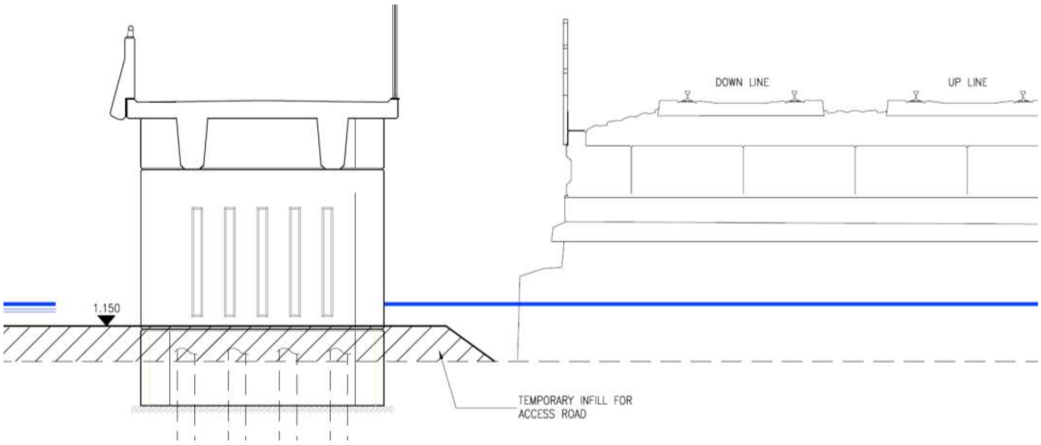
Malahide Viaduct Reinstatement

Temporary Works

Computer modelling for Environmental Analyses



FLUVIO R&D Limited
Fifth Floor, 5 Lapps Quay, Cork, Ireland
Tel: +353-21-4271456

July 2015

FLUVIO R&D Limited
Fifth Floor, 5 Lapps Quay, Cork, Ireland
email: info@fluvioresearch.com

Irish Rail, Structural Design Section

Track and Signals HQ
Inchicore, Dublin 8

Malahide Viaduct Reinstatement

Temporary Works

Computer modelling for Environmental Analyses

July 2015

FLUVIO R&D Limited
Fifth Floor, 5 Lapps Quay, Cork, Ireland
email: info@fluvioresearch.com

TABLE OF CONTENTS

Glossary of terms iii

1 Introduction 1

2 Computer model for Temporary Works 4

2.1 Set-up of a detailed Mike21 computer model for the temporary works 4

2.2 Mike21 Model parameters 5

3 Model results for Temporary Works 6

3.1 Estuary hydrodynamics during Neap tides 6

3.2 Estuary hydrodynamics during spring tides 7

3.3 Exposure at neap low and spring low 7

4 Conclusions 9

5 References 10

6 Appendices

GLOSSARY OF TERMS

Terms	Definition
2-D model	A depth-averaged models that assume uniform velocity and hydrostatic pressure along water depth, and considering vertical velocities and accelerations to be negligible.
3-D model	Process of developing a mathematical representation of any three-dimensional surface of object via specialized software or in laboratory.
Armouring	Protective covering (e.g. rocks) used to prevent erosion damage to coastal and fluvial structures, banks, beds and beaches.
Attenuating	Gradual reduction
Bathymetry	A study of underwater depth of lake or ocean floors, and usually refers to the measurement of ocean depth through depth sounding.
Bed roughness	(see roughness coefficient)
Breach of defences	A structural failure at a flood defence allowing water to flow through.
Boundary condition	Conditions applied on the model open boundaries.
Catchment	The area that is drained by a river or artificial drainage system.
Climate change	Long-term variations in global temperature and weather patterns, which occur both naturally and as a result of human activity, primarily through greenhouse gas emissions.
Coastal erosion	The gradual wearing away of the coastline through a combination of wave attack and, in the case of coastal cliffs, slope processes (e.g. high groundwater levels). This may include cliff instability, where coastal processes result in the periodic reactivation of landslide systems or promote rock falls.
Coastal flooding	Flooding from the sea which is caused by higher than normal sea levels and/or high waves resulting in these a overflowing onto the land.
Computer model	(see mathematical model)
Continuity	The fundamental law of hydrodynamics, which states that, for incompressible fluids and for flow independent of time, the sun of differential changes in flow velocities in all directions must ne zero.
Conveyance function	When a river overflows its banks, it continues to flow over the flood plain, conveying water down-stream, as well as storing water where the flood plain may be obstructed and releasing it slowly.
Coriolis force	Directed normal to the direction of the movement and proportional in magnitude to the speed of the moving body.
Design iterations	Various trial designs which were tested and evaluated.
Model domain	Spatial area comprised in models.
Enhanced weir	Modified weir to provide long term stability and safety.
Environmental Impact Assessment (EIA)	Pursuant to EU Directive 85/ 337/ EEC (as amended in 1997), EIA is a legislative procedure used for identifying the environmental effects of development projects to be applied to the assessment of the environmental effects of certain public and private projects which are likely to have significant effects on the environment.
Erosion	A process of weathering and transport of solids (sediment, soil, rock and other particles) in the natural environment or their source and deposits them elsewhere.
Estuary	The mouth of a river, subject to tidal effects, where fresh water and sea water mix.

Terms	Definition
Estuarial flooding	Flooding from an estuary, where water level may be influenced by both river flows and tidal conditions, with the latter usually being dominant.
Exposure	Quantification of the receptors that may be influenced by a water.
Fetch	The area of water in which waves are generated by a wind having a fairly constant direction and speed. Sometimes used synonymously with "fetch length," the horizontal distance over which a wind generates waves.
Finite-difference model	A digital computer model based upon a rectangular grid that sets the boundaries of the model and the nodes where the model will be solved.
Flooding (or inundation)	Flooding is the overflowing of water onto land that is normally dry. It may be caused by overtopping or breach of banks or defences, inadequate or slow drainage of rainfall, underlying groundwater levels or blocked drains and sewers. It presents a risk only when people, human assets and ecosystems are present in the areas that flood.
Floodplain	A floodplain is any low-lying area of land next to a river or stream, which is susceptible to partial or complete inundation by water during a flood event.
Fluvial flooding	Flooding from a river or other watercourse.
Flume	An open channel constructed of wood, steel, or reinforced concrete and used to convey water for various purposes, including grade control.
Froudian criteria	A type of hydraulic modelling where model results are extrapolated to prototype (e.g. river or estuary) using scaling laws based on similarity of Froude Number in model and prototype.
Froude number	A hydraulic number representing the ratio of inertia forces and gravity forces action upon water, and making it possible to distinguish between subcritical and supercritical flow velocities.
GCM	Global Climate Model.
Gabions	Rock-filled wire cages used on streams for erosion control and construction of dams and other structures.
Geometrical similarity	Similarity of shape and the geometric characteristics can usually be described by a series of lengths and angles.
Geotechnical	Study of soils and rocks.
Groundwater flooding	Flooding caused by groundwater escaping from the ground when the water table rises to or above ground level.
Hybrid models	Combining two or more models (e.g. physical and mathematical) in a solution method is hybrid modelling. Hybrid models attempt to use the best modelling methods available for each "part" of hydraulic problems.
Hydraulic	Study of flow in rivers, canals, pipes and structures using fundamental laws and equations.
Hydraulic characteristic	Hydraulic performance such as relationship between water level and flow rate.
Hydraulic control	A point in open channel river or estuarine flow where there is a definite relationship between water level and flow rate.
Hydraulic jump	A phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise (a step or standing wave) occurs in the liquid surface.
Hydrology	The study of the occurrence, distribution and chemistry of all waters of the earth.
Hydrostatic	Conditions when the pressure on a fluid at rest is isotropic; i.e., it acts with equal magnitude in all directions.
Laboratory model	(see physical model)

Terms	Definition
Manning's number	A resistance coefficient used in the Manning equation for uniform steady flow.
Mathematical model	A model that simulates a system's behaviour by a set of equations, perhaps together with logical statements, by expressing relationships between variables and parameters.
Model calibration	The process by which the independent variables of a digital computer model are varied in order to calibrate a dependent variable against a known value.
Model verification	The process by which a computer model that has been calibrated is tested to see if it can generate a transient response that matches the known history of the water body.
Modelling	The simulation of physical or abstract phenomenon or system with another system believed to obey the same physical laws or abstract rules of logic, in order to predict the behaviour of the former by experimenting with the latter.
Neap tides	When the Moon is at first quarter or third quarter, the Sun and Moon are separated by 90° when viewed from the Earth, and the solar gravitational force partially cancels the Moon's. At these points in the lunar cycle the tide's range is at its minimum.
Non uniform flow	If at a given instant, the velocity or depth is not the same at every point the flow is non-uniform.
Numerical model	(see mathematical model)
Overtopping of defences	Failure of a flood defence or exceedance mechanism, when flood water reaches levels that are higher than the flood defence level and flows over the top of the structure. While the structure may remain stable, however, erosion of the landward face of the defence could cause the defence to collapse.
Permeability	The property of a porous substance, as rock or a membrane, of allowing the flow of a fluid through it.
Physical model	A smaller or larger physical copy of an object. The geometry of the model and the object it represents are often similar in the sense that one is a rescaling of the other. In such cases the scale is an important characteristic.
Reno mattresses	A low profile flexible wire basket filled with stones and used to control scour.
Roughness coefficient	A dimensionless parameter appearing in Manning's equation for uniform steady flow in open canals, related to surface irregularity and material retardance of the wetted perimeter.
Run-off	The flow of water, caused by rainfall, from an area which depends on how permeable the land surface is. Run-off is greatest from impermeable areas such as roofs, roads and hard standings and less from vegetated areas – moors, agricultural and forestry land.
Runoff coefficient	A parameter (0 to 1) which quantifies the degree of permeability of surfaces.
Scour	The removal of sediment around or near structures located in flowing water.
Seepage	The slow movement of water though small cracks, pores, or interstices of a material, in or out of a body if surface or subsurface water.
Sensitivity analysis	A study of how the variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model.

Terms	Definition
Simulation	A technique of representing the real world by a computer program; "a simulation should imitate the internal processes and not merely the results of the thing being simulated".
Source	Source refers to a source of hazard (e.g. the sea, heavy rainfall).
Spatial resolution	Defines the density of information produced from the flood risk assessment process across the area of interest. A mosaic of flood risk data produced by different tools and base data, with a range of certainty in the output.
Spring tides	Around new and full moon when the Sun, Moon and Earth form a line, the tidal force due to the Sun reinforces that due to the Moon. The tide's range is then at its maximum.
Steady state	A fluid motion in which the velocities at every point of the field are independent of time in either magnitude or direction.
Toe	The lower portion of a channel bank or where a levee slope meets the ground or river bed.
Topography	The configuration of a surface and the relations among its man-made and natural features.
Turbulent flow	Flow of water, agitated by cross-currents and eddies, as opposed to laminar flow. Any particle may move in any direction with respect to any other particle, and the head loss is approximately proportional to the second power of the velocity.
Uniform flow	Flow of water with no change in depth or any other element of flow (ie cross-sectional area, velocity, and hydraulic gradient) from section to section along a canal.
Unsteady flow	Flow in which the velocity changes, with time, in magnitude or direction.

1 Introduction

The computer modelling of the Malahide Weir and the Broadmeadows estuary have been explained in detail in previous Technical Papers by University College Cork in 2010 [1,2,3,4,5]. The As-Constructed 2010/2011 design of the Malahide Weir was based on those Technical Papers. In the design of weir profile in 2010 the requirements of NPWS were also adopted to reinstate the Broadmeadows Estuary to its historic condition. An important requirement was that the birdlife feeding and breeding grounds, on the mud-flats area at the western end of the estuary, be restored and have the same periods of time submerged and exposed during the tidal cycle as had existed previously. The mud-flats are on a very shallow gradient so consequently a small variation in water level has an effect over a wide area. A conservative design approach was taken in the mathematical model to ensure that the NPWS requirements were met.

To strengthen the weir stability the stone material was added to both the eastern and western faces of the weir, which considerably widened the weir width. Having strengthened and re-profiled the top face of the weir in accordance with the submission to NPWS it was found that the weir performance had ‘over-shot’ the target. The Broadmeadows estuary retained a lesser volume of water than before and considerably more area of mud-flats was exposed throughout the tidal cycle.

As the water levels within the Broadmeadows estuary for As-Constructed 2010/2011 weir were found to be lower than historic water levels, a revised mathematical model was developed in October 2011 [6]. In November 2011 the NPWS approved the application to adjust the weir. On the basis of the New Design Weir [6] the adjustment works were carried out in 2012 in order to improve the hydraulic effect of the weir on the wider estuary.

The performance of the New Design Weir was hydraulically tested and elaborated in University College Cork report from July 2012 [7]. A comparison of the recorded and historic water levels showed that the weir replicates the hydrodynamic conditions on entire Broadmeadows estuary and throughout the tidal cycle that occurred before the collapse of the weir.

Figure 1. New Design Weir at Malahide Viaduct during ebb tide, looking west

There is now a need for construction of a greenway on the western weir side. For the footbridge construction it is necessary to create a temporary access adjacent to the western face of the railway viaduct, extending across the full length of the viaduct. This temporary access will be constructed on the top of the weir and the road surface level will be elevated above the original weir level to a level of +1.15mOD.

As the increase of weir crest level will affect the hydrodynamic conditions of inner estuary and the mud-flats exposure during the tidal cycle, a 2-D computer model of the temporary works was developed. This report '*Malahide Viaduct Reinstatement: Temporary Works - Computer modelling for Environmental Analyses'* gives computer results and simulations for the New Design Weir (from 2011) and for the weir with temporary works in place. The Report includes:

- Set-up of a detailed Mike21 computer model for the weir with temporary works in place
- Analysis of estuary hydrodynamics at neap and spring tides
- Water extent analysis at neap low and spring low

The main aim of computer modelling was to determine the hydrodynamic performance of the weir with temporary works in place and to check the mud-flats exposure at the inner estuary. The performance was analysed by comparing water levels and water extent for the Temporary Works Weir and the New Design Weir. The water levels for the Temporary Works were also compared to the 2010 data on spring and neap water levels. The 2010 water levels are related to the weir in the emergency conditions that prevailed after viaduct collapse with an access road constructed at similar top surface level as the temporary infill.

This study involved the analysis of the hydrodynamics of the inner and the entire Broadmeadow estuary for the Temporary Works and the New Design Weir by comparing water levels at four control points. The dynamics of the inner estuary was analysed at control point 3-1, located closer to the motorway bridge, and control point 3-2, located in the western estuary (Appendix 1, Appendix 2). In such a way, the dynamics of the inner estuary (points 3-1, 3-2) could be compared to the dynamics on the weir (point 1-1) and to the eastern estuary (point 1-2).

2 Computer model for Temporary Works

2.1 SET-UP OF A DETAILED MIKE21 COMPUTER MODEL FOR THE TEMPORARY WORKS

As presented in *Technical Paper 4* the Mike21 model of the Broadmeadow estuary was set-up on four complementary computational domains (see Appendix 9), as follows:

- A basic 9.9m grid resolution domain for the entire estuary area
- A 3.3m sub-grid domain at the inner estuary
- A sub-grid domain around the weir at 3.3m grid spacing
- A 1.1m grid spacing domain for the weir crest

The Mike21 model has two open boundaries: upper as inflow boundary from the Broadmeadow and Ward Rivers, and lower as the tidal boundary at the bay inlet (see Appendix 1 and Appendix 2).

The Mike 21 model of the weir crest (a 1.1m grid spacing domain) for Temporary Works was set-up on the basis of the New Design Weir but to include temporary infill for access road (Appendix 5 and Appendix 6). The temporary infill will be placed on the western face of the viaduct with surface level at +1.15mOD.

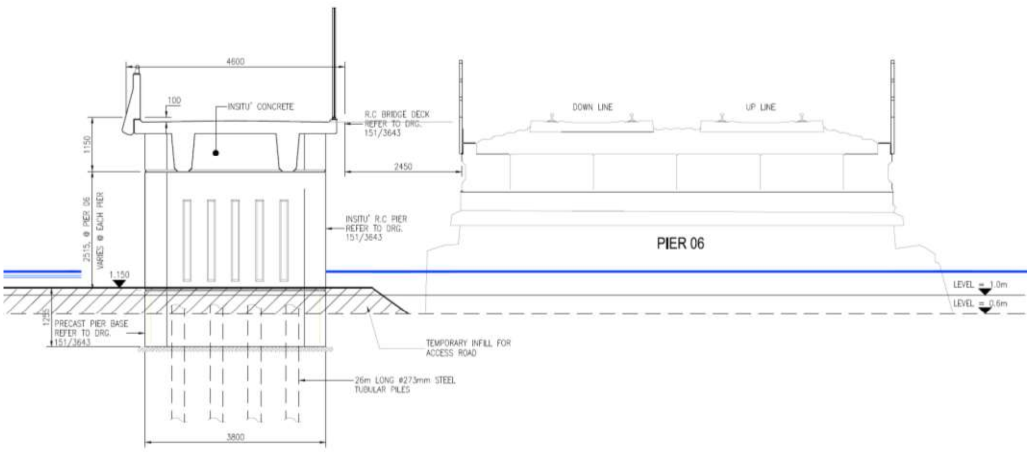


Figure 2. East-west elevation profile of the temporary infill

The infill for access road will level the weir profile on the entire length of the weir and in approx. width of 13.3m (Appendix 5 and Appendix 6). The weir profile along the viaduct centreline and along the eastern side will be unchanged (Appendix 7). The top infill at +1.15mOD is actually the lowest that levels the weir profile (Appendix 8) and as such makes the minimum changes for the weir geometry.

Presented infill of the weir crest, together with the original bathymetry surveys, are combined into a single database with bed level specified relative to Ordnance Datum (Malin Head). A computer modelled DEM of the New Design Weir crest is shown in Appendix 3 and Appendix 4, and of the Temporary Works crest is shown in Appendix 5 and Appendix 6.

2.2 MIKE21 MODEL PARAMETERS

Using the detailed Mike21 model, simulations were performed for the entire Broadmeadow estuary. Two open boundaries are located on the Broadmeadow River (upper boundary) and on the bay inlet (lower boundary), as shown in Appendix 1. Computer simulations for the neap and spring tides were performed by using recorded water levels at control point 1-2 as the lower boundary condition, and a constant river inflow of $0.5m^3/s$ for neap and $1.0m^3/s$ for spring tides as the upper boundary condition.

The model parameters for Temporary Works were overtaken from the computer simulations for the New Design Weir, except that additional bed roughness value was used for the temporary infill. Computer simulations were performed by using bed roughness values on the outer (9.9m spacing) and middle (3.3m spacing) domains at $n_{9.9m}$=$n_{3.3m}$=0.03, together with a constant Smagorinsky coefficient at s=0.50. For the weir crest (1.1m spacing), a bed roughness value $n_{1.1m}$ is: $n_{1.1m}$ = 0.090 for neap tides (shallower depths) and $n_{1.1m}$ = 0.066 for spring tides.

Several initial test runs were simulated in order to estimate the bed roughness for the temporary infill. The infill will be most probably made of the crushed stones, so the test simulations were performed by using bed roughness values of 0.035, 0.025 and 0.015 for the infill area. Having obtained the test results the adopted value of bed roughness value for the infill area is 0.025.

3 Model results for Temporary Works

3.1 ESTUARY HYDRODYNAMICS DURING NEAP TIDES

Appendix 11 shows water levels during neap tides for New Design Weir (magenta), for Temporary Works (orange) and recorded levels in April 2010 (green). The first two figures show water levels at the weir (WSE 1-1 and WSE 1-2). Although the water levels at control point 1-2 on the eastern side are similar (New Design Weir, Temporary Works and April 2010), the water levels at control point 1-1 on the western side are the highest for the Temporary Works. The water levels on the western side (WSE 1-1) are around +0.80mOD for the New Design Weir and +0.95mOD for Temporary Works, and at constant level of +1.20mOD for the Temporary Works.

As the neap tide level in the estuary of +1.20mOD for the Temporary Works is 0.05m higher than the top infill level of +1.15mOD, the computed water levels for the neap tides are found to be reliable. The temporary infill will raise the invert levels of weir crest channels by 0.55m (from +0.60mOD to +1.15mOD), so 0.40m water level increase from the New Design Weir +0.80mOD to +1.20mOD for the Temporary Works is found to be realistic.

April 2010 recordings during neap tides (Appendix 11, second figure) show constant water level decrease on the western weir side (WSE 1-1), and most likely is a result of water seepage through the weir profile. Such decrease is not evident for the Temporary Works (orange), which may suggests that the water level of +1.20mOD in the estuary for the Temporary Works at neap tides are slightly conservative and could be somewhat lower.

The 3rd figure in Appendix 11 shows water levels in the estuary during neap tides at the weir (WSE 1-1) and on the inner estuary (WSE 3-1 and WSE 3-2). For the New Design Weir water surface slopes from the +0.90mOD at the inner estuary to +0.80mOD at the weir, while for the Temporary Works water level is constant at +1.20mOD on the entire estuary. This implies that there would be an additional back-up in the estuary during neap tides for the Temporary Works.

The 4th figure in Appendix 11 shows flow velocities in the estuary during neap tides at the weir (Vel 1-1) and on the inner estuary (Vel 3-1 and Vel 3-2). The increase of water levels at inner estuary results in the decrease in flow velocities from 0.20m/s of the New Design Weir to 0.05m/s for the Temporary Works (Vel 3-1).

3.2 ESTUARY HYDRODYNAMICS DURING SPRING TIDES

Appendix 12 shows water levels during spring tides for New Design Weir (magenta), for Temporary Works (orange) and recorded levels in March 2010 (green). The first two figures show water levels at the weir (WSE 1-1 and WSE 1-2). Although the water levels at control point 1-2 on the eastern side are similar (New Design Weir, Temporary Works and April 2010), the water levels at control point 1-1 show different behaviour. The peak flood tide levels in the estuary (WSE 1-1) are the same for the New Design Weir and for the Temporary Works (around +1.72mOD), and are lower than March 2010 recordings (around +1.80mOD). The spring lows for the Temporary Works are increased by 0.20m when compared to the spring lows for both the New Design Weir and the March 2010 recordings.

The 3rd figure in Appendix 12 shows water levels in the estuary during spring tides at the weir (WSE 1-1) and on the inner estuary (WSE 3-1 and WSE 3-2). Water levels for points 3-1 and 1-1 show no water surface slopes in the estuary for both the New Design Weir and the Temporary Works. Apart from the water level increase for the Temporary Works there will be no significant change of estuary hydrodynamics during spring tides.

The 4th figure in Appendix 12 shows flow velocities in the estuary during spring tides at the weir (Vel 1-1) and on the inner estuary (Vel 3-1 and Vel 3-2). The increase of water levels at inner estuary results in the decrease in flow velocities from 0.10m/s the New Design Weir to 0.05m/s for the Temporary Works (Vel 3-1).

3.3 EXPOSURE AT NEAP LOW AND SPRING LOW

The morphology of the inner estuary can be divided into two parts: the upper and the lower part. The upper part has generally higher ground levels, and it is characterised by distinctive streams together with well defined and steeper channel banks. In the lower part streams are shallow, and the channel banks are less defined and shallow. This morphological difference gives different hydrodynamics and water extent at these two parts of the inner estuary.

During a four-day simulated tidal event (12th to 16th March 2011), neap low in the western Broadmeadow estuary occurred on the 15th March, at 06:09

hours (Appendix 11), resulting in maximum land exposure for the simulated neap tide period. Appendix 13 shows water surface maps on the inner estuary at neap low for the New Design Weir (magenta) and the Temporary Works (orange). The 3rd figure shows a comparison of water surfaces between two geometry cases. It can be seen that in the upper part of the inner estuary the water extent is similar between two geometry cases. In the lower part it can be seen that land exposure for the Temporary Works is significantly smaller compared to the New Design Weir.

For the simulated tidal event of the 19th to 21st March 2011, the spring low in the western Broadmeadow estuary occurred on the 20th March 2011, at 09:34 hours (Appendix 12), resulting in a maximum land exposure for the simulated spring tide period. Appendix 14 shows water surface maps on the inner estuary at spring low for the New Design Weir (magenta) and the Temporary Works (orange). The 3rd figure shows a comparison of water surfaces between two geometry cases. It can be seen that there is no significant land exposure difference between the two geometry cases in the lower part. In the upper part the land surface is somewhat less exposed for the Temporary Works compared to the New Design Weir.

4 Conclusions

1. The top of the temporary infill at +1.15mOD provides minimal changes to the New Design Weir while enables a reasonable amount of access to the footbridge during tidal cycle.

2. Several computer simulations have been carried out for spring and neap tides to test the weir performance with the temporary infill. Computed water levels at the weir and in the estuary for the Temporary Works during neap and spring tides are found to be realistic.

3. The access road construction will raise the neap and spring tide water levels in the Broadmeadows estuary and will raise the volume of water retained within the estuary during the tidal cycle. A consequent effect will be that the mud-flats on the inner estuary will be submerged for a longer period of time during the tidal cycle.

4. The weir profile currently in place (New Design Weir) must be maintained into the future. Therefore, whatever temporary works are to be carried out when constructing the footbridge must, on completion of those works, reinstate the weir to its current profile and in accordance with the approval granted by NPWS from November 2011.

5 References

[1] Eamon McKeogh, Damir Bekic, *Malahide Viaduct Reinstatement: Technical Paper 1 - Collapse Mechanism and Initial Emergency Works*, Flood Study Group University College Cork, May 2010.

[2] Eamon McKeogh, Damir Bekic, *Malahide Viaduct Reinstatement: Technical Paper 2 - Physical Models*, Flood Study Group University College Cork, May 2010.

[3] Eamon McKeogh, Damir Bekic, *Malahide Viaduct Reinstatement: Technical Paper 3 - Computer Models and Hybrid Modelling*, Flood Study Group University College Cork, May 2010.

[4] Eamon McKeogh, Damir Bekic, *Malahide Viaduct Reinstatement: Technical Paper 4 - Computer modelling for Environmental Analyses*, Flood Study Group University College Cork, May 2010.

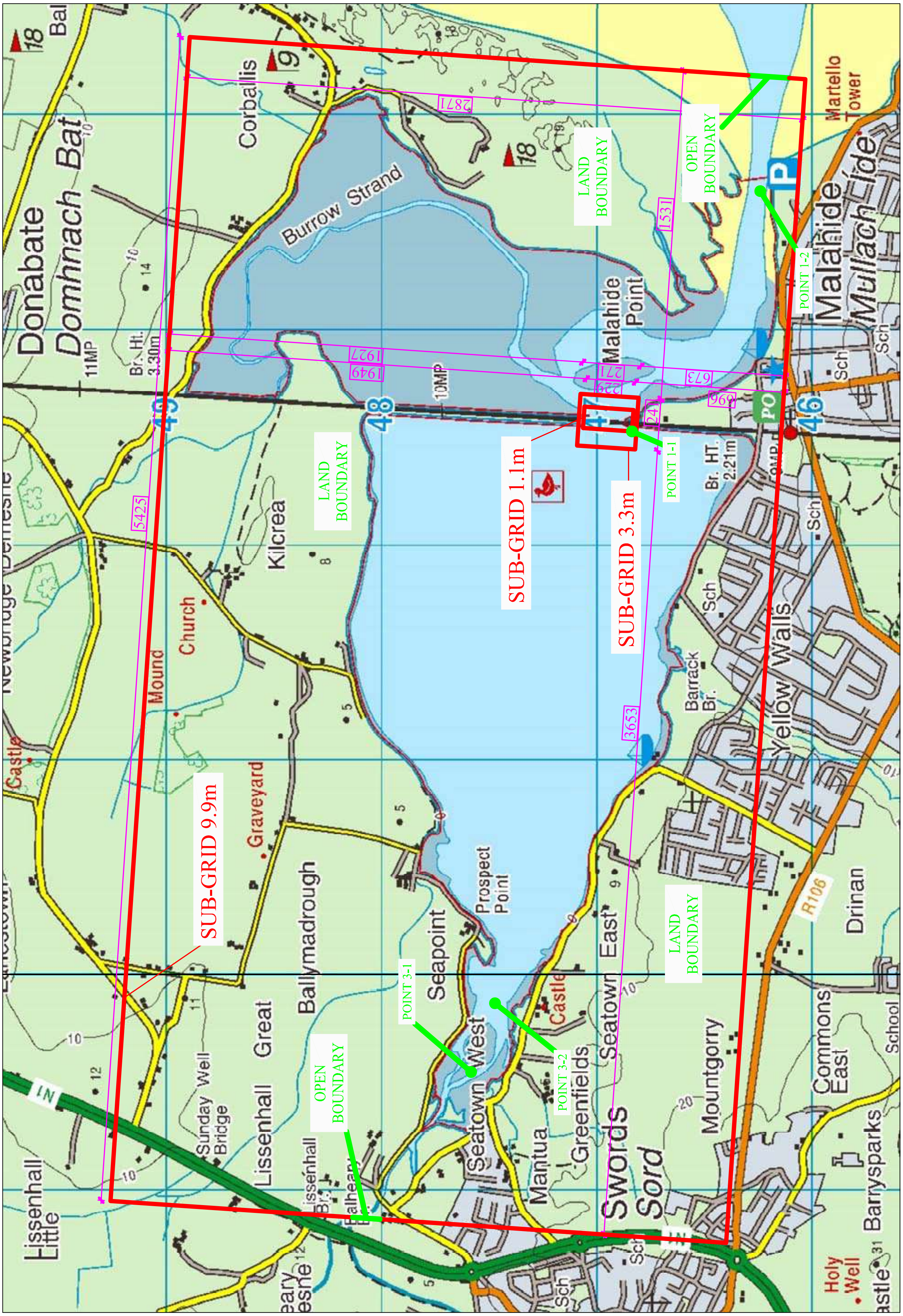
[5] Eamon McKeogh, Damir Bekic, *Malahide Viaduct Reinstatement: Technical Paper 5 - Final Design and Performance Simulations*, Flood Study Group University College Cork, July 2010.

[6] Eamon McKeogh, Damir Bekic, *Malahide Viaduct Reinstatement: New Design Weir - Computer modelling for Environmental Analyses*, Flood Study Group University College Cork, October 2011.

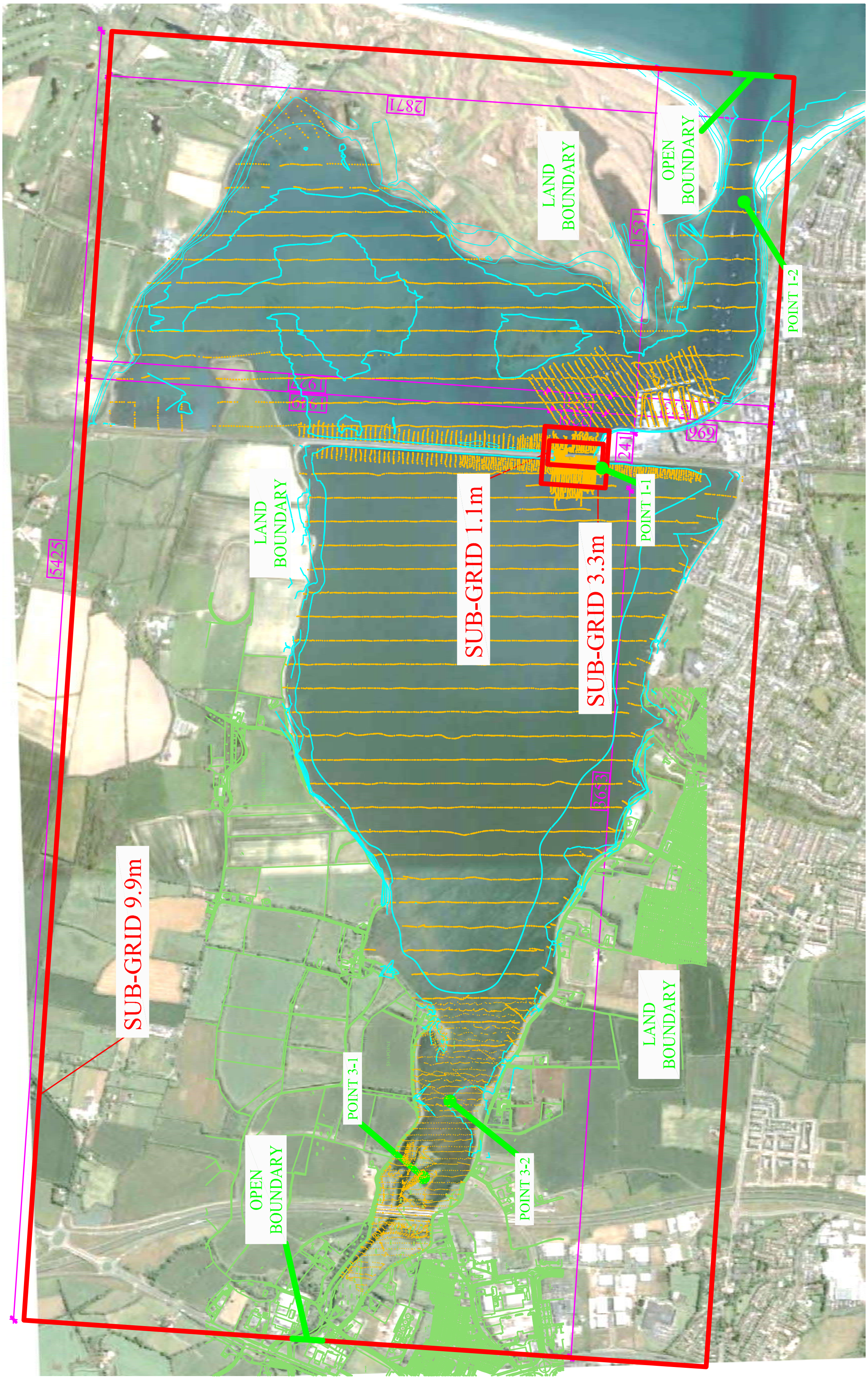
[7] Eamon McKeogh, Damir Bekic, *Monitoring of Malahide Viaduct - Report on water level recordings*, Flood Study Group University College Cork, July 2012.

6 Appendices

Appendix 1	Broadmeadows estuary with extents of model domains on OS map
Appendix 2	Broadmeadows estuary with field survey data on Google Earth
Appendix 3	New Design Weir - DEM with locations of cross-sections
Appendix 4	New Design Weir - DEM detail
Appendix 5	Temporary Works - DEM with locations of cross-sections
Appendix 6	Temporary Works - DEM detail
Appendix 7	New Design Weir and Temporary Works - Elevation profile for cross-sections
Appendix 8	New Design Weir and Temporary Works - Elevation profile for Viaduct central axis
Appendix 9	Refined Mike21 model
Appendix 10	Water levels in 2010 at control points 1-1, 1-2
Appendix 11	Hydrodynamic at neap tides
Appendix 12	Hydrodynamic at spring tides
Appendix 13	Exposure at neap low
Appendix 14	Exposure at spring low



fluvio R&D Limited Hydrological and Hydraulic Engineering	MALAHIDE VIADUCT REINSTATEMENT
	Broadmeadow estuary with extents of model domains on OS map — Scale 1:25000 — Appendix 1



fluvio R&D Limited
Hydrological and Hydraulic Engineering

MALAHIDE VIADUCT REINSTATEMENT		
Broadmeadow estuary with field survey data on Google Earth		Scale 1:25000
		Appendix 2

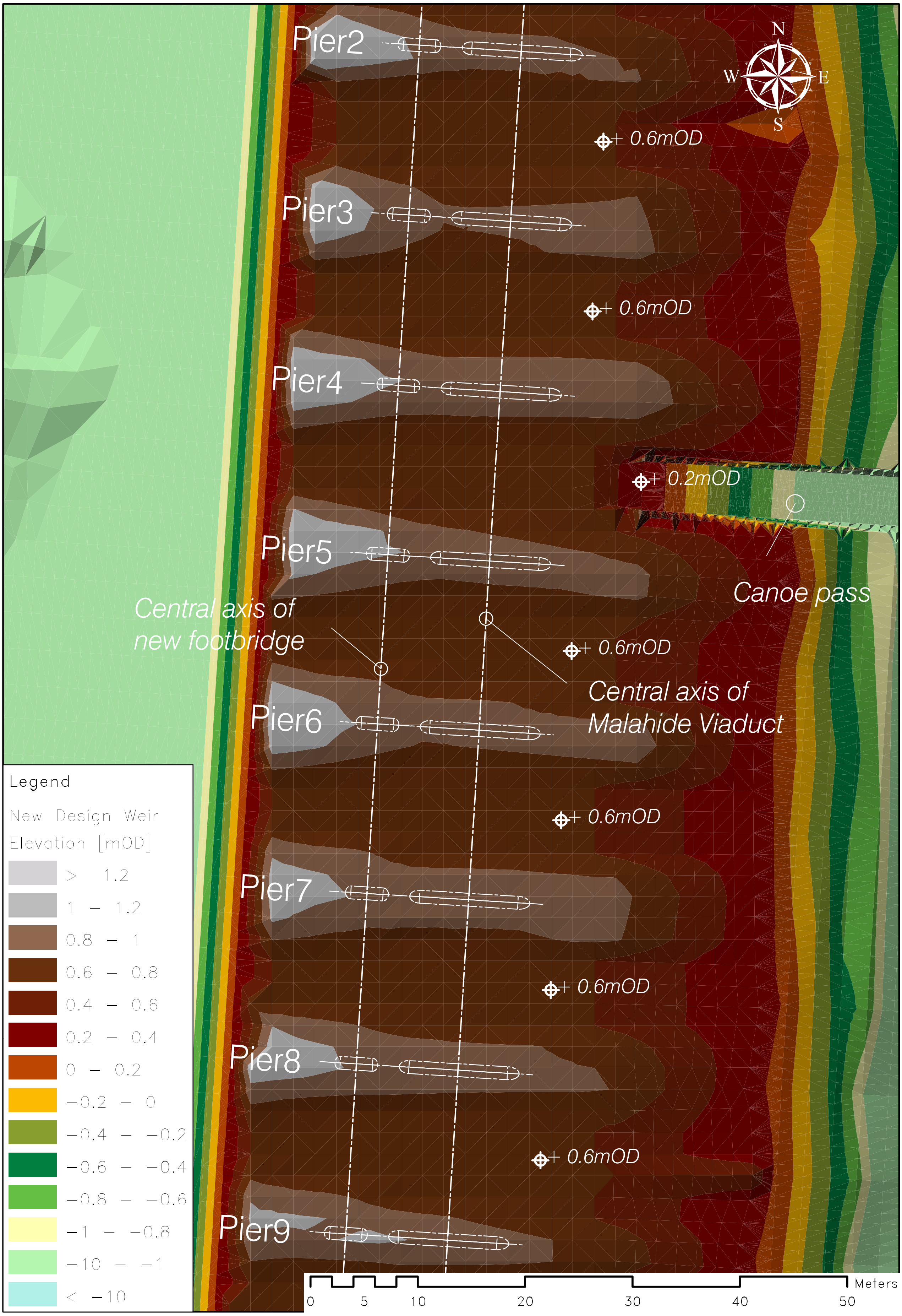
fluvio R&D Limited
Hydrological and Hydraulic Engineering

MALAHIDE VIADUCT REINSTATEMENT

New Design Weir – DEM
with locations of cross–sections

Scale 1:1000

Appendix 3



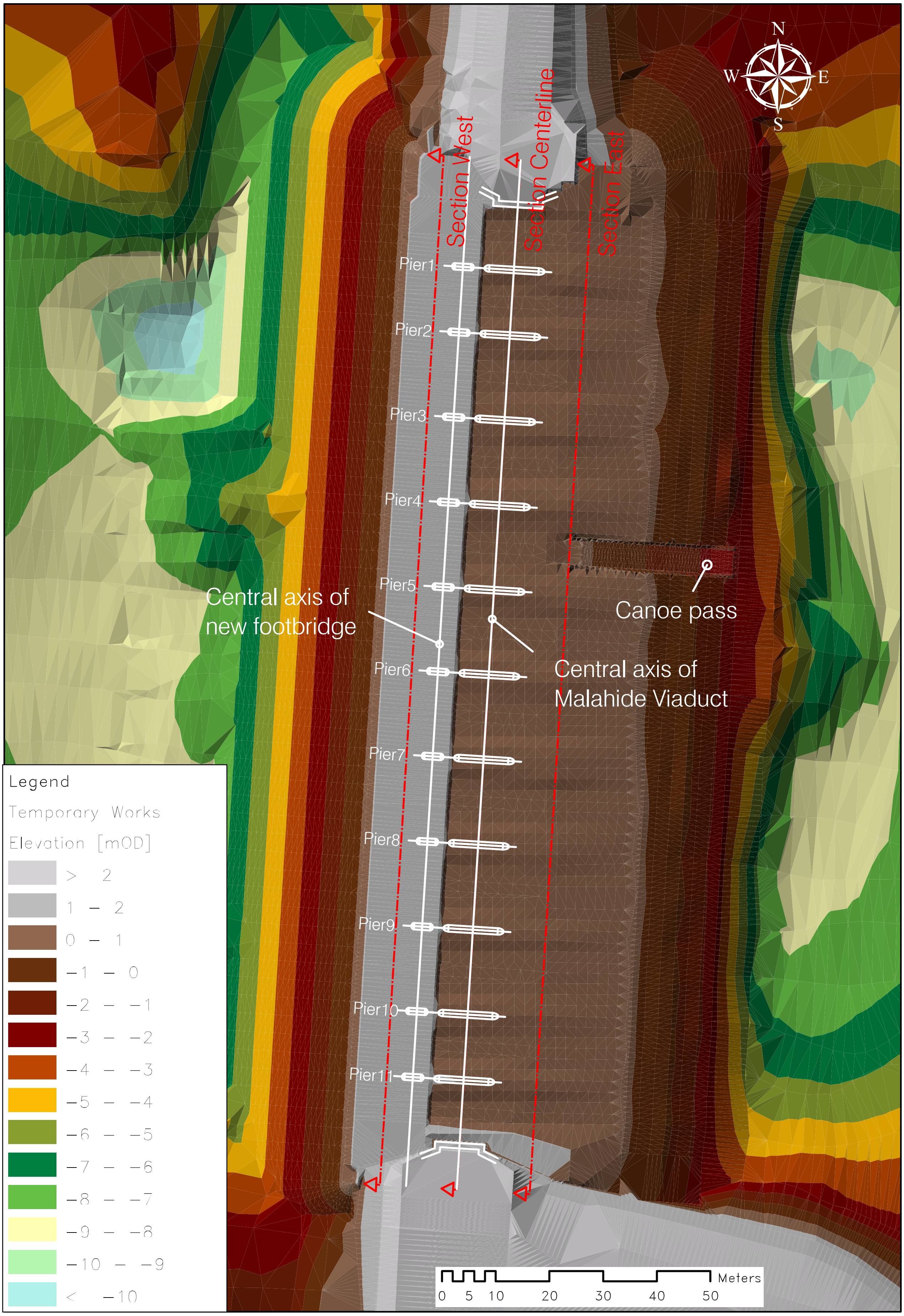
fluvio R&D Limited
Hydrological and Hydraulic Engineering

MALAHIDE VIADUCT REINSTATEMENT

New Design Weir – DEM detail

Scale 1:500

Appendix 4



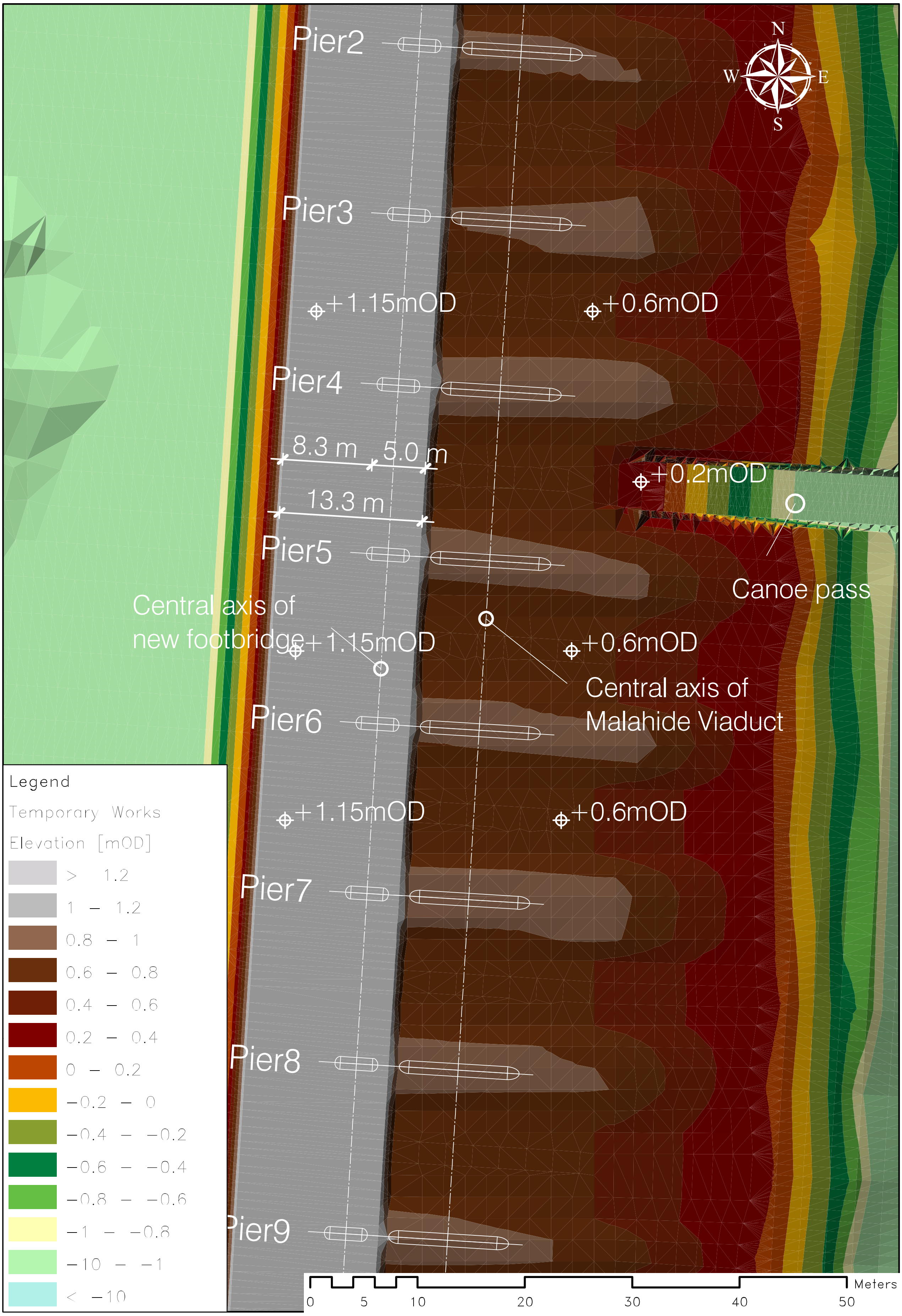
fluvio R&D Limited
Hydrological and Hydraulic Engineering

MALAHIDE VIADUCT REINSTATEMENT

Temporary Works
DEM with locations of cross-sections

Scale 1:1000

Appendix 5



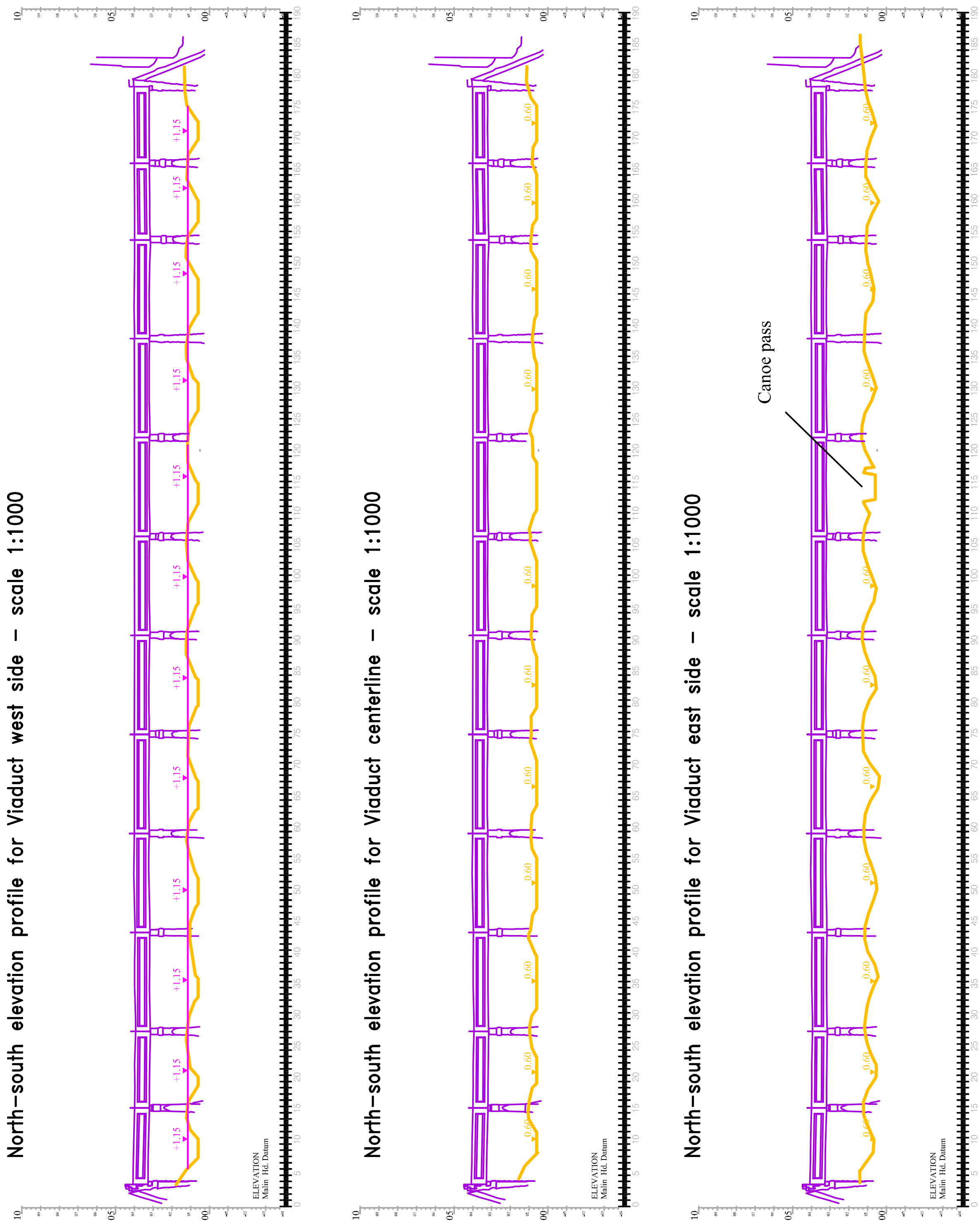
fluvio R&D Limited
Hydrological and Hydraulic Engineering

MALAHIDE VIADUCT REINSTATEMENT

Temporary Works – DEM detail

Scale 1:500

Appendix 6



LEGEND:

New Design Weir
Temporary

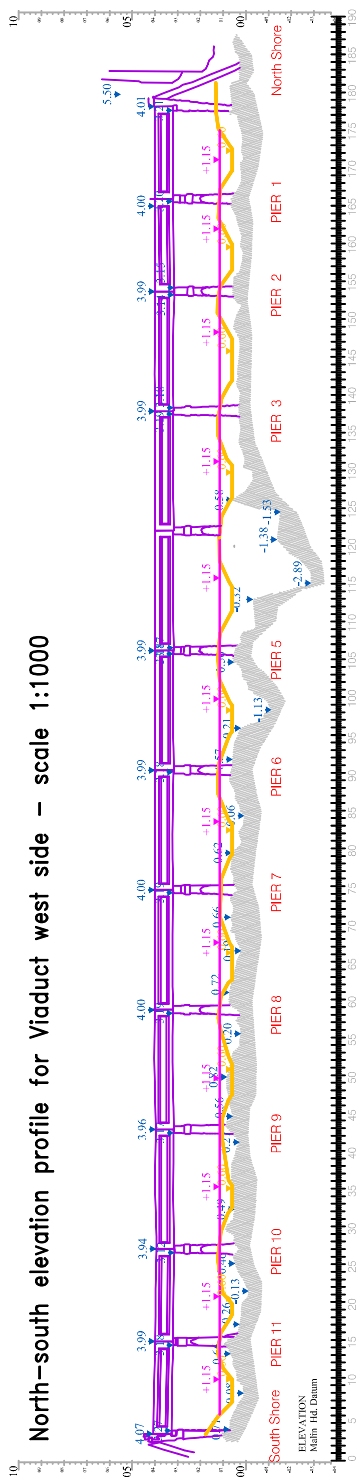
MALAHIDE VIADUCT REINSTATEMENT

New Design Weir and Temporary Works
- Elevation profile for cross-sections

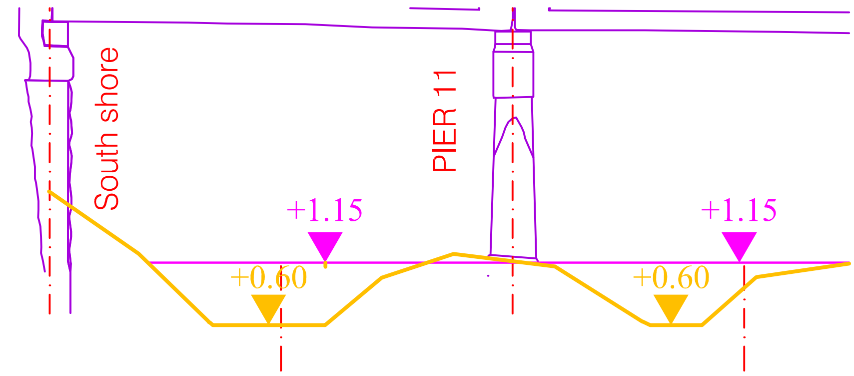
Scale 1:1000

Appendix 7

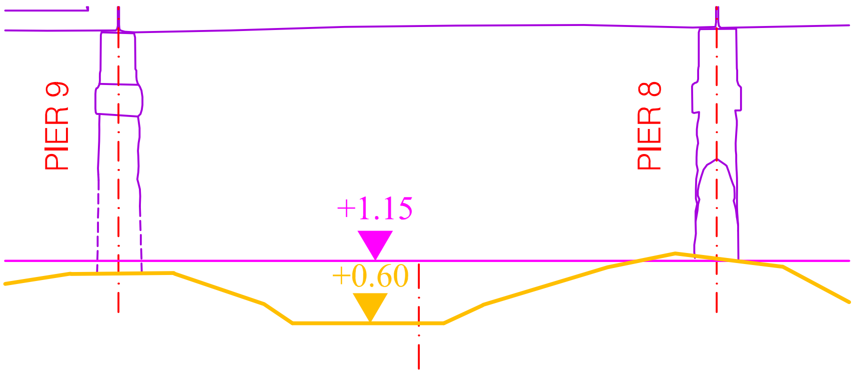
North-south elevation profile for Viaduct west side – scale 1:1000



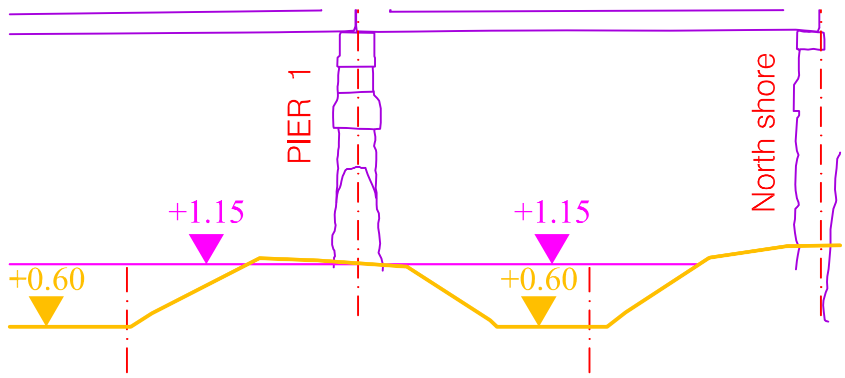
North–south elevation profile at South shore – scale 1:200



North–south elevation profile at piers 8&9 – scale 1:200



North–south elevation profile at North shore – scale 1:200



LEGEND:

New Design Weir

Temporary

R&D Limited fluvio

Hydrological and Hydraulic Engineering

MALAHIDE VIADUCT REINSTATEMENT

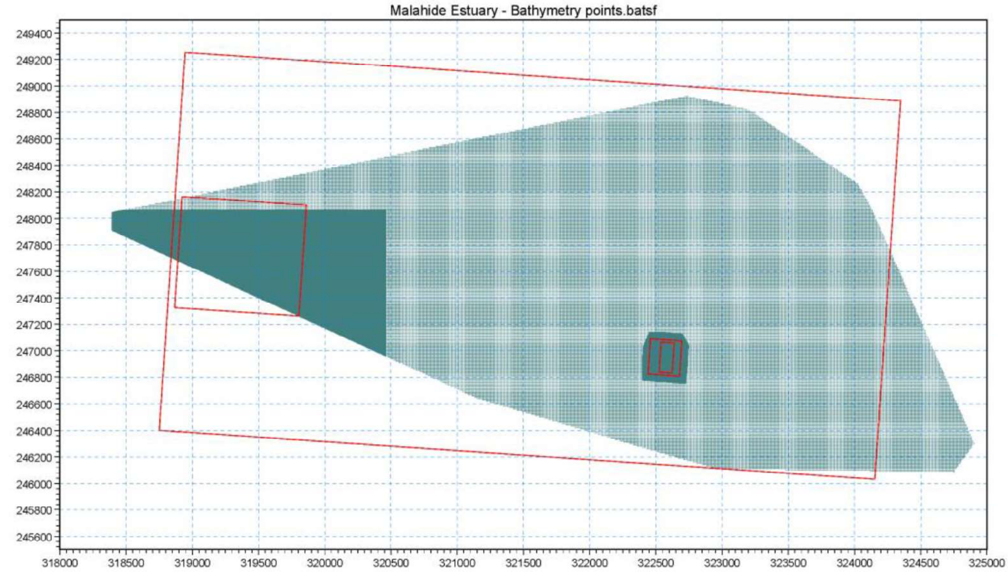
New Design Weir and Temporary Works
- Elevation profile for Viaduct central axis

Scale 1:1000
1:200

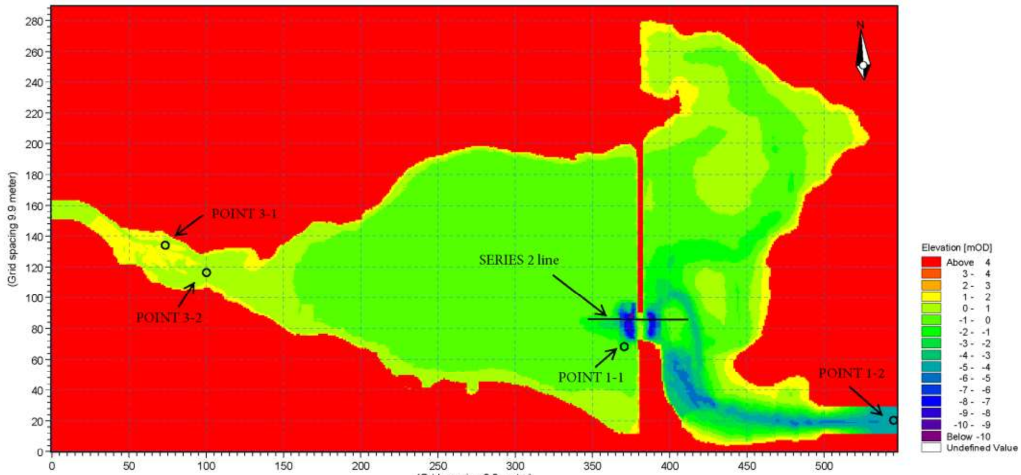
Appendix 8

Appendix 9 Refined Mike21 model

Mike21 sub-grid domains and DEM points

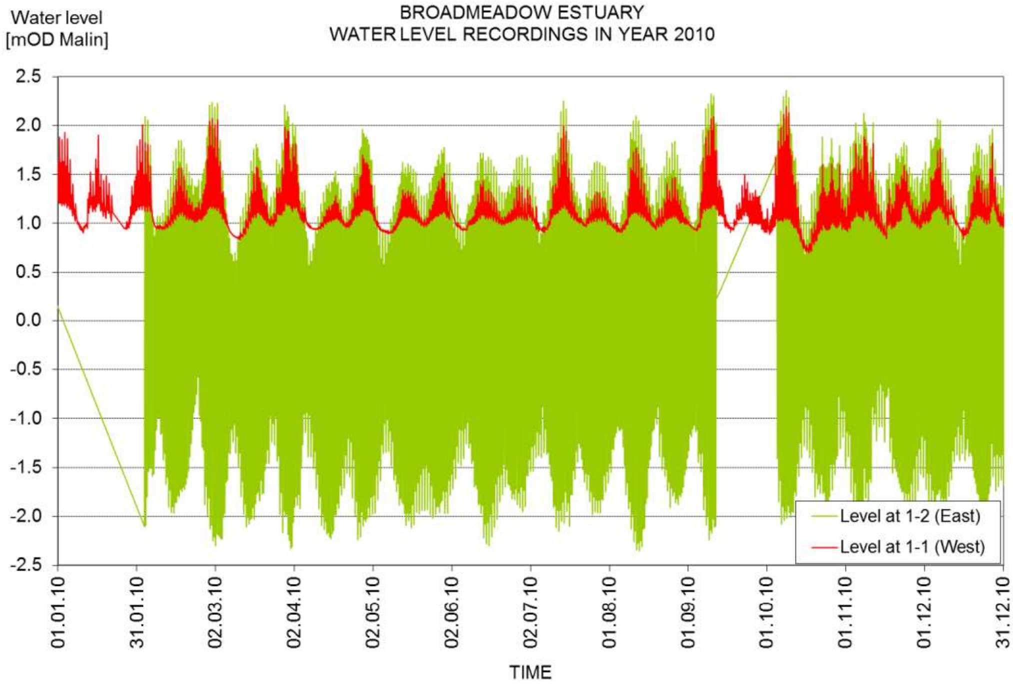


Mike21 sub-grid domain 9.9m resolution with control points

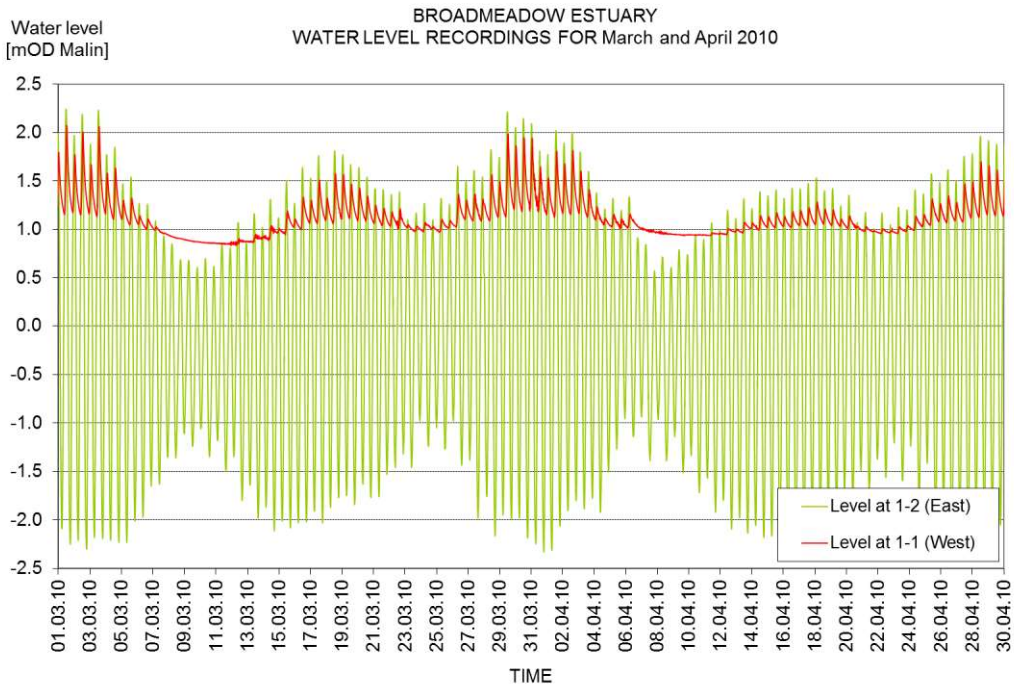


Appendix 10 Water levels in 2010 at control points 1-1, 1-2

Water level recordings in 2010



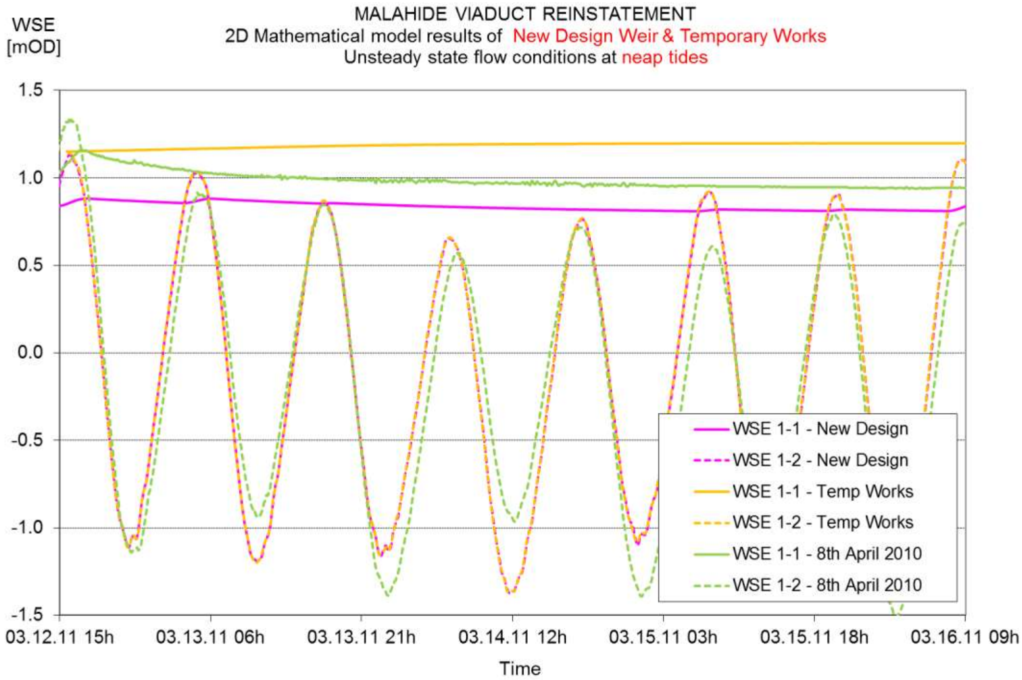
Water level recordings in March and April 2010

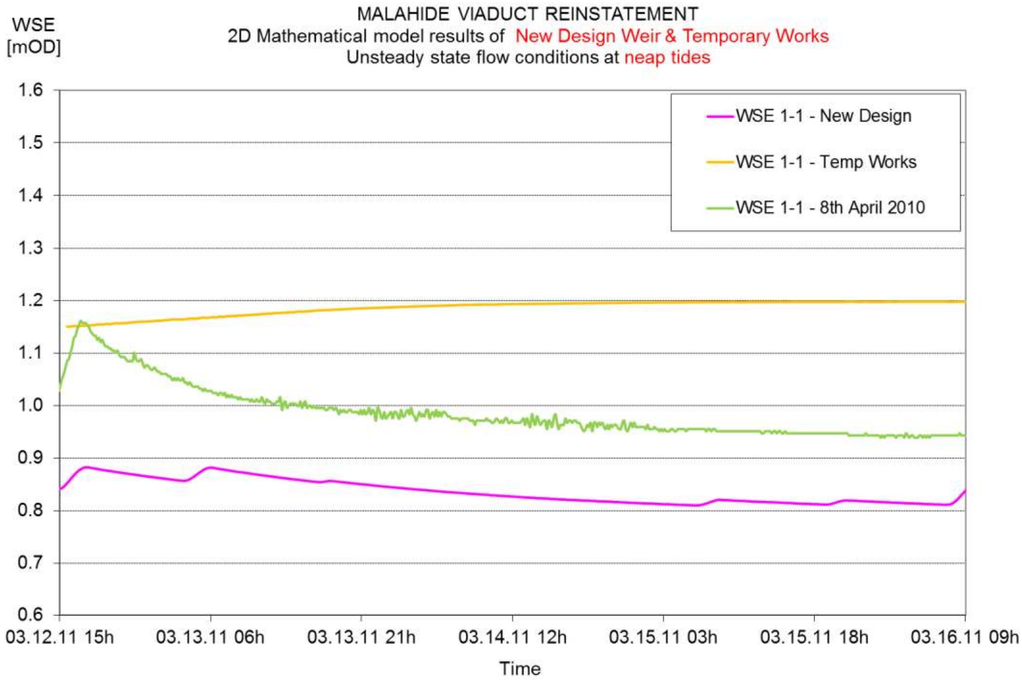


Appendix 11 Hydrodynamic at neap tides

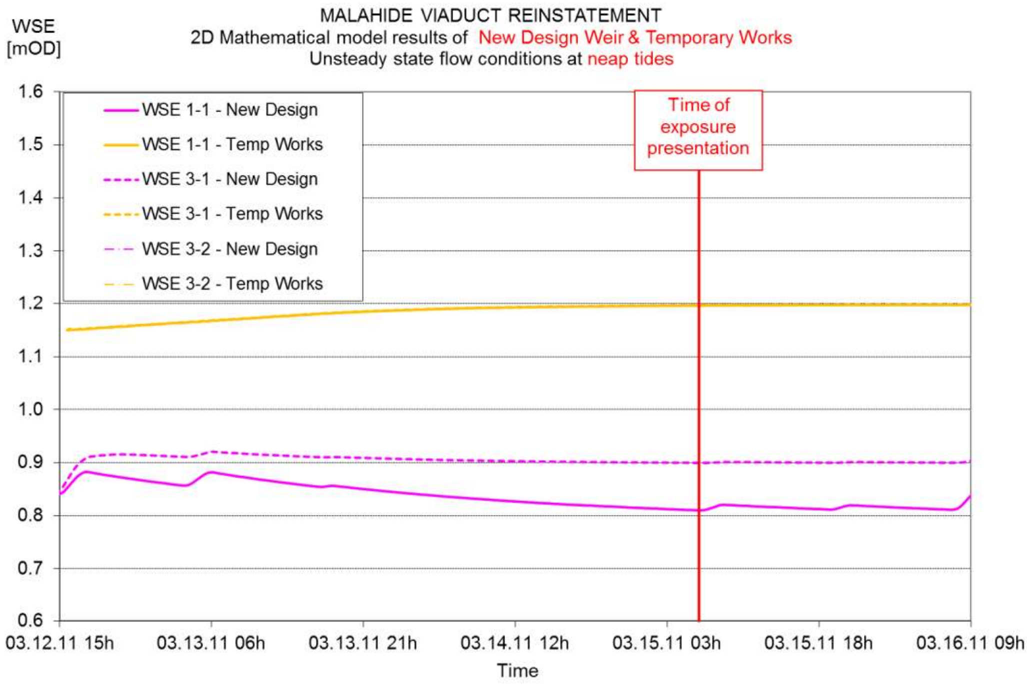
West boundary conditions: Q_{west} = 0.5m^3/s
East boundary conditions: WSE_{east} = Recorded water levels
Manning roughness values: $n_{9.9m} = n_{3.3m}$ = 0.03; $n_{1.1m}$ = 0.09 and 0.025
Smagorinsky coefficient: s = 0.5

Water levels at the weir (control points 1-1 and 1-2)

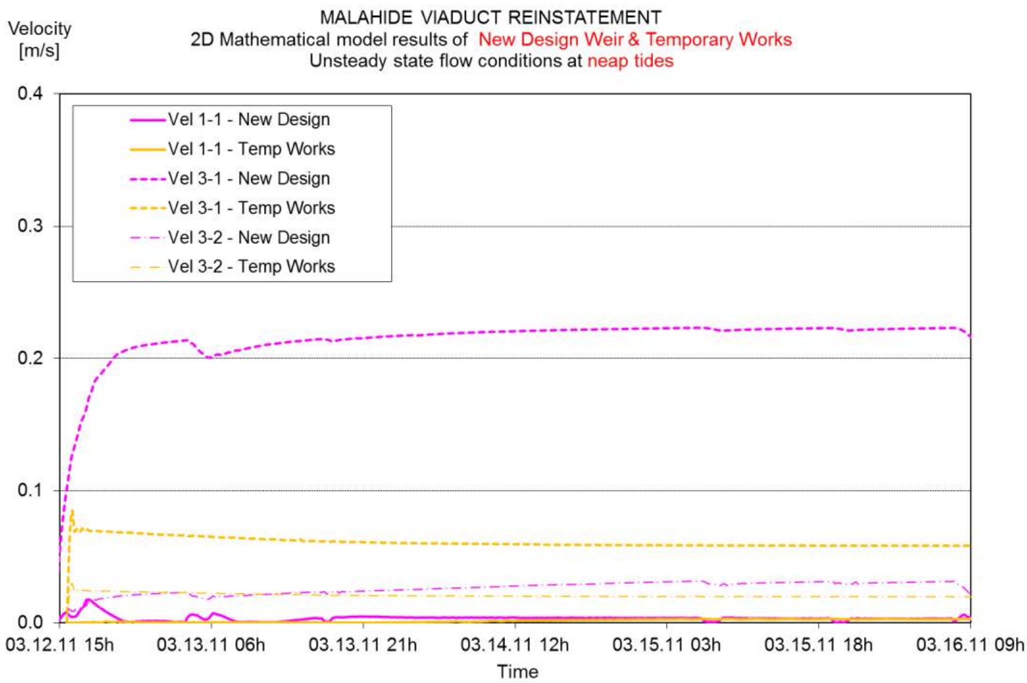




Water levels at the weir (control point 1-1) and on the inner estuary (control points 3-1 and 3-2)



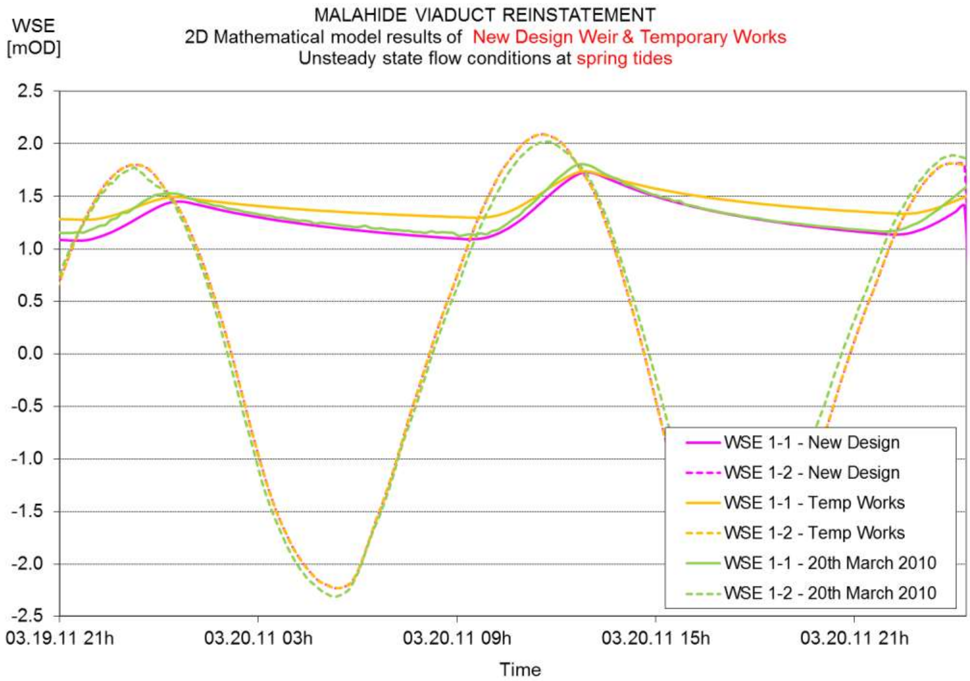
Flow velocities at the weir (control point 1-1) and on the inner estuary (control points 3-1 and 3-2)

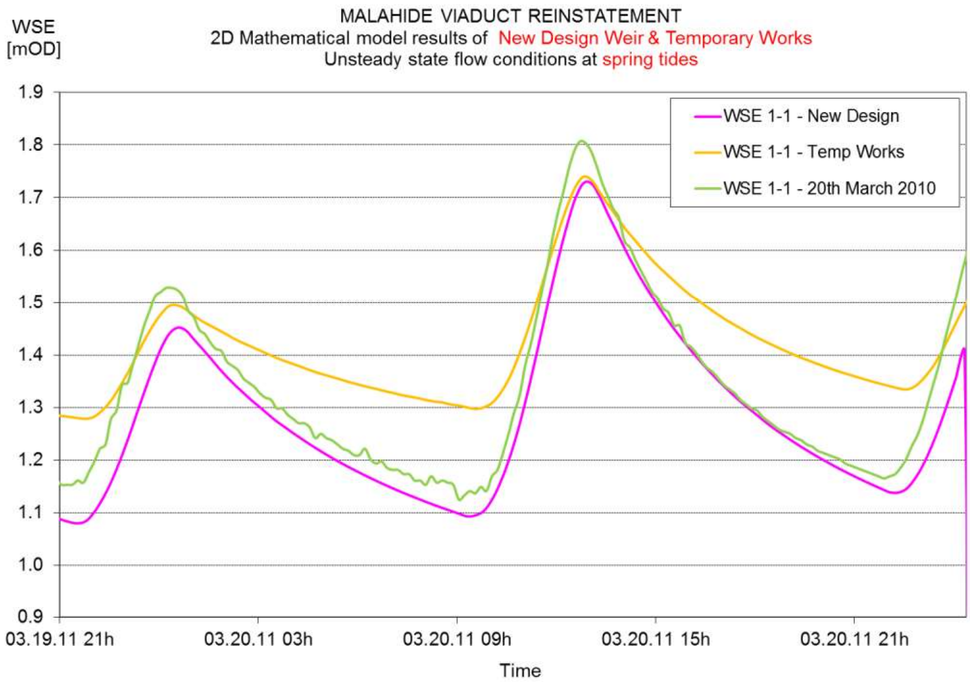


Appendix 12 Hydrodynamic at spring tides

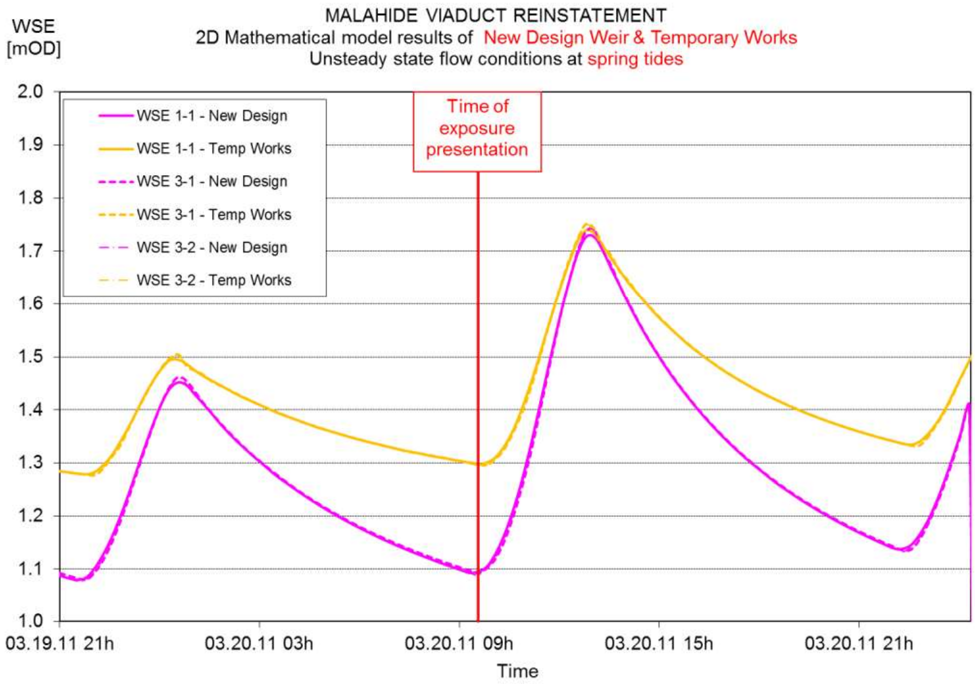
West boundary conditions: $Q_{west} = 1.0 m^3/s$
East boundary conditions: WSE_{east} = Recorded water levels
Manning roughness values: $n_{9.9m} = n_{3.3m} = 0.03$; $n_{1.1m} = 0.066$ and 0.025
Smagorinsky coefficient: $s = 0.5$

Water levels at the weir (control points 1-1 and 1-2)

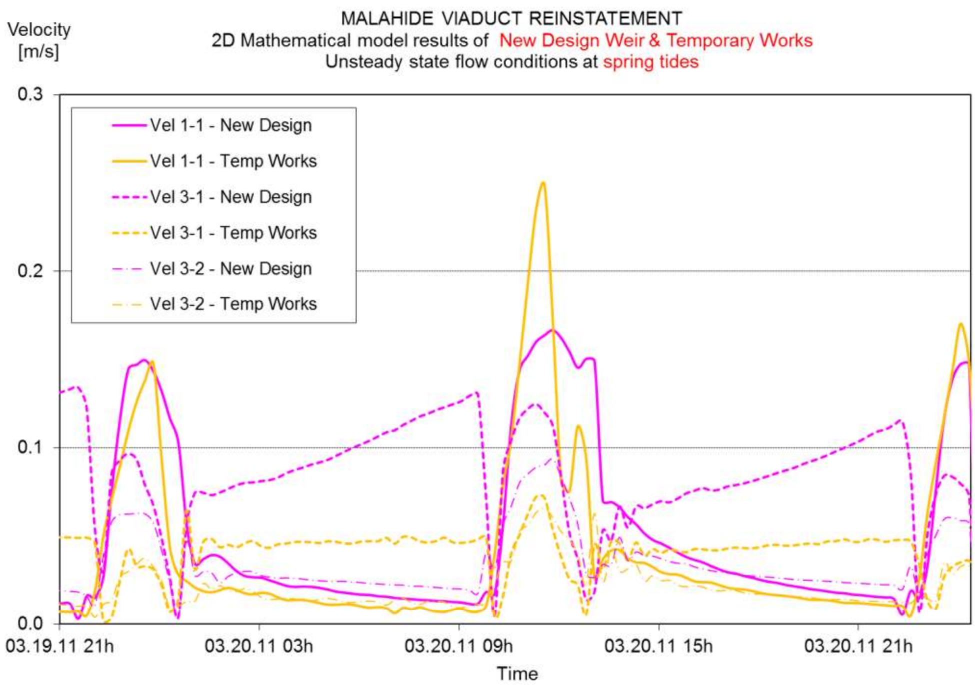




Water levels at the weir (control point 1-1) and on the inner estuary (control points 3-1 and 3-2)



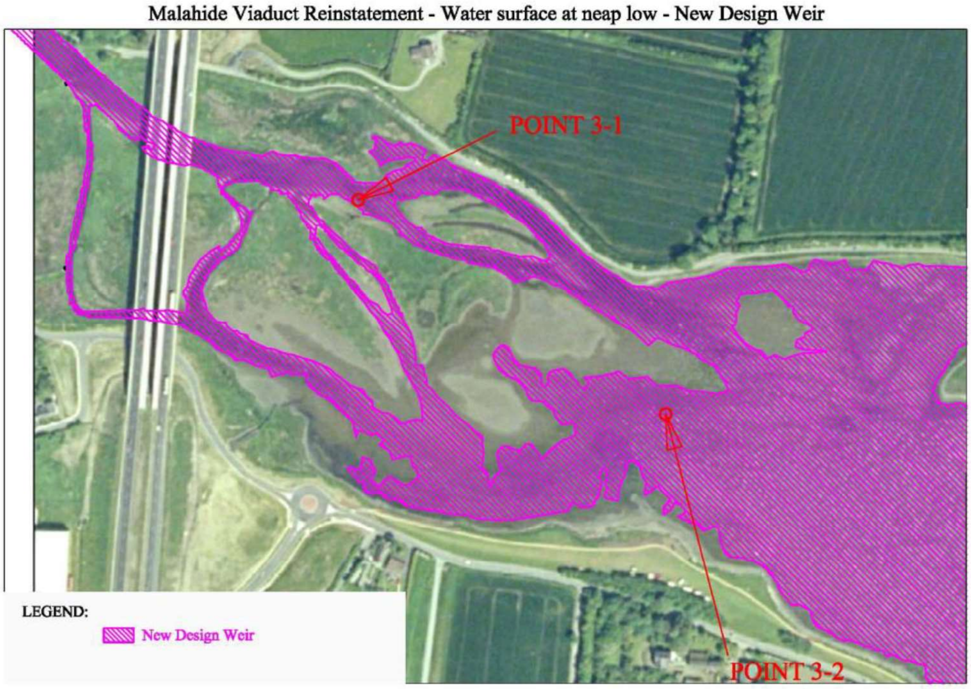
Flow velocities at the weir (control point 1-1) and on the inner estuary (control points 3-1 and 3-2)



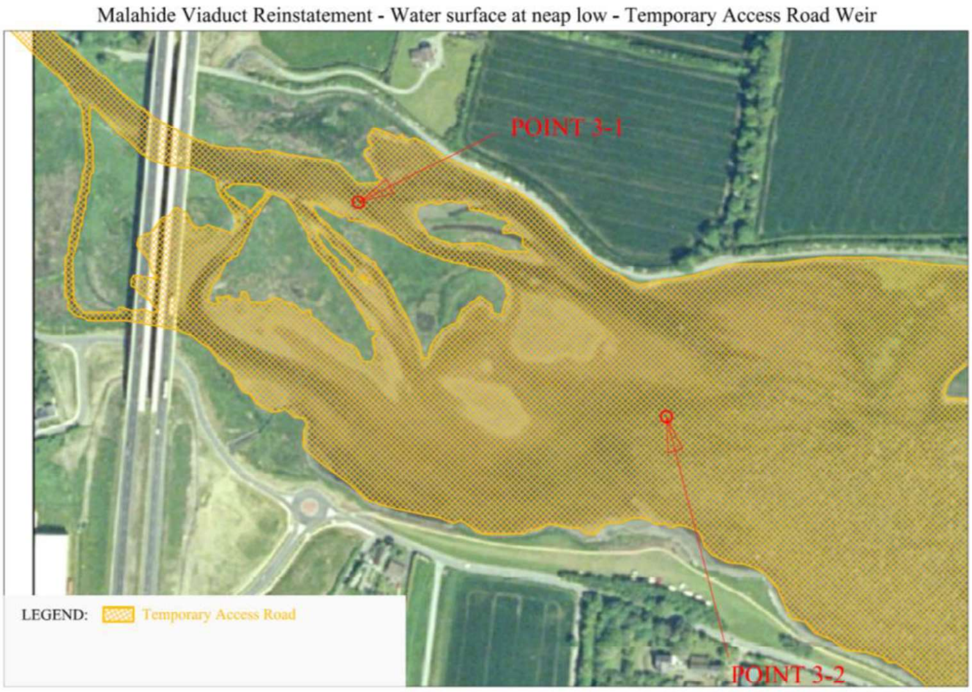
Appendix 13 Exposure at neap low

Time of presentation: 15th March 2011, 06:09 hrs

Water surface for New Design Weir

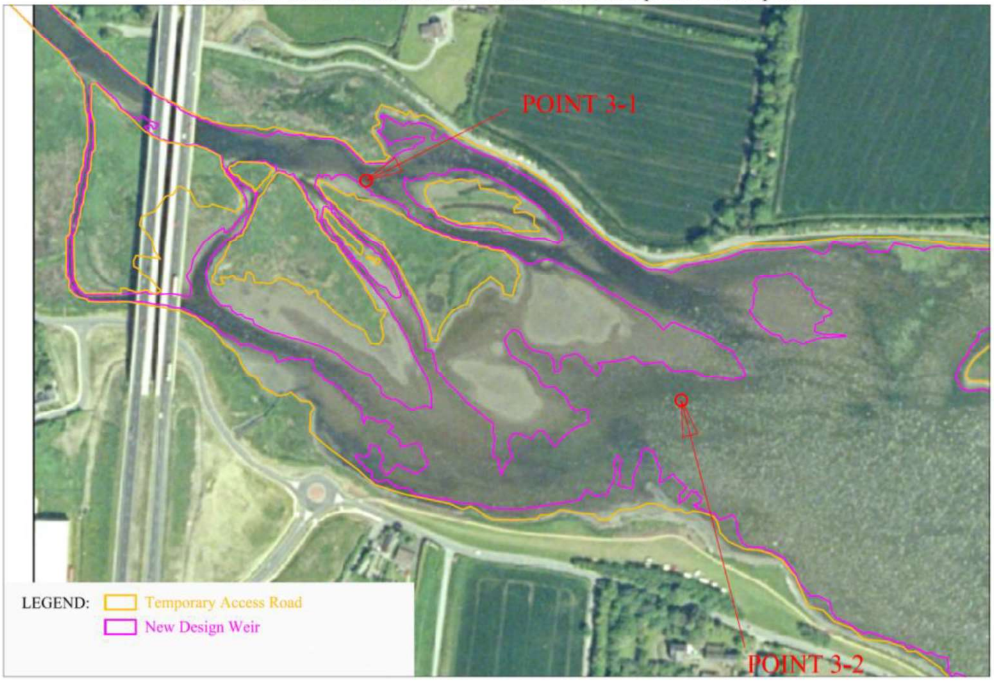


Water surface for Temporary Access Road Weir



Water surface comparison for neap low

Malahide Viaduct Reinstatement - Water surface comparison at neap low

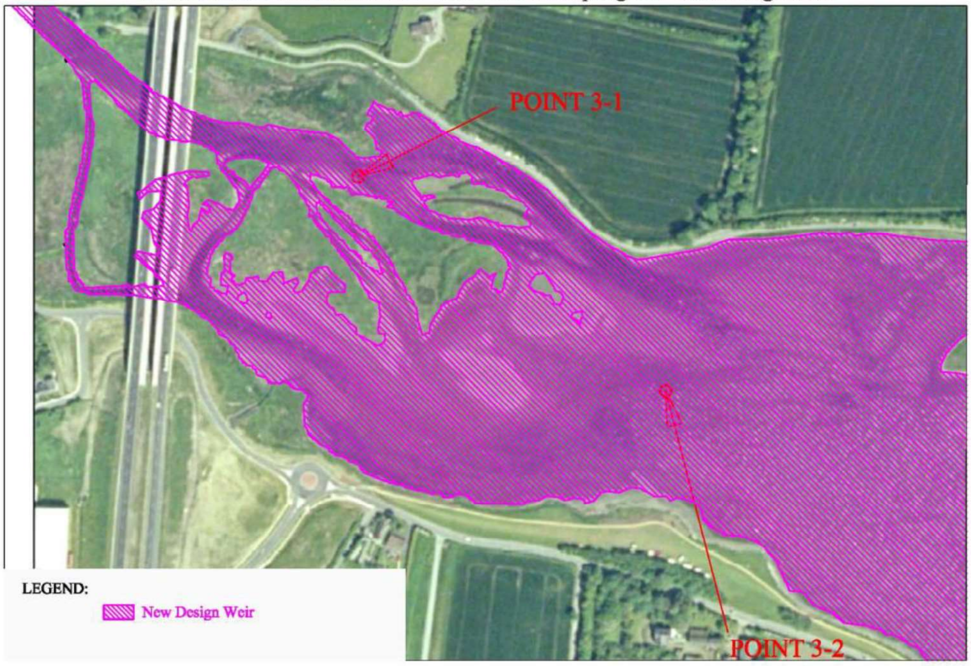


Appendix 14 Exposure at spring low

Time of presentation: 20th March 2011, 09:34 hrs

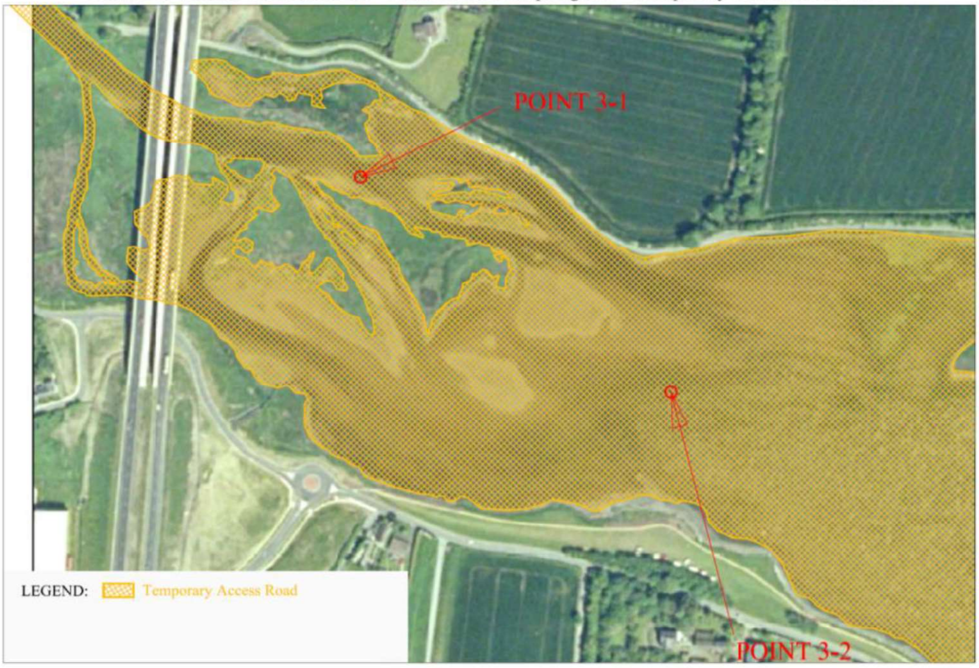
Water surface for New Design Weir

Malahide Viaduct Reinstatement - Water surface at spring low - New Design Weir



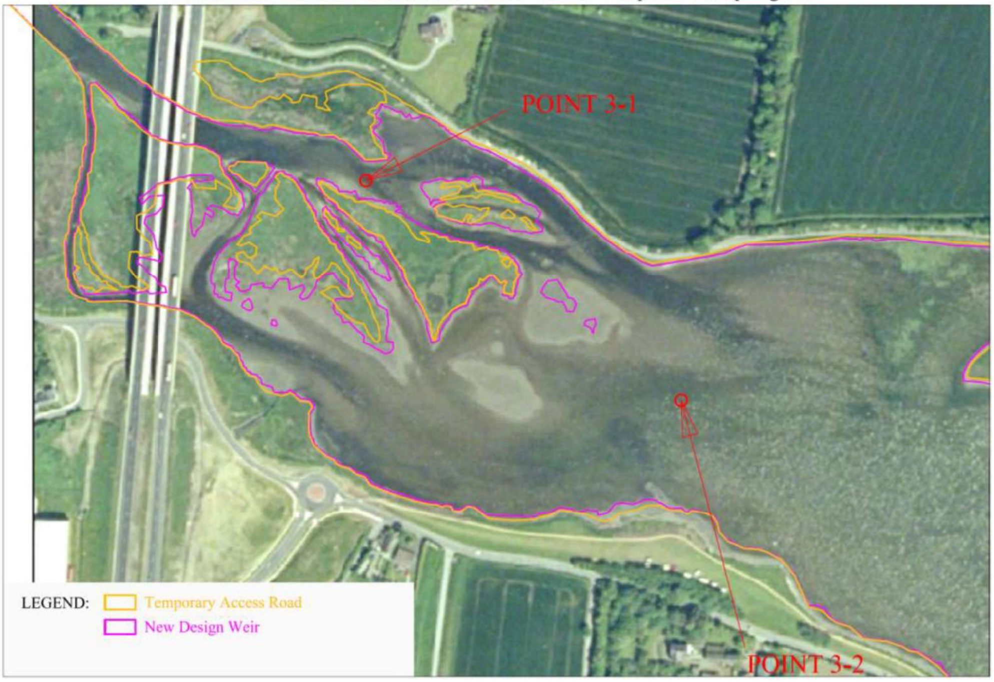
Water surface for Temporary Access Road Weir

Malahide Viaduct Reinstatement - Water surface at spring low - Temporary Access Road Weir



Water surface comparison for spring low

Malahide Viaduct Reinstatement - Water surface comparison at spring low



Appendix 6

Aquatic Environment - Methodology and Plates 1 to 7

(A) Soft Sediment Survey, Malahide Weir Maintenance Track (September 2009)

A soft sediment survey was undertaken in September 2009 which covered the sites within the footprint of the weir maintenance track. Fieldwork was carried out on the 21st September 2009. All sampling stations were positioned using a differential GPS (Trimble Geo XM). A complete list of stations sampled are presented in Table 1 and these stations are displayed on a map (Figure 1).

Overall species abundances and diversity would be considered low with four stations returning no fauna and diversity would be considered low across all sites (Table 1). The sites in closest proximity to the maintenance track (S1-S8) had considerably lower abundances than those closest to the weir development (S9-S12). The most faunally abundant sites (S11 and S12) were present immediately to the west of the weir at Malahide. These sites are in mixed shell gravel exposed to a greater degree of water movement than the more southerly sites. The sites present in the vicinity of the track consist of low faunal diversity and abundances. Moreover, the fauna present in the area consist primarily of oligochaetes (with the exception of S9 – which contains coarser material and is dominated by keelworm, *Pomatoceros lamarcki*).

Biotope Classification

Data from the survey was compared against data for the latest JNCC Biotope classification scheme (Conor *et al.*, 2004). Results from all surveys undertaken during the present survey indicate the presence of several distinct habitats.

The area of the access track along the western side of the southern causeway has been classified as SS.SMu.SMuVS.OlVS (Oligochaetes in variable or reduced salinity infralittoral muddy sediment). This biotope is usually found towards the edges of tidal channels in estuaries where current velocities allow for the deposition of silt and the establishment of the infaunal communities identified here. This biotope is present across most of the access track route (from Grabs 1-8). This corresponds with results obtained in another survey of the Broadmeadow Estuary (Aquafact, 2008) which covered a much greater footprint than the survey reported here. Results from that survey indicated that the same habitat type is located along large parts of the southeastern area of the Broadmeadow Estuary extending well beyond the footprint of the trackway.

The remaining grab sites surveyed along the inner estuary (Grabs 9-12) consist of species and sediment, which are consistent with the SS.SCS.CCS.PomB (*Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles). This biotope is characterised by a few robust, fast growing species, which are able to colonise benthos and are subjected to being regularly moved by wave and tidal action. The main cover organisms tend to be restricted to tube worms (*Pomatoceros* sp.) and barnacles (*Balanus crenatus*) both of which were recorded at these locations.

Table 1. Positions of subtidal biological sampling stations. All sampling locations are given in Irish National Grid. Sites highlighted in green fall within the footprint of the weir maintenance track development.

Subtidal Grab Stations	Co-ordinates (Irish National Grid)	
	Easting (m)	Northing (m)
S1	322507.571	246367.090
S2	322478.311	246374.105
S3	322471.502	246415.946
S4	322507.378	246454.032
S5	322506.994	246572.468
S6	322482.778	246575.019
S7	322492.349	246727.322
S8	322521.951	246729.182
S9	322528.983	246832.255
S10	322486.733	246842.925
S11	322510.098	246948.660
S12	322501.300	246960.564

Figure 1. Map showing locations of subtidal grab samples along the inner estuary at Malahide, Co. Dublin.

(B) Aquatic Habitats – Methodology

Sub-tidal Grab Sampling

A total of 12 stations were sampled by means of a 0.025m^2 Van-Veen Grab for benthic faunal and particle size analysis. At all sites, samples were taken where there was sufficient penetration of the Van-Veen grab.

At each station:

- 1 x 0.025m^2 Van-Veen grabs were deployed for samples for benthic faunal analysis, and the samples were transferred to separate, labelled, 10 litre buckets (12 samples).
- 1 x 0.025m^2 Van-Veen grab from which 100g of well-mixed sediment was transferred to a sealed plastic container for granulometric and organic carbon analysis (12 Samples).

Sample Processing

Granulometric Analysis

Granulometric analysis was carried out on oven dried sediment samples from each station. The sediment was passed through a series of nested brass test sieves with the aid of a mechanical shaker. The brass sieves chosen were 4mm, 2mm, 1mm, 500μm, 250μm, 125μm and 63μm. The sediments were then divided into three fractions: % Gravel (>2mm), % Sand (<2.0mm >63μm) and % Silt-Clay (<63μm). Further analysis of the sediment data was undertaken using the Gradistat package (Blott & Pye, 2001).

Organic Matter Analysis

Organic matter was estimated using the Loss on Ignition (LOI) method. One gram of dried sediment was ashed at 450˚C for 6 hours and organic carbon was calculated as % sediment weight loss.

Biological Sample Processing

On returning to the laboratory all faunal samples were sieved on a 1.0mm sieve within 24 hours of collection. Samples were preserved in 4% buffered formalin to which an organic dye (Rose-Bengal) had been added. All fauna were identified to the lowest taxonomic level possible using standard keys to northwest European fauna.

Pre-Construction Assessment Results

Results from the sediment analysis indicates that the sediment is dominated by fine sands and muds (Table 2 and Figure 2).

Grab Data

A total of 15 taxa were encountered in the grab samples along the western shore of the southern arm of the viaduct (Table 3). All species encountered are common in Irish coastal waters.

Table 2 Sediment characteristics for all subtidal grab samples.

Site ID	% Gravel	% Sand	% Mud	% LOI	Sediment Textural Group
Grab 1	2.3	45.8	51.9	3.7	Slightly gravelly sandy mud
Grab 2	0	85.9	14.1	1.7	Muddy sand
Grab 3	0	44.3	55.7	4.9	Sandy Mud
Grab 4	0.9	27.9	71.2	8.0	Slightly gravelly sandy mud
Grab 5	22.7	23.6	53.8	7.9	Gravelly mud
Grab 6	0	51.1	48.9	5.7	Muddy sand
Grab 7	0	40.4	59.6	6.0	Sandy mud
Grab 8	0	48.9	51.1	7.4	Sandy mud
Grab 9	33.7	24.9	41.4	2.2	Muddy gravel
Grab 10	93.3	4.4	2.3	5.6	Gravel

Table 3 Abundance data (per 0.025m^2) for all grab samples taken in the inner estuary at Grab sites 1-12. Sites highlighted in green are taken within the footprint of the weir maintenance track development.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Chironomdae sp.	0	0	1	0	0	0	0	0	0	0	0	0
Diptera larvae	0	1	2	0	0	0	0	0	0	0	0	0
Crangon	0	1	1	0	0	0	0	0	0	0	0	0
Carcinas maenas	0	0	0	0	1	0	0	0	1	1	0	0
Gammarus sp.	0	0	0	0	0	0	0	0	1	0	0	0
Melita palmata	0	0	0	0	0	0	0	0	0	0	1	0
Balanus crenatus	1	0	0	0	3	0	0	0	0	2	7	33
Mytilus edulis	0	0	0	0	0	0	0	0	0	0	1	0
Pomatoceros lamarcki	0	0	0	0	0	0	0	0	28	7	58	27
Tharyx sp.	2	7	0	0	0	0	0	0	0	0	14	4
Capitella capitata	2	2	0	0	0	0	0	0	0	0	0	0
Eteone longa	0	0	0	0	0	0	0	0	0	0	1	0
Heterochaeta costata	1	0	0	0	0	0	0	0	0	0	0	3
Oligochaetae	0	0	1	0	0	0	0	0	0	0	0	0
Tubificoides benedii	1	0	0	0	0	0	0	0	0	1	17	0

Table 4 Primary and derived diversity indices for all grab samples in the inner part of Malahide Estuary. Sites highlighted in green are located within the footprint of the weir maintenance track development.

	S1	S2	S3	S4	S5	S6
Number of Species	5	4	4	0	2	0
Number of Individuals	7	11	5	0	4	0
Margellef's Dominance Index	2.06	1.25	1.86	****	0.721	****
Shannon-Wiener Index	1.55	1.03	1.33	****	0.562	****
Pielou's Evenness	0.963	0.746	0.961	****	0.811	****
	S7	**S8**	**S9**	**S10**	**S11**	**S12**
Number of Species	0	0	3	4	7	4
Number of Individuals	0	0	30	11	99	67
Margellef's Dominance Index	****	****	0.588	1.25	1.31	0.713
Shannon-Wiener Index	****	****	0.291	1.03	1.22	1.02
Pielou's Evenness	****	****	0.265	0.746	0.626	0.738

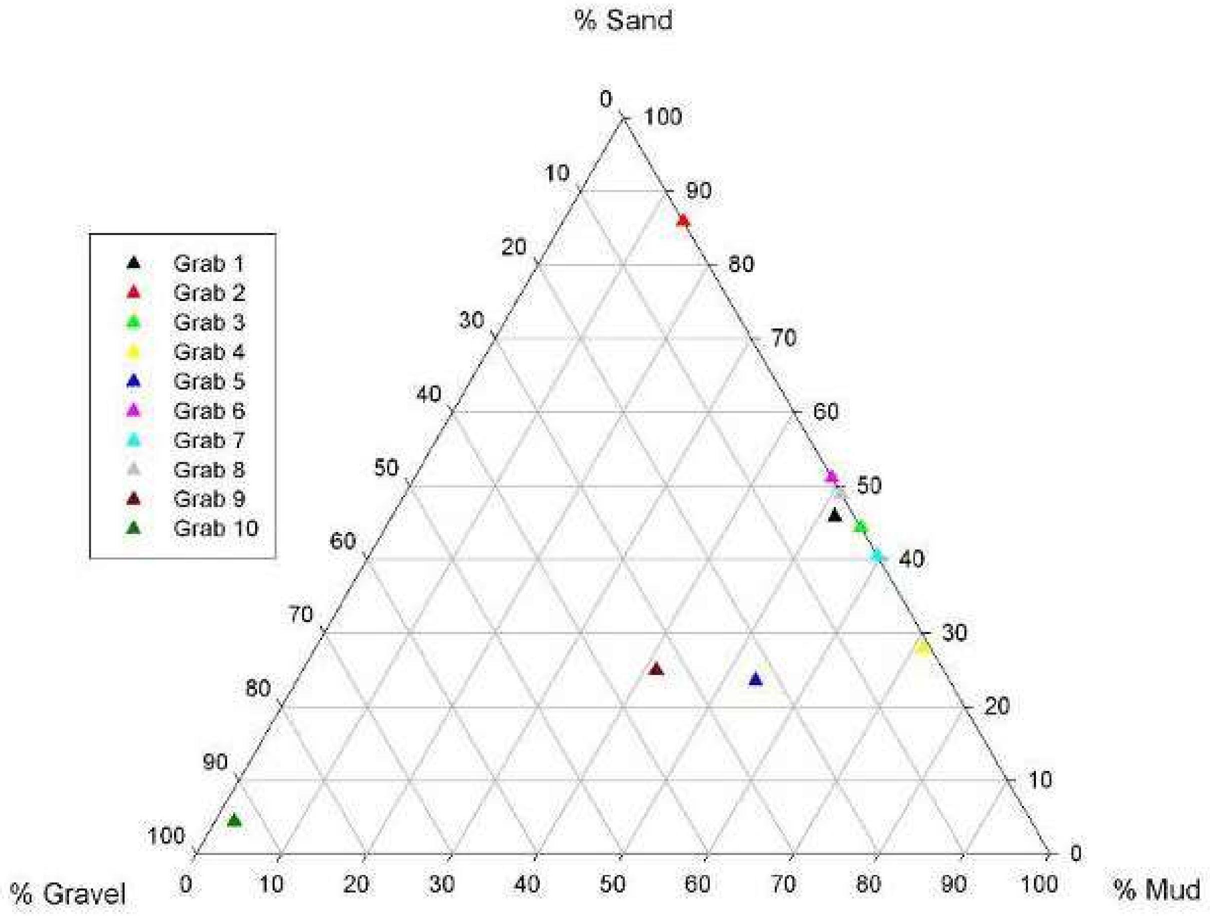


Figure 2 Ternary plot of particle size analysis along the subtidal grab sampling stations within and adjacent to the footprint of the weir maintenance track.

(C) Aquatic Environment – Plates 1 to 7

Plate 1: View of the exposed mud and sand flats of Malahide Estuary (outer) to the left of the railway embankment and of the lagoon-like Malahide Estuary (inner) to the right. View south toward Malahide.

Plate 2: View of distinct vertical zonation pattern along Malahide railway embankment – outer (eastern) face.

Plate 3: View of the tidal flaps on the River Pill outlet beneath the railway embankment viewed from the Malahide Estuary side.

Plate 4: The channel on the River Pill within the Malahide estuary at low tide viewed from its outlet under the railway embankment. Note the extensive adjoining mudflats.

Plate 5: View of the fringing saltmarsh (*Spartina*) at the top of the shore close to the Pill River outlet to the Malahide Estuary.

Plate 6: View of Pill River at kick sample site just upstream of road bridge.

Plate 7: View of Pill River channel at approximate position of proposed pedestrian bridge crossing point - view upstream.