University of BRISTOL

THE AVON BARRAGE

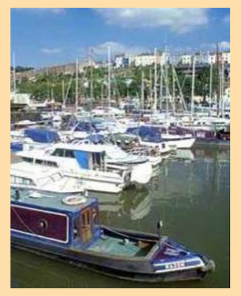
A Vision for Bristol (top) • **Conceptual Design** (centre) • **Viability Studies** (perimeter)

ARUP

A VISION FOR BRISTOL

- Avon Barrage close to the M5 crossing
- Constant level fresh water impound to Bristol City Centre
- Unrestricted Waterborne Navigation

- Physical Road Link between North Somerset & Bristol City
- Potential for future rail link



- Fully automated control system
- Zero net energy barrage
- Innovative Hydropower Saline Flushing System
- Improved tidal flood protection

- Provision of alternative wildlife habitat
- Environmental monitoring and mitigation measures employed

- Promote Development
- Modern Engineering focal point for the City of Bristol

Model Scenarios

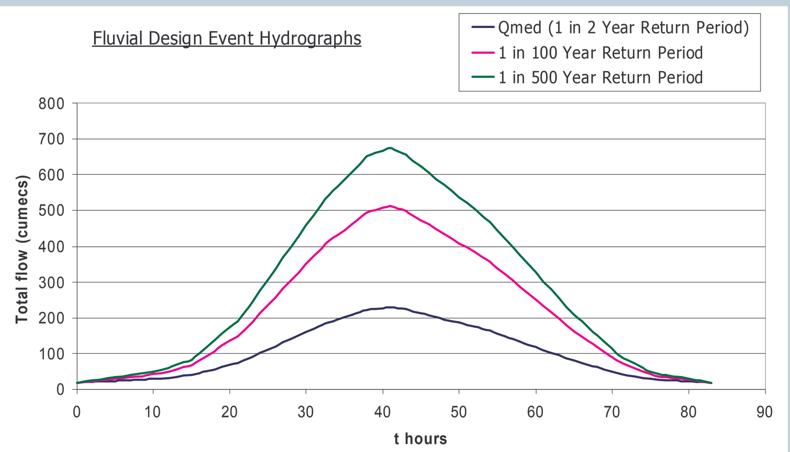
There are two main inputs in to the Hydrological control model of the barrage, the tidal model and the fluvial river flow model.

Very few structures are tested to be able to withstand both the most severe tide and fluvial acting at the same time as the probability of this occurring is very low. The following cases are tested in the control model.

	Tide	Fluvial
1 Normal	Mean Sea level	Summer/winter
2 Extreme	1 in 1 yr	1 in 100 yr
3 Extreme	1 in 100 yr	1 in 1 yr
4 Extreme	1 in 1 yr	1 in 500 yr
5 Extreme	1 in 500 yr	1 in 1 yr

River

Using procedures in the Flood Estimation Handbook, the design event fluvial flood hydrographs at the barrage site were determined.



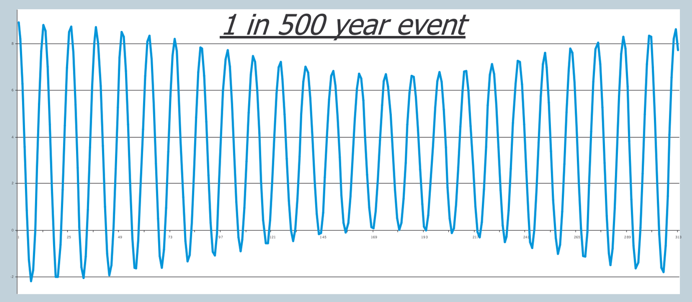
Statistical procedures used to find peak flows:
- Gauged donor site on Bristol Avon at Bathford, 4 km upstream of Bath, is used to provide Qmed, the median annual river flood.
- By comparison of donor and barrage catchments, Qmed at barrage site determined.
- WINFAP used to derive growth curve to determine more extreme fluvial flows

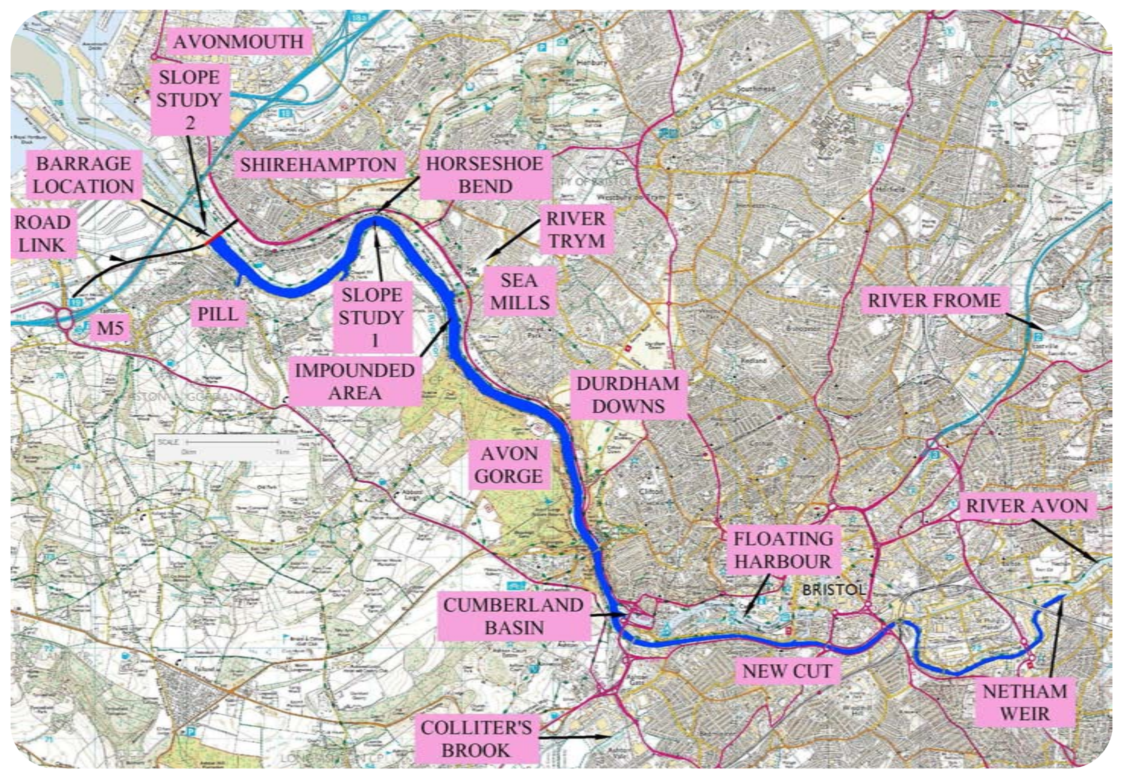
Standard hydrograph shape borrowed from Rainfall-Runoff method to determine design hydrograph.

Tidal Data

The gravitational attraction of the Sun and Moon are the main constituents of the tide. Two high and two low tides occur each day and the tidal range changes from a maximum (Spring) to a minimum (Neap) twice a month. The tide was modelled as a combination of cosine waves for each case.

1 in 500 year event





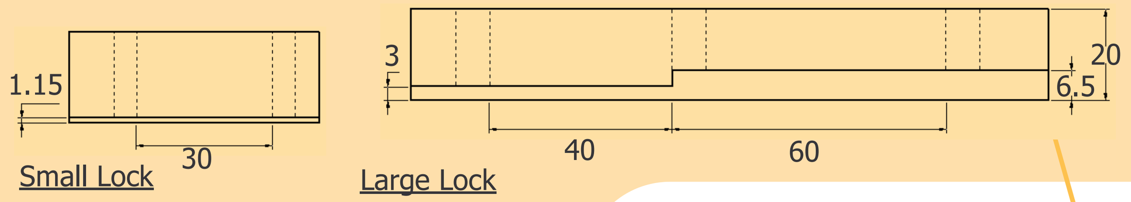
CONCEPT DESIGN

Locks

Two locks will be incorporated in the barrage to allow for the predicted 5,000 to 12,000 ships a year to navigate along the river.

The locks will have varying sill heights to reduce the volume of water in each locking process and vary the availability of the locks according to the size of vessel.

The large lock will have a third set of gates half way along the lock to effectively create two medium locks that can be combined to accommodate ships up to 100m in length.



	Small Lock	Large Lock
Width	10m	15m
Sill level (AOD)	-5.35m	-3.5m & 0m
Time available (per 12 hr tide)	10 hrs	7 hrs & 5 hrs

Fish Pass

Slotted Fish Pass, 87 m in Length

Lock Gates

Vertically hinged sector gates seal in both directions, are visually unobtrusive and have fast operation

Both the lock and sluice gates will be actuated by hydraulic systems due to proven reliability.

Impoundment level

The 6.1m AOD Floating Harbour is retained by the locks at Cumberland Basin. A lower impoundment level than this in the impoundment provides:

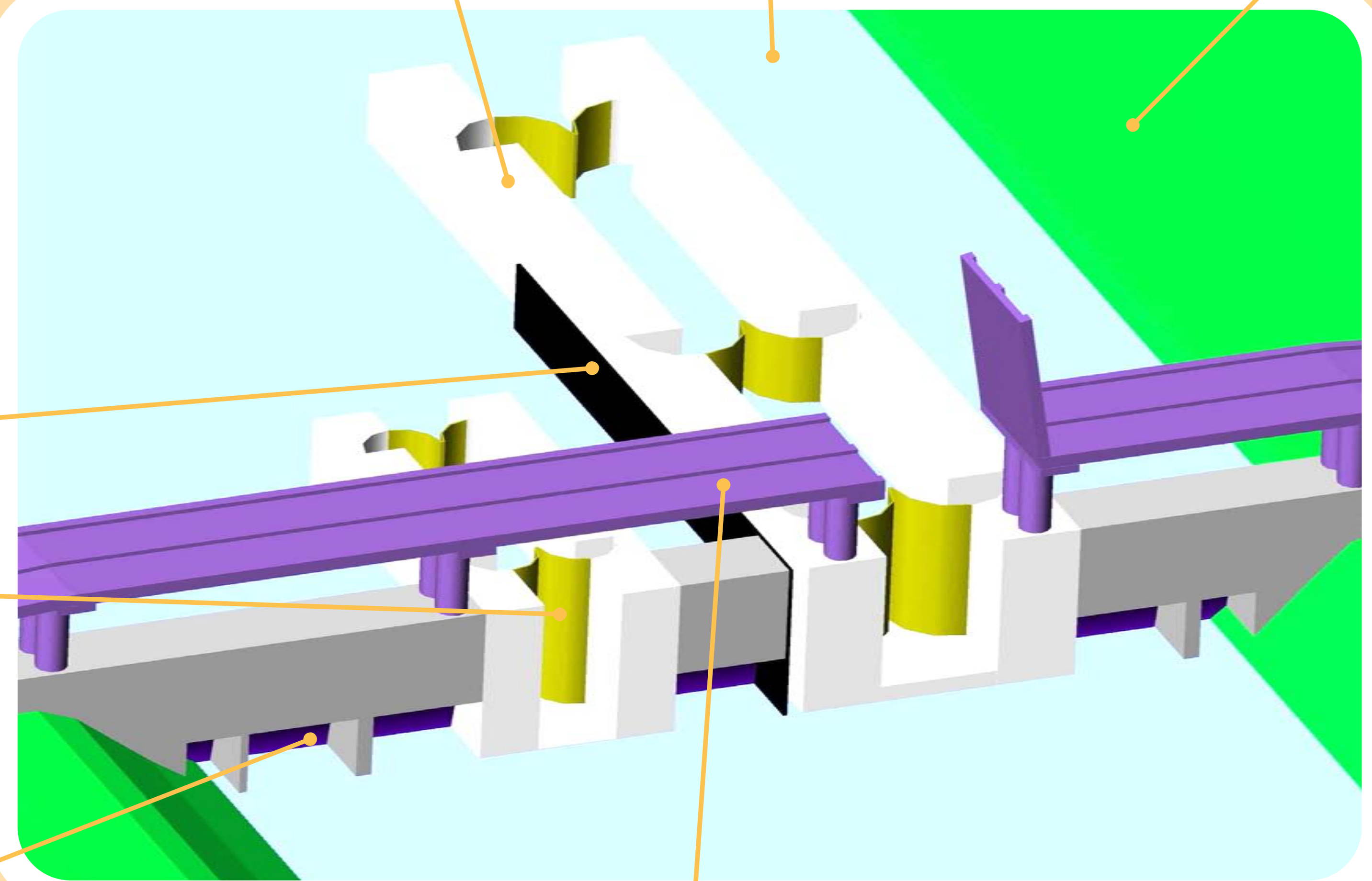
- Increased storage for fluvial events
- Reduced risk of groundwater flooding
- Less stratification problems
- Floating Harbour remains constant

The impoundment level should be greater than the current mean water level, to retain the character of the Gorge. The impound level chosen is 5.1m AOD.

Geology

The site consists of alluvium ~ 15m thick (5m thick from the bed of the river). Mercia Mudstone forms the bedrock below, which is a good material to underlay the barrage.

Alluvium will be excavated down to the bedrock and pad foundations will be built in concrete onto the Mercia Mudstone.



Additional Details

Design	Solution
Location	Close to M5 Crossing
Barrage Type	Total Exclusion
Width of River at Barrage location	165m
Height of Structure	20m
Materials	Reinforced Concrete
Construction	3 Stage Cofferdam
Water Quality Systems	Saline Flushing Pipe Aeration System
Power System	Axial Turbine
Secondary Works	Sewage Interceptor Inlet Harbour Landscaping
Cost Estimate*	£78 million

* Cost does not include the cost of sewage interceptor which could cost an additional £100 million - £500 million

Sluice Gates

Radial gates with an overflow section were chosen. These provide overflow capability to pass debris and undershot facility to scour the built up sedimentation.

The sluice gates needed to give sufficient discharge are:

- 4 of 14m wide x 8.5m high
- 2 of 7m wide x 8.5m high

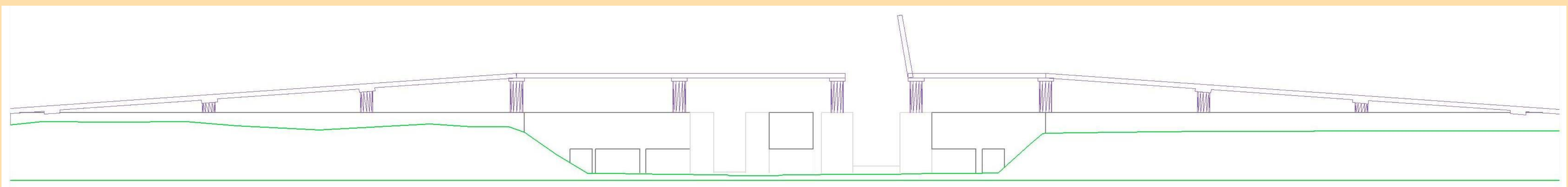
Bridge and Transport

The transport link will be provided by a road crossing consisting of a dual carriageway.

The 25m AOD high crossing was determined using a six degree incline and permits 95% of vessels passage without opening the bridge.

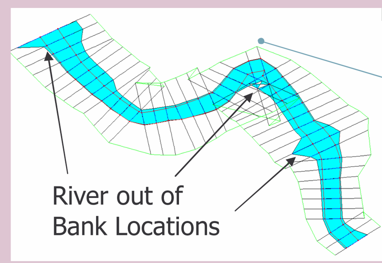
A Bascule Bridge will allow a low level crossing minimising visual impact. The advantages include:

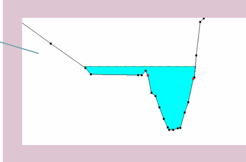
- Allowing small boats past when only partially opened
- Fast operation speeds
- Low space requirement



Cross Sections

Using OS maps and 'LIDAR' Data, a model of the river impoundment was created in 'HEC-RAS' to perform one-dimensional steady and unsteady flow calculations.



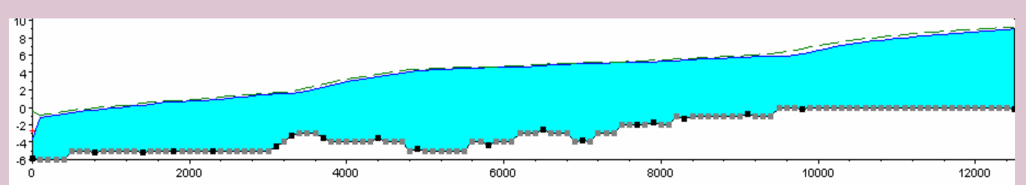


Cross-section of Horseshoe Bend

This identified potential flood areas at the barrage location, Horseshoe Bend and Sea Mills for extreme tidal events.

The model identified that due to the small cross-section of the channel, the river will be unable to cope with the capacity of water in extreme fluvial events. Additional flood protection may be required upstream of Bristol.

Cross-sections and HEC-RAS were also used to determine the storage volume and surface area of the impoundment for use in the control model



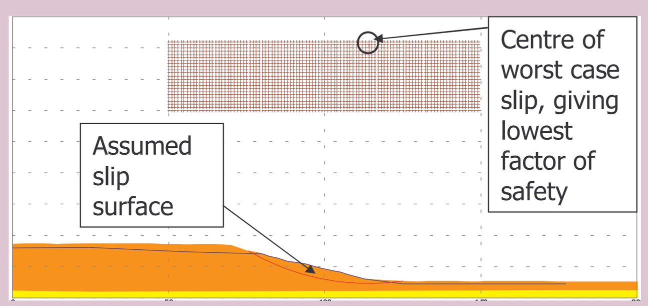
Section of Channel Bed along 13km reach

Slope Stability Study

Two studies were performed to ensure river banks remain stable after barrage construction. Study 1, upstream and study 2, downstream (see map). Current and future situations were observed for differing water levels.

A back analysis of the soil parameters was also performed using Infinite Effective Slope Analysis to verify the correct soil parameters to use.

'SLOPE' software was used to model the river banks using the Circular Arc Method.



Where slopes are unstable, stabilising measures will need to be taken such as building a retaining wall.

Downstream Results

Situation	Factor of Safety
Current HT	2.59 (stable)
Current LT	1.18 (barely stable)
Dredged HT	2.40 (stable)
Dredged LT	0.98 (unstable)
Dredged by 3m HT	1.36 (stable)
Dredged by 3m LT	0.58 (very unstable)

Upstream Results

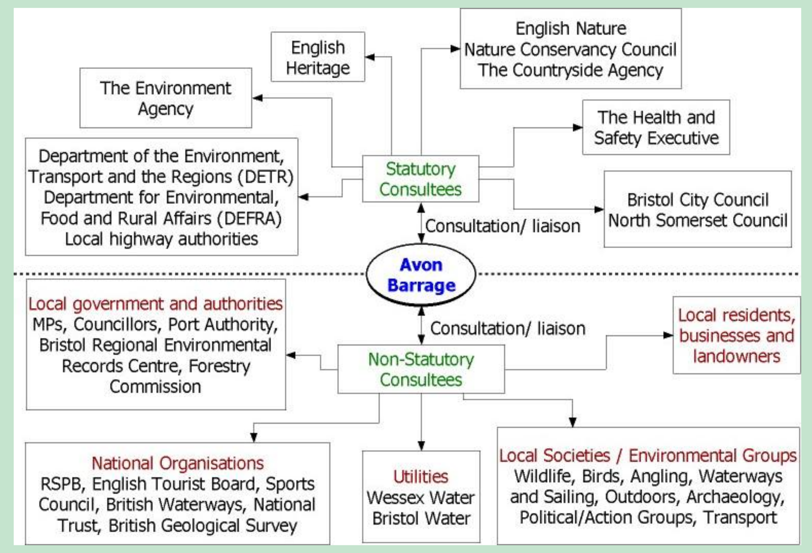
Situation	Factor of Safety
Current HT	2.55 (stable)
Current LT	1.04 (barely Stable)
Impounded	2.55 (stable)
Rapid Drawdown	1.04 (barely stable)

Key to Results
LT = Low Tide, HT = High Tide

Environmental

An Environmental Impact Assessment was performed with reference to "Environmental impact assessment :a guide to procedures" by the Department for Transport, Local Government and the Regions (2000).

Stakeholder Analysis



Key Impacts

- Water – changing from estuarine environment to freshwater lake, water quality, flooding.
- Landscape – Loss of mudflats, sedimentation, land use changes.
- Social/Economic – Regeneration, job creation.
- Ecology – Designated sites, rare species, fish migration.

Other Impacts

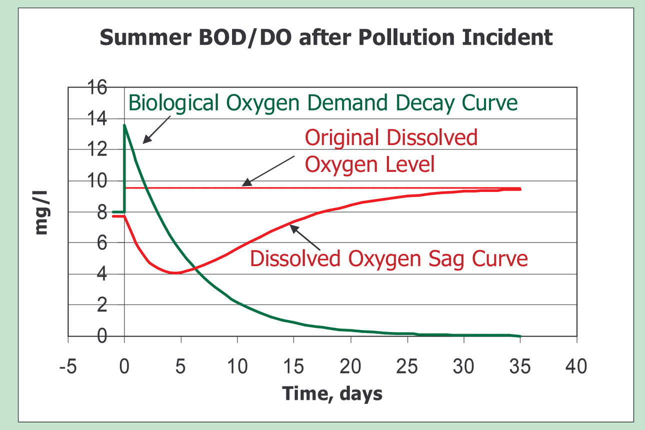
- Transport – Reduce congestion, road/public transport link
- Noise – From construction and road
- Archaeological and Historic Heritage
- Air quality and climate changes
- Soil and Geology – drainage, slope stability, erosion

Mitigation

- Pre and post construction monitoring
- Earlier and Fuller Consultation
- Noise reduction strategies
- Preservation schemes

Water Quality Modelling

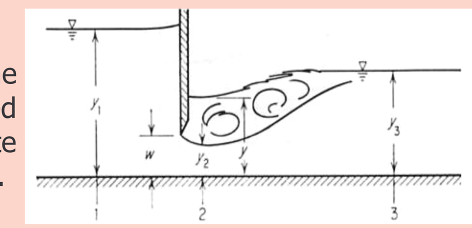
- What would happen if pollution event occurred?
- Summer months critical (low flows, little wind, reduced mixing).
- Dissolved Oxygen drops below 5 mg/l (concentration required to support aquatic wildlife).
- Retention time = 25 days (summer) – algal blooms may develop.
- Require diversion of treatment of sewer discharges (interceptor sewer/water treatment).
- Water may require aeration/oxygen injection.



Control Modelling & Power Generation

A fully automated system was created in Matlab to control the size of sluice opening, to maintain desired impound level (5.1m AOD).

Flow through the sluices was modelled using appropriate hydraulic equations.



Different types of controller were optimised and their responses evaluated for settling time, integral squared error and ability to limit noise.

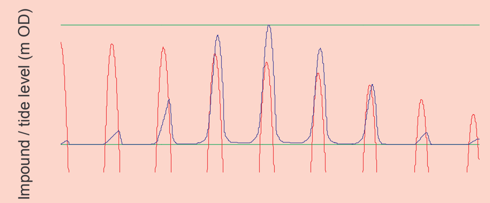
Proportional Integral control is the most suitable control method.

Extreme Events & Sluice Sizing

The model was tested against a range of fluvial and tidal extreme events.

Sluice gates were sized on the worst case fluvial event (Extreme case 4) shown below.

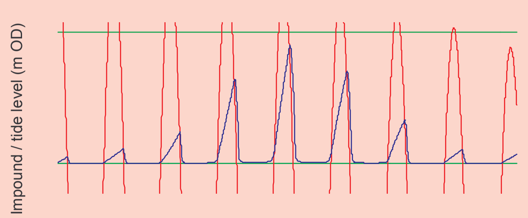
Worst fluvial flooding case



The worst case tidal event (Extreme case 5) shown below, shows that the barrage will reduce the risk of tidal flooding in Bristol.

This will be increasingly important for Bristol as significant rises in sea levels are forecast, during the next century.

Worst tidal flooding case



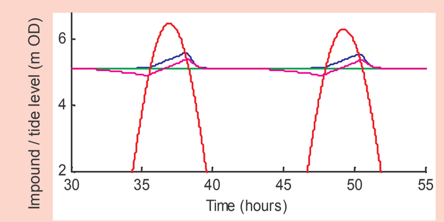
Graph Key: RED = Tide, BLUE = Impound Height, GREEN = Max allowable impound (7.8m AOD) & Desired impound (5.1m AOD)

Management Strategies

Different management strategies were incorporated into the control model including:

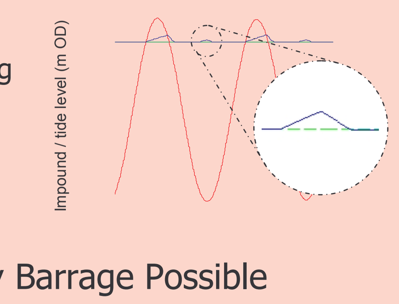
Tidelock Compensation – lowering the impound in advance of the unavoidable gain from river flow during tidelock. This system involves forecasting future river flow based upon telemetry readings.

Effect of Tidelock Compensation



Scouring – raising the impound just before low tide in order to discharge a burst of high velocity flow to scour built up sediment.

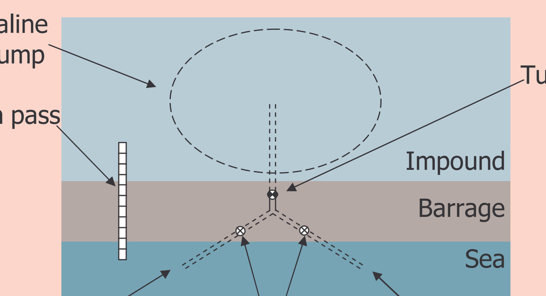
Effect of Scouring



Zero Net Energy Barrage Possible

Analysis has shown that an innovative hydropower generation system (below) could meet the barrages 39MWh predicted monthly demand.

Plan View



Joss Boxford, John Buchanan, Jennifer Darracott, Nicola Gautrey, Jameel Lalani