unique environment:

- Owing to its particular formation and the effects of tidal resonance, the Estuary experiences some of the highest tides in the world, with spring tides regularly topping 14m several times each year
- The surrounding coastline is a mix of low-lying land, cliffs, with rivers pouring in fresh water to mix with the incoming seawater to create turbulent waters with varying salinity gradients
- The resulting ecosystem (biome?) is particularly complex, with:
    - Sites of Special Scientific Interest (SSSIs),
    - Heritage Coasts,
    - Areas of Outstanding Natural Beauty (AONB),
    - Unique archaeological sites,
    - an important, major inter-tidal feeding zone for wading birds,
    - the Somerset Levels, much in the news last year due to extensive and long-lasting floods of farmland
    - a population in excess of 1 million and rising rapidly, many living and working in…
    - .. towns, cities and resorts, including Cardiff, Minehead, Watchet. Burnham-on-Sea, Weston-super-Mare, Clevedon, Penrith, Barry, and many more…

Figure 1 shows a landscape map of the Severn Estuary, with surrounding terrain: Quantock Hills, Somerset Levels, Mendips, Cotswolds, Wye Valley, AONB, Heritage Coasts, Power Stations (including Hinckley Point), maritime access to Bristol Docks, Avonmouth, etc., rivers including those draining the Levels, Severn Crossings, and of course, many popular resorts towns.

Obsession with Barrages

The unusually high tidal range has attracted the attention of those seeking to harness tidal power as an alternative source of energy for the nation. There has been considerable interest in forming a tidal barrage across the estuary at various points, the latest being from Penarth to Brean Down; like many before it, the proposal has been rejected.

Unfortunately, tidal barrages – wherever they may be sited – have the propensity to seriously degrade and disturb local ecosystems. A barrage effectively dams the estuary or river: building the barrage, then, involves:

- diverting the flow of water during the long building phase, which virtually destroys the local ecosystem,
- damming the estuary/lagoon twice per day when in operation, so ensuring that the original ecosystem could not recover, even if it were possible.

Instead, a substantially different mix of flora and fauna would eventually emerge… Governments, including those in the UK, have been reluctant to approve barrage schemes for these reasons, considering that the energy, which would be derived from a barrage, would not really compensate for the disruption/destruction of complete ecosystems, the outcome from which disruption would be unknowable, but would surely not be beneficial…

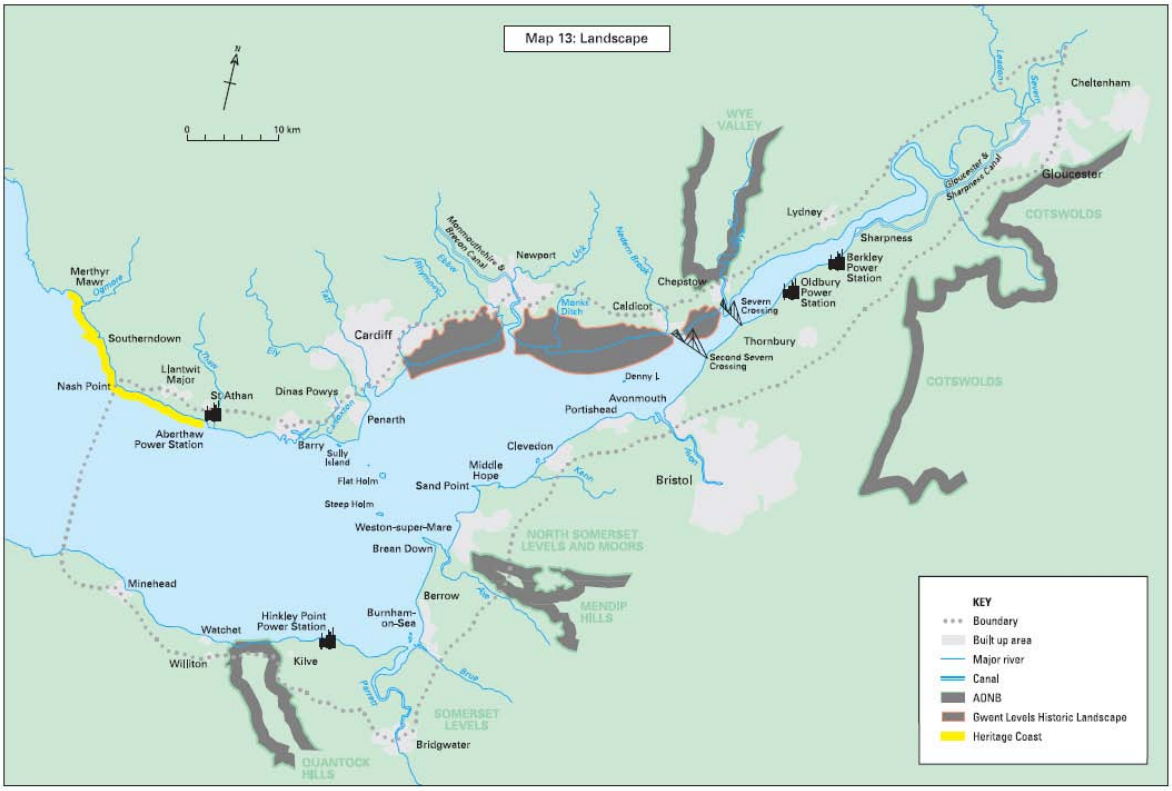


Figure 1. Severn Estuary Landscape & Topography. (Severn Estuary Partnership Maps) Showing the main hill formations, Somerset Levels, power stations (including Hinckley C nuclear), resort towns, AONB, and built-up areas outside the nominal boundary of the Severn Estuary.

Existential Threat to the Severn Estuary: Storm Tides/Storm Surges

Concern over tidal barrages may have diverted attention from the *existential threat* to the Severn Estuary: Storm Tides/Storm Surges. A storm tide is a tsunami-type event associated with low atmospheric pressure, which can raise the level of the sea, creating a storm surge of 5-6m above mean sea level. Should a low-pressure event (storm) moving up the Bristol Channel coincide with a high spring tide, then a Storm Tide/Surge would sweep up the Severn Estuary, overwhelming even recently-reinforced sea defences, inundating the land, destroying property, habitats, SSSIs, archaeological sites, and drowning many people.

It has happened before. In 1953, a major flood was caused by a heavy storm. A combination of high spring tide and severe European windstorm over North Sea caused a storm tide along the east coast of England and Scotland; wind, high tide, and low pressure saw the water level rise by some 5.6 metres (18.4 ft.) above mean sea level.

It overwhelmed sea defences and caused extensive flooding.[1] In England, 307 people were killed in Lincolnshire, Norfolk, Suffolk and Essex. As a direct result, the Thames Barrier programme was started to secure central London against future storm tides. But, the Severn Estuary, which is as much–if not more–at risk from Storm Tides, has no such Barrier.

This, despite a history of storm tides affecting the Somerset Levels,[2] which are at risk from both tidal and land-based floodwaters:

- The Bristol Channel Floods of 1607 resulted in the drowning of an estimated 2,000 or more people, with houses and villages swept away, an estimated 200 square miles (51,800 ha) of farmland inundated and livestock destroyed, wrecking the local economy along the coasts of the Bristol Channel and Severn Estuary
    - The coasts of Devon and the Somerset Levels as far inland as Glastonbury Tor, 14 miles (23 km) from the coast, were also affected. The sea wall at Burnham-on-Sea gave way and the water flowed over the low-lying levels and moors.
    - Eyewitness accounts of the disaster told of "huge and mighty hills of water" advancing at a speed "faster than a greyhound can run" and only receding 10 days later.
- Great storm of 1703, waves came 4 feet (1.2 m) over sea walls.
- Sea wall breached in 1799, filling Axe valley with seawater.
- 1872, flood covered 7,000 acres (28 km^2), and in…
- 1919, 70,000 acres (283 km^2) were inundated with seawater, *poisoning the land for up to 7 years*.

From the above, we may reasonably deduce that the threat to the Estuary and the Somerset Levels may be infrequent, since the last major event was in 1919. Alternatively, if the interval between such events is observed to be about 100 years, then we might expect another such storm tide within a decade? Or sooner?

However, that would be to reckon without the effects, already being felt around our coasts,

[1] https://en.wikipedia.org/wiki/North_Sea_flood_of_1953

[2] https://en.wikipedia.org/wiki/Somerset_Levels

of global warming, which is having several coordinated effects:[3]

- The mean sea level is set to rise by about 1m by the end of the century (and by some 15m by 2500AD); that implies a very large increase in the amount of water in the seas around our coast.
- The mean global temperature, which has already risen by over 1˚C since the start of the Industrial Revolution, is set to rise by another 1˚C – or more – by the end of the century, which implies a major increase in both the energy and humidity in the atmosphere.

These two taken together indicate that: tides will be higher; depressions will become deeper; storms (and surges) will become more severe; will be more frequent; and will precipitate more rainwater…which can amplify the effects of tidal surge as the heavy rains drain off surrounding land into rivers feeding the estuary upper reaches…

For the Severn Estuary in particular, this means that the probability of occurrence, the frequency of occurrence, and the severity of storm tides/storm surges when they do occur, will increase in the coming years. The effects of global warming are already noticeable around our battered shores…

Governments of all persuasions have been properly concerned over the potential damage that would be wreaked by proposed tidal barrages. Meanwhile, with attention diverted by such "barrage issues," the *existential and burgeoning threat* to the environment, ecosystem and over one million inhabitants of the Severn Estuary from storm tides/storm surges appears to have been largely overlooked… Meanwhile, there is an alternative way to generate eco-friendly, precisely predictable, tidal *stream* power using invisible, submerged turbines. This is *lunar* power, and – unlike wind power – it is highly predictable, as well as invisible, and it is already in operation at nearby Lynmouth.

Is there anything to be done?

One approach is to trust to luck that a Storm Tide and a Spring Tide do not coincide…History suggests that would be a foolish course, and certainly one that would be inconsistent with government's duty of care for the environment and for the people.

It may be, however, that there is some time before the next Storm Tide devastates the Estuary. How much? Uncertain, but it does suggest that any project to conserve the Severn Estuary could be undertaken over a number of years.

Is it practicable to build a Barrier against Storm Tides, Inundations and Floods?

Which goes to suggest that we may have a little time to construct a barrier, a Severn Estuary Eco-Barrier, that may be activated at any time to block the surge of a Storm Tide, but which otherwise has *no negative effect* on the Estuarine environment and ecosystem(s).

It would be possible to build an Eco-Barrier across the Estuary at some convenient point, with its shutters normally open, allowing water to flow, erosion and deposition to continue, drift to, uh, drift: an Eco-Barrier that would have *zero effect* on ecosystem, flora and fauna,

[3] Notwithstanding COP21/SIF15, the agreements from which have yet to be ratified and implemented…

salinity, deposition, erosion, etc., all the year round. Such an Eco-Barrier's shutters would be closed if, and only if, there was a Storm Tide surging up the Bristol Channel…at which time, it would protect and conserve the Severn Estuary, its ecosystem(s), habitats, SSSIs, AONB, archaeological sites, RAMSAR[4] sites, and it's ever-growing population, from flooding, inundation and the destructive, deadly Tidal Surge.

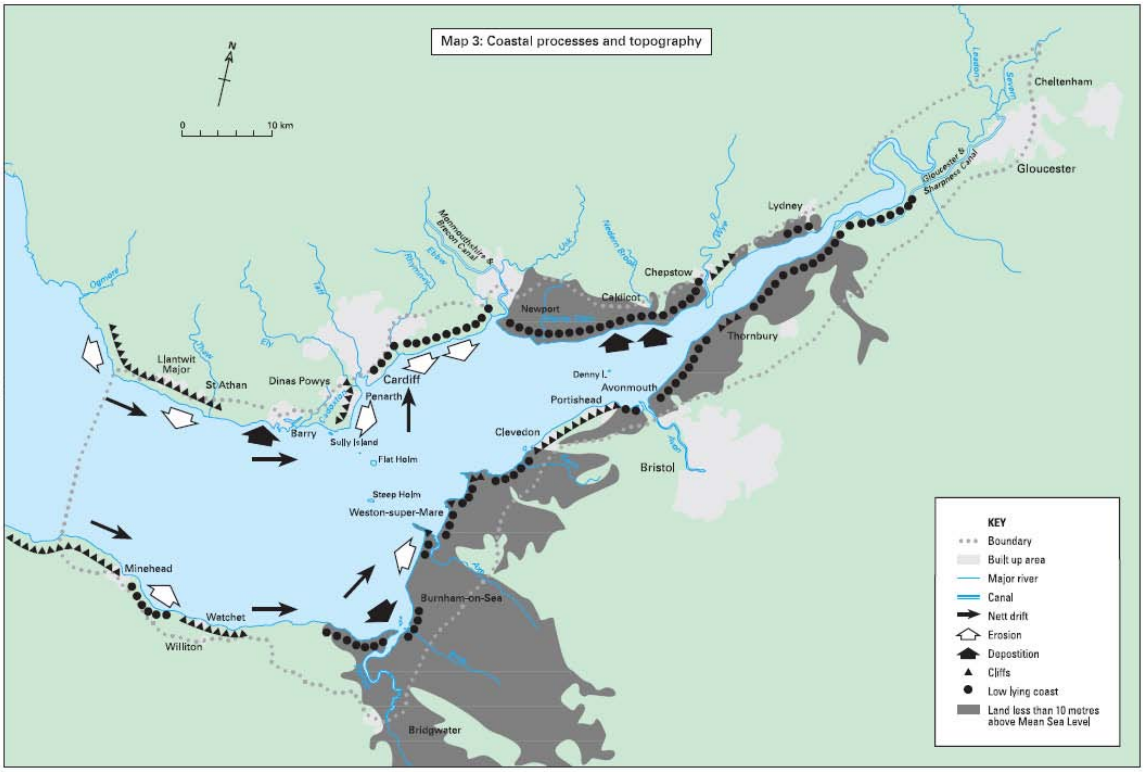


Figure 2. Coastal Processes & Topography. (Severn Estuary Partnership Maps) Shows the continuing processes of drift, erosion and deposition, together with cliffs, low-lying coast, and land less than 10m above Mean Sea level, which would be threatened by storm-tide/storm surge.

Such a Severn Estuary Eco-Barrier may not appear unreasonable in principle, but it would surely:

- be a major challenge to span the Estuary, which is some 20km across at its boundary;
- take a long time to build;
- disturb the Estuarine ecosystem(s) in the process, see Figure 2;
- interfere with shipping going in and out of Avonmouth and the Bristol Docks, and…
- be an eyesore, at the very least damaging an area of Outstanding Natural Beauty (AONB)?
- be *unaffordable*.

If we could overcome those very real objections, we could then have a Severn Estuary Eco-Barrier to protect, conserve and preserve the precious and unique Estuarine environment

[4] RAMSAR sites are wetlands of international importance designated under the RAMSAR Convention.

and ecosystem(s), peoples, properties, farmland, habitats, SSSIs, etc. And, we could harness a safe amount of the tidal stream energy flowing through the Eco-Barrier, pursuant to both *conserving* the estuarine ecosystem *and affording* the Eco-Barrier?

These, and many more questions indicate the need for an objective examination of a Severn Estuary Eco-Barrier against Storm Tide, one which explores the many ramifications of introducing such an Eco-Barrier which, although intended to conserve and protect, could – without proper care – disturb and upset in the process…

Severn Estuary Eco-Barrier

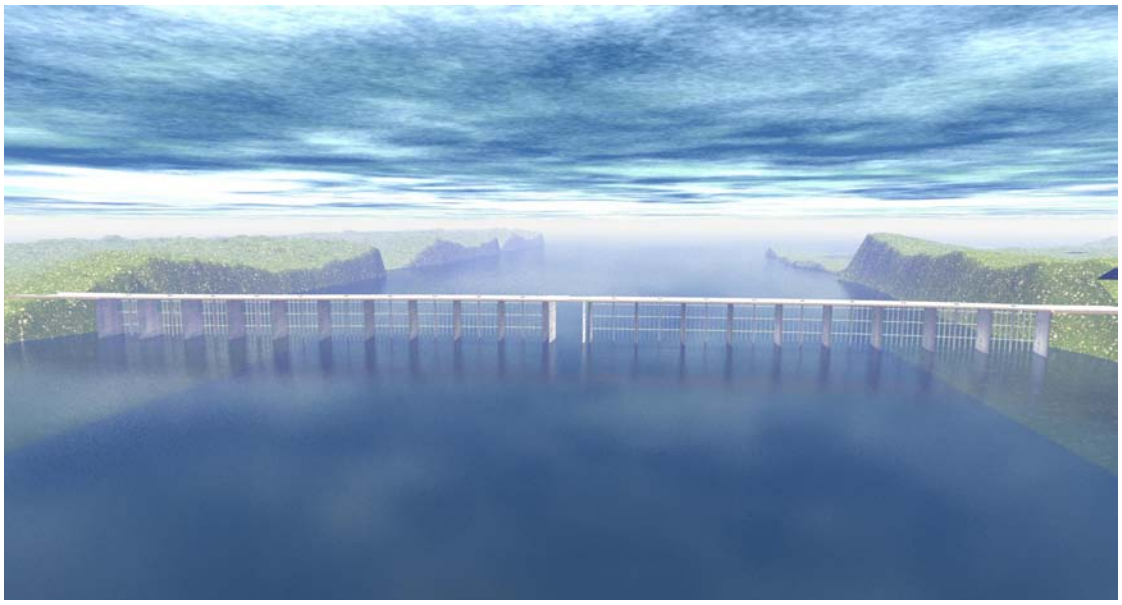


Figure 3. Severn Estuary Eco-Barrier Concept Many bays are connected together to form an Eco-Barrier across the opening, and between cliffs on opposing banks. Each bay is fitted with shutters, shown open. In addition there is an open lock (surge gate), to facilitate marine traffic. The whole offers little or no resistance to the flow of Estuary waters… Surge gates and shutters would be closed only to block Tidal Surge. Underwater turbines may be operating, but are not evident…The upper deck, in this artist's impression, is bare…but need not be in practice.

The Challenge

Is it practicable to build a ***Severn Estuary Eco-Barrier*** (corresponding with the ***Thames Barrier***, so most definitely ***not*** to be confused with *a barrage)* that:

1. Protects low-lying coast, including population, towns, cities, power stations, resorts, Somerset Levels, etc., against storm tides, floods and inundations.
2. Future-proofs Estuary's, habitats, littoral/intertidal/sub-tidal zones, archaeological sites, RAMSAR, SSSIs, AONB, hydrology and salinity etc. in face of rising tides and global warming
3. Conserves unique, precious, dynamic Estuarine ecosystem(s)

4. Assists with draining floods from Somerset Levels
5. Generates more than sufficient energy to fund its own construction, consistent with 1 - 4?

The last bullet is of particular interest. The notion of generating energy may smack to many of a tidal barrage scheme in thin disguise. That would be quite incorrect. There is an alternative to the damaging tidal *barrage* for generating electrical energy from the tide, a.k.a. Tidal Energy Conversion (TEC): *tidal stream* employs submerged propeller turbines (like small wind turbines) to generate more modest amounts of electrical power four times per day using the kinetic energy of both ebb and flood tides. Tidal stream turbines, used in this instance to fund the otherwise unaffordable Eco-Barrier – and of course to provide much-needed energy to the National Grid – would have little or no effect on the flow of water…and the vast amount of estuary water would continue through the Eco-Barrier around, over, under and through the turbines unimpeded, with minimal or no risk to marine life.

After successful trials, part DTI-funded research at nearby Lynmouth is showing promise for tidal stream power generation. Twin 600kW propeller turbines (SeaGen) mounted on a single pile driven into the bedrock are to be installed to generate power for the local area.[5] The Lynmouth location benefits from a particularly high tidal stream velocity, which suggests that propeller turbines submerged in the bays of a Severn Estuary Eco-Barrier might not all generate quite as much tidal stream power, per bay, since the water may not flow quite so fast. On the other hand, it may be possible to shape the plinths of each bay, such that the water speeds up as it passes between each bay's plinths, so enhancing the potential to generate power, which is proportional to the cube of the water velocity. Further, there might be 400 such bays, so that the aggregated power from all of these bays could prove an invaluable source of revenue and legacy.

So, *provided it can be done with zero impact on the Severn Estuary ecosystem(s),* it seems "not unreasonable" to mount submerged tidal stream turbines in each of the many bays that will go to make up the Severn Estuary Eco-Barrier, and to sell the electrical power so produced to the National Grid, as a means of funding construction of an Eco-Barrier to conserve the Estuarine ecosystem. And thereby can be realized the essence of a plan…

Construction: Concept of Operations

Broad philosophy: introduce successive parts of an Eco-Barrier structure in sequence, very few at a time, without any dams or other impediments to flow. Piers, plinths, etc., to be constructed from the water's surface downward:

- e.g. drive piles into bedrock from tethered platform/boat;
- fit preformed blocks around piles;
- lower gently to bottom, to construct reinforced plinths each with a hydrofoil plan-form.
- Pile-drivers will disturb above and below water, but minimally and for limited period…

[5] http://www.reuk.co.uk/Worlds-First-Open-Sea-Tidal-Turbine.htm

- Install tidal stream power generators (and associated equipment) either on a pile within each bay, or suspended from each bay, or both, to allow for maintenance.

Carefully phased introduction. Allow Estuary to rest and recover between activities. Ecosystem disturbance and recovery to be monitored by ecologists, who should research, plan and test reasonable rates of introduction.

The whole to progress in phases, and to be spaced out irregularly across the estuary, with recovery-breaks punctuating phases…

Orchestrating the Eco-Barrier

It may prove necessary to control each and every bay, individually and collectively to ensure and maintain the natural flow, drift, deposition, turbulence, etc., of the waters. This may be referred to as "Orchestrating the Eco-Barrier," i.e. operating the whole Eco-Barrier, bay-by-bay, and as a complete suite of bays.

'Orchestration' will deploy several means of control to ensure optimum operation:

- Individual bay shutters may be open or closed,
- Turbines may be engaged, idling, or possibly driven as fans to clear deposition, to accelerate or decelerate flow. They may be raised or lowered in the water to access different stream velocities at different levels in their respective water columns…

Activating these various features differentially on a bay-by-bay basis should allow the control/modification/restitution of water and deposition dynamics to be maintained at "pre-Barrier levels."

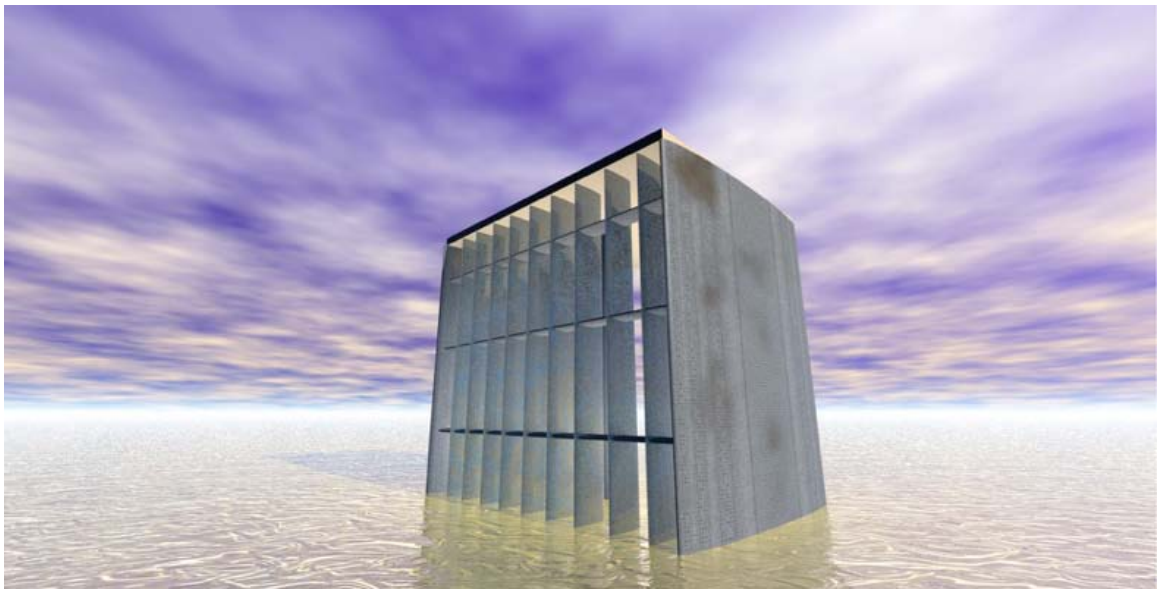


Figure 4. First Bay Complete. Each Bay consists of two reinforced end-plinths, a top deck, horizontal louvres supports, full-length sectioned louvres with top-mounted drive motors, and–barely visible–a shaft (pile?) extending from the top deck down to submerged turbine(s). Each Bay is under-lit using light-pipes to convey sun/daylight from the top deck underneath, to prevent shadows of the deck attracting marine life.

This level of control and regulation will require embedded Estuarine sensors to monitor and

adjust overall Eco-Barrier "behaviour" to maintain Estuarine ecosystems, hydro-dynamics, to optimally-extract tidal stream power and, of course to anticipate storm tides!!!

Not only will this "orchestration" be necessary for the Eco-Barrier complete, but during development too when the Eco-Barrier is still incomplete, with bays, blocks of bays, and gaps…the Estuarine sensors will initially establish a database showing the varying conditions within the Estuary at different points, depths, times of tide/day/month/season. The database will show the natural state of the Estuary *in the absence of any Eco-Barrier*. Subsequently, and as the Eco-Barrier is constructed, the "orchestration" features of the part-complete, and eventually fully-complete, Eco-Barrier may be employed to maintain the eco-environment in line with its pre-Barrier state, according to the tide, time, season, etc.

This might seem like a challenging prospect, but it is both feasible and sensible. In the event, much of this "orchestration" will be amenable to automatic control and management.

Figure 5. Block of 5 Bays. All bays under-lit, shutters open in streamlined position. The bays will be of a height greater than the highest storm tide, allowing for rising tides and global warming. They will have to be sufficiently robust, too, to resist the impact of Storm Tides that, like a tsunami, may have the potential to arrive as a powerful wave front. This suggests that each bay may be of limited width, as shown, so that there are many reinforced plinths and that louvres are strongly supported and robust. (Shutters may not be vertical louvres as shown: instead, they could be dropped down as needed–c.f. shop window horizontal steel security shutters–leaving the bay open to marine traffic, while the turbines would be deep under the water surface.)

Project Design Outline

Initiating, organizing and managing such an Eco-Barrier project is illustrated in the project *causal loop model* of Figure 6. The focus of the model is the building of individual bays, including submerged tidal stream generators. As each bay is commissioned, it will generate tidal stream power, which will be sold to the National Grid. The money accrued in this fashion will contribute to financing a second bay, which will also sell power to the grid, so accruing more money, and so on.

To make this so-called "bootstrap" system work requires "pump-priming:" the injection of sufficient funds at the outset to set the process in motion, i.e., to build and commission the first few bays, until a point is reached where there are sufficient bays selling sufficient

power to the National Grid at a pre-agreed price for the remainder of the project to be self-funding, and eventually profitable, enabling the repayment of the initial pump-priming funds. The whole project essentially "pulls itself up by its bootstraps."

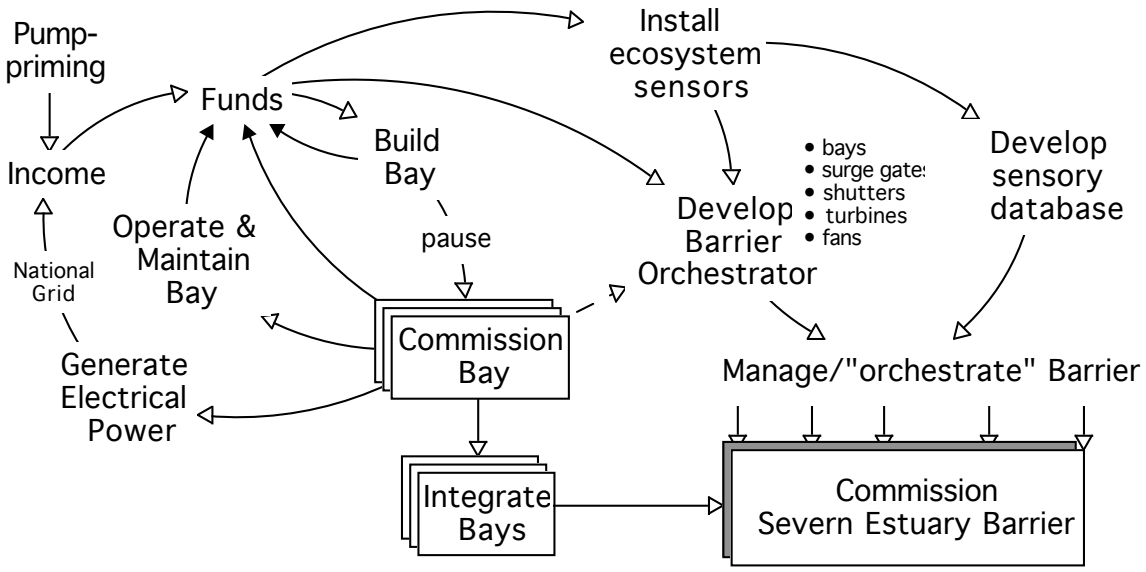


Figure 6. A Causal Loop Model (CLM) of the Severn Estuary Eco-Barrier Project

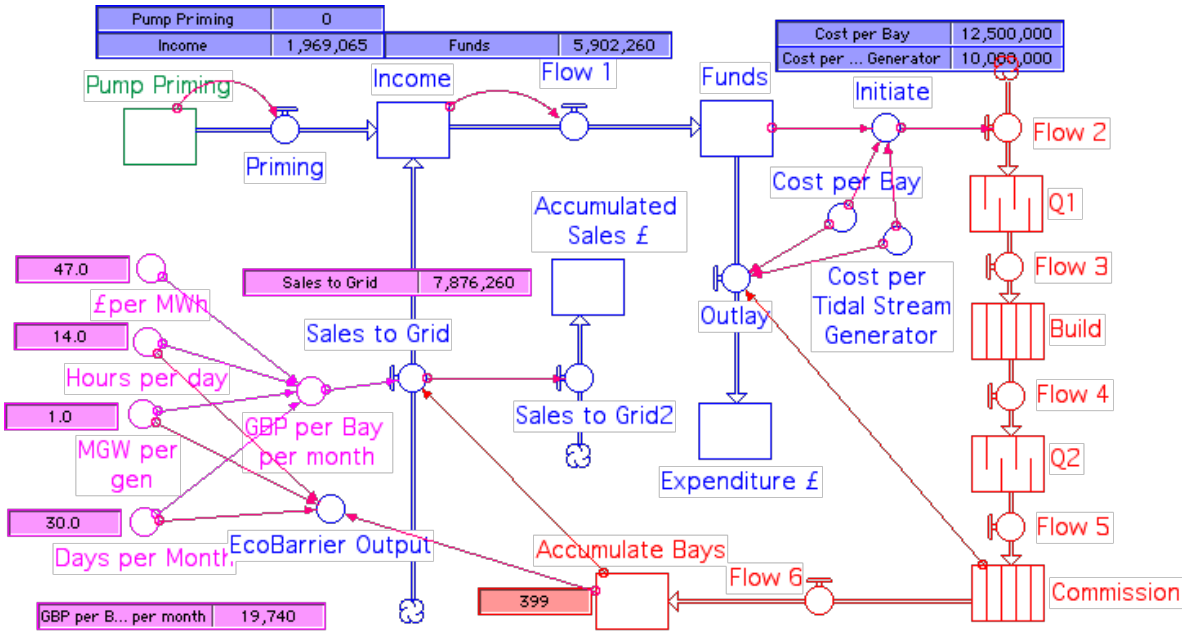
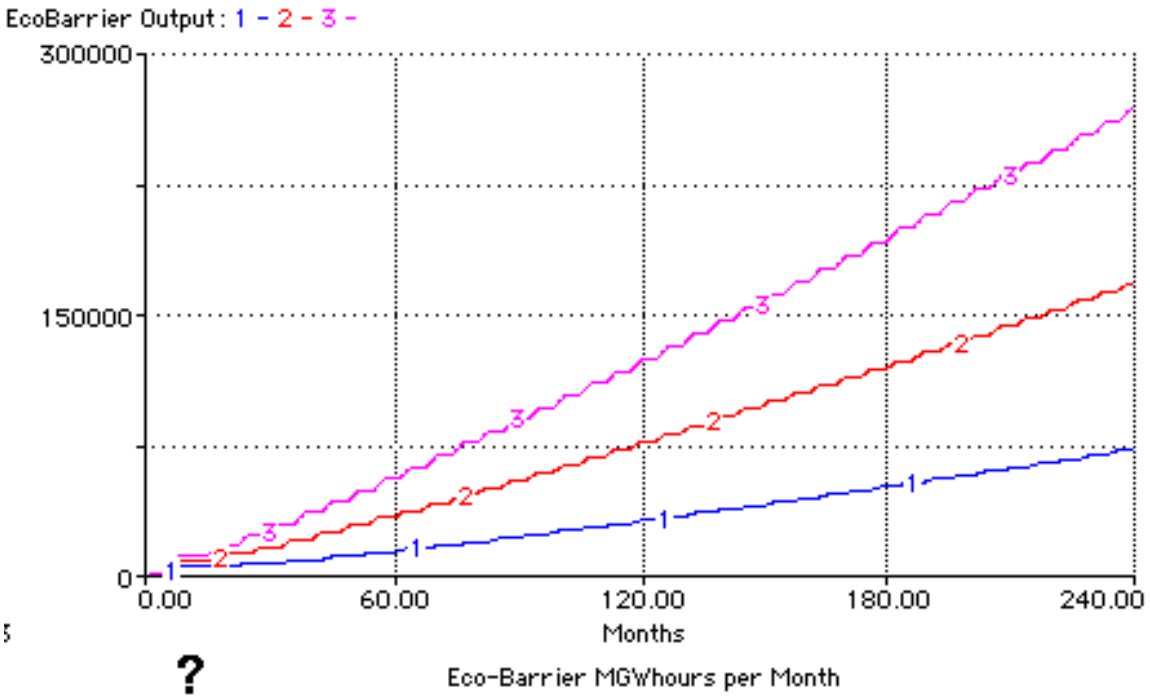


Figure 7. Dynamic Model of the Severn Estuary Eco-Barrier Project. Equivalent to the CLM at Figure 6: generation data shown at left; financial data shown in centre and top; build and commission shown at right and bottom. Numbers indicate states toward the end of the Build-Commission phase, with 399 out of c. 400 bays complete. Orchestration elements are omitted for clarity.

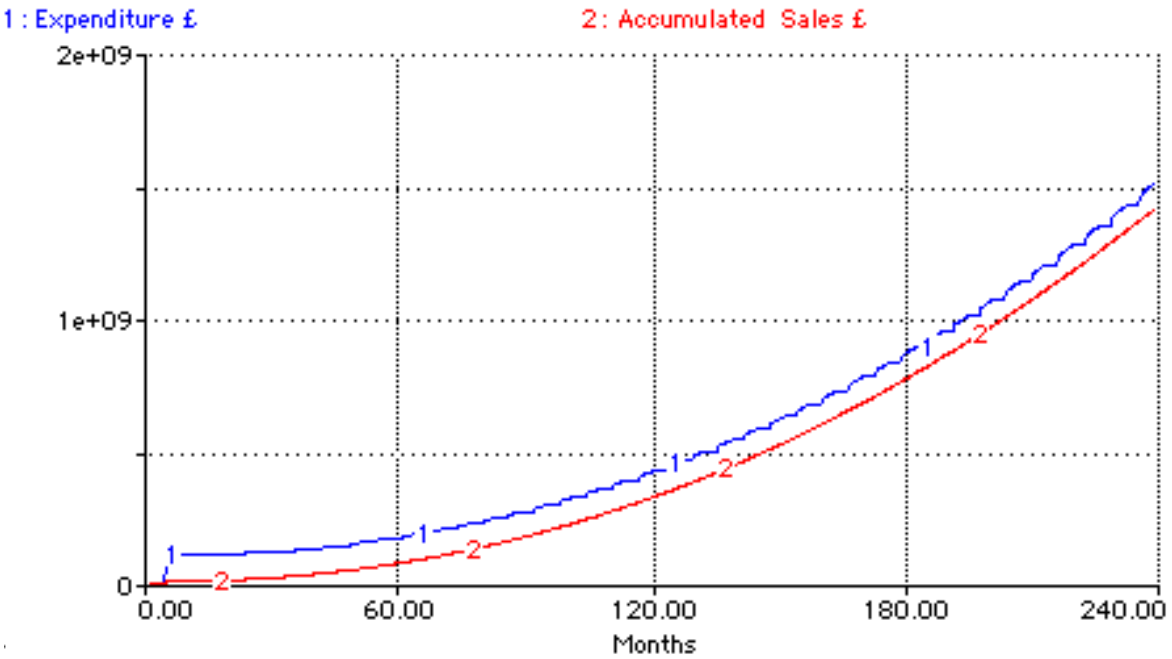
Figure 7 shows a dynamic computer model of the project, with figures to confirm its viability, and on the basis of a 20-year build, assumed as necessary to minimize damage to the Estuarine ecosystem that would otherwise result from an all-out build. Estimated figures from the model are as follows, including arbitrary assumptions where needed:

▪ Cost of Energy to National Grid: £47 per MW-Hour (half Hinckley C)	▪ £19,740 per month revenue per bay from a nominal 1MW generator.
▪ Mean Tidal Stream Power per Bay: rated at 0.5 to 1.5MW, mean 1MW	▪ Pump Priming £100M, to build the first bays, to start earning income…
▪ Hours per day generating: 14h	▪ Cost per Bay, of 400* bays = c. £12.5M, to include shutters
▪ Days per month generating: 30 days	▪ Cost per Generator, of 400* generators = c. £10M

* According to this model configuration, the cost of the Eco-Barrier Build-Commission phase = £9billion, to be met from 20 years of sales of electrical energy to the National Grid at £47 per MWh. Different build times, different energy prices, different pump priming and different bay and generator costs will change the balance of the model and give different results. Nonetheless, by evaluating different variations of these parameters, it does appear that the model – and hence the project – is financially viable.



Graph 1. Eco-Barrier Output Sensitivity – MW-Hours per month. Three lines correspond with mean Generator power per bay of 0.5MW, 1.0MW and 1.5MW respectively. With all 400 bays in operation, this corresponds to 0.2GigaWatt, 0.4GW and 0.6GW respectively in power terms, and 70,350, 167,580 and 269,010 MW-Hours per month respectively in energy terms.



Graph 2. Expenditure Tracking Sales Revenue. Typical of bootstrap projects, the graph lines for accumulated Expenditure tracks the Accumulated Sales Revenue from sales of electrical energy to the National Grid, showing that expenditure on successive bays and generators occurs only once funds have been received from sales. The gap between the two lines corresponds with the £100M 'pump-priming' input, which will be refunded. The curve results from more generators coming on line as the project proceeds, generating more energy for sale each period. In both cases, the end amount is some £1.5Billion over the (assumed) 20-year build period for both accumulated Sales Revenue and Project Expenditure.

How much power would the Eco-Barrier, complete, generate? That is a difficult question… Tidal stream technology is not yet mature; competing approaches show promise in different locations and environments. And the SeaGen experience at nearby Lynmouth may not be representative of the power to be safely and sensibly extracted in each and every one of the 400 or so bays of the Severn Estuary Eco-Barrier: some might extract more, some less… It is reasonable to expect further developments over the next 20 years to enhance generated power performance, and reduce problems of corrosion, damage, repair, maintenance and outages.

As a broad "guesstimate," then, it might be "not unreasonable to assume" that the power per bay, some twenty years from now, and using two, three or more turbines as appropriate, might be between O.5MW and 1.5MW, or 1 ± 0.5MW. Graph 1 shows three lines, for each of the three notional power generated levels, over a total build time of 240 months, during which times some 400 bays come on line. From the graph, it can be seen that the power build-up is gradual, and reaches its potential (after 20 years using this particular project model) of 0.4 GW ± 0.2GW. Being tidal (i.e. lunar) power, this output would vary daily, weekly monthly and seasonally, but importantly, and unlike wind power, it will also be *predictable*.

As a reference, Hinckley C Nuclear Power Station is expected to produce some 3.2GW, and that would be less likely to vary…Aberthaw Power Station, also nearby, generates some 1.56GW, using a mix of coal-fire and biomass; suggestions that it should become a

nuclear powered site have been rejected as it is too near habitation, but its future as a coal-fired site must surely be in doubt.

The Eco-Barrier would be primarily there to protect, conserve and future-proof: power generation may be a means to an end, rather than an end in itself. Nonetheless, 0.4GW ± 0.2GW would afford a healthy legacy of exceedingly green, highly predictable/dependable, totally renewable energy of over 2,100GWh per annum.

Figure 8. Dusk View of the Eco-Barrier, showing Hazard Lights

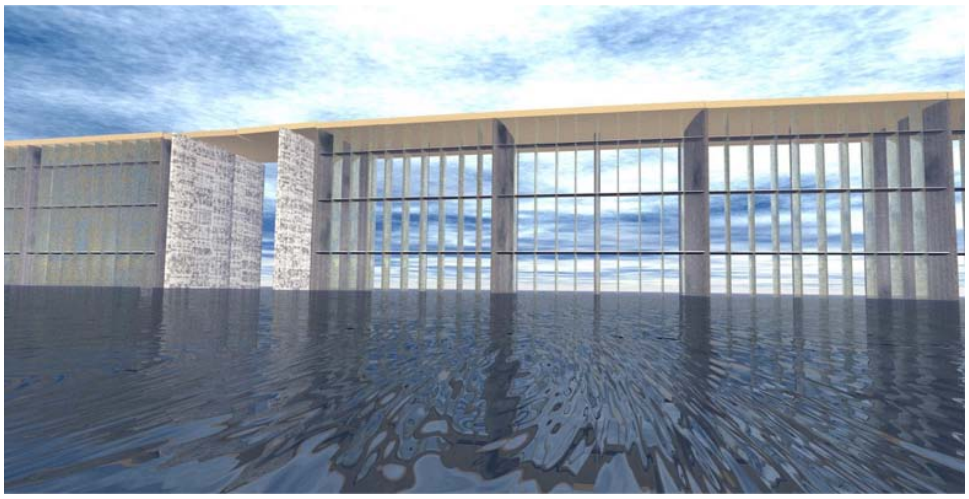


Figure 9. The Eco-Barrier: Open, Ready for Business. One surge gate is shown in the open position. There could be several such gates, to facilitate the passage of shipping. The height of the Eco-Barrier may be sufficient to pass shipping underneath; else draw- or swing-bridges will be needed over the surge gates.

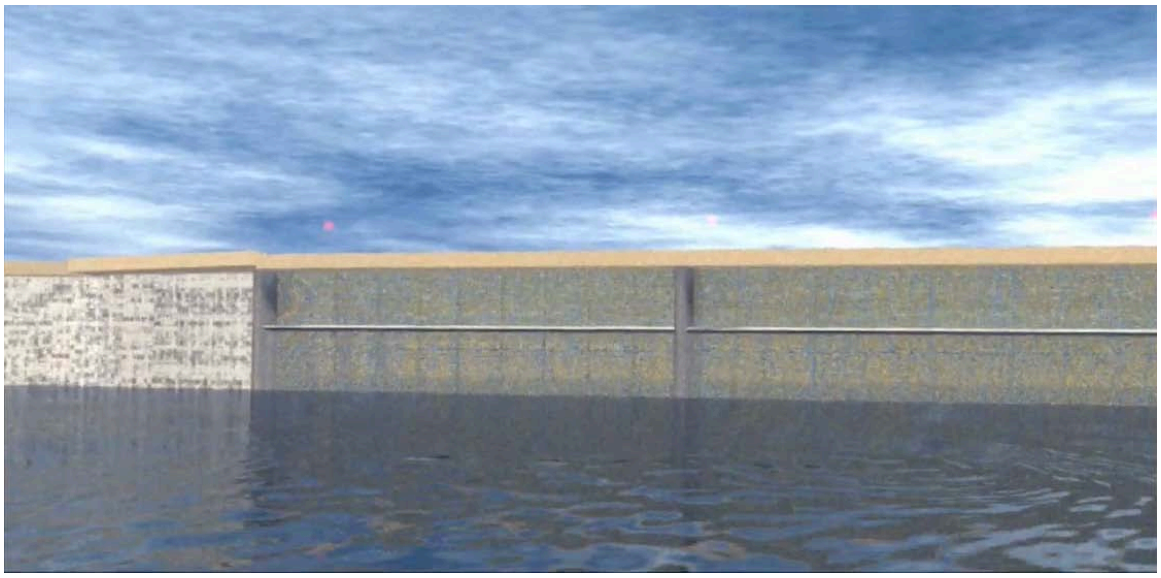


Figure 10. Eco-Barrier Closed! In the face of imminent Storm Tide. Both Surge Gates and shutters are closed as the water rises to dangerous levels…

Draining the Somerset Levels

The Severn Estuary Eco-Barrier could, in principle, aid in draining the Somerset Levels.

The mouth of River Parrett, principal drain of the Somerset Levels, is tidal, which can cause drain-off to back up, rather than flow into the Estuary, so prolonging flooding on the Levels. This happened during the damaging 2014 floods, which covered much of the levels for months… and is likely to recur when there is a low-pressure storm event coming up the Bristol Channel, with accompanying heavy rain.

In such extreme circumstances, the Eco-Barrier could close-off incoming waters, such that only a low neap tide occurred, reducing/stopping tidal back up in the Parrett and other rivers, but without undue effect on Estuarine wildlife….

This would be a rare occurrence, necessary only after the Storm Tide/Storm Surge had subsided, or when–as in 2013/14–heavy rains had flooded the levels, but appears both feasible and reasonable…

Locating the Severn Estuary Eco-Barrier

The preferred location would, on the face of it, appear to coincide with nominal boundary of the Severn Estuary: see Figure 1 and Figure 2.

- An Eco-Barrier at that location would protect most, if not all, vulnerable sites and situations
- There would be cliffs at both ends, to prevent water from skirting around the ends of the Eco-Barrier
- There is adequate water tidal stream velocity, etc., although faster would be better: tidal stream energy is proportional to the cube of the water stream velocity

However…locating the Seven Estuary Eco-Barrier on, or near, the Estuary boundary:

- To the South, would impinge on the Exmoor Heritage Coast and the South-West Coast Path in West Somerset
- To the North, would impinge on the Glamorgan Heritage Coast

So, a second question arises:

Is it possible to reconcile an Eco-Barrier on the Estuary boundary with the interests of preserving the unique natural environment of the Severn Estuary?

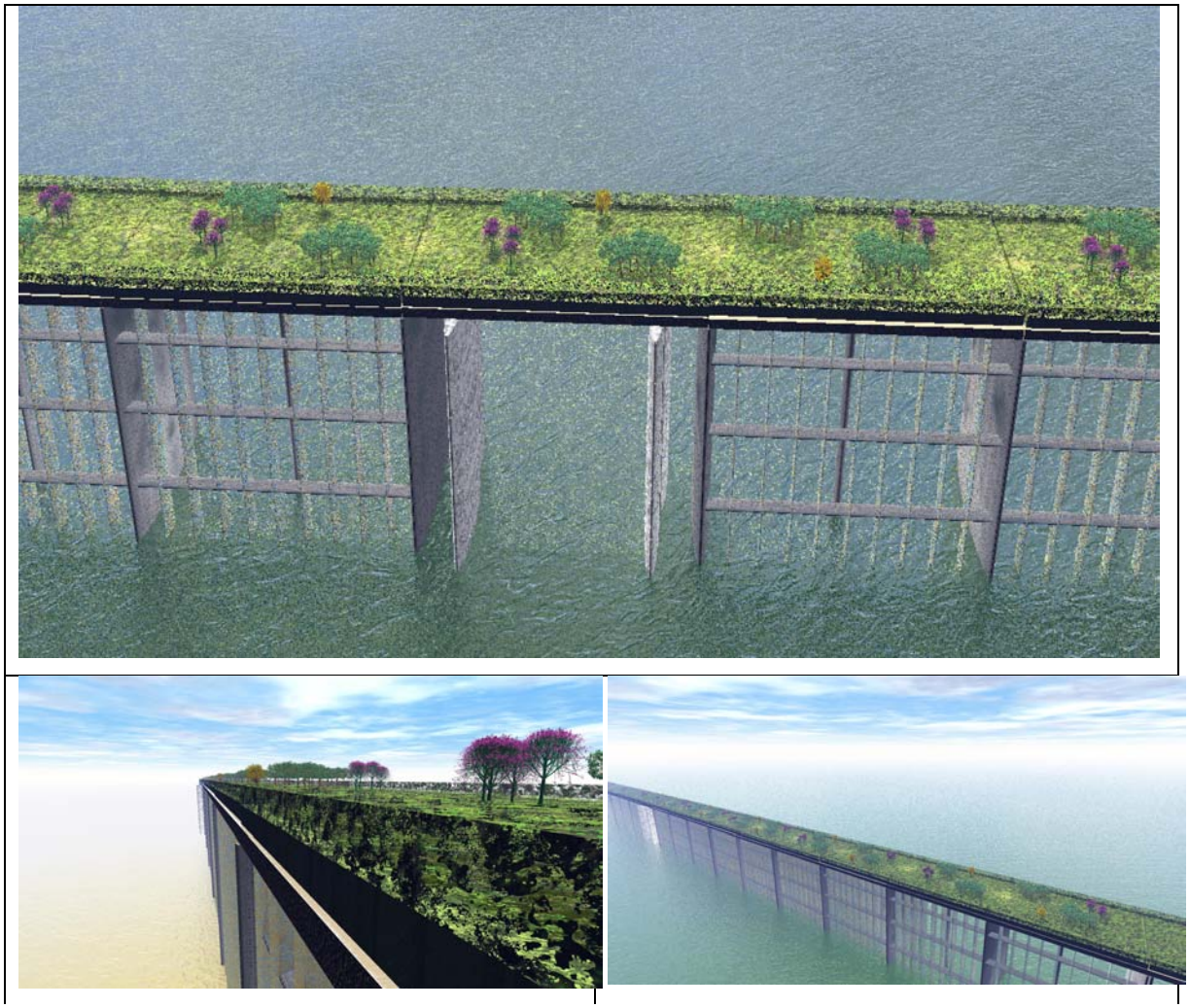


Figure 11. Greening the Eco-Barrier. Three views of the Severn Estuary Eco-Barrier showing the top deck protected by stout hedges to serve as security fencing and windbreaks (the flowering trees may be too ambitious). The top would be planted out with soil and flora indigenous to the South Wales and West Somerset coasts, would connect at either end with their respective Heritage Coast environments, with paths for walkers, cyclists, joggers, etc., so becoming a tourist attraction and promoting local wildlife

"Greening" the Eco-Barrier

First, the Severn Estuary Eco-Barrier would be very green anyway… It would

- Protect/conserve the estuarine environment against destructive and deadly storm tides

- Invisibly-generate v. green "lunar" tidal power - as opposed to fossil fuel, nuclear, bio-fuel, wind-farms, etc.

But, the Eco-Barrier can also be *physically* "greened," see **Figure** 11, by…

- planting the upper deck with trees, bushes, grasses, etc., indigenous to the two interconnected coastlines, and…
- .. turning the Eco-Barrier deck into a natural park area, accessible by the public via existing coastal pathways, etc., and a natural habitat and corridor for birds, insects, small mammals, etc.
- providing pathways for pedestrians and joggers, buggies for the disabled, cycle paths for cyclists, i.e.,
- creating potential tourist attraction, and income, for both Glamorgan and West Somerset

One area requiring further investigation, but beyond the scope of this study, is the interaction between the proposed Eco-Barrier and marine traffic within the Estuary, and to and from the Bristol Channel, Avonmouth, Portbury, etc. There is continual dredging activity, too, within the Estuary area, and pilot ships meeting marine through traffic.

Conclusions

The Severn Estuary's ecosystems can be conserved against the existential threat of storm tides, floods and inundations, made increasingly probable by global warming, rising sea levels and the threat of more severe depressions off the western approaches to Bristol Channel: such conservation is challenging, yet feasible.

Using the "eco-sensitive" project model presented here, it is practicable to have:

- A self-funding Eco-Barrier that preserves, possibly even *enhances*, the unique Severn Estuary environment/ecosystem/biome…
- A healthy supply of truly renewable, exceedingly green, predictable lunar energy for the nation, which will not only build the Eco-Barrier, but also provide…
- .. income for thru-life development, operating and maintenance costs…

This *Severn Estuary Eco-Barrier* would correspond to existing the *Thames Barrier* built to protect the seat of government from storm tides…

The primary purpose and function of the Severn Estuary Eco-Barrier would be to protect and conserve: tidal stream power generation would not generate as much power as might be obtained from a damaging Estuary barrage, but would do no damage either, and should provide more than sufficient to fund construction and to avoid any damage to the precious and unique Estuarine ecosystem /biome (?)

The Severn Estuary Eco-Barrier would be a major civil engineering project, phased-in over a number of years, and would require careful *planning, research, design, development, technology, project & financial management*. But, on the plus side, it would bring protection, conservation, employment, income *and energy* to a deprived area with little current prospect for employment…

The project could be largely self-funding, harnessing *tidal stream* renewable/lunar energy

that, with care, *will not damage* — may even *enhance* — the unique & precious estuarine ecosystem/environment, allowing time for natural evolution.

(Derek Hitchins) August 2016