



The Menai Strait: environmental design as a fundamental requirement in assessing engineering options

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1 INTRODUCTION

The Menai Strait is an open coastal strait separating the Isle of Anglesey from mainland North Wales. The narrow central section of the Strait, confined by steep rocky shores, experiences extreme tidal currents which scour the seabed and inhibit sediment accumulation. At either end, however, where the channel is wider, extensive mudflats and sandbanks are present.

This region of North Wales is recognised as an area of outstanding natural beauty and conservation interest. The Strait is located in a popular tourist area, and as such there is a heavy demand on the waterway for recreational and leisure use with the National Outdoor Pursuit Centre located at Plas Menai, north of Caernarfon. There is also a thriving shellfish industry within the Strait, with numerous mussel beds in the areas of Bangor and Brynsiencyn. The Menai Strait also supports an abundant and varied marine ecosystem, for which the Countryside Council for Wales (CCW) propose the Welsh Office award the area Marine Nature Reserve (MNR) status.

The summer population of the area is approximately 50,000, concentrated primarily in Bangor and Caernarfon. *Table 1* lists the resident and summer populations of the principle conurbations adjoining the Strait. At present, all domestic sewage effluent is discharged into the Strait; Dŵr Cymru-Welsh Water currently discharge at over twenty-five separate locations, the majority of them untreated.

Welsh Water Plc have publicly stated their commitment to improving water quality in the Strait, and have allocated £22 million to upgrade existing sewage disposal facilities. Wallace Evans Limited (WEL) have been engaged to act as engineering and environmental consultants to Dŵr Cymru-Welsh Water (DCWW), with the brief of developing and implementing future strategic engineering options to ensure that relevant environmental standards are achieved and the diverse environmental uses protected.



2 FUNDAMENTAL DESIGN PARAMETERS

2.1 Constraints on Environmental Design

Bangor is one of the major conurbations adjoining the Menai Strait. At present, the major Bangor outfall discharges onto the intertidal zone of the Lavan Sands, into a small river. This leads to low dispersion of the crude sewage effluent, which consequently results in poor water quality over Lavan Sands and in the vicinity of Bangor. The objective of the Menai scheme is to improve water quality in the Strait; the key first step in achieving this is therefore to mitigate against the effect of the main Bangor outfall.

Other critical objectives of the Menai Improvement scheme are to protect existing and future uses of the Strait, and also to adhere to the timescale and budgetary requirements of the client.

2.1.1 Regulatory, Leisure and Recreational Requirements

The 'Menai Improvement Scheme' is not driven explicitly by current legislation but by Welsh Water Plc's stated commitment to improving water quality within the Strait. There are still, however, quantifiable environmental standards to be achieved. The relevant UK regulatory body, the National Rivers Authority (NRA), have the responsibility of ensuring:

- That no detriment in water quality occurs throughout the Strait, with particular emphasis on areas where immersion and water contact sports are prevalent;
- Compliance with the future requirements of the Urban Waste Water Treatment Directive;
- That regional NRA policy requirements, such as initial dilution criteria and the frequency of storm spill operation, are adequately addressed;
- That the methods and solutions derived to ensure compliance with standards are soundly based and are of practical value.

2.1.2 Aquacultural Requirements

The EC Directive 91/492/EEC: Classification of Shellfish Harvesting Beds lays down the conditions for the placing on the market of live bivalve molluscs (such as oysters, mussels, cockles and cultivated scallops) and marine gastropods (such as winkles and whelks). A fundamental requirement of the Directive is that certain bacteriological criteria must be met in mollusc harvesting areas. These areas are classified according to the degree of contamination by faecal indicator bacteria present in samples of mollusc flesh. The classification categories and the criteria for them are outlined in *Table 2*.



The Ministry of Agriculture, Fisheries and Food (MAFF) are responsible for protecting the interests of the shellfish harvesting industry in the Strait. It is not possible to precisely quantify the relationship between faecal bacteria in the ambient water body and the concentrations of these indicator organisms in shellfish flesh. However, it is clear that water quality has a strong bearing on subsequent shellfish flesh quality. In order to ensure the continuing commercial viability of the shellfisheries, MAFF therefore require a significant improvement in water quality over the designated shellfish beds.

2.1.3 Conservation Requirements

The diverse range of habitats in the Menai Strait support a variety of marine wildlife. Concerned that increasing pressures on the resources of the Strait could reduce this diversity, the Countryside Council for Wales (CCW) propose to designate the entire Strait as a Marine Nature Reserve (MNR). Particular conservation interest is concentrated on the region known as the 'Swellies', which is designated as the core of the proposed MNR.

The environmental design constraints are illustrated in *Figure 2*.

2.2 Constraints on Engineering Design

The engineering feasibility of proposed design scenario is dependant on a wide range of factors. Due consideration must be given to:

- Areas of key environmental impact, such as the Lavan Sands and those identified above.
- Existing discharge scenario and state of existing sewerage network. To limit costs, existing infrastructure should be utilised where possible.
- Availability of land and planning constraints

3 DEVELOPMENT OF ASSESSMENT TOOLS

3.1 Selection of Assessment Tool

Before any environmental assessment can be contemplated, it is essential that appropriate assessment tools have been developed. When selecting an appropriate tool, the following criteria must be met:

- the tool must be capable of identifying existing areas of environmental concern.
- the tool must be capable of identifying the contributors to existing problems
- the tool must be capable of predicting the impact of future design scenarios.



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An additional constraint on assessment tool selection, both in the choice of tools and their validation, is agreement with the regulators, such that the selected approach will satisfy their requirements thereby reducing the likelihood of subsequent disagreements.

Due to the physical conformation of the Menai Strait, the only feasible method of adequately predicting the hydrodynamic characteristics of the water body was to utilise a 'curvilinear grid' type mathematical model. Delft Hydraulics Limited, as the leading exponents of the curvilinear grid approach to model design, were therefore commissioned to develop hydrodynamic and dispersion models of the Strait. An example of the curvilinear grid approach, where the grid follows the geographical confines of the area, is shown in *Figure 3*, along with an illustration of the extents of the model grid.

3.2 Model Calibration and Verification

3.2.1 Rationale

Mathematical models are based on equations which describe the tidal, wind driven and density driven currents at discrete points in space. The distance between these points, the grid spacing, defines the smallest scale motion that can be resolved by the model, and in complex areas of the Strait is of the order of 30 x 150m (*Figure 3*). However, in any coastal waterbody flows are invariably turbulent with a plethora of small scale random flow features which enhance the mixing of contaminants and increase friction within the flow, thereby modifying the large scale flow field. These small scale features are indirectly included in the model as friction and dispersion coefficients, and are evaluated by comparing the model output with field measurements. This process is known as calibration. To increase confidence that the friction and dispersion parameters were accurately estimated in the calibration stage, the same process is repeated, but under different flow conditions. This repeat process is known as verification.

3.2.2 Data Collection

With the benefit of its in-house survey capability, WEL conducted an extensive oceanographic survey to obtain data to calibrate and verify the models. The hydrodynamic model was calibrated and verified through comparison with thirty day records of tidal elevations, from two locations in Caernarfon Bay, and current velocities, from two locations within the Strait. Tidal elevation and current velocity are the basic forcing mechanisms for water movement within the Strait. If the hydrodynamic model calibrates and verifies well against these parameters, then we have confidence that the model accurately predicts water movement throughout the Strait.

Calibration and verification of the dispersion model was achieved by comparison of model predictions with dye dispersion data, which



were processed to calculate horizontal and vertical dispersion coefficients for the Strait. Dye tracer experiments were conducted from two locations, Brynsiencyn and Llanfairpwll, on spring tides, and from Brynsiencyn and Treborth on neap tides.

Additionally, input loadings surveys, incorporating simultaneous flow monitoring and quality sampling, were conducted on 15 major discharges and freshwater inputs. Bacterial and pollutant loads and the diurnal loading variation for each input could therefore be accurately described, and subsequently used in the water quality model to ensure high quality data input.

To aid in the engineering design stage, and subsequent geotechnical appraisal of the preferred solutions, bathymetric measurements, side scan sonar and shallow seismic sub-bottom profiling were also performed at the proposed new outfall locations.

3.2.3 Model Calibration Results

Standard calibration procedure is to compare model predictions with measured data in a number of locations and for a number of model parameters, and assess the standard of the model's performance by the quality of these comparisons. *Figure 4* illustrates the level of correlation between long term current meters in the Strait and the model predictions, *Figure 5* illustrates a comparison of historical with predicted water quality data. The high correlation between data sets for both the hydrodynamic and dispersion models therefore gives us confidence that the model is adequately calibrated and verified, and that the model predictions are valid.

Throughout the model development and calibration, close liaison was maintained with the regulator at each stage of the programme. This facilitated the final acceptance of the model by the NRA as a 'fit for purpose' design tool.

3.3 Model Data Interpretation

In order to render the often complex model data useable, a number of interpretive techniques were developed:

- i) Longitudinal sections, averaged over a tidal cycle, were used to compare different discharge scenarios to determine the distribution of contaminants along the central axis of the Strait, and thereby determine the impact of each option on each significant area;
- ii) Three dimensional representation of water quality over significant areas, such as shellfish beds and the core of the proposed MNR, to give a good comparative assessment of the impact of each option;
- iii) Temporal and spatial averages of the dilution of contaminants over general amenity areas, to determine the effect of different discharge scenarios on the water quality of recreational areas;



- iv) Plan view animations, providing an excellent overall view of the time varying impact of various discharge scenarios.

A selection of these techniques are illustrated in *Figure 6*.

4 OPTION ASSESSMENT PROCEDURE

The option assessment procedure used in this scheme is generic, and serves equally well as a general guideline for future sewage improvement schemes.

The procedure, when applied in practice, is not linear. It requires that options be reviewed regularly in the light of subsequent information, leading to an iterative approach to the solution. The basic steps are (*Figure 7*):

- Determine objectives of the scheme
- Determine constraints on engineering and environmental design
- Identify key sources of environmental impact
- Outline engineering solutions
- Environmental assessment of options - assess compliance with objectives
- Detailed engineering design.

For the Menai Scheme, the steps involved the following:

i) **Identify sources of environmental impacts**

Mitigating against the effect of the main Bangor outfall, which currently discharges crude effluent into shallow water on Lavan Sands, is the key environmental objective of the scheme.

ii) **Identify engineering options to mitigate against these impacts**

Constraints on the selection of engineering options were as follows:

- Availability of land
- Existing discharge scenario and state of existing sewerage network
- Likelihood of obtaining planning consent.

Within these constraints, identified engineering options that would effectively lead to a reduction in the impact of the Bangor discharge were to either extend the current Beach Road outfall into the middle of the Strait (the Beach Road option), or to pump all Bangor flows to an existing treatment works at Treborth, and then discharge the flows into the Strait from there (the Treborth option).

iii) **Refine engineering options to satisfy environmental objectives**

This stage develops the engineering options in the following key areas:



- Identify level of treatment required
- Identify length of outfall required
- Identify amount of storage required, either to limit the frequency of storm spills or to ensure compliance with initial dilution criteria.
- Assess compliance with environmental objectives.

There are inevitably trade-offs between these factors. Using the model, alternatives can be efficiently identified and compared. Basic costing information allows a range of preferred options to be developed.

For the Beach Road option, an outfall extended into the main channel with primary treatment would result in the following improvements over sensitive areas:

- **Lavan Sands.** There would be a significant improvement in water quality over the Lavan Sands
- **Bangor Shellfish Beds.** Water quality would not change significantly, as the increased level of treatment would be offset by the closer proximity of the discharge location.
- **Proposed MNR.** Water quality in the core area would improve slightly.
- **Plas Menai Area.** Water quality in this area would improve over its current high level

For the Treborth option, with primary treated effluent discharged through a minor extension to the existing outfall, the following changes were predicted:

- **Lavan Sands** There would be a significant improvement in water quality over the Lavan Sands.
- **Bangor Shellfish Beds.** There would be a significant improvement in water quality over the Bangor shellfish beds.
- **Proposed MNR.** Water quality in the core area would not significantly change, as the increased treatment is balanced by the closer outfall.
- **Plas Menai Area.** Water quality in this area would remain high.

Both of these options satisfy the environmental objectives in part, with significant improvement in water quality over the Lavan Sands and the continued high quality of the water in the Plas Menai area common to each. The Beach Road option, however, does not offer any improvement in water quality over the Bangor Shellfish Beds, while the



Treborth option has little impact on water quality in the core of the proposed MNR.

The overall conclusion of the environmental assessment was that, in order to satisfy all of the environmental objectives fully, it would be necessary to provide secondary treatment to the Bangor flows.

iv) Revise costings

The provision of secondary treatment at both sites were costed.

v) Prioritise favoured solutions

The provision of secondary treatment at Beach Road was forecast as both expensive and likely to incur public opposition, leading to problems in obtaining planning permission.

The Treborth option, where land was already available, would be the most cost effective solution that would satisfy the environmental criteria.

vi) Incorporate remaining environmental impacts

Once a preliminary preferred option was identified the other catchments, such as Brynsiencyn, Menai Bridge, Llandegfan, Beaumaris, Llanfaes and Port Dinorwic could be incorporated into the overall scheme. This involved repeating steps (iii) to (v).

The final design option that was selected was as follows, and is illustrated in *Figure 8*:

- Secondary treatment works at Treborth; treating flows from Bangor, Treborth, Port Dinorwic, Menai Bridge and Llandegfan.
- Secondary treatment works at Brynsiencyn; treating the flows from Brynsiencyn only
- Phased introduction of secondary treatment at Llanfaes; to treat flows from Llanfaes and Beaumaris.

To summarise the process detailed above, the essence of the option selection procedure is to develop the optimum balance between three essential, but often conflicting requirements:

- Obtain regulatory approval for the scheme expediently
- Minimise the cost of obtaining regulatory approval
- Minimise the expenditure involved in implementing the selected option.



5 CONCLUSIONS

- 5.1 In order to assess the environmental aspects of selected options, it is essential to develop appropriate analytical tools and interpretative methods.
- 5.2 In order to progress the scheme efficiently towards completion, 'external' communication, i.e. between the client, consultant and regulator, and 'internal' communication, i.e. between survey, environmental and engineering consultancies are critical.
- 5.3 Experience with the Menai Improvement Scheme illustrates a logical and evolutionary process of option design assessment.
- 5.4 Without accurate costings of all aspects of the engineering design, there is a potential for delays in the option assessment stage, thereby leading to escalating costs.
- 5.5 The environmental design stage is now firmly established as an integral part of the option selection process.

**Table 1: Residential and Total Populations of the Conurbations Adjoining Menai Strait**

Town	No. of Outfalls and Level of Treatment	Population	
		Residential	Total Residential & Tourist
Bangor	8 crude outfalls	17275	18220
Caernarfon	1 secondary treated outfall	9675	11710
Llanfaglan	1 secondary treated outfall	3517	5340
Llanfairpwll	1 secondary treated outfall	3068	4418
Menai Bridge	5 crude outfalls	3258	4357
Llandegfan	1 secondary treated outfall	1940	2700
Beaumaris	1 crude outfall	1671	2674
Port Dinorwic	3 crude outfalls	1470	1565
Treborrh	1 primary treated outfall	1100	1242
Brynsiencyn	1 crude outfall	666	928
Llanfaes	1 secondary treated outfall	310	430

Table 2: Classification of Shellfish Harvesting Areas

Category	Environmental Criteria	Treatment Required
A	< 230 <i>E.coli</i> /100g flesh or < 300 faecal coliforms	May go direct for human consumption if end product standard met.
B	< 4600 <i>E.coli</i> /100g flesh (in 90% of samples) or < 6000 faecal coliforms/100g flesh (90%)	Must be depurated, heat treated or relaid to meet category A.
C	< 60,000 faecal coliforms/100g flesh	Must be relaid for a long period (at least two months) to meet category A or B, or heat treated.
D	> 60,000 faecal coliforms/100g flesh	Harvesting prohibited.

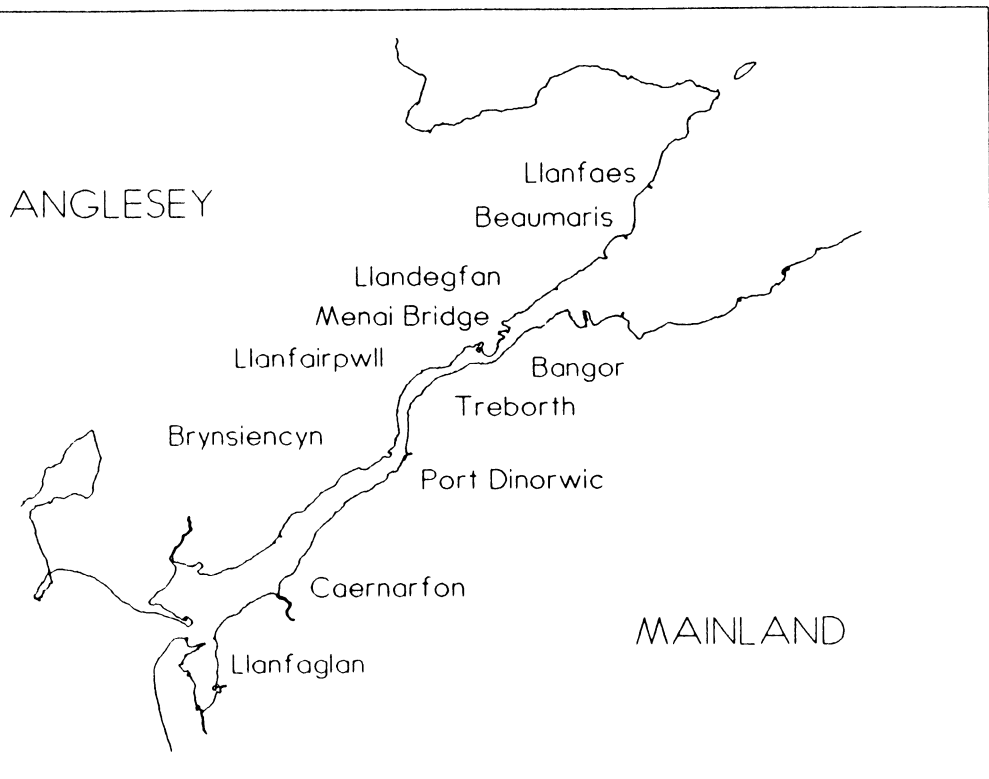


Figure 1: Location Map

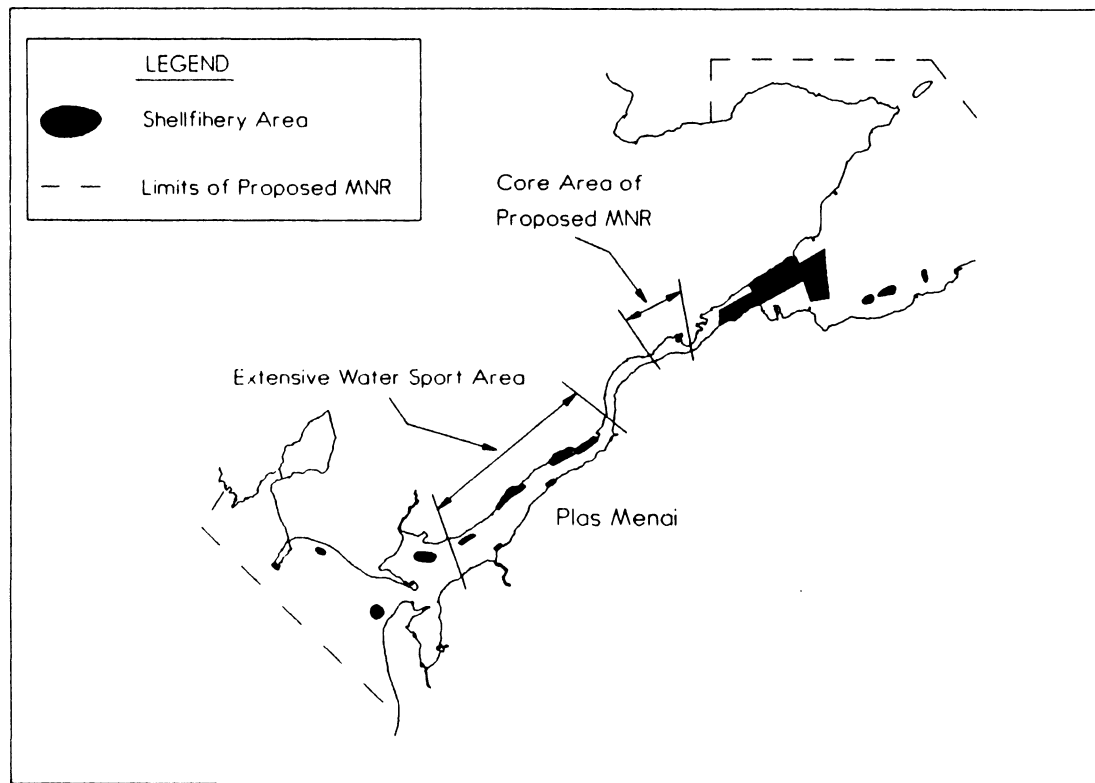


Figure 2: Constraints on Environmental Design

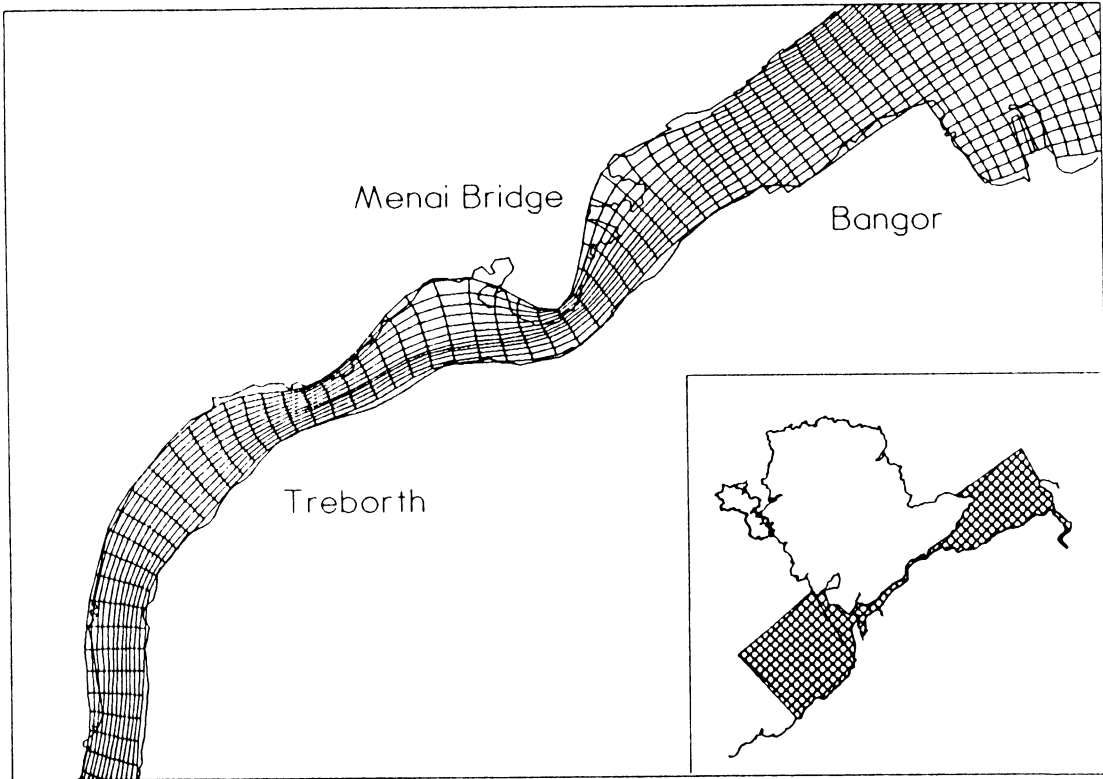


Figure 3: Model Grid in the Region of Menai Bridge and (insert) Extents of Model Grid

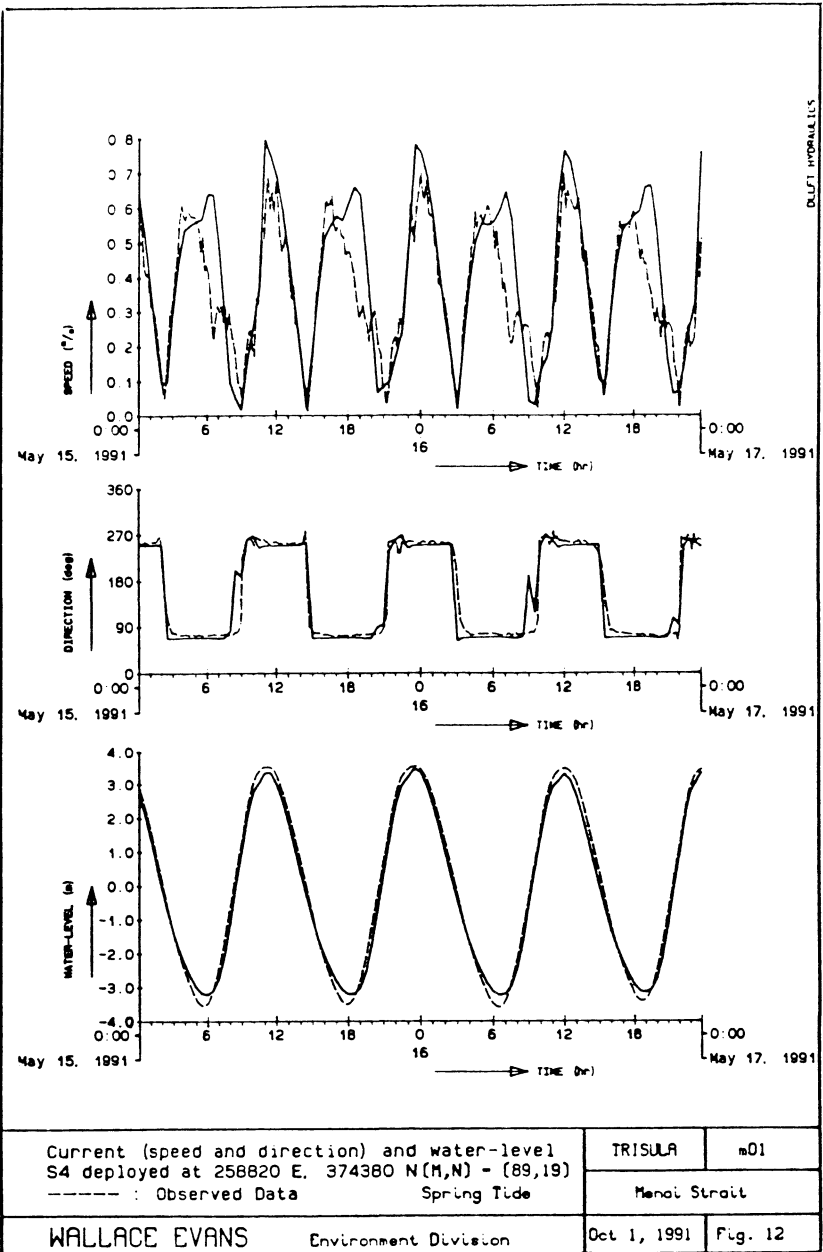


Figure 4: Hydrodynamic Model Calibration

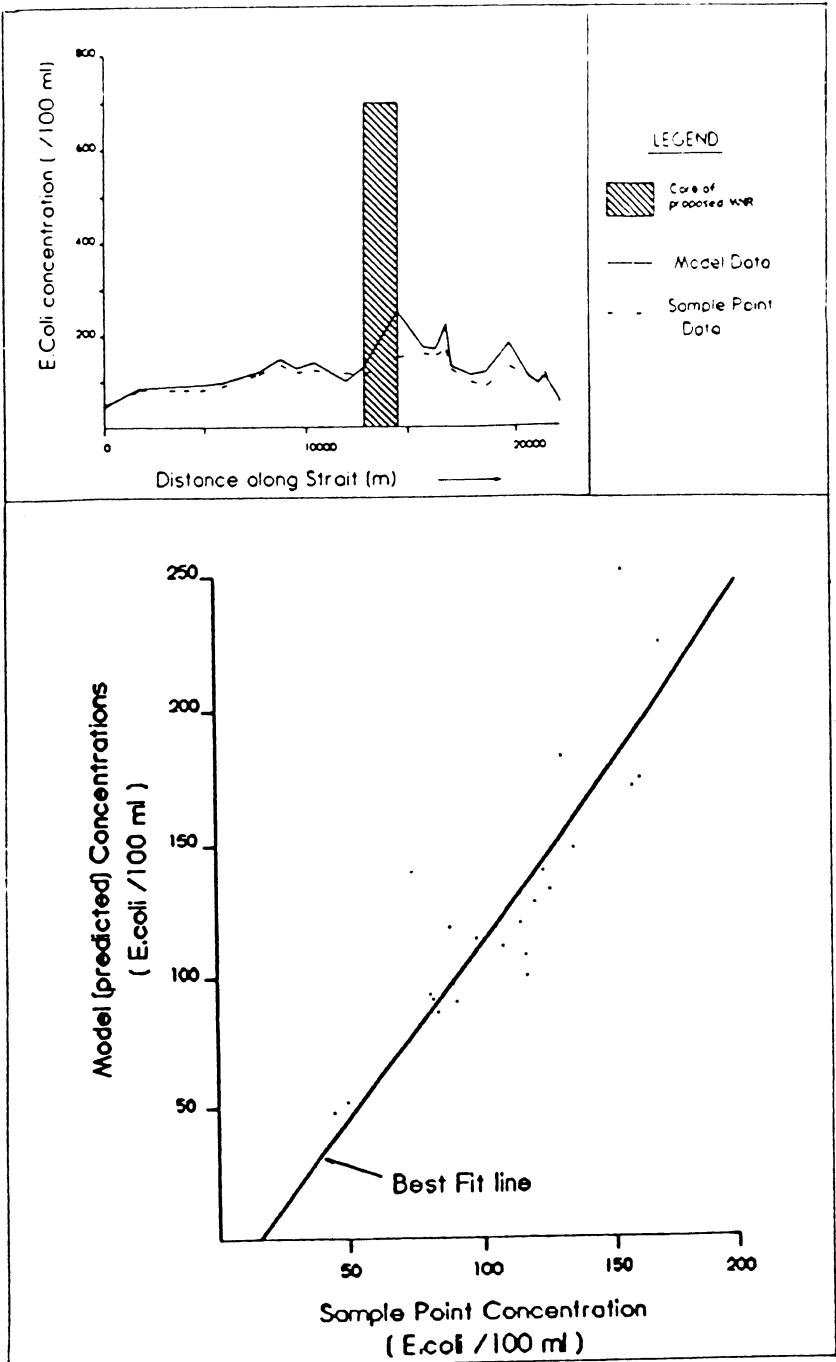


Figure 5: Dispersion Model Calibration

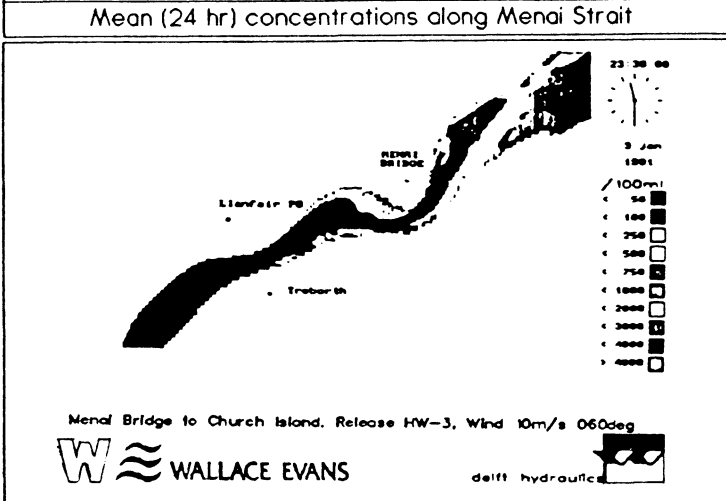
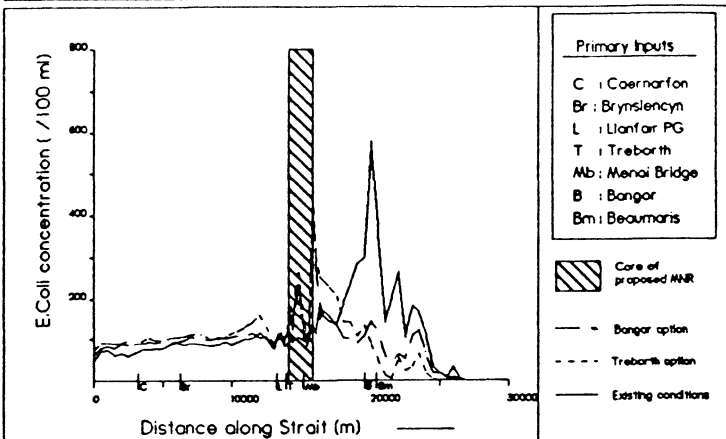
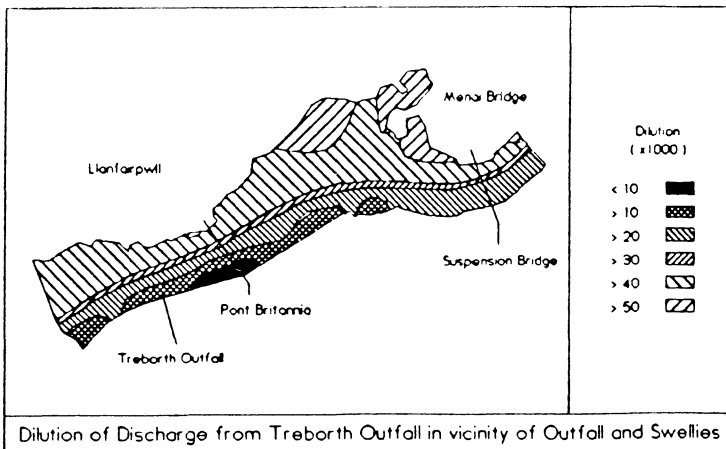


Figure 6: Sample Interpretive Techniques

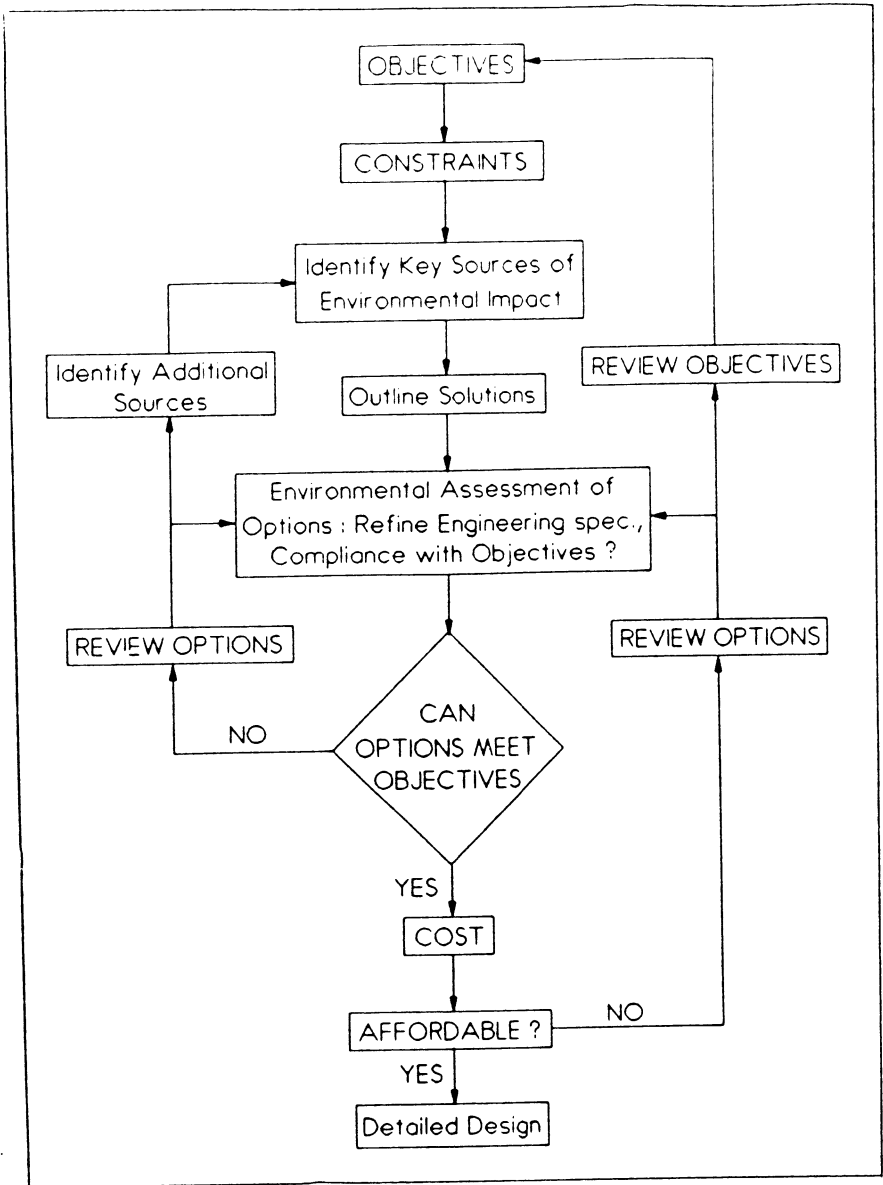


Figure 7: Option Appraisal Procedure

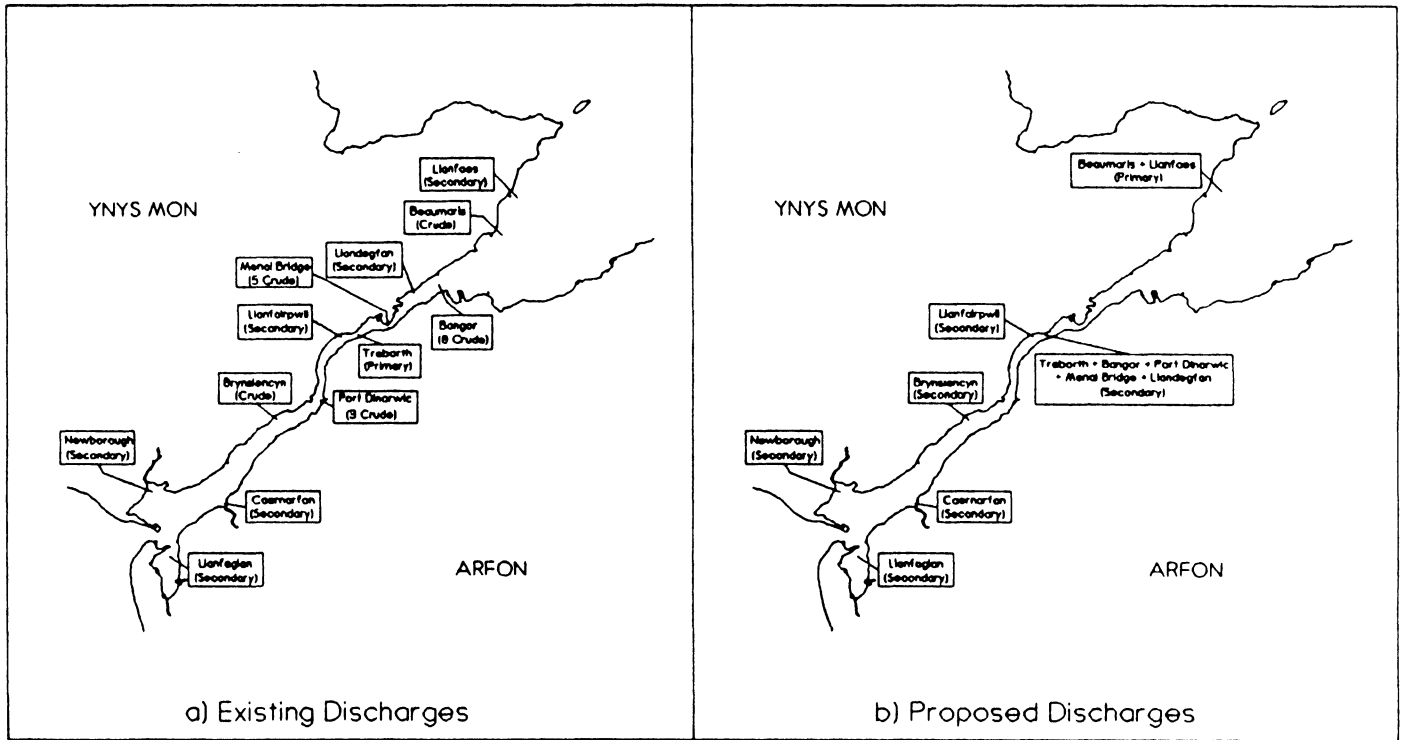


Figure 8: Existing and Proposed Discharge Scenarios