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Gladstone Western Basin EIS - Numerical Modelling Studies

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Gladstone Western Basin EIS
- Numerical Modelling Studies

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Title :	Gladstone Western Basin EIS - Numerical Modelling Studies
Author :	Craig Witt, Ian Teakle, Joris Jorissen
Synopsis :	This report documents numerical modelling undertaken for the Gladstone Western Basin Dredging and Reclamation EIS. It assesses potential impacts associated with tidal hydraulics, flushing characteristics, dredge plume dispersion, waves and sedimentation.

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EXECUTIVE SUMMARY

Background

This report details numerical modelling of Port Curtis undertaken by BMT WBM Pty Ltd (WBM) as part of the Gladstone Western Basin Strategic Dredging and Reclamation EIS. The numerical models have been used as tools to quantify the physical processes and to assess the potential impacts of proposed dredging and reclamation works in the area know as the Gladstone Western Basin. Model results have been provided for use and to inform environmental impact assessments being undertaken by GHD Pty Ltd (GHD) for the project. The modelling has included tidal hydrodynamics and flushing characteristics, turbid dredge plume dispersion, wave conditions and sedimentation processes.

The proposed works include dredging in a number of stages from the Clinton Bypass channel to various swing basins and berth areas up to Laird Point. This will include both deepening and widening of some existing channels and swing basins as well development of new dredged channels, swing basins and berths. The proposed reclamation area that will be used for the placement of dredged material will be in the area to north of the existing Fisherman's Landing reclamation.

For the purposes of this study, modelling was undertaken for a base case and three development scenarios containing various stages of dredging and the proposed reclamation as follows:

- Base Case – Existing Channels + Recent Dredging at Fisherman's Landing + Proposed Wiggins Island Coal Terminal Dredging
- Scenario 1 – Base + Clinton Bypass Channel dredging + Curtis Spur Channel & Swing Basins dredging + initial Targinie Channel and Fisherman's Landing Swing Basin dredging + Western Basin Reclamation
- Scenario 2 – Scenario 1 + additional dredging of Targinie Channel and Fisherman's Landing Swing Basin + Channel to Laird Point and Swing Basin
- Scenario 3 – Scenario 2 + additional dredging to Laird Point + additional dredging between Swing Basins and near Hamilton Point on Curtis Island

The results of the modelling of developed case scenarios have been compared to the Base Case to assess the potential impacts of the works.

Tidal Hydraulics

The tidal hydraulic processes of the Project Area and the potential impacts of the proposed works were assessed using a calibrated and validated TUFLOW-FV hydrodynamic model of Port Curtis. This is a flexible mesh two dimensional (depth averaged) model which is appropriate for the high-energy macro-tidal regime and predominantly well-mixed conditions of Port Curtis. The model has been used to simulate a two month period of representative tide and wind conditions including large spring tides. The simulations utilised recorded tide data for the main tidal boundaries.

The dredging and reclamation works introduce various inter-related, additive and sometimes compensating effects to modify water levels, currents and. The staging of works also adds to the complexities with some impacts in early stages being mitigated in certain areas by subsequent works while others increase.

The proposed reclamation results in a reduction of up to about 408ha of available tidal storage area at high tide levels. This loss of inter-tidal storage area contributes to a reduction in tidal prism, which subtly alters the tidal propagation dynamics (i.e. water levels and currents) within the system.

In general, current velocities tend to decrease in dredged areas where the depths are greater following dredging as well as those areas laterally adjacent to the dredging due to the increased flow through the more efficient dredged areas. Increases in velocity are typically evident in adjacent un-dredged areas upstream and downstream of the newly dredged areas where the higher flows exit. The reclamation can also act to modify velocities in the immediately adjacent channel and inter-tidal areas by confining and redirecting the flow.

The model results indicate that the dredging and reclamation works will have negligible impact (1cm or less) on high tide levels throughout the area. Low tide levels will be affected to varying degrees depending on the location relative to the development and there will be some slight changes to the phasing (timing of the tides). There is a general tendency for spring tide low water levels to be:

- 2 to 5cm higher in the Narrows (ie north of Friend Point);
- 2 to 5cm higher in the northern part of the project area (ie the main channel areas between Fisherman's Landing and Friend Point);
- 1cm lower to 3cm higher in the southern part of the project area (ie the main channel areas between the Calliope River and Fisherman's Landing); and
- 2cm lower to 2cm higher in the Auckland Point area.

The relative impact of the various staged scenarios is much more subtle than the impacts relative to the base case, which indicates that the reclamation and associated loss of inter-tidal storage is a more significant perturbation on the broad-scale hydrodynamics within the project area than the dredging works.

Locations on the inter-tidal flats adjacent to the extended reclamation are impacted more than those in the channel with the ebb tide fall of the tide in theses areas being attenuated by the reduced flow area draining the remaining inter-tidal flats in the Western Basin.

With respect to velocities, the predicted impacts vary depending on location relative to the proposed works as well as time and the magnitude of the tidal range. For Scenario 1, velocities are predicted to:

- decrease in the dredged areas (by up to 0.6m/s) and along the eastern wall of the reclamation (by up to 0.45m/s);
- generally decrease (by up to 0.2m/s) downstream of the Western Basin in the Wiggins Island Basin, Clinton Basin, Auckland Channel and Clinton Bypass Channel;
- generall increased (by up to 0.25m/s) in the channels upstream of the dredged areas (between Fisherman's Landing and the entrance to the Narrows), and locally increase at a few other locations including the north-eastern corner of the reclamation and along the Passage Island shoals (by up to 0.3m/s); and

- increase on the ebb tide in the shallow areas of the Curtis Island frontage onto the Project Area.

The incremental increase in dredged footprint associated with Scenario 2 and Scenario 3 increases the extent of velocity-reduction impacts and decreases the extent of velocity-increase impacts (relative to Scenario 1). The ultimate dredging configuration associated with Scenario 3 causes the footprint of increased ebb tide velocities to extend further north into the Narrows. Ebb tide velocity increases at Hamilton Point are accentuated under Scenario 3 and extend through to Boatshed Point.

The model integrated flows indicate a slight reduction (about 5%) in the peak flow entering and leaving the project area at the southern (downstream) end between Mud Island and Hamilton Point linked primarily to the loss of tidal storage volume associated with the reclamation.

Negligible changes in flood tide flows (about 1%) entering the Narrows to the north (upstream) of the project area are predicted while some slight increases in the peak ebb tide flows (up to about 4% for Scenario 3) leaving the Narrows are predicted in line with the slight increases in ebb tide velocities in this area.

Targinie Channel ebb and flood tide flows are reduced due to the loss of tidal storage volume associated with the reclamation. Peak flows are most significantly reduced in Scenario 1 (by about 16% flood and 13% ebb) before increasing slightly again (back to about a 10% reduction) with the additional dredging north of Fisherman's Landing undertaken for Scenario 2 and Scenario 3.

"Curtis" Channel flows are increased relative to the Base Case in all of the developed scenarios due to the dredging of in this channel. Scenario 1 peak flood tide flows increase by about 27% and are higher relative to Scenario 2 and Scenario 3 (which have increases of around 11%) due to the additional dredging of the western channel associated with the latter stages of development. Peak ebb tide flows for Scenario 1 also increase by about 27% and are only slightly smaller (with an increase of about 25%) for Scenario 2. The additional dredging between the Swing Basins and around Hamilton Point in Scenario 3 results in a further increase in peak ebb tide flows (total up to 29%) through this transect relative to the Base Case.

Tidal Flushing Characteristics

Port Curtis is a macro-tidal estuary with high tidal current speeds in the main channels and large intertidal wetting/drying extents. As such, Port Curtis is a naturally well-flushed system. Upstream of the Narrows, the tidal prism and tidal excursion length is reduced and consequently this part of the system is less well flushed than the Project Area and outer harbour areas. Changes to the hydrodynamic regime as a consequence of reclamation and dredging may also impact the flushing characteristics of the estuary.

The TUFLOW-FV hydrodynamic model and advection-dispersion module were used to assess the flushing of a conservative tracer from the entire Port Curtis system over a 2-month period. This assessment was undertaken for the base case geometry and the same three developed scenarios as for the hydrodynamic assessments.

The base and developed case flushing results were compared in terms of time series at a number of key locations, spatial contour plots of concentration at the end of the 2-month simulation and spatial contour plots of "e-folding" time.

e-Folding times within the Project Area range from around 25 days at Barney Point to around 37 days at Fisherman's Landing. Upstream in the Narrows and Graham Creek, e-Folding times range upward from 45 days. Compared with the base case, the three developed case scenarios all cause increases in e-folding times (reductions in flushing efficiency) within and upstream of the Project Area of 0-4 days.

Dredge Plume Dispersion

The impact of dredging activities associated with the Western Basin port expansion was assessed by modelling the advection, dispersion and settling of fine sediments introduced into the water column. The modelling quantified the "dredge plume" which has been defined as the quantity of Total Suspended Solids (TSS) in the water column due to dredging above the natural background levels.

A range of dredging activities were assessed, including; Cutter Suction Dredging; Trailer Suction Hopper Dredging including overflow; Hopper Dumping adjacent to the extended Fisherman's Landing reclamation; Cutter Suction Dredge rehandling of dumped material into the reclamation and decant discharge from the reclamation. These activities were modelled in 8 separate simulations, which were subsequently super-imposed to represent the likely dredging activities associated with 4 stages of the Western Basin expansion.

The dredge plume modelling was undertaken for a 2-month simulation period using the TUFLOW-FV hydrodynamic, advection-dispersion and cohesive sediment modules. The dredge plume was simulated as three sediment fractions; fine sand with settling velocity of 1e-2m/s, silt with settling velocity of 2e-4m/s and clay with settling velocity of 2e-5m/s. The relative proportions of these fractions in the dredge plume source were estimated based on field measurements associated with the "Wombat" dredging at Fisherman's Landing performed in mid-2009. The assumed effective source term rates of sediment entrainment into the "long-term" plume are summarised as:

- Large Cutter Suction Dredge: 4kg/s;
- Trailer Suction Hopper Dredge (including overflow): 75kg/s for 1 hour every 3 hours;
- Hopper dumping: 340kg/s for 10 minutes every 3 hours;
- Medium Cutter Suction Dredge (rehandling): 4kg/s; and
- Decant discharge concentration: 100mg/L.

The dredge plume results were summarised as time series of plume Total Suspended Solids and plume deposition at key locations of interest, maximum and 10% exceedance plume concentration spatial contour plots and spatial contour plots of average rates of sediment deposition. The highest (across the 4 modelled scenarios) 10% exceedance level plume TSS concentrations are summarised below:

- Upper Narrows (Black Swan Island): 8mg/L;
- Lower Narrows (Friend Point): 47mg/L;
- Tidal flats south-east of Fishermans Landing: 20mg/L;
- Boatshed Point: 22mg/L;
- Barney Point: 33mg/L;

- South-Trees Island: 19mg/L; and
- Gatcombe Head: 7mg/L.

The remaining tidal flats to the north of the extended Fisherman's Landing reclamation are predicted to experience high TSS concentrations in excess of 100mg/L and average sediment deposition rates of up to 1mm/day. Elsewhere in the Project Area, except in close vicinity to the dredge plume source locations, sediment deposition rates are predicted to be much smaller.

The plume impacts are predominantly due to the operations of the Trailer Suction Hopper Dredge and the large plume source rates associated with hopper overflow and dumping. The Cutter Suction Dredge and reclamation decant discharge produce much less significant impacts.

Wave Climate

A wave modelling analysis was undertaken using the numerical spectral wave model SWAN to assess potential impacts of various development scenarios on the local wave climate and extreme waves under elevated water level conditions. Significant wave heights near Fisherman's Landing under specified 100 year ARI wind and storm tide conditions are up to about 2.5m with a peak period of about 5s from the longest fetches to the southeast.

The results of the day to day wave climate analysis indicate the following trends:

- The Project Area experiences a mild to moderate wave climate with a dominant wave direction from the southeast at most locations.
- To the east of the proposed Fisherman's Landing reclamation, the small amount of wave action from the western sector is reduced. Note that for the existing case about 81.7% of the year waves with a significant wave height of less than 0.3m are predicted. For all development cases modelled, this is predicted to increase to about 83.9% of the year.
- To the north of the proposed Fisherman's Landing reclamation, there is a significant reduction in wave action from the southerly sector. Also, for the developed cases there is an increase from 86.3% to 97.7% of waves less than 0.3m.
- Further to the north of the proposed Fisherman's Landing reclamation, there is a marginal reduction in wave action from the southerly sector.
- To the east of North Passage Island, there will be no significant changes in wave action for all three development scenarios. Note that there are about 91% of waves less than 0.3m for all cases.
- Between the swing basins near Curtis Island, waves from the southeast (i.e. from 120 and 150 degrees) will be marginally larger, due to the dredged channel to North China Bay. For Development Scenario 1 and 2, there is an increase from 16.2% to 18.5% of waves greater than 0.3m. For Development Scenario 3, this is predicted to increase to 18.6%.

Sediment Transport

Port Curtis seabed sediments are a mixture of gravels, sands, silts and clays. The coarser fractions predominantly occur in the high current areas while the finer particles occur in the lower energy environments. Due to the mixed nature of the sediments and sediment transport processes a dual approach has been adopted to assess the implications of sediment transport processes on the Western Basin expansion.

Sand-sized sediment transport due to the action of tidal currents was assessed using the TUFLOW-FV hydrodynamic results and the Meyer-Peter-Muller bed load formula. Silt deposition rates and volumes within the dredged areas were assessed using an assessment based on the TUFLOW-FV hydrodynamic results and assumed ambient TSS levels within the project area. Multiple assumptions were required for both the sand transport and in particular the silt-deposition assessments leading to significant uncertainties in the quantitative estimates.

Keeping in mind these quantitative uncertainties the following key points can be concluded regarding future maintenance dredging requirements:

- The potential for sand transport into the project dredged areas including the existing Fisherman's Landing and Targinie Channel is significantly less than for the downstream dredged areas (Clinton Swing Basin, Clinton Bypass Channel and the Wiggins Island Coal Terminal Swing Basin);
- The impact of the reclamation and additional dredging works is to reduce the potential sand transport into the base case dredged areas;
- Sand-sized sediment deposition into the project dredged areas could occur at a rate of around 50,000m^3/year;
- Silt deposition is not a major source of sedimentation problems in the existing Port Curtis dredged areas (excluding enclosed harbours) due to high current speeds and associated bed shear stresses; and
- The project dredged areas are likely to experience significant silt deposition due to the relatively low-energy hydrodynamic regime that will occur following dredging. A fine-material siltation rate of 255,000m^3/year has been predicted for the ultimate dredging scenario.
- It is estimated that there will be for the ultimate scenario a total maintenance dredging requirement of the order of 300,000m^3/year on average. Predicted rates of siltation (<0.1m/year) are such that this may accommodated for a number of years by modest overdredging thereby limiting the frequency of maintenance dredging activities.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

This report details numerical modelling of Port Curtis undertaken by BMT WBM Pty Ltd (WBM) as part of the Gladstone Western Basin Strategic Dredging and Reclamation EIS. The numerical models have been used as tools to quantify the physical processes and to assess the potential impacts of proposed dredging and reclamation works in the area know as the Gladstone Western Basin. Model results have been provided for use and to inform environmental impact assessments being undertaken by GHD Pty Ltd (GHD) for the project.

The modelling has included tidal hydrodynamics and flushing characteristics, turbid dredge plume dispersion, wave conditions and sedimentation processes. The numerical models used in the studies have been established and enhanced over many years by WBM and updated with further specific data collected for this project. Details of the modelling software, establishment, calibration and validation are provided in a separate model validation report (BMT WBM, 2009) with base descriptions included in this report as appropriate.

1.2 Site Description

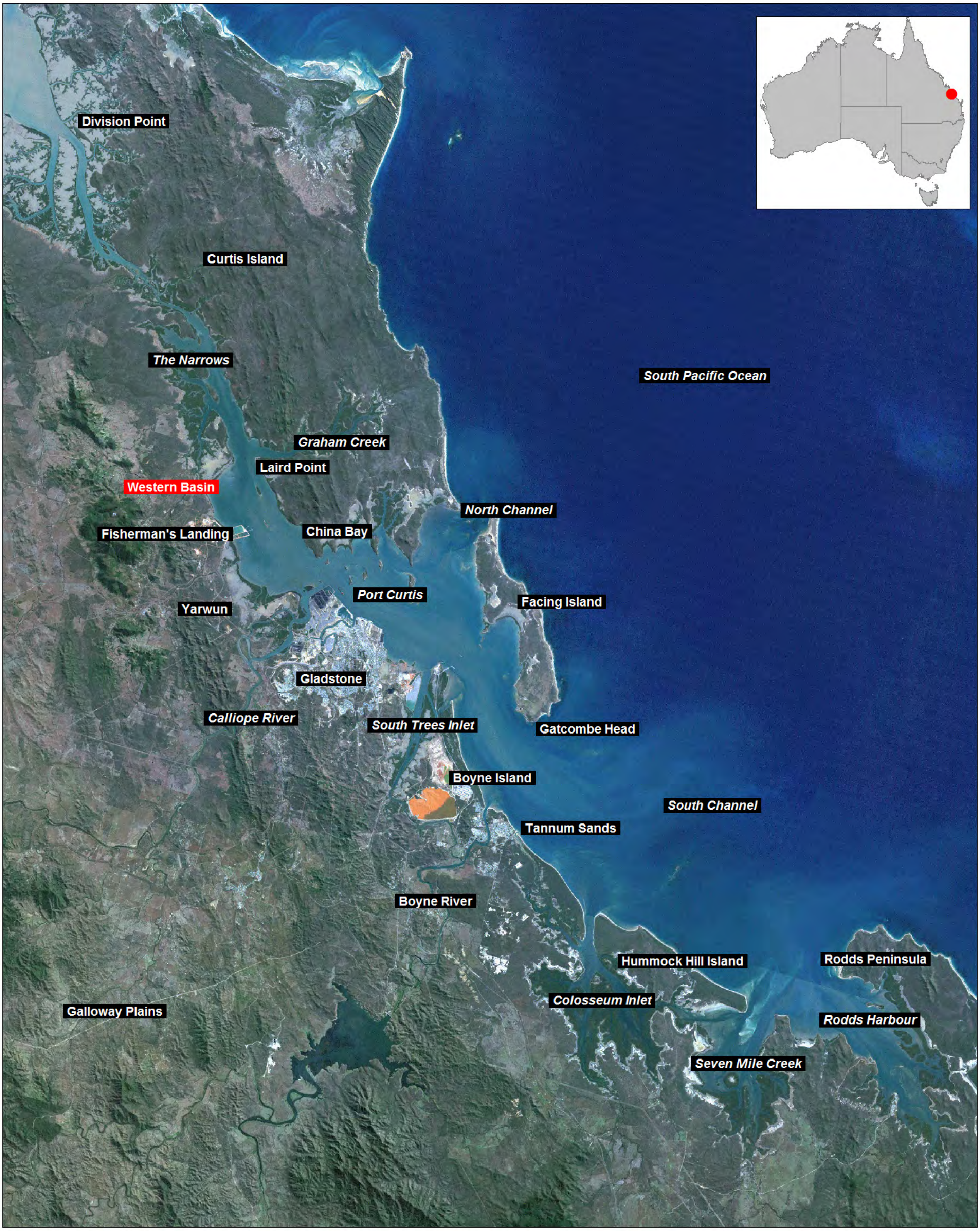
The proposed works are primarily located in the broad tidal basin (the Project Area) between Curtis Island and the mainland in the vicinity of the existing Fisherman's Landing reclamation and wharf facilities in Gladstone (refer Figure 1-1 for locality and Figure 1-2 for project area). The Port of Gladstone has been established in the naturally sheltered waters of Port Curtis behind Facing and Curtis Islands to the east and north. Port Curtis is connected to the ocean via a major opening to the south of Facing Island (South Channel), a smaller opening between Facing and Curtis Islands (North Channel) and "The Narrows" which extend some 40 km to the north behind Curtis Island.

The Calliope and Boyne Rivers as well as Auckland and South Trees Inlets discharge into the central section of the Port. Further to the south are the connected waterways of Colosseum Inlet, Seven Mile Creek and Rodds Harbour while Grahams Creek and a number of smaller tributaries connect to The Narrows.

These extensive waterway areas and a large tidal range result in significant current velocities in some areas. The high tidal velocities generally assist in maintaining Gladstone harbour as a natural, deep-water port. However a navigation channel has been established and is maintained to provide access for larger draft vessels.

The Port area also contains a number of smaller islands and has extensive areas of inter-tidal flats, which become exposed at low water. For very low tides, some areas reduce to several narrow meandering channels. There are also very large intertidal mangrove and saltpan areas in Port Curtis, which are inundated at higher tide levels.

The Project Area containing the proposed works extends from near Barney Point in the south, past Hamilton Point and up to the entrance to the Narrows including the broad basin between Curtis Island and the mainland. The embayment on the western side of this basin near Fisherman's Landing is known as the Western Basin.



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Locality Plan

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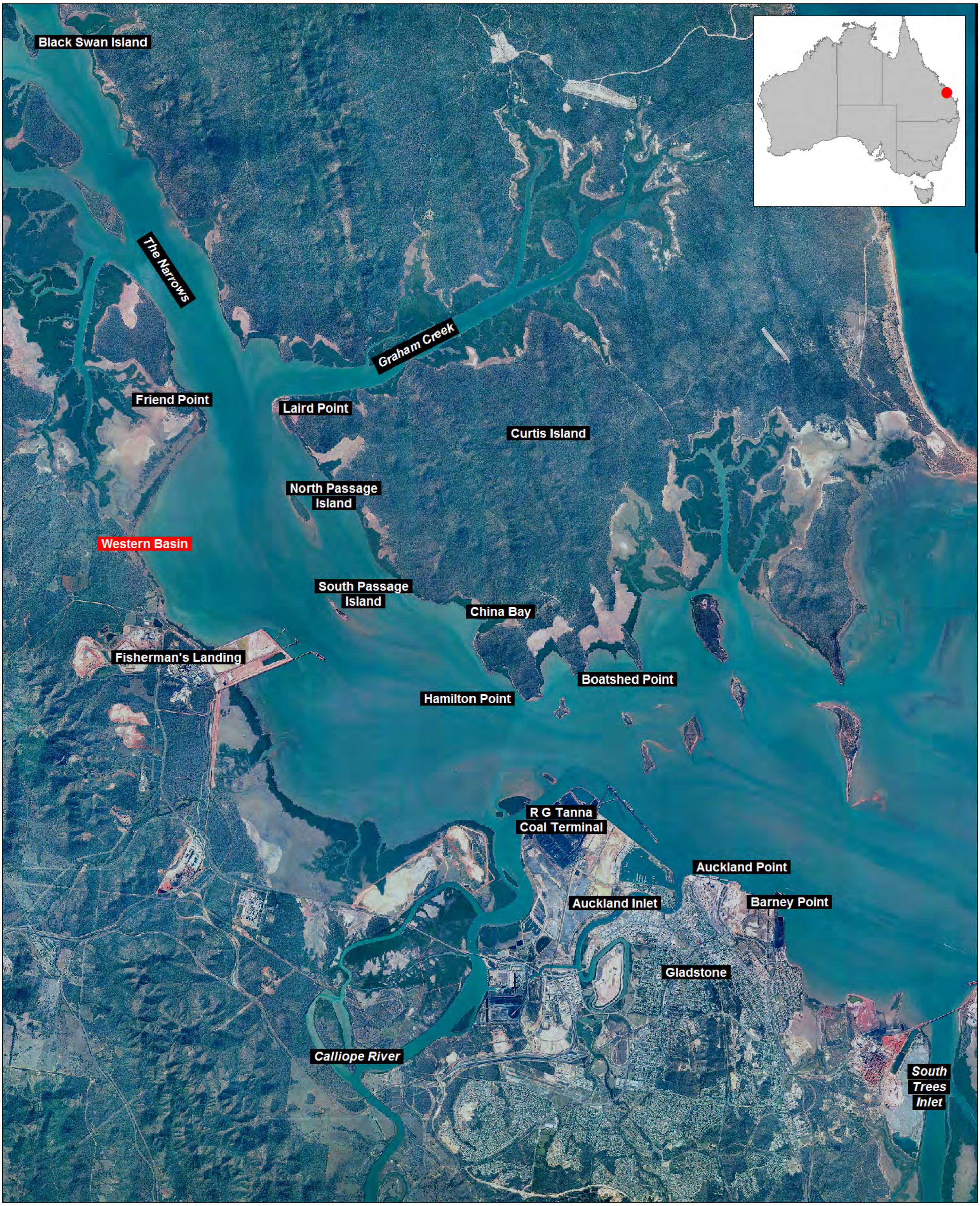

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Project Area

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1.3 Scope of Works

The scope of works broadly relate to numerical modelling to investigate the individual and cumulative impacts of dredging and reclamation works in the Project Area on the hydrodynamic, flushing, dredge plume dispersion, wave and sedimentation processes in Port Curtis. This has included the following tasks:

- **Additional data collection** – The collection of additional targeted data for model validation and assessment purposes. The data and its use are described in the separate model validation report (BMT WBM, 2009) with base descriptions included in this report as appropriate. The data includes:
  - Tide water levels at the model boundaries and within Port Curtis over the period of data collection.
  - Acoustic Doppler Current Profiler (ADCP) transects of total flow and velocity distributions as well as backscatter as indication of suspended sediment concentrations during spring and neap tides.
  - Coincident physical water quality measurements of turbidity and laboratory analyses of Total Suspended Sediment concentrations as well as particle characteristics.
  - Continuous ADCP measurements from bottom-mounted instruments to provide longer term time series of currents, waves and backscatter as indication of suspended sediment concentrations (commissioned and arranged by GHD).
  - Continuous nephelometer measurements to provide longer term time series of turbidity in the Project Area (commissioned and arranged by GHD).
  - Plume monitoring of turbidity and suspended sediment concentrations generated by dredging in the vicinity of Fisherman's Landing by the "Wombat" cutter suction dredge. This included physical water quality measurements of turbidity and laboratory analyses of Total Suspended Sediment concentrations as well as particle characteristics. ADCP transects of currents and backscatter were also collected as an indication of suspended sediment concentrations.
  - Meteorological data in terms of wind speed/direction and atmospheric pressure from the Bureau of Meteorology for regional stations over the period of other data collection.
- **Model refinement and validation** – Refinement of existing models to include sufficient detail for the appropriate representation of proposed works and validation using the above data to provide a suitable base for impact assessment purposes. Details of the model establishment and validation are described in the separate model validation report (BMT WBM, 2009).
- **Hydrodynamic impact assessments** – Assessment of the impacts of specific dredging and reclamation scenarios on tide levels, velocities and flows.
- **Flushing impact assessment** – Assessment of the impacts of specific dredging and reclamation scenarios on the flushing characteristics of Port Curtis.
- **Plume dispersion assessments** – Simulation of the potential transport, dispersion and settling of turbid plumes of suspended sediment generated by dredging for specific scenarios of loadings

and locations of dredges including cutter suction dredges (CSD), trailer suction hopper dredges (TSHD) and tailwater discharge from reclamation areas.

- **Wave climate assessment** – Modelling of the day to day wave climate from the local wind climate and potential extreme wave conditions for specified wind speeds and water levels for design and impact assessment purposes of specific dredging and reclamation scenarios.
- **Sedimentation assessment** – Assessment of the implications of the specific dredging and reclamation scenarios on sediment transport processes within Port Curtis and the potential siltation of dredged areas.

Interpretation of the results of modelling have been undertaken by authors of associated technical reports with respect to the potential impacts on the coastal processes and ecology of the region.

1.4 Scenarios Assessed

The proposed works include dredging in a number of stages from the Clinton Bypass channel to various swing basins and berth areas up to Laird Point. This will include both deepening and widening of some existing channels and swing basins as well development of new dredged channels, swing basins and berths. The proposed reclamation area that will be used for the placement of dredged material will be in the area to north of the existing Fisherman's Landing reclamation.

Full description of the project works are provided elsewhere with a summary provided here of specific scenarios adopted for the purposes of modelling the potential impacts. The details of the scenarios are as supplied by Gladstone Ports Corporation (GPC) and GHD.

The modelling scenarios include a Base Case and three developed scenarios as summarised in Table 1-1. Figure 1-3 to Figure 1-6 illustrate the bathymetry and the extent of dredging/reclamation in each of the scenarios. A brief description of each of the components is as follows:

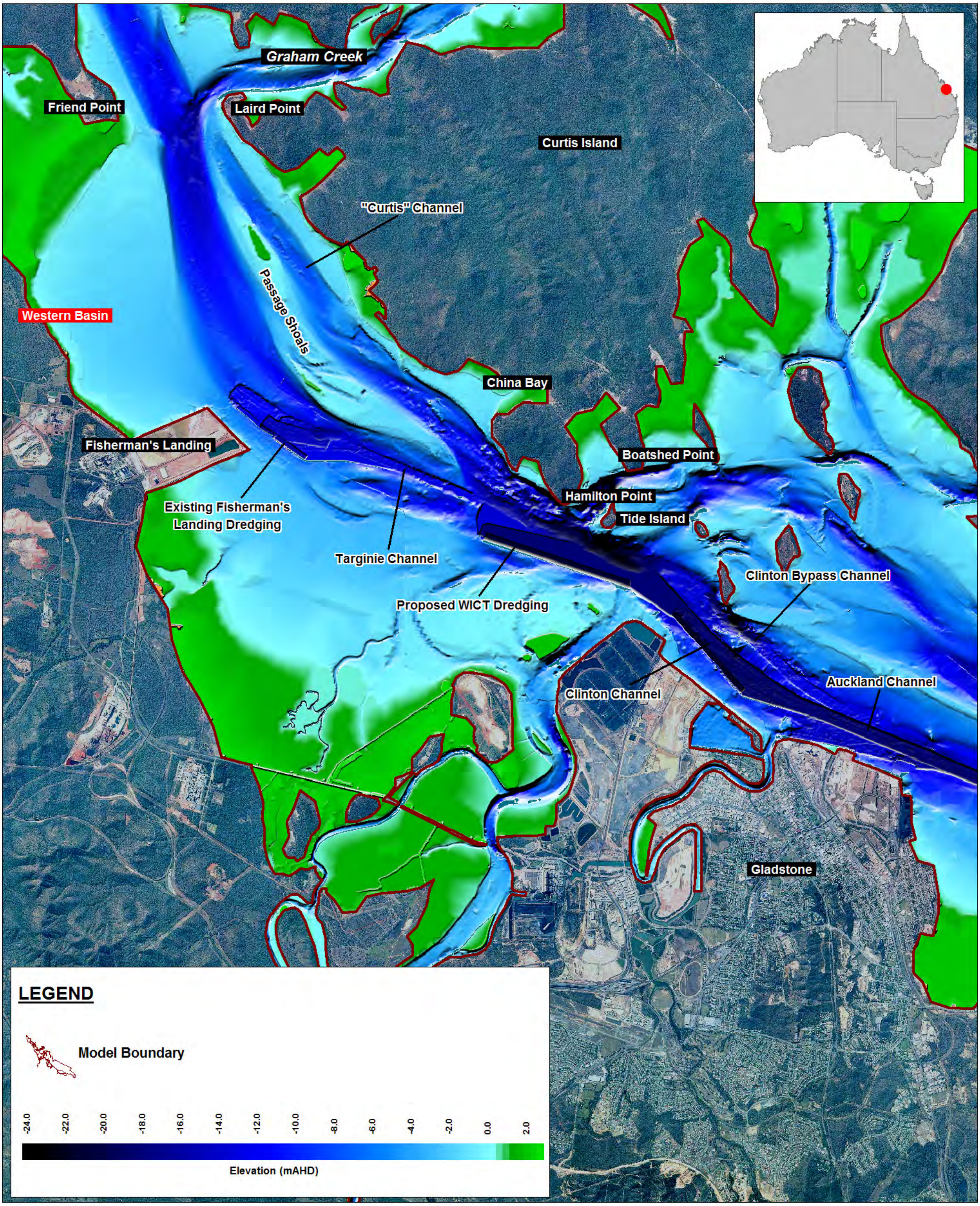
- Base Case Dredging:
  - all existing channels, swing basins and berths
  - dredging presently being undertaken for Fisherman's Landing Berth 1
  - the proposed ultimate dredging for the Wiggins Island Coal Terminal (WICT) project
- Base Case Reclamation:
  - Existing Fisherman's Landing reclamation
- Stage 1A Dredging:
  - Clinton Bypass channel 200m wide at -13m LAT
  - Spur channel to China Bay 200m wide at -13m LAT
  - China Bay Swing Basins (2) 600m wide at -13m LAT
- Stage 1B Dredging (Stage 1):
  - Targinie Channel 180m wide at -10.6m LAT
  - Fisherman's Landing Bulk Liquids Wharf Swing Basin 550m wide at -10.6m LAT
  - Fisherman's Landing Bulk Liquids Wharf Swing Berth to 430m long at -12.5m LAT

- Stage 1B Dredging (Fully Developed):
  - Targinie Channel 180m wide at -13.0m LAT
  - Fisherman's Landing Swing Basin 650m wide at -13.0m LAT
  - Fisherman's Landing Bulk Liquids Wharf Swing Berth to 430m long at -13.0m LAT
- Stage 2 Dredging:
  - Channel extension to Laird Point 200m wide at -13m LAT
  - Laird Point Swing Basin approx 600m wide at -13m LAT
- Stage 3 Dredging:
  - Berth and Swing Basins to Laird Point 400m wide (total 600m) at -13m LAT
- Stage 4 Dredging:
  - China Bay and Hamilton Point additional Swing Basins and Departure Areas at -13m LAT
- Developed Case Reclamation (All):
  - Area to north of existing Fisherman's Landing reclamation (approx 408ha)
  - Setback buffer from shoreline 40m

For all dredging scenarios, an over-dredging allowance of 0.3m has been included in the model simulations. Figure 1-7 illustrates all components and the locations of model output time series.

Table 1-1 Modelling Scenarios

Scenario	Dredging	Reclamation
Base Case	Existing Channels Present Fisherman's Landing Berth 1 Ultimate Wiggins Island Coal Terminal	Existing Fisherman's Landing reclamation
Scenario 1 (Base +)	Stage 1A Stage 1B (Stage 1)	Western Basin reclamation fully constructed
Scenario 2 (Base +)	Stage 1A Stage 1B (fully developed) Stage 2	Western Basin reclamation fully constructed
Scenario 3 (Base +)	Stage 1A Stage 1B (fully developed) Stage 2 Stage 3 Stage 4	Western Basin reclamation fully constructed



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Base Case Geometry

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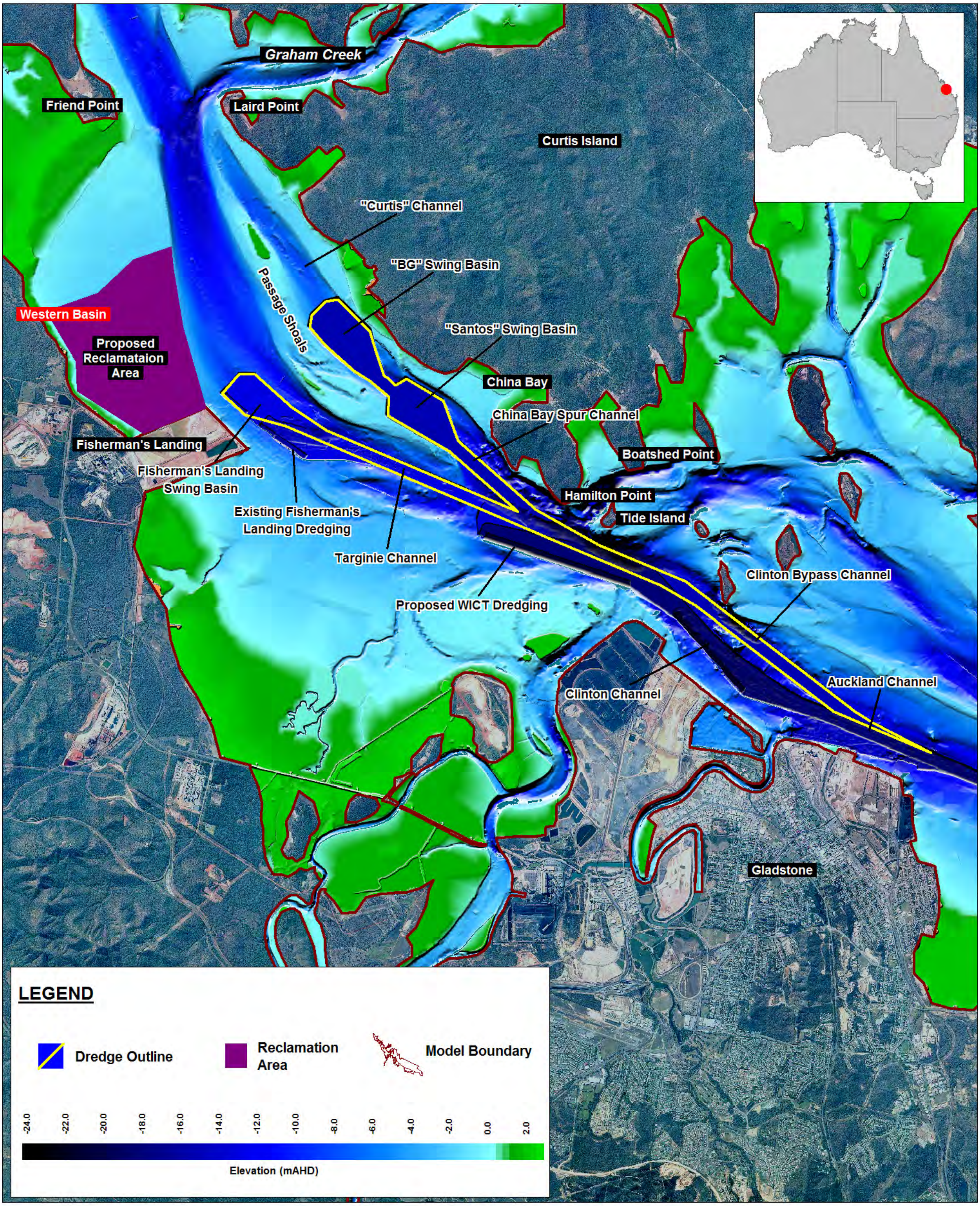

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Scenario 1 Geometry

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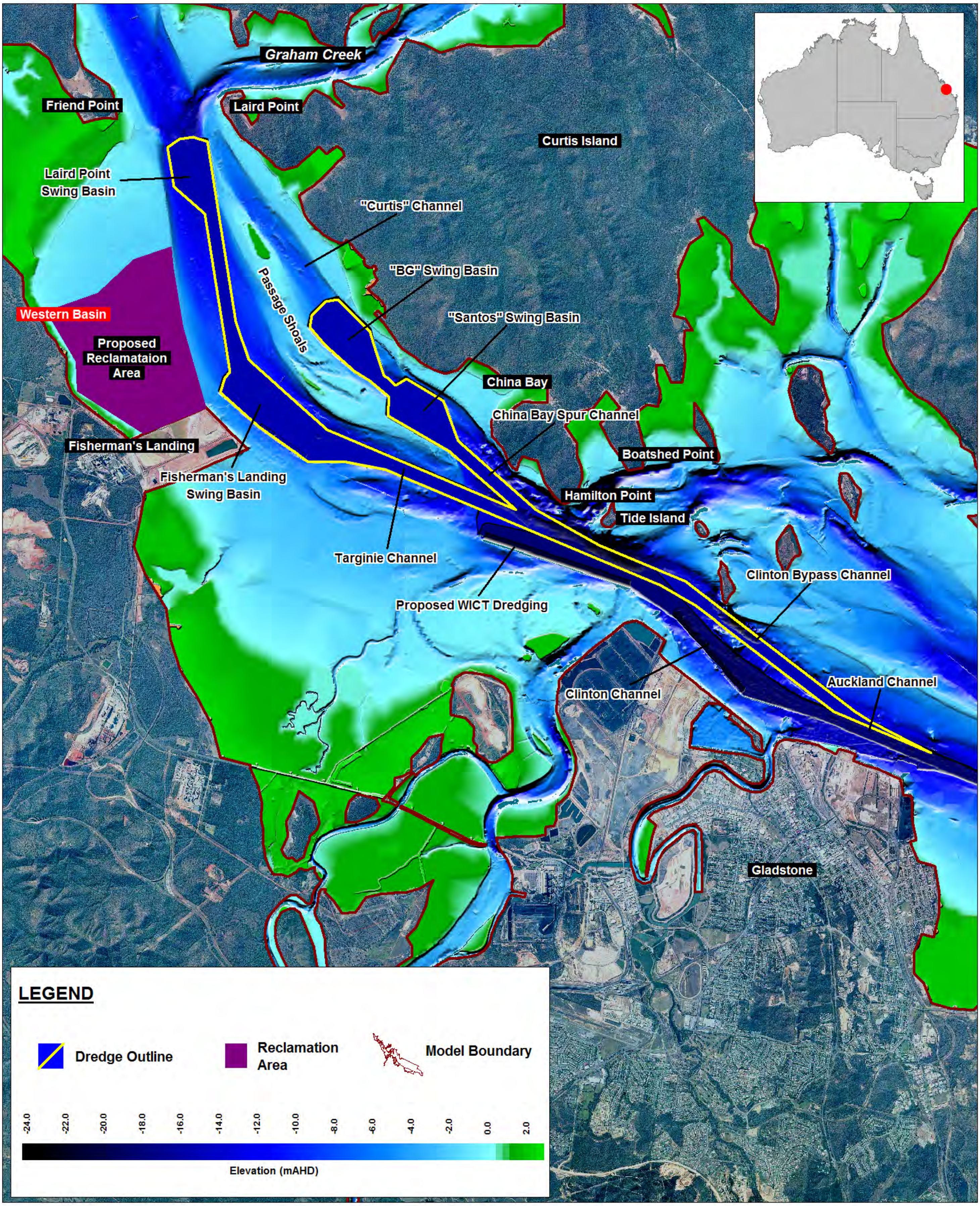

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Scenario 2 Geometry

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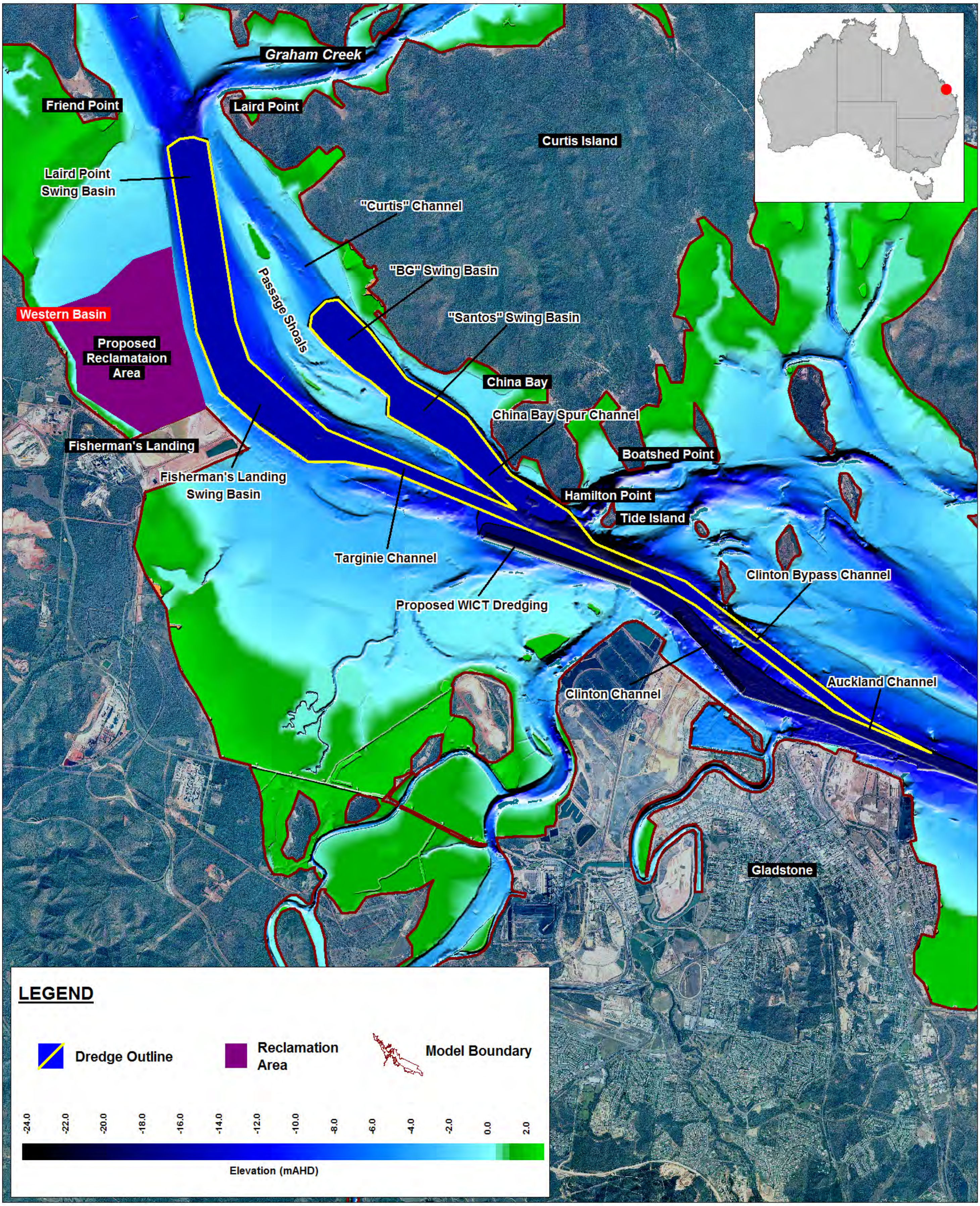

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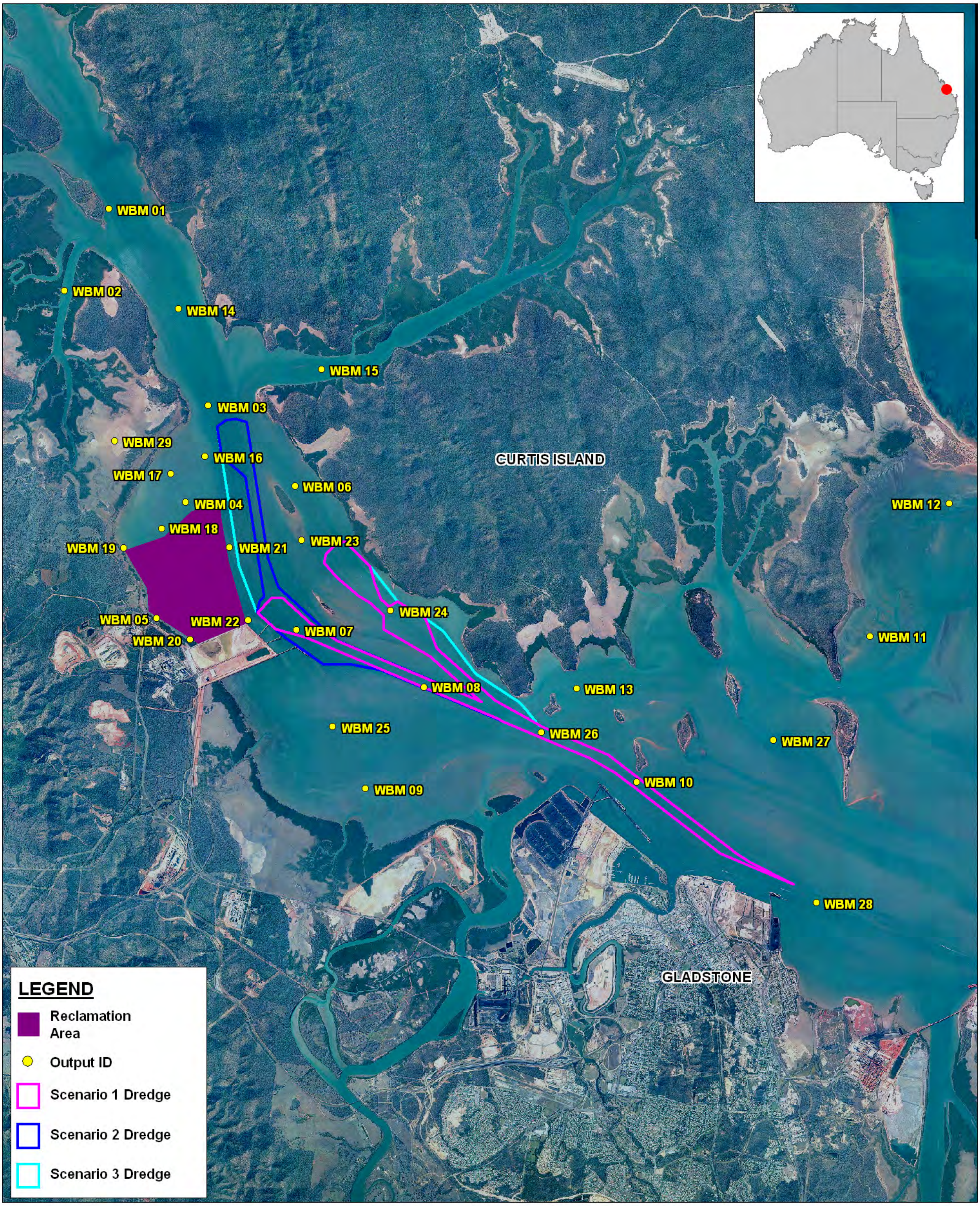

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Model Output Locations

Figure: 1-7

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2 TIDAL HYDRAULICS

2.1 General Considerations

An understanding of the tidal hydrodynamics is important not only for the project design in terms of tide level variations and current speeds/directions but also for its controlling influences on flushing and sediment transport processes. The project involves channel / swing basin dredging and reclamation works. As such, it is necessary to understand the potential direct impacts these may have on tidal hydraulic processes as well as any follow on effects for water quality, sedimentation and associated ecological implications.

The extent of the tidal hydraulic system considered in the context of this study includes the whole of the estuarine waters of Port Curtis and connected rivers/inlets as described above. Tides propagate into the port from the south (south of Facing Island), east (between Facing and Curtis Islands) and the north (from Keppel Bay into The Narrows). This results in complex interactions with the tidal waves meeting near the centre of The Narrows.

The large tidal range and extensive intertidal banks, mangrove and saltpan areas result in changes to the available storage areas at different tidal elevations. These changes cause the estuary to exhibit non-linear behaviour for tides of large range (i.e. tidal flow velocities and rate of rise and fall vary greatly depending on the extent of coverage of the saltpans and mangroves).

Tidal variations in this area are reasonably well understood from extensive recordings and analyses by the Queensland Government, and accurate predictions are available for Standard and Secondary ports in the region. The tidal times, heights and planes are published by Maritime Safety Queensland (MSQ) for the Standard Port of Gladstone Harbour at Auckland Point in their publication “Queensland Tide Tables 2009” (Maritime Safety Queensland, 2008). Secondary tidal planes are also published for a variety of locations in Port Curtis, such as The Narrows (Boat Creek and Ramsay Crossing) to the north. These, together with tidal planes for Fisherman’s Landing obtained separately from MSQ are presented in Table 2-1 as heights above the local Lowest Astronomical Tide (LAT) level.

It can be seen that the mean spring tidal range for Gladstone is 3.24m, the mean neap tidal range is 1.54m and the maximum tidal range is 4.69m. The tidal range amplifies as it travels north with the range at Fisherman’s Landing being approximately 6% greater than at Gladstone (Auckland Point) and the range at Boat Creek in The Narrows being 17% greater.

It should be noted that close to the completion of this report, MSQ published on their website new tidal planes for Standard Ports and Secondary Places in Queensland based on recent measurements and updates for the current Tidal Datum Epoch 1992-2011 (Maritime Safety Queensland, 2009). It is understood that these new values will be incorporated in their forthcoming publication “Queensland Tide Tables 2010.” The new values for the study area have been included (in brackets) in Table 2-1 as well for comparison. It can be seen that in general, the mean tidal plane ranges are similar, although the absolute values including that of Highest Astronomical Tide (HAT) have increased.

There are no specific calculations using tidal planes in this report. All numerical model simulations referred to below are based on measured data which are in fact compatible with the new tidal planes.

These simulations include a tide close to the level of the new HAT. As such, the assessments of the effects of the development scenarios are up to date.

Table 2-1 Gladstone Region Tidal Planes (m LAT)

Tidal Plane	Gladstone (Standard Port)	Fisherman's Landing	The Narrows (Boat Creek)	The Narrows (Ramsay Crossing)
Highest Astronomical Tide (HAT)	4.69 (4.83)	4.97 (5.12)	5.44 (5.60)	6.00 (6.17)
Mean High Water Springs (MHWS)	3.91 (3.96)	4.14 (4.20)	4.52 (4.58)	5.02 (5.08)
Mean High Water Neaps (MHWN)	3.06 (3.11)	3.24 (3.30)	3.53 (3.59)	3.95 (4.01)
Mean Level (ML)	2.35 (2.34)	2.439 (2.41)	2.68 (2.68)	3.01 (3.01)
Australian Height Datum (AHD)	2.268 (2.268)	2.429 (2.43)	-	-
Mean Low Water Neaps (MLWN)	1.52 (1.57)	1.61 (1.66)	1.73 (1.79)	2.00 (2.07)
Mean Low Water Springs (MLWS)	0.67 (0.72)	0.71 (0.76)	0.73 (0.79)	0.93 (1.00)
Lowest Astronomical Tide (LAT)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Note: Main figures from Queensland Tide Tables 2009 (MSQ, 2008) apart from Fisherman's Landing that were supplied independently by MSQ. Figures in brackets are new values published on the MSQ website (MSQ, 2009) including Fisherman's Landing.

Due to the large tidal storage areas and the amplification effect on water levels, good tidal flushing and large tidal velocities generally exist within the main channels of Port Curtis. Further understanding and detailed assessment of the tidal hydraulic processes of Port Curtis in the vicinity of the site as well as the potential impacts of the proposed works have been obtained through hydrodynamic modelling and targeted data collection as outlined below.

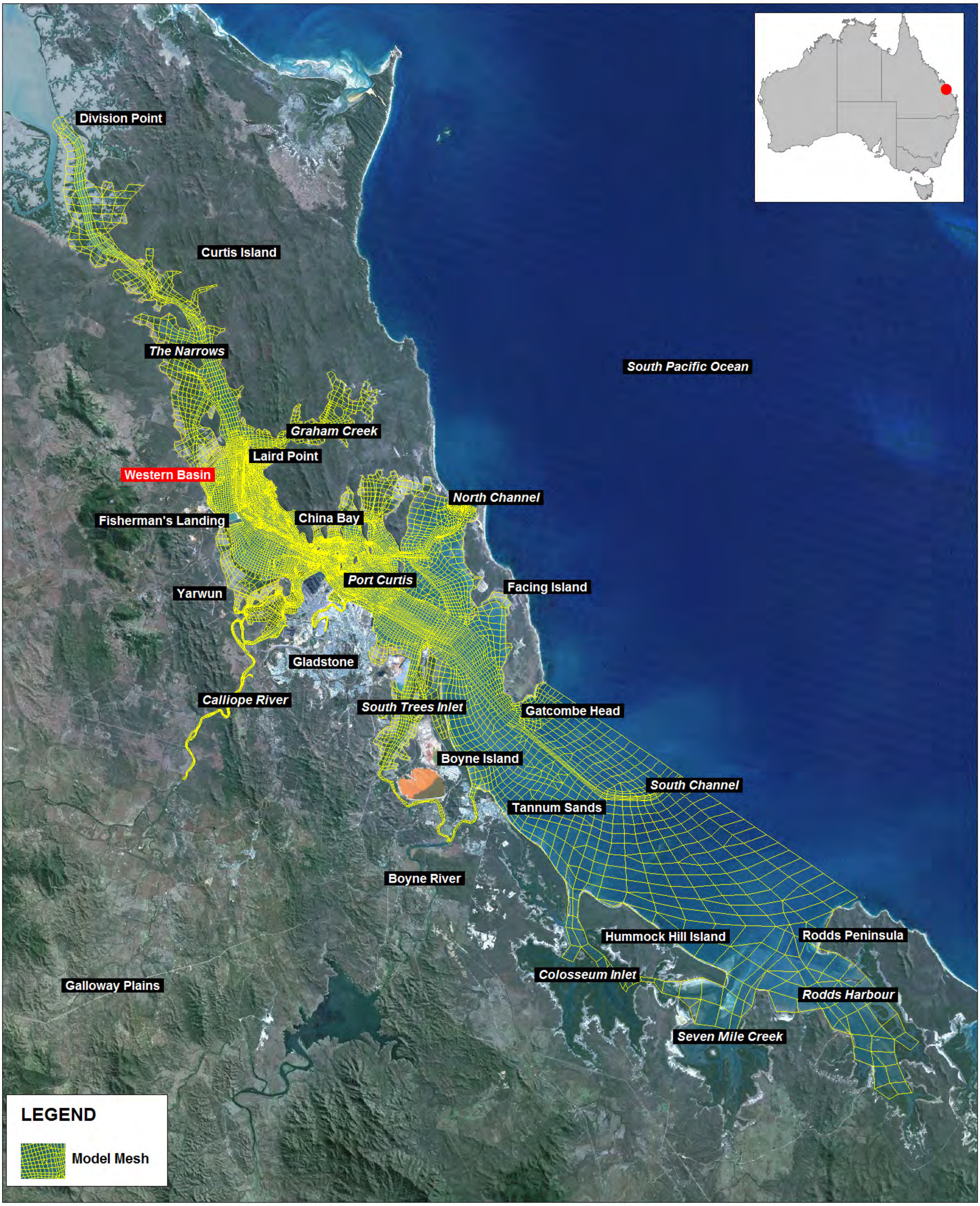
2.2 Methodology

The potential impacts of the proposed works on tidal hydraulics have been assessed with the calibrated and validated TUFLOW-FV model of Port Curtis. The base hydrodynamic model is two dimensional (2D) depth averaged which is appropriate for the high-energy macro-tidal regime and predominantly well-mixed conditions of Port Curtis. Descriptions and further details of the model are provided in the in the separate model validation report (BMT WBM, 2009).

As demonstrated in that report, the model provides excellent reproduction of the base tidal hydraulics of Port Curtis. The model has been subsequently used to simulate the base case and the three developed scenarios as described in Section 1.4.

The model covers the overall tidal network of Port Curtis from the main opening south of Facing Island through the main Port area and extends up through the Narrows to the north as described above and illustrated in Figure 2-1. The model mesh in the vicinity of the Project Area is presented in Figure 2-2 for the base case. This mesh has been configured to allow the developed scenarios to be incorporated by simply changing the bed elevations to represent the proposed dredging and reclamation. This avoids any potential small impacts that may be generated by changes to the mesh. A free-slip model boundary condition was assumed along the outer walls of the reclamation.

The model does not resolve flow features of a much finer scale than the mesh resolution, nor does it resolve turbulent fluctuations of the flow. Nevertheless, model resolution is considered to be appropriate for the determination of bulk hydrodynamic impacts associated with the proposed reclamation and dredging works. Assumptions regarding the "slip" condition at the reclamation walls will have only a minor bearing on predicted impacts, and in this regard a free-slip boundary condition will predict slightly higher velocities near the wall than a no slip or partial slip boundary condition.



Title:
Finite Volume Model Mesh

Figure: 2-1

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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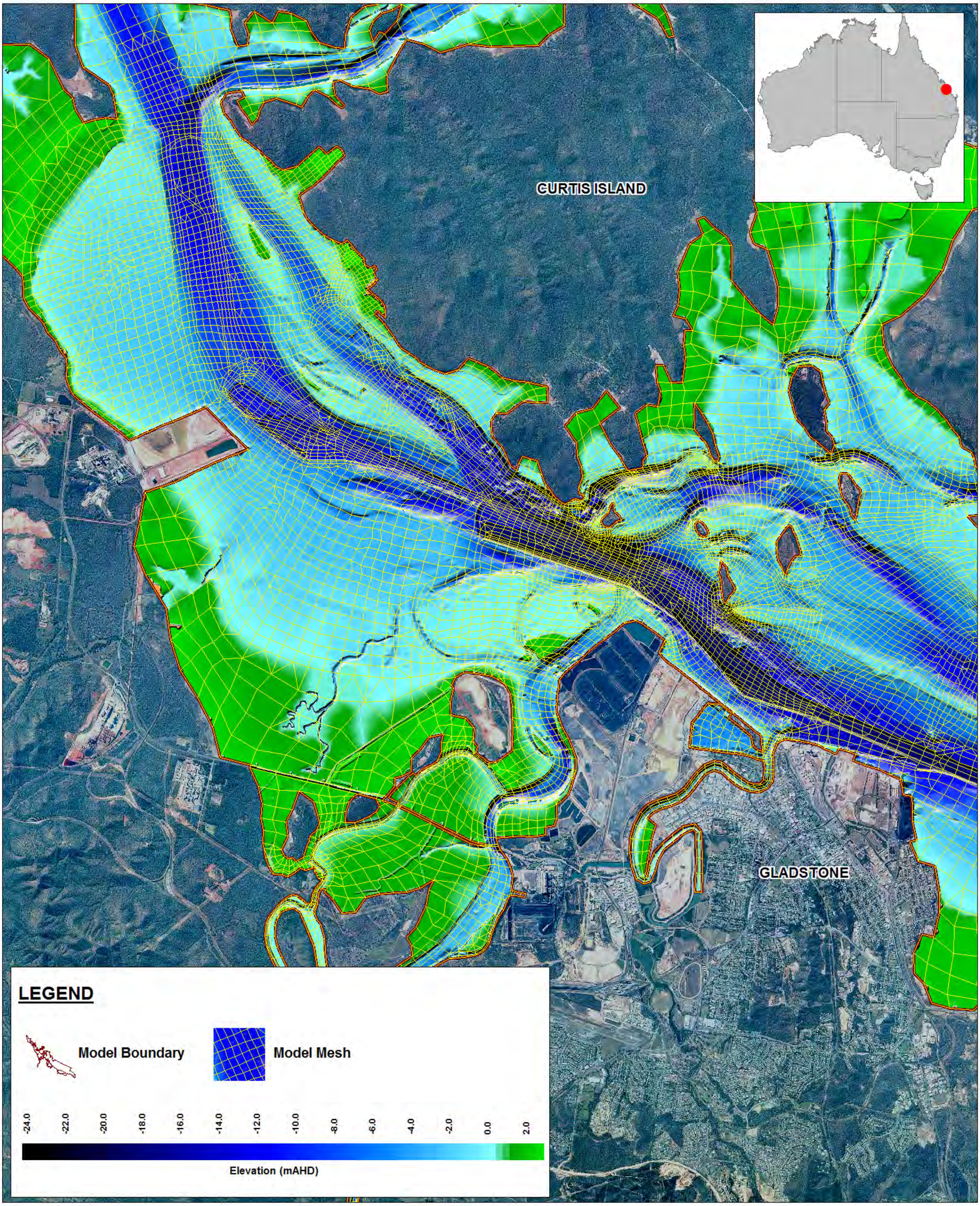

Title:

Model Mesh - Study Area

Figure: 2-2

Rev: A

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All simulations were carried out for a two month period using tidal boundaries derived from data recorded in February and March 2009. The main ocean boundary to the south of Facing Island was based on data directly measured at three locations (both ends and the centre). The opening between Facing and Curtis Island also used directly measured data at that location while the boundary at Division Point in the Narrows was based on relationships to recorded data from South Trees as provided by MSQ. These relationships were determined from a previous period of simultaneous measurements as described in the model validation report (BMT WBM 2009).

The two month simulation period was chosen from a longer six month data set of recorded tides to include large spring tides and small neap tides which are likely to maximise potential impacts. The water levels at Auckland Point for this period are illustrated in Figure 2-3. It can be seen that this period includes large spring tides with ranges up to 4.55m at Auckland Point.

The naturally occurring wind through this period was also applied as forcing to the model. This data was obtained from the Bureau of Meteorology (BOM) for the Gladstone Radar station and is illustrated in Figure 2-4. While fresh water discharges into Port Curtis will occur from time to time, the base hydrodynamics are dominated by the large tidal range. As such, fresh water inflows have not been included. This is not expected to affect the impact assessment.

An analysis of longer term tide and wind data was also carried out to illustrate that the selected two month simulation period was representative for assessment purposes. Figure 2-5 illustrates the high tides and low tides and the associated tidal ranges for one year of data (1/07/2008 – 30/06/2009) recorded at the standard port gauge at Auckland Point (data source MSQ) which includes the selected two month simulation period (4/02/2009 – 3/4/2009) as indicated. The tidal ranges have also been “binned” in 0.25m increments and analysed for percentage occurrence and cumulative percentage occurrence for the whole year and the two month simulation period as presented in Figure 2-6. This illustrates that the two month simulation period includes:

- the largest range of the year;
- the lowest low tide of the year;
- the equal highest high tide of the year;
- generally a higher percentage of larger ranges (> 3.25m) than the 12 month period;
- a higher percentage of smaller ranges (< 1.75m) than the 12 month period; and
- a lower percentage of mid ranges (> 1.75m < 3.25m) than the 12 month period.

Other observations include:

- The smallest range in the simulation period (0.645m) is only slightly more than the smallest of the year (0.499m).
- The September/October period has the smallest ranges.
- The simulation period covers the large variations in ranges.
- The May/June period (as well as others) has less variation in ranges (no extremes) and longer periods with mid size ranges.

Wind records from the BOM have also been analysed to produce a long term wind rose for the Gladstone Radar site as presented in Figure 2-7. A similar wind rose analysis has also been undertaken for the two month simulation period as shown in Figure 2-8. The long term data demonstrates the dominance of winds from east-north-east through to south-south-east. The simulation period includes a similar trend but with a higher percentage of winds from the south-east sector than the long term average. This is a reflection of the time of the year. Previous assessments of the influence of wind including simulations with and without wind have demonstrated that that the overall hydrodynamic and flushing characteristics of the main channel areas of Port Curtis are dominated by the macro-tidal water level variations with wind having only a small influence (Connell Hatch, 2006 and BMT WBM, 2009).

In general, it is considered that the two month simulation period chosen is representative for the purposes of impact assessment. It contains a wide variation in ranges including the largest range of the year and a high percentage of winds from the south-east sector.

Note also that the model is established and run with all bed levels and water levels relative to the fixed Australian Height Datum (AHD). While hydrographic survey data and design dredging depths are usually referenced to Lowest Astronomical Tide (LAT) for navigation purposes, the relationship to AHD varies throughout the port. A fixed horizontal datum is necessary for modelling purposes. The relationships between AHD and LAT at Auckland Point and Fisherman's Landing are provided in Table 2-1.

All scenarios were simulated for the two month period as described above with model results being extracted to assess the impacts of each developed scenario relative to the base case as described below.

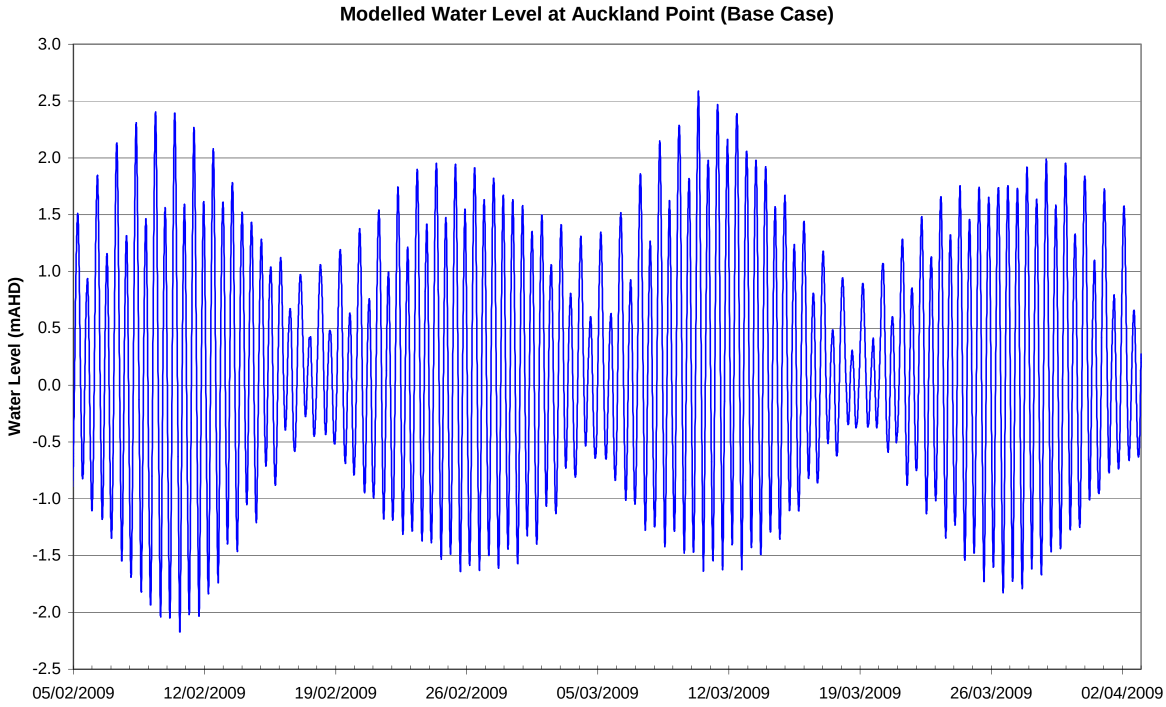


Figure 2-3 Simulation Period Water Levels – Auckland Point

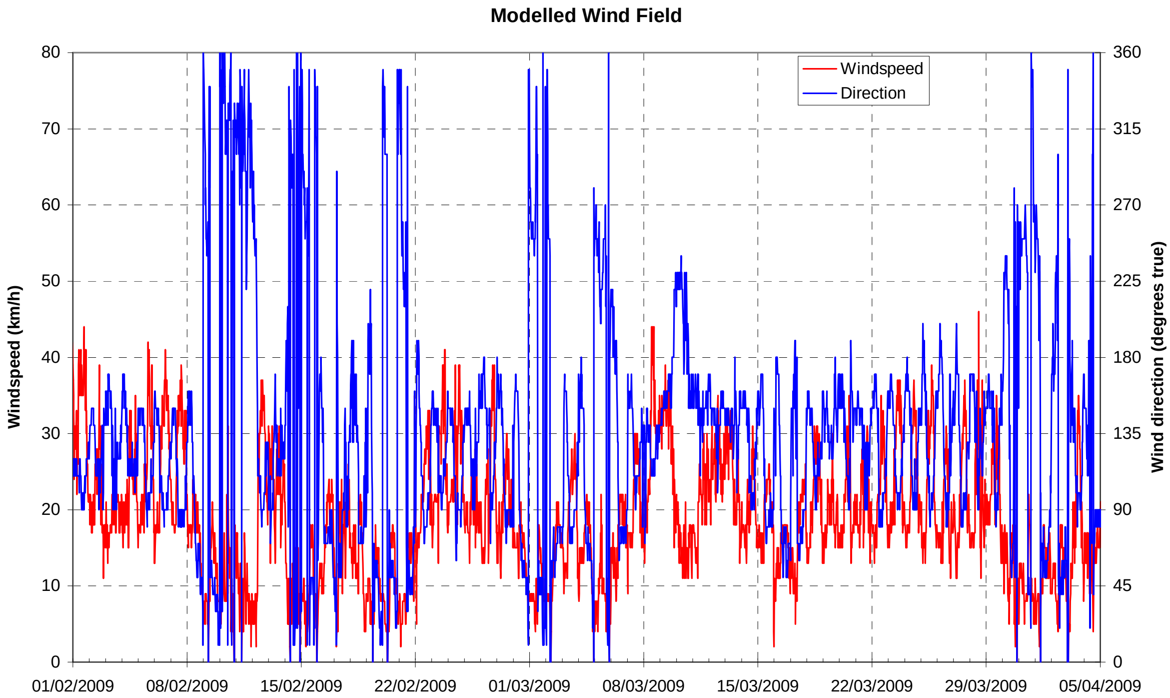


Figure 2-4 Simulation Period Wind Speed and Direction

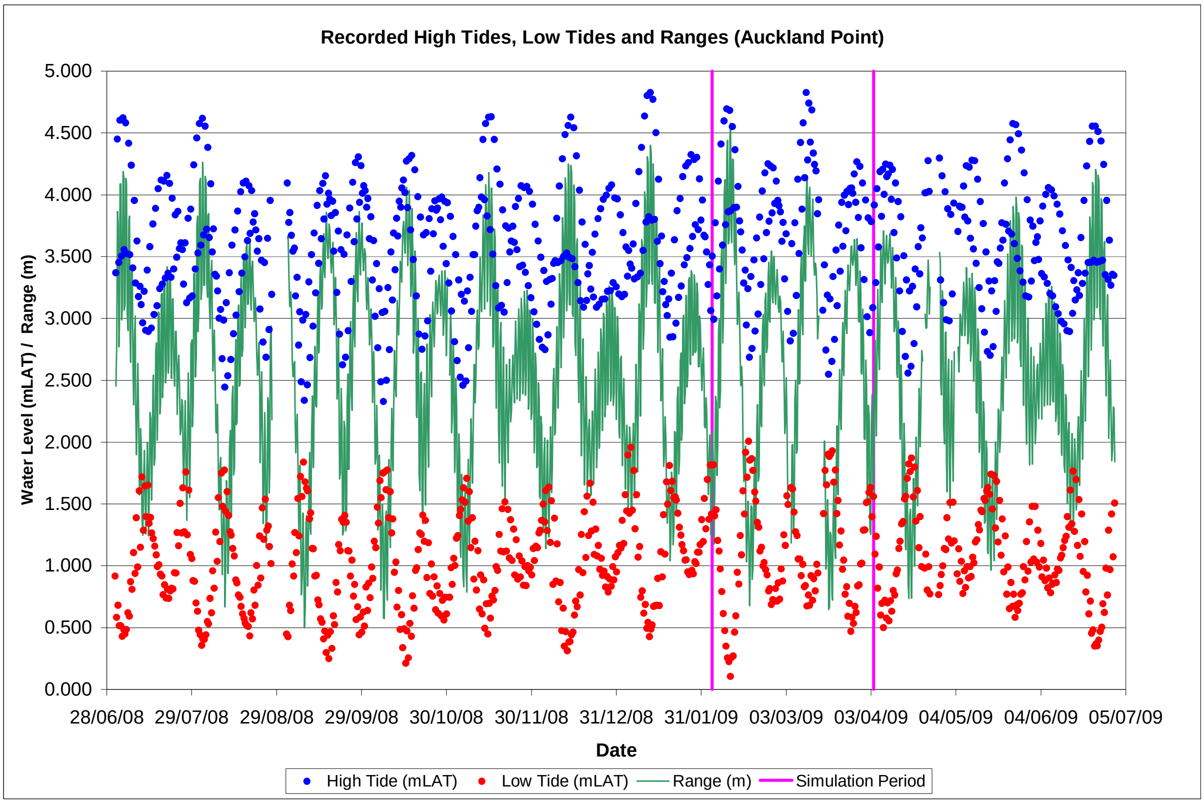


Figure 2-5 Annual Tidal Variations – Auckland Point (Data Source MSQ)

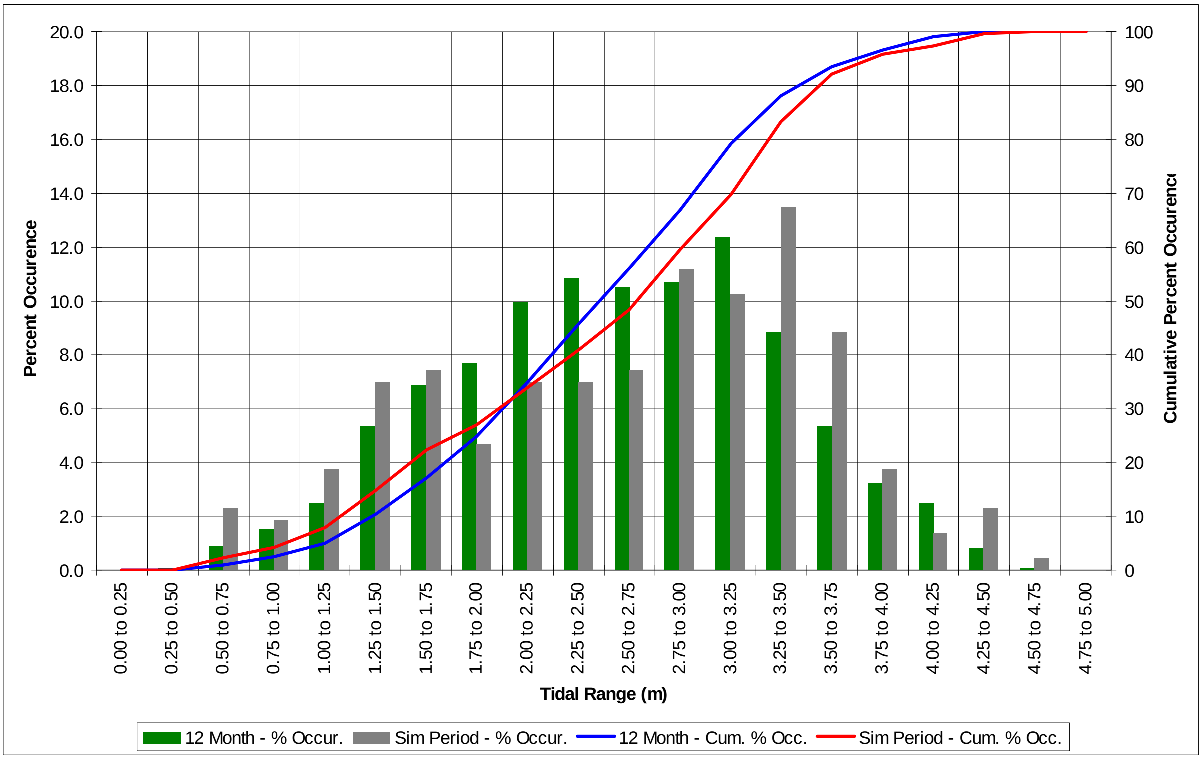


Figure 2-6 Tidal Range Occurrence Comparison - Auckland Point (Data Source MSQ)

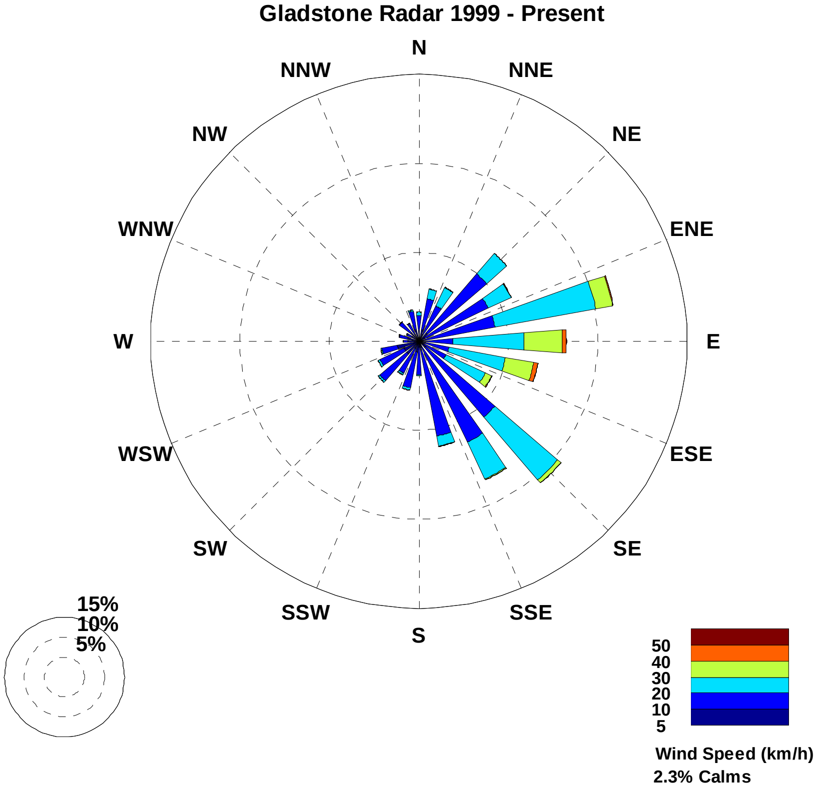


Figure 2-7 Long Term Wind Rose – Gladstone Radar (Source BOM)

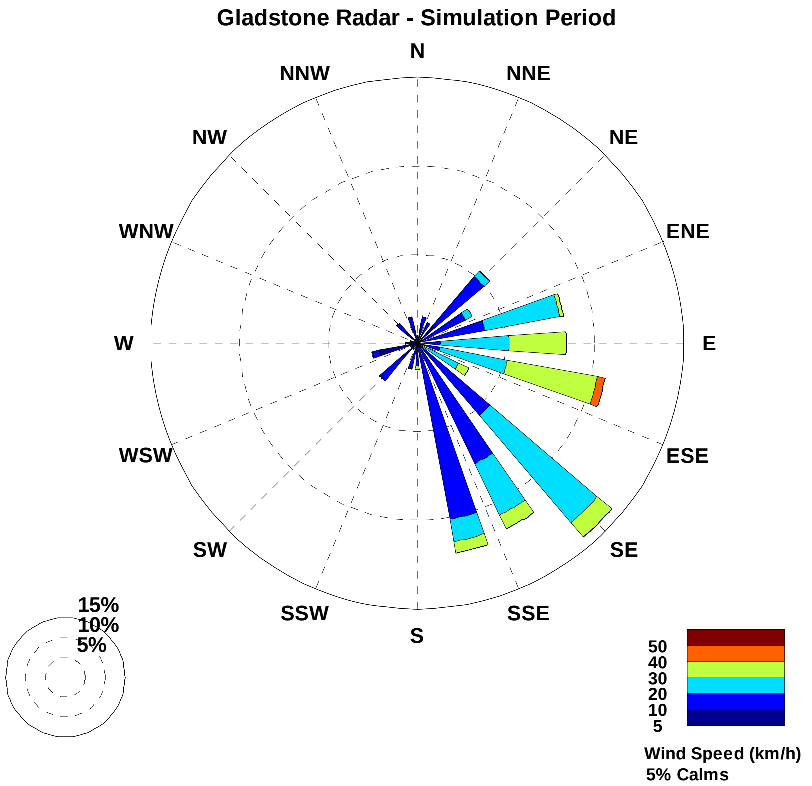


Figure 2-8 Simulation Period Wind Rose - Gladstone Radar (Source BOM)

2.3 Potential Tidal Hydraulic Impacts

2.3.1 Water Level Impacts

Time series of water level for the four simulations were extracted at the 28 locations throughout the model illustrated in Figure 1-7. Plots of the water level time series at each location are presented in APPENDIX A: for 4 days of the largest spring tidal period during the model simulation. The maximum flood tide range at Fisherman's Landing during this period was 4.66m and the maximum ebb tide range was 4.85m (refer Figure 2-9) compared to a mean spring tide range of 3.43m (refer Table 2-1). Each plot illustrates the water levels for the base case and the three design scenarios at that location to allow direct comparison and visual assessment of impacts. Some locations are in shallow areas which dry at low tide as evidenced by flat sections at the bed level which is above the low tide level.

Cumulative exceedance probability plots of water levels for the entire simulation period at each location are presented in APPENDIX B:. These illustrate the probability (or percentage of time) that water levels are exceeded at that location for the base case and each design scenario. For example, a water level with a probability of exceedance of 0.01 means that water level is exceeded for 1% of the total simulation time reflecting a high spring tide level. Similarly, a water level with a probability of exceedance of 0.99 means that water level is exceeded for 99% of the total simulation time reflecting a low spring tide level. Again flat spots at low levels indicates drying of the bed at low tide.

2.3.2 Velocity Impacts

Time series of current speed for the four simulations were also extracted at the 28 locations throughout the model illustrated in Figure 1-7. Plots of the velocity magnitude time series at each location are presented in APPENDIX C: for 4 days of the largest spring tidal period during the model simulation as described above. Each plot illustrates the velocity magnitude for the base case and the three design scenarios at that location to allow direct comparison and visual assessment of impacts. Some locations are in shallow areas which dry at low tide as evidenced by extended periods with zero velocity.

Maps of typical large spring tide velocity patterns are presented below for the base case and the three design scenarios. They illustrate colour shading of velocity magnitude as well as vectors of velocity magnitude and direction at about the time of peak flood and ebb tide velocities in the main channel near Fisherman's Landing. Maps of the typical impacts to peak flood and ebb tide velocity magnitude for each design scenario are also presented below. The impacts are illustrated by colour shading of the difference between the developed scenario velocity magnitude and the base case magnitude at the selected time. The impact plots include the developed case velocity vectors at that time for reference purposes.

The modelled water levels at Fisherman's Landing over the period and the times chosen for mapping and comparison purposes are presented in Figure 2-9. The period represents large spring tides as described above and the times chosen relate to peak velocities in the main channel at that location.

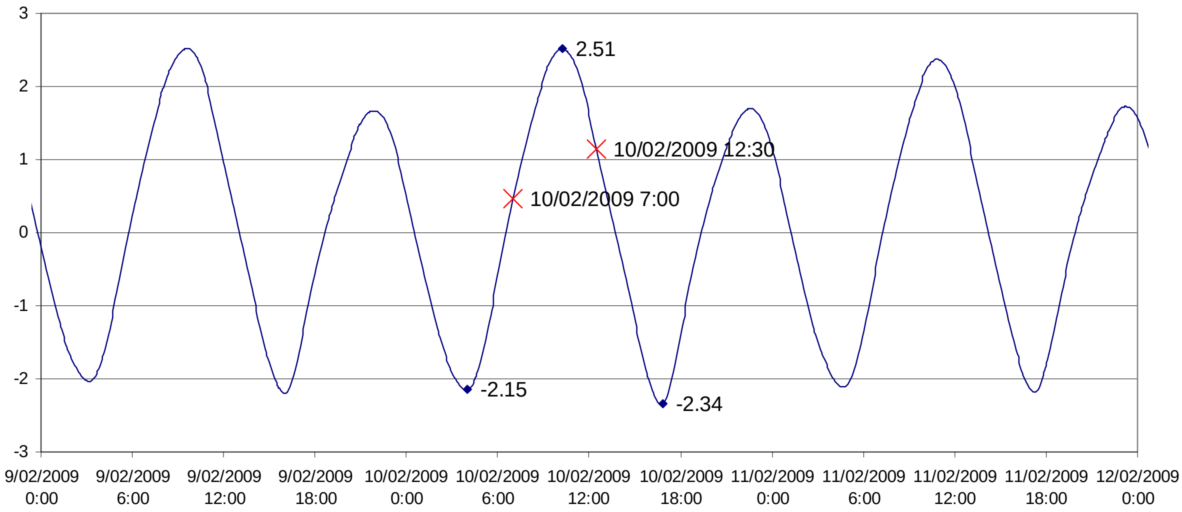


Figure 2-9 Velocity Comparison Times and Water Level at Fisherman's Landing Berth

2.3.3 Flow Impacts

Time series of modelled flow through the four transects shown in Figure 2-10 were extracted from the model and are shown in Figure 2-25 to Figure 2-28. The four-day period again corresponds to the largest spring tidal period during the model simulation as described above. Each plot illustrates the flow for the base case and the three design scenario to allow direct comparison and visual assessment of impacts. The adopted sign convention is positive flows correspond to flood tides and negative flows correspond to ebb tides.

2.4 Discussion of Potential Impacts

The dredging and reclamation works introduce various inter-related, additive and sometimes compensating effects to modify water levels, currents and flows making impact assessment complex. The staging of works also adds to the complexities with some impacts in early stages being mitigated in certain areas by subsequent works while others increase.

The proposed reclamation results in a reduction of up to about 408ha of available tidal storage area at high tide levels (above 2.5m LAT). As the reclamation area extends across the flat inter-tidal zone, the amount of tidal storage area it alienates is less at lower levels being around 320ha at 1.0m LAT, about 250ha at 0.5m LAT and approximately 110ha at 0.0m LAT. The reduction at high tide levels represents about 8% to 9% of the water surface area within the region bounded by the entrance to the Narrows in the north, and the Calliope River entrance to Hamilton Point in the south. At low tide levels, the reduction in water surface area in this region is about 10% to 11% while it is only about 5% at 0.0m LAT. The percentage reductions of the overall inter-tidal water surface area of Port Curtis are much lower.

This loss of inter-tidal storage area contributes to a reduction in tidal prism, which subtly alters the tidal propagation dynamics (i.e. water levels and currents) within the system. Within the above defined region, the reclamation reduces the volume of water above 0.0m LAT by about 9% to 10% at the various intertidal levels. Again much smaller percentage reductions in volume apply to the overall Port Curtis system.

In general, current velocities tend to decrease in dredged areas where the depths are greater following dredging as well as those areas laterally adjacent to the dredging due to the increased flow through the more efficient dredged areas. Increases in velocity are typically evident in adjacent un-dredged areas upstream and downstream of the newly dredged areas where the higher flows exit. The reclamation can also act to modify velocities in the immediately adjacent channel and inter-tidal areas by confining and redirecting the flow.

The water level time series results (APPENDIX A:) indicate that the dredging and reclamation works will have negligible impact (1cm or less) on high tide levels throughout the area. Low tide levels will be affected to varying degrees depending on the location relative to the development and there will be some slight changes to the phasing (timing of the tides). There is a general tendency for spring tide low water levels to be:

- 2 to 5cm higher in the Narrows (ie north of Friend Point);
- 2 to 5cm higher in the northern part of the project area (ie the main channel areas between Fisherman's Landing and Friend Point);
- 1cm lower to 3cm higher in the southern part of the project area (ie the main channel areas between the Calliope River and Fisherman's Landing); and
- 2cm lower to 2cm higher in the Auckland Point area.

The relative impact of the various staged scenarios is much more subtle than the impacts relative to the base case, which indicates that the reclamation and associated loss of inter-tidal storage is a more significant perturbation on the broad-scale hydrodynamics within the project area than the dredging works. Low tide water levels are generally within 1cm of each other for the three scenarios. The impacts are generally slightly more pronounced for Scenario 2 relative to Scenario 1 and likewise for Scenario 3 relative to Scenario 2.

The water level exceedance probability plots (APPENDIX B:) indicate the negligible changes to high tide levels and the time of inundation of most levels above about -1.2m AHD (approx 1.2m LAT) are essentially unchanged. The influence of the slight increase in low tide levels is that the lowest tide will be slightly higher and some of the lower inter-tidal areas will be dry for a slightly smaller percentage of time (inundated for a slightly greater percentage of time). For example at "WBM 01" in the Narrows, the level of -2.0m AHD was dry for approximately 0.80% (or about 11.1 hours) of the 2 month simulation period in the base case. For the three developed cases, this reduces to approximately 0.67% (or about 9.3 hours) of the period.

Locations on the inter-tidal flats adjacent to the extended reclamation are impacted more than those in the channel due to experiencing significantly altered flow pathways. This can be seen in the water level time series and exceedance probability plots for WBM 04, 18, 19, 05 and 20 where the ebb tide fall of the tide is attenuated by the reduced flow area draining the remaining inter-tidal flats in the Western Basin. The model predicts a shallow depth (<0.3m) of water pondage at WBM 20 and WBM 05 due to a high spot in the narrow drainage path along the western side of the reclamation. This may be a consequence of limits in the accuracy and extent of the survey data combined with the model resolution in this area.

With respect to velocities, the predicted impacts vary depending on location relative to the proposed works as well as time and the magnitude of the tidal range as illustrated in the time series plots in APPENDIX C:. They can be summarised with reference to the spatial difference plots at about the time of peak flood and ebb spring tide currents at Fisherman's Landing as discussed below.

Scenario 1 Velocity Impacts - (refer Figure 2-14 for peak flood tide differences and Figure 2-16 for peak ebb tide differences). The main impacts can be summarised as follows:

- Both flood and ebb tide velocities typically decrease in the dredged areas. Decreases of up to 0.45m/s (flood) and 0.6m/s (ebb) are predicted across large areas of the BG Swing Basin and up to 0.4m/s (flood) to 0.5m/s (ebb) on the eastern side of the Santos Swing Basin due to the large increases in depth. Reductions of up to 0.4m/s (flood) to 0.45m/s (ebb) are predicted at the upstream end of the Fisherman's Landing Swing Basin.
- Velocities are predicted to reduce by about 0.2m/s in Targinie Channel and laterally adjacent areas, 0.15m/s (flood) and <0.05m/s (ebb) in the WICT area and 0.05m/s to 0.1m/s in the Clinton Channel area. Slight reductions (<0.1m/s) are also predicted in the area to the east of Hamilton Point although small localised zones of increases (<0.1m/s) occur around Hamilton Point on the ebb tide.
- Decreases in velocity are predicted along the eastern wall of the reclamation by up to 0.2m/s (flood) and 0.45m/s (ebb) as a result of changes to flow patterns to/from the adjacent inter-tidal areas.
- Both ebb and flood tide velocities are generally increased in the channels upstream of the dredged areas (between Fisherman's Landing and the entrance to the Narrows). In the "Curtis" Channel immediately upstream of the BG Swing Basin, increases of up to 0.3m/s are predicted while adjacent to North Passage Island the increases are around 0.1 to 0.15m/s. In the main channel to the west of North Passage Island, ebb tide velocities are predicted to increase by up to 0.25m/s.
- Velocities are locally increased at a few other locations including the north-eastern corner of the reclamation by up to 0.3m/s (ebb) and along the Passage Island shoals by up to 0.3m/s (flood) upstream of the Santos Swing Basin as a result of changes in flow patterns. Ebb tide velocities also tended to increase in the shallow areas of the Curtis Island frontage onto the project area.

Scenario 2 Velocity Impacts - (refer Figure 2-18 for peak flood tide differences and Figure 2-20 for peak ebb tide differences). The incremental increase in dredged footprint associated with Scenario 2 increases the extent of velocity-reduction impacts and decreases the extent of velocity-increase impacts (relative to Scenario 1). The main impacts can be summarised as follows:

- The decreases in the BG Swing Basin are predicted to be up to 0.5m/s (flood) and 0.6m/s (ebb). In the Santos Swing Basin, decreases are predicted to be up to 0.4m/s (flood) to 0.55m/s (ebb). These are reductions are slightly greater than Scenario 1 due to the decreased proportion flow through the "Curtis" Channel as a result of the increased dredging in Targinie Channel and the Fisherman's Landing Swing Basin. Reductions of up to 0.45m/s (flood) to 0.55m/s (ebb) are predicted at the upstream end of the Fisherman's Landing Swing Basin and laterally adjacent areas due to the increased dredging there.
- Velocity decreases downstream of the main swing basin areas are predicted to be similar to Scenario 1 reducing by about 0.2m/s in Targinie Channel and laterally adjacent areas, 0.15m/s

(flood) and <0.05m/s (ebb) in the WICT area and 0.05m/s to 0.1m/s in the Clinton Channel area. Slight reductions (<0.1m/s) are also predicted in the area to the east of Hamilton Point although the small localised zone of increase around Hamilton Point is up to 0.2m/s on the ebb tide.

- The decreases in velocity predicted along the eastern wall of the reclamation are up to 0.5m/s (ebb) while the predicted decreases in the Laird Point Swing Basin are only up to 0.1m/s due to the limited depth changes there.
- In the “Curtis” Channel immediately upstream of the BG Swing Basin, increases of up to 0.2m/s (flood and ebb) are predicted while adjacent to North Passage Island the increases are around 0.1m/s (ebb). Adjacent to the dredged channel leading to the Laird Point Swing Basin, velocities are predicted to increase by up to 0.1m/s (flood) and 0.3m/s (ebb). Ebb tide velocities upstream of the Laird Point Swing Basin are predicted to increase by 0.1m/s.
- Velocities are locally increased at a few other locations including the north-eastern corner of the reclamation by up to 0.3m/s (ebb) and along the Passage Island shoals by up to 0.3m/s (flood) upstream of the Santos Swing Basin as a result of changes in flow patterns. Ebb tide velocities also tended to increase in the shallow areas of the Curtis Island frontage onto the project area.

Scenario 3 Velocity Impacts - (refer Figure 2-22 for peak flood tide differences and Figure 2-24 for peak ebb tide differences). Again, the incremental increase in dredged footprint associated with Scenario 3 increases the extent of velocity-reduction impacts (relative to Scenario 1) in a similar manner to Scenario 2. While there are some decreases in the extent of velocity-increase impacts (relative to Scenario 1) again, there are also additional areas of velocity-increase impacts associated with the additional dredging. The main impacts can be summarised as follows:

- The decreases in the BG Swing Basin are predicted to be up to 0.5m/s (flood) and 0.6m/s (ebb). In the Santos Swing Basin, decreases are predicted to be up to 0.4m/s (flood) to 0.45m/s (ebb). These are reductions are similar to Scenario 2 for the flood tide. The ebb tide decreases are slightly less due to the increased proportion flow through the “Curtis” Channel on the ebb tide as a result of the increased dredging between the Swing Basins and around Hamilton Point. Reductions of up to 0.45m/s (flood and ebb) are predicted at the upstream end of the Fisherman’s Landing Swing Basin and laterally adjacent areas.
- Velocity decreases downstream of the main swing basin areas are predicted to be similar to Scenarios 1 and 2 reducing by about 0.2m/s in Targinie Channel and laterally adjacent areas, 0.15m/s (flood) and <0.05m/s (ebb) in the WICT area and 0.05m/s to 0.1m/s in the Clinton Channel area. Slight reductions (<0.1m/s) are also predicted in the area to the east of Hamilton Point on the flood tide although the small localised zone of increase around Hamilton Point is up to 0.7m/s on the ebb tide with a general increase of up to 0.1m/s extending to the Boatshed Point area as a result of the dredging around Hamilton Point.
- The decreases in velocity predicted along the eastern wall of the reclamation are up to 0.6m/s (ebb) while the predicted decreases in the Laird Point Swing Basin and the channel leading to it are up to 0.1m/s (flood).
- In the “Curtis” channel immediately upstream of the BG Swing Basin, increases of up to 0.3m/s (flood) and 0.25m/s (ebb) are predicted while there are essentially no predicted increases adjacent to North Passage Island. Adjacent to the dredged channel leading to the Laird Point Swing Basin, velocities are predicted to increase by < 0.05m/s (flood) and 0.2m/s (ebb). Ebb tide velocities immediately upstream of the Laird Point Swing Basin are predicted to increase by

0.1m/s with the ultimate dredging configuration associated with Scenario 3 causing the footprint of increased ebb tide velocities to extend further north into the Narrows.

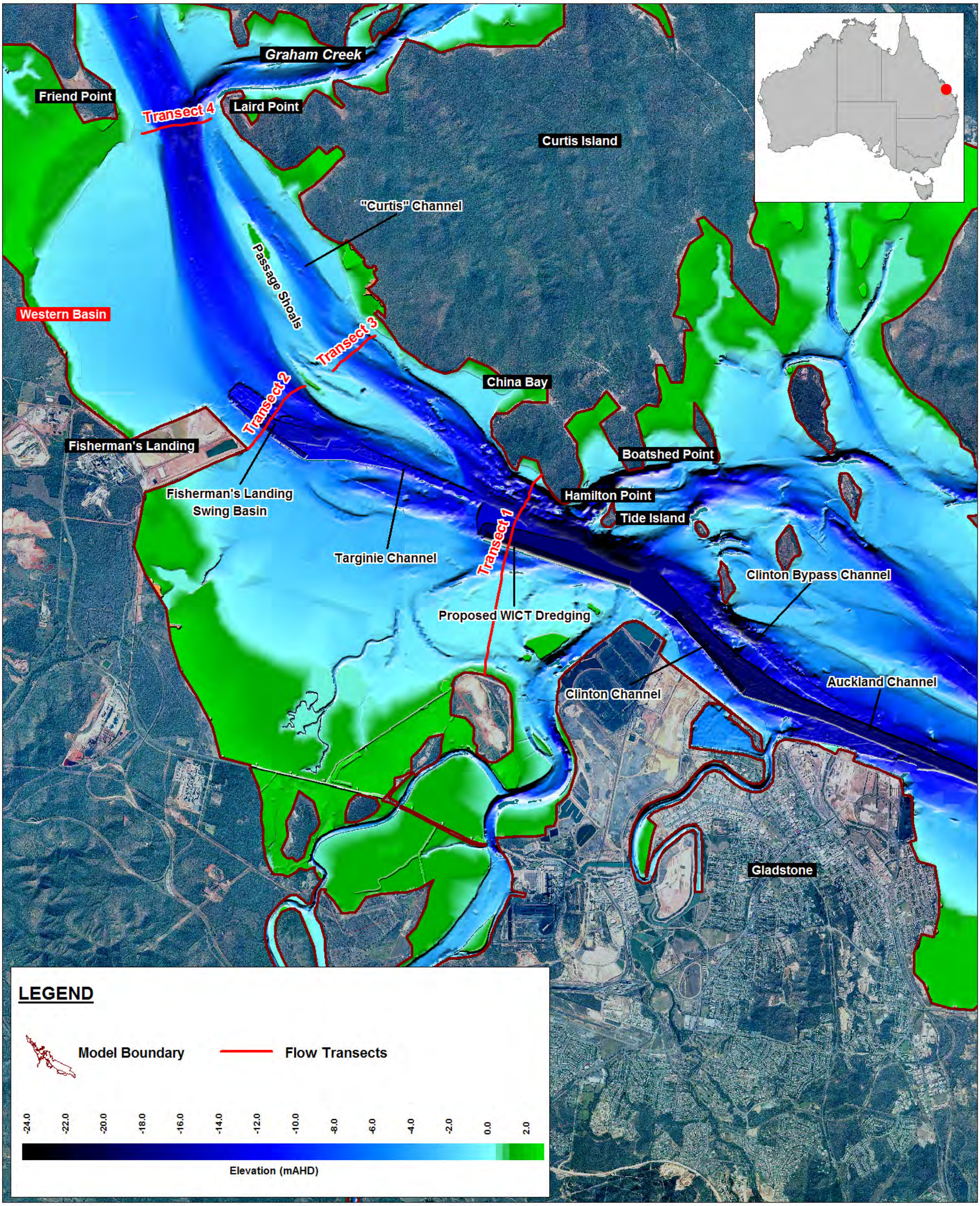
- Velocities are locally increased at a few other locations including the north-eastern corner of the reclamation by up to 0.25m/s (ebb) and along the Passage Island shoals by up to 0.3m/s (flood) upstream of the Santos Swing Basin as a result of changes in flow patterns. Ebb tide velocities also tended to increase in the shallow areas of the Curtis Island frontage onto the project area. Ebb tide velocity increases at Hamilton Point are accentuated under Scenario 3 and extend through to Boatshed Point.

The model integrated flow results (Figure 2-25 to Figure 2-28) reflect the changes in velocities outlined above. They indicate a slight reduction (about 5%) in the peak flow entering and leaving the project area at the southern (downstream) end between Mud Island and Hamilton Point (Transect 1) linked primarily to the loss of tidal storage volume associated with the reclamation.

Negligible changes in flood tide flows (about 1%) entering the Narrows to the north (upstream) of the project area (Transect 4) are predicted while some slight increases in the peak ebb tide flows (up to about 4% for Scenario 3) leaving the Narrows are predicted in line with the slight increases in ebb tide velocities in this area.

Targinie Channel (Transect 2) ebb and flood tide flows are reduced due to the loss of tidal storage volume associated with the reclamation. Peak flows are most significantly reduced in Scenario 1 (by about 16% flood and 13% ebb) before increasing slightly again (back to about a 10% reduction) with the additional dredging north of Fisherman’s Landing undertaken for Scenario 2 and Scenario 3.

“Curtis” Channel (Transect 3) flows are increased relative to the Base Case in all of the developed scenarios due to the dredging of in this channel. Scenario 1 peak flood tide flows increase by about 27% and are higher relative to Scenario 2 and Scenario 3 (which have increases of around 11%) due to the additional dredging of the western channel associated with the latter stages of development. Peak ebb tide flows for Scenario 1 also increase by about 27% and are only slightly smaller (with an increase of about 25%) for Scenario 2. The additional dredging between the Swing Basins and around Hamilton Point in Scenario 3 results in a further increase in peak ebb tide flows (total up to 29%) through this transect relative to the Base Case.



Title:
Flow Transect Locations

Figure: 2-10

Rev: A

N

0 1.25 2.5km
Approx. Scale

BMT WBM
www.wbmpl.com.au

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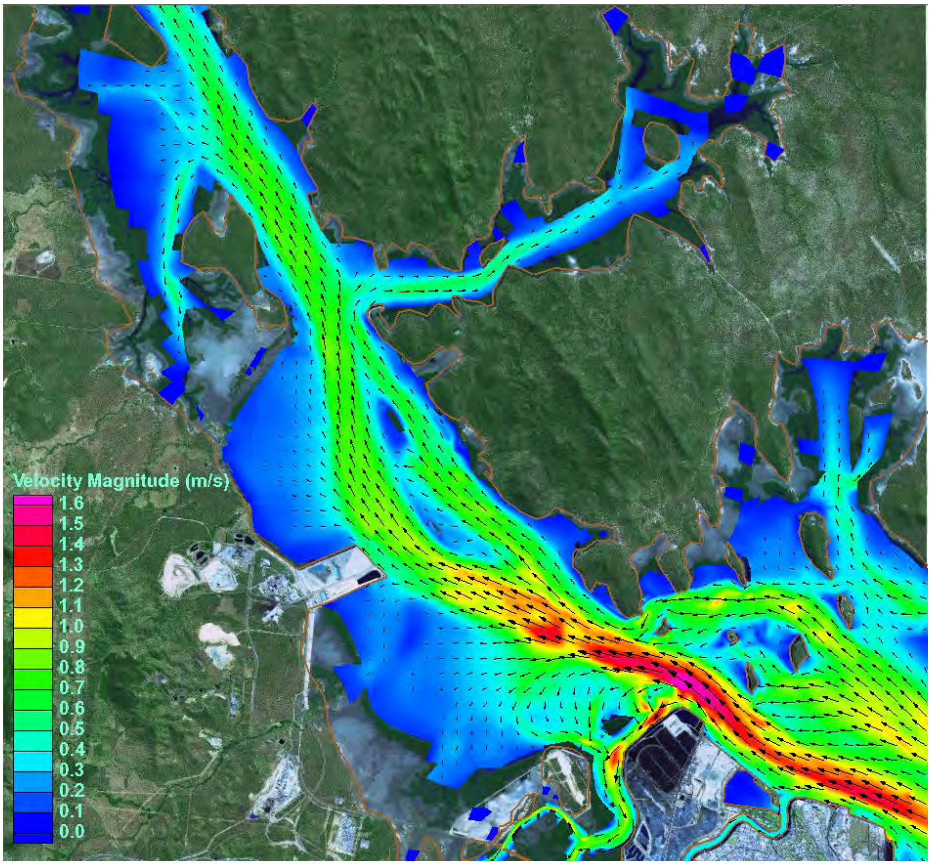


Figure 2-11 Base case peak flood tide velocities

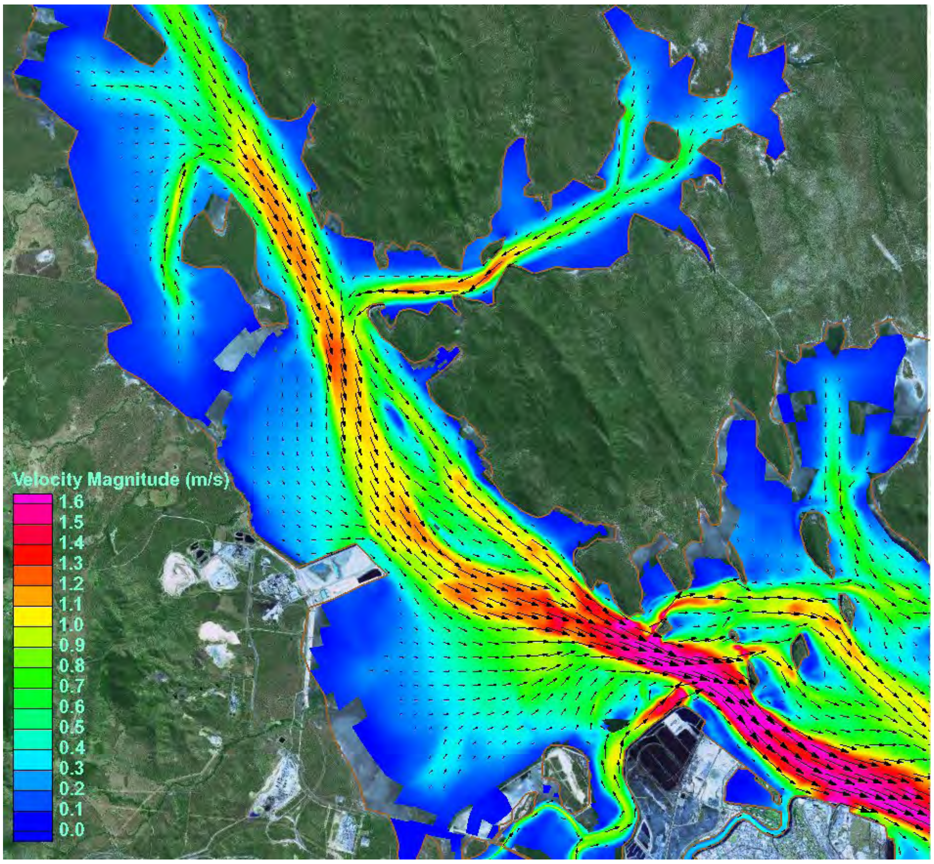


Figure 2-12 Base case peak ebb tide velocities

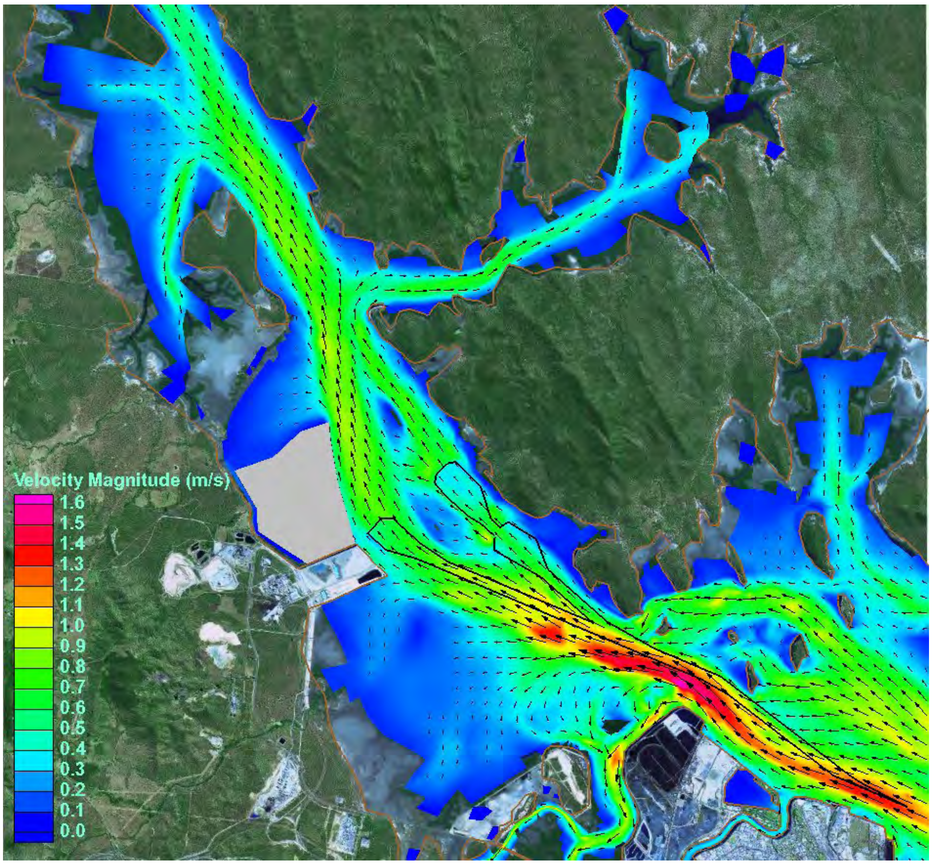


Figure 2-13 Scenario 1 peak flood tide velocities

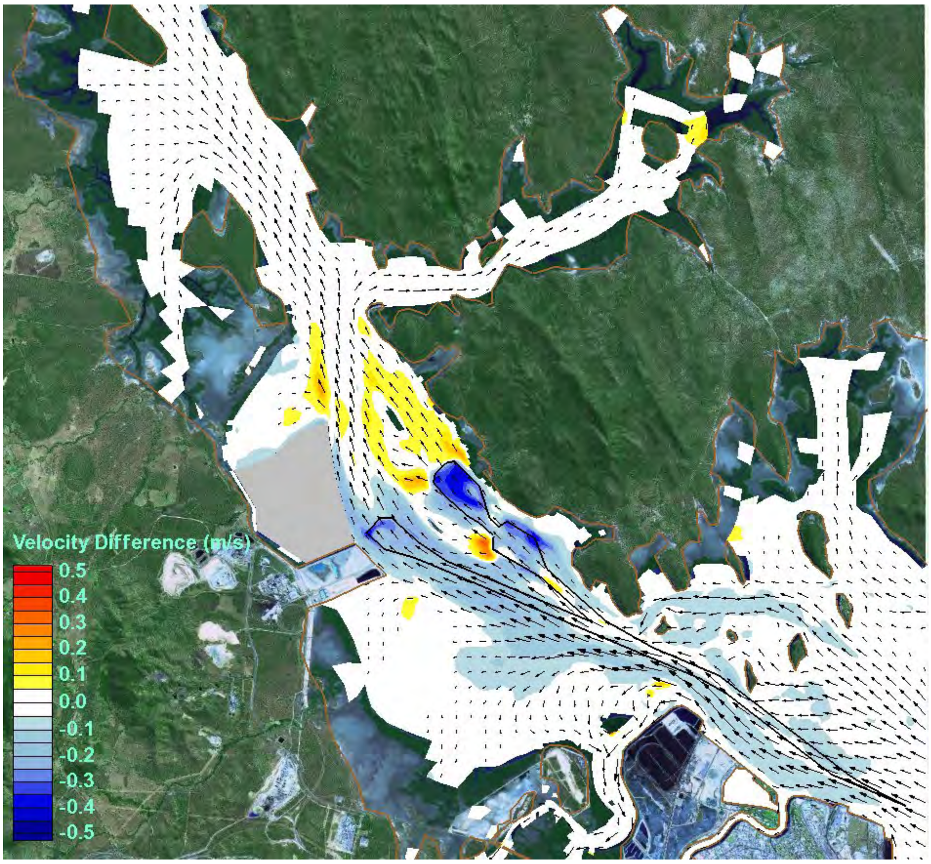


Figure 2-14 Scenario 1 peak flood tide velocity differences

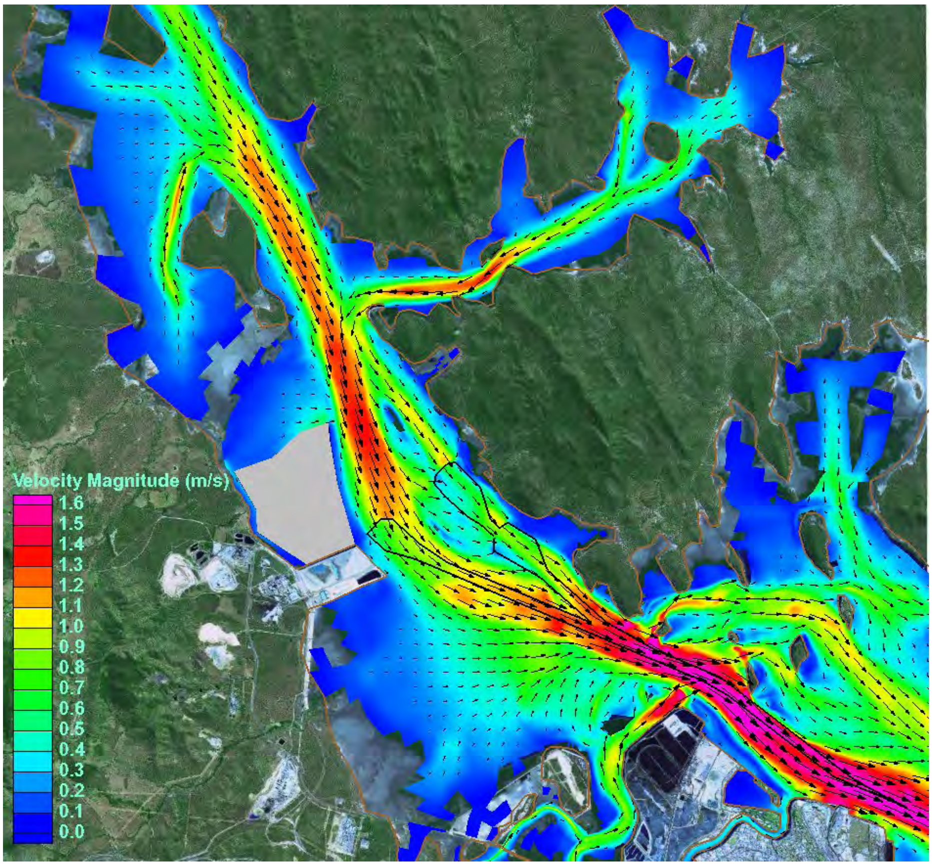


Figure 2-15 Scenario 1 peak ebb tide velocities

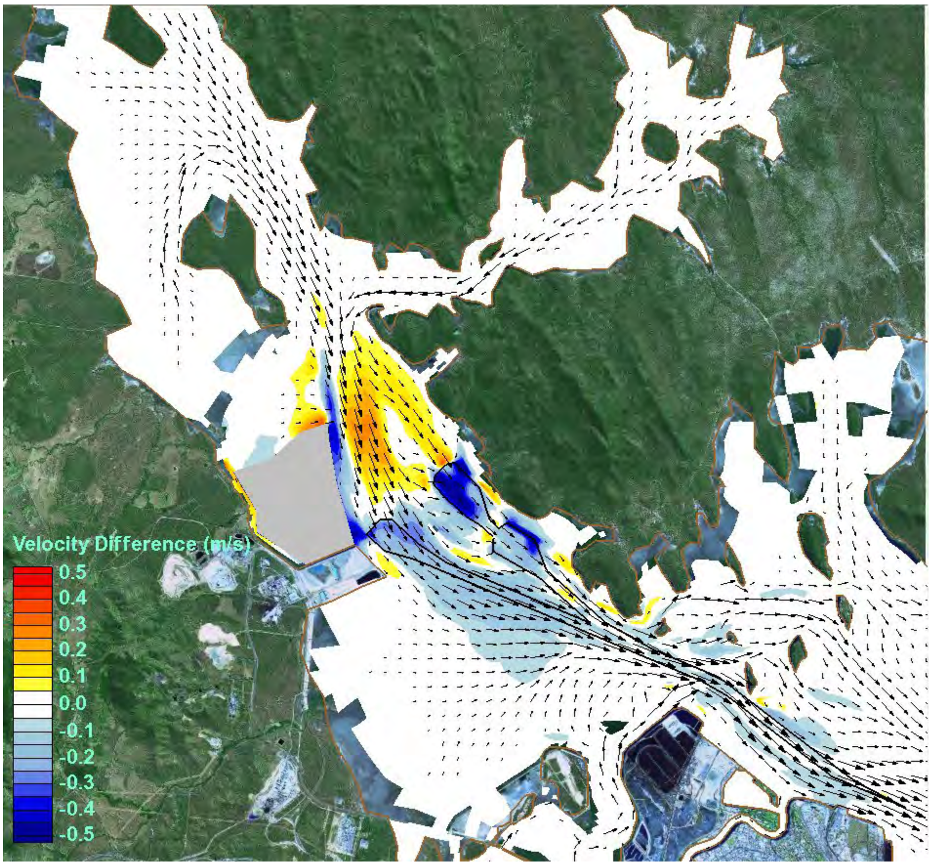


Figure 2-16 Scenario 1 peak ebb tide velocity differences

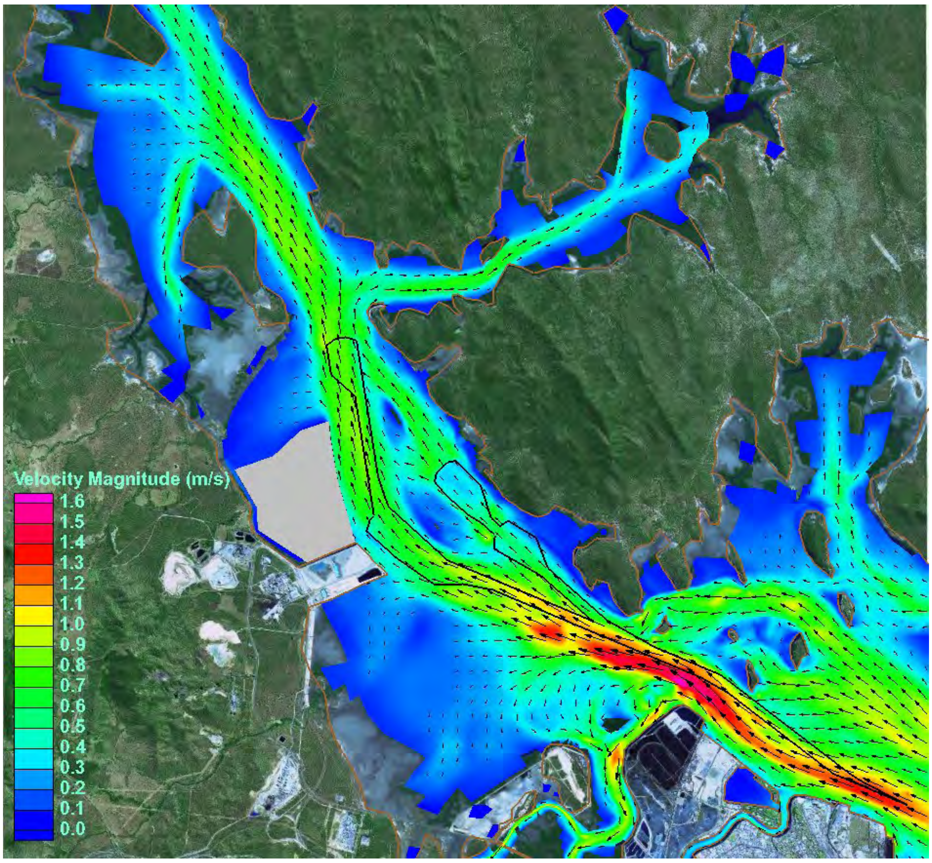


Figure 2-17 Scenario 2 peak flood tide velocities

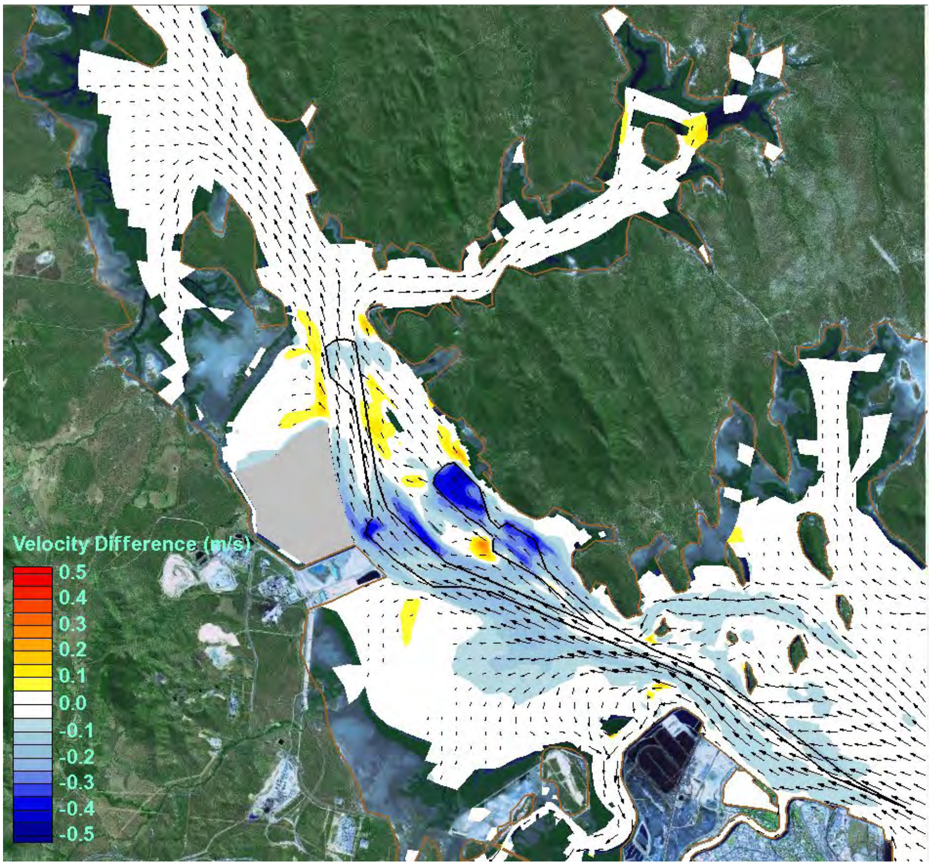


Figure 2-18 Scenario 2 peak flood tide velocity differences

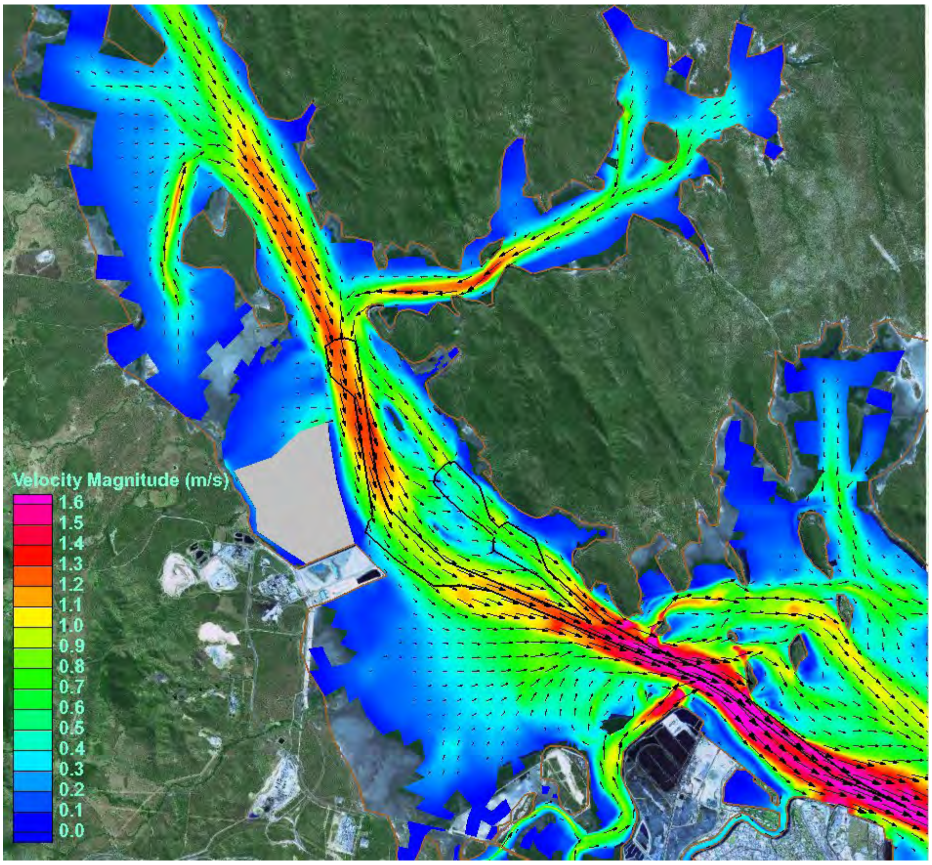


Figure 2-19 Scenario 2 peak ebb tide velocities

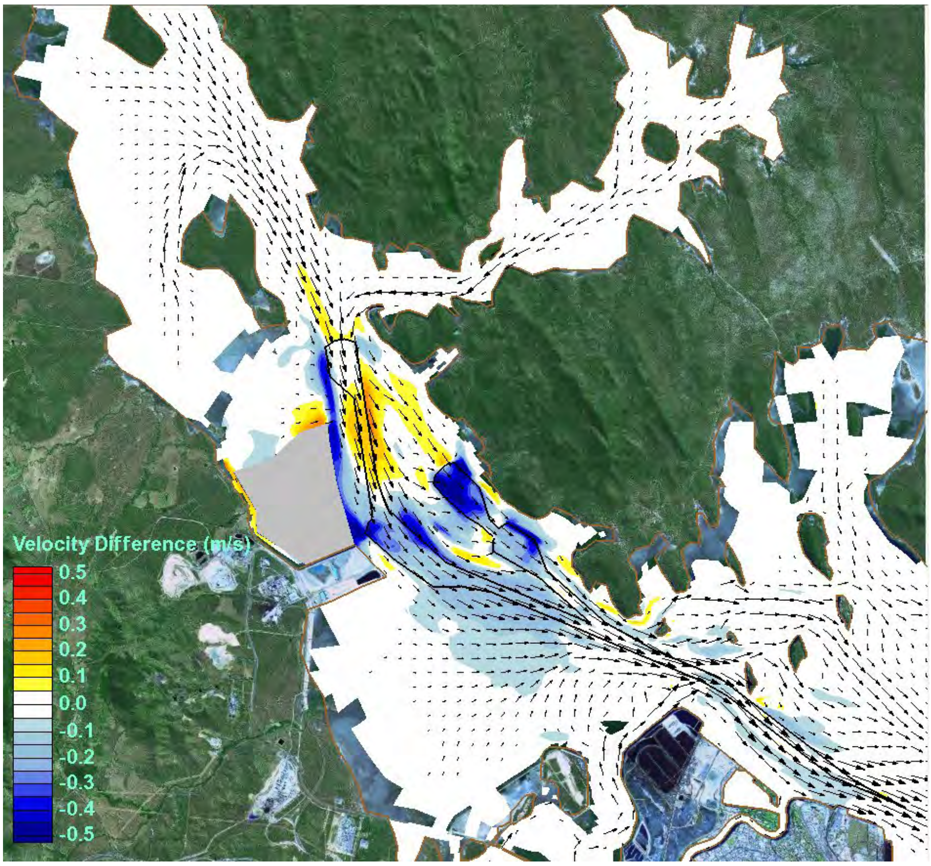


Figure 2-20 Scenario 2 peak ebb tide velocity differences

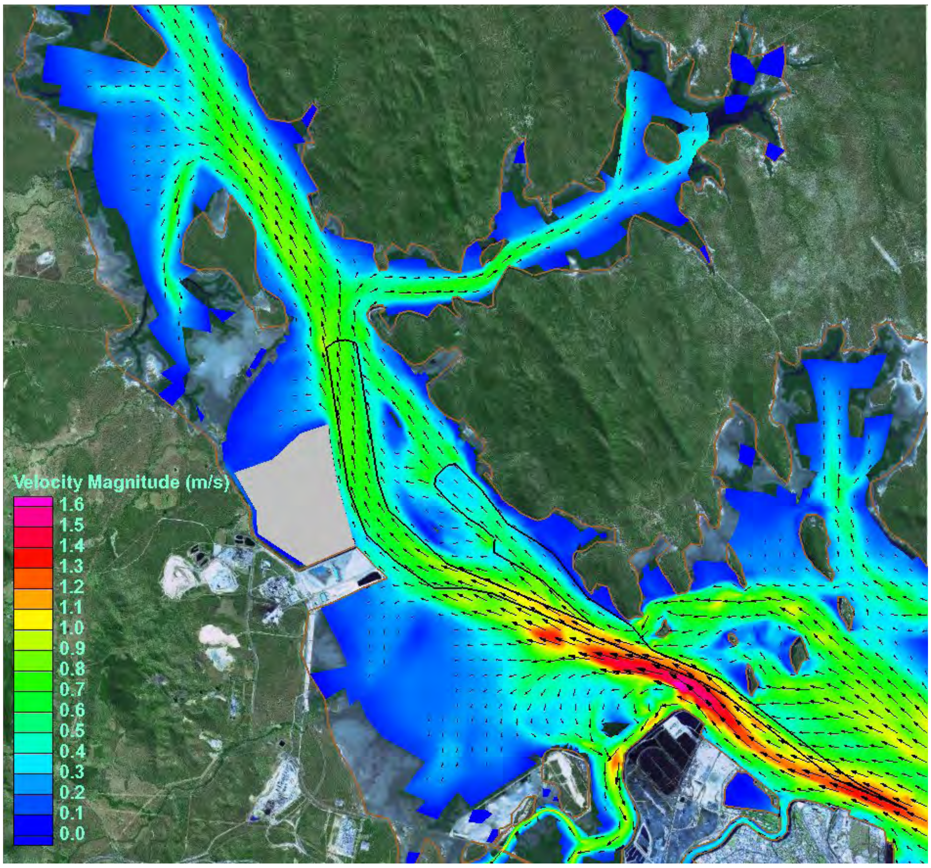


Figure 2-21 Scenario 3 peak flood tide velocities

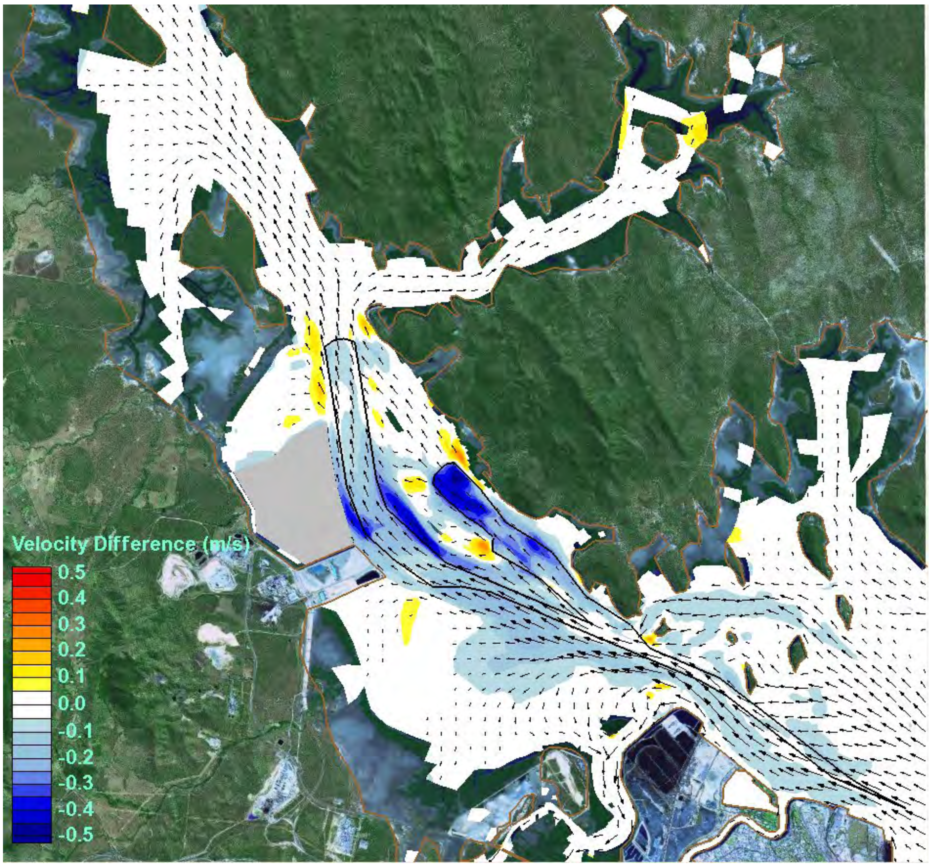


Figure 2-22 Scenario 3 peak flood tide velocity differences

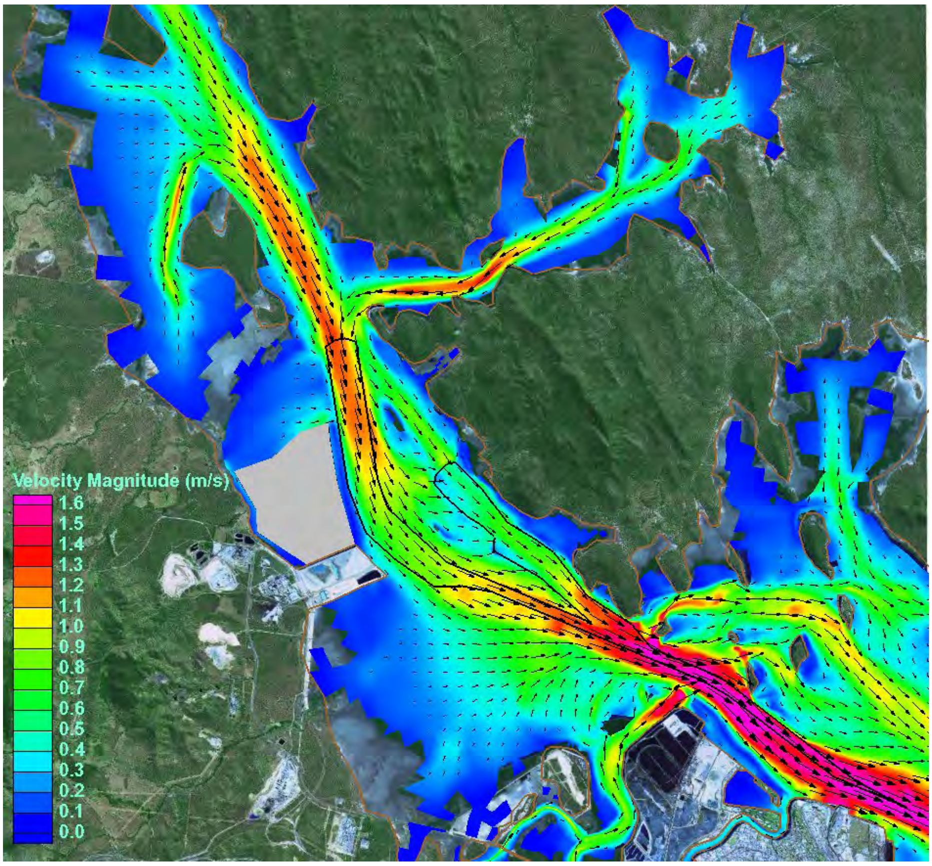


Figure 2-23 Scenario 3 peak ebb tide velocities

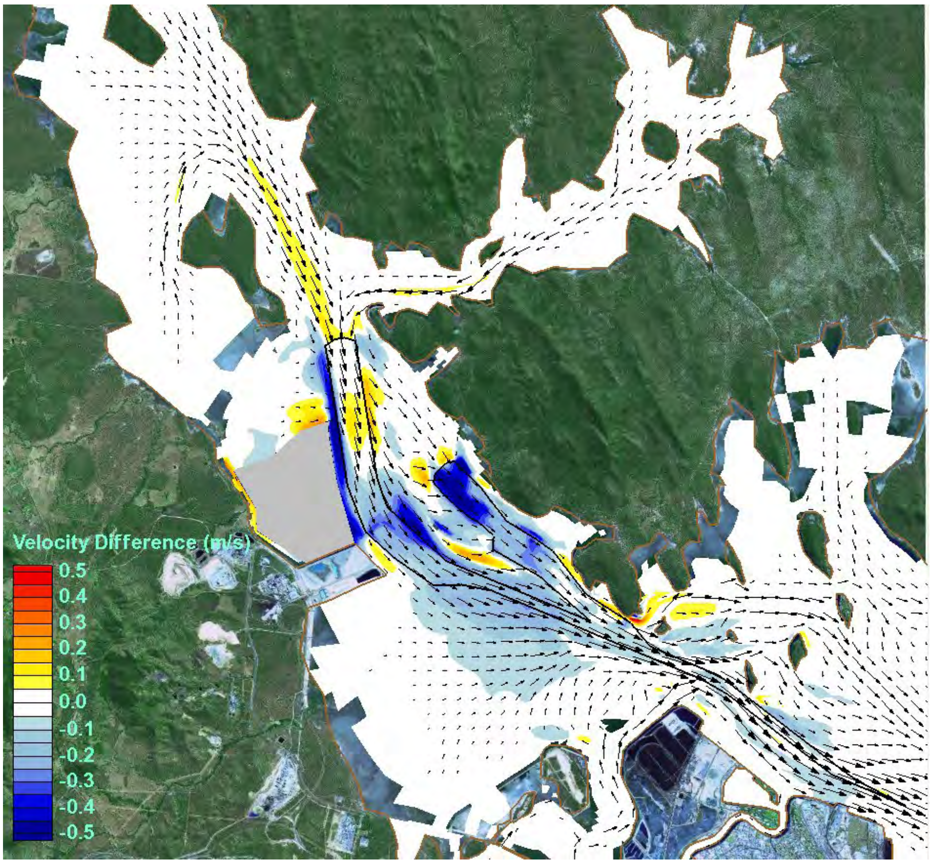


Figure 2-24 Scenario 3 peak ebb tide velocity differences

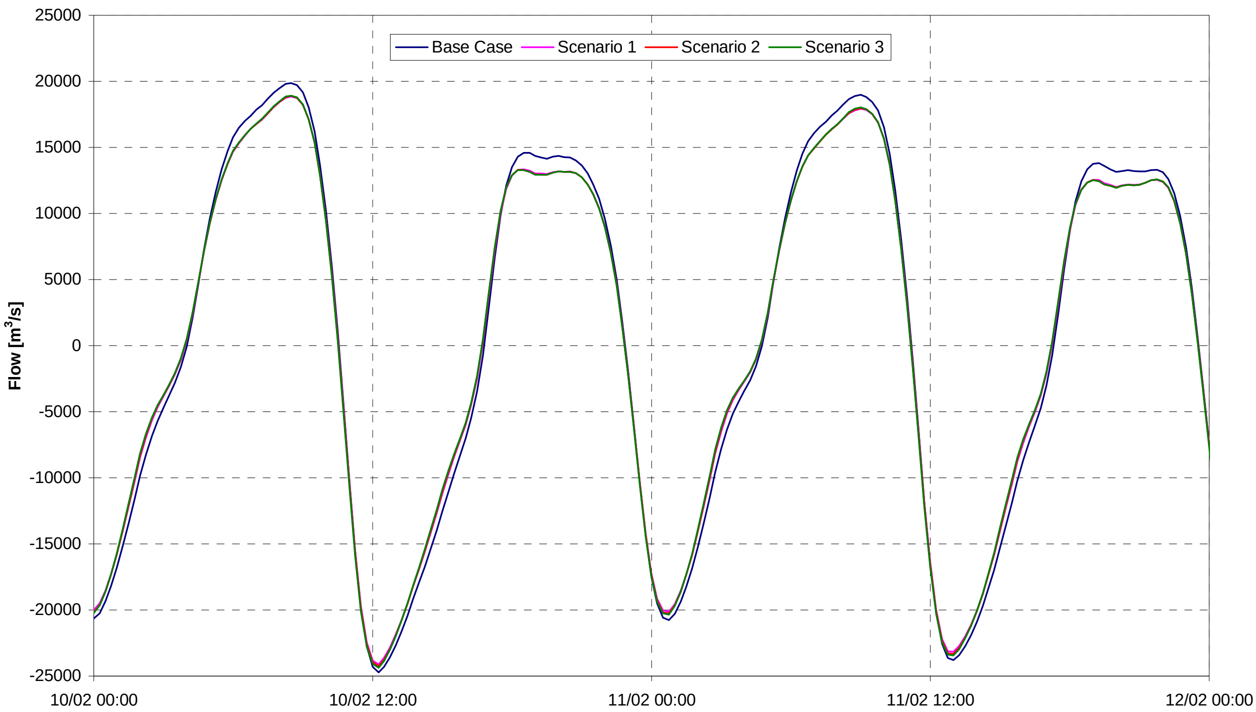


Figure 2-25 Transect 1 (Hamilton Pt to Mud Is) Flow Time Series.

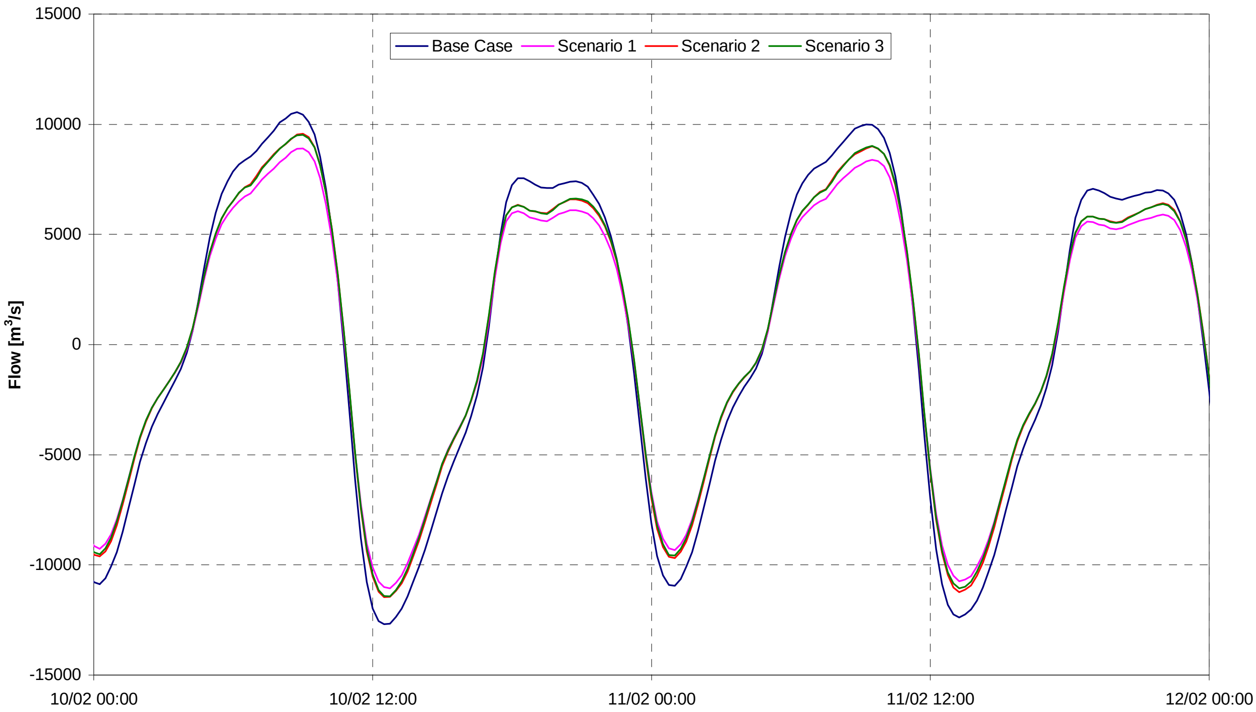


Figure 2-26 Transect 2 (Targinie Channel) Flow Time Series.

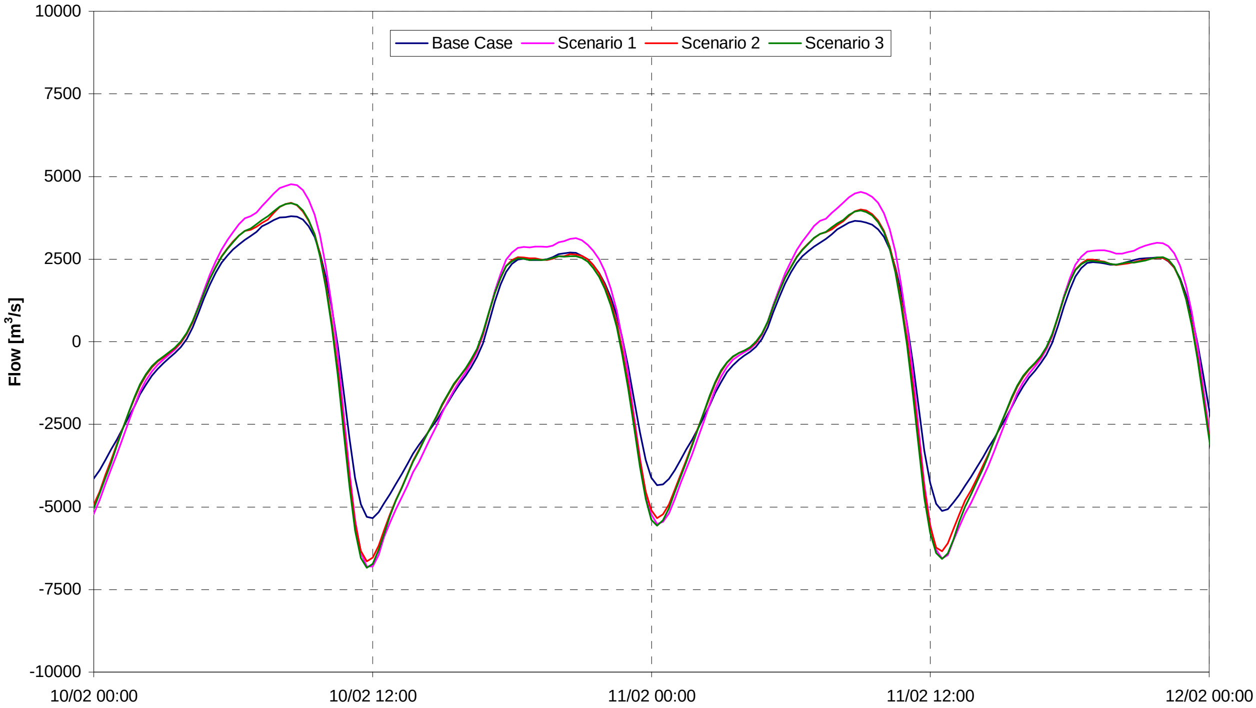


Figure 2-27 Transect 3 ("Curtis" Channel) Flow Time Series.

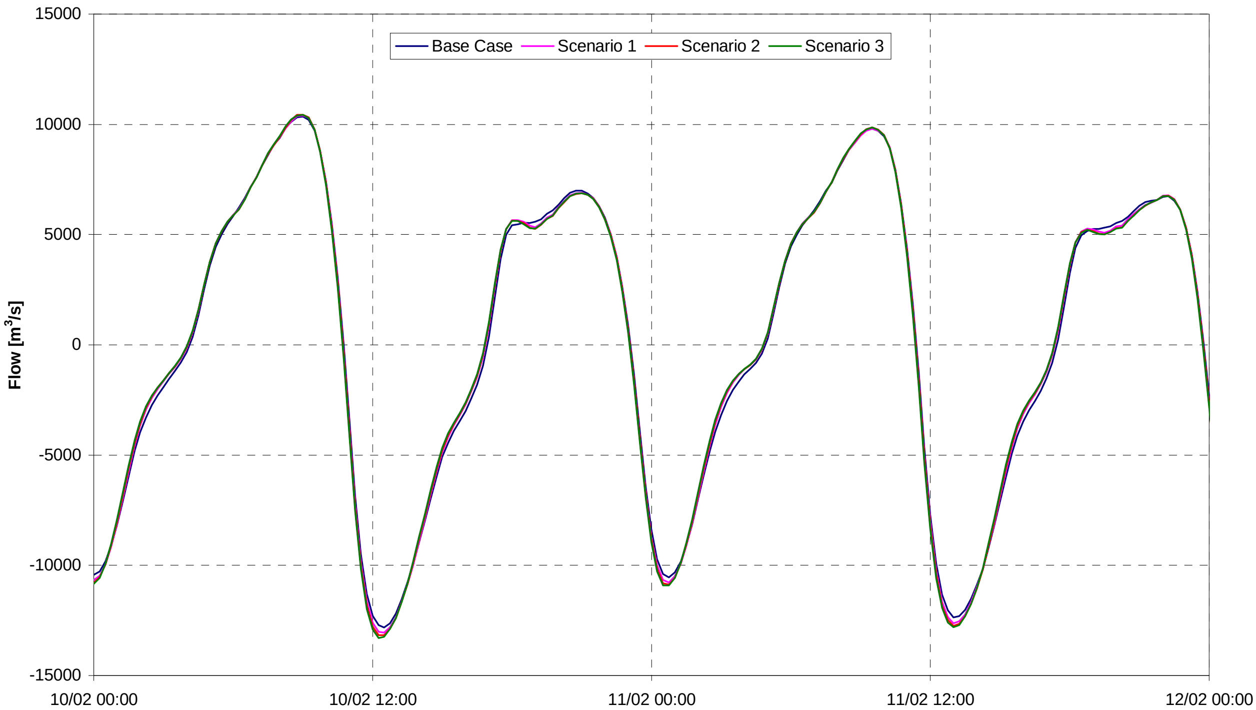


Figure 2-28 Transect 4 (Entrance to Narrows) Flow Time Series.

3 TIDAL FLUSHING CHARACTERISTICS

3.1 General Considerations

Port Curtis is a macro-tidal estuary with high tidal current speeds in the main channels and large intertidal wetting/drying extents. As such, Port Curtis is a naturally well-flushed system. Upstream of the Narrows, the tidal prism and tidal excursion length is reduced and consequently this part of the system is less well flushed than the Project Area and outer harbour areas.

Changes to the hydrodynamic regime as a consequence of reclamation and dredging may also impact the flushing characteristics of the estuary.

3.2 Methodology

The calibrated and validated TUFLOW-FV model was used to assess the base flushing characteristics of Port Curtis and the potential impacts of dredging and reclamation works in the Project Area on those flushing characteristics. Four different geometries were modelled representing the base case and the three developed scenarios as described in Section 1.4.

The four geometry scenarios described above were all run with the advection-dispersion module of the model as outlined below. The simulations covered the same 2 month period used for the hydraulic modelling previously described in Section 2.

The following approach was adopted in this assessment to quantify changes in the tidal flushing regime due to the potential dredging and reclamation scenarios.

- All model configurations (Base and Design Scenarios 1 to 3) were assumed to have a uniform initial concentration of a conservative tracer, with the concentration assigned an arbitrary value of 100.0 [-] across the whole model domain.
- Boundaries of the models were also appropriately configured with a defined tracer concentration of 0.0 [-]. That is, when the tide is flooding and oceanic waters are moving ‘into’ the model, inflowing waters have no conservative tracer; whereas when the tide is ebbing, tracer from within the model leaves through the model boundaries and does not return; and
- The models were simulated for a 2 month period using tidal boundaries derived from data recorded in February and March 2009 as described in Section 2-2 with the calculated tracer concentration throughout the model domain being recorded over the time frame of the simulations.
- Spatial and temporal changes in tracer concentrations were assessed to describe the base case flushing characteristics and impacts of the three development scenarios.

An Elder type model was used to represent the variation of horizontal dispersion with flow conditions (Fisher et al., 1979)

$$D_l = K_l u^* h;\ D_t = K_t u^* h$$

where D_l is the dispersion coefficient in the direction of the flow advection, u* is the friction velocity, h is the depth, D_t is the transverse dispersion coefficient and K_l, K_t are scaling coefficients. Based on a WBM dye release study conducted in Port Curtis several years ago, values of K_l=60 and K_t=6 have been adopted in previous RMA modelling studies (Connell Hatch, 2006) and in the current study using the TUFLOW-FV model. These dispersion coefficients result in flushing time predictions that are consistent with another hydrodynamic modelling study of Port Curtis undertaken by Hertzfeld et al. (2004).

3.3 Potential Flushing Impacts

3.3.1 Time-Series Results

Time series of tracer concentration were extracted at the 28 locations shown in Figure 1-7. Plots of the time series results at each location are presented APPENDIX D: for the whole simulation period. Each plot illustrates the tracer concentration for the base case and the three design scenarios at that location to allow direct comparison and visual assessment of impacts. Some locations are in shallow areas which dry at low tide. The tracer concentration is blank at these times.

3.3.2 Spatial Plan Results (Snap Shots)

Tracer concentration was extracted towards the end of each simulation and the design scenarios compared to the base case. This allowed the spatial distribution of the flushing impacts to be evaluated. The comparison was done at a high water slack tide near the end of the simulation.

Spatial plots of end tracer concentration are presented below for the Base Case and the three design scenarios as well as the associated impacts of each design scenario relative to the base case.

3.3.3 e-Folding Time

The e-folding time has been calculated as another measure of flushing and assessment of potential impact. The e-folding time is a measure of the flushing time-scale for a particular point in the system given an initial tracer dosage. The e-folding time is typically defined as being the time for the concentration at a point in the system to reduce by a factor 1/e. This is analogous to the exponential-decay timescale for the removal of tracer from the system.

A moving average filter is often applied to the concentration prior to assessing the e-folding time. In this case, the e-folding time has been calculated as the decay time scale of an exponential curve fitted to the scalar concentration time series at each point. Only the first part of the time-series is used to ensure that the tail of the exponential curve does not skew the result (ie, the time-series is truncated after the 25-hr moving average concentration has fallen below 20). Figure 3-2 illustrates the method. The red curve is the fitted exponential.

Direct use of the 25-hr moving average concentration for calculation of was not used in this assessment, as this technique introduced artefacts in the e-folding time calculation which arise from the spring-neap tidal variation. Locations that approach the e-folding concentration around the onset of the neap tidal period could experience a significant delay before actually dropping below the e-folding concentration. This is obviously an artefact of the simulation starting time (relative to the spring-neap cycle) and therefore a procedure which removed or reduced this artefact was considered more appropriate to construct spatial representation of e-folding time for use in this impact assessment.

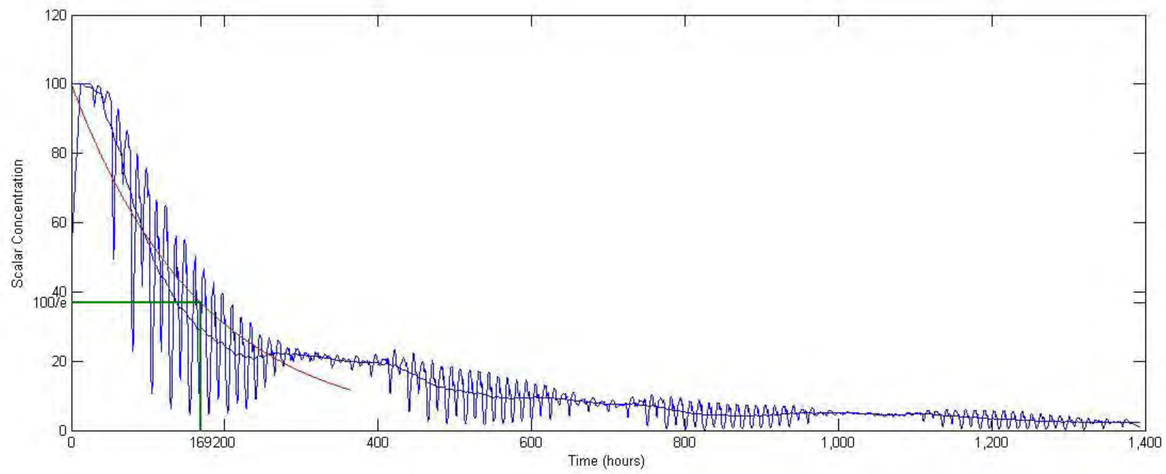


Figure 3-1 e-Folding Time Calculation

Spatial plots of the e-folding time for the Base Case and the three design scenarios as well as the associated impacts relative to the base case are presented below.

3.4 Discussion of Potential Impacts

Over the 2-month period of the base case simulation tracer concentrations are reduced from 100 units to around 10 units at the mouth of the Calliope River (east of the Project Area), 16 units around Fisherman's Landing (in the middle of the Project Area), with highest final concentrations in the upper Narrows and Graham Creek of around 26 units. Relatively large concentration gradients are predicted between the Laird Point (mouth of the Narrows) and Fisherman's Landing.

Compared with the base case, the three developed case scenarios all cause increases of 0-2 units in final tracer concentration upstream of the Project Area (i.e. the Narrows and Graham Creek). Within the Project Area final tracer concentrations generally increase by 0-2 units with some areas around the Passage Islands increasing by between 3-4 units due to subtle shifts of the relatively large concentration gradients in this area. In the narrow channel to the West of the reclamation, final tracer concentration increase by around 4 units compared with the base case.

e-Folding times within the Project Area range from around 25 days at Barney Point to around 37 days at Fisherman's Landing. Upstream in the Narrows and Graham Creek, e-Folding times range upward from 45 days. Compared with the base case, the three developed case scenarios all cause increases in e-folding times within and upstream of the Project Area of 0-4 days.

The flushing impact of the three scenarios is broadly similar in magnitude and spatial distribution, indicating that the reclamation and associated loss of inter-tidal storage is the major broad-scale hydrodynamic perturbation to the system (as discussed in Section 2.4). However, the tracer concentration and e-folding time impacts for scenario 2 are consistently marginally lower than for scenario 1 and scenario 3, which indicates that the impacts of dredging configurations on net-circulation patterns is also contributing to the hydrodynamic and flushing impacts on the system.

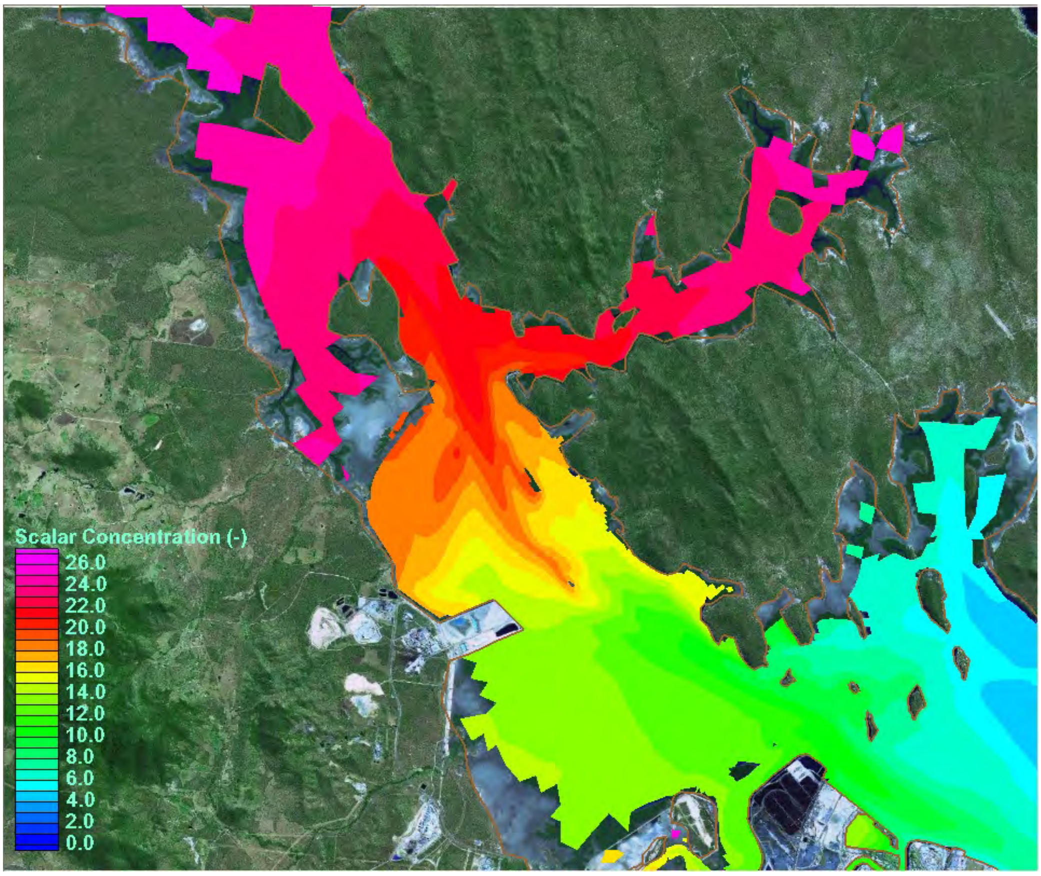


Figure 3-2 Base case tracer concentration

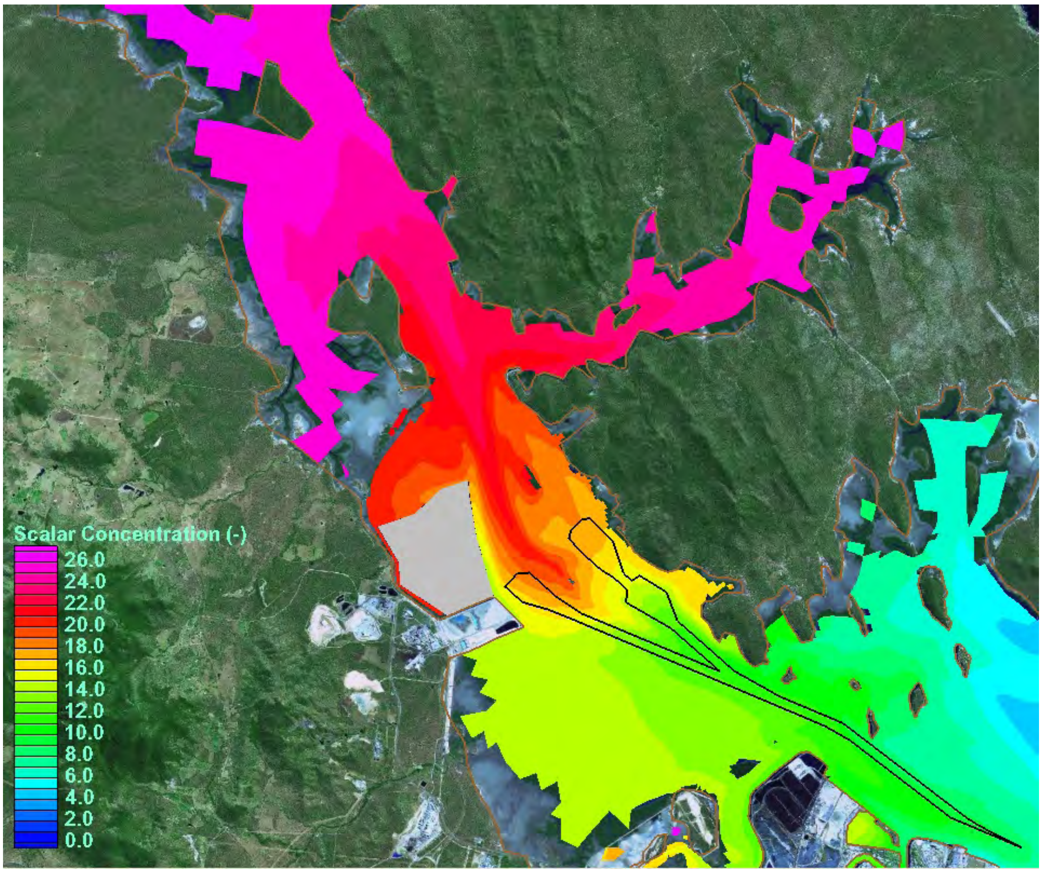


Figure 3-3 Scenario 1 tracer concentration

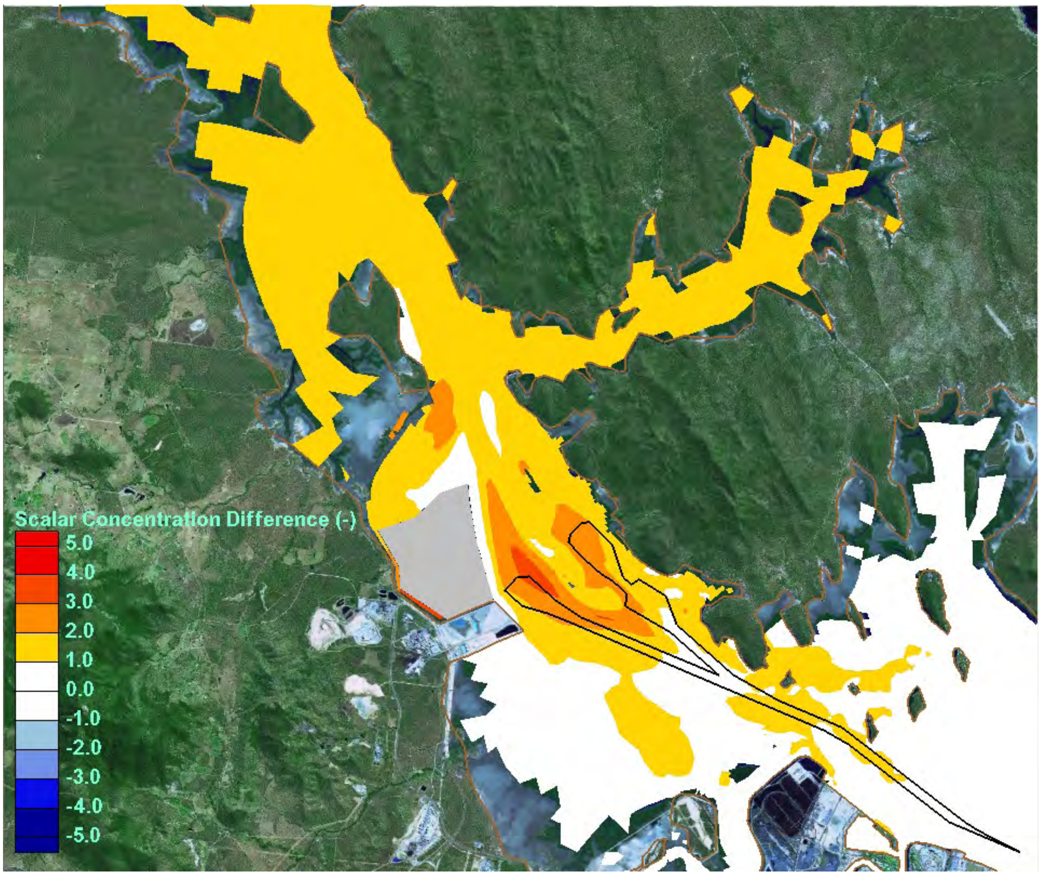


Figure 3-4 Scenario 1 tracer concentration differences

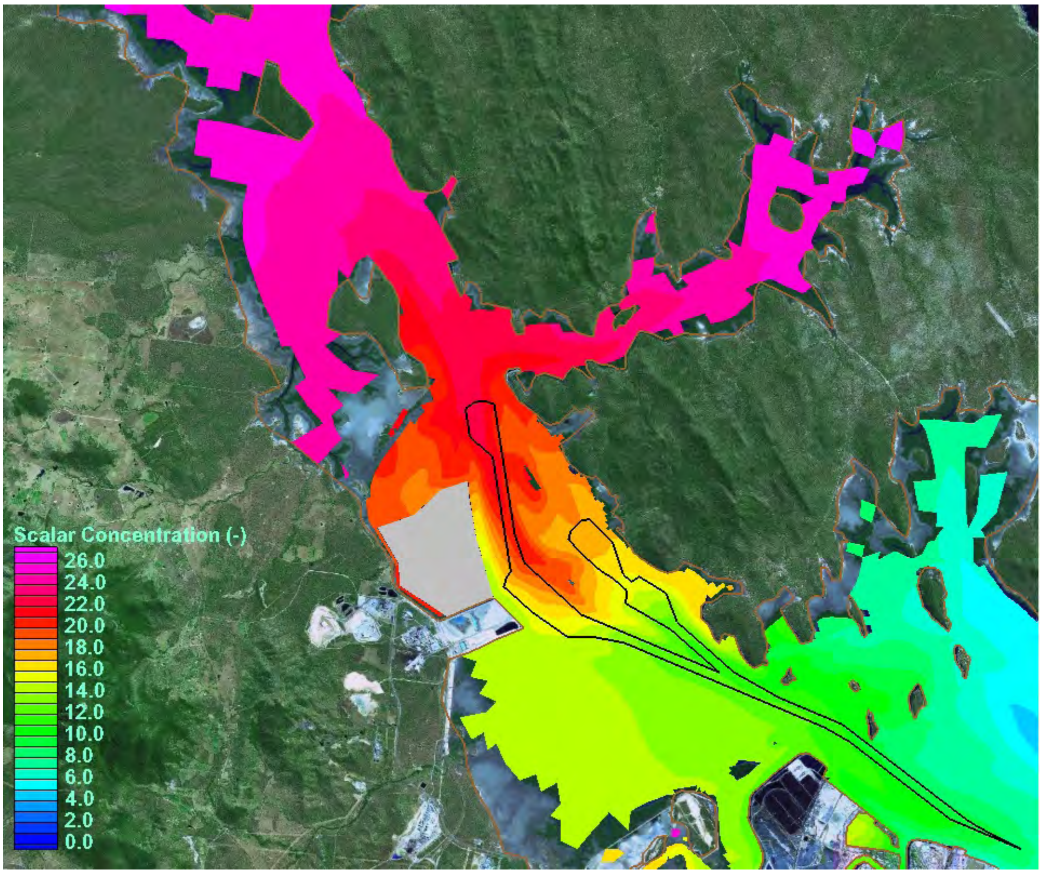


Figure 3-5 Scenario 2 tracer concentration

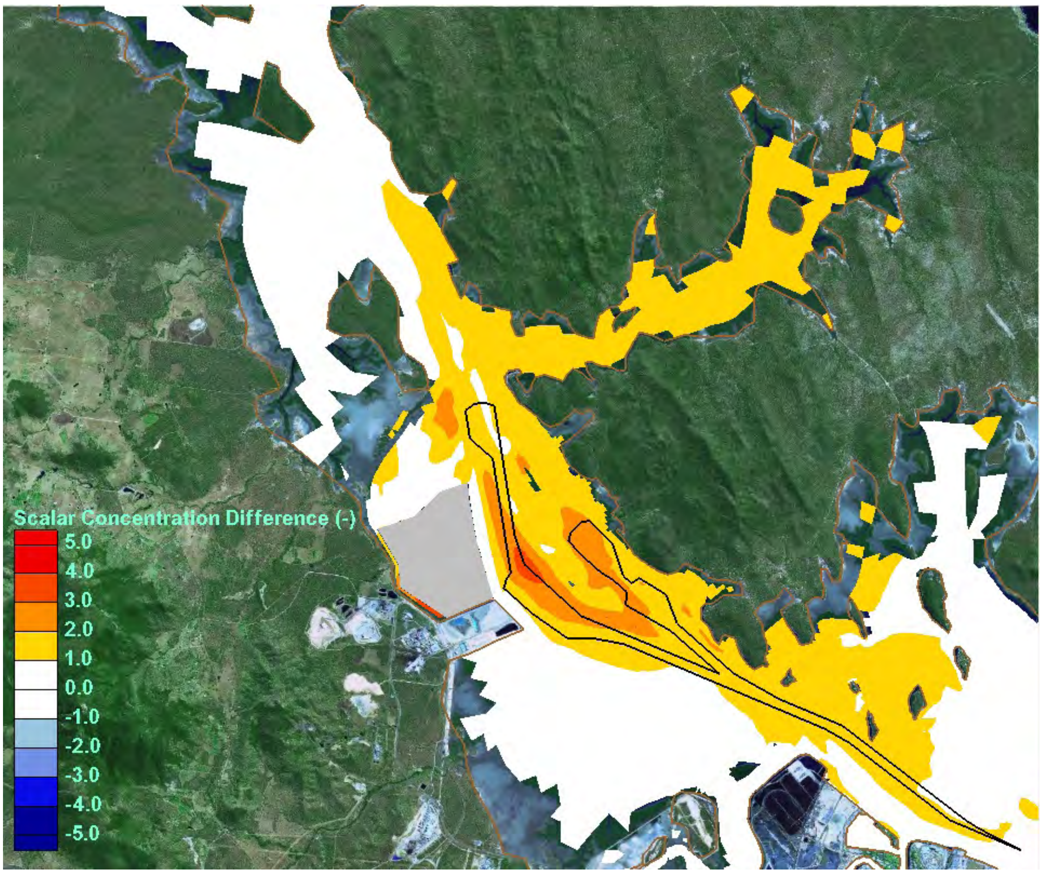


Figure 3-6 Scenario 2 tracer concentration differences

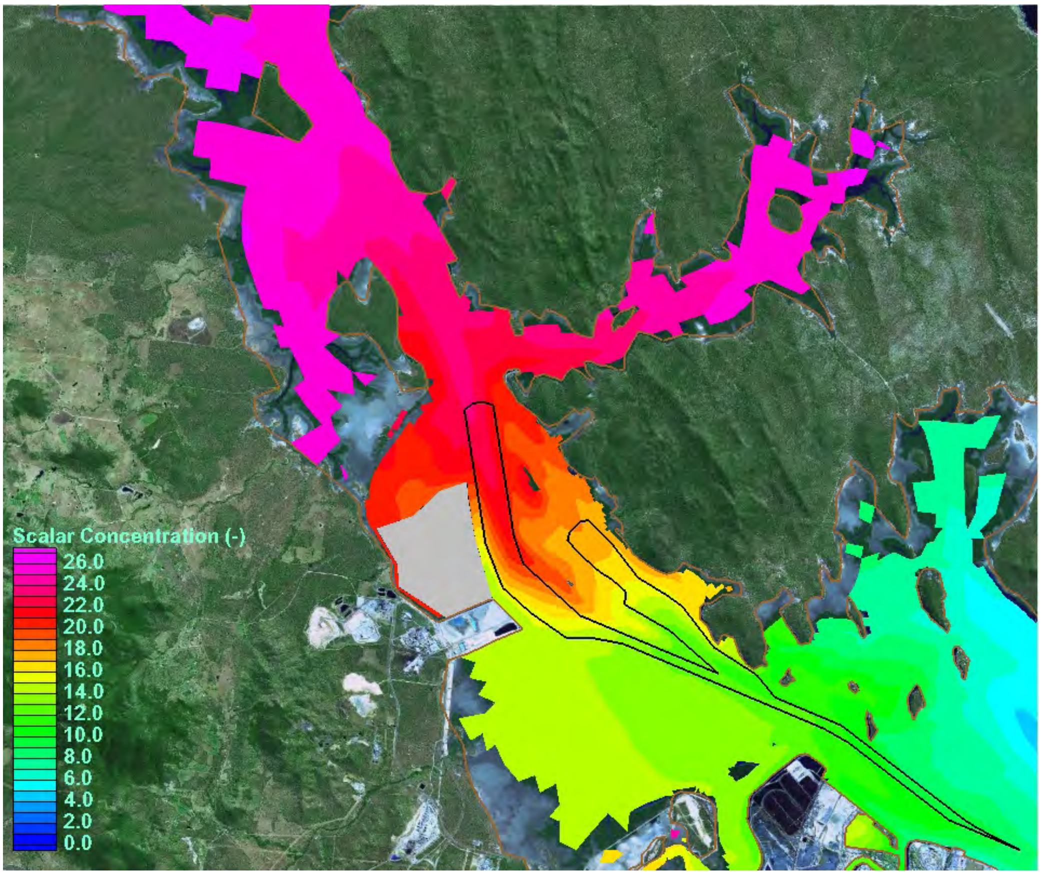


Figure 3-7 Scenario 3 tracer concentration

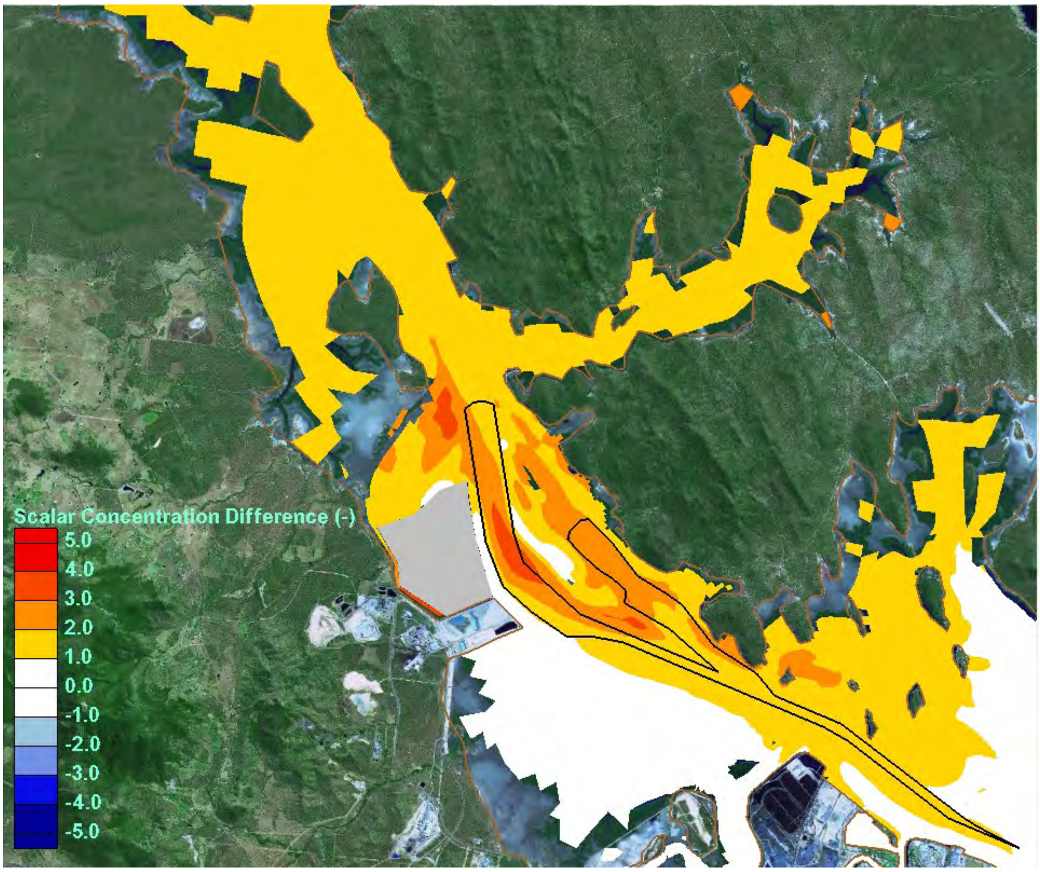


Figure 3-8 Scenario 3 tracer concentration differences

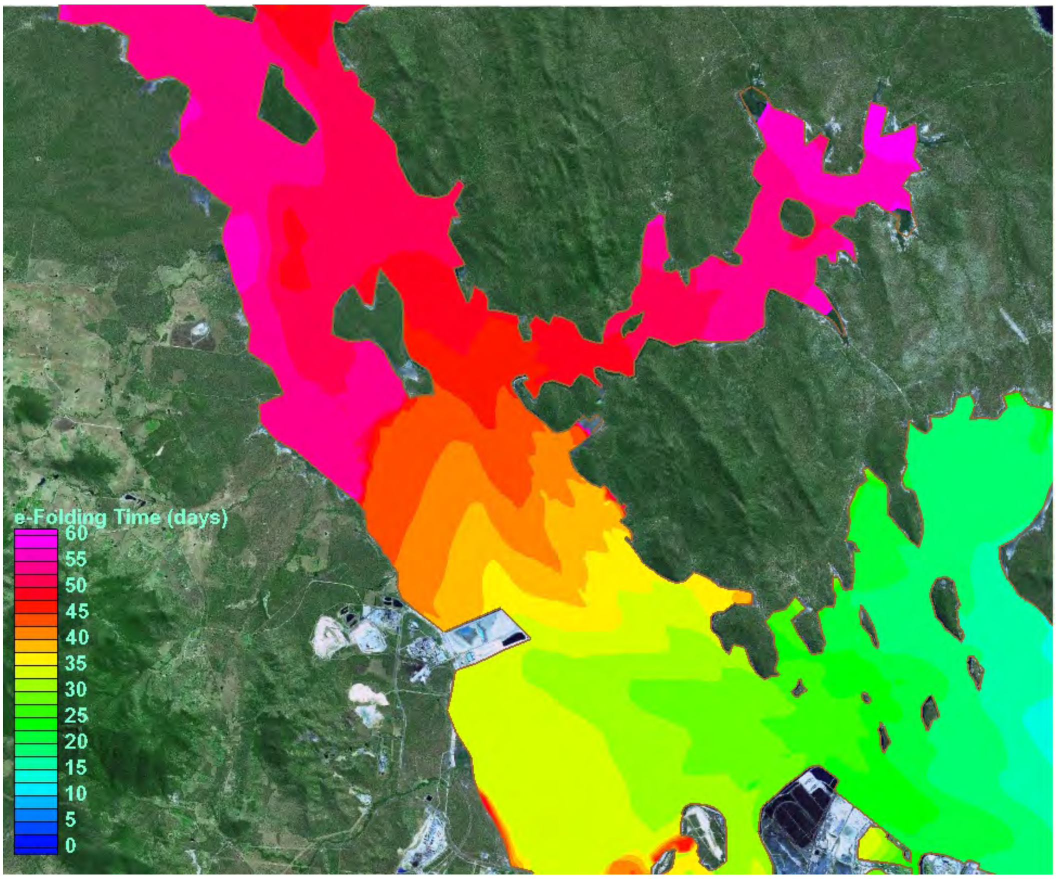


Figure 3-9 Base case e-folding time

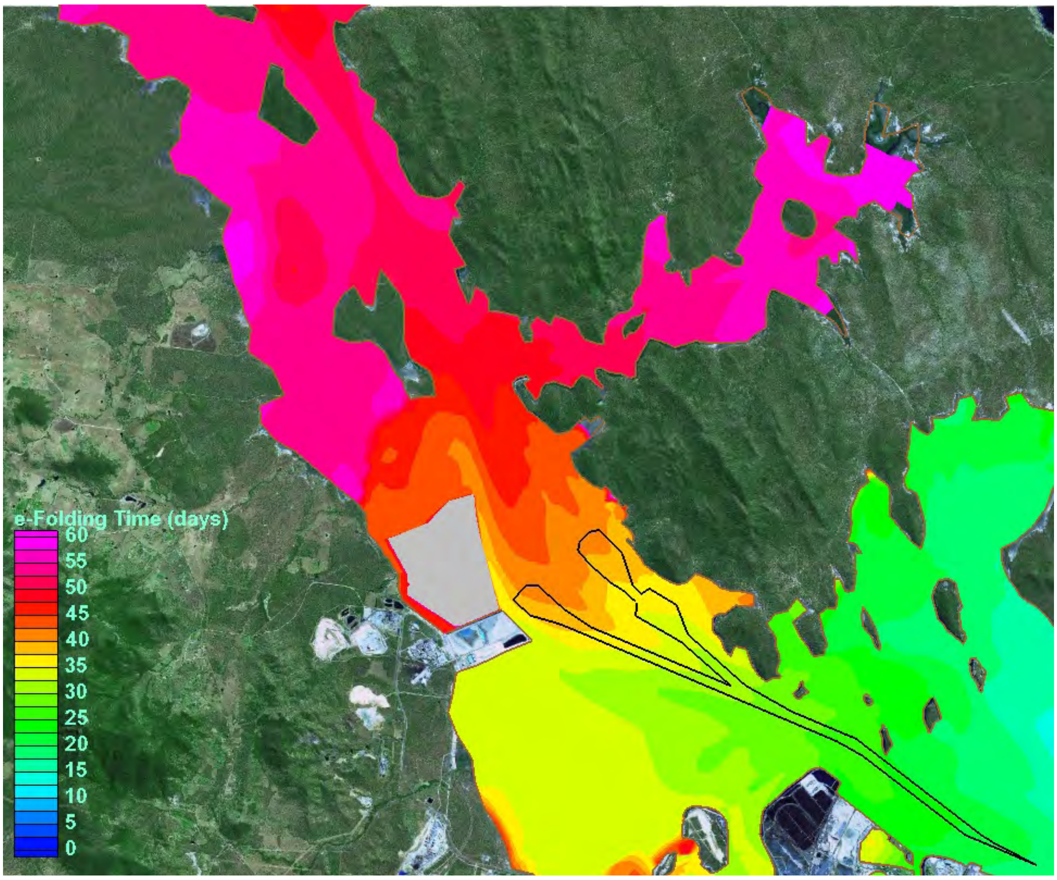


Figure 3-10 Scenario 1 e-folding time

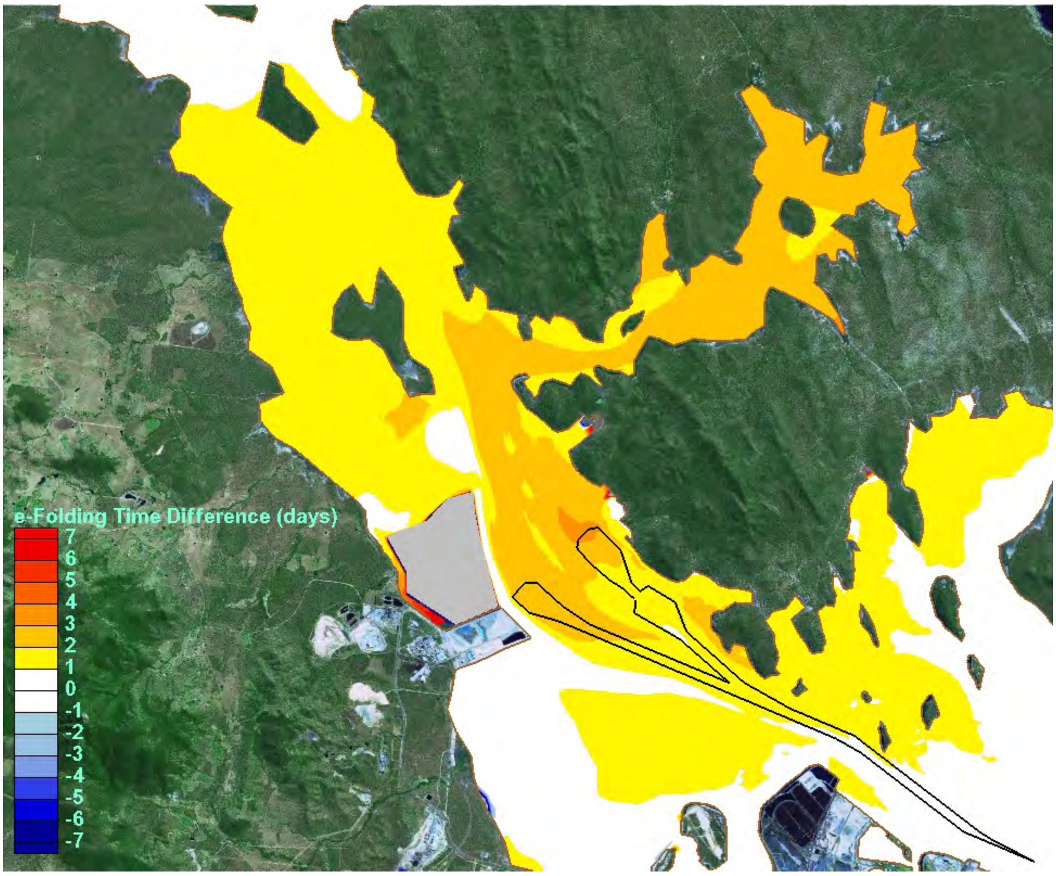


Figure 3-11 Scenario 1 e-folding time differences

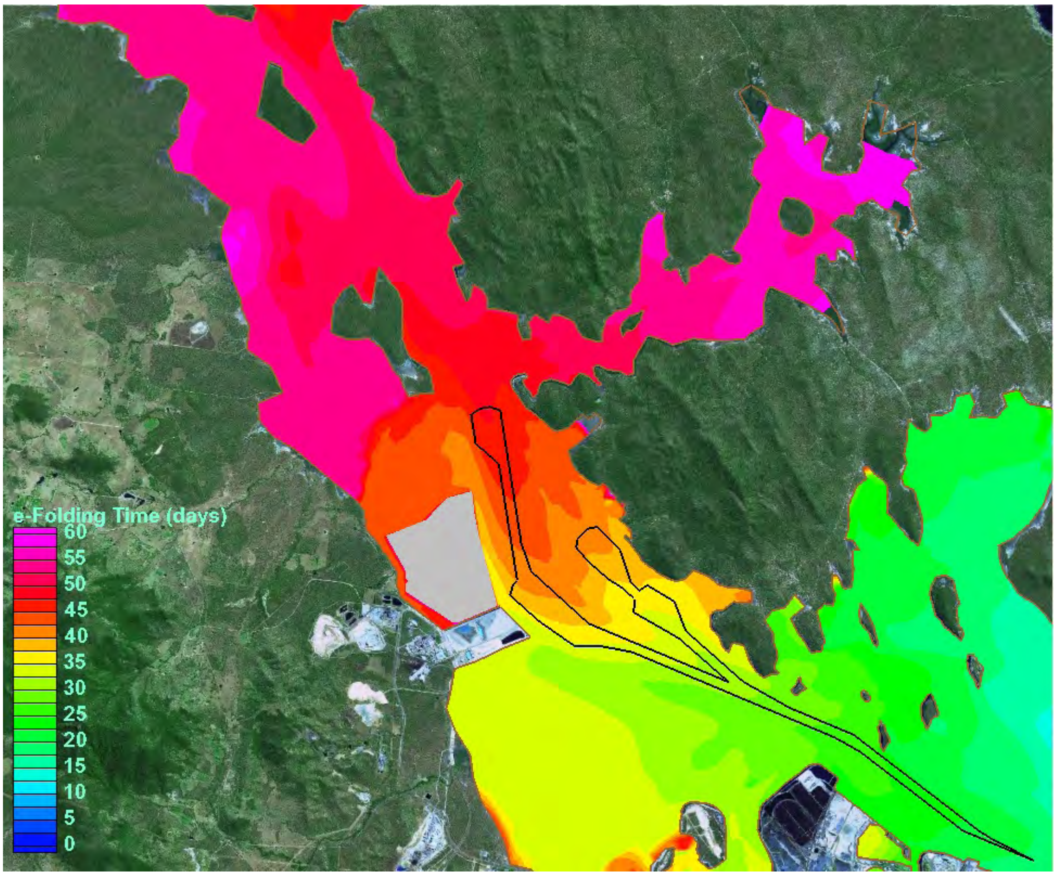


Figure 3-12 Scenario 2 e-folding time

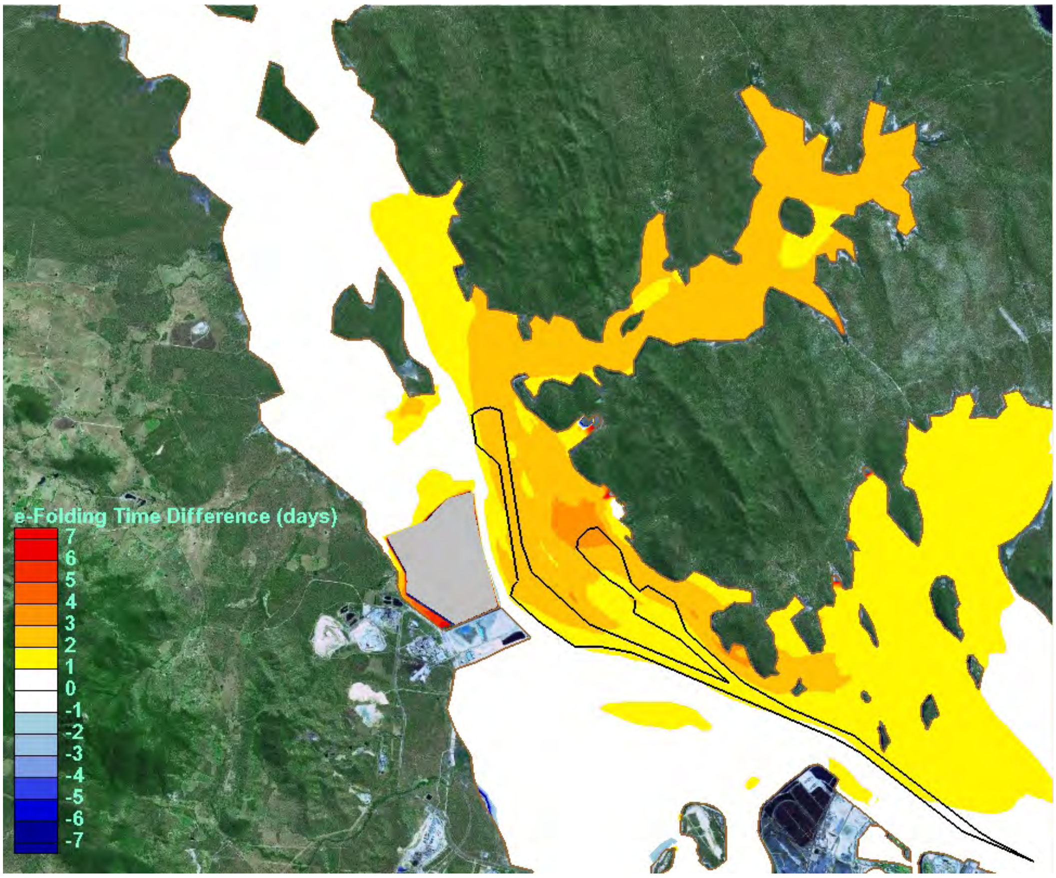


Figure 3-13 Scenario 2 e-folding time differences

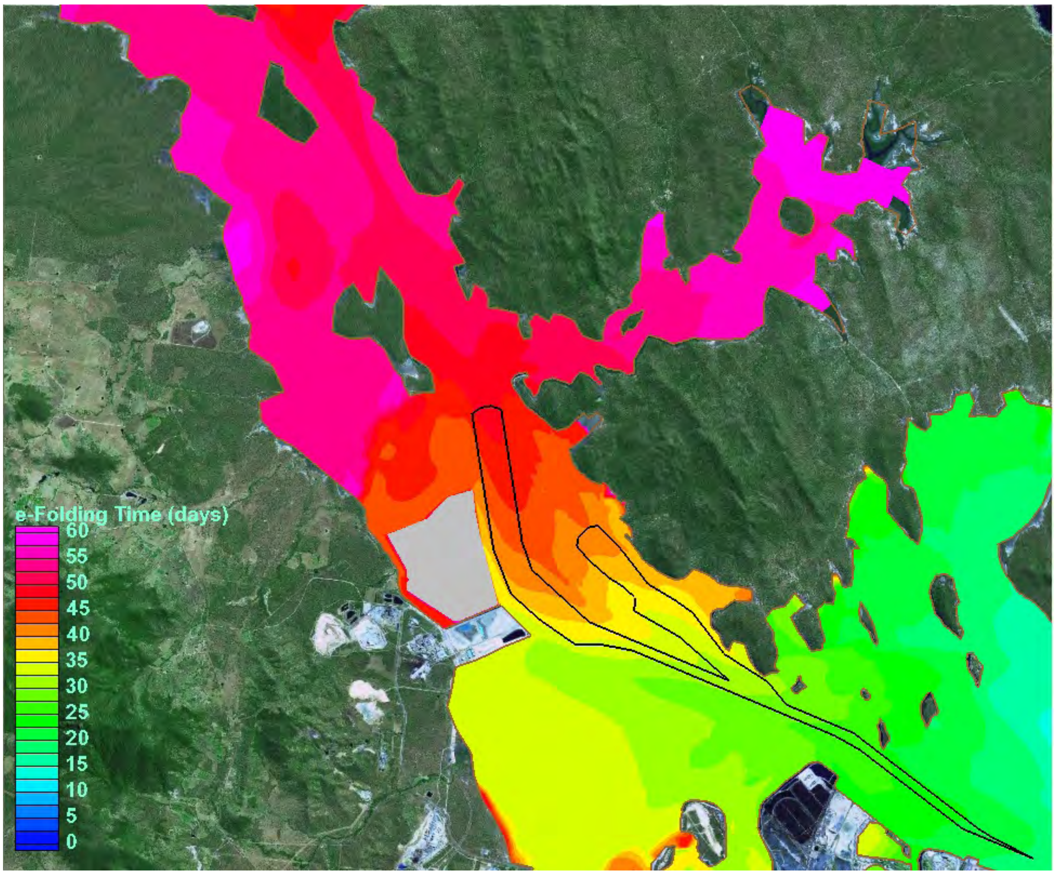


Figure 3-14 Scenario 3 e-folding time

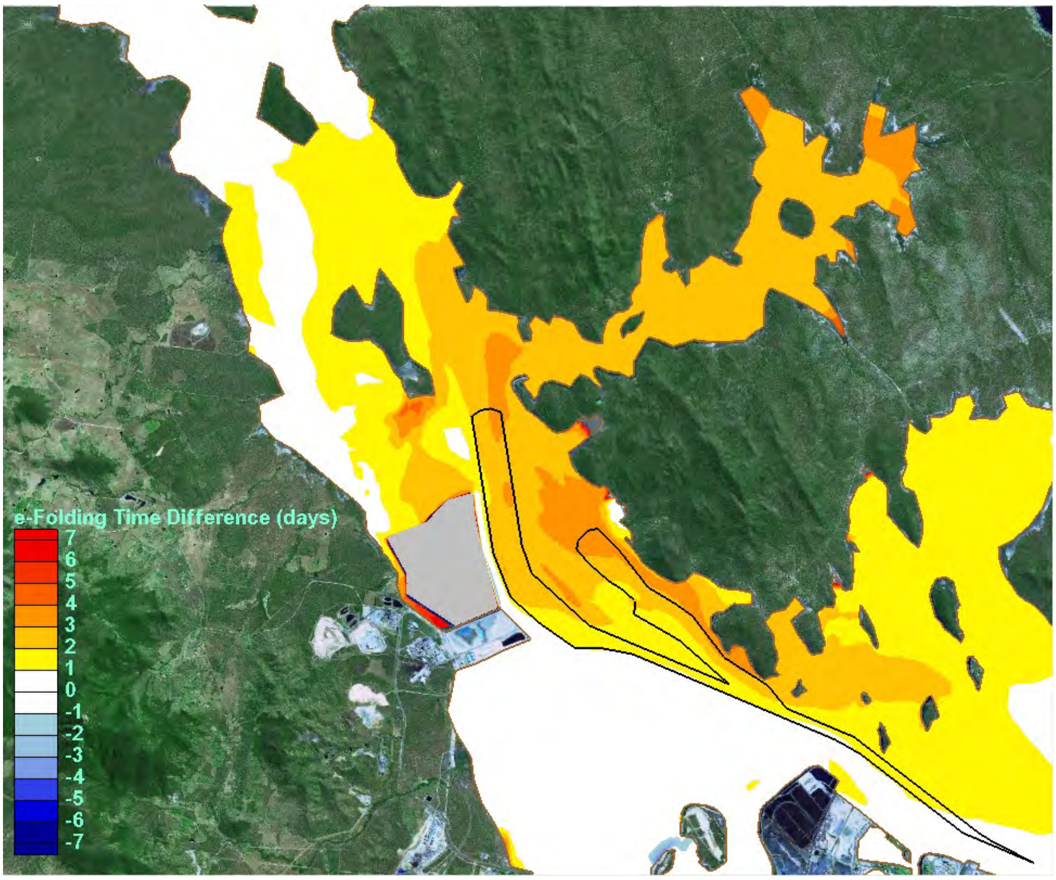


Figure 3-15 Scenario 3 e-folding time differences

4 DREDGE PLUME DISPERSION

4.1 General Considerations

The Port Curtis Project Area seabed and intertidal areas are made up of mixed sediments comprising varying proportions of gravels, sands and fine silt/clay materials. These materials can become re-suspended by tidal currents and the action of locally-generated wind-waves on shallow areas. Continuous measurements of turbidity variations over periods in excess of a fortnight indicate that the spring-neap tidal cycle is a dominant signal in the suspended sediment timeseries as seen in Figure 4-1 for data collected by BMT WBM adjacent to Fisherman's Landing in August/September 2008. Any direct correlation between wave-height and suspended sediment levels are much less clearly discerned from the available measurements, which indicates that tidal-currents are the dominant natural re-suspension mechanism within the Port Curtis Project Area.

Dredging works cause additional re-suspension of bed material and the generation of plumes of suspended sediment through a number of potential sources/mechanisms. The nature and extent of these plume sources will be dependent on the characteristics of the sediment as well as the type and operational characteristics of the dredging operations such as:

- Dredge head re-suspension during dredging – Trailing Suction Hopper Dredge (TSHD), Cutter Suction Dredge (CSD);
- Hopper overflowing and propeller disturbance during dredging – TSHD only;
- Hopper dumping – TSHD if not pumped out;
- Decant pond discharge – from dredge material placement area.

The "dredge plume" is defined as the quantity of Total Suspended Solids (TSS) which is in the water column due to dredging, and is above the natural background levels for that location and time. The increased turbidity associated with the dredge plume and the additional sediment deposition associated with settling of the dredge plume material are two of the primary sources of potential environmental impacts caused by dredging activities.

Prediction of dredge plume impacts involves a number of components, namely:

- Source strength definition, i.e. mass load and characteristics of sediment entrained by the dredging activities;
- Prediction of plume advection/dispersion;
- Prediction of plume settling.

The first of these is the most variable, and depends intimately on the type of dredging activities (e.g. type and size of dredge) as well as the material being excavated. As such, this component of the dredge plume impact assessment is also the most subject to variation. The prediction of plume advection/dispersion has been undertaken in the current study using the calibrated and validated TUFLOW-FV model of Port Curtis. The rate and cumulative extent of plume settling has been predicted within the TUFLOW-FV cohesive sediment module, using best-estimates of the plume suspended-sediment size and settling characteristics.

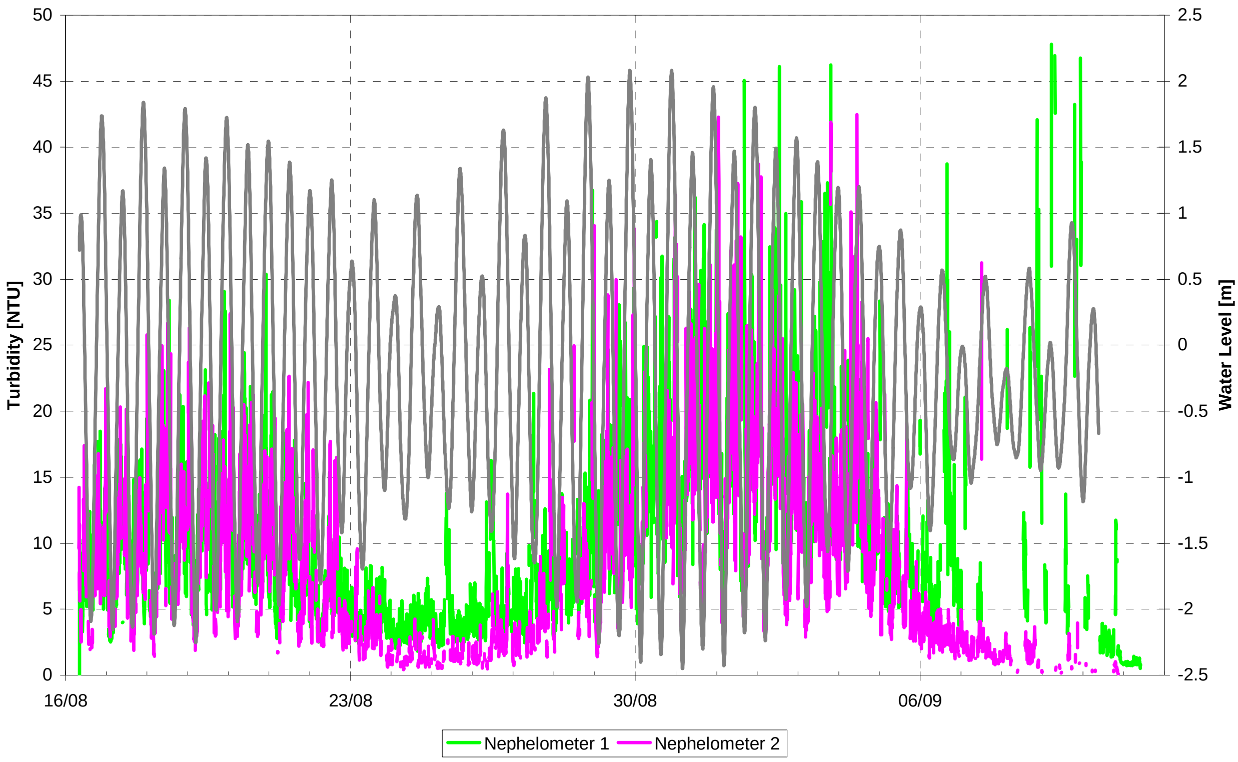


Figure 4-1 Turbidity time series collected by BMT WBM

4.1.1 Bed Sediment Characteristics

The following table provides an overview of the different substrate sediment compositions (expressed as percentage composition) for each of the stages of dredging as provided by GHD. Note that Stage 1A has been spilt into zones Stage 1A-i (Clinton Channel and Bypass) and Stage 1A-ii (Project Area North Middle and South) that roughly corresponds to the areas where the dredges are to be operating.

Table 4-1 Summary of Substrate Composition (%) for Staged Dredge Areas (source: GHD)

Stage	Gravel (>2mm)	Sand (0.06-2.00 mm)	Silt (2-60 µm)	Clay (<2 µm)	Total
Stage 1A-i	14	52	12	22	100
Stage 1A-ii	25	57	7	11	100
Stage 1B	13	41	19	28	100
Stage 2	17	44	14	26	100
Stage 3	11	34	20	35	100
Stage 4	30	37	14	20	100

4.1.2 Suspended Sediment Characteristics

A number of different sources of field measurements have been compiled in order to characterise the levels and composition of naturally re-suspended solids, as well as the likely characteristics of dredge plumes.

BMT WBM undertook water quality profiling and sampling in conjunction with ADCP measurements of currents and acoustic backscatter for both neap tide conditions (April 2009) and spring tide conditions (June 2009). Over the two sampling periods, more than 100 concurrent measurements of turbidity (NTU) and TSS (mg/L) were collected in order to characterise the naturally re-suspended material within the Port Curtis Project Area. These data and a fitted relationship are shown in Figure 4-2. Particle size analysis was performed on 10 of these natural TSS samples and the results are summarised in Table 4-2. The average particle size composition of naturally re-suspended material was 3% sand (d>159ηm), 68% silt (5ηm<d<159ηm) and 29% clay (d<5ηm).

Sampling of turbidity and TSS within dredge plumes was also undertaken on two occasions; firstly during RG Tanna Berth Pocket maintenance dredging performed by the TSHD “Brisbane”, and secondly during capital dredging of the Fisherman’s Landing Berth 1/Swing Basin by the CSD “Wombat”. The concurrent turbidity/TSS measurements for the two dredge plume sampling exercises are also plotted in Figure 4-2 and can be seen to systematically sit above the turbidity/TSS line fitted to the natural samples. Particle size analysis was performed on 12 of the “Wombat” dredge plume samples (3 of these samples were identified to have been obtained outside the plume). The results of the particle size analysis indicate that the average particle size composition of the dredge plume samples was 7% sand, 68% silt and 25% clay.

Two samples were obtained from the Fisherman’s Landing reclamation pond decant discharge. These samples had no sand content and a higher clay proportion than other samples. The average particle size composition of these two samples was 0% sand, 46% silt and 54% clay.

Table 4-2 Particle Size Characteristics of Both Natural and Dredge Plume Suspended Sediments

Description	Depth (m)	TSS (mg/L)	Turbidity (NTU)	d10 ηm	d50 ηm	d90 ηm	% Med Sand >159 ηm	% Fine Sand <159 ηm >71 ηm	% Silt <71 ηm >5 ηm	% Clay <5 ηm
U/S of dredger	5	8	6.2	2.5	7.6	25	0.03	1.65	71.7	26.6
Dredge plume close to dredge head	6	8	6	2.8	8.6	32	0.00	1.55	75.9	22.6
25-30m D/S dredge head	10	67	17	2.4	12.0	60	0.35	8.67	68.2	22.8
Dredge plume	7	11	7	2.3	7.0	25	0.01	2.79	67.4	29.8
Dredge plume	10	70	19.9	2.4	10.0	60	1.04	7.97	66.0	25.0
Dredge plume	10	21	10.5	2.5	8.9	40	0.06	4.19	70.8	25.0
D/S of dredger	10	67	19.5	2.4	12.7	58	0.03	8.20	68.7	23.1
D/S of dredger	5	20	6.6	2.3	10.3	77	1.45	12.52	59.9	26.1
D/S of dredger (outside of plume)	10	5	4.8	2.2	8.1	24	0.00	0.35	71.2	28.5
U/S of dredger	3	8	5.9	2.1	6.1	16.2	0.00	0.00	64.7	35.3
D/S of dredger	10	15	6.8	2.8	10.0	49	0.00	5.72	72.6	21.7
Dredge plume	12.5	37	10.6	2.3	11.0	62	0.49	9.19	65.2	25.1
Pond outlet	-	9	-	1.6	3.5	7.5	0.00	0.00	34.7	65.3
Pond outlet	-	10	-	2.8	8.6	32	0.00	0.00	57.9	42.1
Passage Transect - West	5	53	18.8	2.5	8.5	40	0.78	4.62	69.5	25.1
Passage Transect - East	5	53	20.5	2.4	9.1	53	3.37	5.09	66.7	24.8
Targinnie Transect - Centre. 10 m deep.	5	12	7.5	2.1	6.3	16.4	0.00	0.00	66.0	34.0
Targinnie Transect - Centre. 15 m deep.	10	29	12.3	2.6	8.2	19.7	0.97	4.35	69.6	25.0
Targinnie Transect - East. 6.8 m deep.	5	20	10	2.0	6.6	22	0.00	0.21	67.1	32.7
Targinnie Transect - Centre. 14 m deep.	5	36	14.4	2.2	8.6	38.9	0.48	4.25	68.8	26.5
Targinnie Transect - Centre. 14 m deep.	10	43	15.5	2.5	9.3	60	1.89	6.89	67.0	24.2
Targinnie Transect - Centre.	10	6	6.1	2.1	5.9	14.2	0.00	0.00	64.3	35.7
Laird Transect - East. 6.8 m deep.	3	22	11.6	2.6	8.3	39	0.65	4.23	70.2	25.0
Laird Transect - Centre. 13 m deep.	10	9	6.8	2.2	6.0	19	0.00	0.69	64.1	35.2
Dredge Plume - Mean		35.1	11.5	2.5	10.1	51.4	0.4	6.8	68.3	24.6
Dredge Plume - Stdev		26.0	5.7	0.2	1.8	16.5	0.5	3.5	4.6	2.5
Dredge Plume - Median		21.0	10.5	2.4	10.0	58.0	0.1	8.0	68.2	25.0
Decant - Mean		9.5	-	2.2	6.1	19.8	0.0	0.0	46.3	53.7
Decant - Stdev		9.5	-	2.2	6.1	19.8	0.0	0.0	46.3	53.7
Decant - Median		9.5	-	2.2	6.1	19.8	0.0	0.0	46.3	53.7
Natural - Mean		23.4	10.8	2.3	7.6	29.8	0.6	2.5	67.8	29.1
Natural - Stdev		17.8	5.2	0.2	1.2	14.9	1.0	2.5	2.6	4.7
Natural - Median		20.0	10.0	2.2	8.1	24.0	0.0	1.7	67.1	26.6

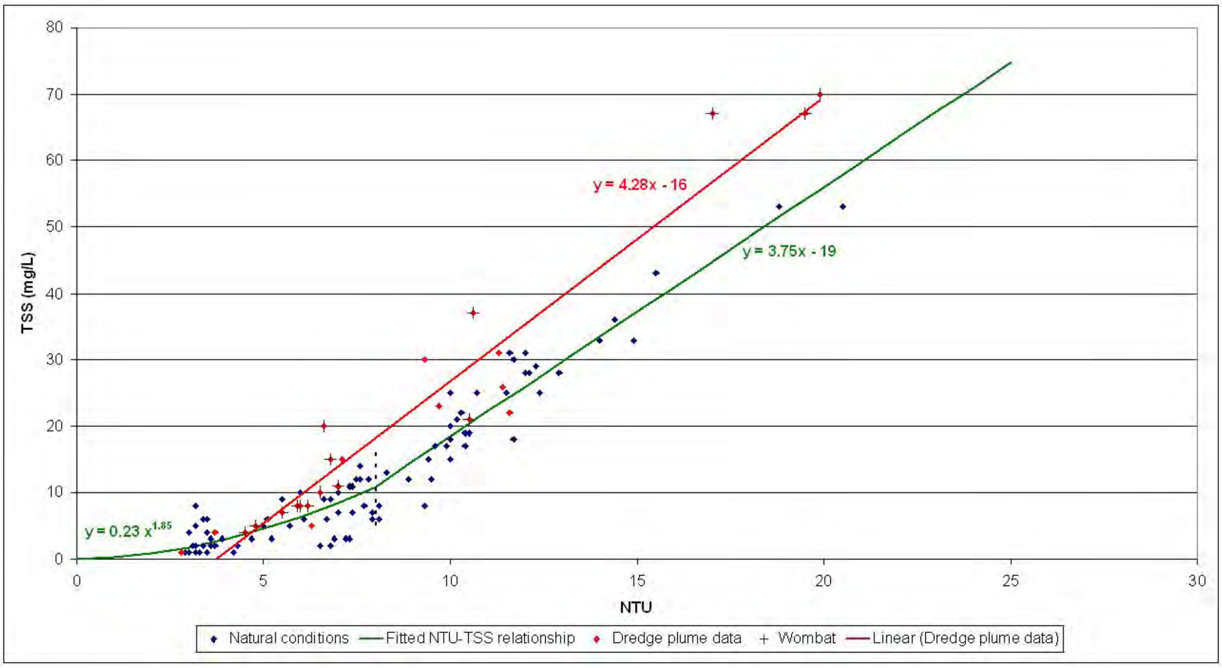


Figure 4-2 Turbidity–TSS Relationships from Both Natural and Dredge Plume Sampling

4.2 Methodology

4.2.1 General Assumptions

Dredging of the Project Area is proposed to occur progressively over a number of stages. During each stage, dredging is proposed to occur at one or more locations using either a CSD or TSHD depending on operational constraints.

A "large" CSD is assumed to have a production rate of 1000m^3/hr (in-situ volume) and a "medium" CSD is assumed to have a production rate of 500m^3/hr. It is proposed to pipe the slurry from all operating CSD directly to the extended Fisherman's Landing reclamation, which would be largely complete prior to the commencement of dredging. The discharge of decant from the reclamation area would be at 2.5m^3/s for the "large" CSD and 1.25m^3/s for the "medium" CSD.

The "large" TSHD is assumed to have a 10,000m^3 hopper capacity and would operate on a 3 hour cycle time, comprising 1 hour of filling (+ overflowing). The TSHD would "dump" its material adjacent to the Fisherman's Landing extended reclamation, where it would then be re-handled into the reclamation by a "medium" CSD.

4.2.2 Simulation Description

In order to simulate the proposed combinations of dredge operations, while maintaining the flexibility to consider alternative permutations, 8 individual plume simulations were devised as detailed in Table 4-3. Each simulation corresponds to 1 or 2 concurrent dredge operations and the corresponding decant discharge from the Fisherman's Landing reclamation. The TSHD operation has been split into separate simulations for filling and dumping, again in order to maintain flexibility in the final combined scenarios. The locations of the source loadings are illustrated in Figure 4-4.

All dredge plume loads are simulated as a stationary source input into a single model “cell”. The CSD and decant sources are maintained continuously for 24 hours a day for the durations of the simulations (2 months), while the TSHD is continuously looped through its 3 hour cycle comprising 1 hour of filling and a 10 minute period of dumping for the duration of the simulations. In reality, these are conservative assumptions (in terms of plume loadings), as the dredges would not be able to maintain operations around-the-clock.

Table 4-3 Description of Plume Simulations

Simulation	Dredge/s – Location/s
1	Large CSD – Middle Curtis Island Large CSD – North Curtis Island
2	Large TSHD Filling - Clinton Bypass
3	Large TSHD Filling - Fisherman’s Landing Swing Basin
4	Large TSHD Filling - Targinie Channel
5	Medium CSD - Dumping Ground
6	Large TSHD Dumping - Dumping Ground
7	Large CSD - Laird Point
8	Large CSD - Fisherman’s Landing (North) Large CSD - Hamilton Point

Combined dredge plume scenarios have been derived from superposition of 1 or more individual plume simulations, as described in Table 4-4. Dredge plume scenario 1a corresponds to Western Basin development Stage 1A and involves dredging of the northern and middle Curtis Island basins and approach channels as well as deepening of the Clinton Bypass Channel. Dredge plume scenario 1b corresponds to ongoing dredging of the northern and middle Curtis Island basins and Stage 1B (Stage 1) dredging of Fisherman’s Landing Swing Basin and the Targinie Channel. Dredge plume scenario 2 corresponds to Stage 1B (Ultimate) dredging of Targinie Channel and the Fisherman’s Landing Swing Basin and dredging of the Laird Point Swing Basin and approach channel. Dredge plume scenario 3 corresponds to dredging of the Fisherman’s Landing North berths alongside the extended reclamation and the berths at Hamilton Point. In all scenarios, the model geometry was assumed to be that at the beginning of the dredging.

Table 4-4 Description of Plume Scenarios

Scenario	Stage	Description	Dredge Simulation Used
1a	1A	North/Middle Curtis Island via CSD and Clinton/Project Area South via TSHD	1, 2, 5, 6
1b	1A & 1B (Stage 1)	North/Middle Curtis Island via CSD and Targinie Channel/FL Swing Basin via TSHD	1, 3, 5, 6
2	2	Targinie Channel/FL Swing Basin via TSHD and Laird Point via CSD	7, 4, 5, 6
3	3 & 4	Fisherman's Landing North & Hamilton Point North & South	8

4.2.3 Plume Source Loadings

There is considerable uncertainty associated with prediction of dredge plume source loadings. In the current assessment the derivation of the source plume loadings has been undertaken using a systematic approach using available estimates of source plume loadings in a realistic but conservative manner in consultation with and based on information provided by GHD.

Some terminology used in expressing the key assumptions made in deriving the plume loadings used in the assessment are defined as follows:

- **In-situ production rate** – volumetric rate of in-situ material excavation;
- **Turbidity generating units** – dry sediment mass rate per unit volume of in-situ material that is entrained during dredge operations. This includes a combination of sands, silts and clay materials. A proportion of this material, in particular the coarser sands and a proportion of the clay fraction as "clumps", settles immediately to the bed;
- **Bulk overflow rate** – dry sediment mass rate overflowing the TSHD during filling;
- **Long term plume fraction** – dry mass percentage of the turbidity generating units/bulk overflow rate which has a sufficiently low settling velocity to remain in suspension as the "long term plume".

Information on the composition of the substrate material to be dredged (Table 4-1) along with information on the suspended sediment characteristics of the "Wombat" plume (Table 4-2) have been used to derive the long term plume fraction and composition of the source long-term plume suspended sediment fractions. It has been assumed that 100% of the entrained fine sand and silt remain suspended in the long term plume while 0% of the gravels and coarse sand fractions remain in suspension. The relative proportion of the clay component is reduced due to the rapid settling of clay clumps that are not broken up during the dredging process. In Table 4-2 the clay-sized fraction typically accounts for about 25% of the suspended sediment plume, accordingly the relative proportion of clay in the long-term plume composition has been reduced relative to the in-situ sediment composition such that it comprises 28% of the long term plume total. Based on these assumptions the long term plume fraction is 30% of the initially entrained bed sediments (excluding gravel). The relative fractions of both the in-situ sediment and the long-term plume source material are detailed in Table 4-5.

Table 4-5 In-situ sediment and long-term plume suspended sediment composition

	Gravel	Coarse Sand	Fine Sand	Silt	Clay	Total
In-situ sediment composition	18%	40%	4%	14%	24%	100%
Long-term plume composition	0%	0%	4% (16% of plume)	14% (56% of plume)	7% (28% of plume)	25% (30% of total minus gravel)

A composition of 35% silt and 65% clay in the decant discharge has been assumed based on the relevant particle size distributions in Table 4-2.

The key plume loading assumptions for each class of dredging operation are detailed below:

Large Cutter Suction Dredge – cutter-head source:

- In-situ production rate: 1000 m^3/hour (source: GHD);
- Cutter-head Turbidity Generating Units: 48 kg/m^3;
- Cutter-head Long term plume fraction: 30%;
- Plume Source Rate: 4 kg/s.

Medium Cutter Suction Dredge (re-handling) – cutter-head source:

- In-situ production rate: 500 m^3/hour (source: GHD);
- Turbidity Generating Units: 96 kg/m^3 (this is twice the assumed volumetric rate of resuspension from the large CSD due to the recently dumped material being less consolidated than in-situ sediments);
- Long term plume fraction: 30%;
- Plume Source Rate: 4 kg/s.

Trailer Suction Hopper Dredge filling – overflow plus dredge-head source:

- Sediment entrainment rate (predominantly overflow): 250 kg/s (source: GHD);
- Long term plume fraction: 30%;
- Plume Source Rate: 75 kg/s.

Trailer Suction Hopper Dredge dumping:

- Hopper dry sediment mass capacity: 8,000 t/load (source: GHD);
- Bulk dump loss proportion: 8.5%
- Long term plume fraction: 30%;
- Plume Source Rate: 204 t/load (dumping occurs every 3-hours over a 10-minute period).

Decant discharge:

- Decant turbidity: 58 NTU (source: GHD);
- Decant TSS: 100 mg/L (based on CQU (2008) reclamation pond samples);
- Decant discharge rate:
  - 2.5 m^3/s for a large CSD (source: GHD);
  - 1.25 m^3/s for a medium CSD (source: GHD);

Based on these assumptions plume source loadings have been derived for each plume simulation and are summarised in Table 4-6.

Table 4-6 Plume Loading Assumptions

Simulation	Source - Location	Total Loading
1	Large CSD – Project Area middle basin Large CSD – Project Area north basin Reclamation Decant @ 100mg/l	4kg/s continuous 4kg/s continuous $5m^3/s$ continuous
2	Large TSHD Filling - Clinton Bypass	75kg/s for 1 hr every 3 hrs
3	Large TSHD Filling - Fisherman's Landing swing basin	75kg/s for 1 hr every 3 hrs
4	Large TSHD Filling - Targinie Channel	75kg/s for 1 hr every 3 hrs
5	Medium CSD - Dumping ground Reclamation Decant @ 100mg/l	4kg/s continuous $1.25m^3/s$ continuous
6	Large TSHD Dumping - Dumping ground	340kg/s for 10min every 3 hrs
7	Large CSD - Laird Point Reclamation Decant @ 100mg/l	4kg/s continuous $2.5m^3/s$ continuous
8	Large CSD – Fisherman's Landing (North) Large CSD - Hamilton Point Reclamation Decant @ 100mg/l	4kg/s continuous 4kg/s continuous $5m^3/s$ continuous

4.2.4 Dispersion Parameters

The same dispersion parameters have been used in the dredge plume assessments as for the flushing assessments detailed in Section 3.2.

4.2.5 Particle Size / Settling Velocity Parameters

In this assessment dredge plumes have been modelled using 3 suspended sediment classes; fine sand, silt and clay. The relative composition of the dredge plume source loads in terms of these 3-fractions, the assumed still-water fall velocities and equivalent Stokes diameter are summarised in Table 4-7.

The modelled rate of sediment settling is a function of the depth-averaged sediment concentration, the still-water fall velocity (w_{s0}) and the bed shear stress (τ_b), according to the relationship:

$$Q_{sd} = w_{s0} * \max(0,(1-\tau_b/\tau_{cd}))$$

where τ_{cd} is a model parameter defining the critical shear stress for deposition. As such, sediment settling is reduced below its still water value by the action of bed shear stress and associated vertical mixing in the water column. A critical shear stress for deposition of 0.5 N/m^2 was adopted following calibration of the settling parameters to the measured reduction in turbidity during the transition from spring-tides to neap-tides, as shown in Figure 4-3. The calibration assessment was undertaken by dosing the model with an initial TSS concentration of 40mg/L (approximately equivalent to 16NTU using the relationship in Figure 4-2), comprising 3% fine-sand, 68% silt and 29% clay based on the natural suspended sediment measurements in Table 4-2. In Figure 4-3 it can be seen that the measured general trend in turbidity decay is reproduced in this assessment, however the strong semi-diurnal variations in turbidity during the spring tides at the beginning are not reproduced. These strong variations in the measurements may be due to a combination of spatial gradients which were advected past the turbidity sensor and/or active re-suspension/deposition over the timescale of a tidal cycle. The former process would not be accurately represented due to the artificial initial condition of this model calibration assessment while erosion processes were not included in the sediment plume assessments as discussed below.

There was no provision for re-suspension of already deposited plume material in the dredge plume assessments. While there is the potential for re-suspension of the fine suspended load which does settle out, it will generally become mixed with and hence indistinguishable from the re-suspension of the natural bed material. Settling will occur when and in areas where currents and waves (and hence bed shear stresses) are lower. These are areas of naturally occurring fine bed sediments and the amount of re-suspension will be a function of the prevailing conditions and the nature of the material rather than the origin of the material. Accordingly, the amount of re-suspension will be dominated by the natural bed material which will not be affected by the project. The sediment composition of the dredge plume suspended load is likely to be similar to the naturally suspended material as evidenced by the comparative particle size distributions in Table 4-2.

Table 4-7 Plume Model Sediment Fractions and Settling Parameters

Particle	Fine Sand	Silt	Clay
Still Water Fall Velocity, w_{s0} (m/s)	1.0E-02	2.0E-04	2.0E-05
Eqivalent Stokes Diameter, d_{s0} (ηm)	110	15	4.8
Critical Shear Stress Deposition, τ_{cd} (N/m^2)	0.5	0.5	0.5
Sediment particle density, ρ_s (kg/m^3)	2650	2650	2650
% Dredge Plume	16	56	28
% Dump Plume	16	56	28
% Decant Plume	0	35	65

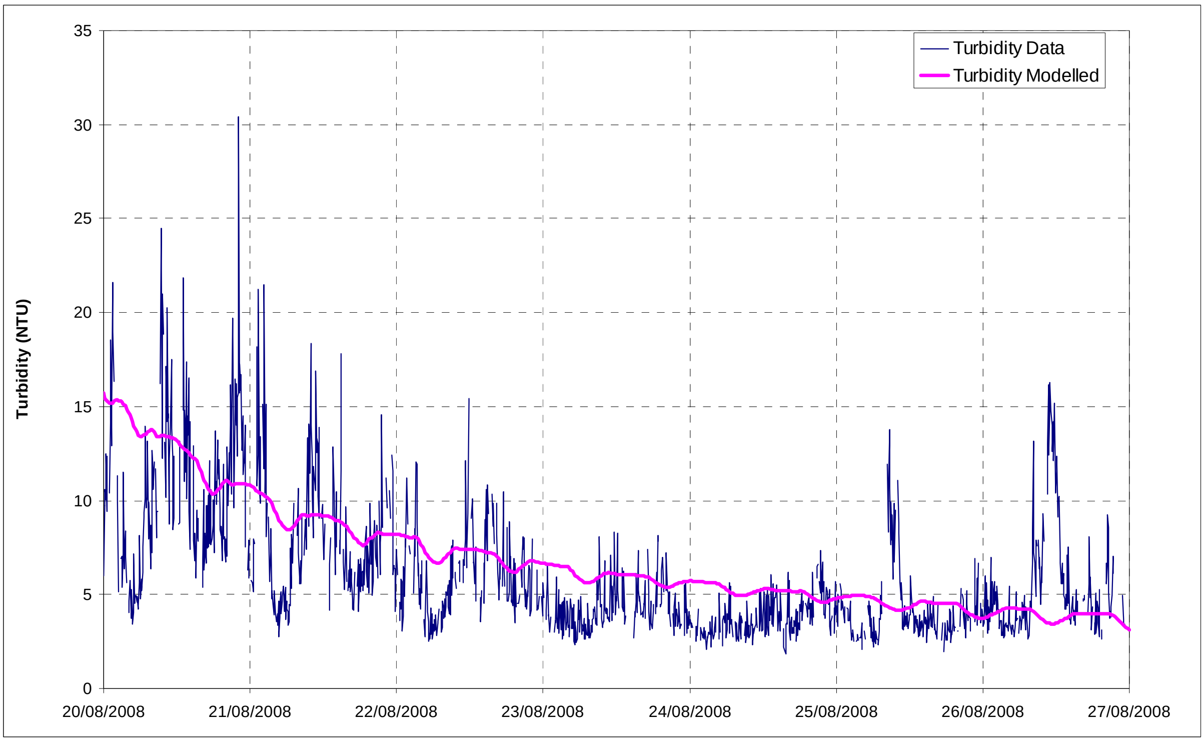


Figure 4-3 Sediment settling velocity calibration comparison

4.3 Potential Dredge Plume Impacts

All dredge plume simulations were modelled for a 2 month period from the 4/2/2009 to the 4/4/2009 using measured tidal and wind boundary condition forcing. The tidal variation at Auckland Point during this period is shown in Figure 2-3 and wind speed and direction used for forcing the model in Figure 2-4.

This period was selected based on the results of some preliminary 6-month plume simulations, which indicated that the large spring-tides during this period generated the peak far-field concentrations while the slack neap-tides during this period generated the peak mid-field concentrations.

The dredge plume simulations were superimposed to generate the four scenarios described in Section 4.2.2. The dredge plume impacts have been presented for each scenario as:

- Timeseries of plume TSS concentration in APPENDIX E:.
- Spatial plots of maximum plume TSS concentration (Figure 4-5, Figure 4-7, Figure 4-9, Figure 4-11);
- Spatial plots of 10% exceedance plume TSS concentration (Figure 4-6, Figure 4-8, Figure 4-10, Figure 4-12);
- Timeseries of plume material deposition in APPENDIX F:;
- Spatial plots of average plume material deposition rates (Figure 4-13, Figure 4-14, Figure 4-15, Figure 4-16).

Animations of the dredge plume simulations were also prepared to assist the EIS team in interpretation of results.

The percentile measures of plume TSS concentration and average sediment deposition rates were derived from the final 6-weeks of the 2 month simulation, where suspended sediment mass levels were seen to have reached a dynamic saturation level.

All results presented below are for the plume TSS level above ambient conditions. A threshold plume TSS concentration of 5 mg/L has been adopted for illustration of the plume spatial extent. Such a level is comparable to natural water column TSS concentrations in the Project Area during neap tides and is a factor 4-10 less than typical natural water column TSS concentrations in the Project Area channels during spring tides (refer Figure 4-1 and Figure 4-2).

Despite simulating TSS concentrations in excess of 100 mg/L near to the TSHD source location/s, this value was adopted as the maximum TSS contour in the spatial plume extent figures in order to retain adequate resolution of small/moderate impacts. Plume TSS concentrations in excess of 100mg/L would be approximately double the natural background TSS during spring tide conditions and more than 10-times the natural background TSS during neap tide conditions.

The mesh cells that the plume was injected into have approximate side dimensions ranging between 30-110m, which will introduce some artificial dilution into the near-field predictions of plume concentration. The model results represent plume concentrations averaged over the extent of the entire element area, whereas in reality near its source the plume will not necessarily be uniformly mixed over an entire element. Therefore higher maximum concentrations than predicted by the model are likely to be intermittently experienced in the near-field vicinity of the source for the prescribed plume loading. In the medium to far-field, the model inaccuracies due to this initial dilution will become small due to the natural flow dispersion and turbulent diffusion processes that result in horizontal mixing of the plume.

4.4 Discussion of Potential Impacts

In general, the time series plots illustrate that suspended sediment concentrations build up over about the first two weeks of the simulation and then reach a dynamic equilibrium varying on a semi-diurnal time-scale and with the magnitude of the tidal range through the spring – neap cycles. In areas close to the sediment sources, concentrations are highest during neap tides when velocities and dispersion are lowest. In far field areas, concentrations are typically highest during spring tides when the tidal excursion is great enough to advect the suspended sediment to those locations.

Maximum and 10% exceedance TSS concentrations are generally high (> 100mg/L) at the plume source/s and decrease with distance from these locations. In general the highest plume concentrations tend to be confined to the main flow channels except perhaps to the north of the extended reclamation where dumping and decant discharge operations directly impact the tidal flats.

Deposition of plume material continues gradually with varying rates again dependent on location and the tidal state. These have been converted into an average long term deposition rate for ease of comparison. The relatively high deposition rates in close proximity to the dredging sources are predominantly due to the fine sand component of the plume material settling out quickly. Much of this will be picked up by the ongoing dredging works in those areas, and hence is not of concern.

The trends observed from the four combined scenarios are outlined below. For brevity some generic comments that pertain to all scenarios are not repeated more than once.

4.4.1 Scenario 1A

- The plume impact footprint shown in Figure 4-5 and Figure 4-6 is relatively extensive due to the spatial separation of the multiple plume sources; ranging from Fisherman’s Landing, the Curtis Island berths and the Clinton Bypass;
- Maximum and 10% exceedance plume concentrations shown in Figure 4-5 and Figure 4-6 are summarised for regions of interest in Table 4-8;
- The locations of the largest sources and highest plume TSS concentrations correspond to the TSHD filling in the Clinton Bypass and the TSHD dumping and re-handling adjacent to the extended Fisherman’s Landing reclamation;
- Maximum plume concentrations occur in the channels adjacent to the dredge source. Concentrations decrease with along channel distance from the source and also generally decrease perpendicularly from the channel centreline towards the shallows;
- Sediment plumes discharged near Fisherman’s Landing on a flooding tide tend to be carried directly into the intertidal flat area to the north of the extended reclamation. Whereas, the intertidal flat area to the south of the existing reclamation does not experience such high plume concentrations on the ebbing tide;

- Average plume TSS deposition rates on the intertidal flat area to the north of the extended reclamation are generally between 0.2-1.0mm/day.

Table 4-8 Regional Summary of Plume Concentration Exceedance for Scenario 1A

Region	Maximum plume TSS (mg/L)	10% exceedance plume TSS (mg/L)
The Narrows adjacent Black Swan Island	11	5
The Narrows adjacent Friend Point	55	28
Graham Creek adjacent Laird Point	23	19
Tidal flats north of extended FL reclamation	>100	90
Tidal flats south-east of existing FL reclamation	20	16
Adjacent Boatshed Point	22	19
Shipping channel Adjacent Barney Point	75	33
Shipping channel adjacent South Trees Island	30	19
Shipping channel adjacent Gatcombe Head	11	7

4.4.2 Scenario 1B

- The multiple plume sources are all situated within the Project Area resulting in relatively high concentration build-up within this area;
- Maximum and 10% exceedance plume concentrations shown in Figure 4-7 and Figure 4-8 are summarised for regions of interest in Table 4-9;
- The largest sources are due to the TSHD filling in the Fisherman's Landing swing basin and the TSHD dumping and re-handling adjacent to the extended reclamation;
- Plume concentrations in The Narrows and Graham Creek are significantly higher for Scenario 1B than for Scenario 1A;
- Average plume TSS deposition rates on the intertidal flat area to the north of the extended reclamation are generally between 0.2-1.0mm/day.

Table 4-9 Regional Summary of Plume Concentration Exceedance for Scenario 1B

Region	Maximum plume TSS (mg/L)	10% exceedance plume TSS (mg/L)
The Narrows adjacent Black Swan Island	21	8
The Narrows adjacent Friend Point	83	47
Graham Creek adjacent Laird Point	41	28
Tidal flats north of extended FL reclamation	>100	100
Tidal flats south-east of existing FL reclamation	27	20
Adjacent Boatshed Point	30	22
Shipping channel Adjacent Barney Point	29	21
Shipping channel adjacent South Trees Island	23	11
Shipping channel adjacent Gatcombe Head	5	<5

4.4.3 Scenario 2

- As for Scenario 1B the multiple plume sources are all situated within the Project Area resulting in relatively high concentration build-up within this area;
- Maximum and 10% exceedance plume concentrations shown in Figure 4-9 and Figure 4-10 are summarised for regions of interest in Table 4-10;
- The largest sources are due to the TSHD filling in the Targinie Channel and the TSHD dumping and re-handling adjacent to the extended reclamation;

- Plume concentrations at the tidal flats to the south-east of the existing Fisherman's Landing reclamation are greater than Scenario 1A/1B;
- Average plume TSS deposition rates on the intertidal flat area to the north of the extended reclamation are generally between 0.2-1.0mm/day.

Table 4-10 Regional Summary of Plume Concentration Exceedance for Scenario 2

Region	Maximum plume TSS (mg/L)	10% exceedance plume TSS (mg/L)
The Narrows adjacent Black Swan Island	15	7
The Narrows adjacent Friend Point	53	37
Graham Creek adjacent Laird Point	28	20
Tidal flats north of extended FL reclamation	>100	95
Tidal flats south-east of existing FL reclamation	27	19
Adjacent Boatshed Point	21	16
Shipping channel Adjacent Barney Point	28	20
Shipping channel adjacent South Trees Island	20	14
Shipping channel adjacent Gatcombe Head	6	<5

4.4.4 Scenario 3

- The multiple plume sources are all situated within the Project Area at Hamilton Point and from the vicinity of the extended reclamation;
- Maximum and 10% exceedance plume concentrations shown in Figure 4-11 and Figure 4-12 are summarised for regions of interest in Table 4-11;
- The absence of the large TSHD plume sources contributes to Scenario 3 potentially creating much lower plume TSS concentrations, over a much smaller footprint than the other assessed scenarios;
- The plume from dredging near Hamilton Point tends to be advected between Hamilton Point and Tide Island towards Boatshed Point rather than remain in the main shipping channel;
- Average plume TSS deposition rates on the intertidal flat area to the north of the extended reclamation are confined to around the decant discharge at a rate generally less than 0.3mm/day.

Table 4-11 Regional Summary of Plume Concentration Exceedance for Scenario 3

Region	Maximum plume TSS (mg/L)	10% exceedance plume TSS (mg/L)
The Narrows adjacent Black Swan Island	<5	<5
The Narrows adjacent Friend Point	12	7
Graham Creek adjacent Laird Point	6	<5
Tidal flats north of extended FL reclamation	70 (adj. decant only)	58 (adj decant only)
Tidal flats south-east of existing FL reclamation	<5	<5
Adjacent Boatshed Point	13	7
Shipping channel Adjacent Barney Point	<5	<5
Shipping channel adjacent South Trees Island	<5	<5
Shipping channel adjacent Gatcombe Head	<5	<5

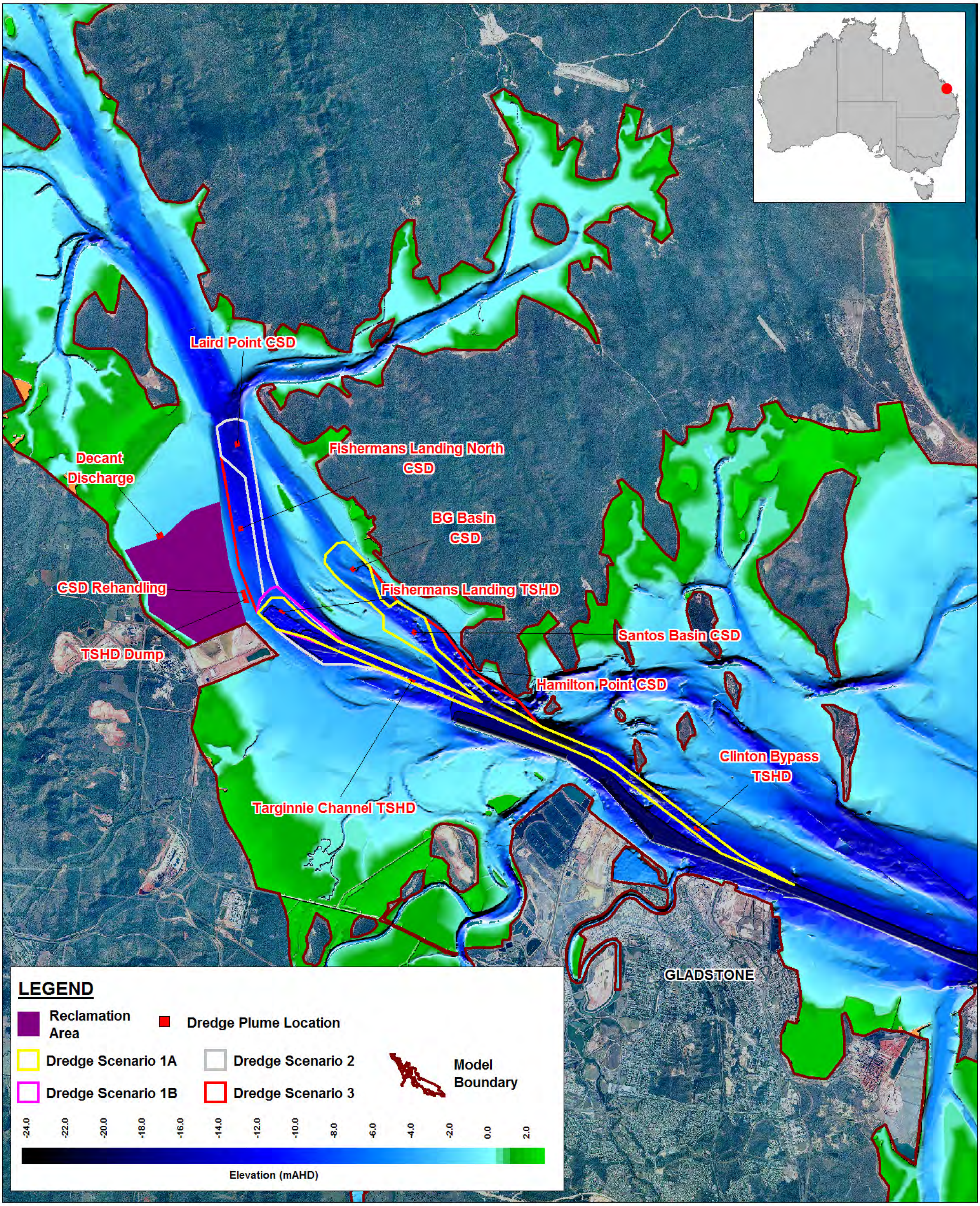
4.5 Results Sensitivity Analysis

Two additional model runs were performed for Scenario 3 in order to assess the sensitivity of the plume exceedance results to:

- The 2-month duration of the simulation and the 6-week period of results used in the percentile calculations;
- The influence of wind forcing.

A 6-month simulation corresponding to Scenario 3 was performed in order to address the former concern, with 10% exceedance levels calculated from all but the first two weeks of the simulation. The original 10% exceedance plume TSS contours for Scenario 3 are reproduced in Figure 4-17 with scaling optimised for the purposes of this sensitivity comparison. The corresponding 6-month simulation results are shown in Figure 4-18 along with the sensitivity analysis difference. It can be seen that the 2-month and 6-month plume simulation results are almost identical, indicating that the percentile exceedance results are not being unduly biased by the simulation duration.

A no-wind (2-month) simulation corresponding to Scenario 3 was also performed in order to assess the sensitivity of the results to wind-induced circulations. The no-wind 10% exceedance contours and sensitivity analysis difference are shown in Figure 4-19. In the absence of wind a slight increase by up to 2mg/L is observed in the vicinity of the Fisherman's Landing north source. There is also a slight increase in the vicinity of Boatshed Point.



Title:

Sediment Plume Source Locations

Figure: 4-4

Rev: A

N

0 2 4km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : \\wbmfs2\drafting\B17382_I_clw_Glad Strategic\DRG\COA_014_090818_Dredge_Plume_Cells.wor

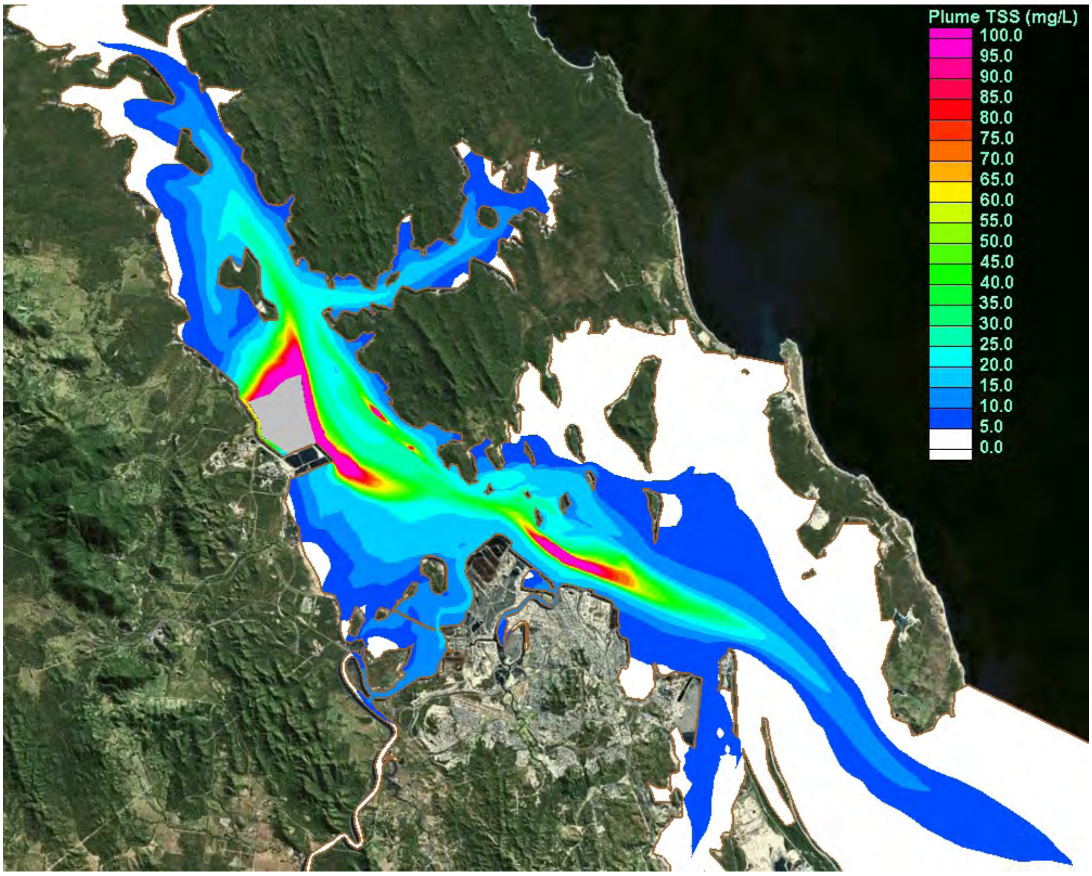


Figure 4-5 Scenario 1A maximum plume TSS concentration

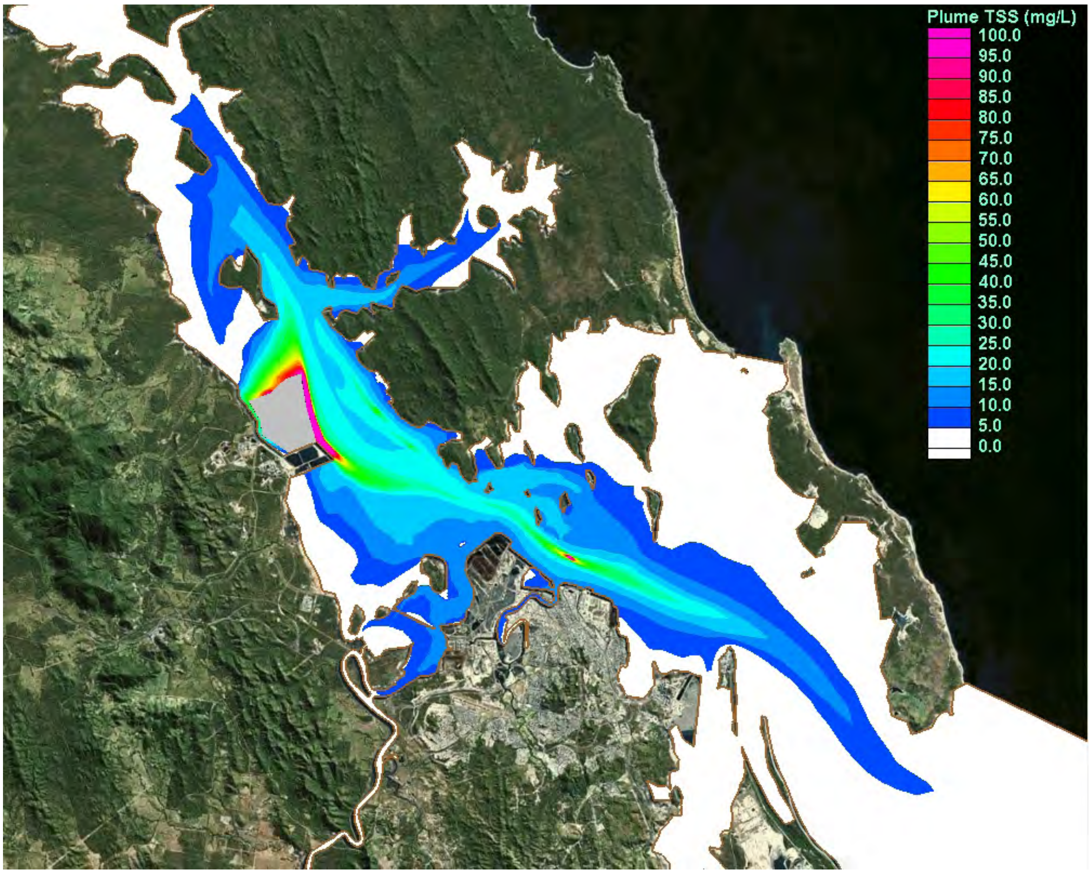


Figure 4-6 Scenario 1A plume TSS concentration exceeded 10% of the time

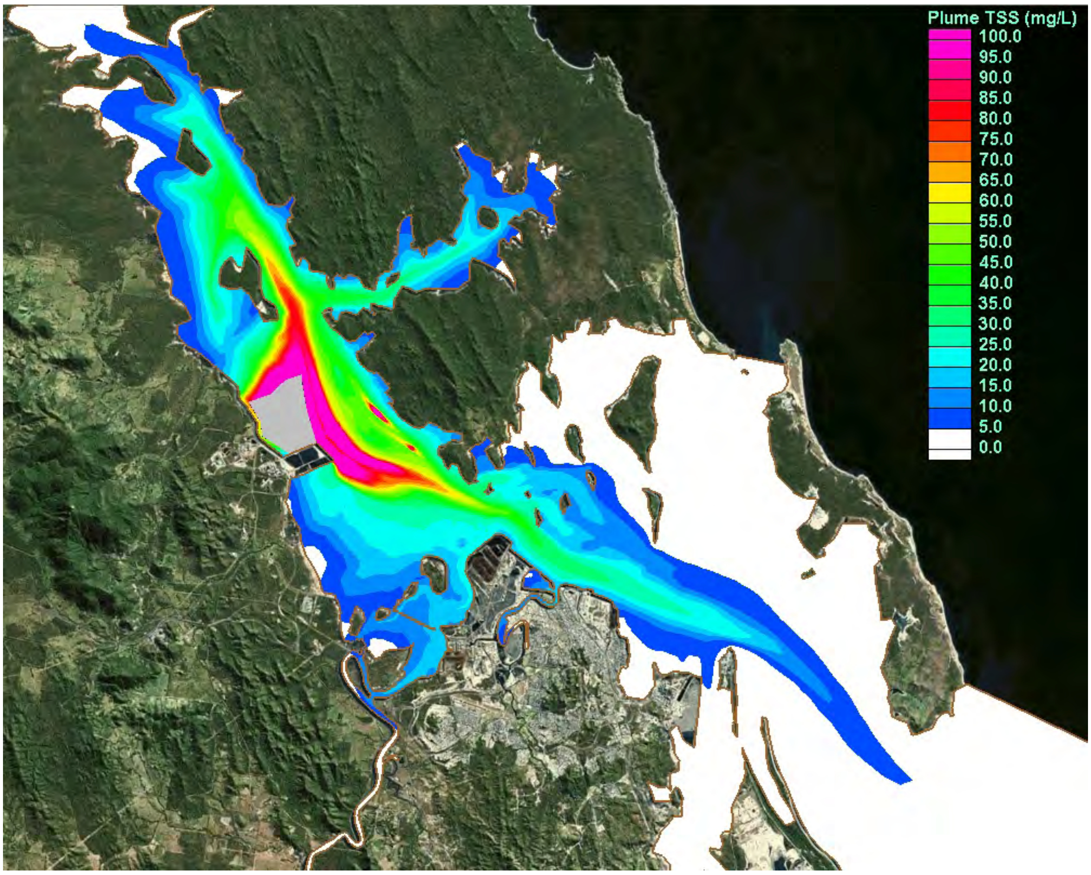


Figure 4-7 Scenario 1B maximum plume TSS concentration

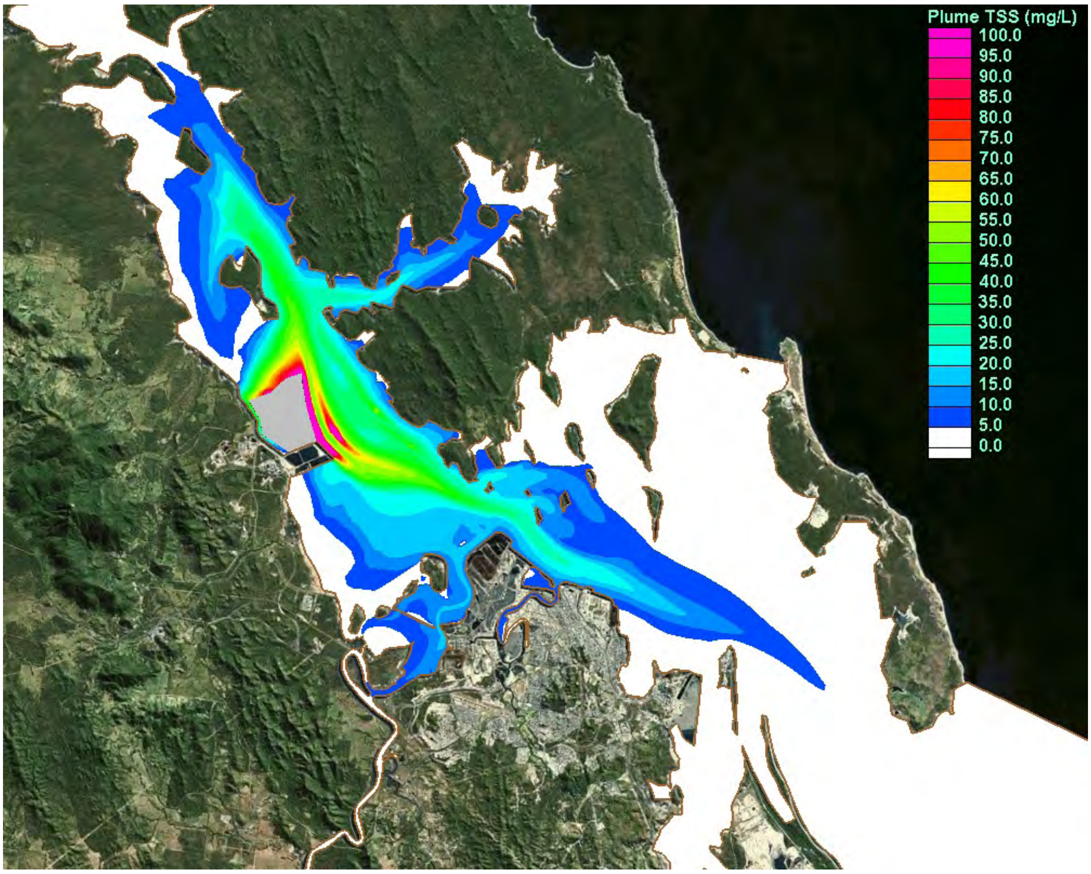


Figure 4-8 Scenario 1B plume TSS concentration exceeded 10% of the time

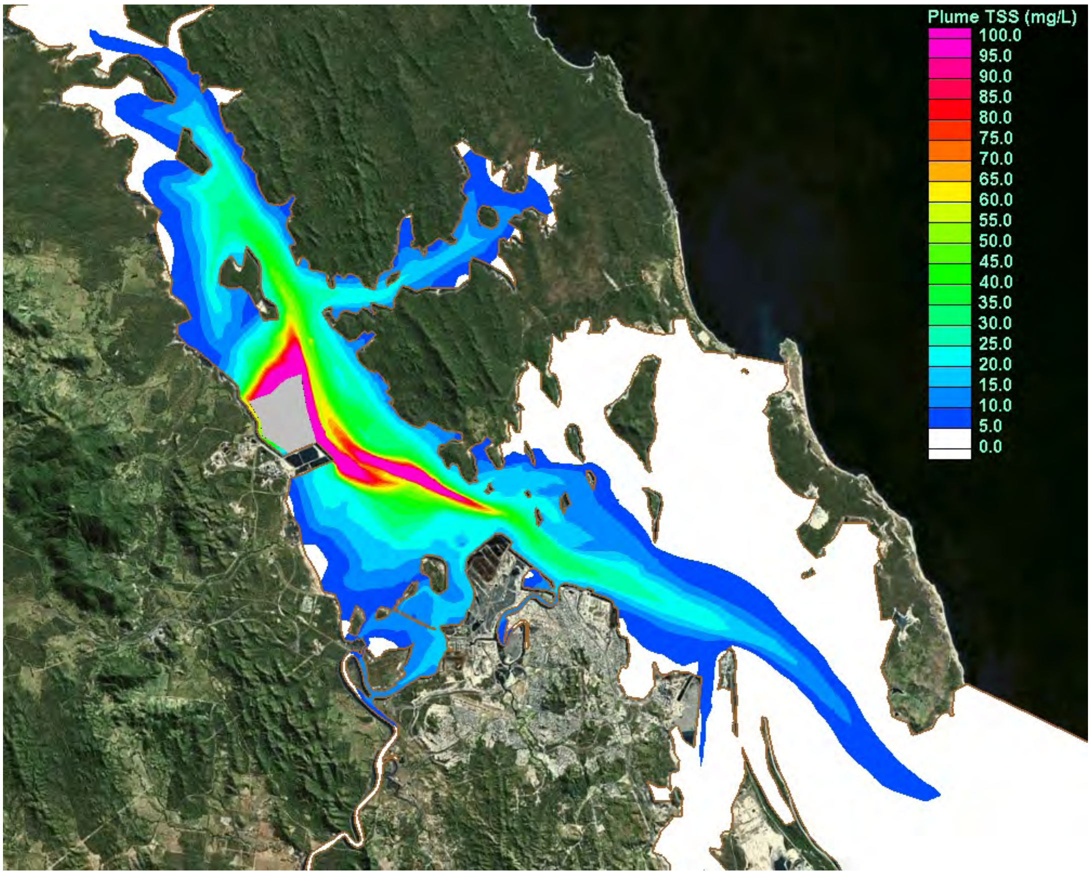


Figure 4-9 Scenario 2 maximum plume TSS concentration

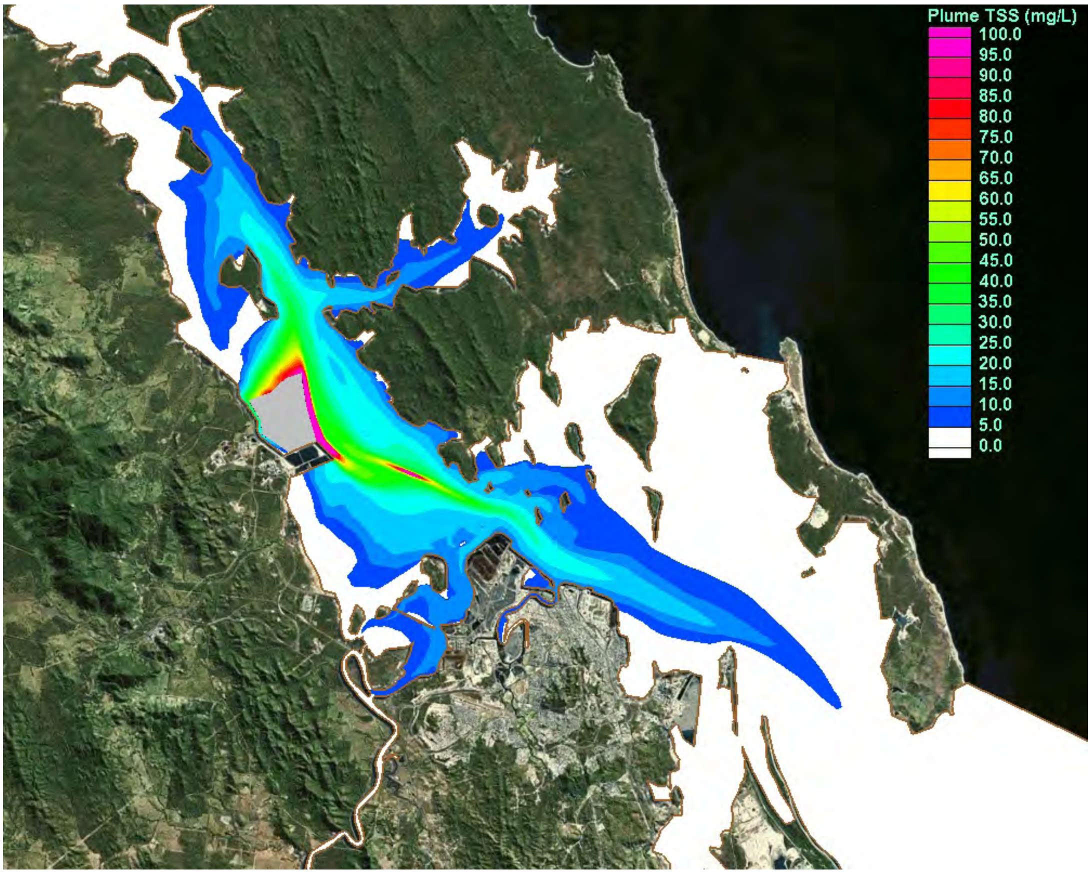


Figure 4-10 Scenario 2 plume TSS concentration exceeded 10% of the time

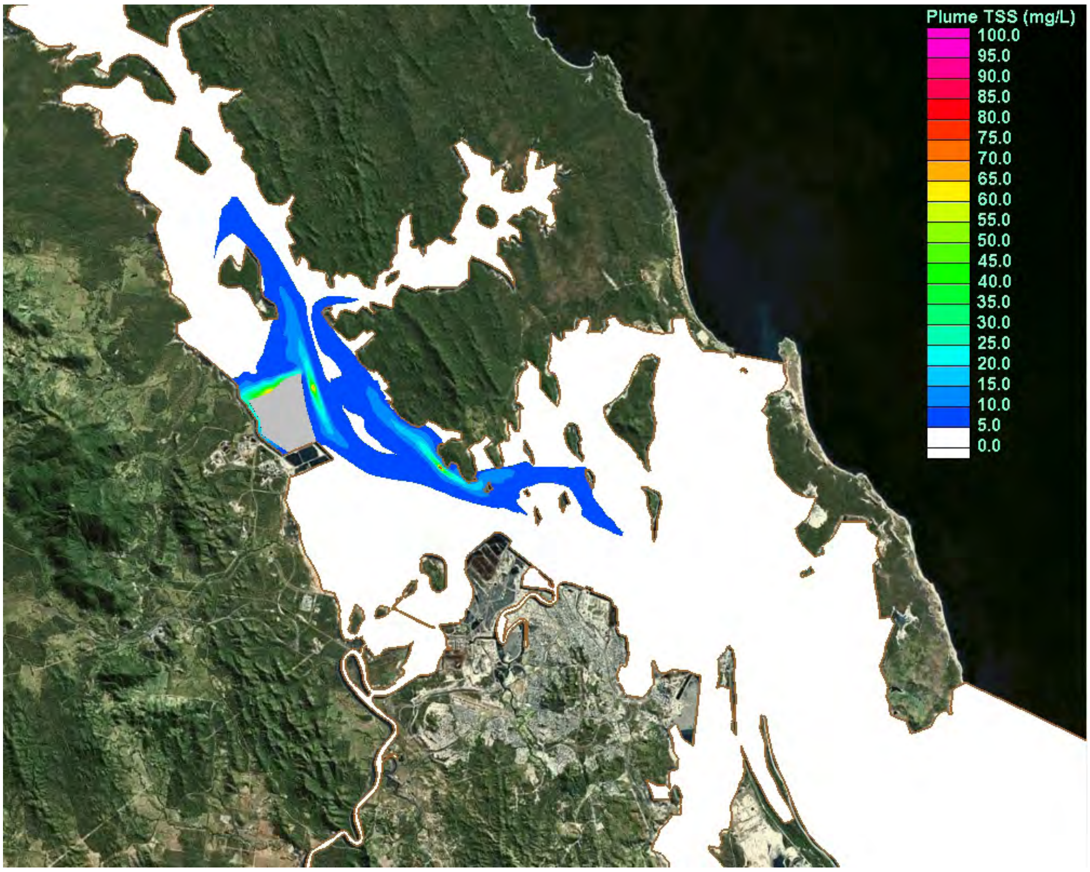


Figure 4-11 Scenario 3 maximum plume TSS concentration

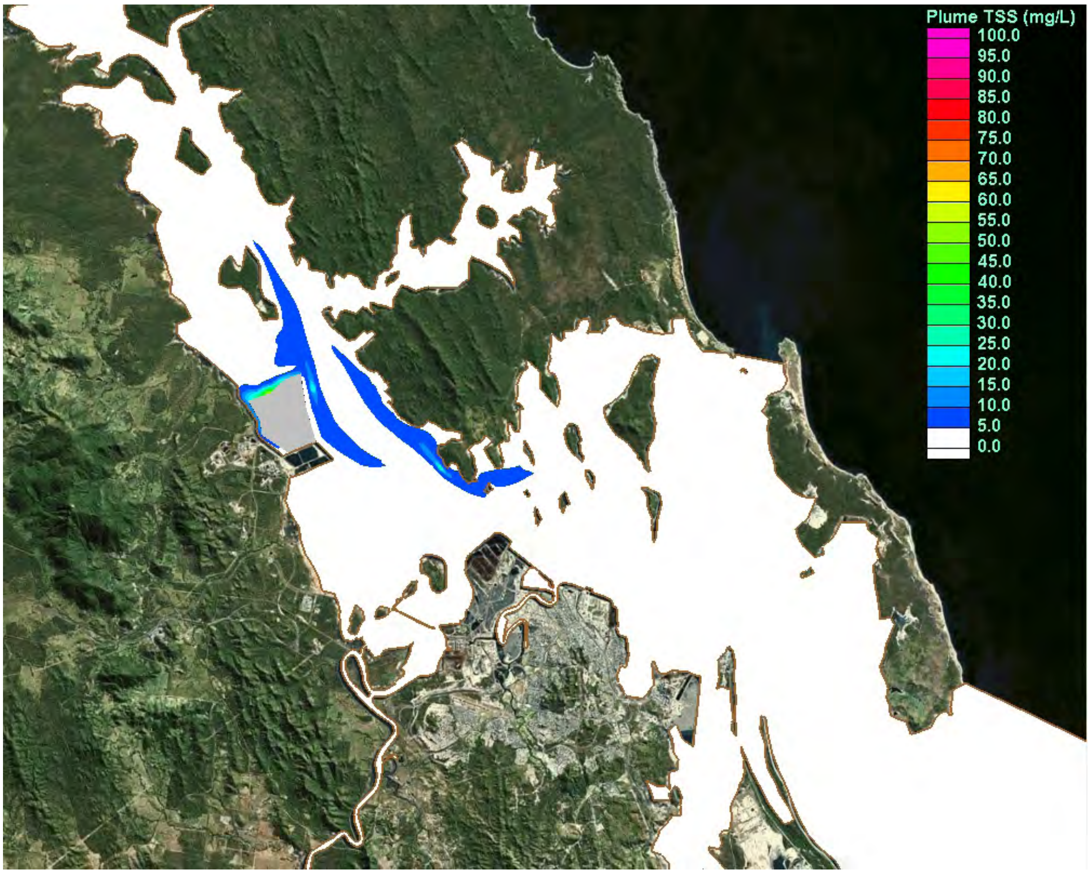


Figure 4-12 Scenario 3 plume TSS concentration exceeded 10% of the time

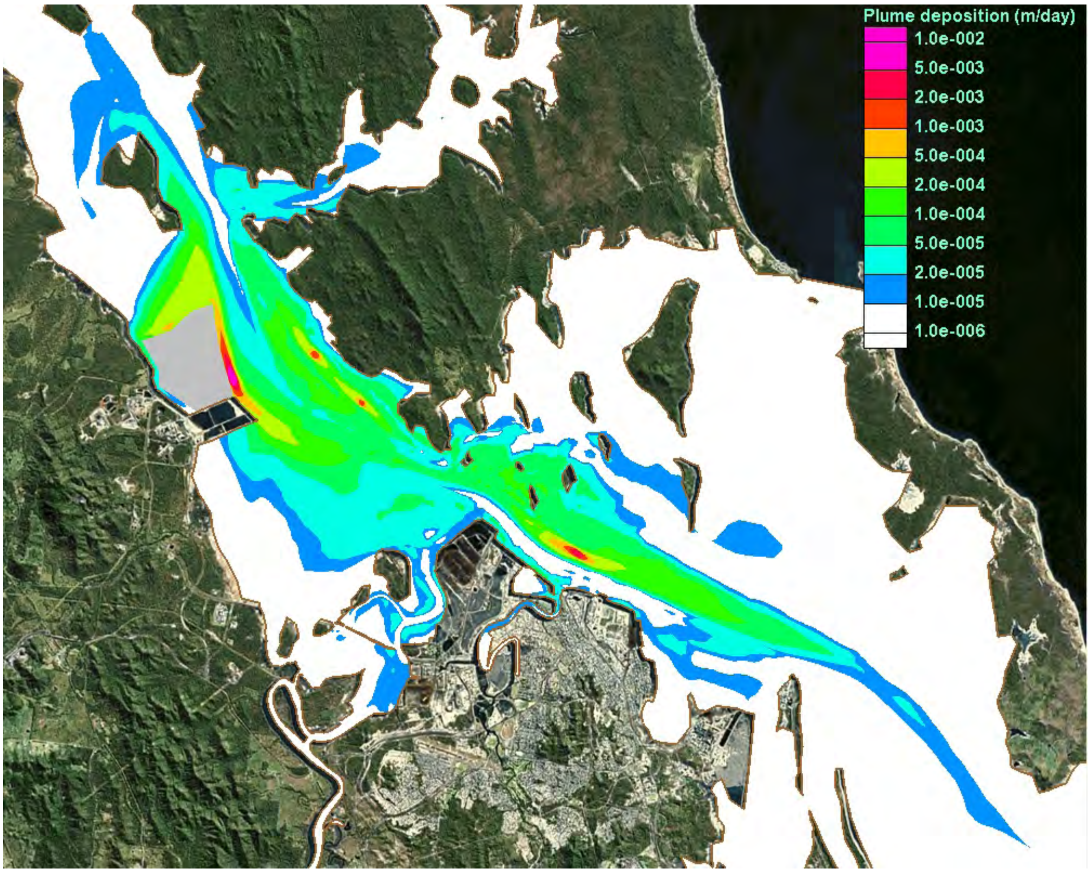


Figure 4-13 Scenario 1A average plume deposition rate

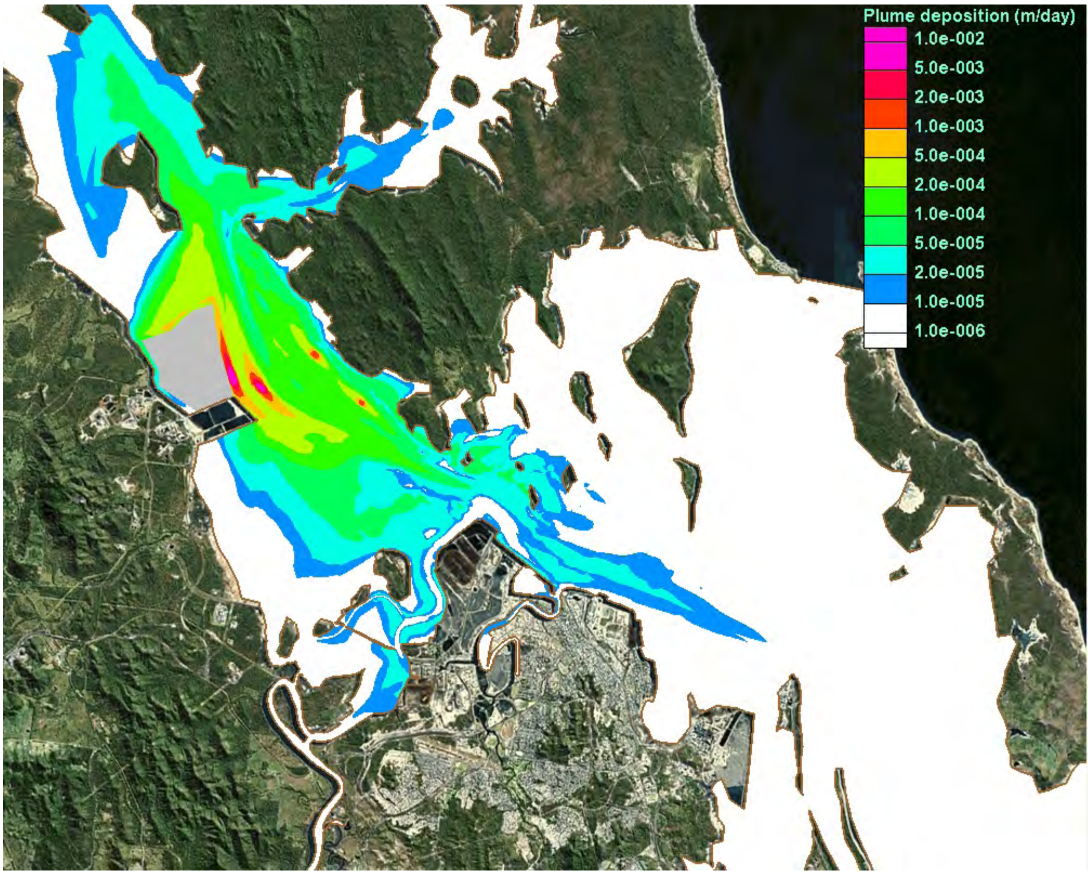


Figure 4-14 Scenario 1B average plume deposition rate

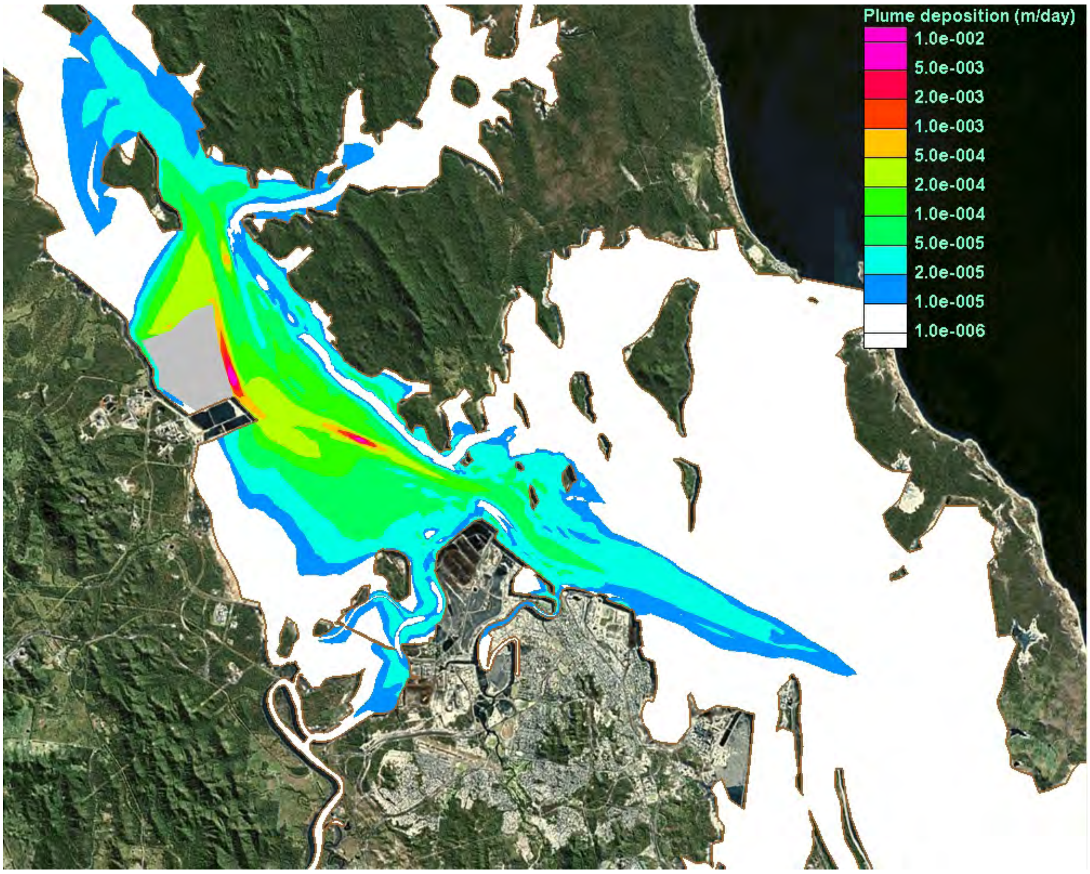


Figure 4-15 Scenario 2 average plume deposition rate

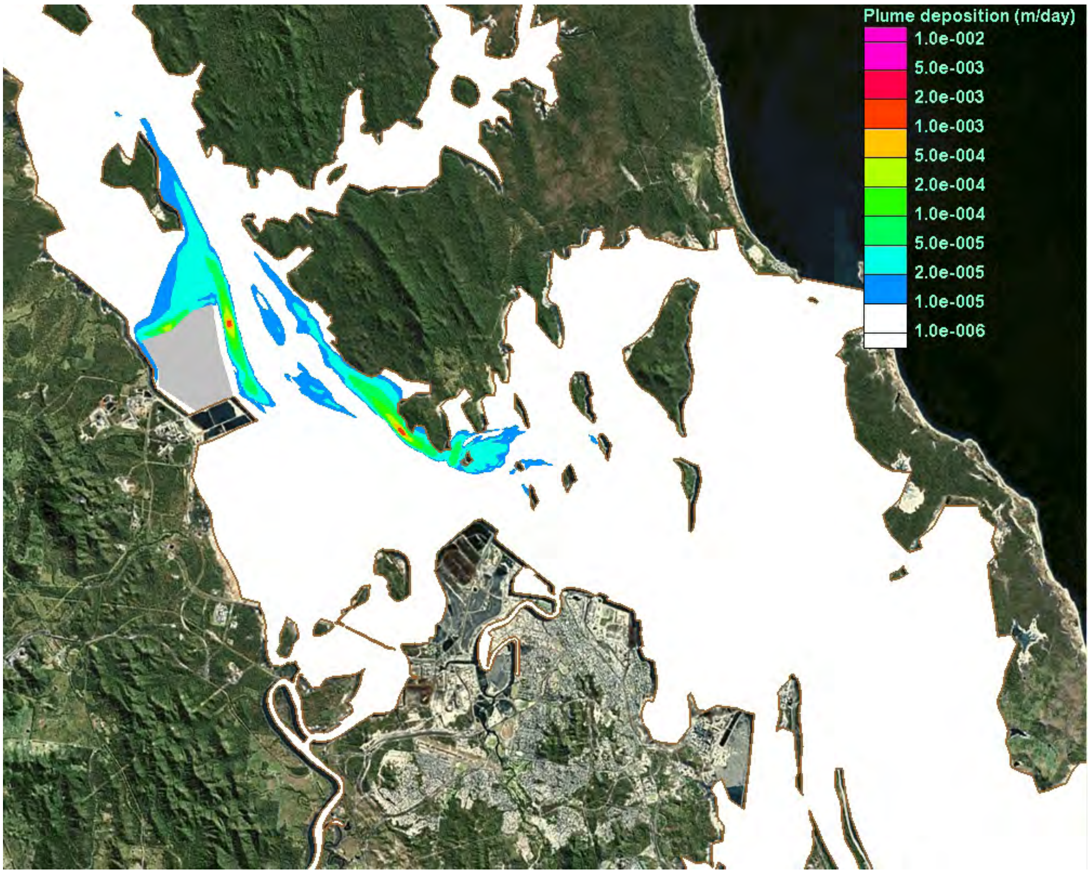


Figure 4-16 Scenario 3 average plume deposition rate

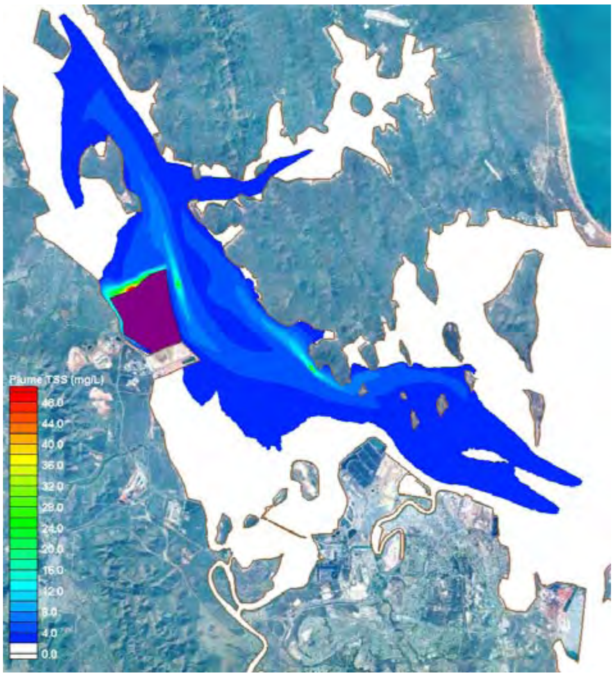


Figure 4-17 Scenario 3 10% Plume Exceedance TSS (for sensitivity comparison).

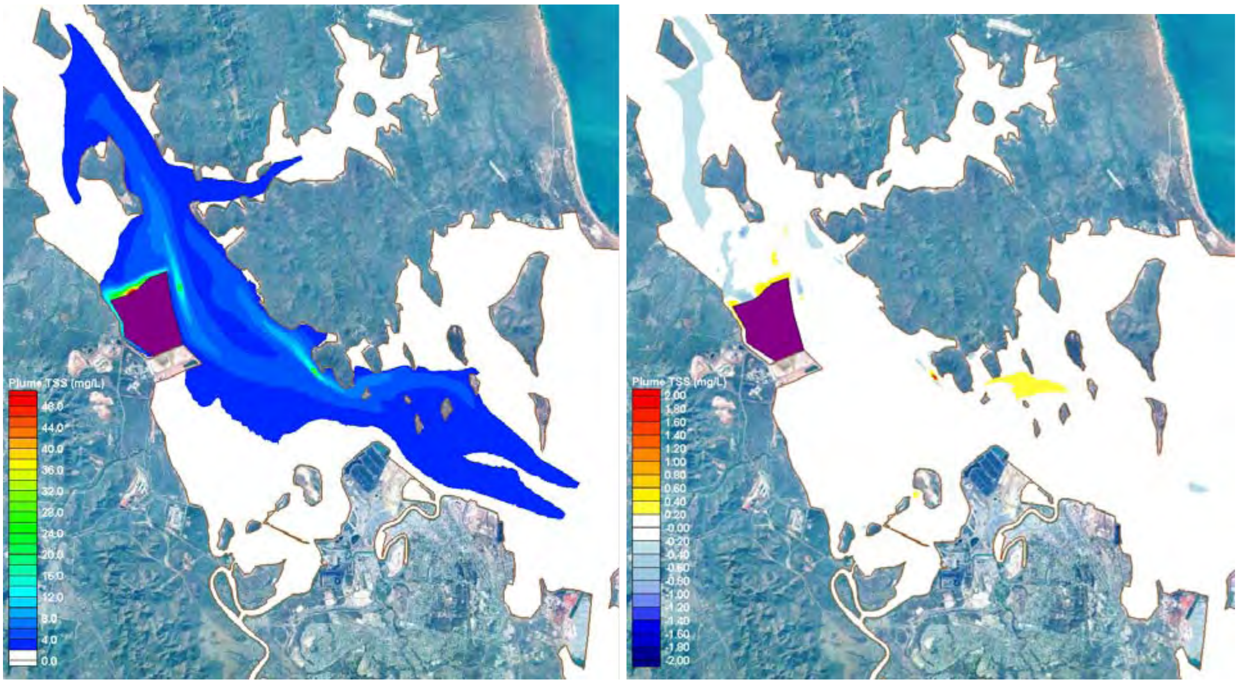


Figure 4-18 6-month Simulation Results for Scenario 3 (for sensitivity comparison)
a) 10% Plume Exceedance TSS
b) 10% Plume Exceedance TSS Difference

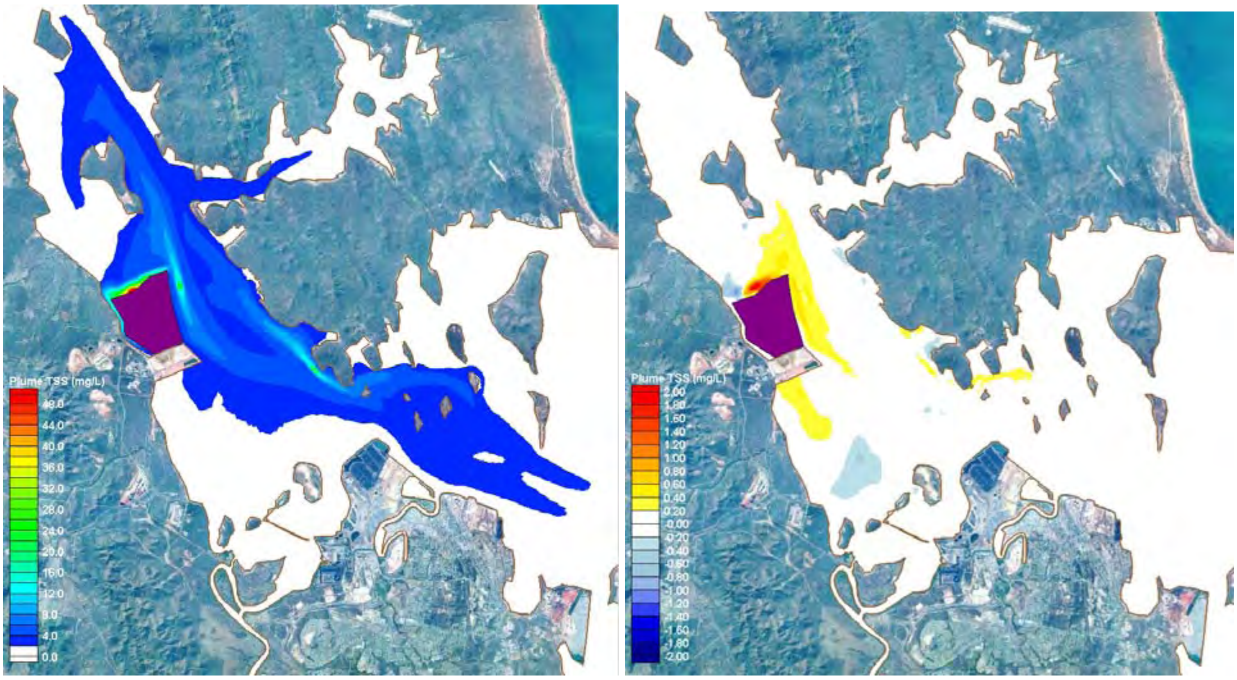


Figure 4-19 No-wind Simulation Results for Scenario 3 (for sensitivity comparison)
a) 10% Plume Exceedance TSS
b) 10% Plume Exceedance TSS Difference

5 WAVE CLIMATE

5.1 General Considerations

Wave action can be important both directly through its influence on structures as well as indirectly for coastal processes through its influences on currents and in mobilising bed sediments.

Facing and Curtis Islands effectively protect the Project Area from ocean-generated sea and swell waves. As such, it is in a sheltered estuarine environment and only exposed to locally generated waves within Port Curtis. The largest fetch lengths in the Project Area are aligned to the south-west to north-west axis. These fetch distances are all relatively short and confined to less than 10km.

5.2 Methodology

In order to assess potential impacts of various development scenarios on the local wave climate and extreme wave conditions, a wave modelling analysis was undertaken using the numerical spectral wave model SWAN. SWAN is a third generation spectral wave model that has been developed by Delft University of Technology and estimates wave parameters in coastal regions from given wind, wave and current conditions.

Two wave models were developed being a regional model and a local model. The regional model extends from the northwest corner of The Narrows to offshore of Facing Island (extent of 64km by 20km) and has a cell size of 200m by 200m. The local nested model covers an area of 7km by 7km in the Project Area and has a cell size of 50m by 50m.

The wave modelling was undertaken for four situations, namely the existing situation (Base case) and three developed scenarios as described in Section 1.4.

5.3 Potential Wave Climate Impacts

5.3.1 Extreme Waves

To assist with the design of the various facilities, extreme wave conditions throughout Project Area were determined for two design storm magnitudes, namely the 100 year ARI and 50 year ARI design storm events as supplied by GHD.

For each design storm magnitude, twelve combinations of wind (direction and speed) and water levels were modelled using the regional and local SWAN models. The combinations of wind and water level are presented in Table 5-1 and Table 5-2.

Wave conditions were derived at seven (7) locations throughout the Project Area. The locations of the output points are shown in Figure H-1 in APPENDIX H:.

Table 5-1 Modelled 100 year ARI Design Storm Conditions

Extreme Wave Scenario	Water Level [mAHD]	Wind Speed [m/s]	Wind Direction [degrees]
1	3.53	34.5	0
2	3.53	34.5	30
3	3.53	34.5	60
4	3.53	34.5	90
5	3.53	34.5	120
6	3.53	34.5	150
7	3.53	34.5	180
8	3.53	34.5	210
9	3.53	34.5	240
10	3.53	34.5	270
11	3.53	34.5	300
12	3.53	34.5	330

Table 5-2 Modelled 50 year ARI Design Storm Conditions

Extreme Wave Scenario	Water Level [mAHD]	Wind Speed [m/s]	Wind Direction [degrees]
13	3.33	31.3	0
14	3.33	31.3	30
15	3.33	31.3	60
16	3.33	31.3	90
17	3.33	31.3	120
18	3.33	31.3	150
19	3.33	31.3	180
20	3.33	31.3	210
21	3.33	31.3	240
22	3.33	31.3	270
23	3.33	31.3	300
24	3.33	31.3	330

Figures showing the wave heights and directions throughout the Project Area for Extreme Wave Scenario 1, 4 and 6 for the Base Case and Development Scenario 3 are presented in Figure G-1 to Figure G-12 in APPENDIX G:. The modelled wave conditions at each of the seven (7) output locations are presented in Table G-1 to Table G-14 in Appendix G.

5.3.2 Day to Day Wave Climate

To assess potential impacts on wave climate, the local wave climate was established for the existing Base case and the three development scenarios using the SWAN models. The local wave climate was established at seven (7) locations throughout the Project Area (Refer to Figure H-1 in APPENDIX H:).

For the establishment of the wave climate, only local wind waves generated within the basin (west of Facing Island) have been considered. The wave energy reaching the site from offshore waves has previously been assessed as negligible.

The wind input data for the model was acquired from the Bureau of Meteorology (BoM). The adopted wind conditions are based on wind records from BoM's weather station at Gladstone Radar (recorded between 1957 and 2007). To account for potential differences between wind speeds over land and over water, the wind speed of all records has been increased by 20%.

The existing and post-development wave climates at the seven (7) locations throughout the Project Area are presented in Appendix H.

The results indicate the following trends:

- The Project Area experiences a mild to moderate wave climate with a dominant wave direction from the southeast at most locations.
- For Location WBM 21 (to the east of the proposed Fisherman's Landing reclamation), the small amount of wave action from the western sector is reduced. Note that for the existing case about 81.7% of the year waves with a significant wave height of less than 0.3m are predicted. For all development cases modelled, this is predicted to increase to about 83.9% of the year.
- For Location WBM 04 (to the north of the proposed Fisherman's Landing reclamation), there is a significant reduction in wave action from the southerly sector. Also, for the developed cases there is an increase from 86.3% to 97.7% of waves less than 0.3m.
- For Location WBM 16 (further to the north of the proposed Fisherman's Landing reclamation), there is a marginal reduction in wave action from the southerly sector. It is noted that it is shallow at this location (dry during low tides).
- For Location WBM 06 (to the east of North Passage Island), there will be no significant changes in wave action for all three development scenarios. Note that there are about 91% of waves less than 0.3m for all cases.
- For Location WBM 24 (at the northern end of the Santos Swing Basin), waves from the southeast (i.e. from 120 and 150 degrees) will be marginally larger, due to the dredged channel to North China Bay. For Development Scenario 1 and 2, there is an increase from 16.2% to 18.5% of waves greater than 0.3m. For Development Scenario 3, this is predicted to increase to 18.6%.

6 SEDIMENT TRANSPORT

6.1 General Considerations

Data on the nature of the seabed sediments and those to be dredged have been obtained through previous investigations (Douglas Partners, 2005; Connell Hatch, 2006) and further specific investigations for this project. The sediments in the main channel/berth area to be dredged are a mixture of gravels, sands, silts and clays. The surface sediments in the high current areas are typically the coarser fractions with the finer particles being swept away.

The shallower inter-tidal areas are again a mixture of sands and silts with fine soft silts dominating in the lower current/wave energy areas.

Mobilisation and transport of bed sediments may occur by the combined action of waves and currents. The influence of waves is affected by water depth. Wave orbital velocities decrease with depth in a manner which depends directly on the wave period (and thus wave length). Shorter period waves have less influence at greater depth.

The short period/low wave height conditions in the Port are such that wave action does not play a significant role in sediment transport processes in the deeper channels. However, the small waves can be important in mobilising the fine sediments in the shallower areas. Once mobilised, these fine sediments are carried in suspension by the prevailing currents and will settle again typically in areas of lower wave/current energy and/or when prevailing conditions moderate.

6.2 Methodology

The potential sedimentation impacts of the proposed reclamation and dredging works have been assessed through the assessment of changes to sediment mobilisation and transport potential. The results of the hydrodynamic modelling assessment have been used as the basis for these determinations (see Section 2). The potential impacts have also been considered in terms of the coarser sand size fractions and siltation due to the settling of fine sediments transported in suspension. Further discussion of the methodology of each of these is provided in the impacts section below.

6.3 History of Dredging and Siltation

Knowledge of the history of dredging and siltation is important with respect to the potential mobility of the sediments and likely future siltation rates. The nearby Targinie and Clinton Channels as well as the Fisherman's Landing swing basin and berth pockets are maintained at various depths for navigation purposes.

Maintenance dredging is typically carried out in the Port on an annual basis in different areas as needed. Table 6-1 presents details of maintenance dredging in the vicinity of the site over the last seven years as determined from dredge log details provided by the Port of Brisbane Corporation (who undertake the dredging). Various capital (development) dredging works have also been carried out during this period.

Table 6-1 Historical Dredging Quantities

Location	Dredging Quantities (m^3)						
	2007	2006	2005	2004	2003	2002	2000
Clinton Berths	3,800	7,600	10,300 (3 berths)	9,700 (3 berths)	3,150 (3 berths)	-	2,000 (2 berths)
Clinton Bypass Ch.	3,900	2,500	800	14,500	DEV+MAINT[1]	-	DEV+MAINT[4]
Clinton Swing Basin	4,200	4,300	5,300	7,800	400	-	1,000
Targinie Ch.	14,600	17,600	12,300	42,500	DEV[2]	DEV[3]	3,600
Targinie Swing	4,400	3,900	1,900	-	-	-	-
Fisherman's Landing Berth	-	1,900	-	-	1,400	6,500	600
TOTAL	30,900	37,800	30,600	74,500	-	-	-

Source: Port of Brisbane Corporation 1) 320,000 2) 95,000 3) 380,000 4) 46,400
Notes: Development is extra to maintenance
All volumes are in-situ cubic metres (tons dry/1.3)
Total sedimentation volume is not for whole of Port Curtis.

The relatively small quantities of maintenance dredging reflects minimal siltation. This in turn is an indicator that there is limited sediment transport and/or that the currents/ship movements are sufficient to keep the sediments in suspension and not settle out in the dredged areas. Examination of historical hydrographic surveys also confirms that in general siltation of the channels and swing basins occurs at a rate of around 1 to 5 cm/annum. At a couple of siltation “hotspots”, for instance a section of the Targinie Channel adjacent to the passage island shoals, siltation may occur at a slightly higher rate of up to around 10 cm/annum.

6.4 Bed Shear Stress Impacts

To aid the assessment of the potential for mobilisation and deposition of fine silts, bed shear stresses have been calculated throughout the model domain over the full two month simulation period. Bed shear stresses less than about 0.1-0.5N/m^2 will generally result in deposition of fine silts in suspension while higher stress will resuspend and keep fine sediments in suspension.

Time series of bed shear stress for the four simulations were extracted at the 28 locations throughout the model illustrated in Figure 1-7. Plots of the bed shear stress time series at each location are presented in APPENDIX I: for 4 days of the largest spring tidal period during the model simulation. Each plot illustrates the bed shear stress for the base case and the three design scenarios at that location to allow direct comparison and visual assessment of impacts. Some locations are in shallow areas which dry at low tide as evidenced by extended periods with zero bed shear stress.

Spatial plots of 5% exceedance bed shear stresses for the base case and each developed scenario as well as the impacts of each scenario relative to the base case are presented below in Figure 6-1 to Figure 6-7. The 5% exceedance bed shear stresses in the channel areas are typically high. During neap tides, the bed shear stresses in the channels are typically at or below the threshold for deposition. However during spring tides, the bottom stresses in the channel are much greater and as such the fine sediments will not be stable deposits in the long term. This is consistent with observations of limited fine material in the main channel. As could be expected, in the shallower less dynamic areas where velocities are lower, the bed shear stresses are typically low and this is consistent with the natural deposition of fine material in these areas.

The dredging tends to reduce bed shear stresses directly in the dredged areas where depths are greater and velocities less as well as laterally adjacent areas where velocities are reduced. For Scenario 1, maximum bed shear stresses increase in the undredged channel areas where velocities increase upstream of the dredged areas. For Scenarios 2 and 3, there are small areas of increased bed shear upstream of the BG swing basin and on the adjacent shoal.

In all developed scenarios, there is a zone of increased bed shear stresses in the shallow area adjacent to the north eastern edge of the reclamation. The surface sediments in this area are expected to be fine cohesive material and the increased bed shear stresses (~0.4N/m^2) would be expected to induce scouring. It should be noted that the base case scenario exhibits a similar zone of increased bed shear stress at the north-eastern tip of the existing reclamation. For the developed scenarios the location of this zone is shifted to the north-eastern tip of the extended reclamation, shear stress magnitudes increase by around 40% and the size of this zone is similarly increased.

The implications of the predicted bed shear stress changes in terms of changes to sand transport potential and fine-sediment siltation are considered and described in Section 6.5.

6.5 Potential Sedimentation Impacts

6.5.1 Sand Transport Potential

Assessments of sand transport potential and tidal current generated bed shear stresses have been undertaken in order to facilitate an assessment of morphological changes induced by the proposed reclamation and dredging scenarios.

The potential for sand transport under tidal current action has been estimated by applying the Meyer-Peter-Muller bed load formula (Nielsen, 1992) to the simulated hydrodynamic results detailed in Section 2. It should be noted that the sediment transport potential calculations assume that the bed is uniformly mobile with a sand sized sediment grain size of 1mm and hence do not account for the presence of non-erodable rocky outcrops. Sand transport potential fluxes have been calculated at each computation point in the model with units of m^3/year/m of bulk sand transport as described in further detail below.

During large spring tides, the strong ebb tide currents generate a high sediment transport potential to the southeast. The flood tide currents are somewhat weaker and generate less sediment transport potential. The potential for sand transport in the Project Area is considerably lower than experienced at the Clinton Wharves, further to the south-east, where currents are constricted between Hamilton Point and the Calliope River mouth.

Net sand transport potential was estimated by averaging the results over two consecutive spring-neap tidal cycles. The results for the base case are shown in Figure 6-8. The sand transport potential estimates have been expressed and illustrated as a bulk volumetric flux density; that is the magnitude of the transport potential is the net bulk volume of sand transport per unit width at each computation point averaged over a 12 month period and has units of m^3/year/m (shown in the contour legend as m^2/year). The net sand transport is generally in the ebb tide direction due to the abovementioned asymmetry in the tidal currents.

The net sand transport potential for the three developed case scenarios are shown in Figure 6-9, Figure 6-11 and Figure 6-13. The net sand transport potential impacts relative to the base case for these three scenarios are shown in Figure 6-10, Figure 6-12 and Figure 6-14.

The modelled sedimentation (sand-sized material only) of a number of existing and proposed dredged areas has been calculated by integrating the boundary-normal component of the sand transport potential flux density along the boundaries to these areas, yielding a volumetric rate of net sediment accumulation in m^3/year. The modelled net (sand-size) transport that is expected to become trapped in the dredged areas is summarised in Table 6-2.

It should be noted that estimates for the Clinton Swing Basin/Bypass, and Wiggins Coal terminal are probably overly high due to the calculations being based upon transport potential whereas in reality these figures would be reduced due to the presence of coarser material and/or immobile reef structure.

Table 6-2 Modelled Net Sand-size Sediment Transport Potential into Dredged Areas

Sedimentation m^3/year	Base Case	Scenario 1	Scenario 2	Scenario 3
Clinton Swing Basin	40,000 (20,000 – 80,000)*	33,000 (16,500 – 66,000)	33,000 (16,500 – 66,000)	33,000 (16,500 – 66,000)
Wiggins Coal Terminal Basin	68,000 (34,000 – 136,000)	44,000 (22,000 – 88,000)	40,000 (20,000 – 80,000)	35,000 (17,500 – 70,000)
Clinton Bypass Channel	32,000 (16,000 – 64,000)	33,000 (16,500 – 66,000)	25,000 (12,500 – 50,000)	24,000 (12,000 – 48,000)
Targinie Channel**	2,400 (1,200 – 4,800)	4,200 (2,100 – 8,400)	3,600 (1,800 – 7,200)	3,000 (1,500 – 6,000)
Fisherman's Landing**	7,200 (3,600 – 14,400)	4,700 (2,350 – 9,400)	1,800 (900 – 3,600)	400 (200 - 800)
BG/Santos Access Channel**		1,400 (700 – 2,800)	1,100 (550 – 2,200)	700 (350 – 1,400)
Santos Swing Basin**		3,000 (1,500 – 6,000)	2,000 (1,000 – 4,000)	100 (50 - 200)
BG Swing Basin**		4,700 (2,350 – 9,400)	2,300 (1,150 – 4,600)	2,800 (1,400 – 5,600)
Laird Point Swing Basin**			13,000 (6,500 – 26,000)	9,300 (4,650 – 18,600)
Total	150,000 (75,000 – 300,000)	128,000 (64,000 – 256,000)	122,000 (61,000 – 244,000)	108,000 (54,000 – 216,000)
Total Hamilton Pt. to Laird Pt. Only	9,600 (4,800 – 19,000)	18,000 (9,000 – 36,000)	24,000 (12,000 – 48,000)	16,000 (8,000 – 32,000)

* Likely error bounds.
** Included in project area (Hamilton Point to Laird Point) total.

6.5.2 Sand Transport Potential Impacts

The base case net sand transport is generally in the ebb tide direction due to the ebb-dominant asymmetry in the tidal currents. Potential sand transport is confined to the channels, where current speeds are sufficient to mobilise coarse sand sediments. The magnitude of net transport potential generally increases with distance downstream, and is much higher in the Project Area than in the Narrows and is correspondingly much higher around the Clinton Wharves than in the Project Area. Within the Project Area, the net sand transport potential is generally higher within the Targinie Channel to the west of the Passage Islands than in the "Curtis" Channel to their east.

The Scenario 1 impacts on net sand transport potential include an increase in the ebb-dominant transport in the channels upstream of the dredging to Fisherman's Landing. Downstream of

Net transport potential into the downstream swing basins (Clinton Swing Basin, and Wiggins Coal Terminal Basin) are significantly reduced by between 17%-35% for Scenario 1 and are marginally further reduced in Scenario 2 and 3. This is due to a reduction in current speeds and hence bed shear stresses due to the combined effects of reclamation and dredging on the system hydrodynamics. As mentioned above, the net transport potential into these areas may be overstated by the assumption of 100%-mobile, uniformly-graded sand, and therefore the predicted reductions are likely to be over-estimated.

Net transport potential into the Clinton Bypass is marginally increased in Scenario 1, which involves further dredging of this channel. In the subsequent stages, the net transport potential is reduced by around 25%. As mentioned above, the net transport potential into the Clinton Bypass channel may be overstated by the assumption of 100%-mobile, uniformly-graded sand, and therefore the predicted reductions may likewise be over-estimated.

Net sand transport potential into the Targinie Channel is increased by 75% in Scenario 1 which involves additional dredging to widen this channel. Subsequently, Scenario 2 and 3 slightly reduce the transport potential into the Targinie Channel (relative to Scenario 1), however this remains increased relative to the base case.

The Fisherman's Landing swing basin experiences a 35% reduction in potential sand siltation in Scenario 1 due to the general reduction in transport potential seen in its vicinity in Figure 6-10. Much greater reductions are expected for Scenario 2 and Scenario 3 due to the additional dredging upstream, which further acts to reduce local transport potential as well as intercepting incoming transport from the north.

In Scenario 1 the proposed dredged areas along the Curtis Island foreshore are predicted to experience coarse material sedimentation of around 9,100m^3/year (4,500-18,000 error bounds). Relative sedimentation hotspots can be qualitatively identified by inspection of the sand transport potential patterns in Figure 6-9 and include:

- Northern end of Fisherman's Landing swing basin;
- Northern end of the BG swing basin; and
- Northern end of the Santos swing basin.

At these locations sand transported into the dredged area is expected to be deposited near the bottom of the batter. The peak sedimentation rates are expected to be in line with or possibly less than those experienced at the current port operation areas, that is generally rates of no more than 1 to 5cm/annum and up to 10cm/annum at a few localised hotspots.

In Scenario 2 the predicted rate of sedimentation into these proposed dredged areas along Curtis Island reduces to 5,400m^3/year (2,700-10,800), however there is also an additional 13,000 (6,500-26,000) sedimentation predicted to occur into the Laird Point Swing Basin. Inspection of Figure 6-11 indicates that the northern end of the Laird point swing basin is an additional potential sedimentation hotspot.

In Scenario 3 the predicted rate of sedimentation of the dredged areas along Curtis Island reduces further to 3,600m^3/year (1,800-7,200) and the Laird Point swing basin is predicted to experience a reduced sedimentation of 9,300m^3/year (4,700-18,600).

The total potential sedimentation rate of all the dredged areas considered in Table 6-2 is predicted to reduce by 15% in Scenario 1 and by 28% in Scenario3. However, this result should be treated with caution as it is dominated by the predicted reductions to sedimentation in the existing downstream swing basins/channels, which are expected to be over-estimated for the reasons stated above. Additional sand-sized sedimentation is predicted to occur in the Project Area for all of the developed scenarios due to the expanded dredge footprint.

6.5.3 Silt Deposition

Assessments of potential silt deposition were undertaken for the base case and three developed scenarios described in Section 1.4. The following calculation procedure was used to assess the net rate of silt deposition/erosion across the model domain:

- A synthesised fortnightly variation in water-column turbidity was derived from continuous nephelometer timeseries collected adjacent to Fisherman's Landing in August 2008, and is shown in Figure 6-15;
- The synthesised turbidity was converted to an equivalent TSS using the derived relationships shown in Figure 4-2;
- Modelled bed shear stresses discussed in Section 6.4 were used in conjunction with the assumed water column TSS to calculate the erosion/deposition potential at each point in the model for the 2 month hydrodynamic simulation period. The following relationships were used to calculate the erosion/deposition rates:
  - o Deposition: $$Q_d = w_s.TSS.\max\left(0,\ 1-\frac{\tau}{\tau_{cd}}\right)$$

  Where, Q_d is the deposition rate, w_s the sediment settling velocity, τ is the bed shear stress and τ_{cd} is the critical bed shear stress for deposition.

  - o Erosion: $$Q_e = E.\max\left(0,\ \frac{\tau}{\tau_{ce}}-1\right)$$

  Where Q_e is the erosion rate, E is the Erosion rate constant and τ_{ce} is the critical bed shear stress for erosion.

- The net erosion/deposition was evaluated for the 2 month simulation period and converted into an annual rate of deposition. A dry density of 450kg/m^3 was used to convert the mass deposition rates into an equivalent depth.

The following parameter values were assumed in this assessment; w_s = 4.0e-5 m/s; τ_{cd} = τ_{ce} = 0.5 N/m^2; E = 0.02 g/m^2/s. The assumed deposition parameters are consistent with observed rates of sediment settling in the Project Area (refer Section 4.2.5 and Figure 4-3). The erosion parameters are based upon literature values along with some parameter tuning to match the expectation that fine silt doesn't accumulate in the channels to the east of the Project Area.

The level of uncertainty surrounding the various assumptions made in the silt deposition assessment (i.e. the synthesised TSS variation and the erosion/deposition parameter values, along with the absence of appropriate calibration/validation measurements) means that the results should be treated as being qualitative/semi-quantitative. These assumptions could be re-visited and the quantitative certainty of the results increased given additional long-term continuous turbidity and sedimentation rate data from sites around the project area, which could be used to calibrate/validate the analysis procedure and input parameters.

The patterns of predicted net silt deposition are shown for the base case in Figure 6-16, and for the three developed scenarios in Figure 6-17, Figure 6-18 and Figure 6-19. Predicted rates are not shown in areas below -2m LAT as the analysis procedure described above is believed to be inaccurate in shallow waters due to over-predicting the sediment concentration (and hence deposition flux) and not accounting for wave re-suspension mechanisms.

6.5.4 Silt Deposition in Dredged Areas

In the base case (Figure 6-16) there is little or no net deposition of fine silt material predicted to occur in the channels downstream of the Project Area. Nor is there fine silt material deposited within the Targinie Channel and its extension towards Laird Point, nor in the “Curtis” channel adjacent to China Bay. Fine silt material is predicted to deposit to varying extents along the various channel fringes and along the western side of the existing Fisherman’s Landing swing basin. The “Curtis” Island channel upstream of South Passage Island and China Bay is also predicted to experience net deposition of fine cohesive sediments.

The predicted volumetric rates of (fine) silt accumulation in the project dredged areas is summarised in Table 6-3. Note that the predicted values in this table should only be treated as indicative due to the calculation uncertainties discussed above.

Total base case silt deposition occurring in the Fisherman’s Landing swing basin is predicted to be 15,000m^3/year. It would appear from maintenance dredging logs (Table 6-1) that this modelled rate is probably a conservative estimate of the existing fine-sediment siltation rate at Fisherman’s Landing. It should also be noted that there is no net silt deposition predicted within the Targinie Channel or further downstream dredged areas due to the high current speeds and associated bed shear stresses. This absence of fine silt deposition in these areas is consistent with historical observations.

In Scenario 1 the following changes are observed to the patterns and rates of fine silt material deposition:

- The newly dredged BG swing basin experiences siltation rates of up to 0.08m/year particularly in the western corner and along the Curtis Island foreshore;
- The BG swing basin is predicted to accumulate 56,000m^3/year of silt across its extent;
- The newly dredged Santos swing basin also experiences considerable silt deposition at a rate of 41,000m^3/year, particularly along the China Bay and South Passage Island sides;
- The Fisherman’s Landing swing basin experiences significantly more fine silt material deposition than was previously the case (52,000m^3/year compared with 15,000m^3/year in the base case);
- The total net silt deposition into dredged areas is 152,000m^3/year (up from 15,000m^3/year in the base case).

In Scenario 2 the Fisherman’s Landing swing basin siltation rate is predicted to increase (to 66,000m^3/year) due to the further widening and deepening of the dredged depth. There is also expected to be a marginal increase in the siltation of the BG/Santos swing basins and approach channel. The Laird Point Swing basin and approach channel are predicted to only experience a fairly low level of fine material siltation due to the natural deepness of these areas and the existing high current speeds that occur in them. The total net silt deposition in project dredged areas is 180,000m^3/year under Scenario 2.

In Scenario 3 the additional dredging along Curtis Island is expected to increase net siltation of the BG/Santos swing basins and access channel including Hamilton Point berths by a further 23,000m^3/year (relative to Scenario 2). The dredged berth's along the extended Fisherman's Landing reclamation are expected to experience fine material siltation, which (including the Laird Point Swing Basin) totals 58,000m^3/year. The total net silt deposition in project dredged areas is 255,000m^3/year under Scenario 3 (up from 15,000m^3/year in the base case).

The significant (17x) increase in fine material siltation of dredged areas is due to:

- The much larger dredged area footprint in the developed cases;
- The fact that this dredge footprint occurs largely in a region of lower tidal flow energy than the existing port channels; and
- The further decrease in tidal velocities due to the dredging associated with the developed cases.

Sedimentation rates of up to 0.08m/year occur at siltation hotspots within the dredged areas. Therefore a 0.3m over-dredging allowance should accommodate 3+ years of sedimentation between maintenance dredging campaigns.

Table 6-3 Modelled Net Silt Deposition into Dredged Areas

Sedimentation m^3/year	Base Case	Scenario 1	Scenario 2	Scenario 3
Fisherman's Landing	15,000	52,000	66,000	69,000
BG/Santos Access Channel	-	3,000	4,000	12,000
Santos Swing Basin	-	41,000	43,000	50,000
BG Swing Basin	-	56,000	58,000	66,000
Laird Point Swing Basin and Approach	-	-	9,000	58,000
Total	15,000	152,000	180,000	255,000

6.5.5 Maintenance Dredging Requirements

The highly variable nature of the sediments and the prevailing processes makes quantification of siltation rates and maintenance dredging requirements complex. Quantitative assessments of both sand and silt deposition were undertaken and are detailed above, however the uncertainties associated with these assessments should be taken into consideration.

Overall maintenance dredging requirements will be due to a combination of sand-sized material transported into the dredged areas where the tidal currents are sufficiently energetic and the bed material is sufficiently mobile, and silt-sized material deposited in sufficiently quiescent parts of the dredged areas. Generally the two types of siltation will occur in different parts of the dredge footprint and superposition of potential sedimentation depths need not be accounted for locally.

The following key points can be concluded regarding future maintenance dredging requirements:

- The potential for sand transport into the project dredged areas including the existing Fisherman's Landing and Targinie Channel is significantly less than for the downstream dredged areas (Clinton Swing Basin, Clinton Bypass Channel and the Wiggins Island Coal Terminal Swing Basin);
- The impact of the reclamation and additional dredging works is to reduce the potential sand transport into the base case dredged areas, however it should be noted that the size of the reduction quantified in Table 6-2 is likely to be over-estimated in this assessment;
- Sand-sized sediment deposition into the project dredged areas could occur at a rate of around 50,000m^3/year;
- Silt deposition is not a major source of sedimentation problems in the existing Port Curtis dredged areas (excluding enclosed harbours) due to high current speeds and associated bed shear stresses;
- The project dredged areas are likely to experience significant silt deposition due to the relatively low-energy hydrodynamic regime that will occur following dredging. A fine-material siltation rate of 255,000m^3/year has been predicted for the ultimate dredging of Scenario 3.
- It is estimated that there will be for the ultimate scenario a total maintenance dredging requirement of the order of 300,000m^3/year on average. Predicted rates of siltation (<0.1m/year) are such that this may accommodated for a number of years by modest overdredging thereby limiting the frequency of maintenance dredging activities.

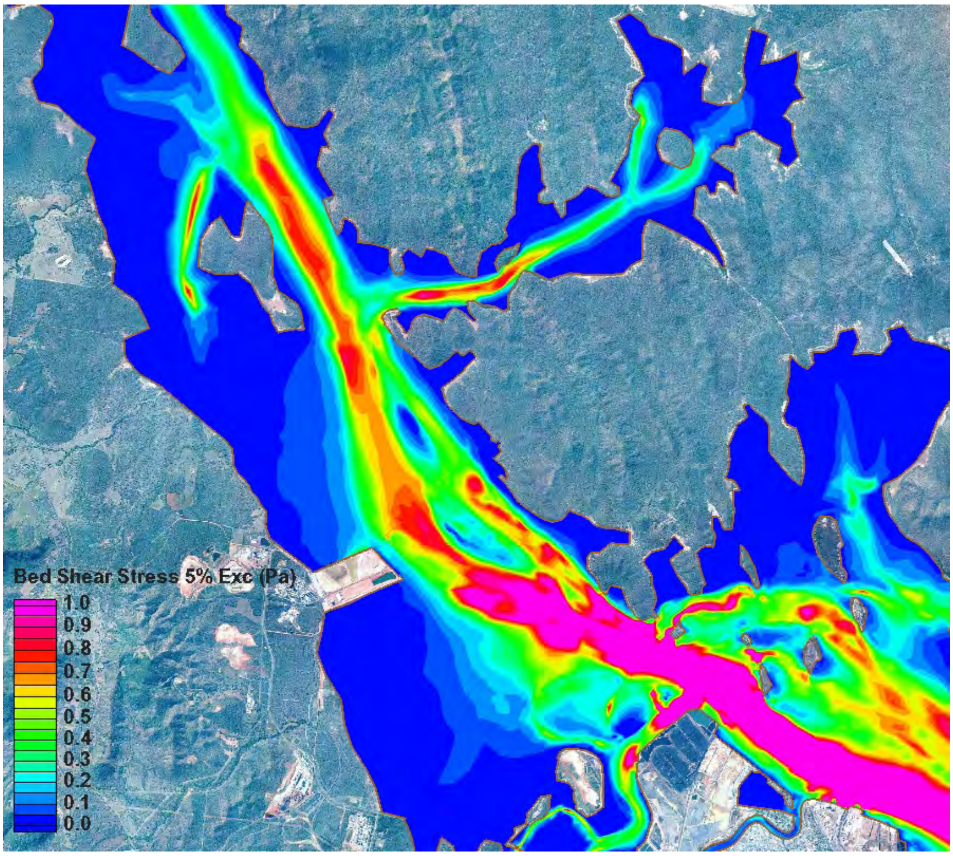


Figure 6-1 Base case 5% exceedance bed shear stress

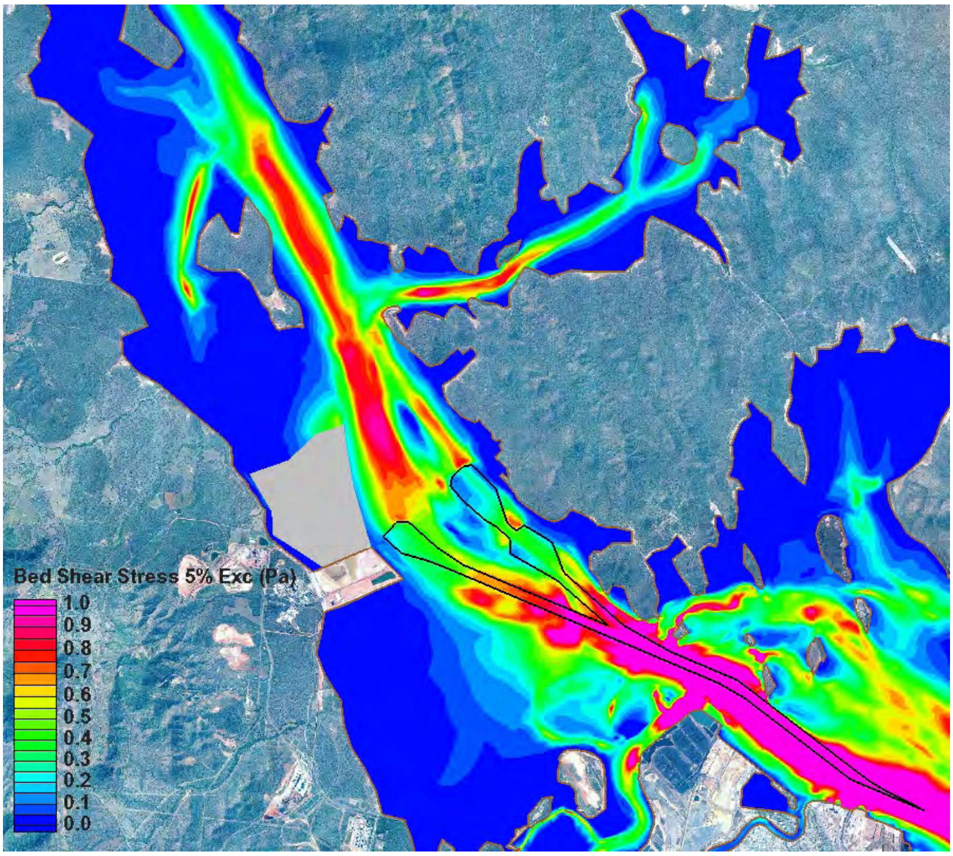


Figure 6-2 Scenario 1 case 5% exceedance bed shear stress

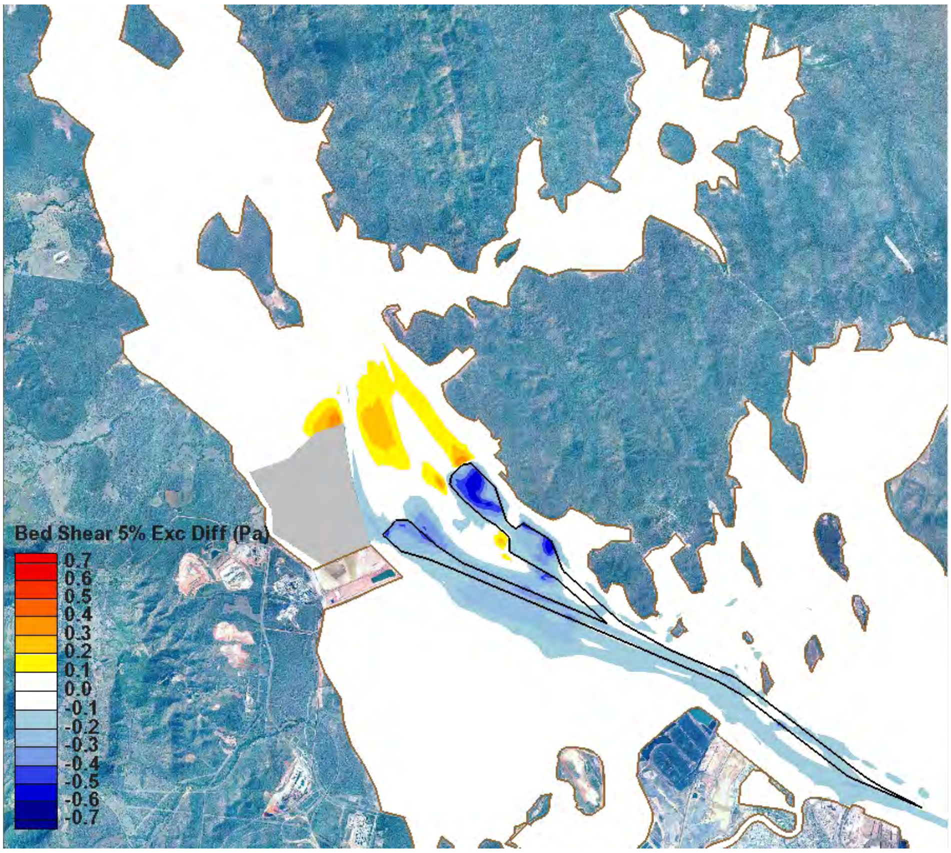


Figure 6-3 Scenario 1 case 5% exceedance bed shear stress differences

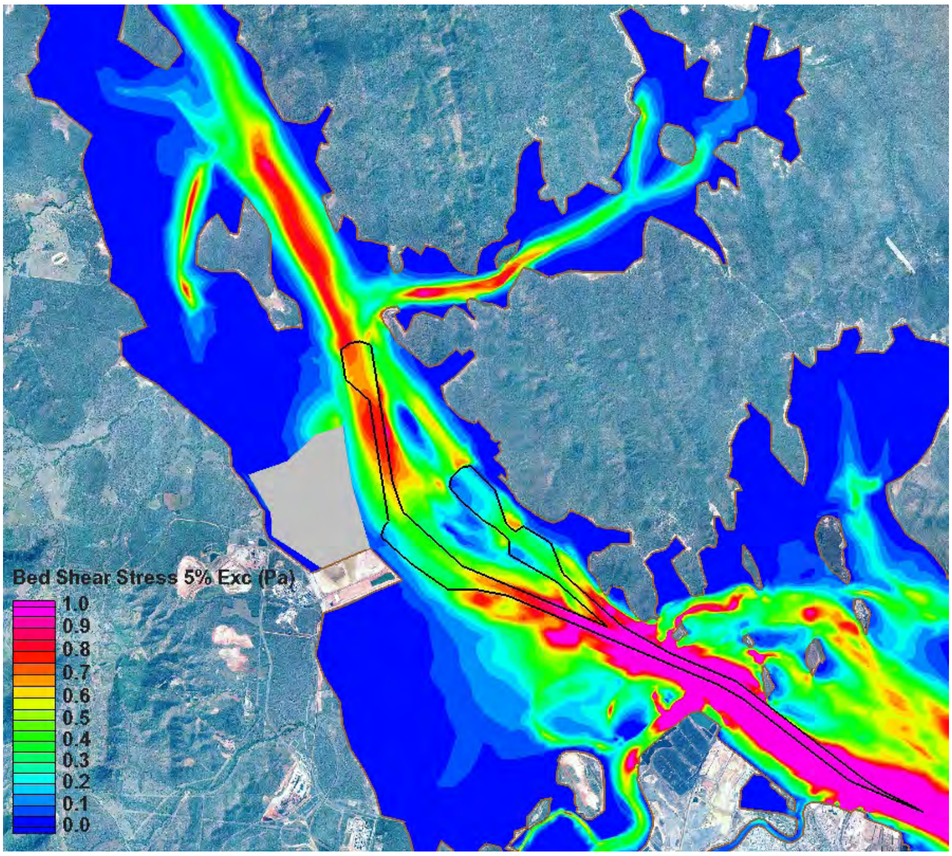


Figure 6-4 Scenario 2 case 5% exceedance bed shear stress

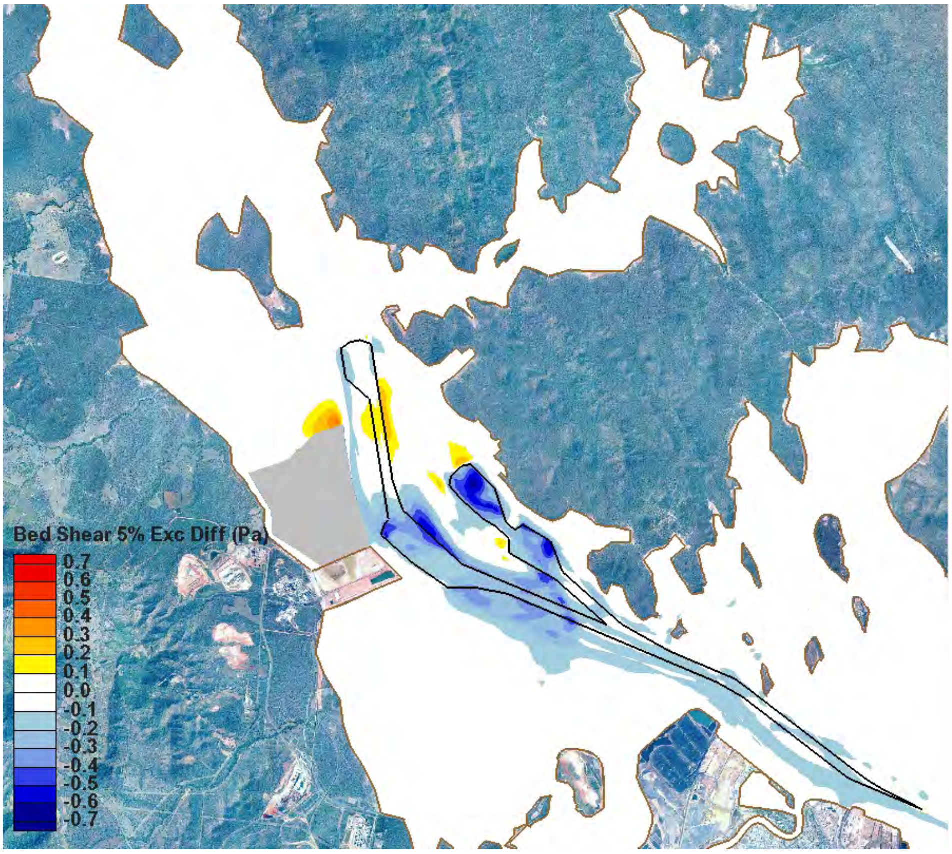


Figure 6-5 Scenario 2 case 5% exceedance bed shear stress differences

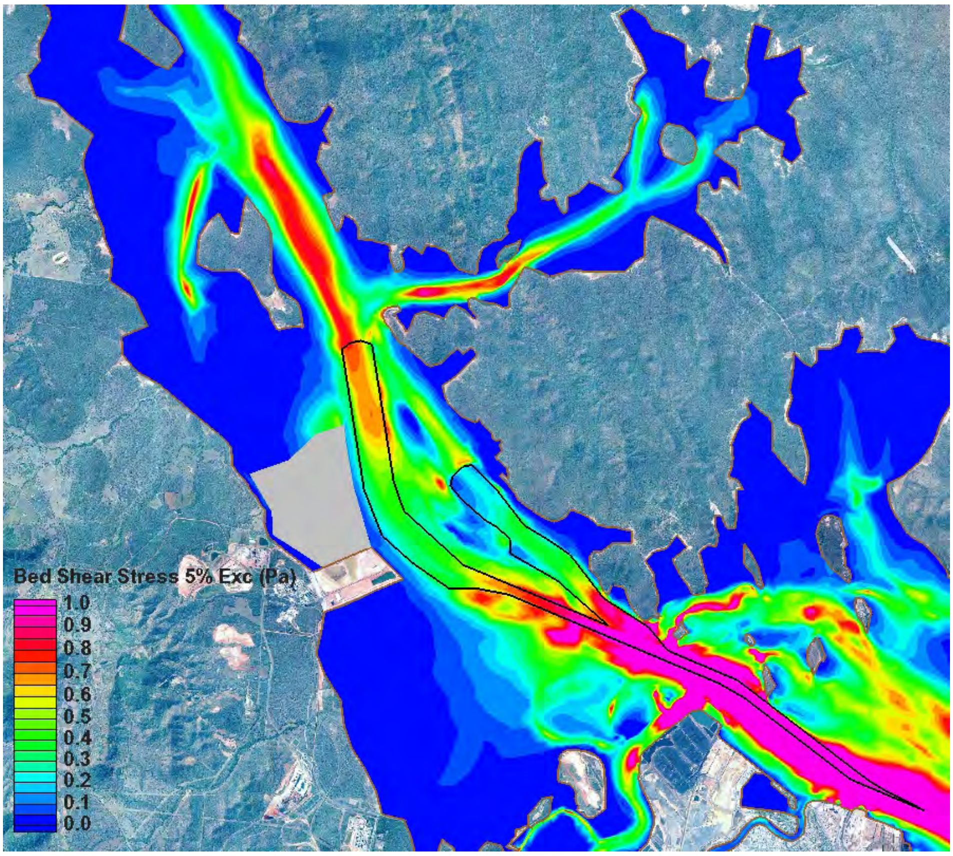


Figure 6-6 Scenario 3 case 5% exceedance bed shear stress

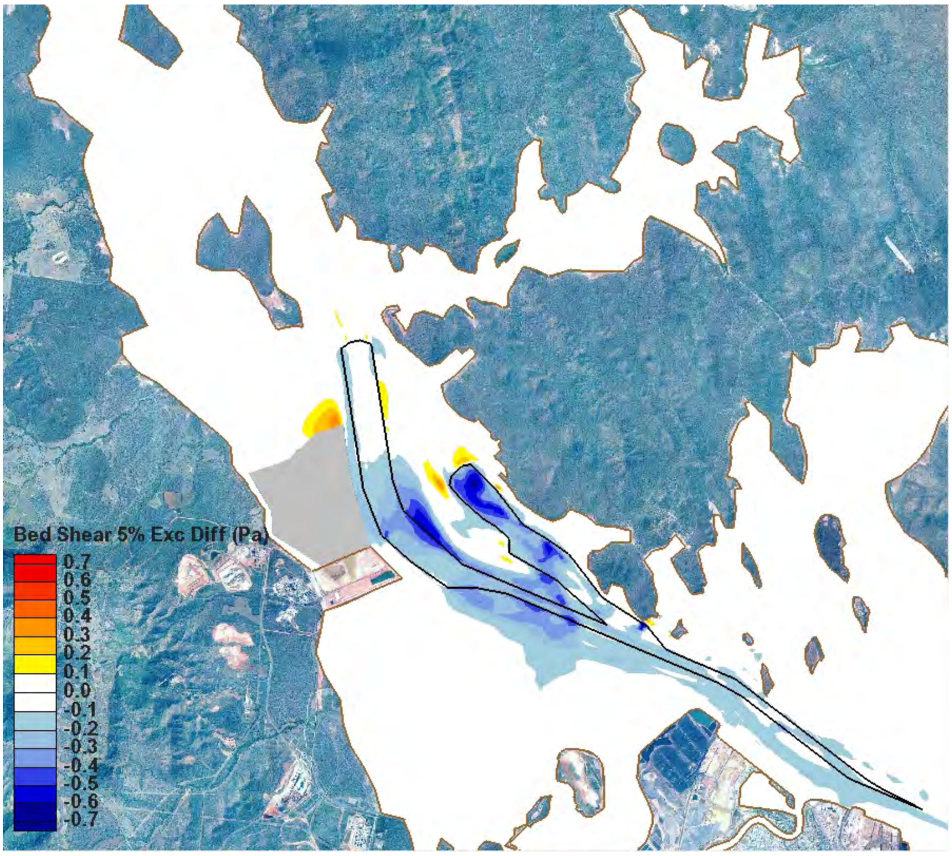


Figure 6-7 Scenario 3 case 5% exceedance bed shear stress differences

BMT WBM

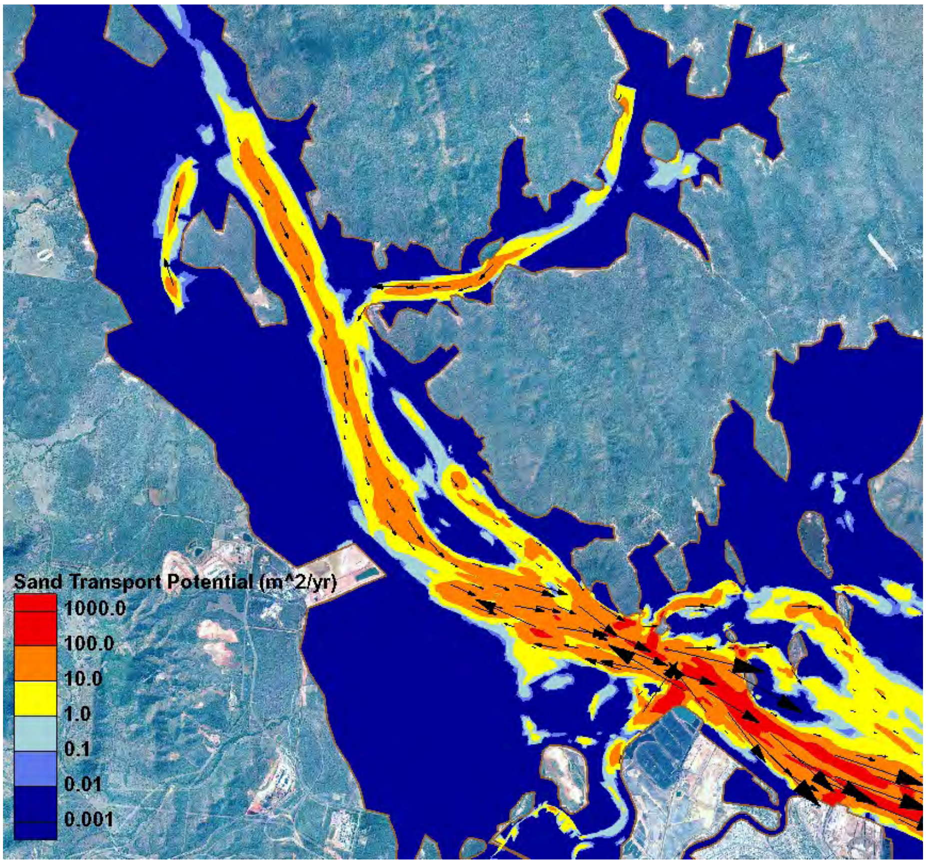


Figure 6-8 Base case net sand transport potential

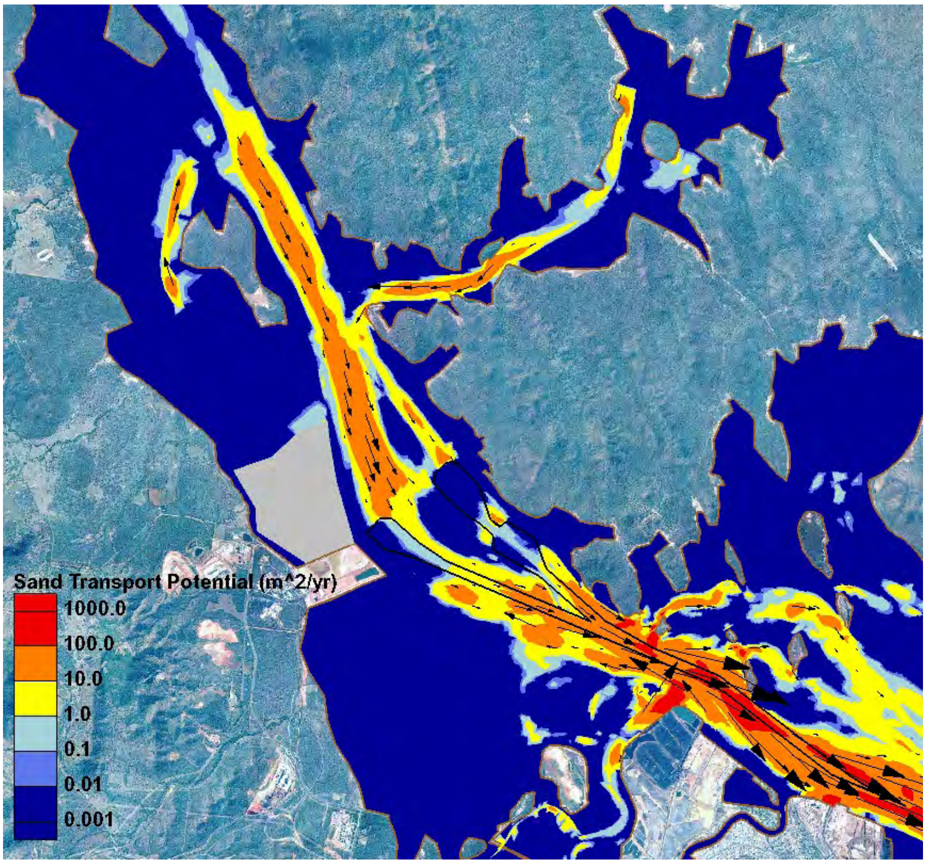


Figure 6-9 Scenario 1 net sand transport potential

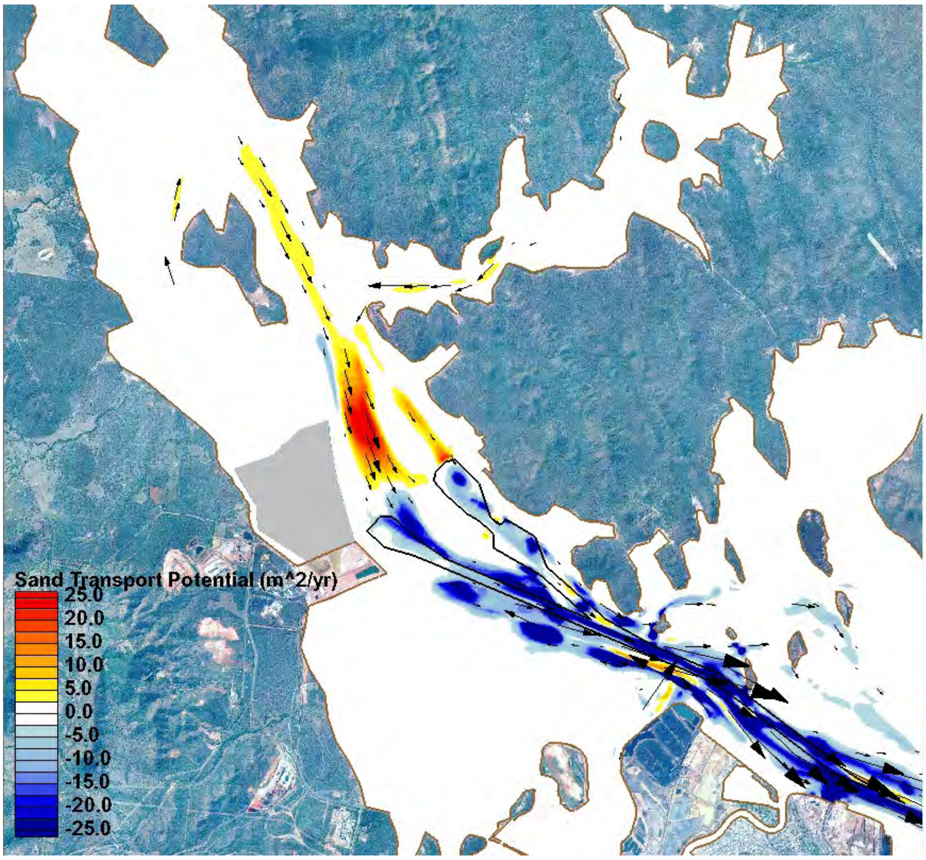


Figure 6-10 Scenario 1 net sand transport potential differences

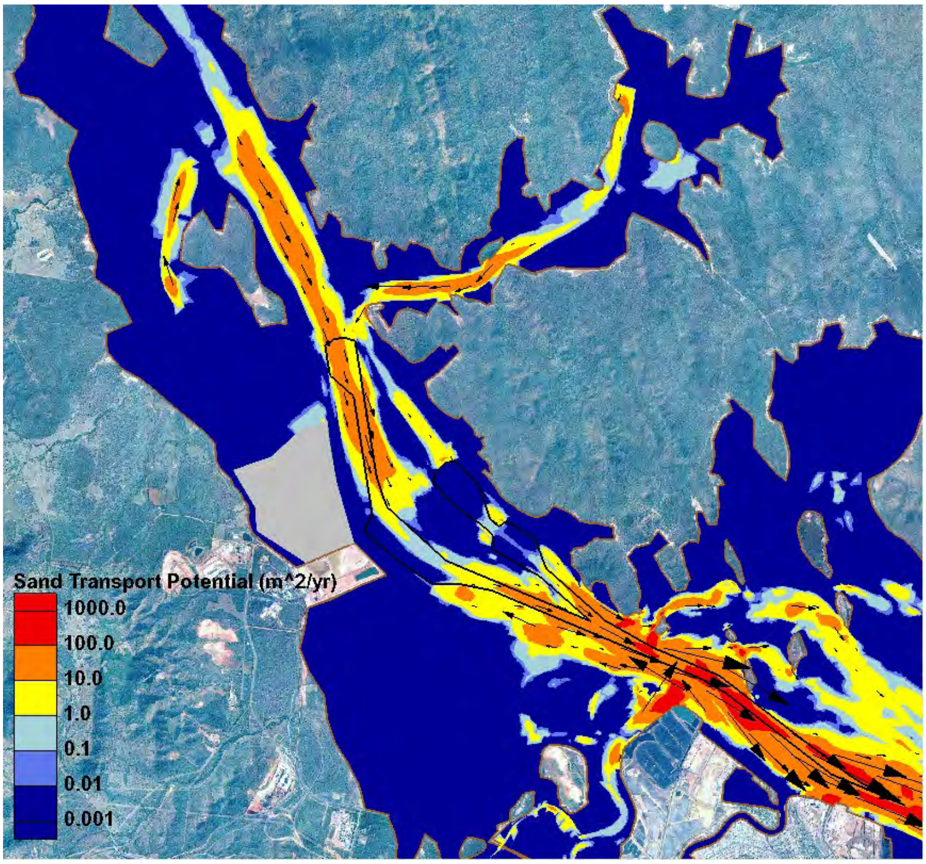


Figure 6-11 Scenario 2 net sand transport potential

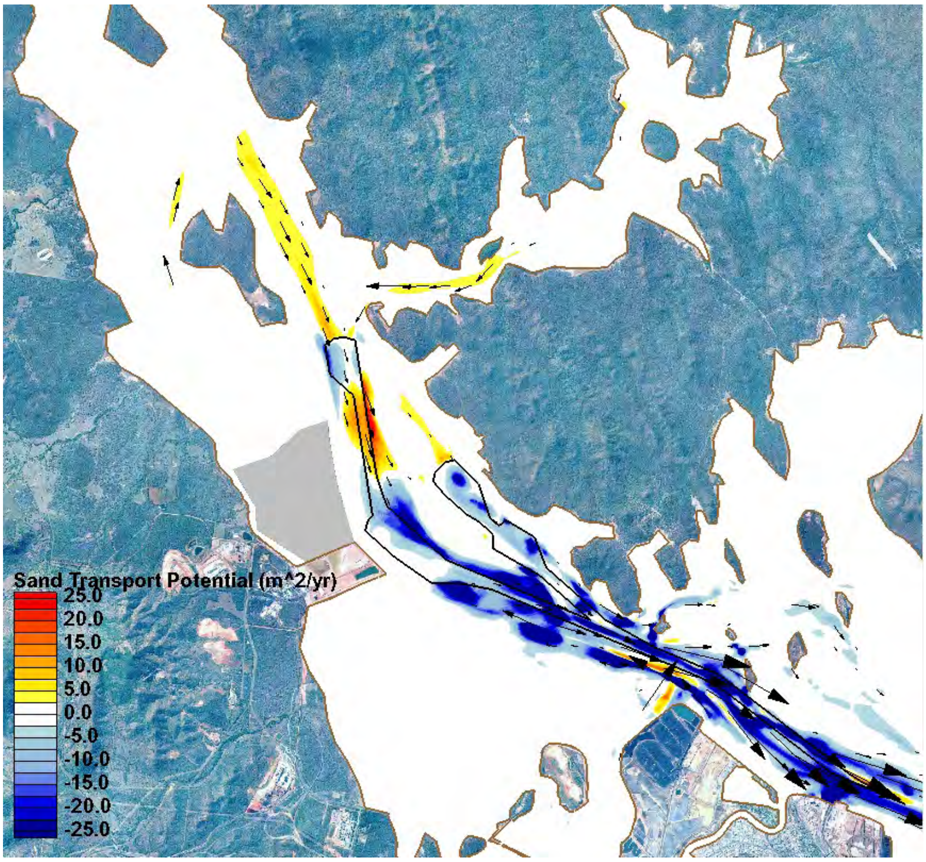


Figure 6-12 Scenario 2 net sand transport potential differences

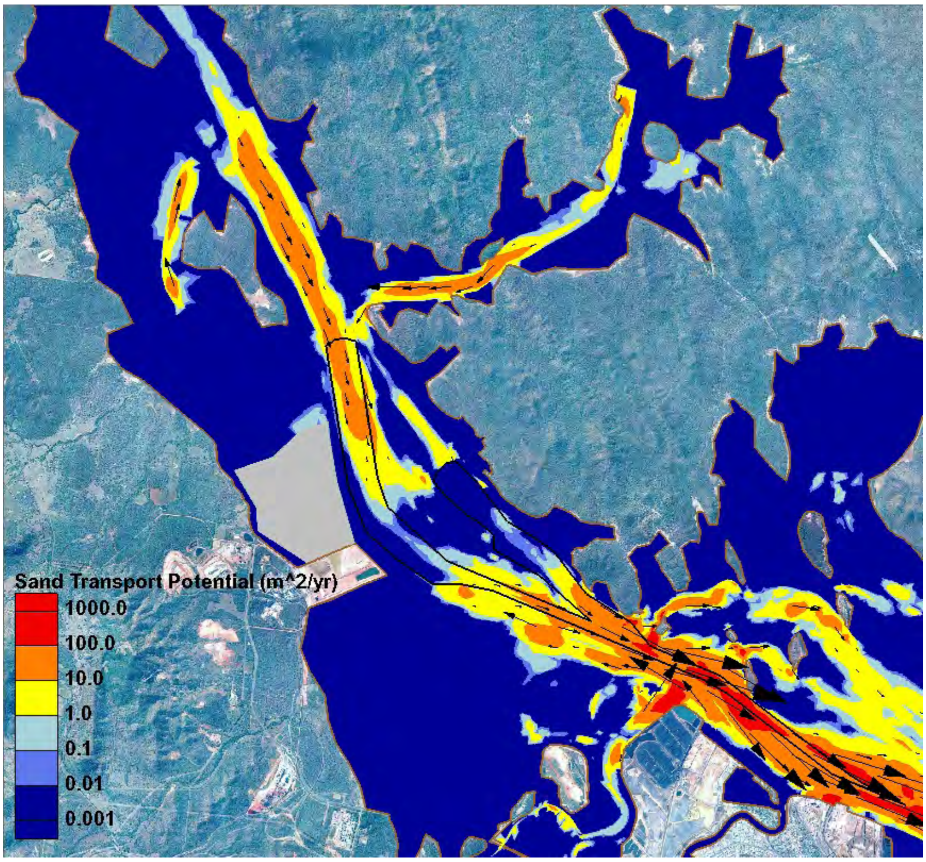


Figure 6-13 Scenario 3 net sand transport potential

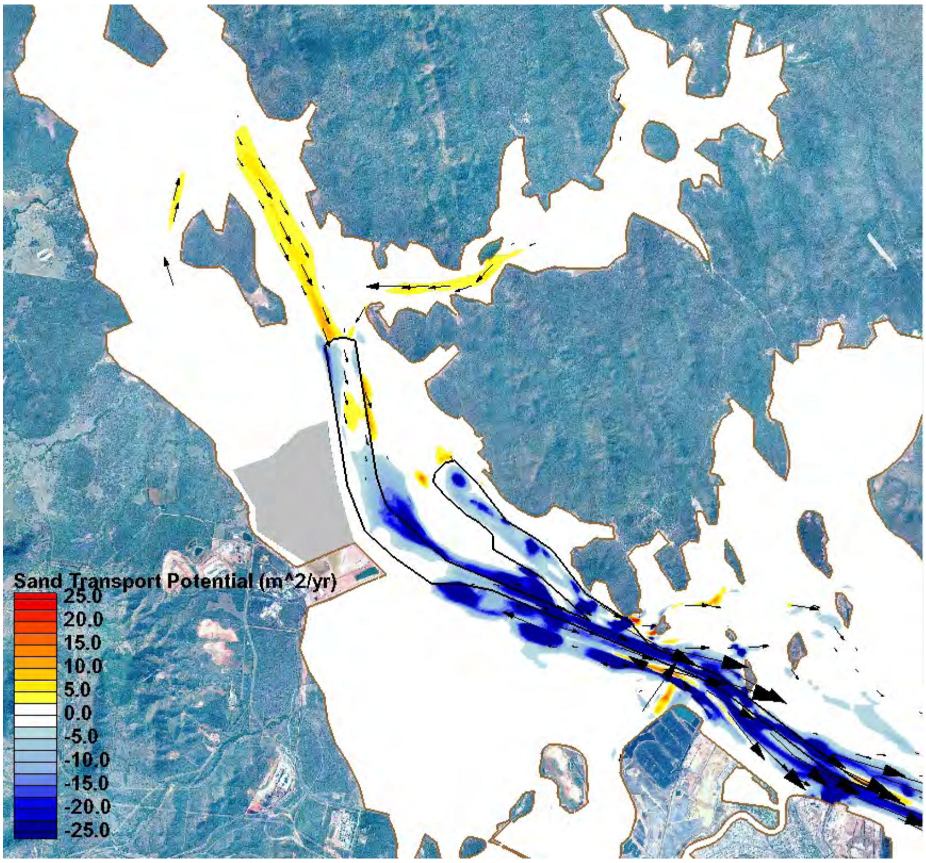


Figure 6-14 Scenario 3 net sand transport potential differences

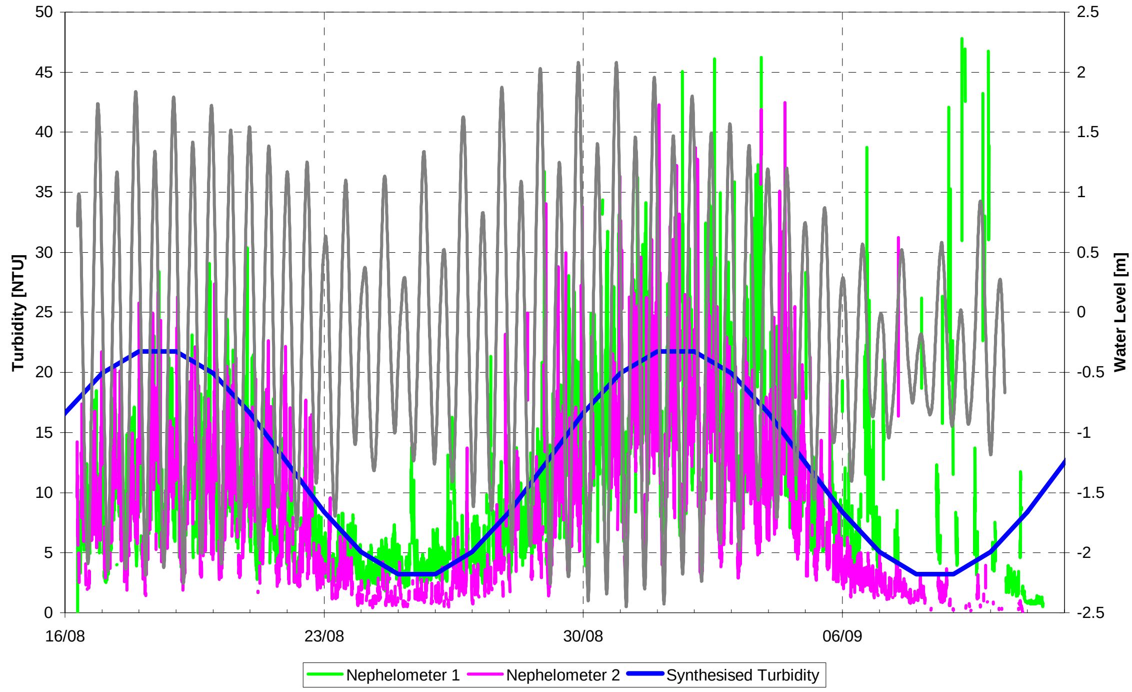


Figure 6-15 Synthesised fortnightly turbidity variation.

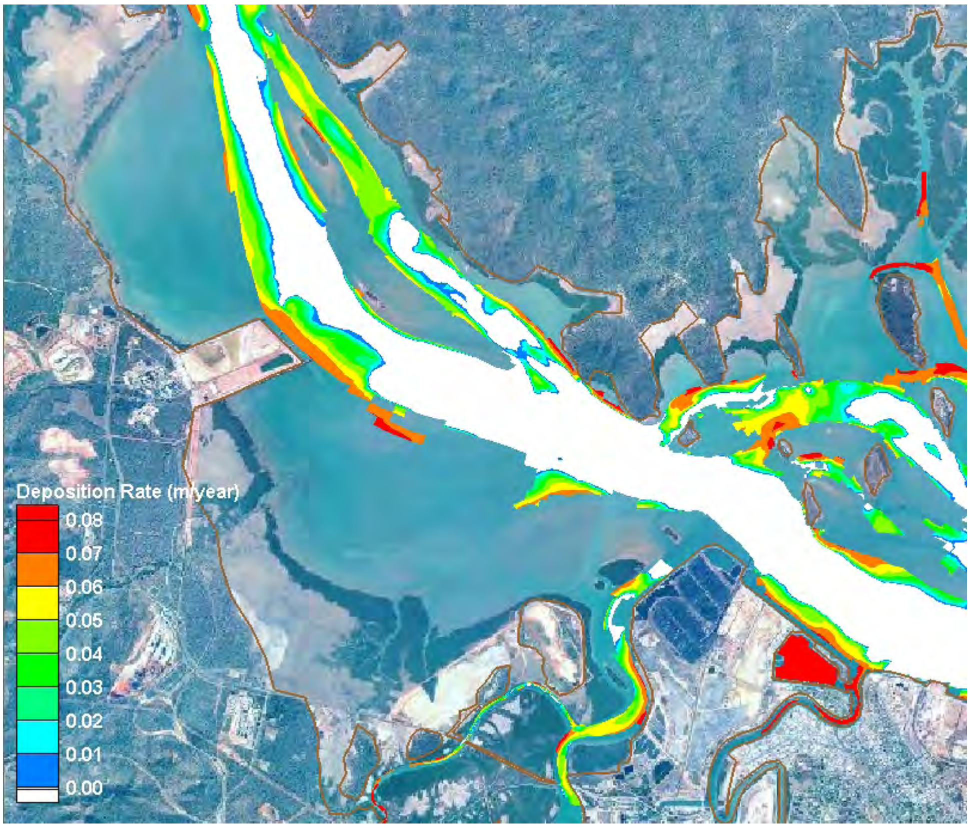


Figure 6-16 Base case silt deposition rates.

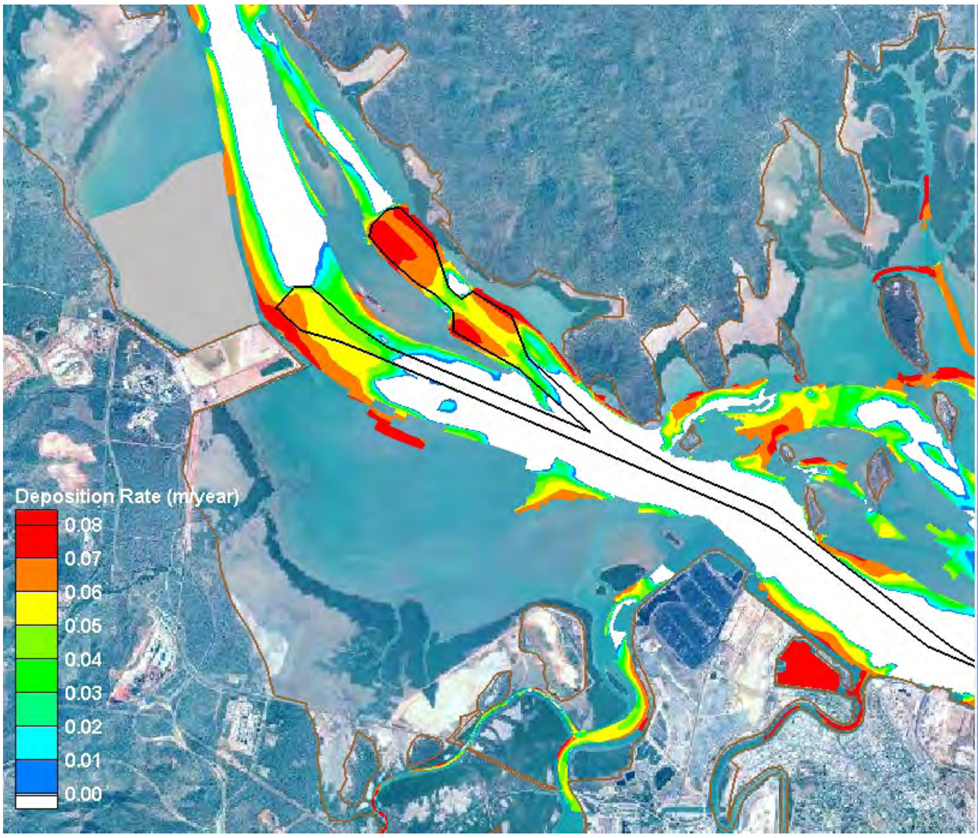


Figure 6-17 Scenario 1 silt deposition rates.

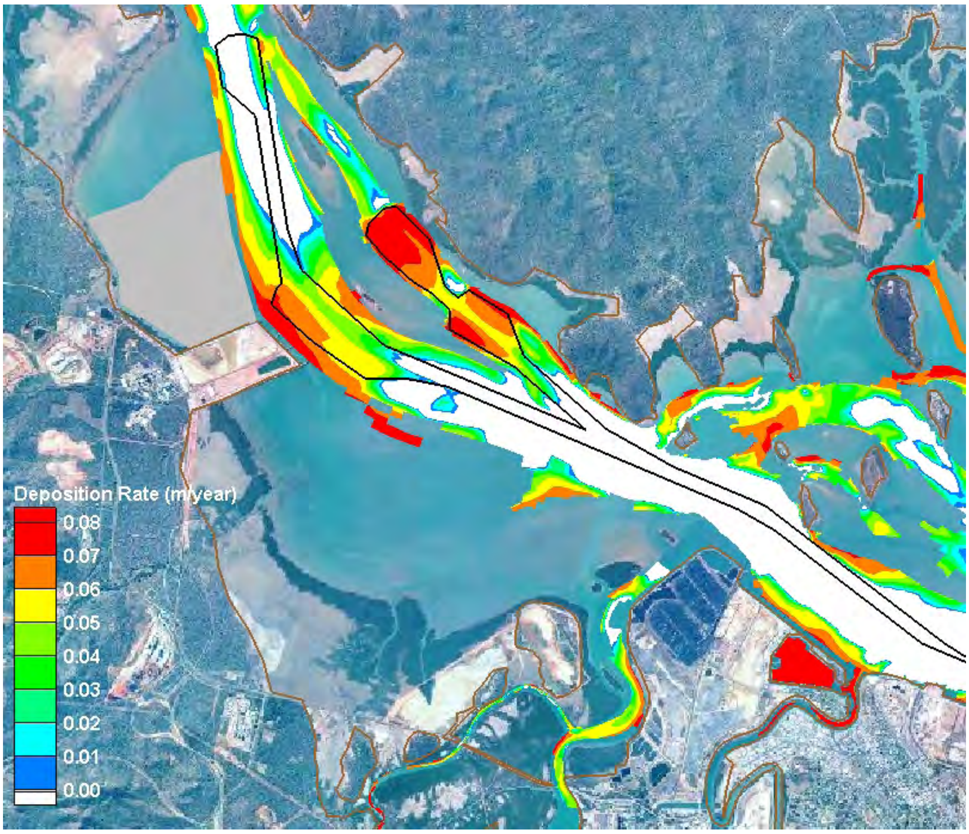


Figure 6-18 Scenario 2 silt deposition rates.

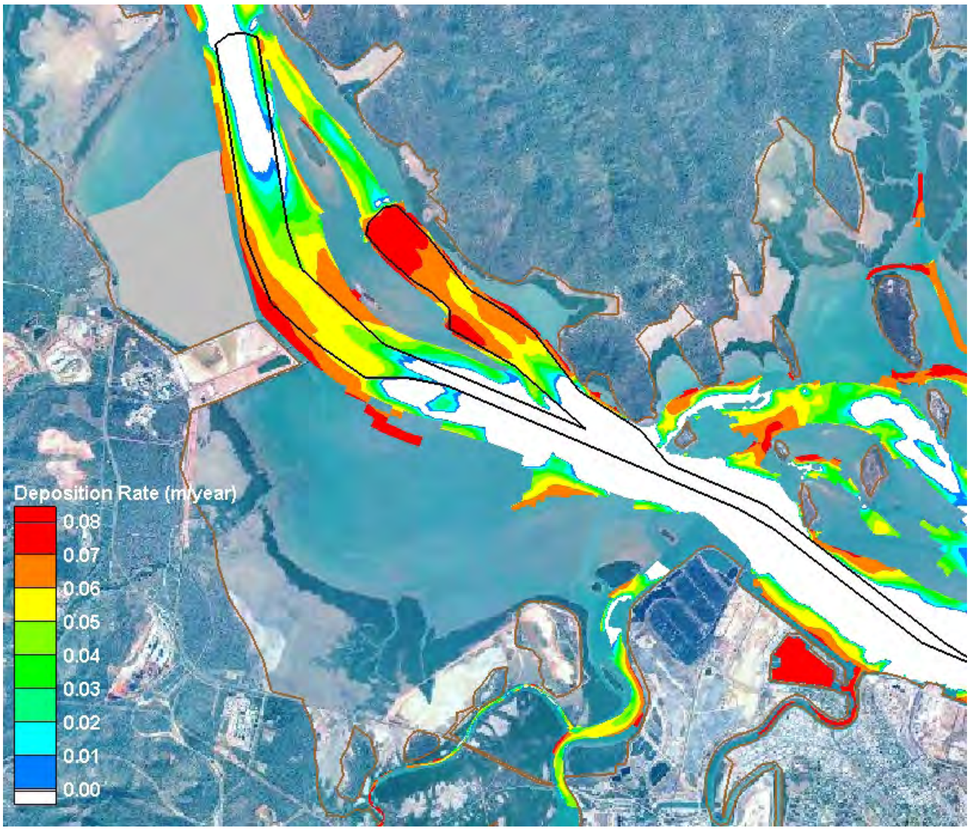


Figure 6-19 Scenario 3 silt deposition rates.

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APPENDIX A: WATER LEVEL TIME SERIES PLOTS

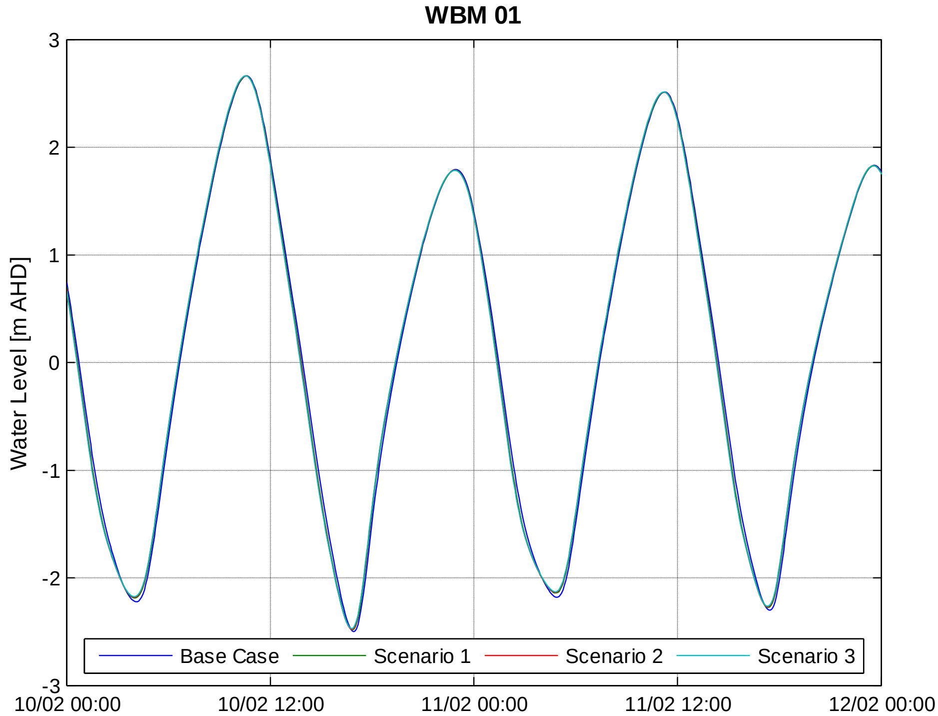


Figure A-1 Water Level Time Series – WBM 01

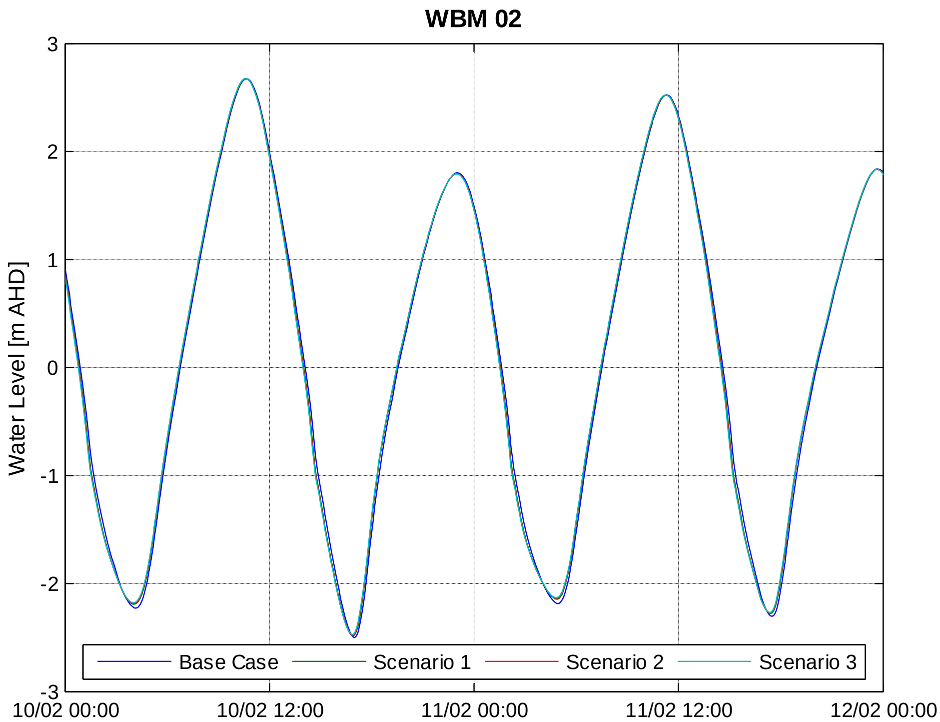


Figure A-2 Water Level Time Series – WBM 02

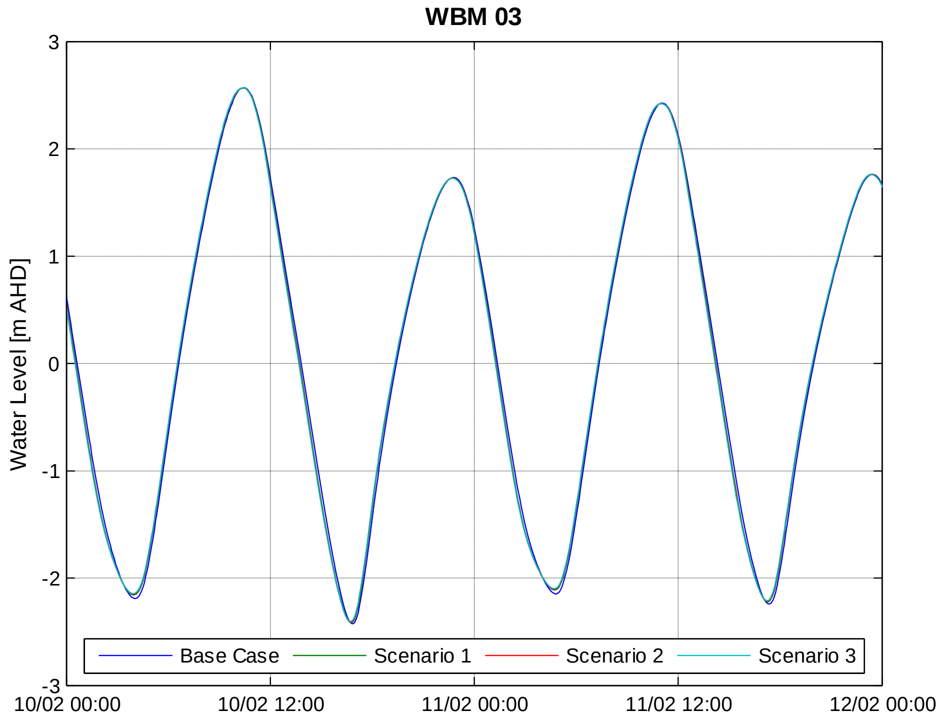
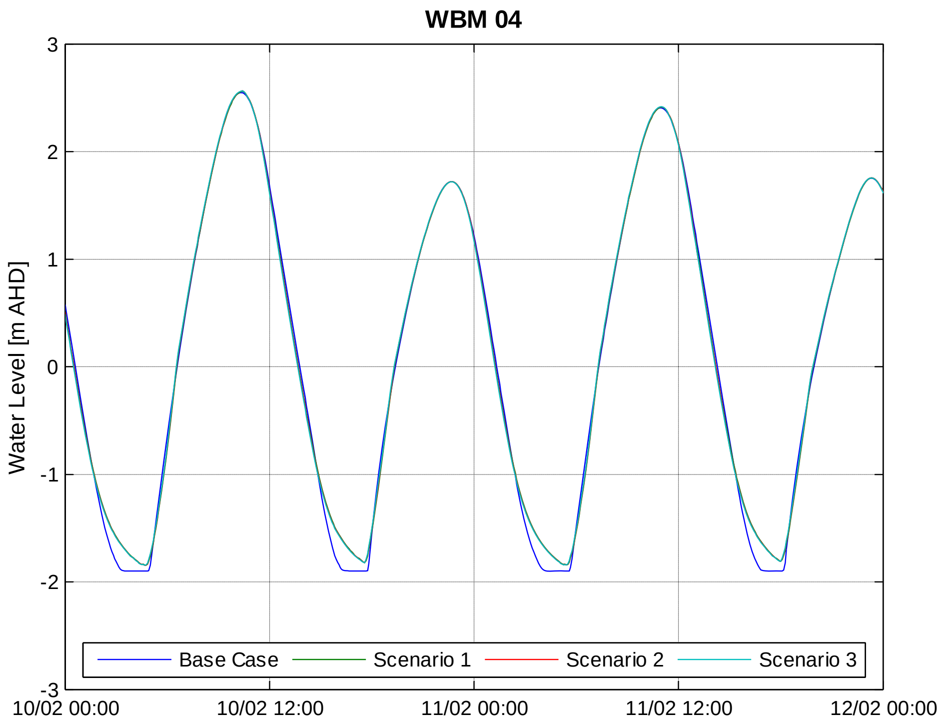


Figure A-3 Water Level Time Series – WBM 03



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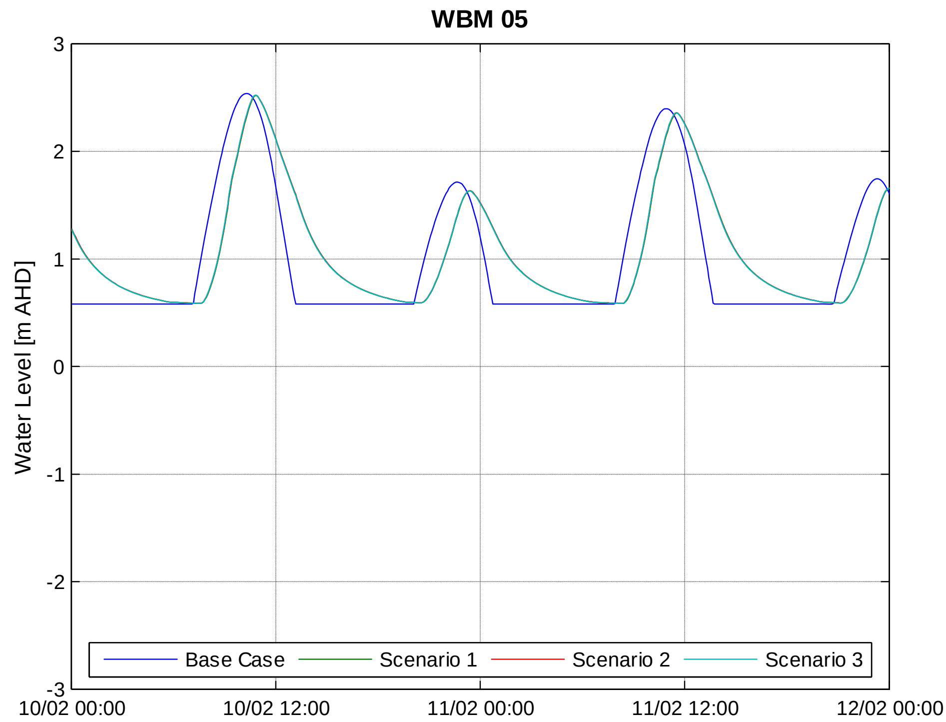
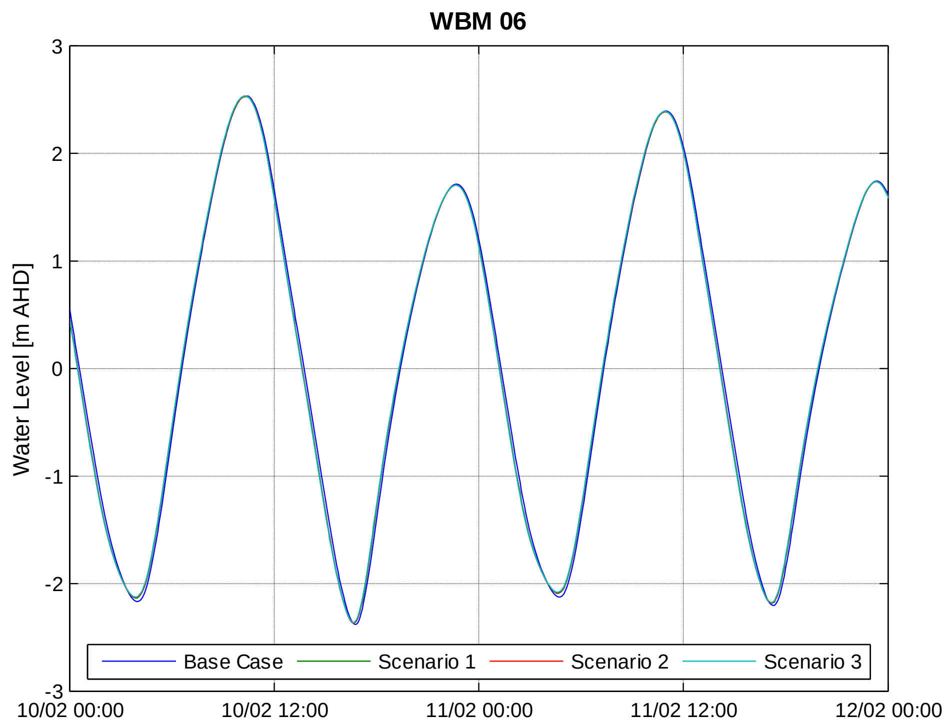


Figure A-5 Water Level Time Series – WBM 05



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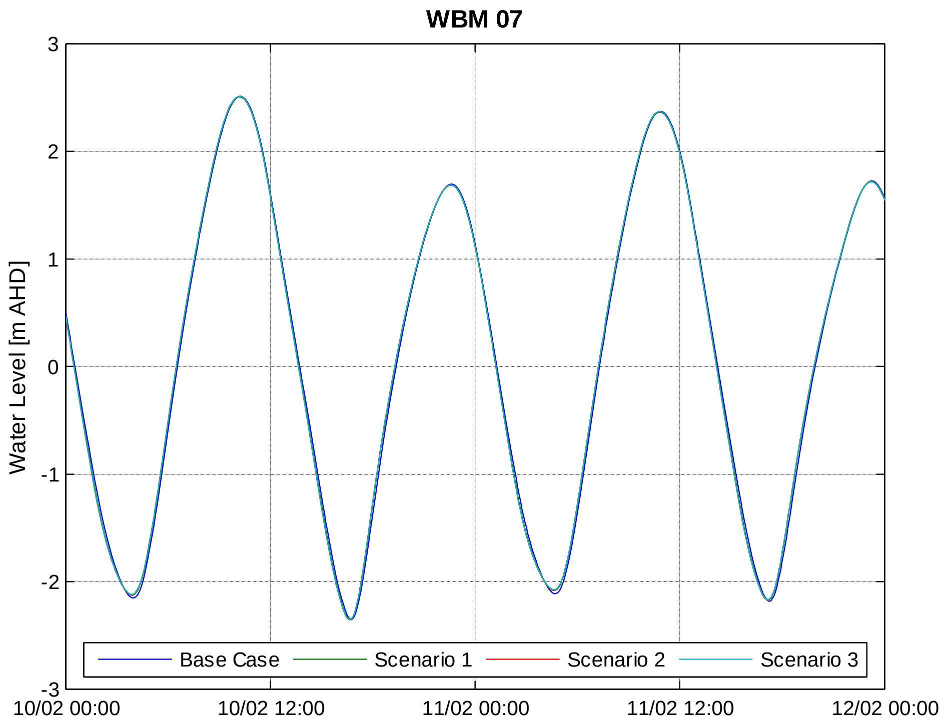

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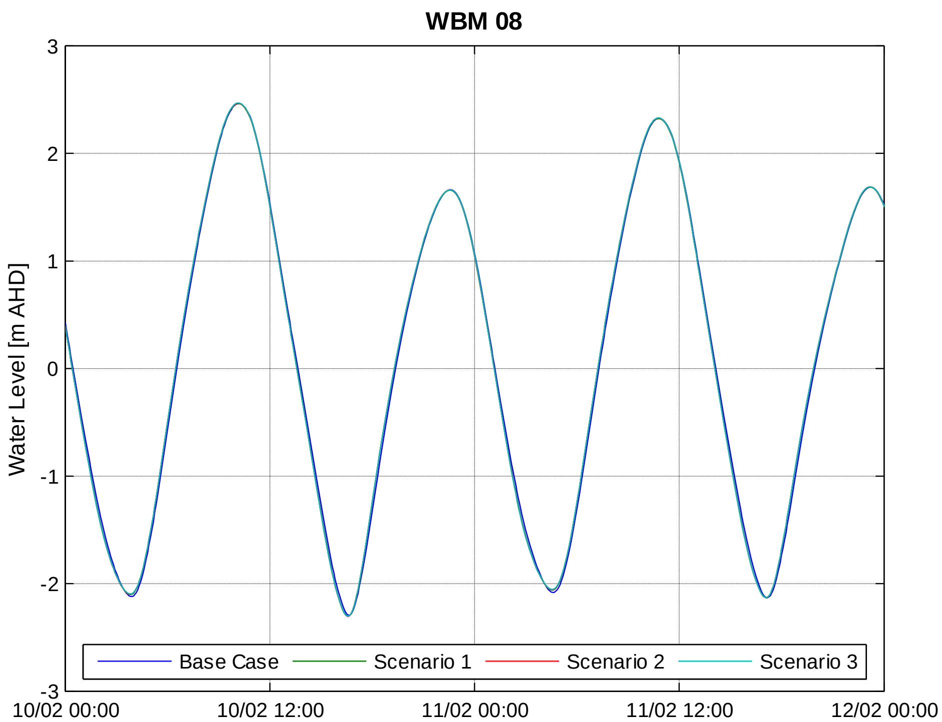

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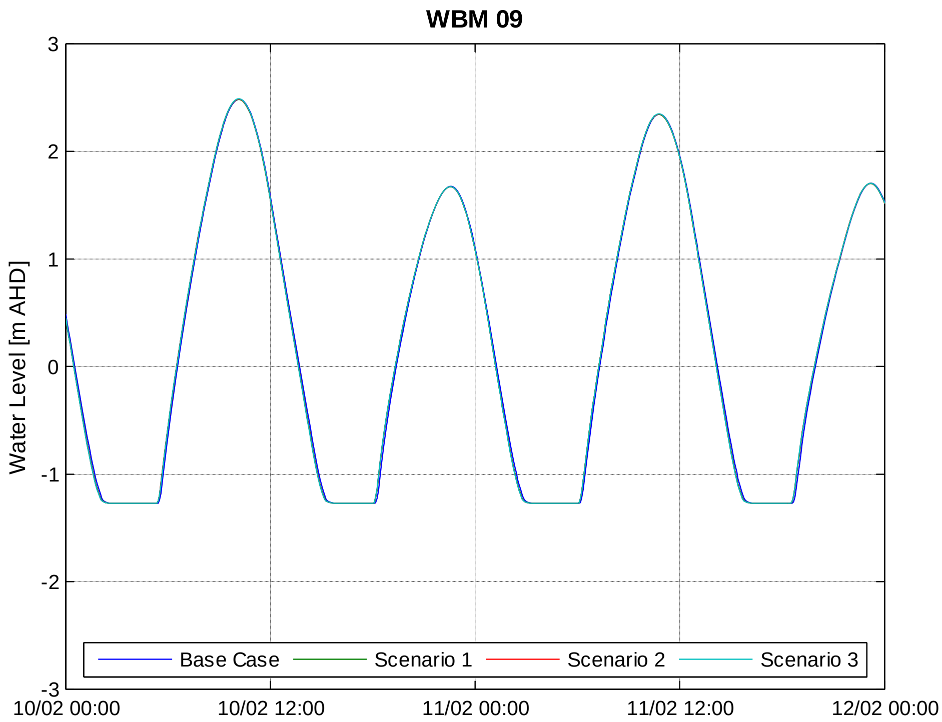

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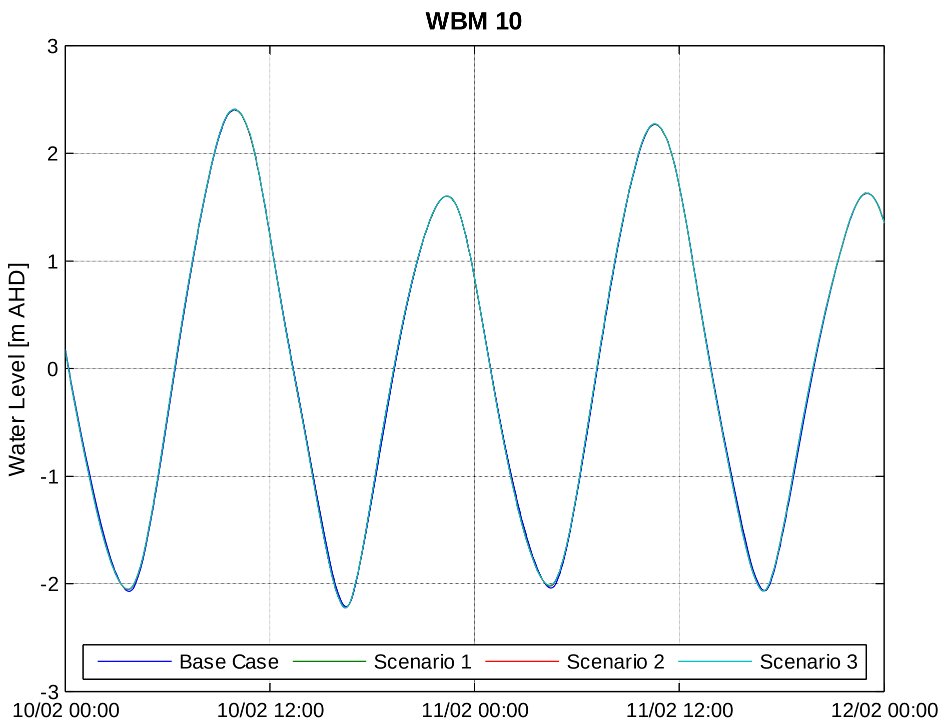

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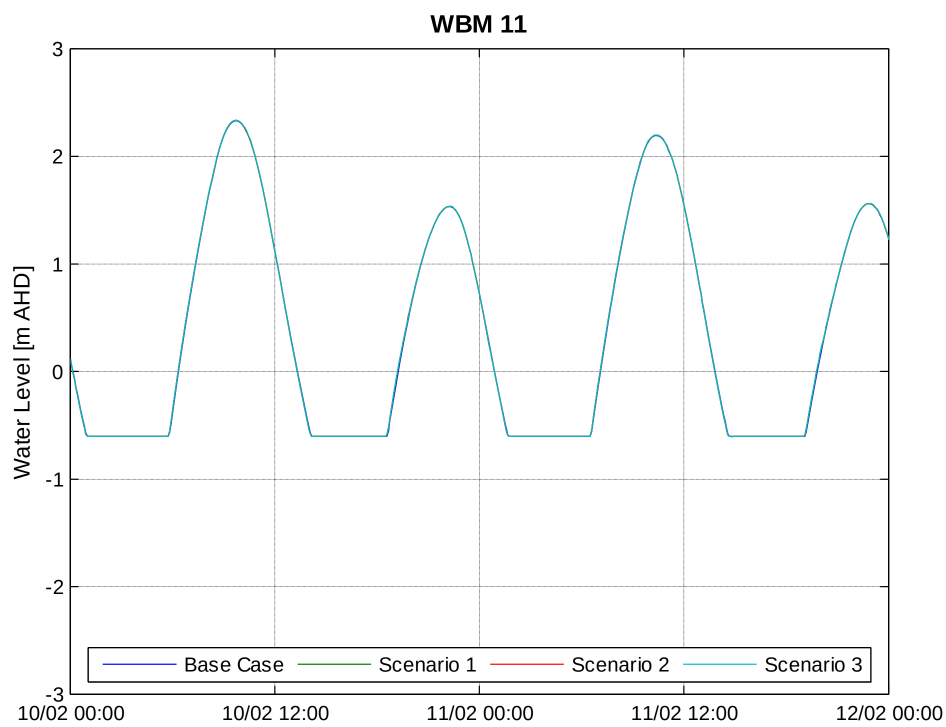

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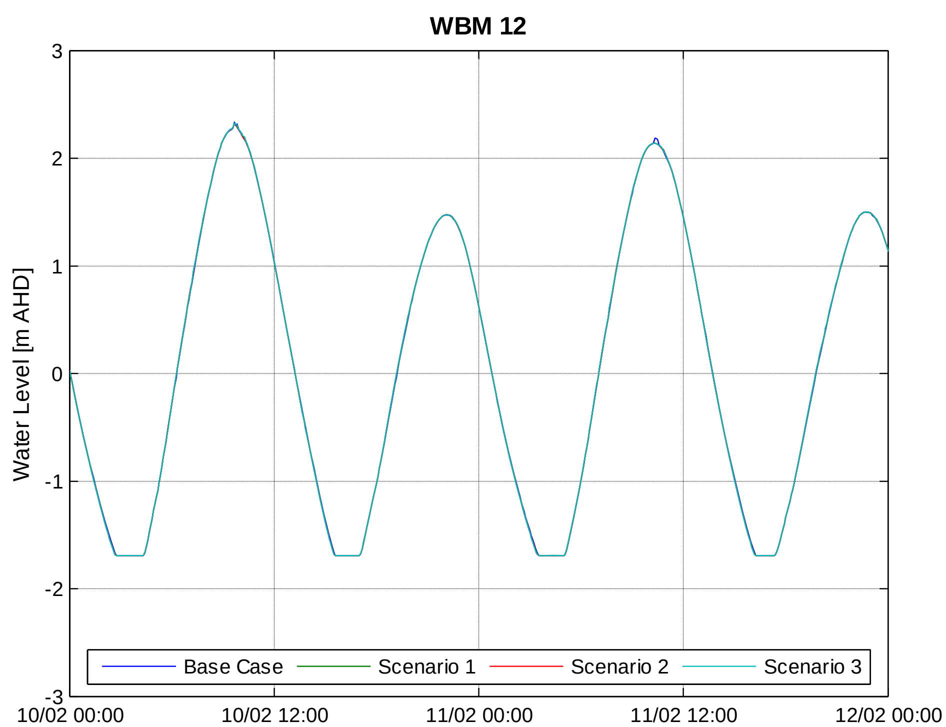

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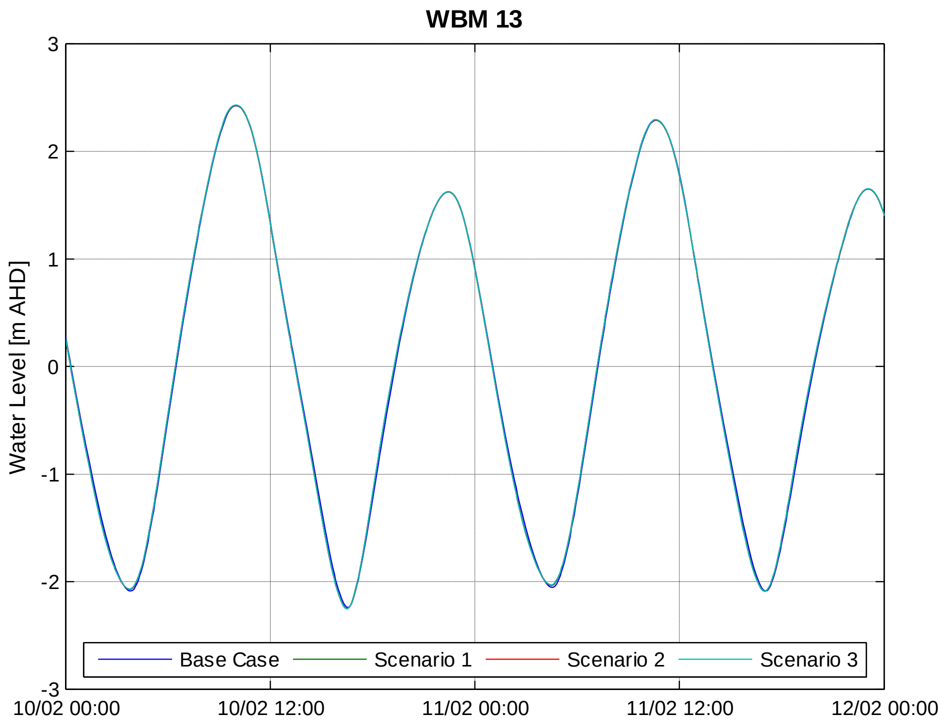

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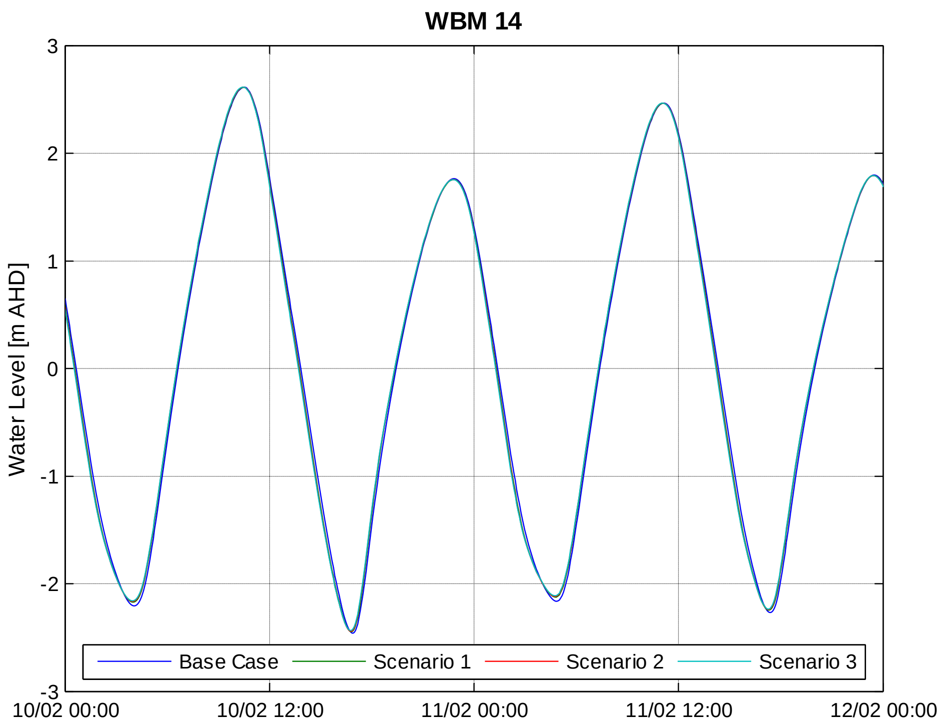

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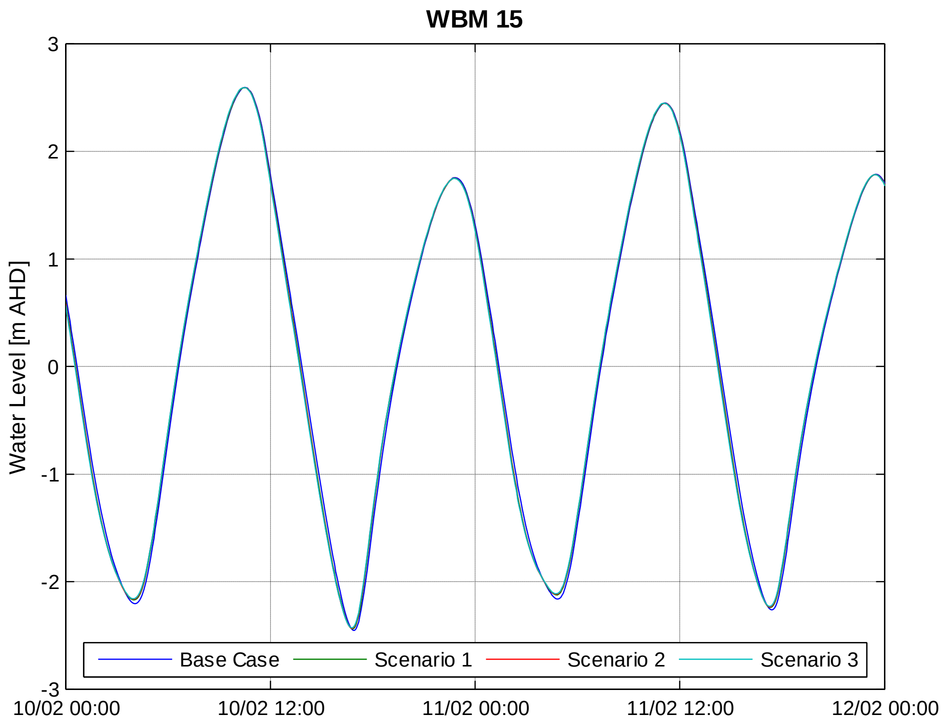

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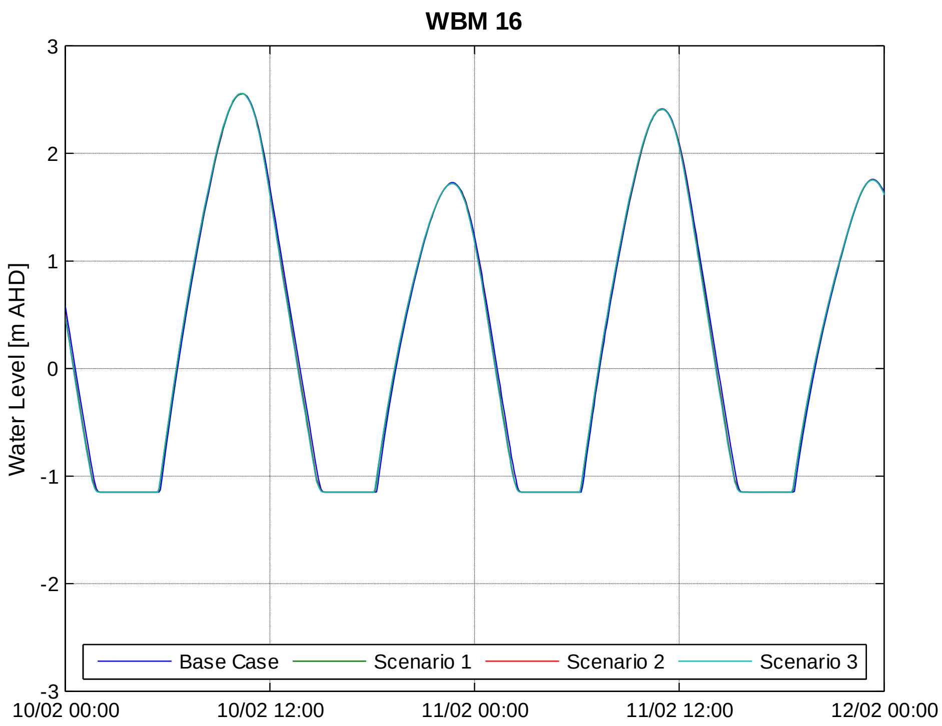

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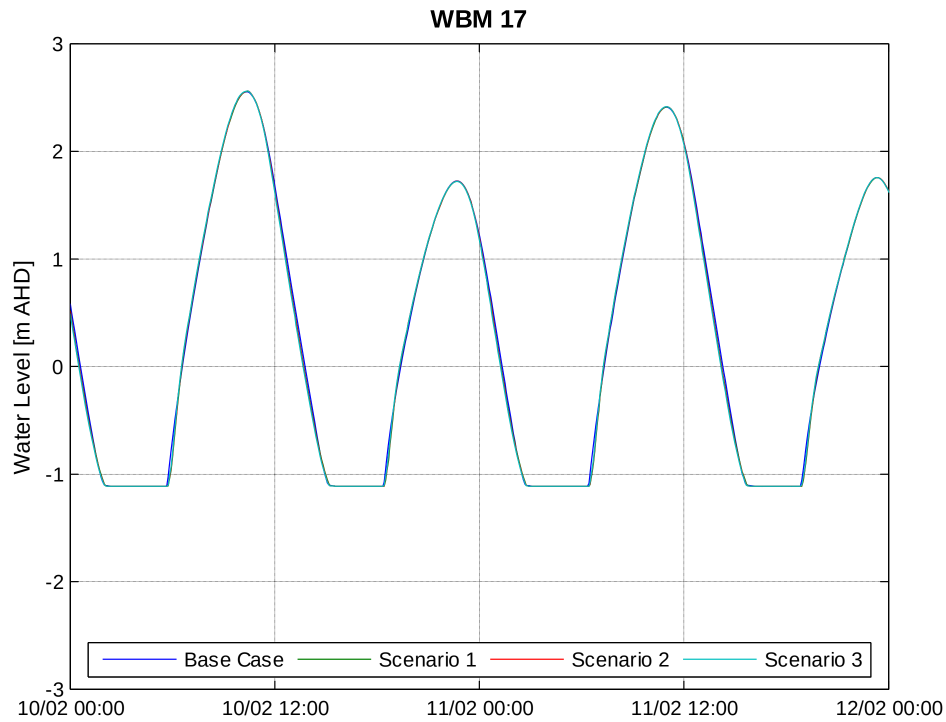

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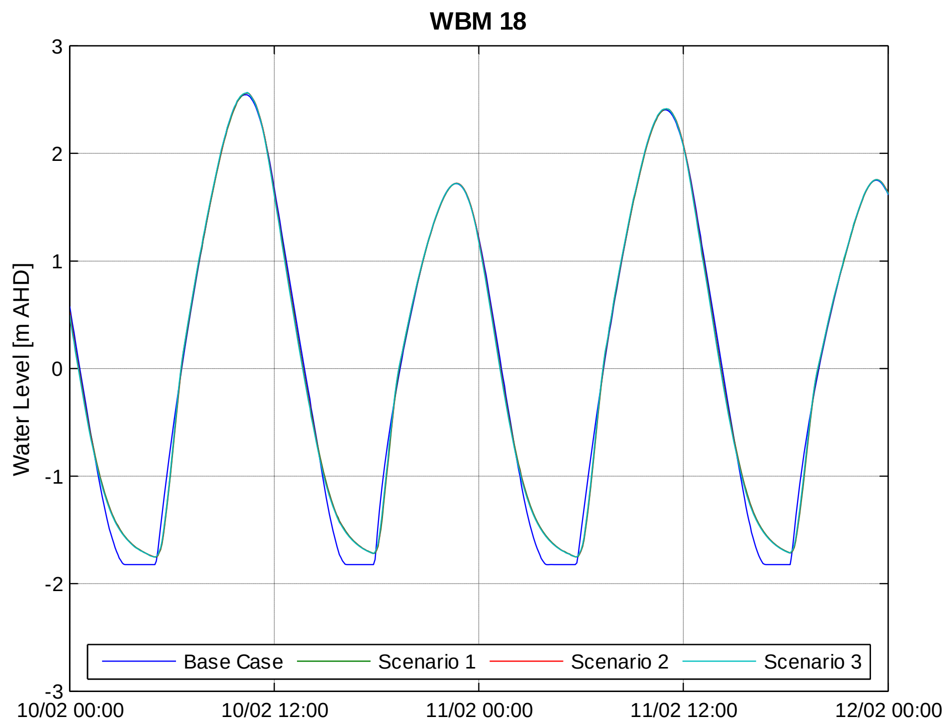

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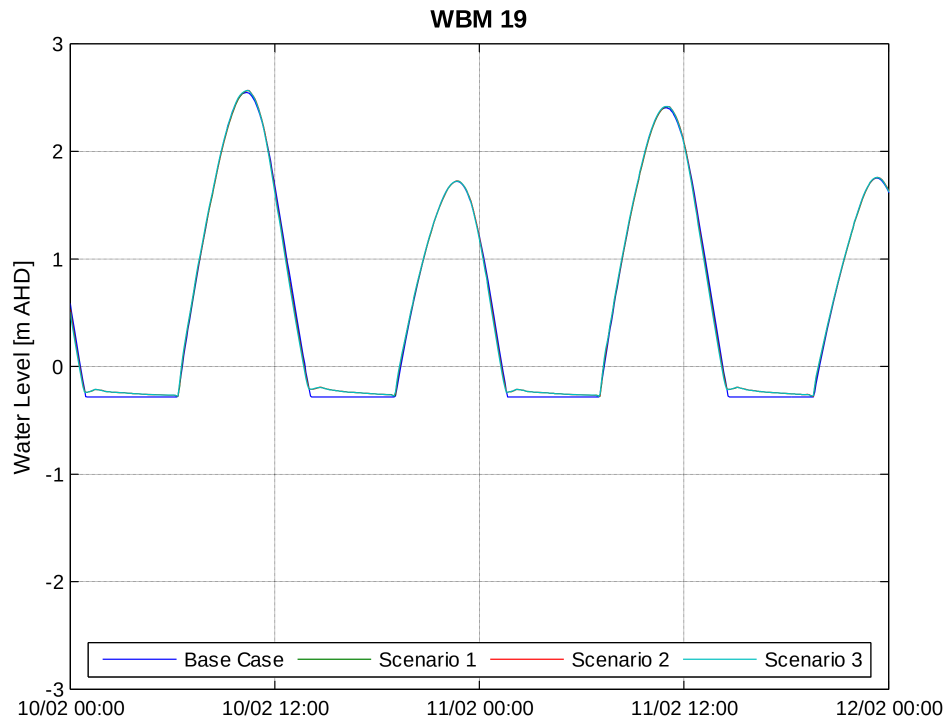

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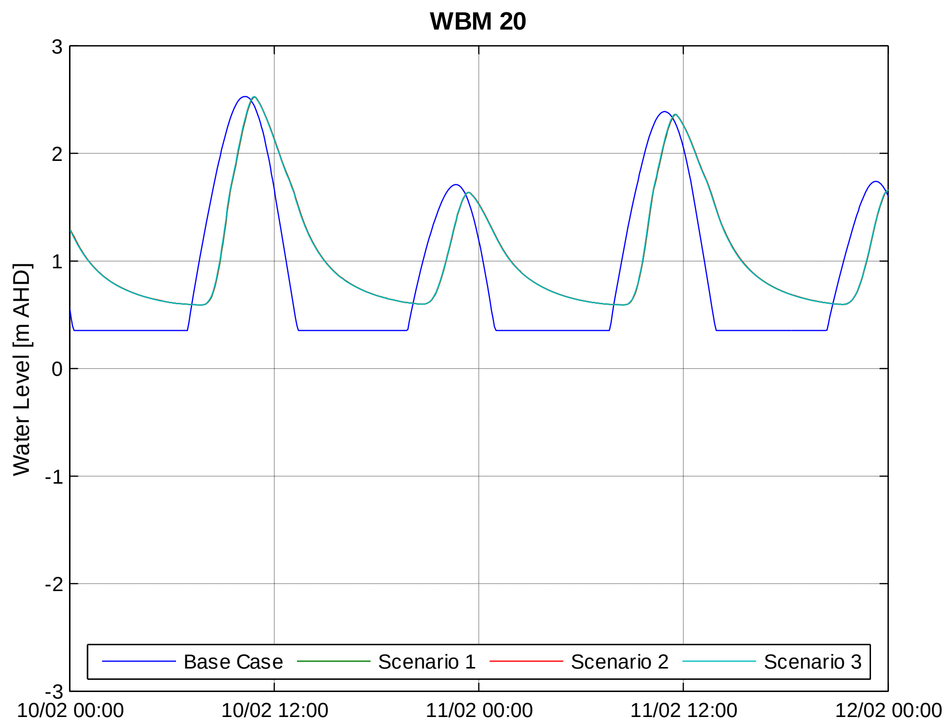

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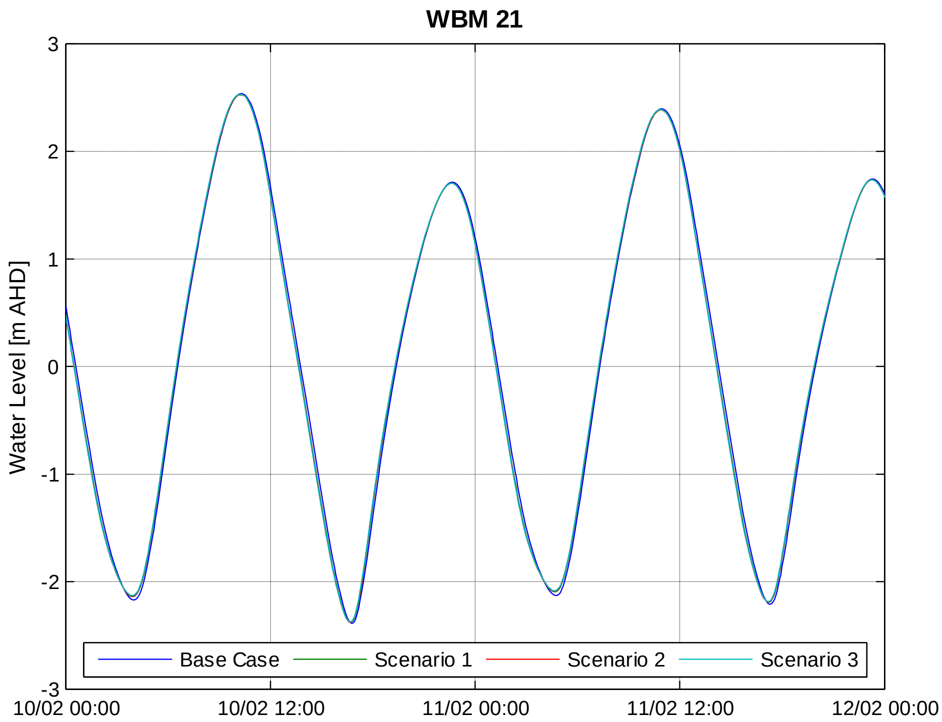

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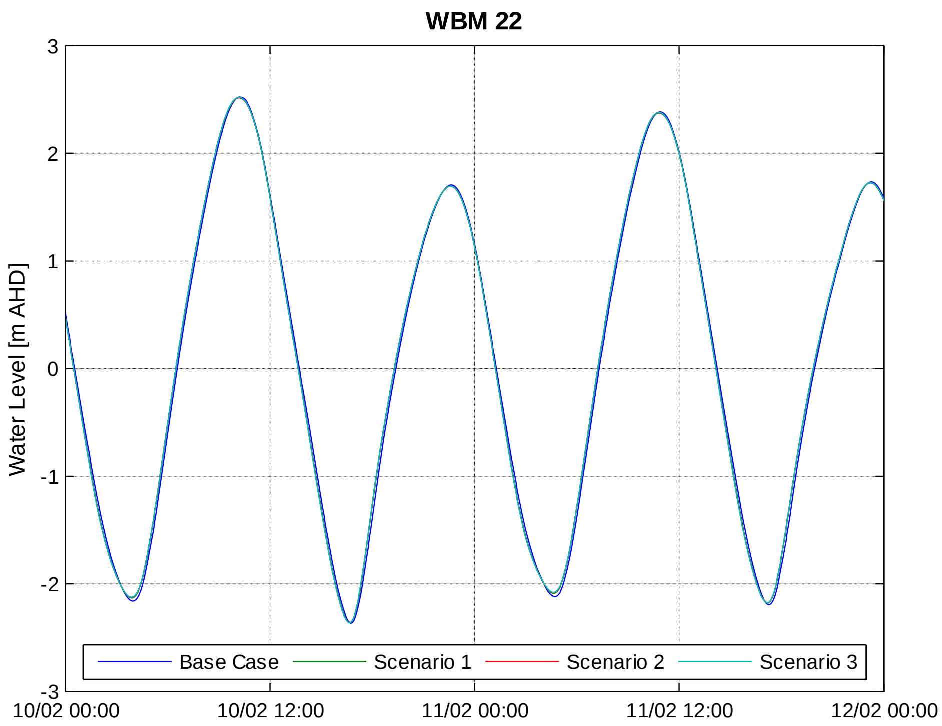

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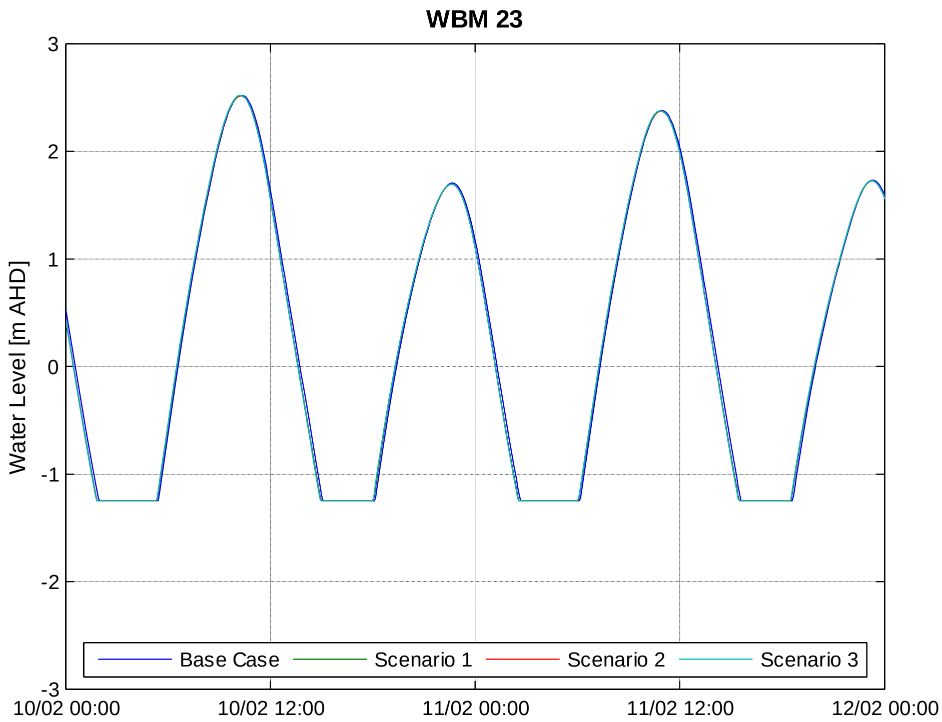

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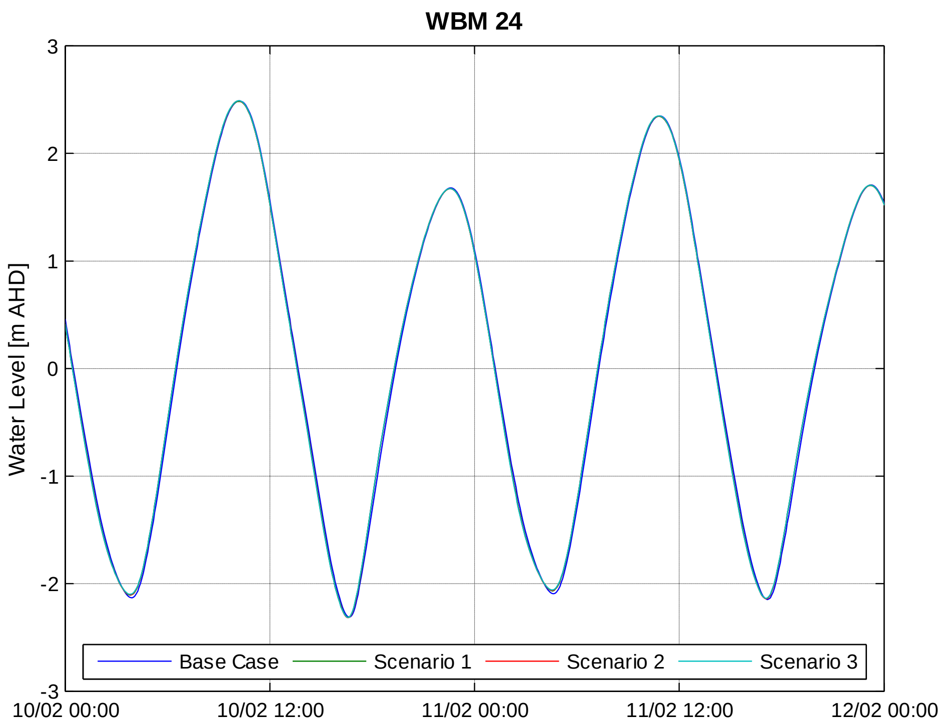

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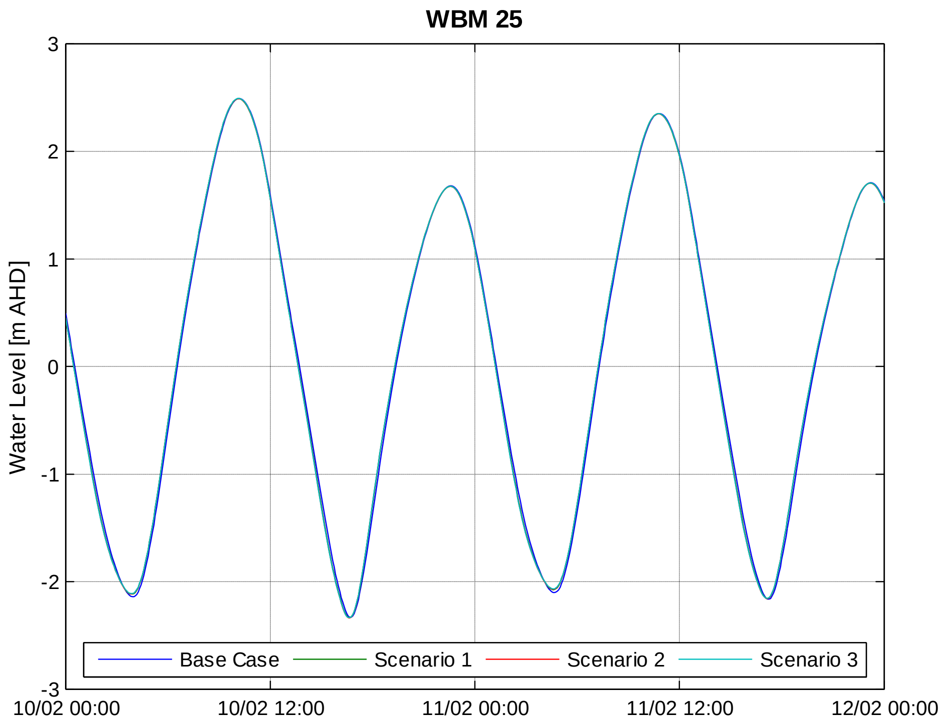

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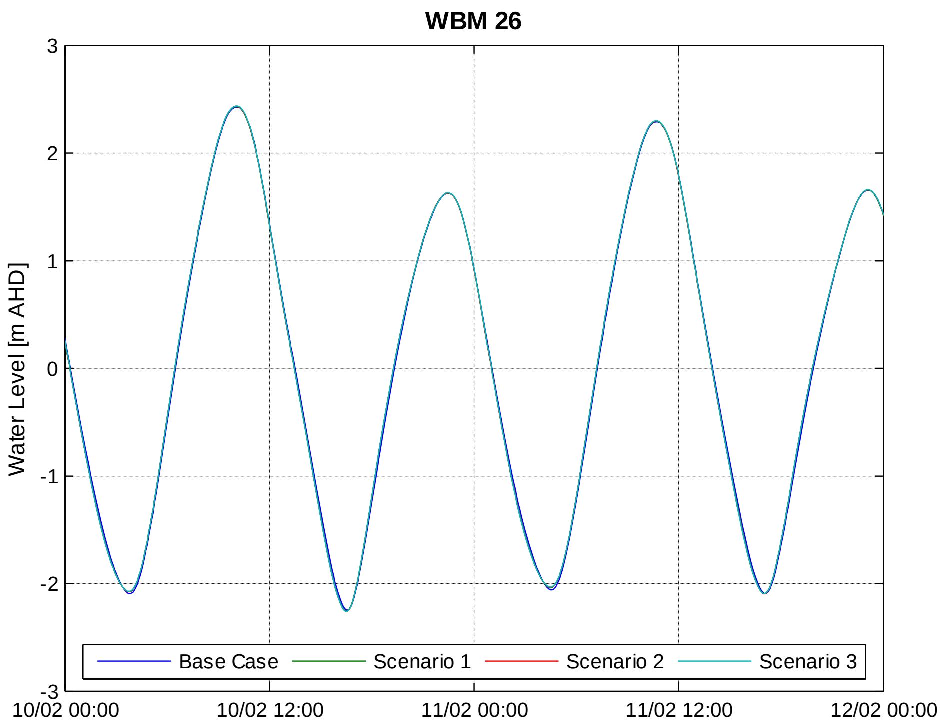

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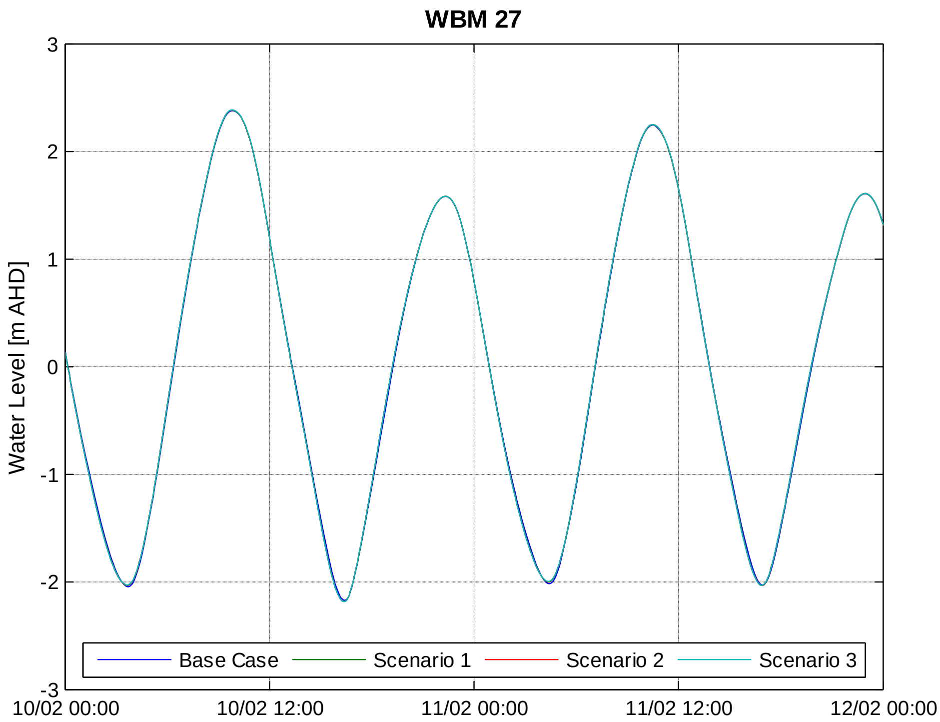


Figure A-27 Water Level Time Series – WBM 27

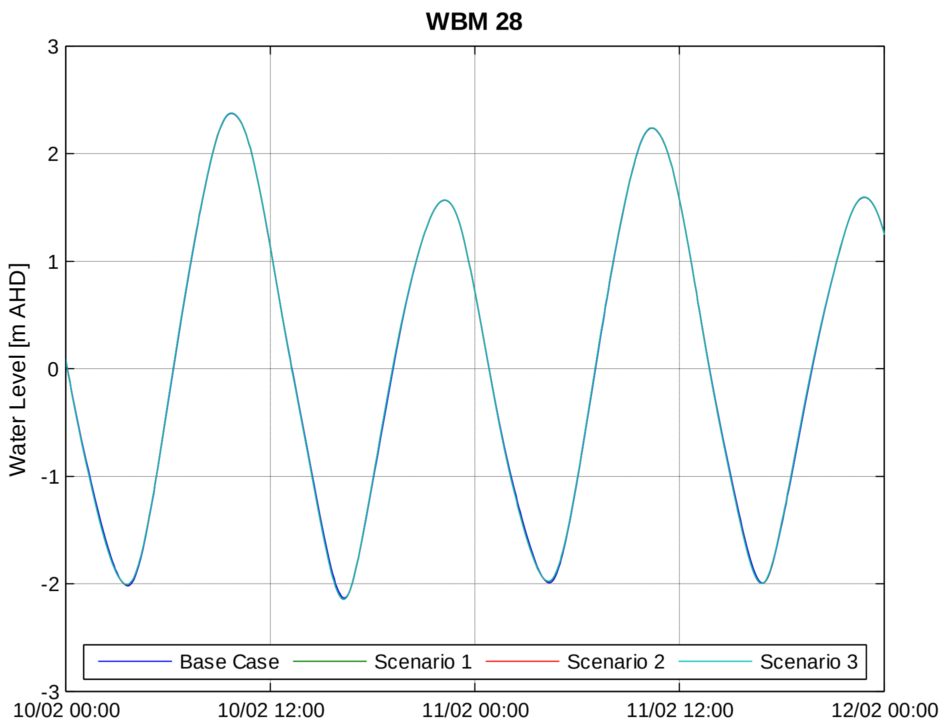


Figure A-28 Water Level Time Series – WBM 28

APPENDIX B: WATER LEVEL EXCEEDANCE PROBABILITY PLOTS

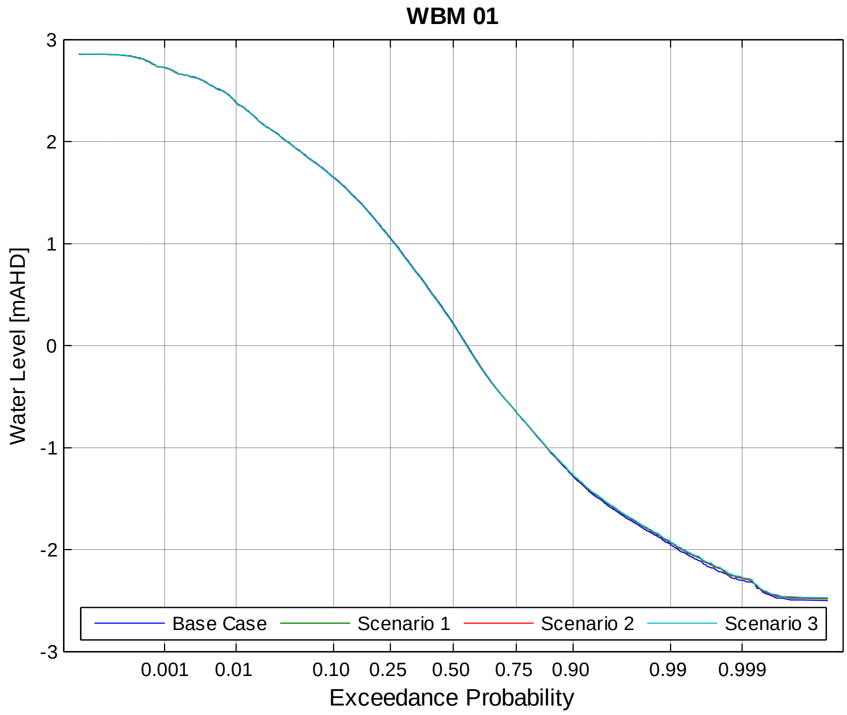


Figure B-1 Water Level Exceedance Probability – WBM 01

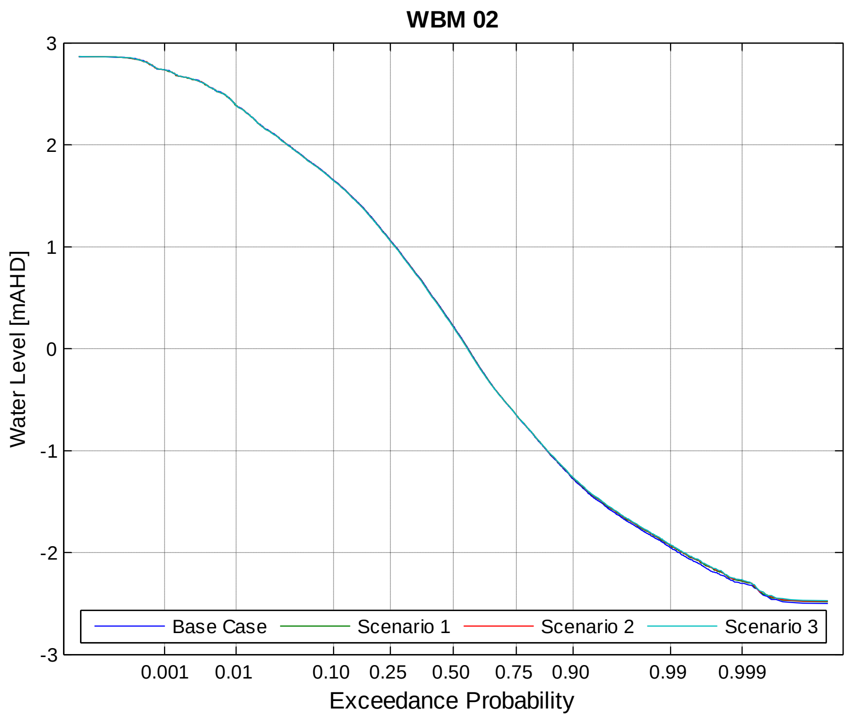


Figure B-2 Water Level Exceedance Probability – WBM 02

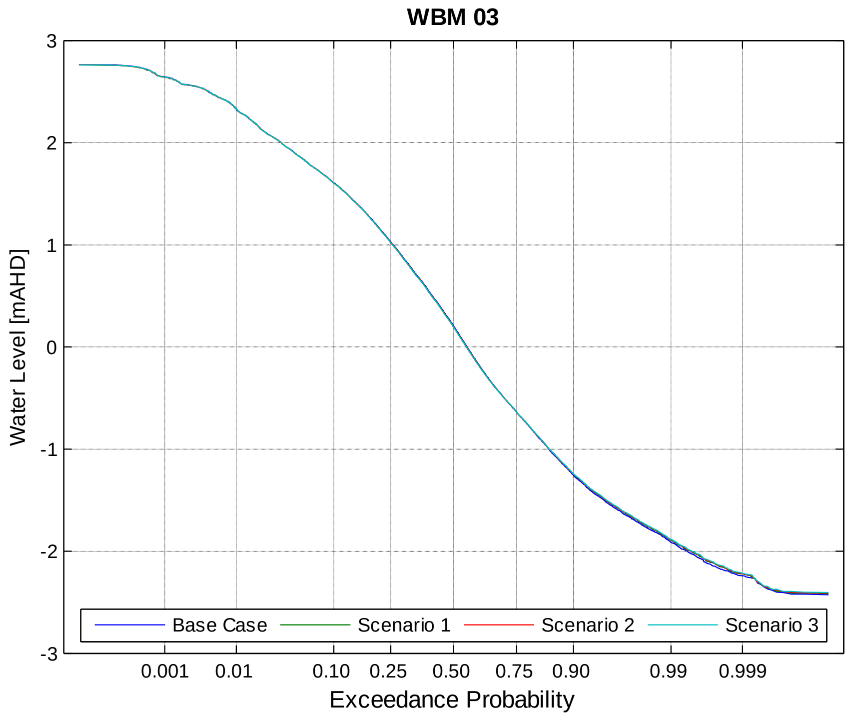


Figure B-3 Water Level Exceedance Probability – WBM 03

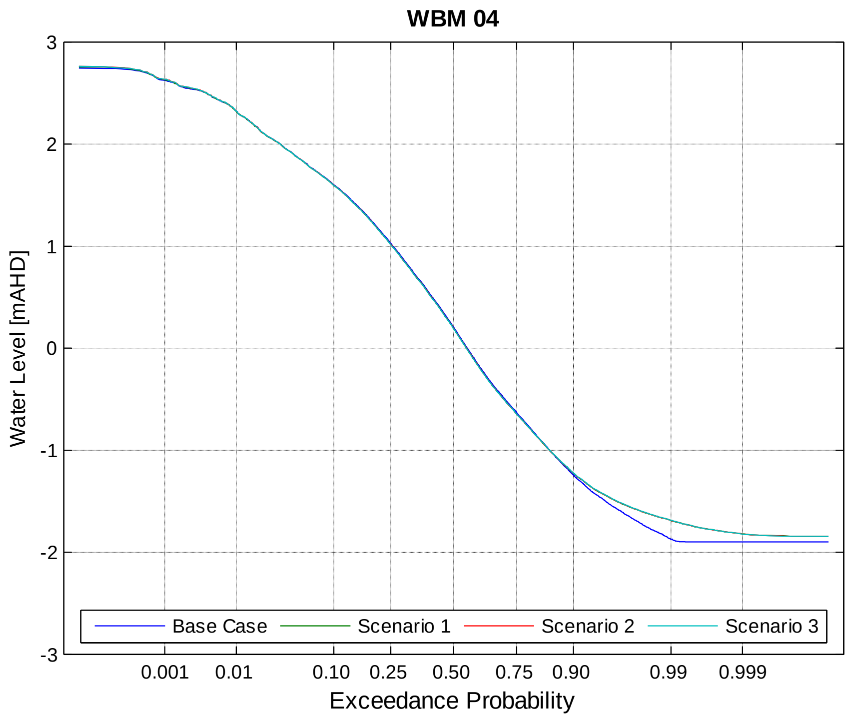


Figure B-4 Water Level Exceedance Probability – WBM 04

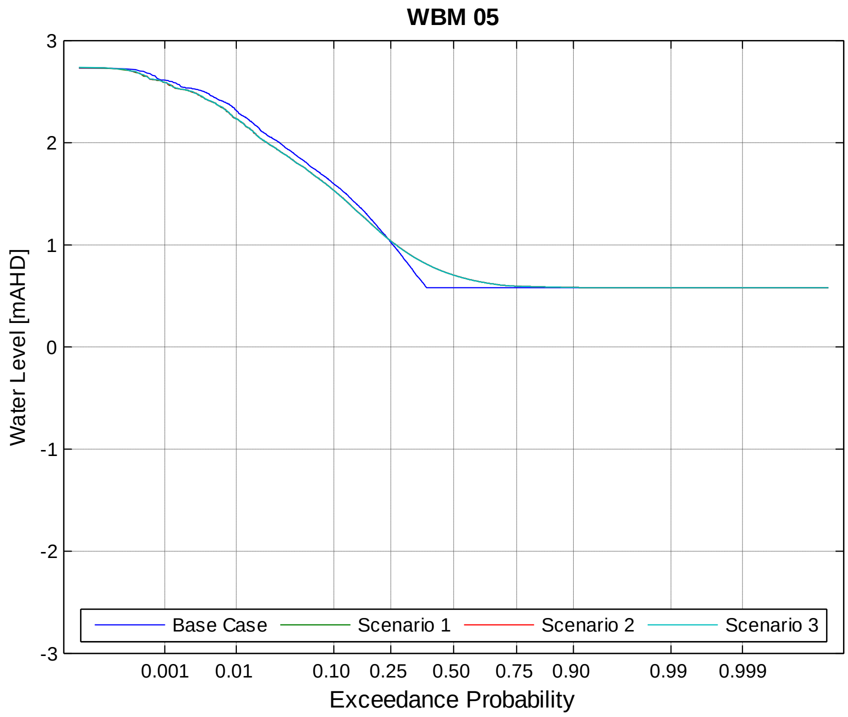


Figure B-5 Water Level Exceedance Probability – WBM 05

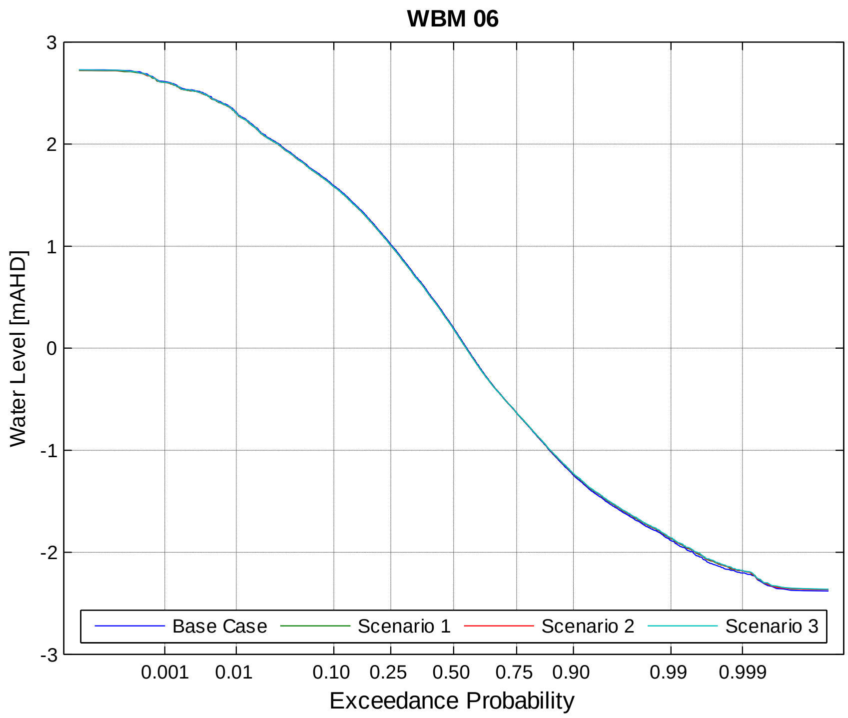


Figure B-6 Water Level Exceedance Probability – WBM 06

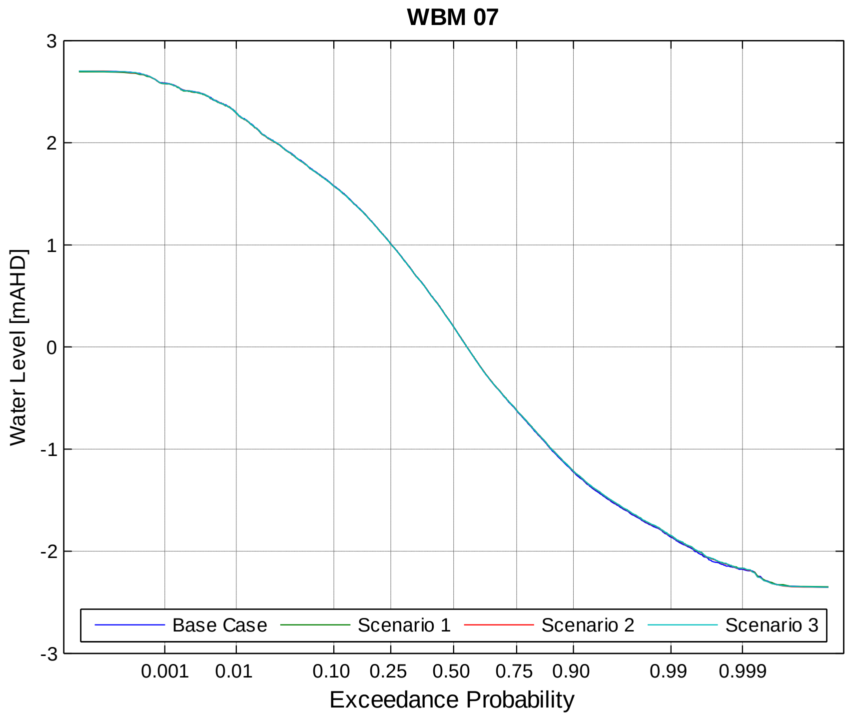


Figure B-7 Water Level Exceedance Probability – WBM 07

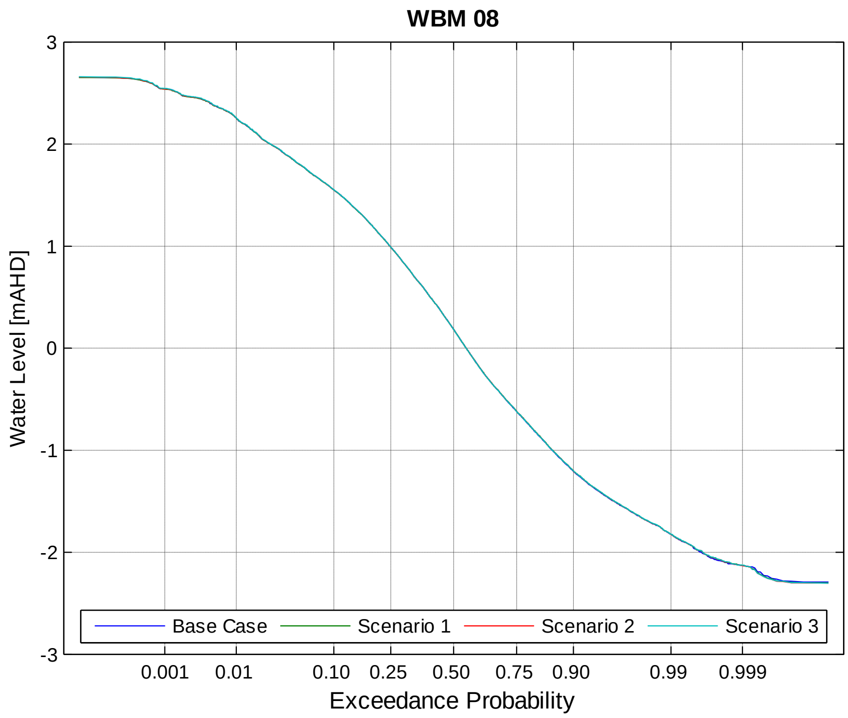


Figure B-8 Water Level Exceedance Probability – WBM 08

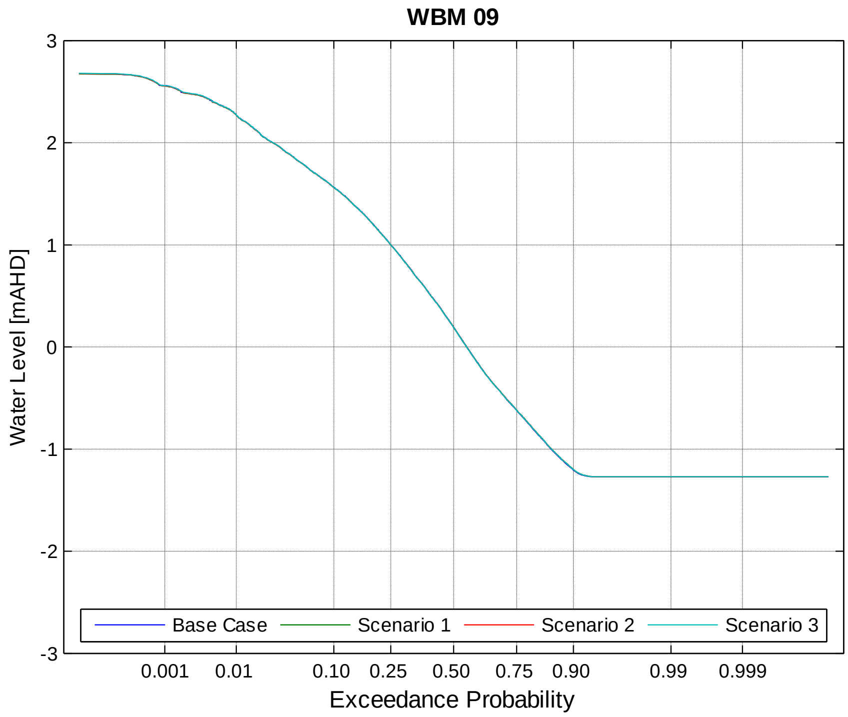


Figure B-9 Water Level Exceedance Probability – WBM 09

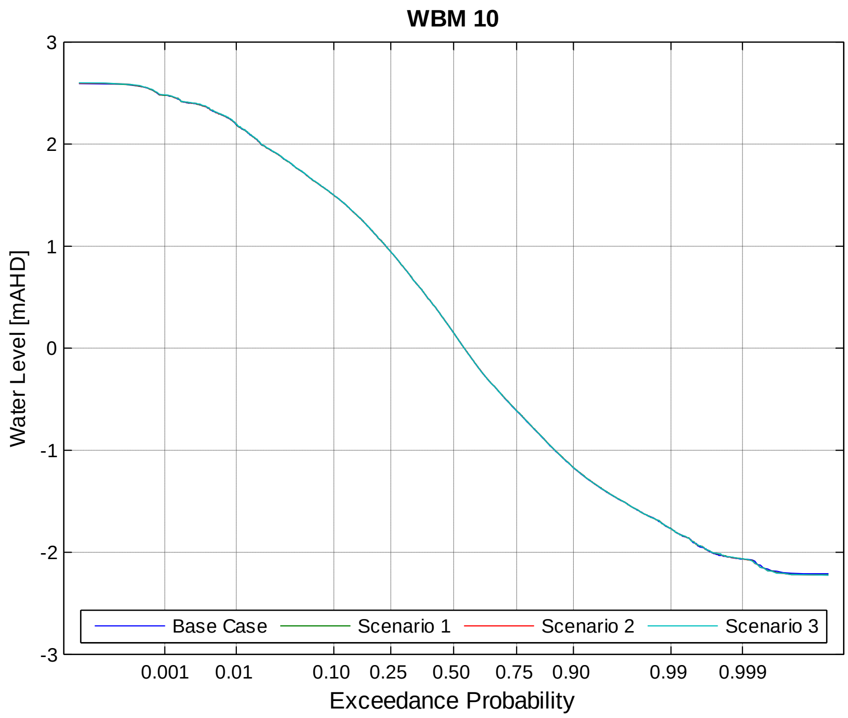


Figure B-10 Water Level Exceedance Probability – WBM 10

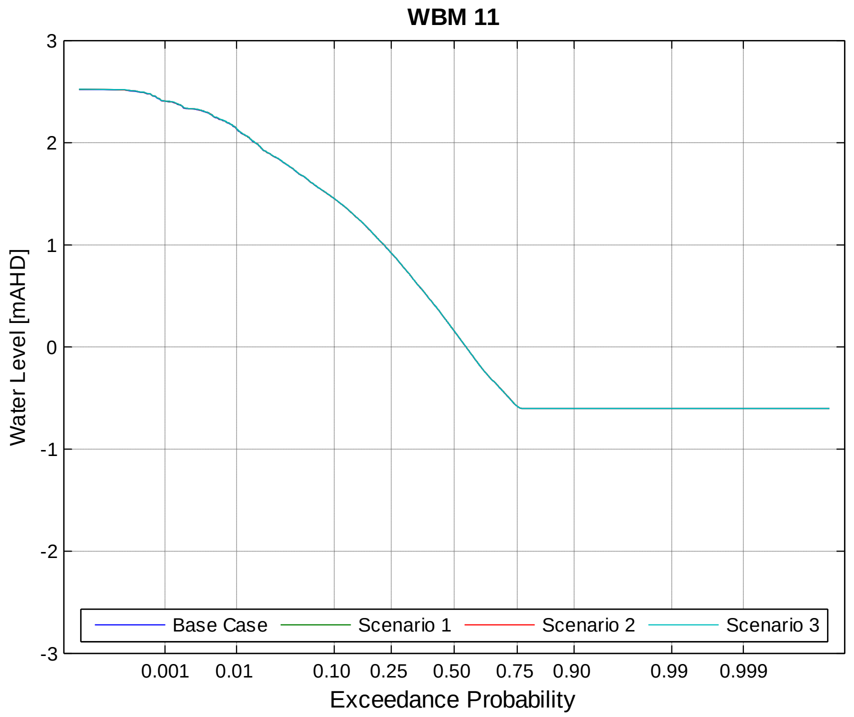


Figure B-11 Water Level Exceedance Probability – WBM 11

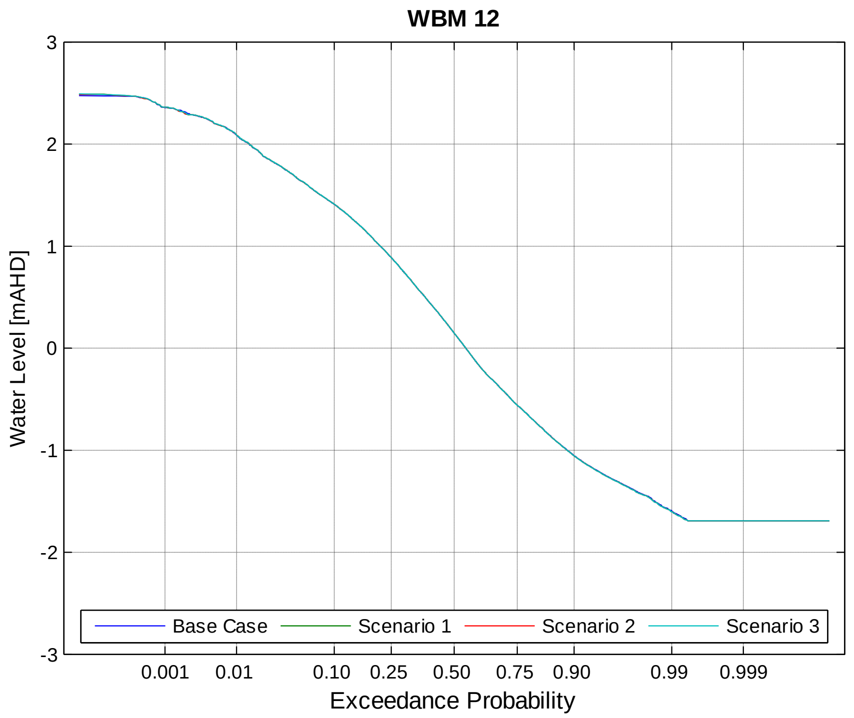


Figure B-12 Water Level Exceedance Probability – WBM 12

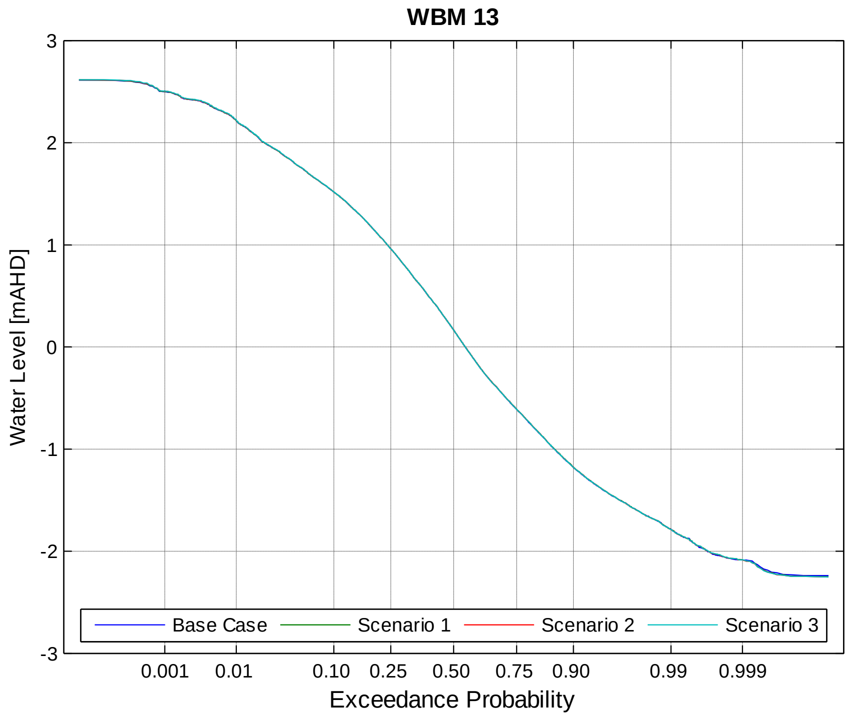


Figure B-13 Water Level Exceedance Probability – WBM 13

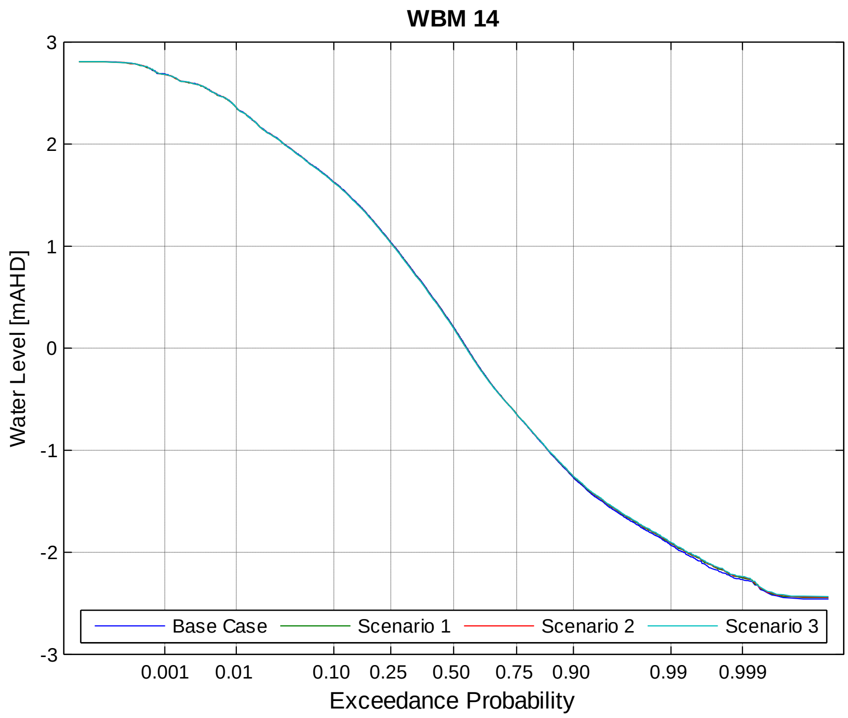


Figure B-14 Water Level Exceedance Probability – WBM 14

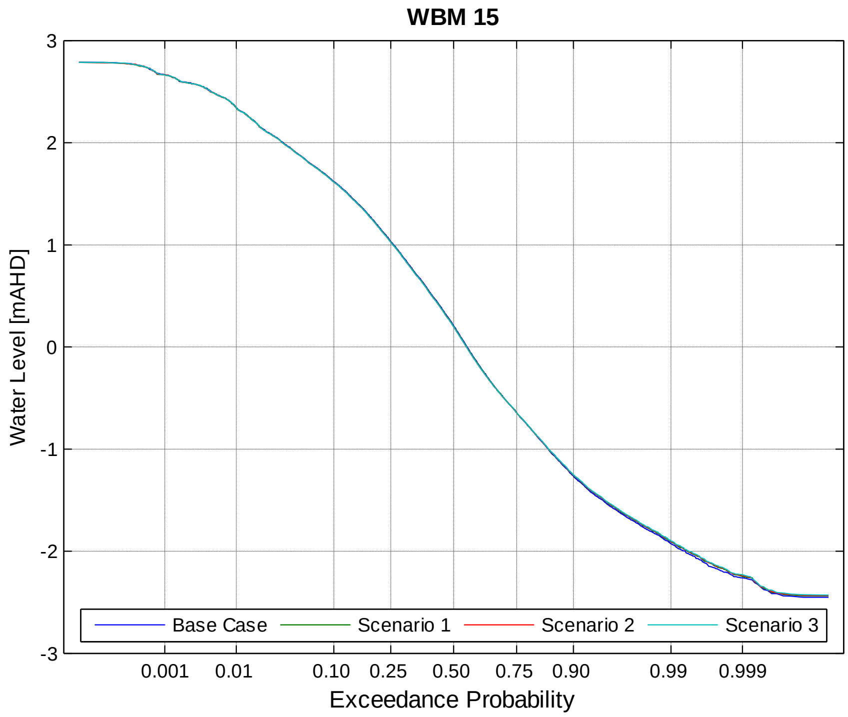


Figure B-15 Water Level Exceedance Probability – WBM 15

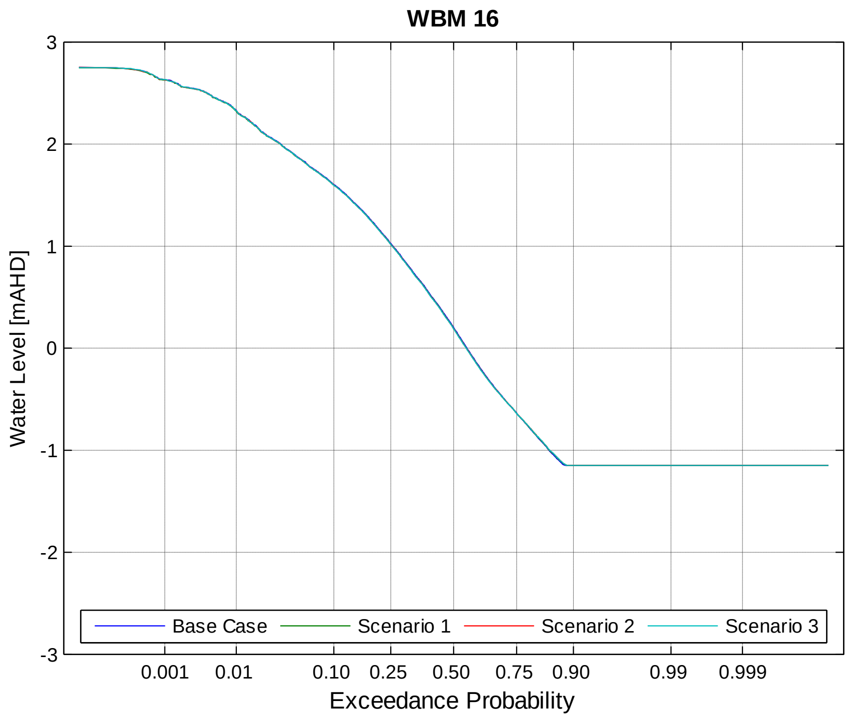


Figure B-16 Water Level Exceedance Probability – WBM 16

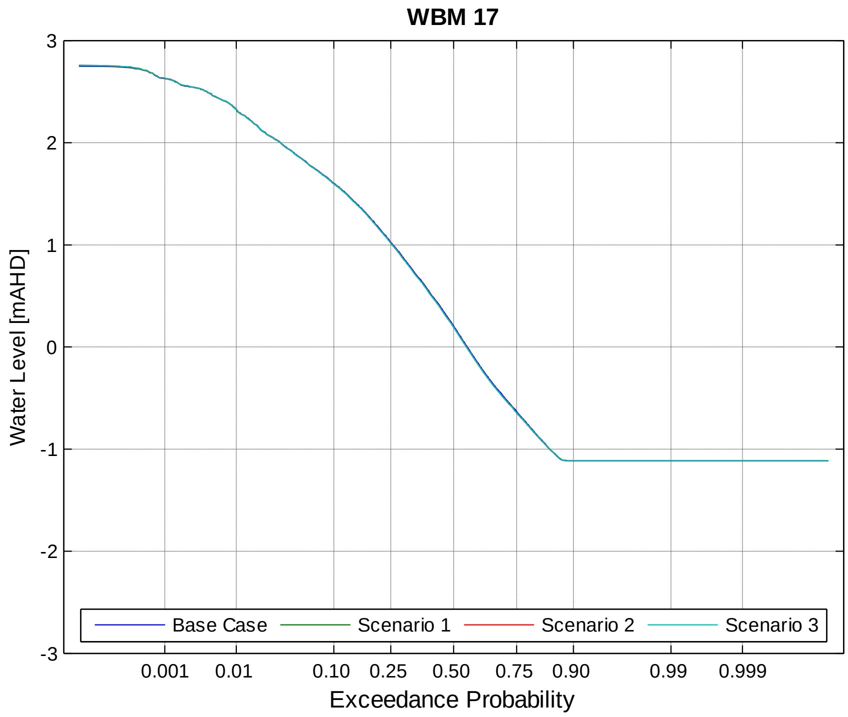


Figure B-17 Water Level Exceedance Probability – WBM 17

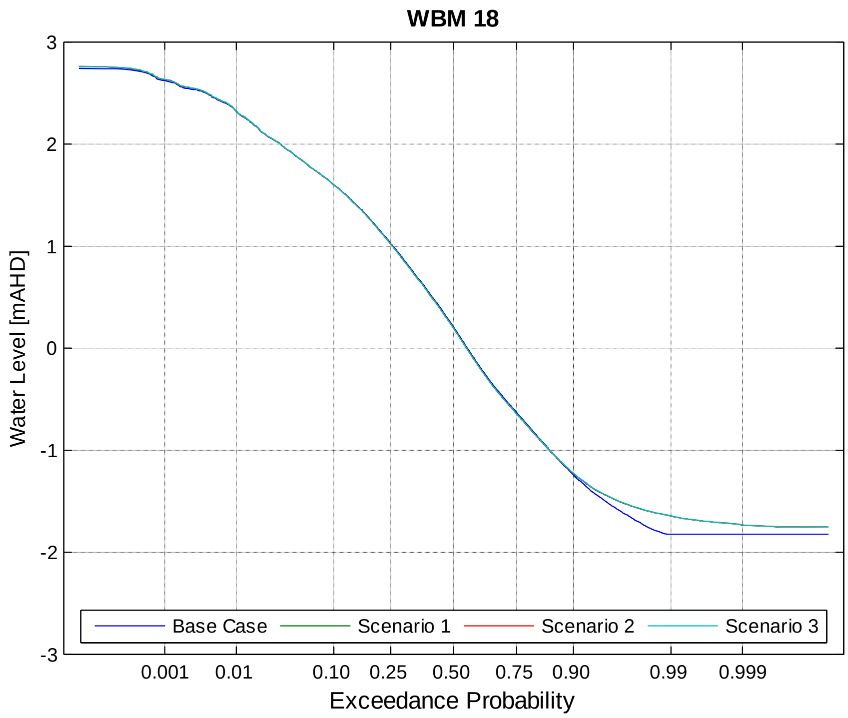


Figure B-18 Water Level Exceedance Probability – WBM 18

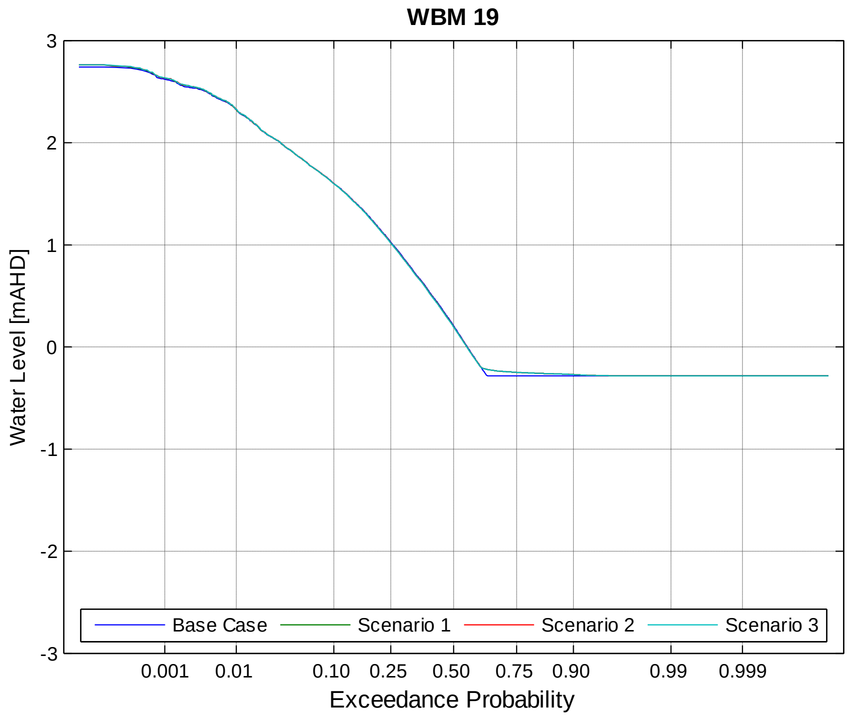


Figure B-19 Water Level Exceedance Probability – WBM 19

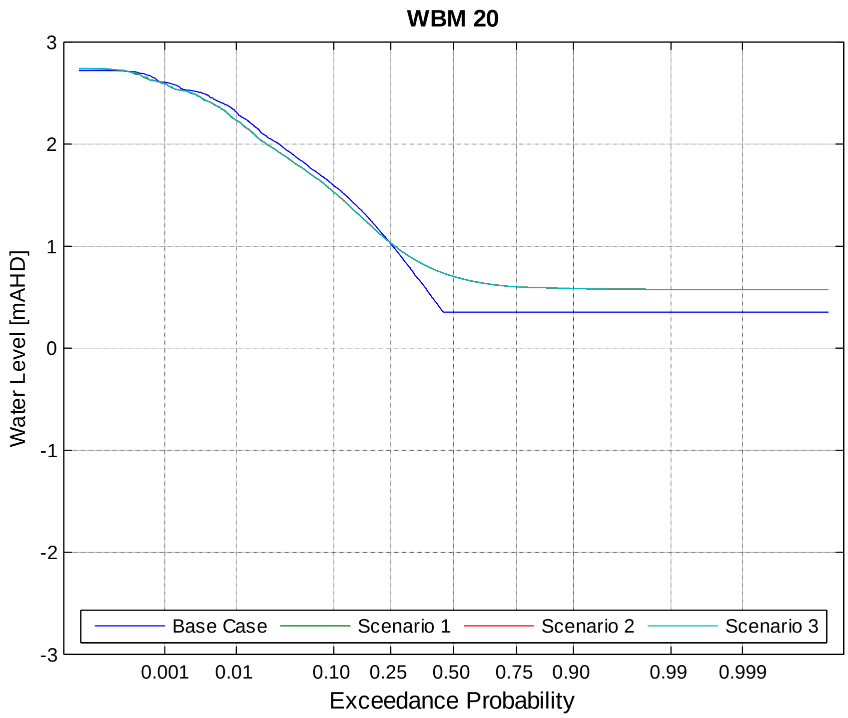


Figure B-20 Water Level Exceedance Probability – WBM 20

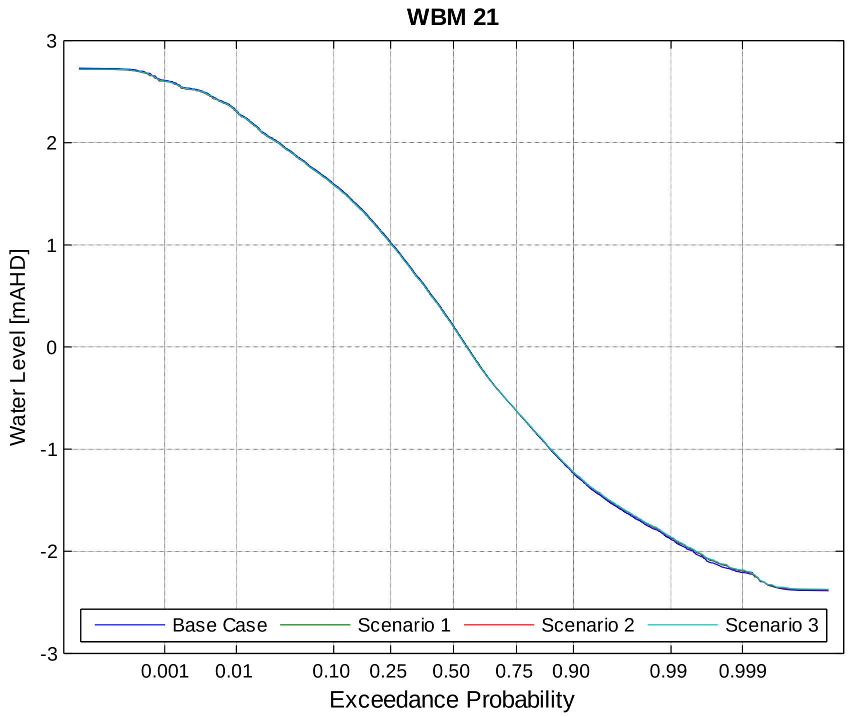


Figure B-21 Water Level Exceedance Probability – WBM 21

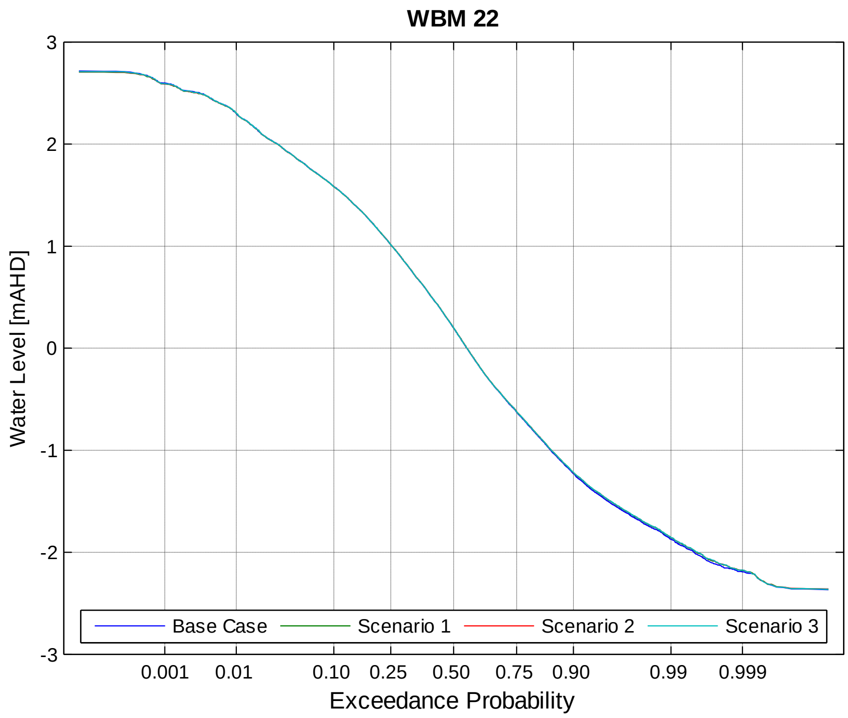


Figure B-22 Water Level Exceedance Probability – WBM 22

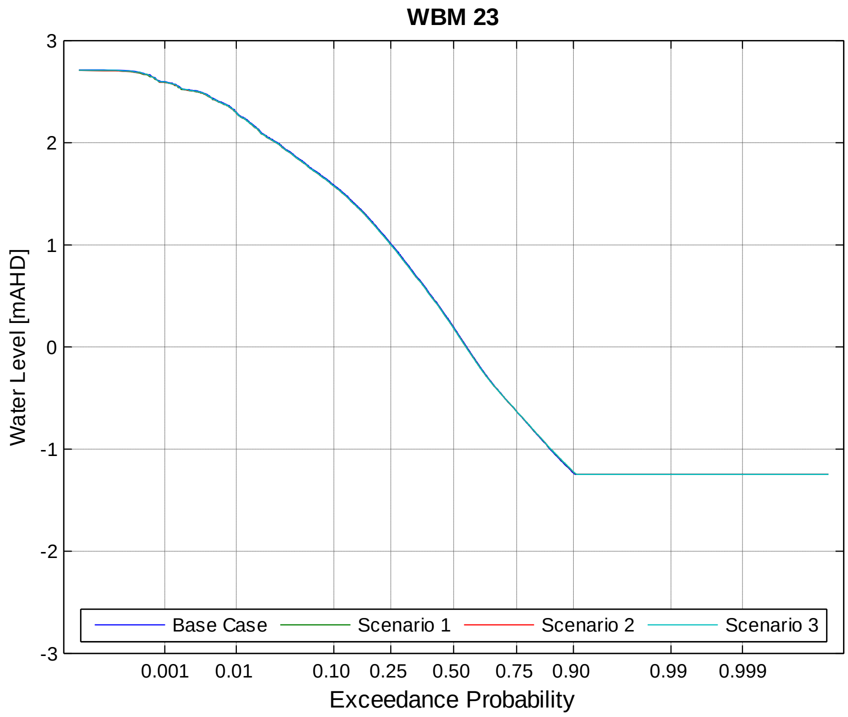


Figure B-23 Water Level Exceedance Probability – WBM 23

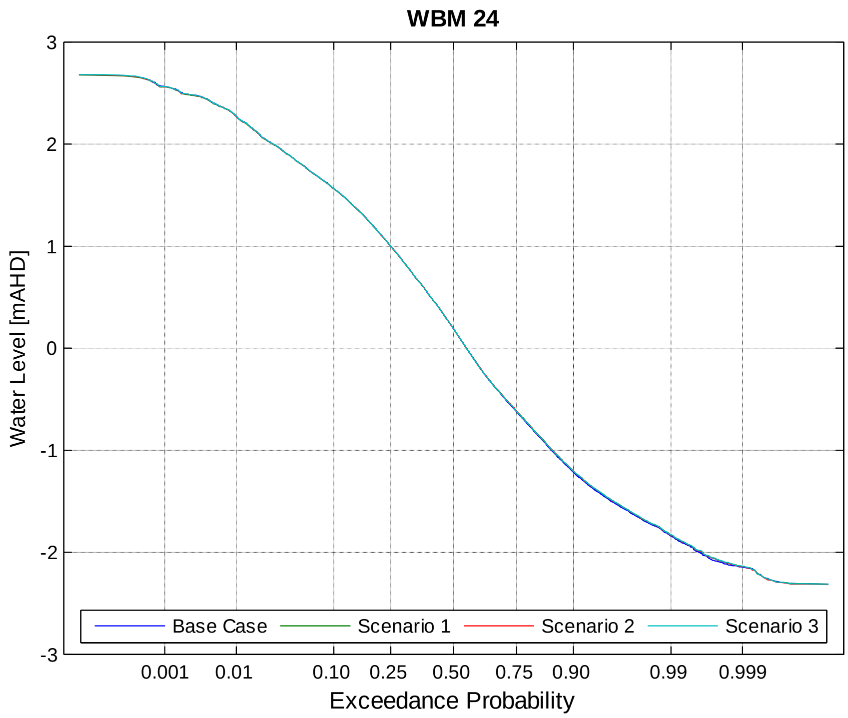


Figure B-24 Water Level Exceedance Probability – WBM 24

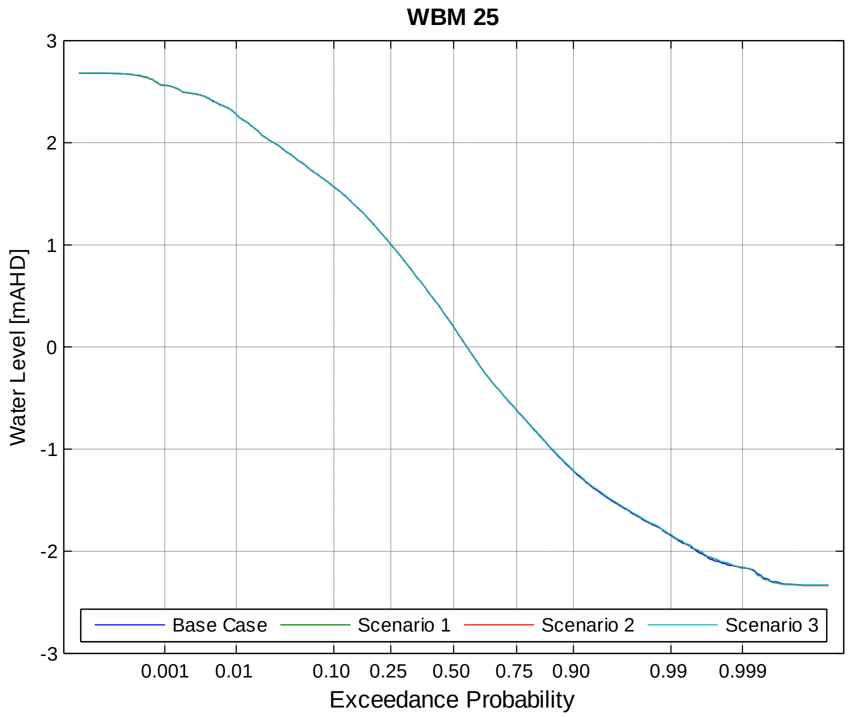


Figure B-25 Water Level Exceedance Probability – WBM 25

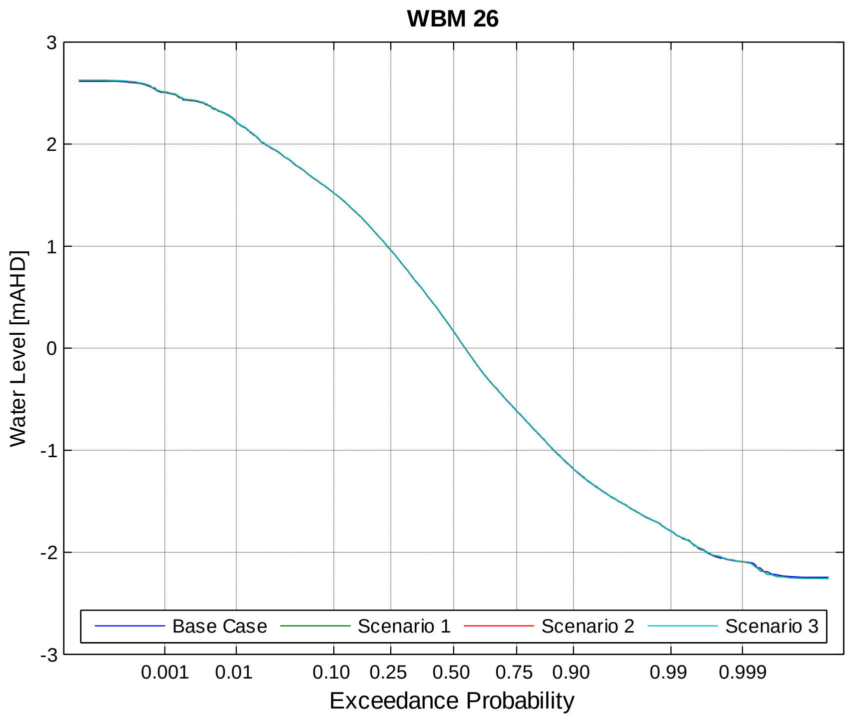


Figure B-26 Water Level Exceedance Probability – WBM 26

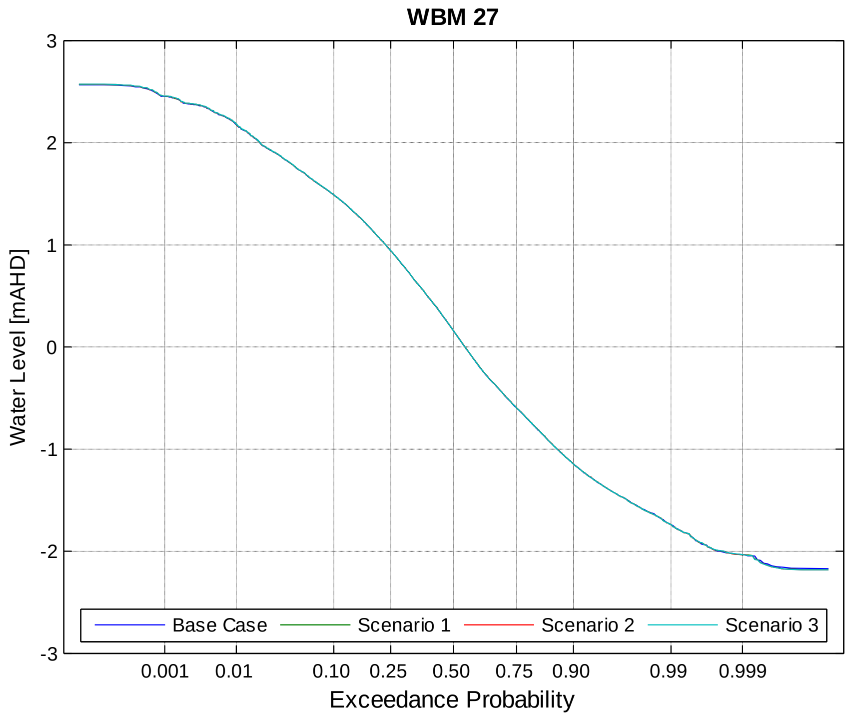


Figure B-27 Water Level Exceedance Probability – WBM 27

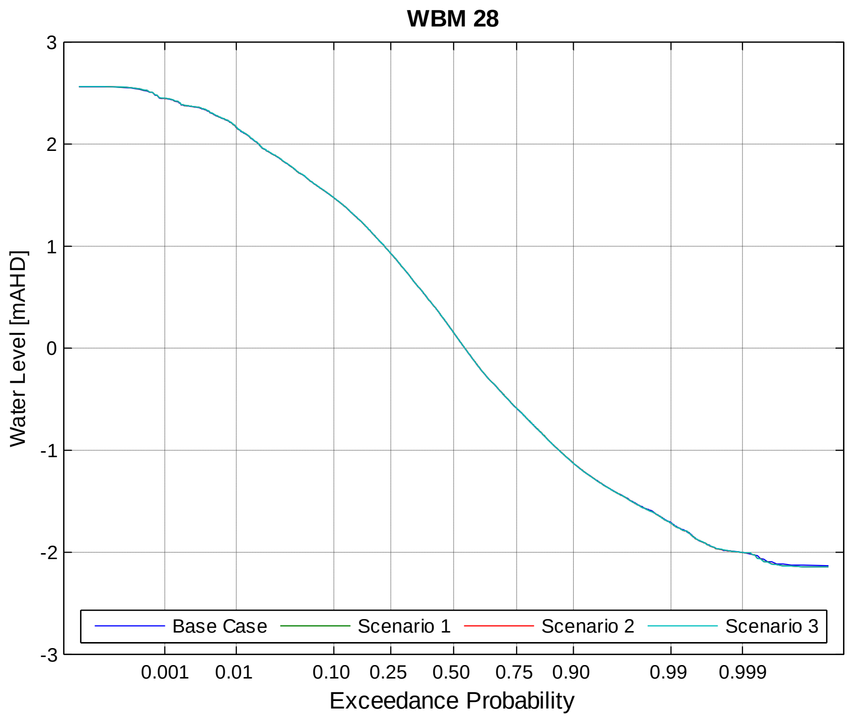


Figure B-28 Water Level Exceedance Probability – WBM 28

APPENDIX C: VELOCITY MAGNITUDE TIME SERIES PLOTS

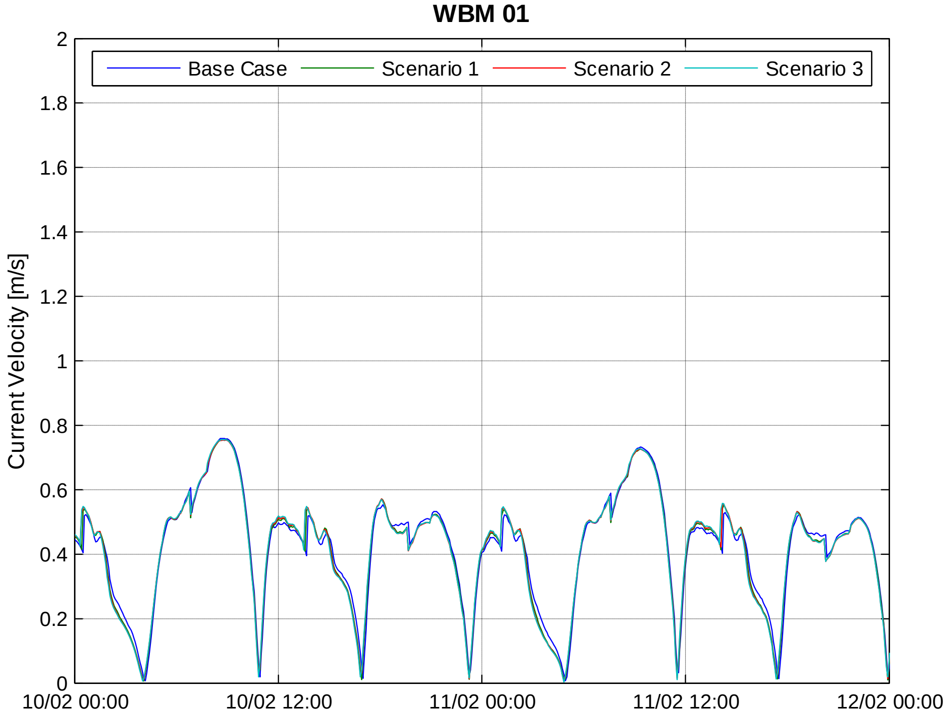


Figure C-1 Velocity Magnitude Time Series – WBM 01

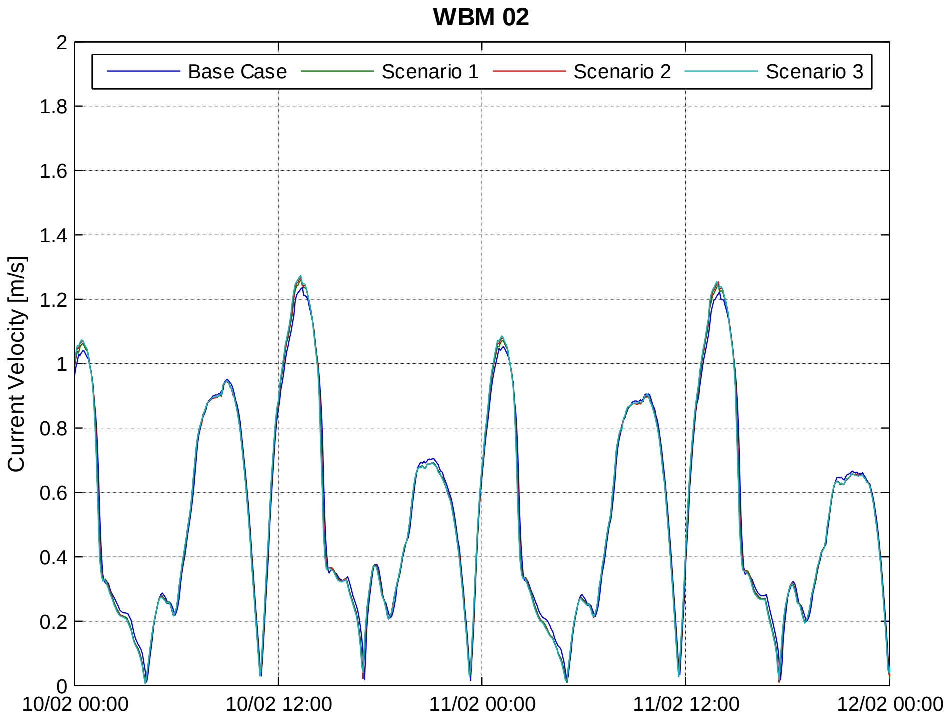


Figure C-2 Velocity Magnitude Time Series – WBM 02

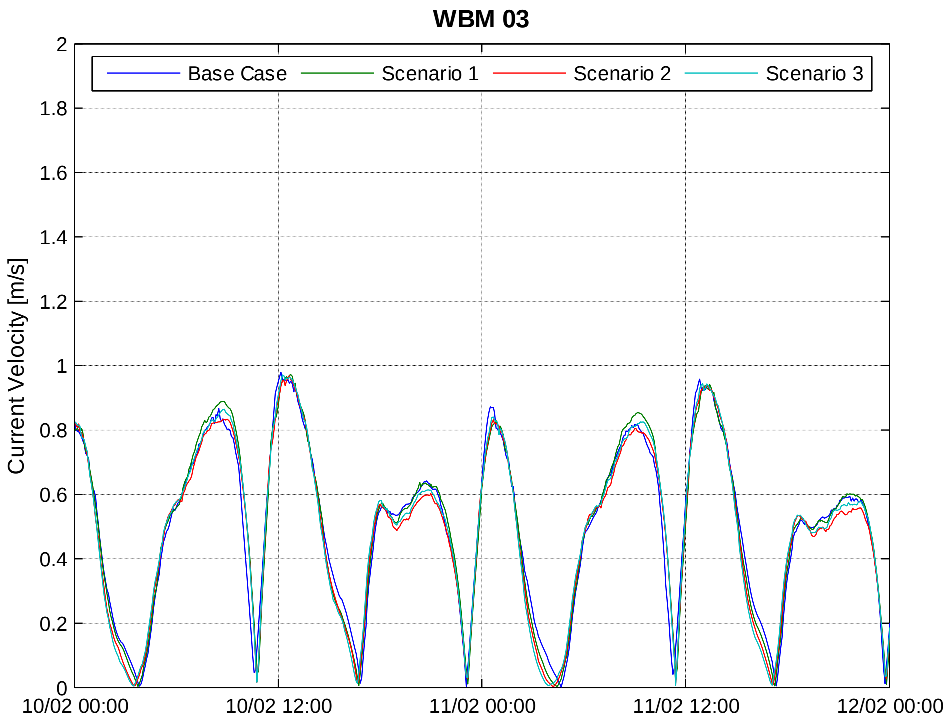


Figure C-3 Velocity Magnitude Time Series – WBM 03

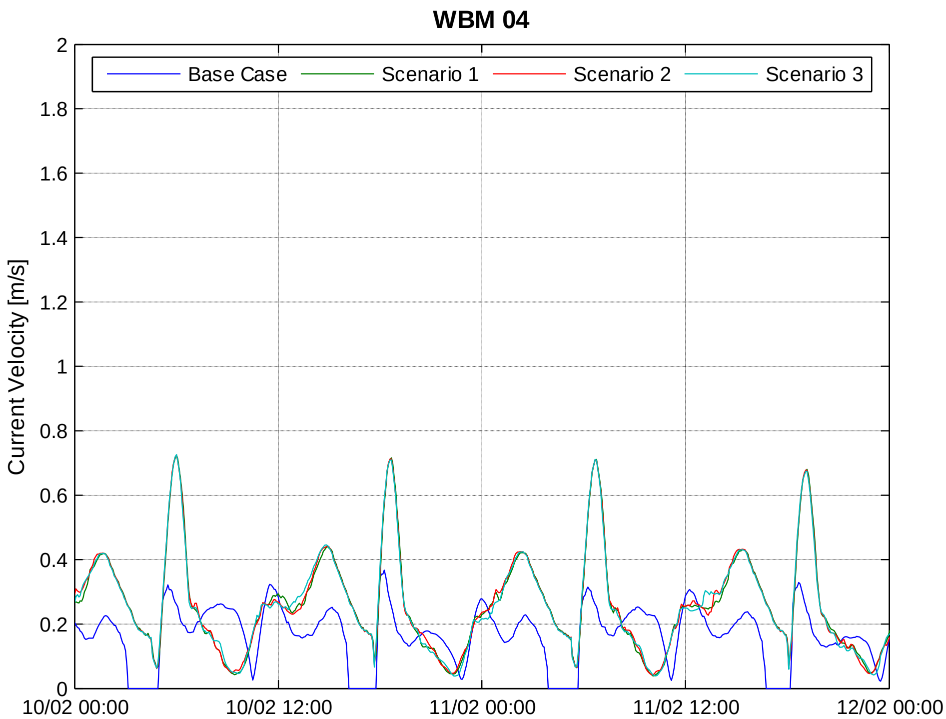


Figure C-4 Velocity Magnitude Time Series – WBM 04

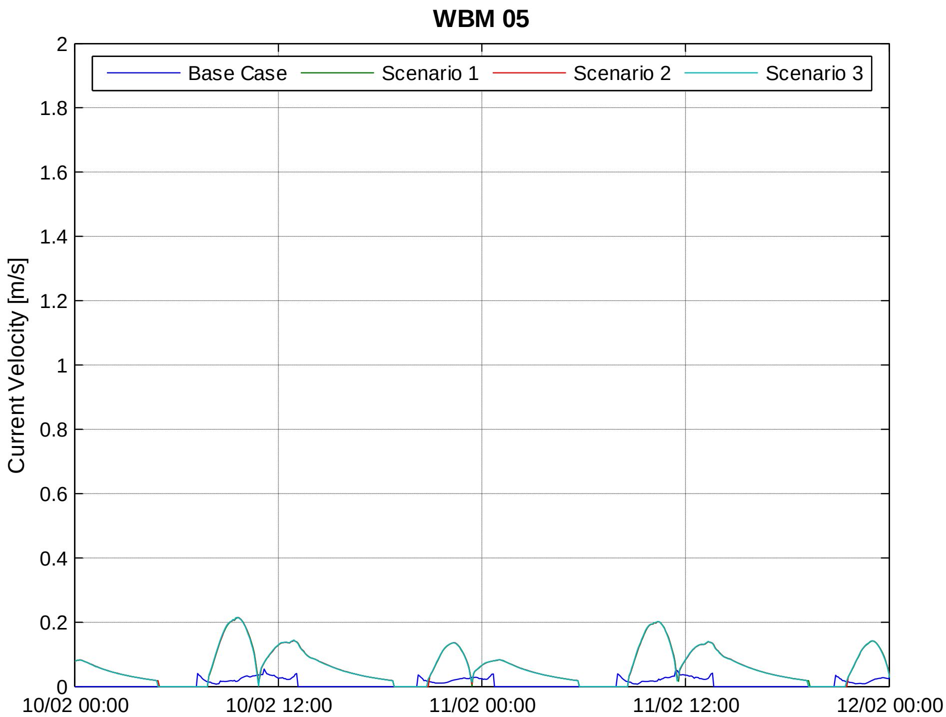
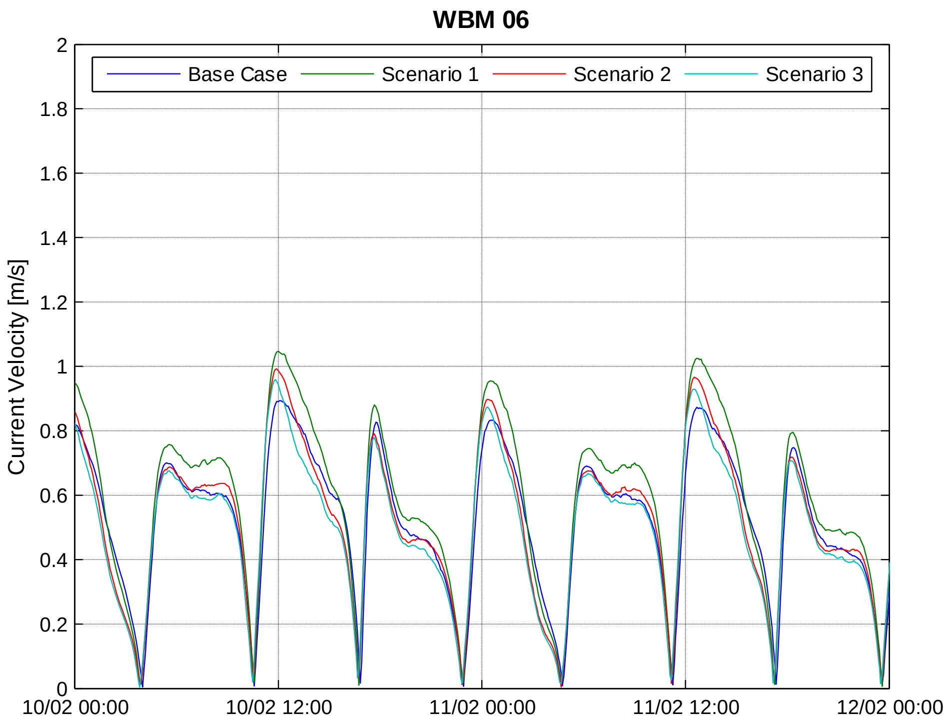


Figure C-5 Velocity Magnitude Time Series – WBM 05



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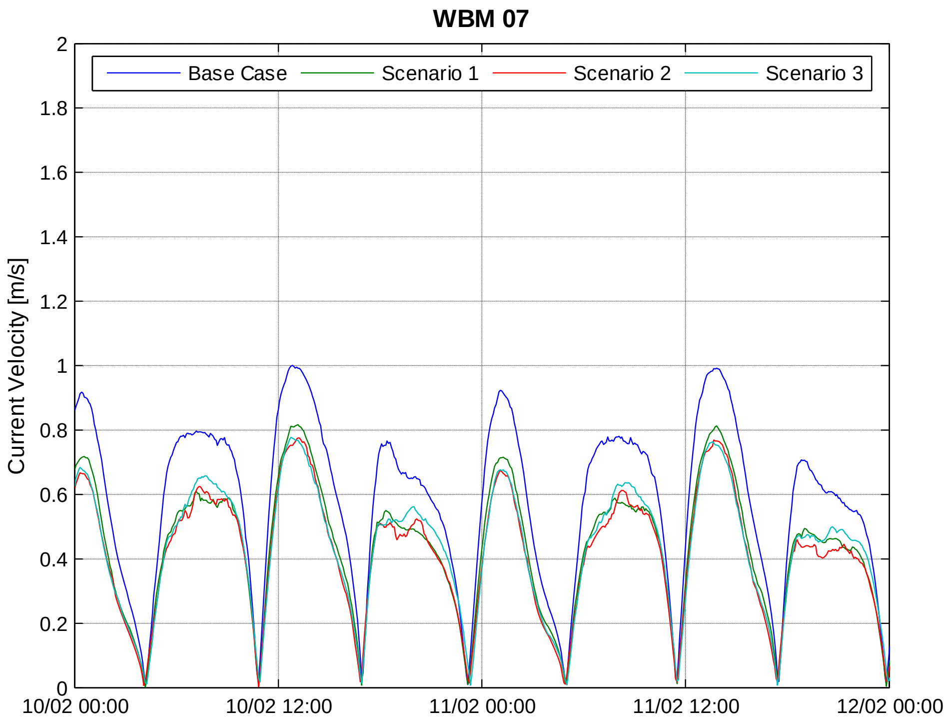


Figure C-7 Velocity Magnitude Time Series – WBM 07

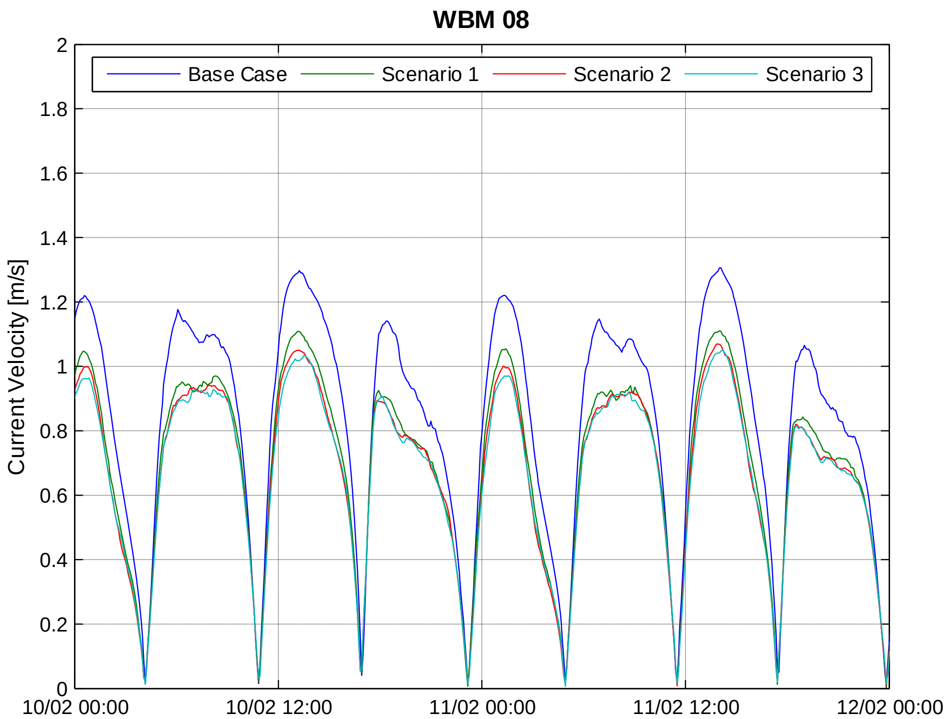


Figure C-8 Velocity Magnitude Time Series – WBM 08

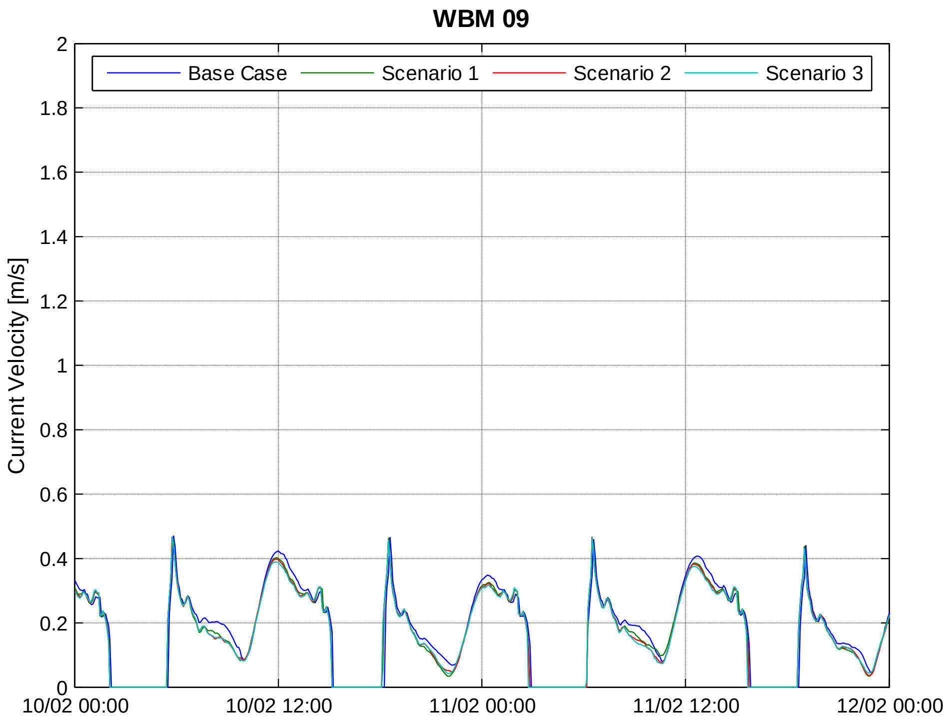


Figure C-9 Velocity Magnitude Time Series – WBM 09

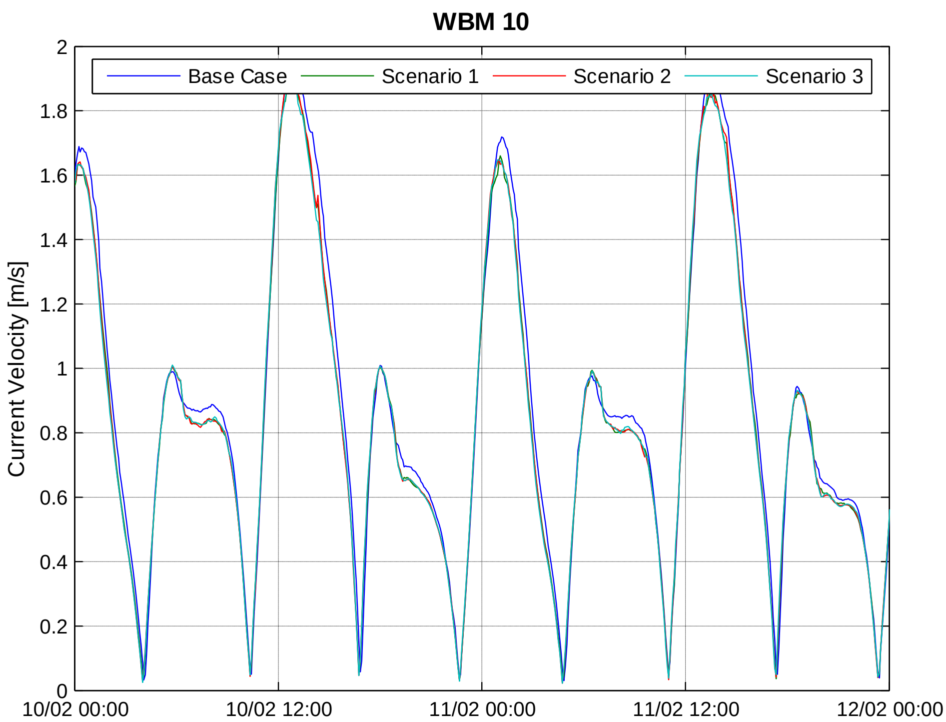


Figure C-10 Velocity Magnitude Time Series – WBM 10

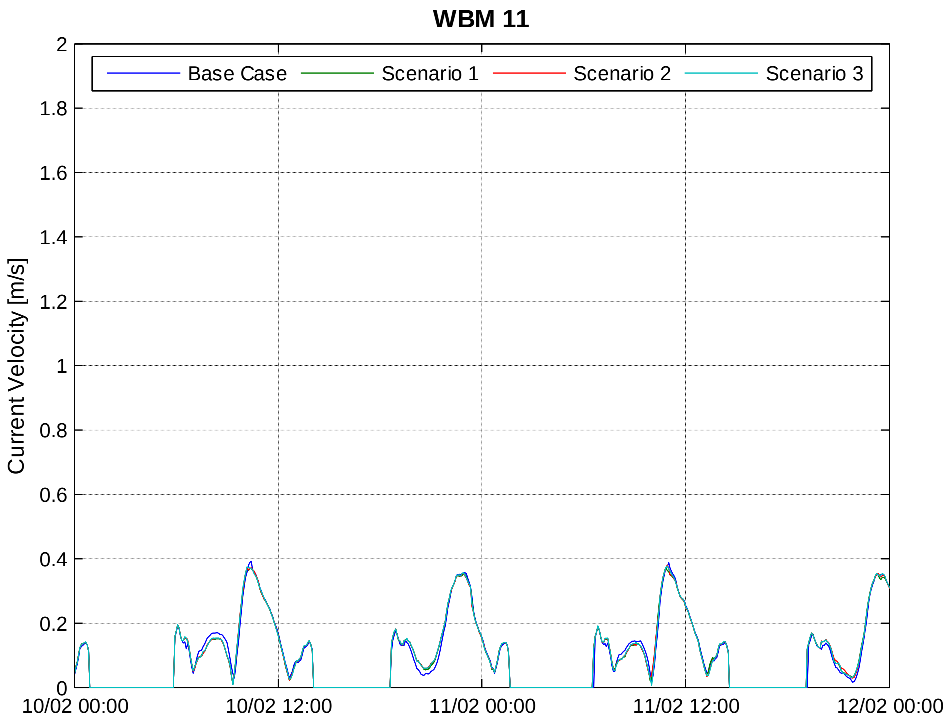


Figure C-11 Velocity Magnitude Time Series – WBM 11

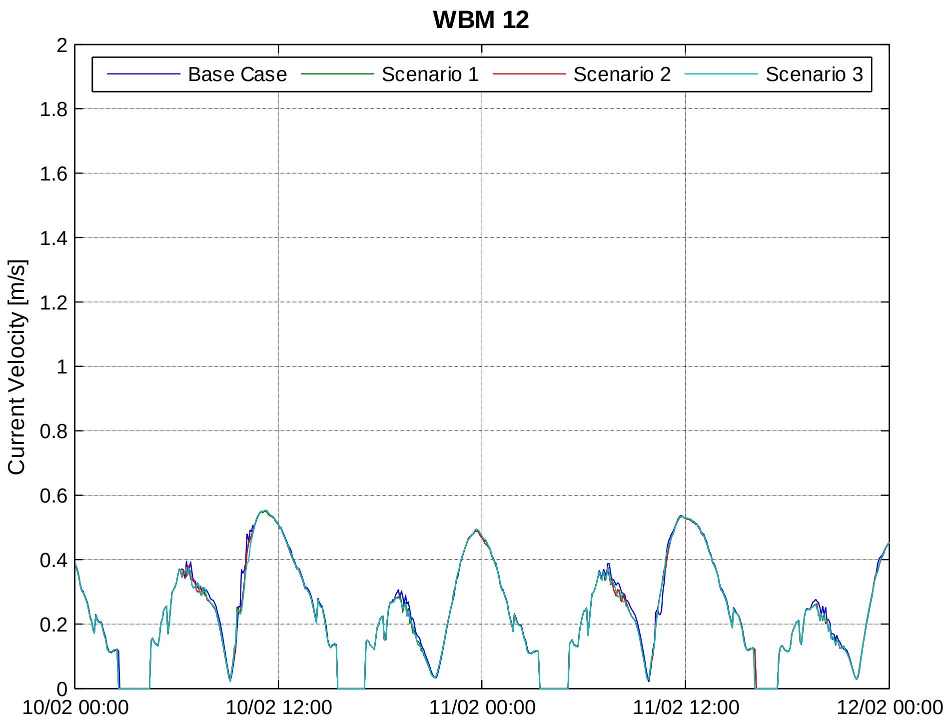


Figure C-12 Velocity Magnitude Time Series – WBM 12

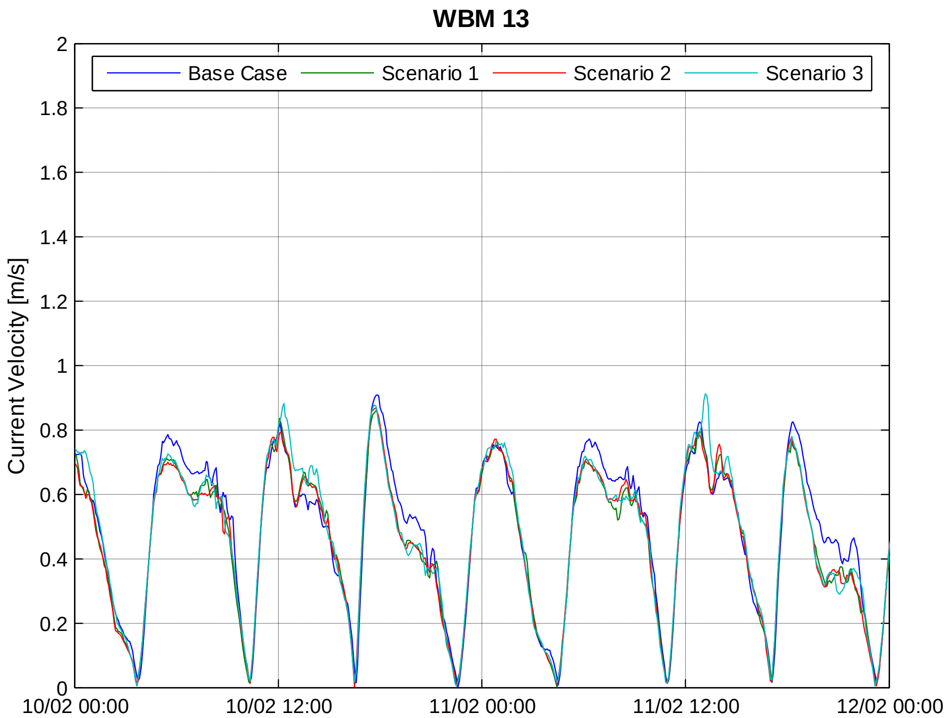


Figure C-13 Velocity Magnitude Time Series – WBM 13

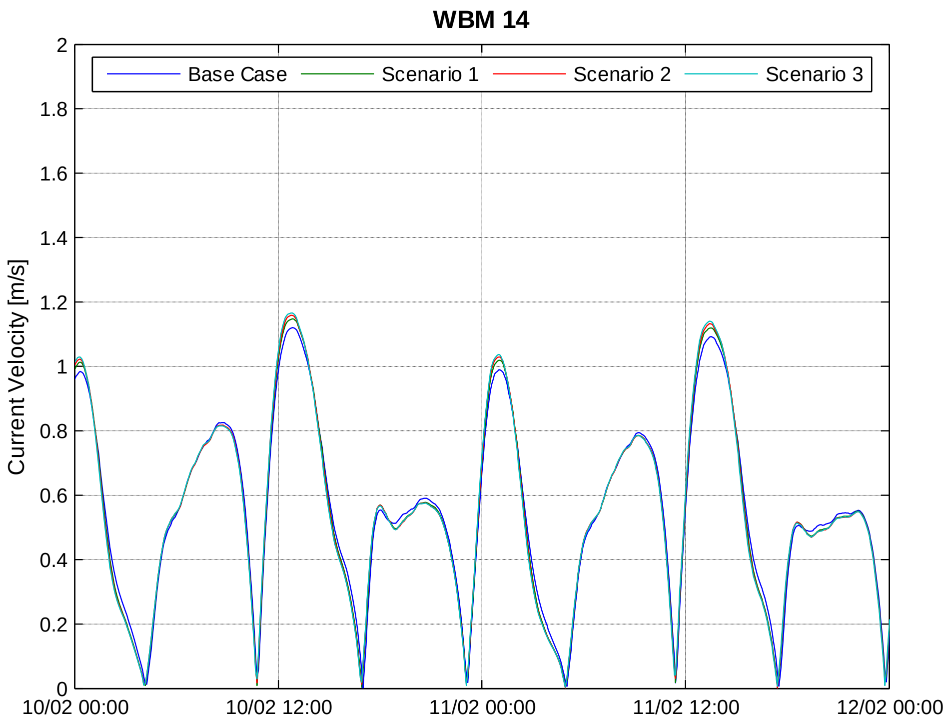


Figure C-14 Velocity Magnitude Time Series – WBM 14

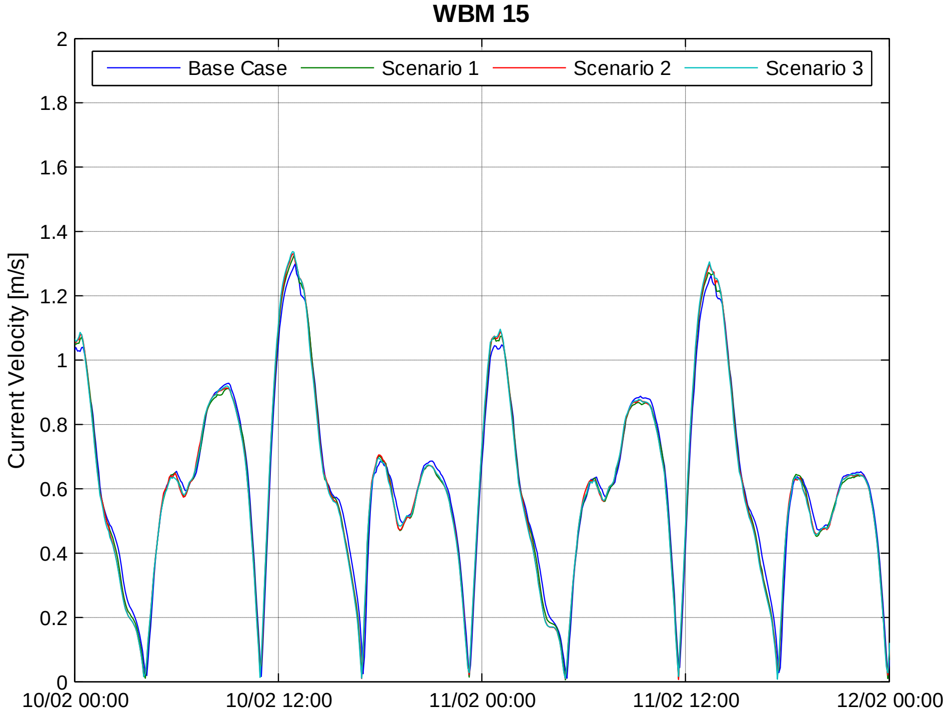


Figure C-15 Velocity Magnitude Time Series – WBM 15

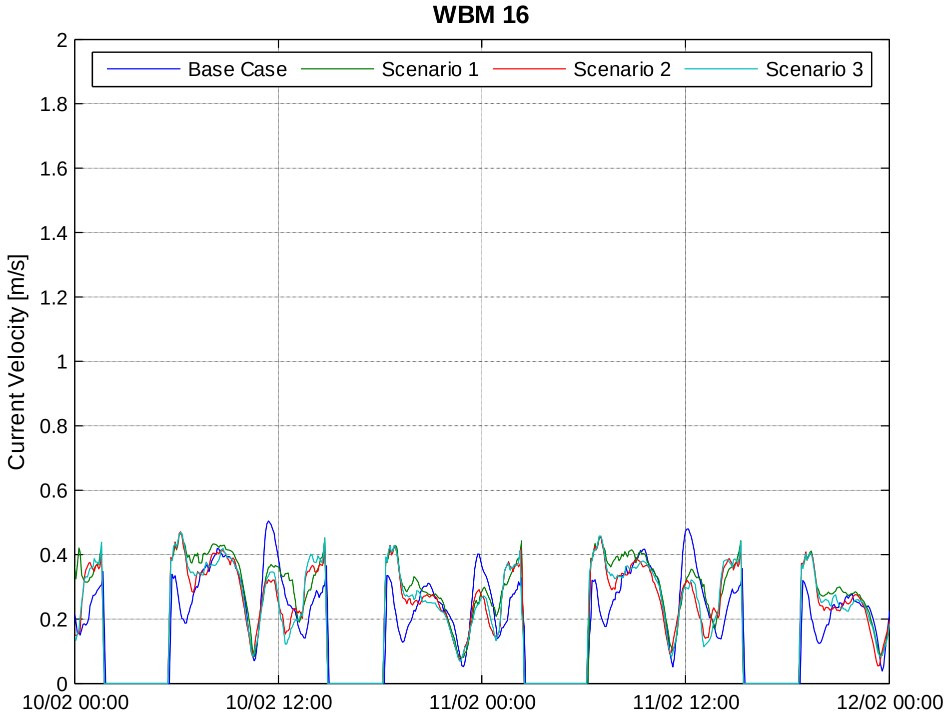


Figure C-16 Velocity Magnitude Time Series – WBM 16

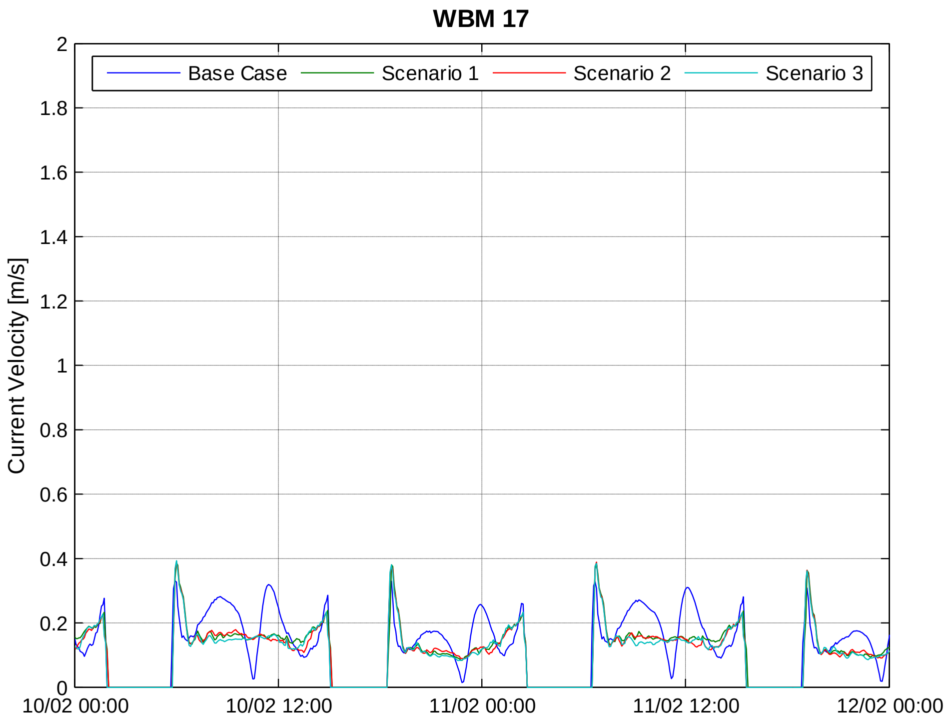


Figure C-17 Velocity Magnitude Time Series – WBM 17

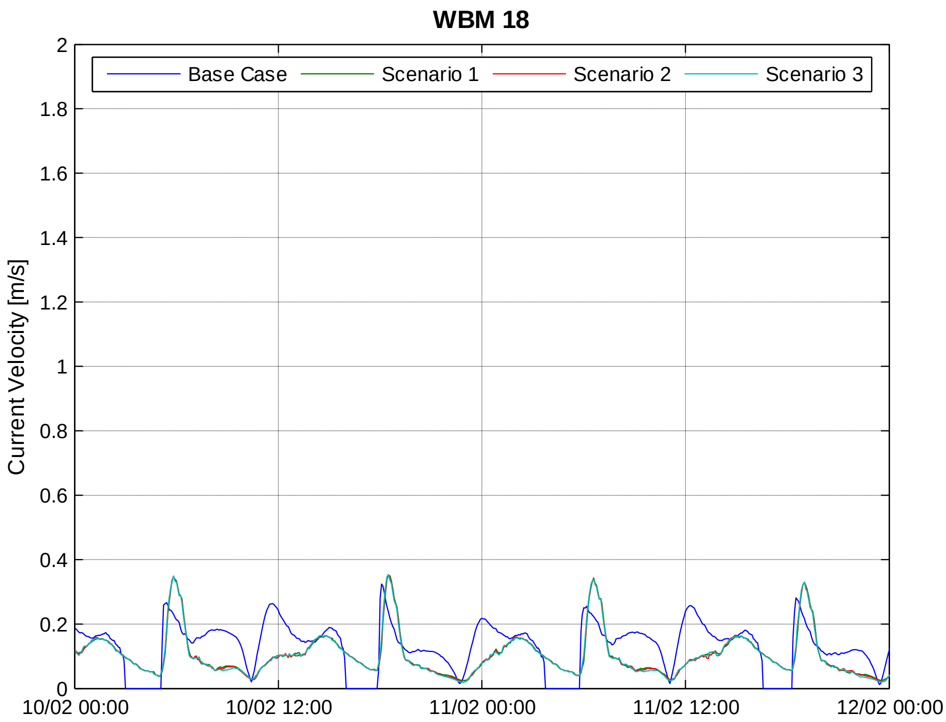


Figure C-18 Velocity Magnitude Time Series – WBM 18

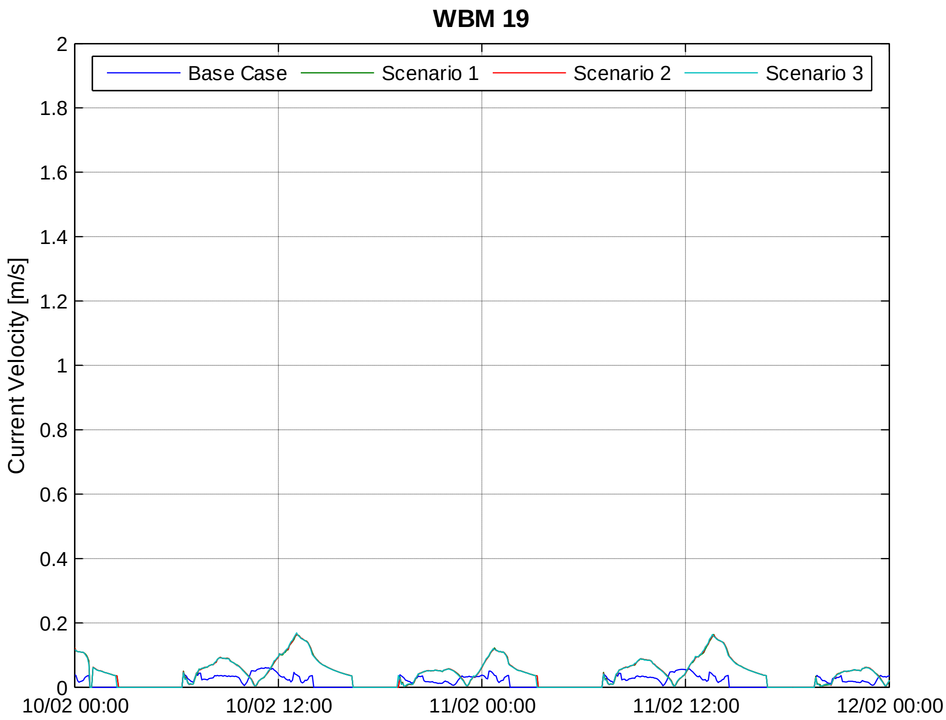


Figure C-19 Velocity Magnitude Time Series – WBM 19

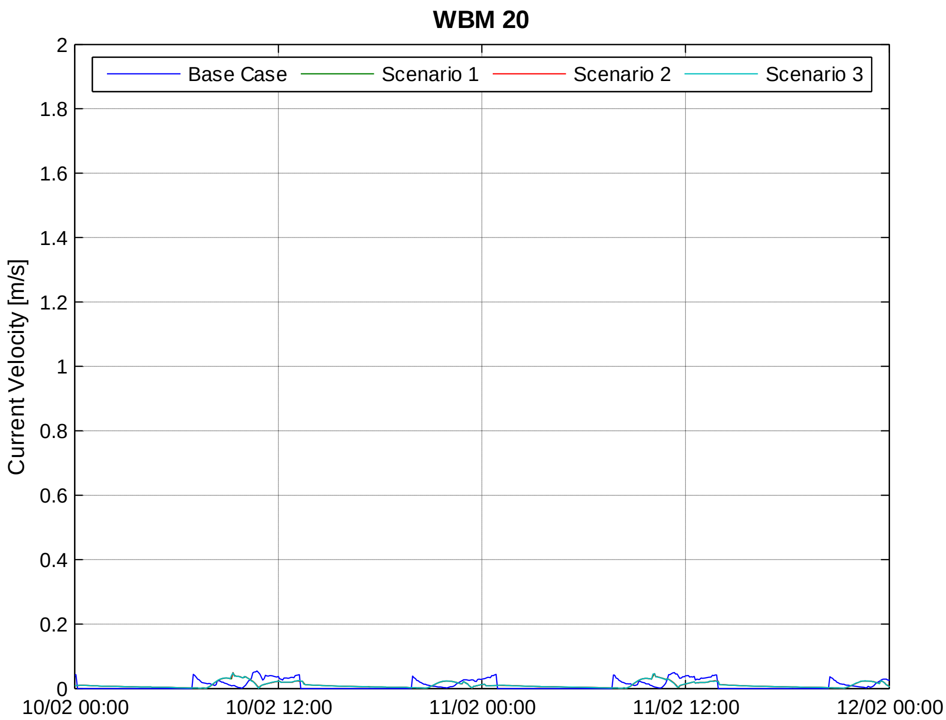


Figure C-20 Velocity Magnitude Time Series – WBM 20

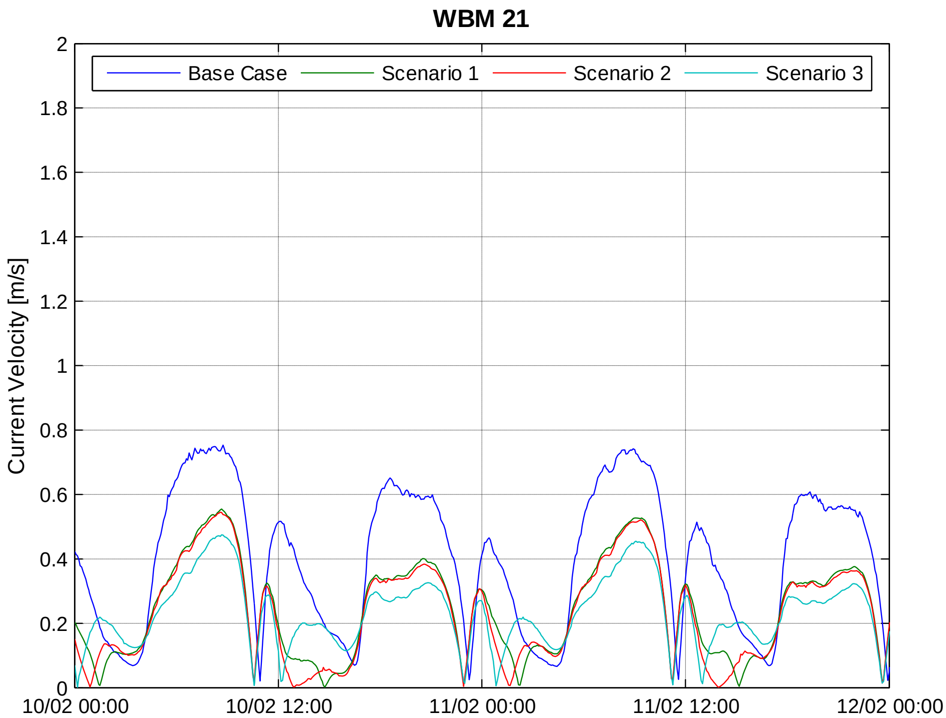


Figure C-21 Velocity Magnitude Time Series – WBM 21

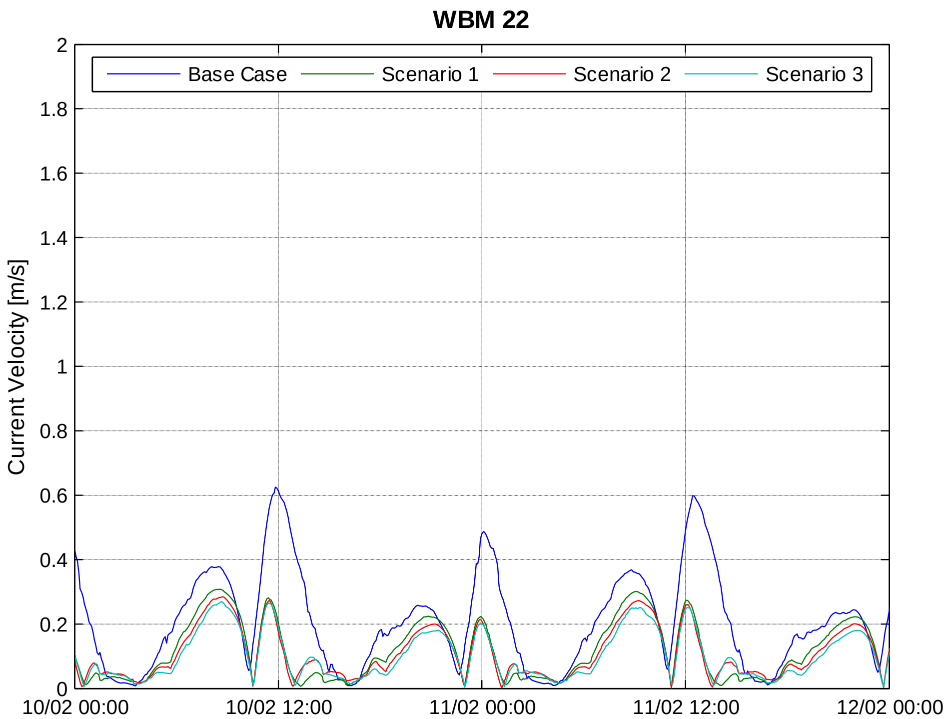


Figure C-22 Velocity Magnitude Time Series – WBM 22

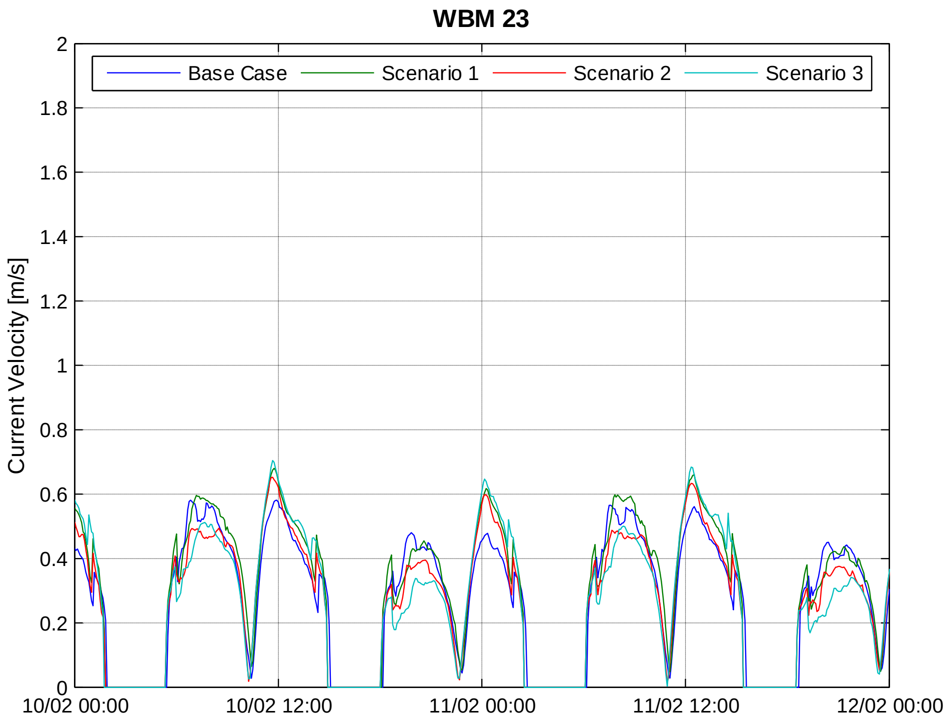


Figure C-23 Velocity Magnitude Time Series – WBM 23

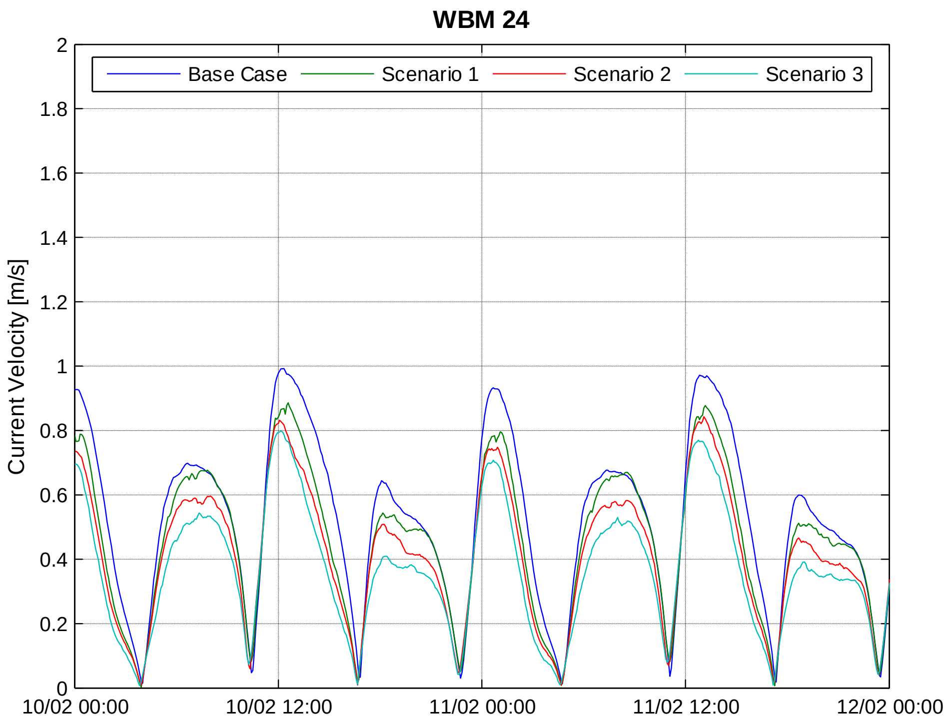


Figure C-24 Velocity Magnitude Time Series – WBM 24

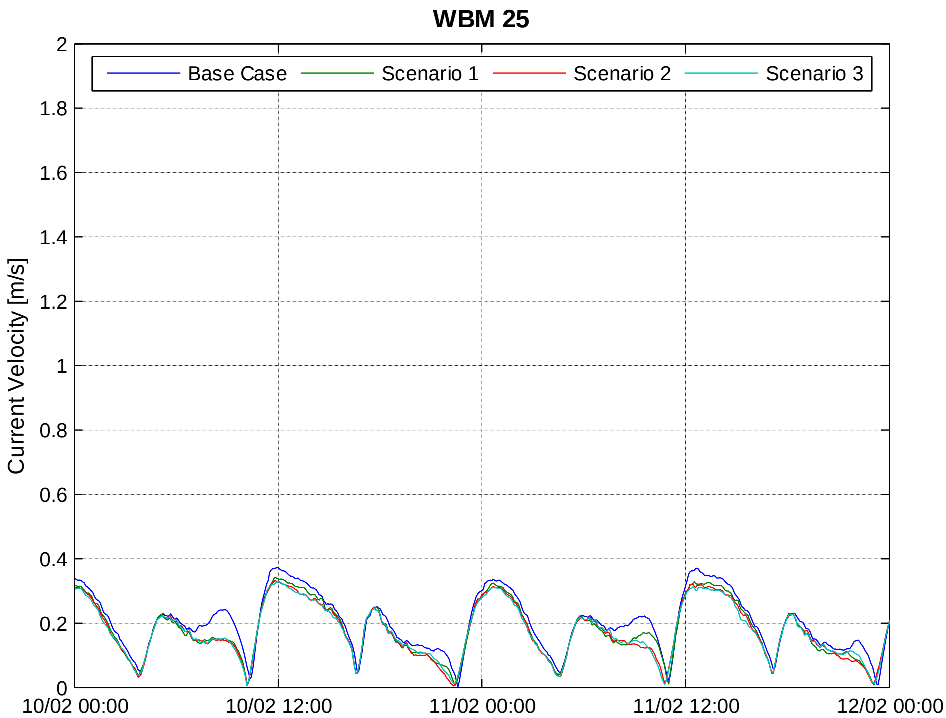


Figure C-25 Velocity Magnitude Time Series – WBM 25

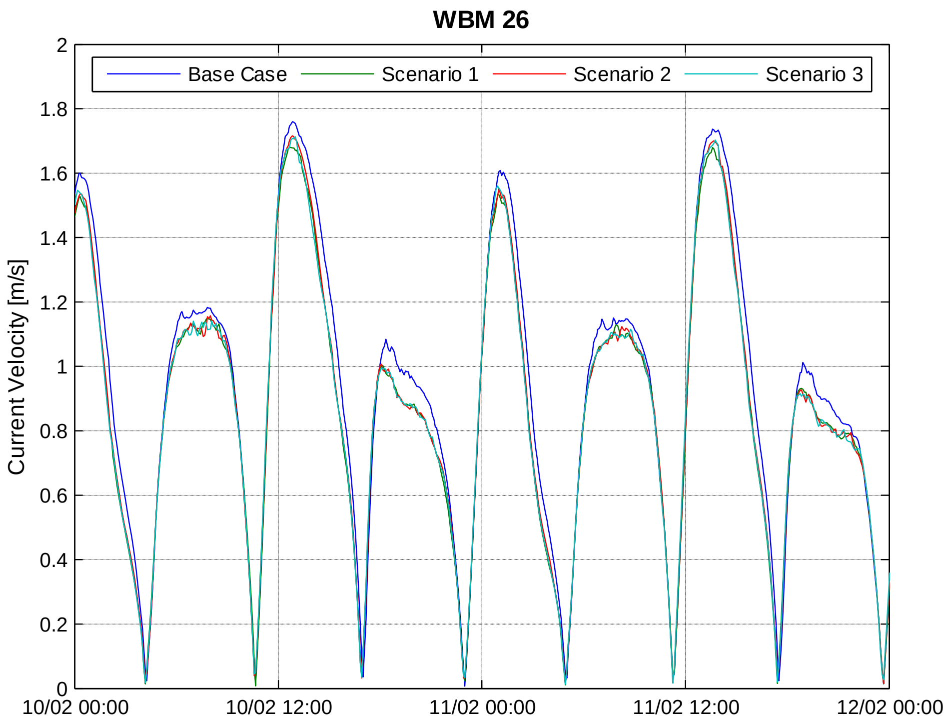


Figure C-26 Velocity Magnitude Time Series – WBM 26

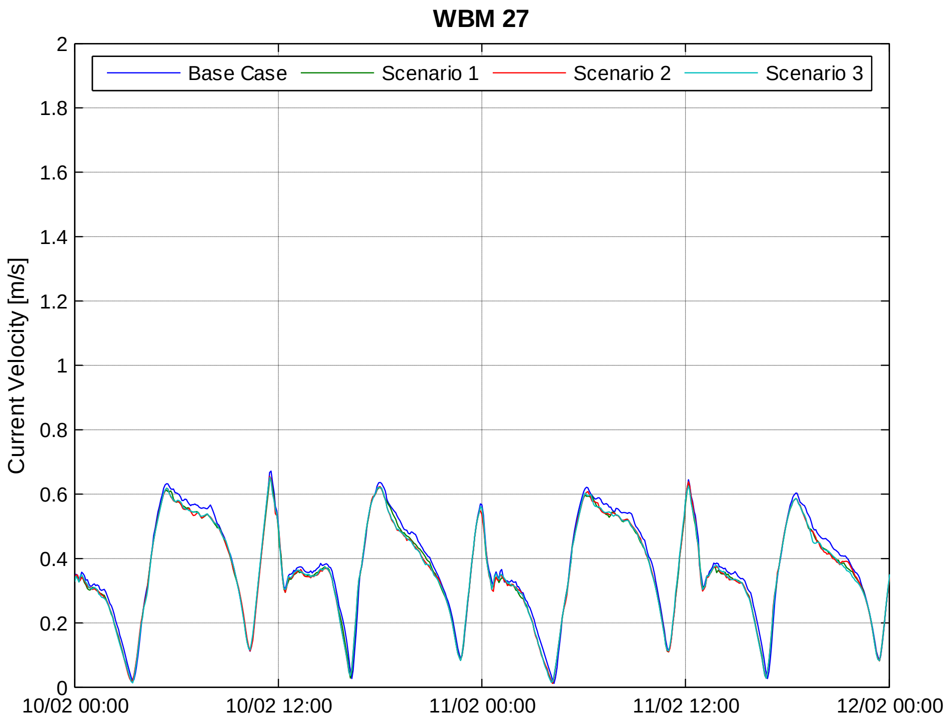


Figure C-27 Velocity Magnitude Time Series – WBM 27

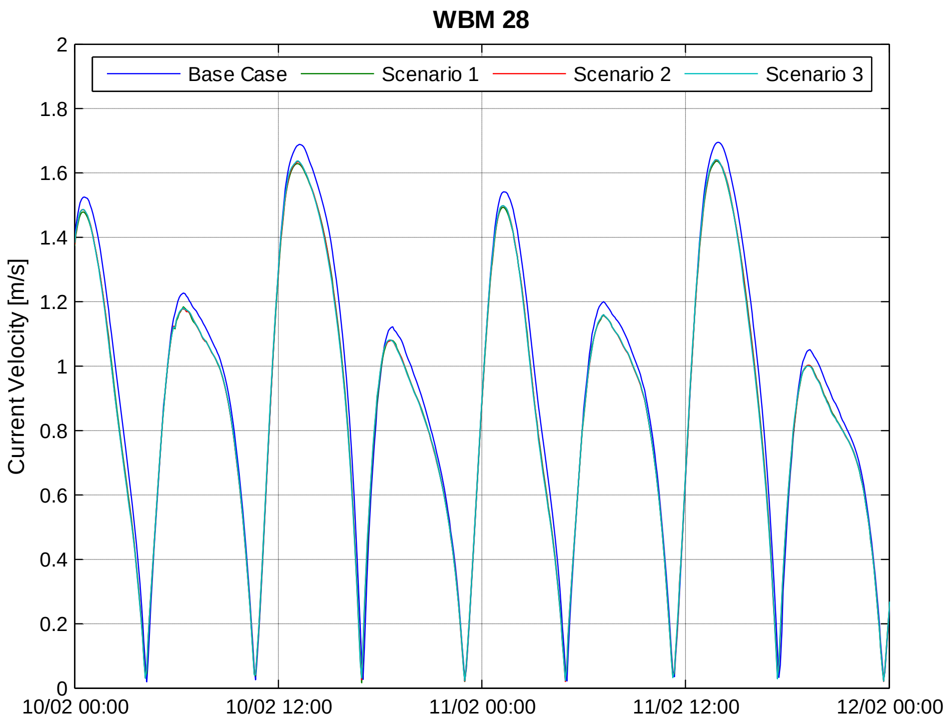


Figure C-28 Velocity Magnitude Time Series – WBM 28

APPENDIX D: FLUSHING CONCENTRATION TIME SERIES PLOTS

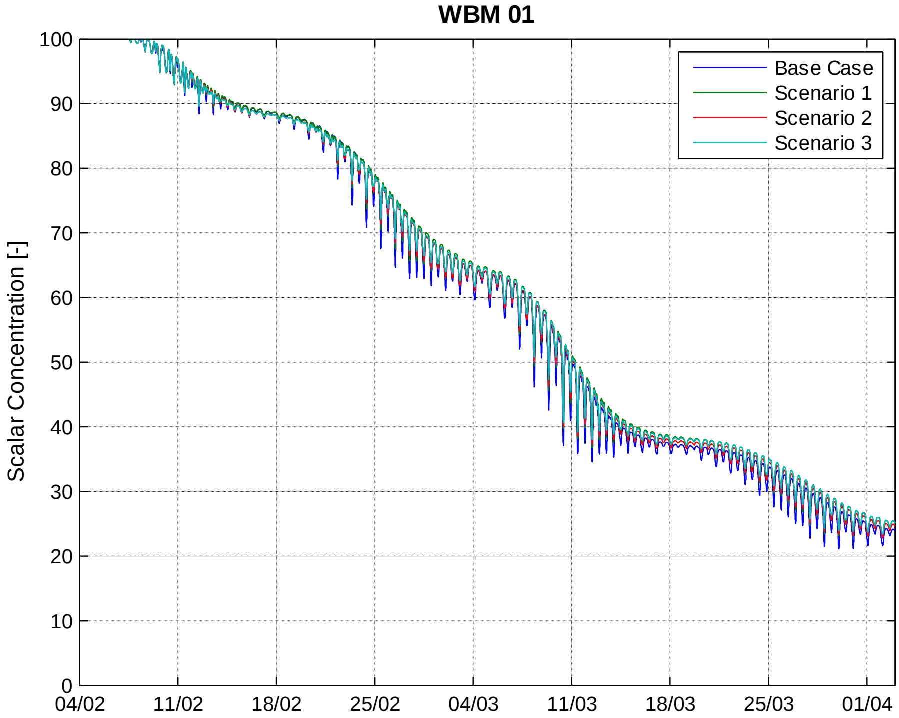


Figure D-1 Flushing Concentration Time Series – WBM 01

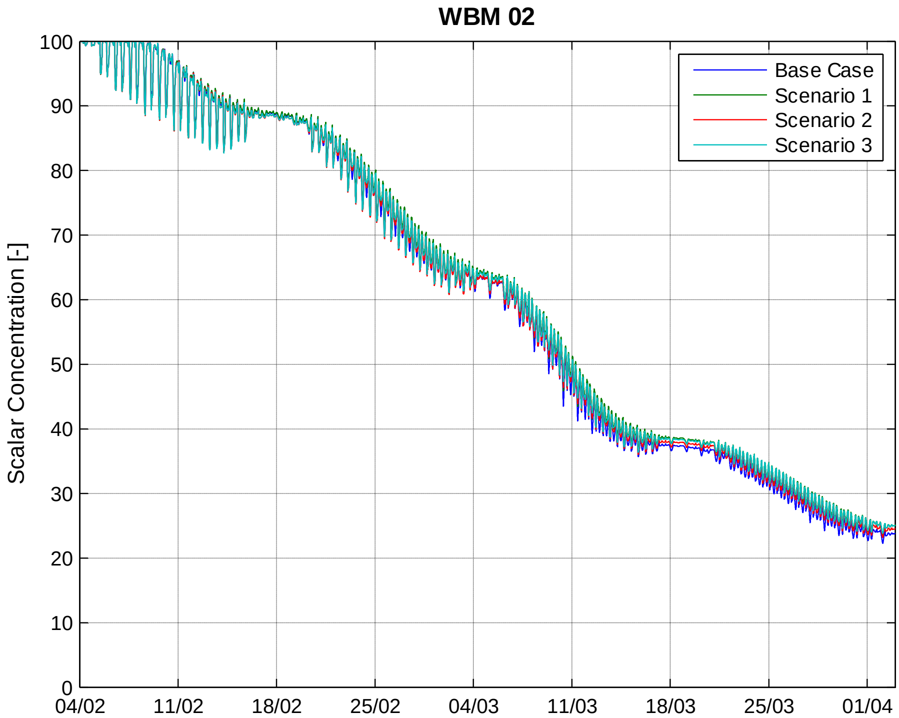


Figure D-2 Flushing Concentration Time Series – WBM 02

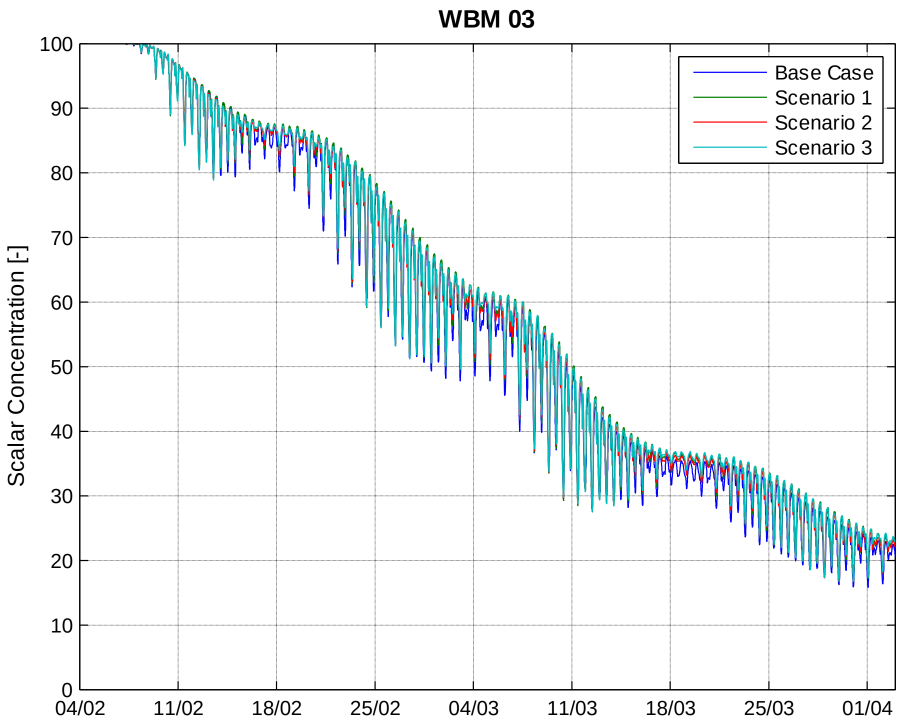


Figure D-3 Flushing Concentration Time Series – WBM 03

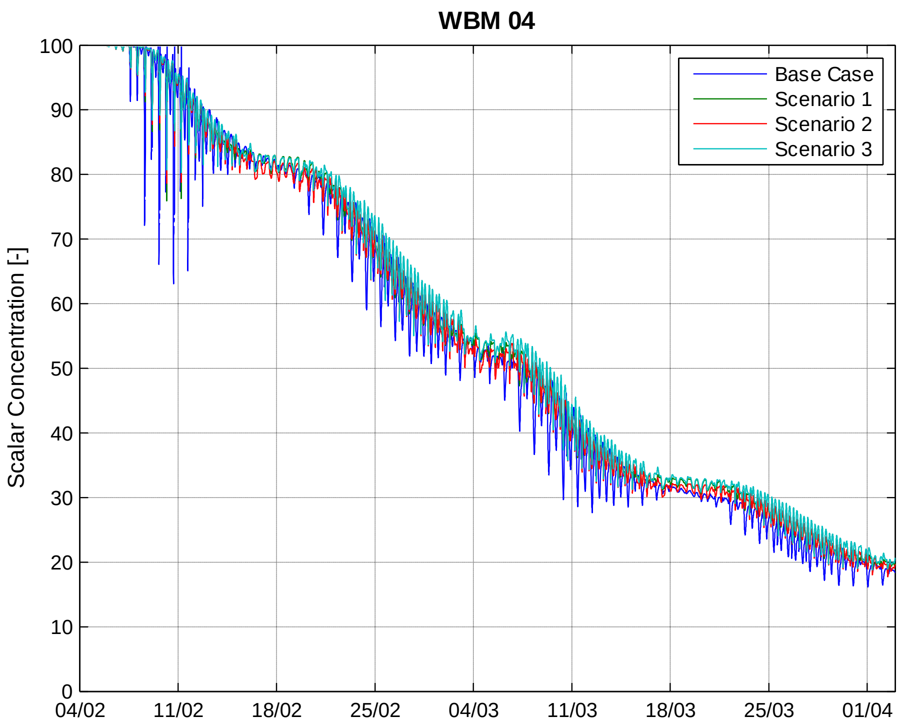


Figure D-4 Flushing Concentration Time Series – WBM 04

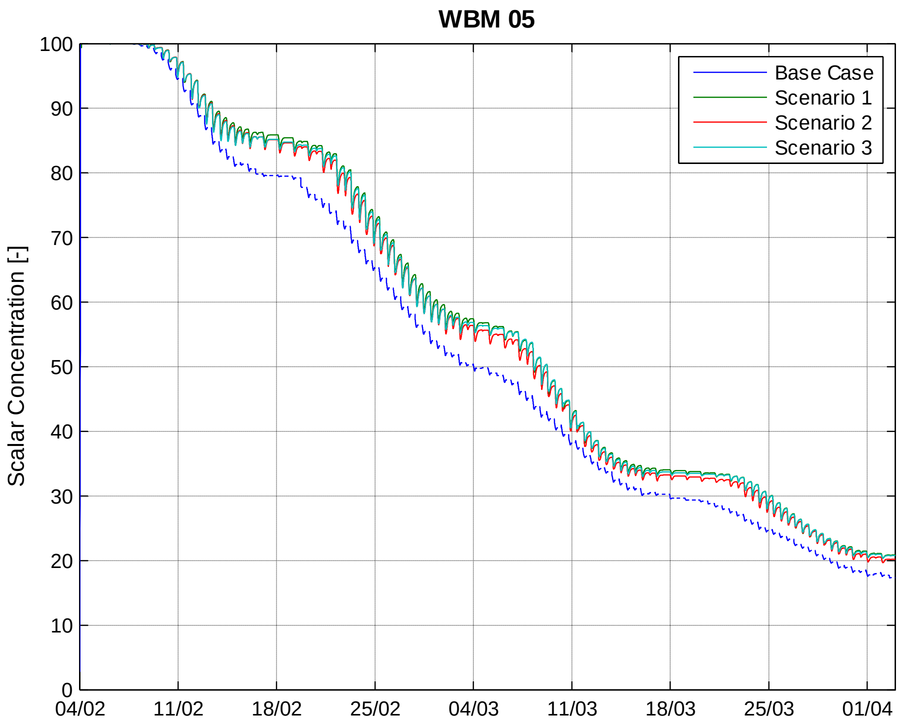


Figure D-5 Flushing Concentration Time Series – WBM 05

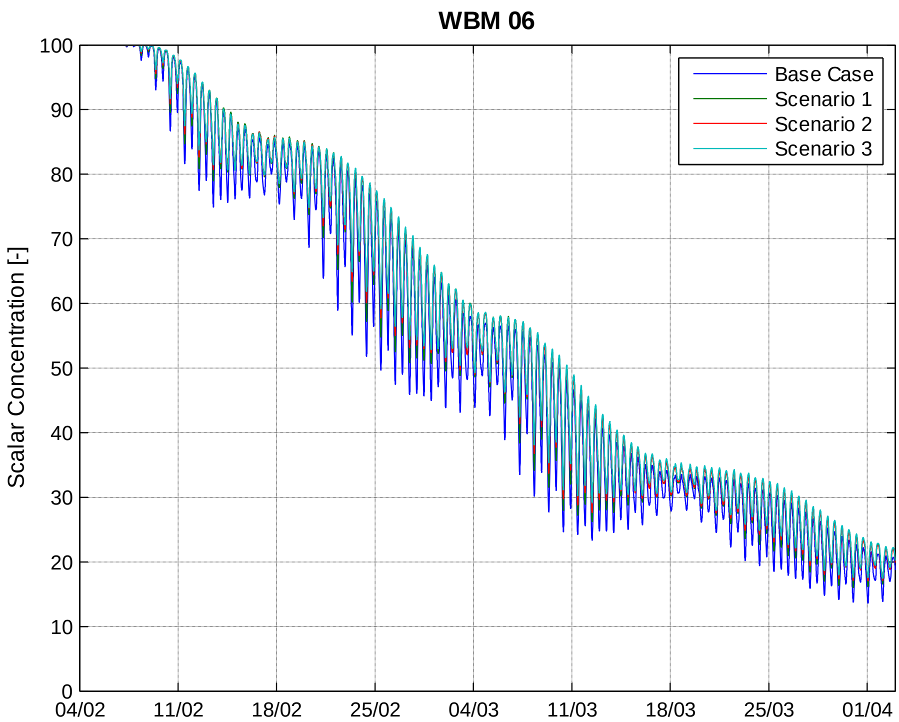


Figure D-6 Flushing Concentration Time Series – WBM 06

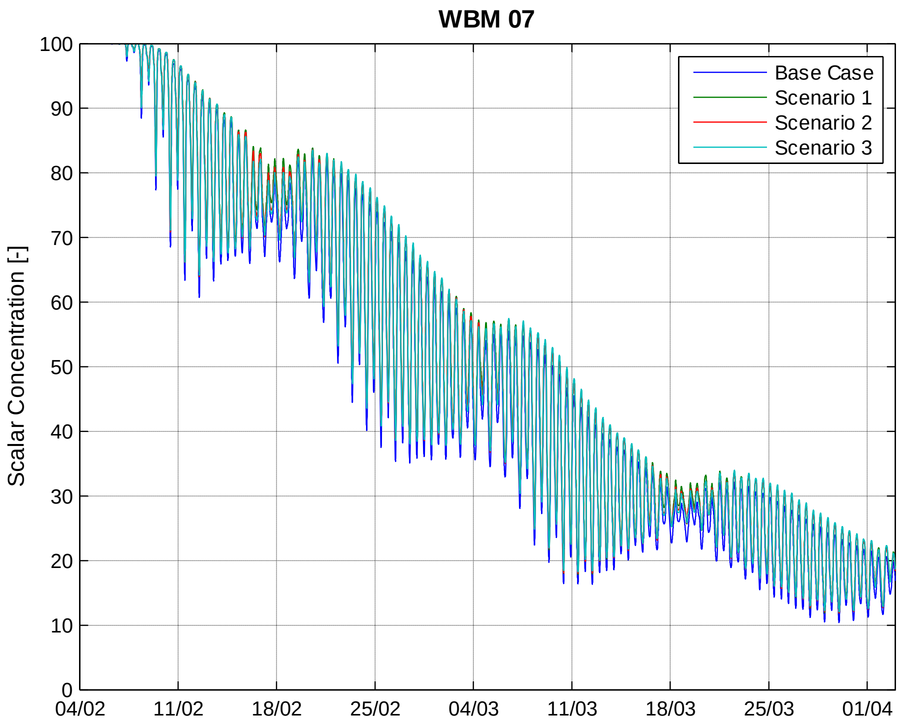


Figure D-7 Flushing Concentration Time Series – WBM 07

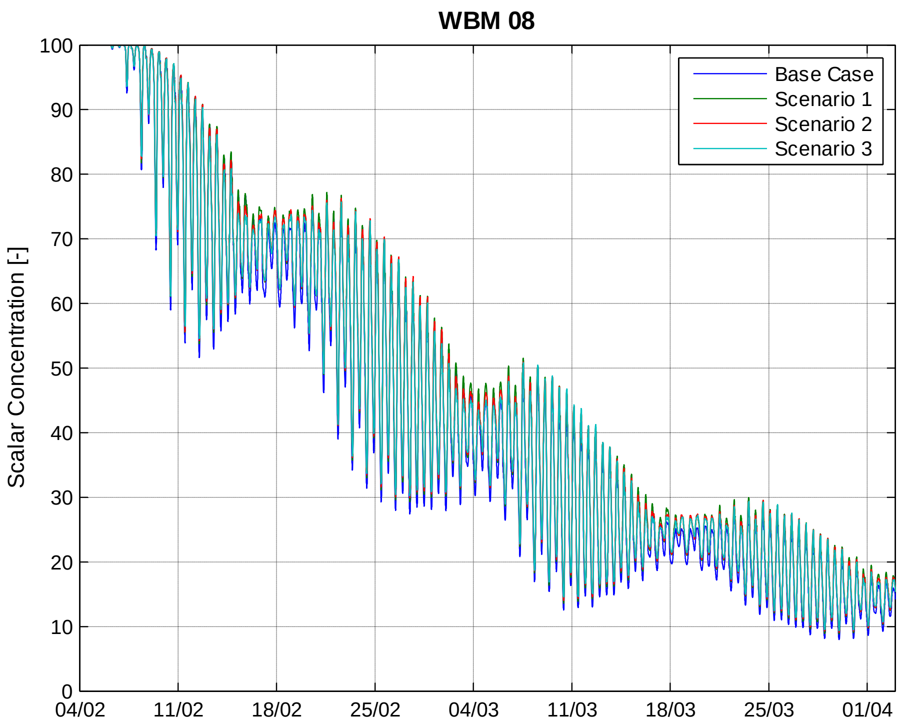


Figure D-8 Flushing Concentration Time Series – WBM 08

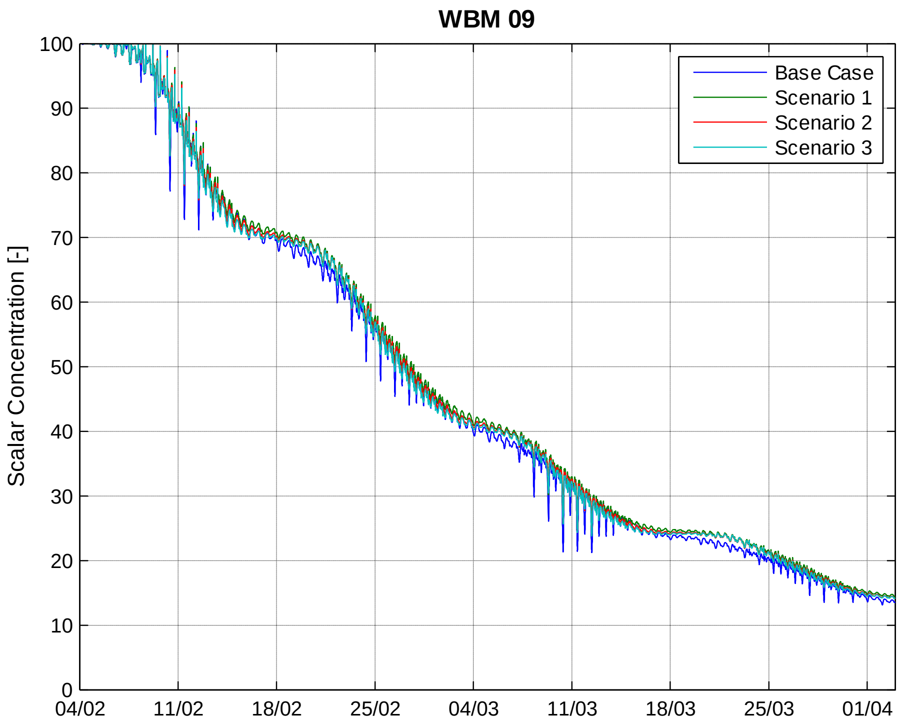


Figure D-9 Flushing Concentration Time Series – WBM 09

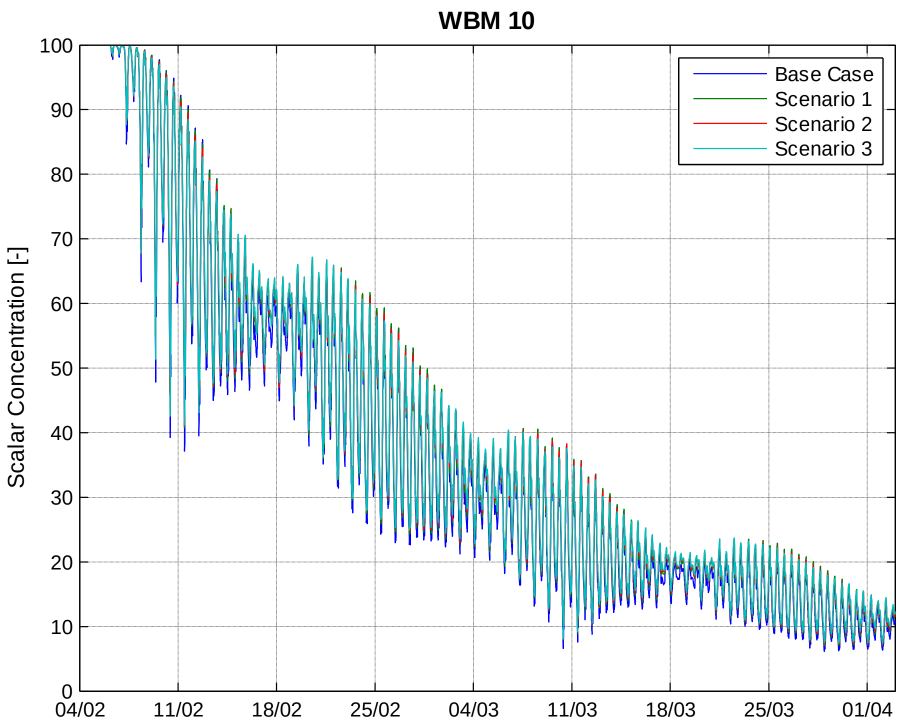


Figure D-10 Flushing Concentration Time Series – WBM 10

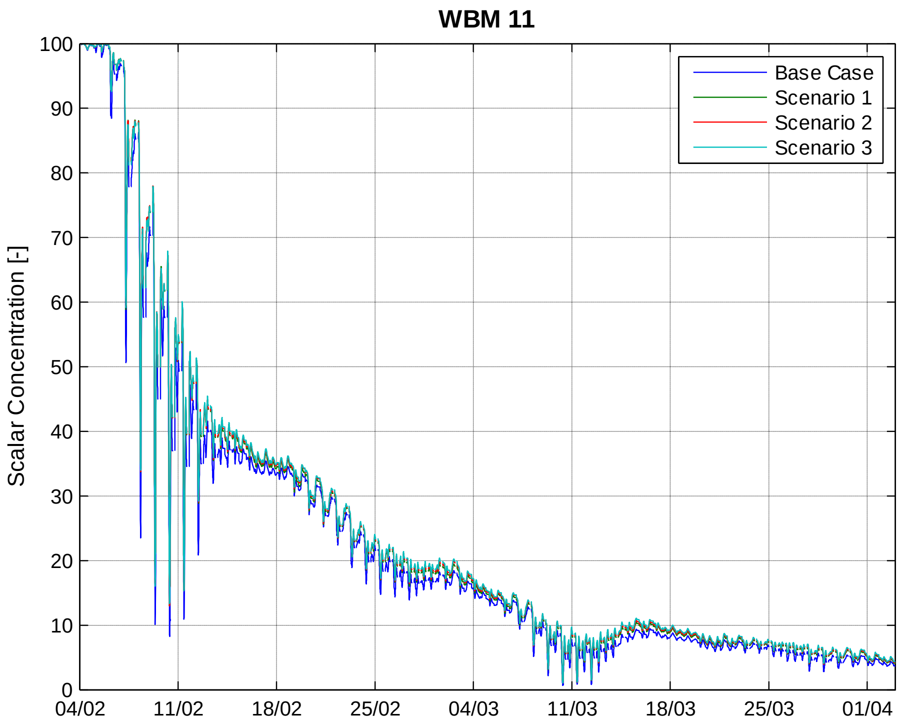
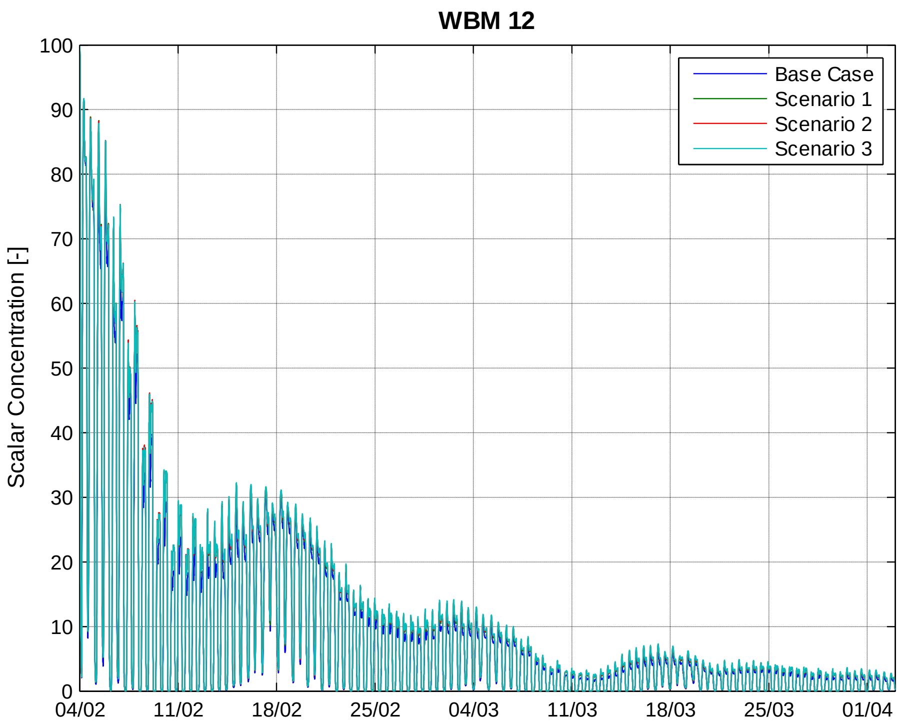


Figure D-11 Flushing Concentration Time Series – WBM 11



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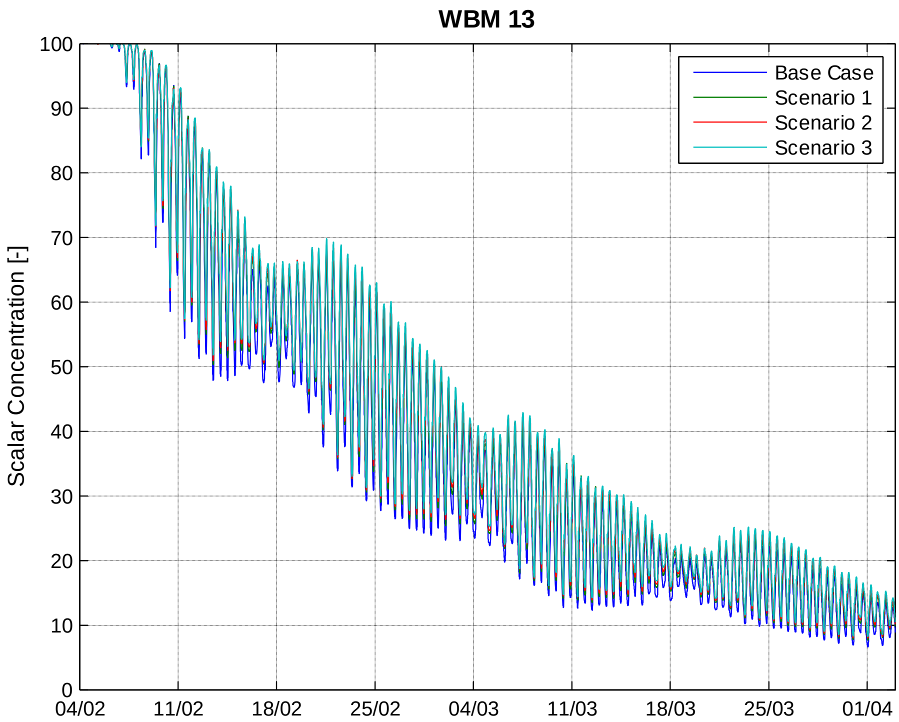

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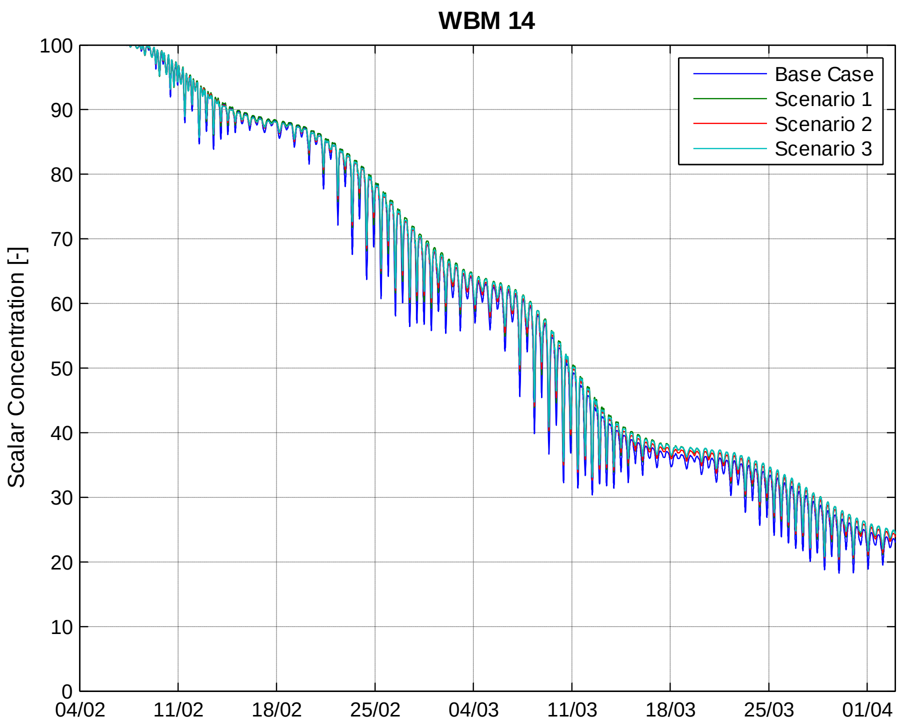
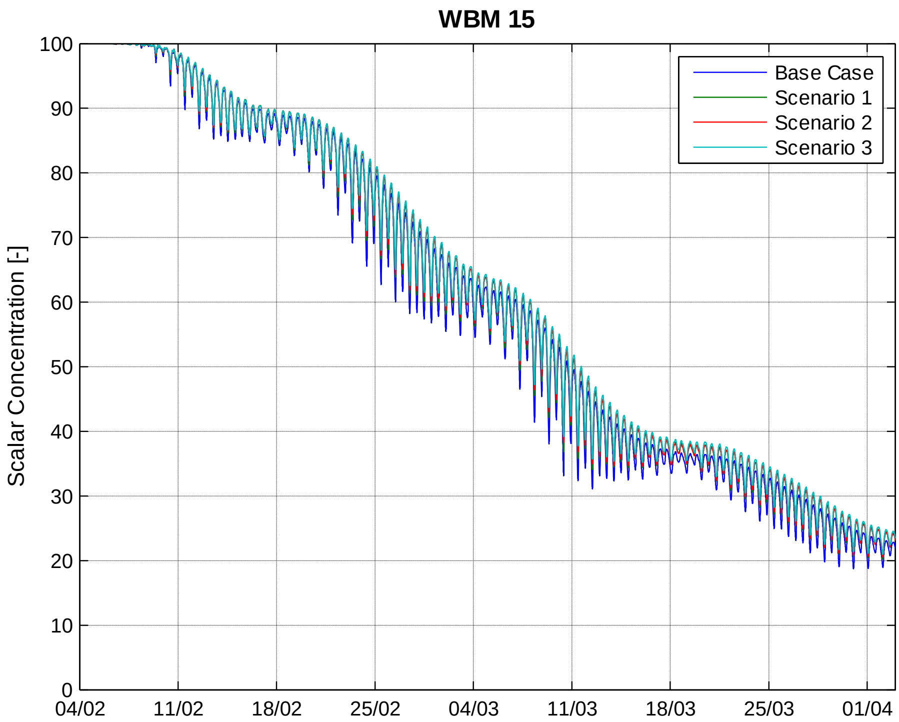


Figure D-14 Flushing Concentration Time Series – WBM 14



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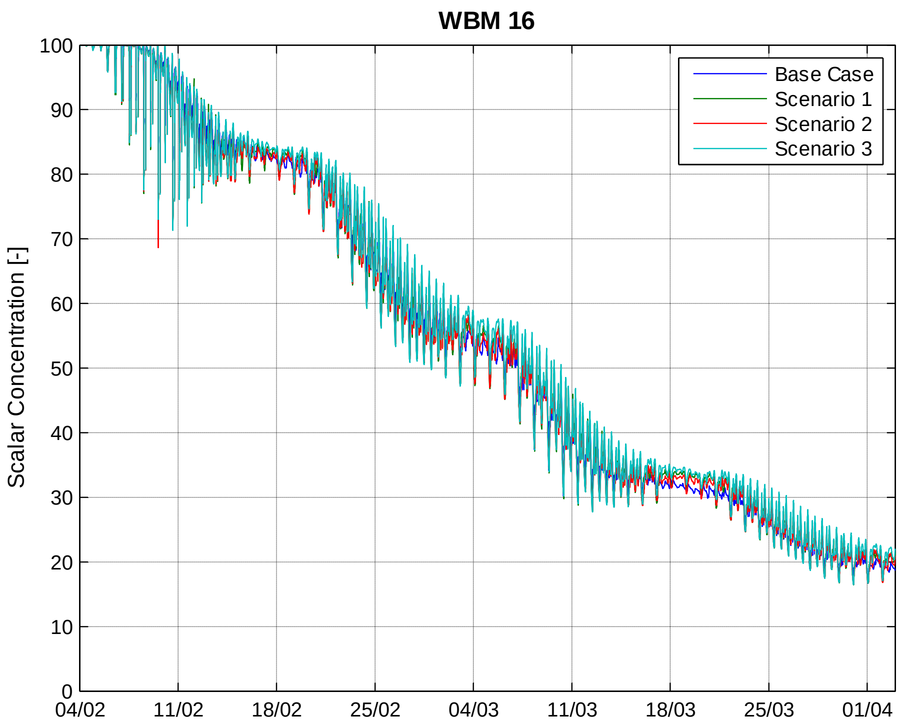

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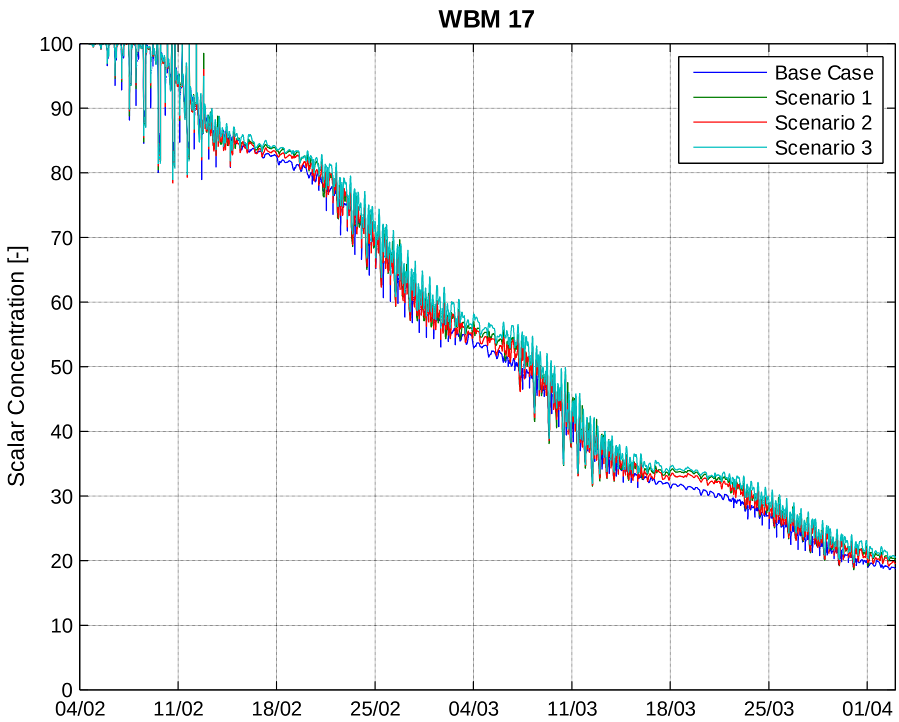
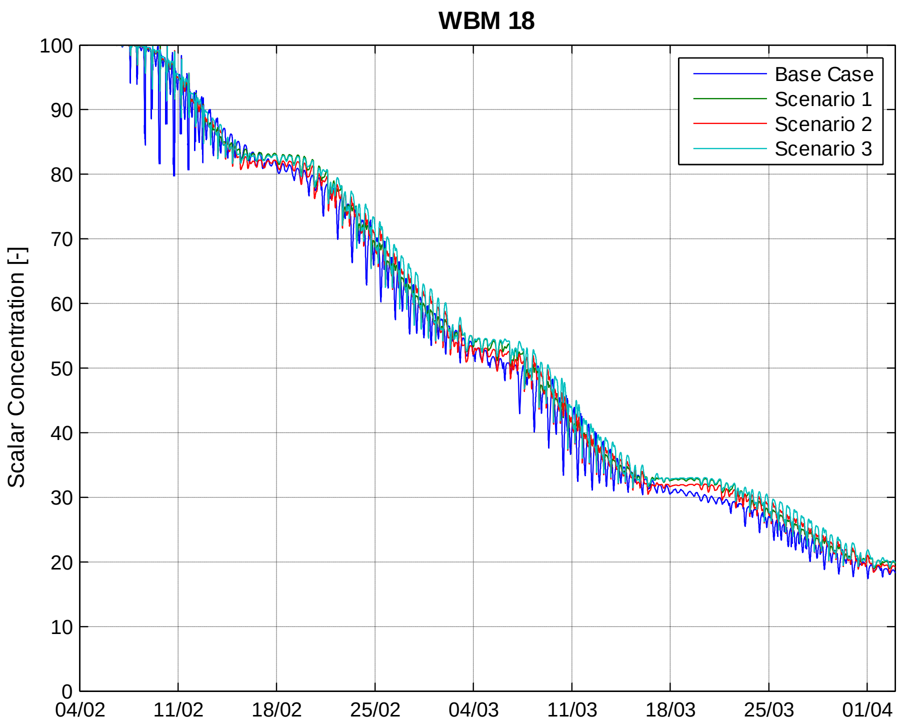


Figure D-17 Flushing Concentration Time Series – WBM 17



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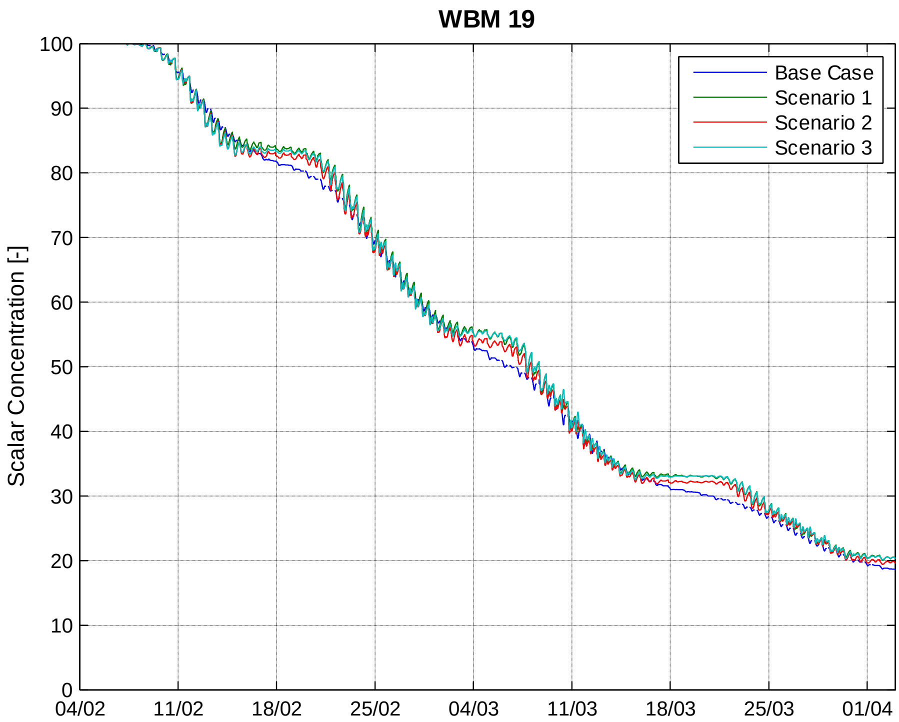
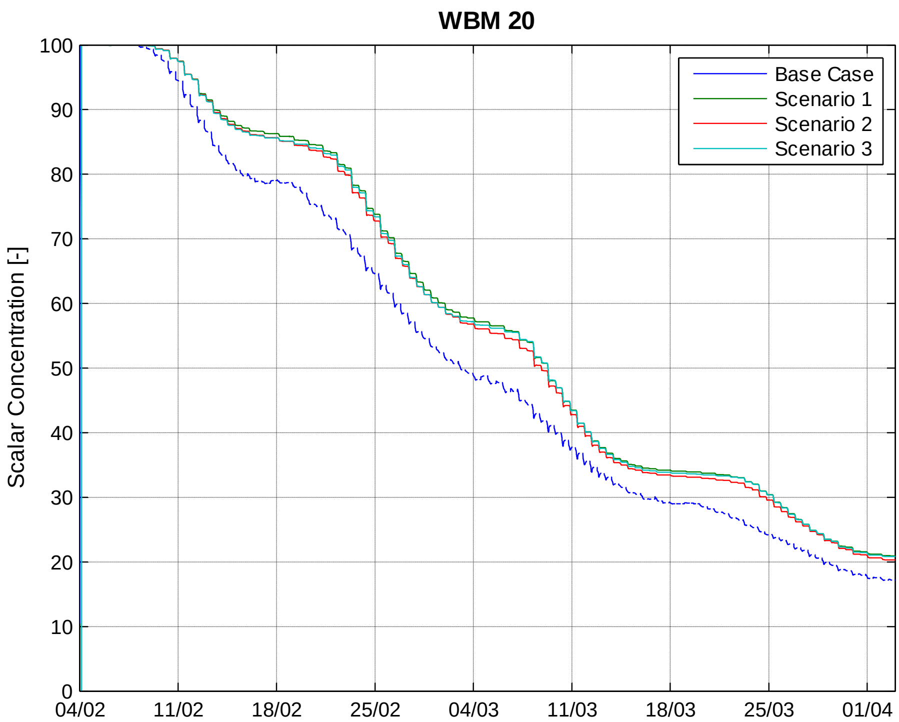


Figure D-19 Flushing Concentration Time Series – WBM 19



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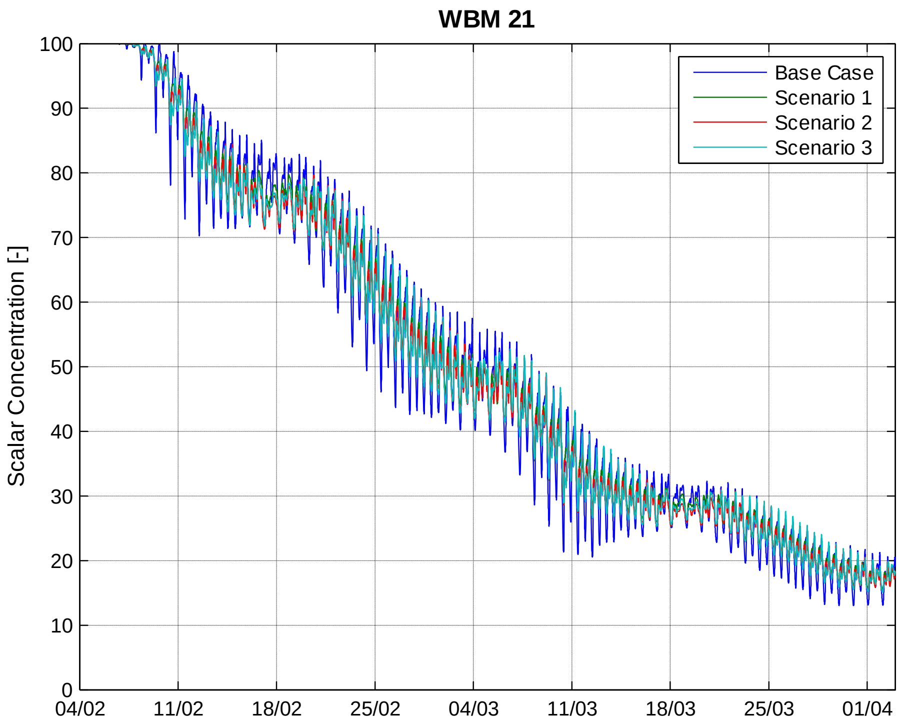
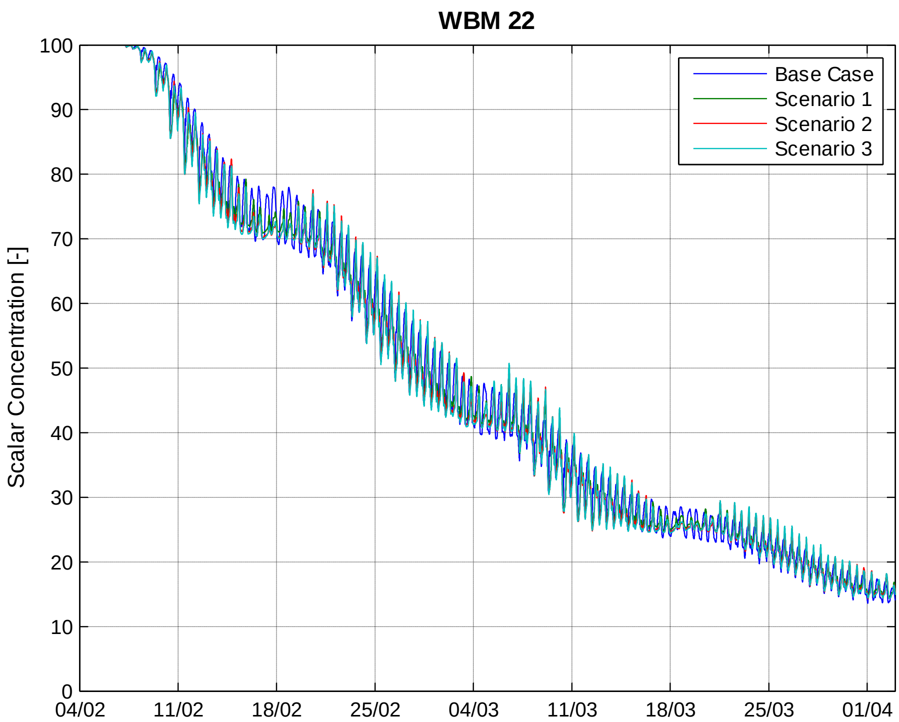


Figure D-21 Flushing Concentration Time Series – WBM 21



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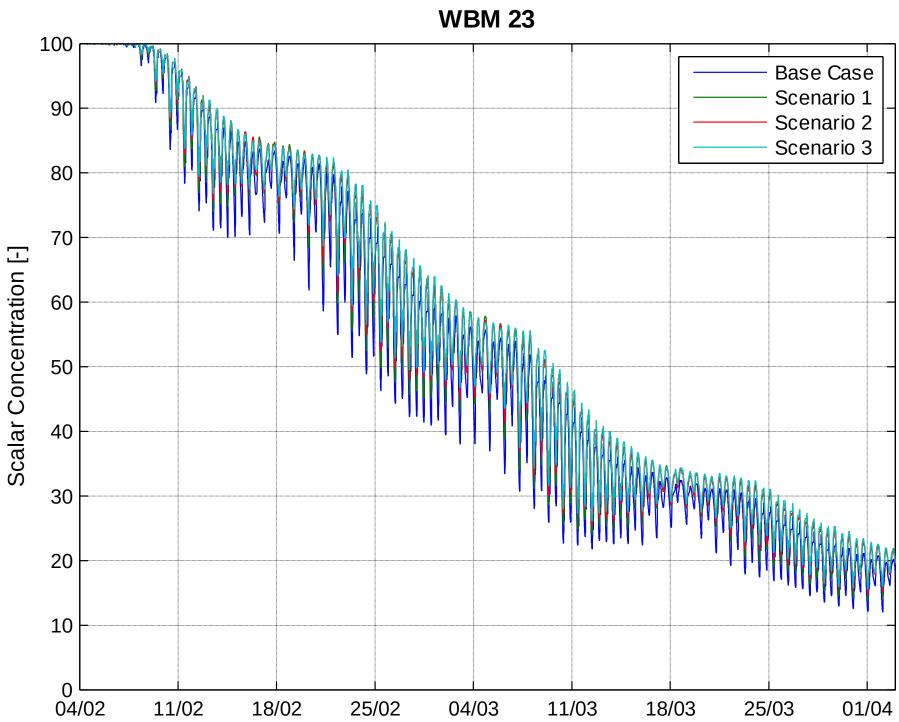

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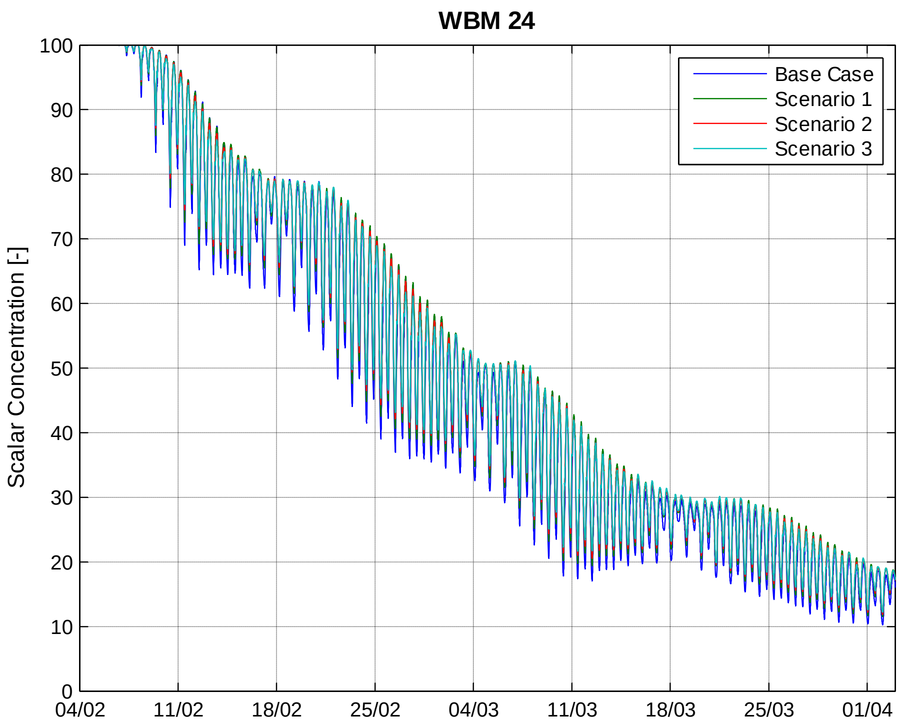


Figure D-24 Flushing Concentration Time Series – WBM 24

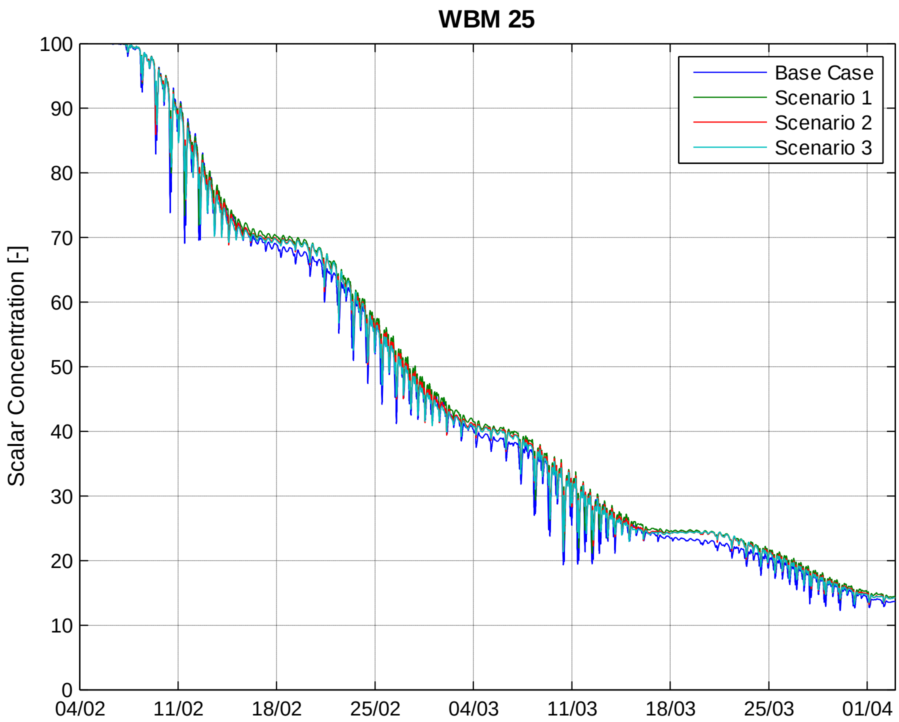


Figure D-25 Flushing Concentration Time Series – WBM 25

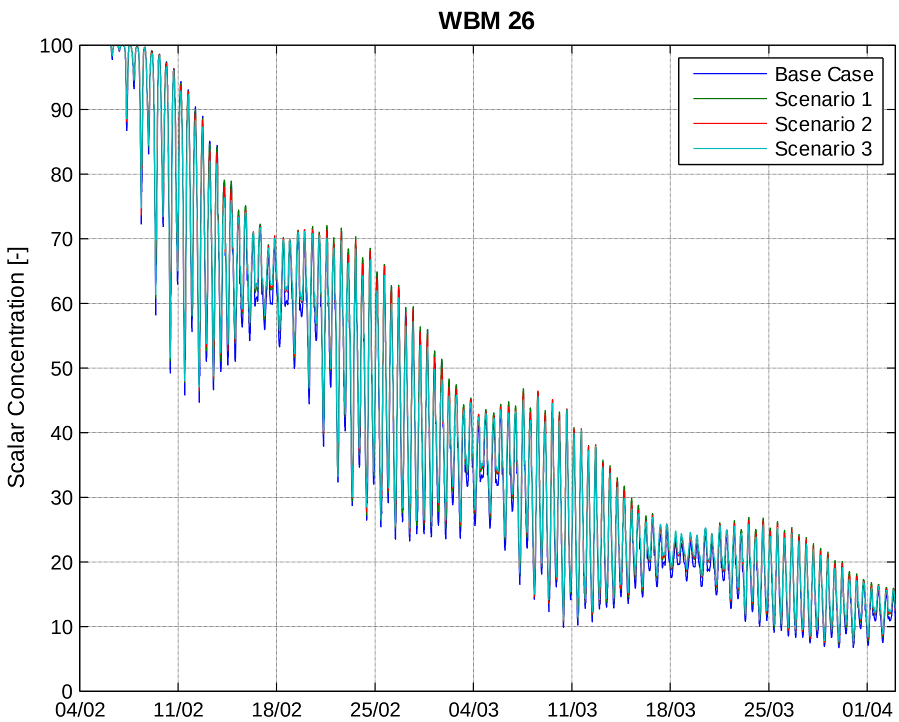


Figure D-26 Flushing Concentration Time Series – WBM 26

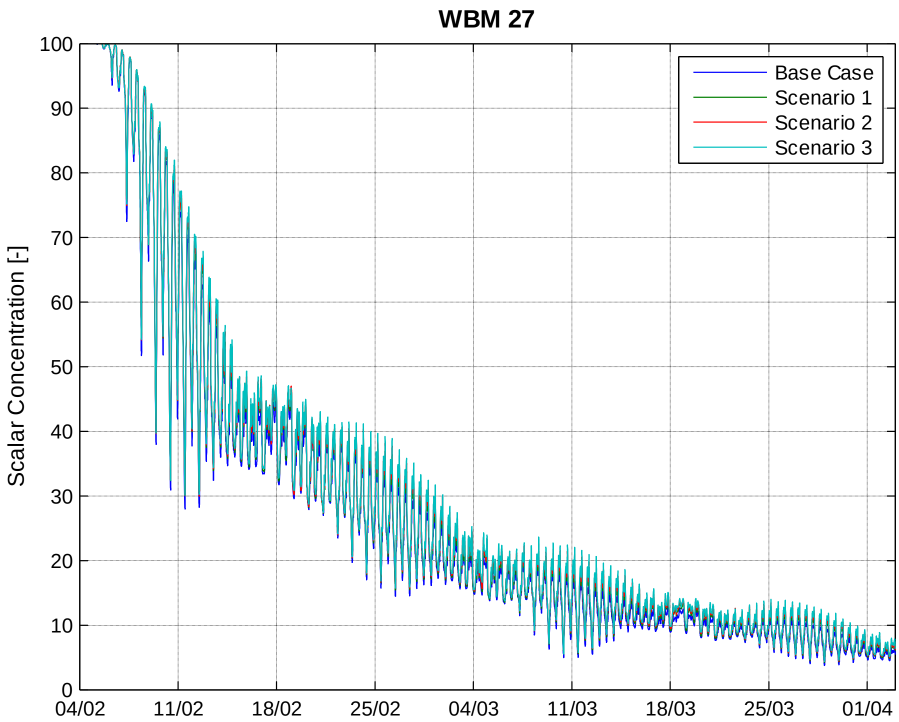


Figure D-27 Flushing Concentration Time Series – WBM 27

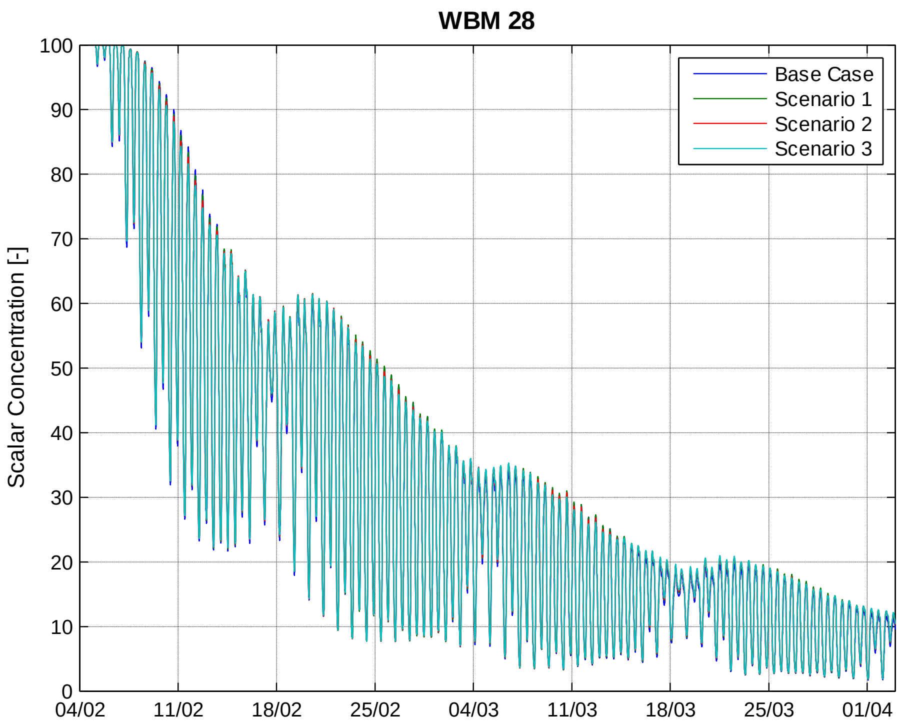


Figure D-28 Flushing Concentration Time Series – WBM 28

APPENDIX E: PLUME TSS CONCENTRATION TIME SERIES

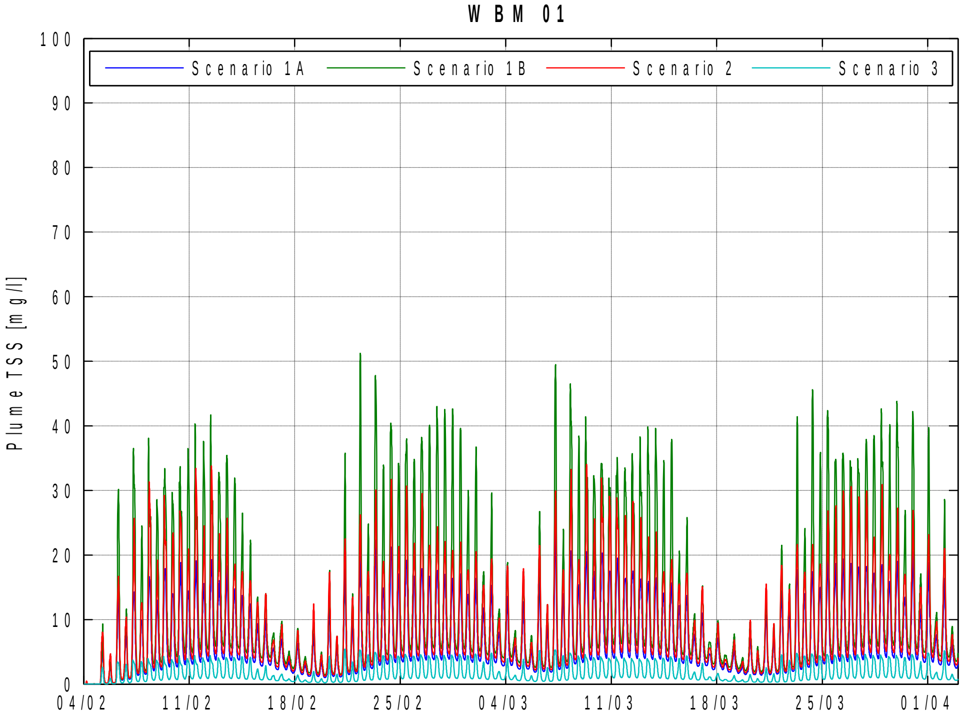


Figure E-1 Plume TSS Concentration Time Series – WBM 01

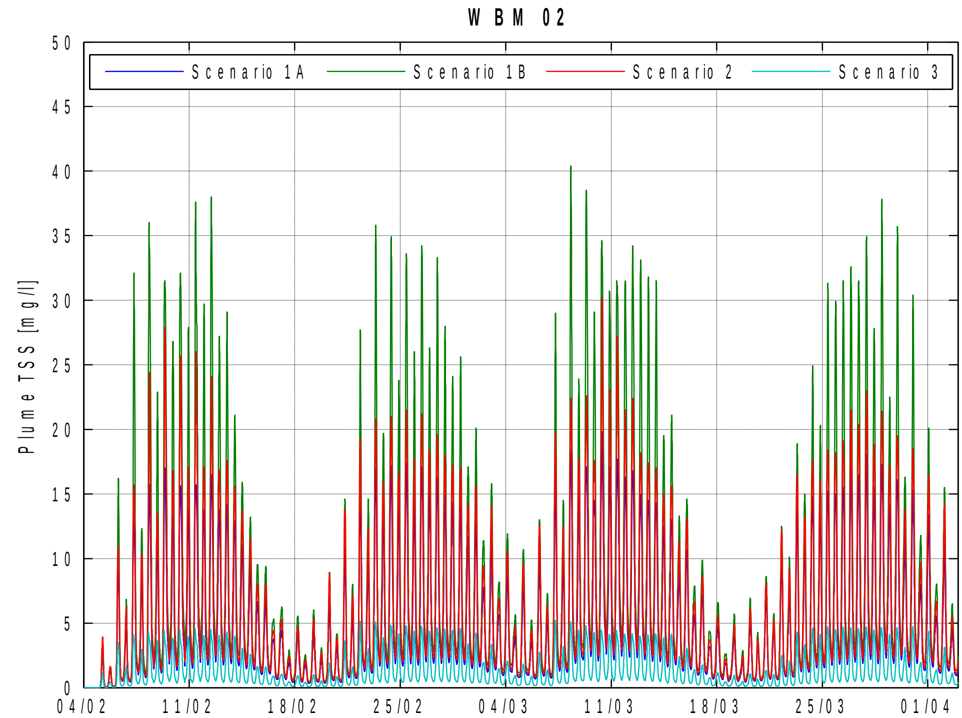


Figure E-2 Plume TSS Concentration Time Series – WBM 02

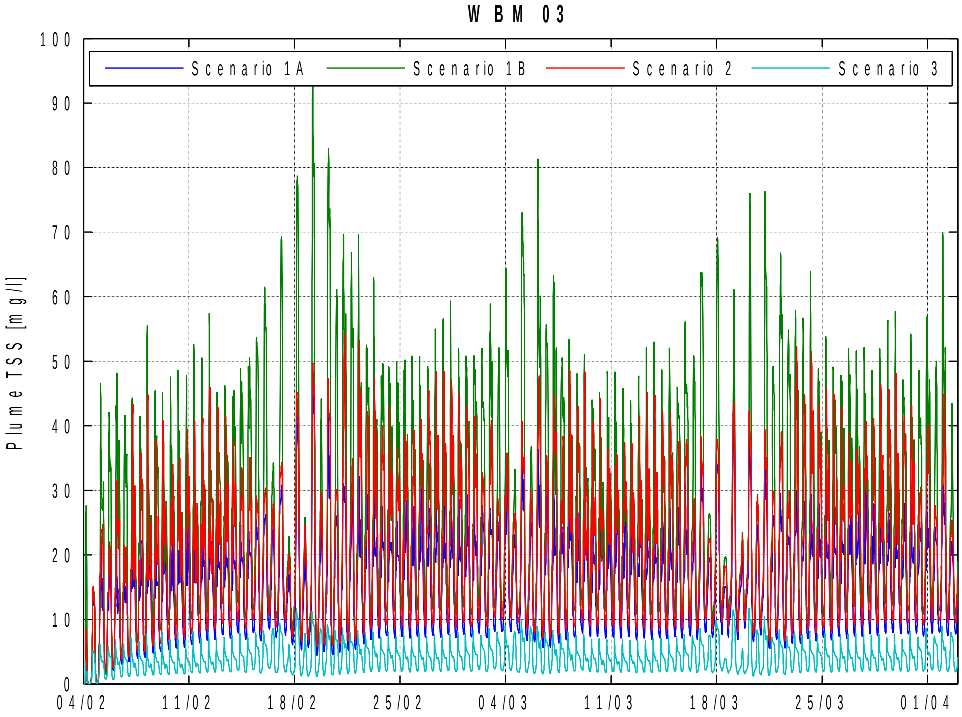


Figure E-3 Plume TSS Concentration Time Series – WBM 03

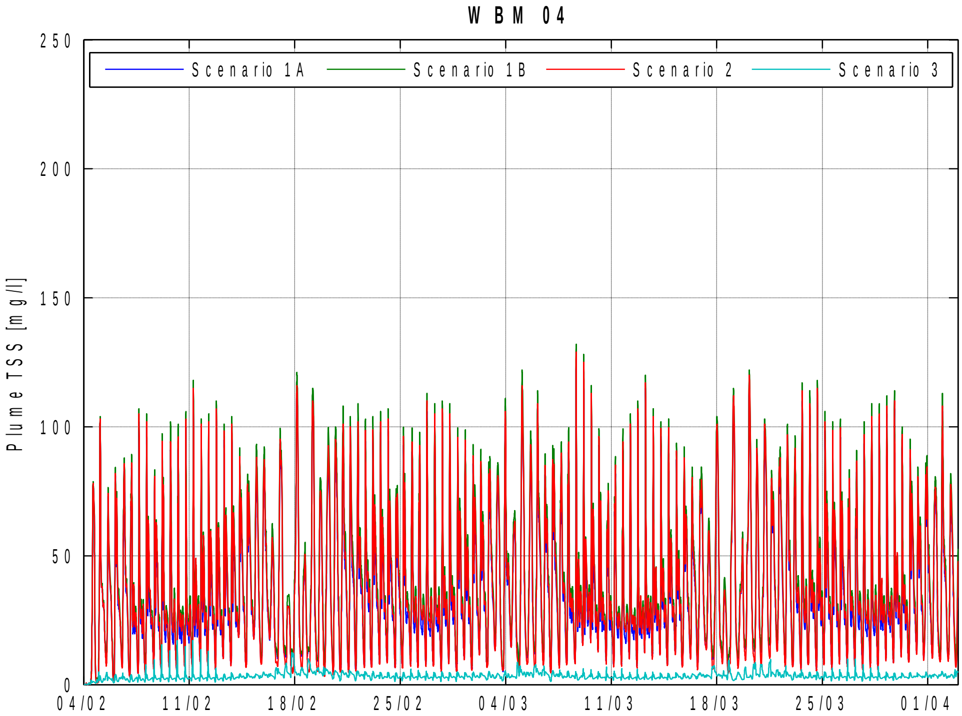
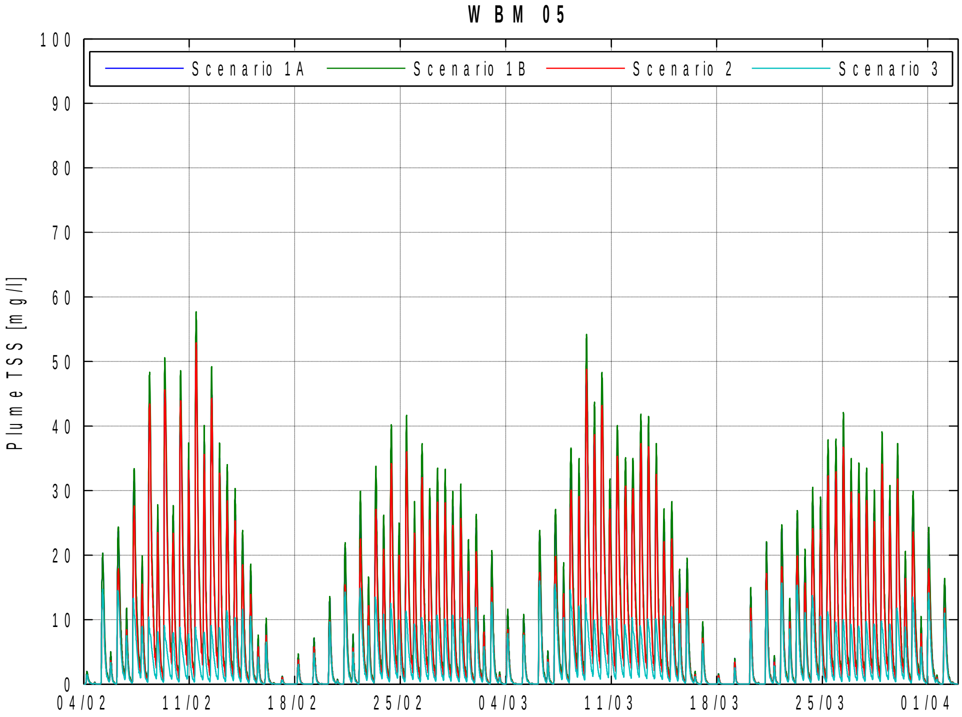


Figure E-4 Plume TSS Concentration Time Series – WBM 04



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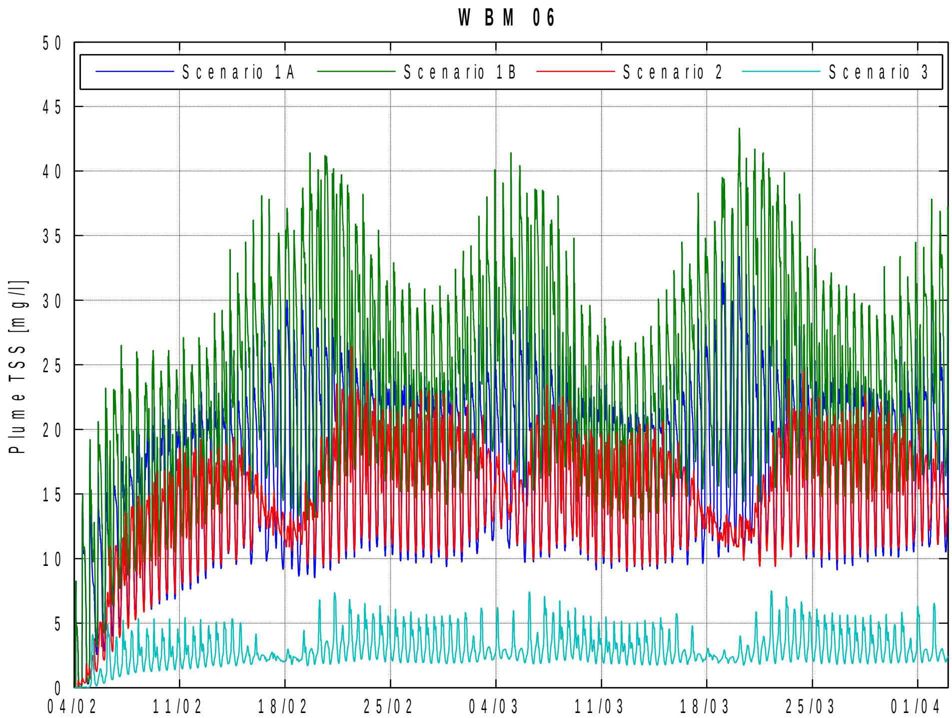

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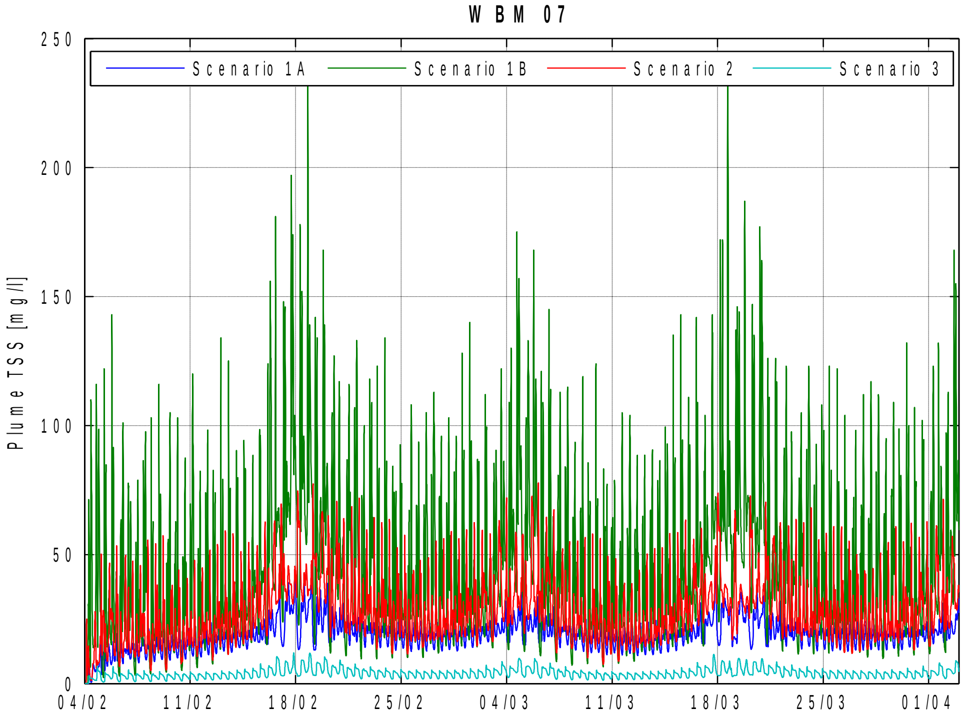

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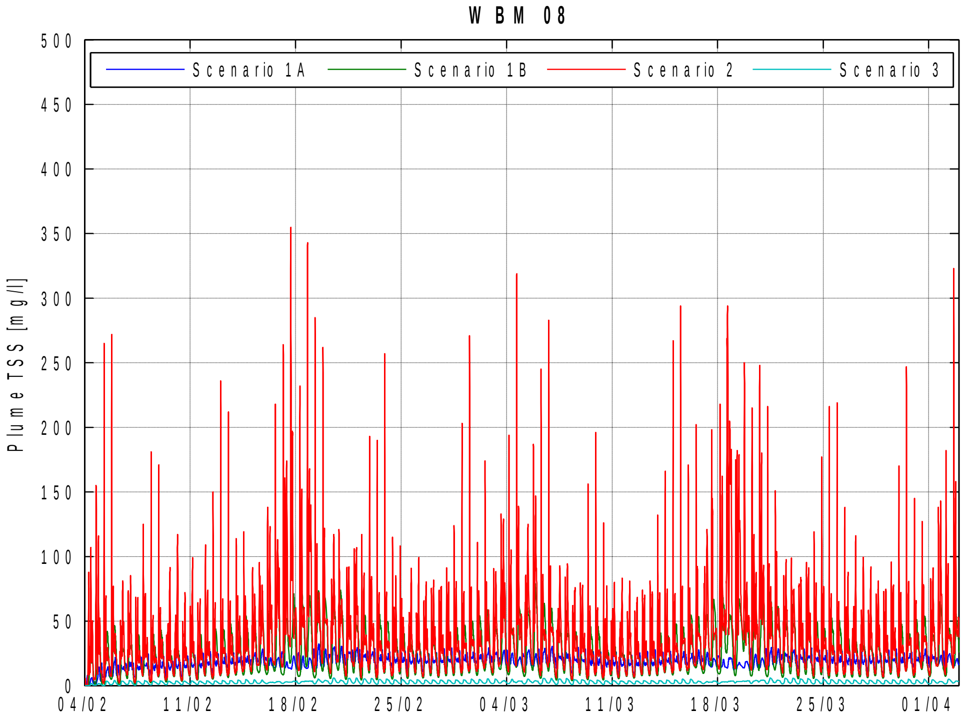

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Figure E-8 Plume TSS Concentration Time Series – WBM 08

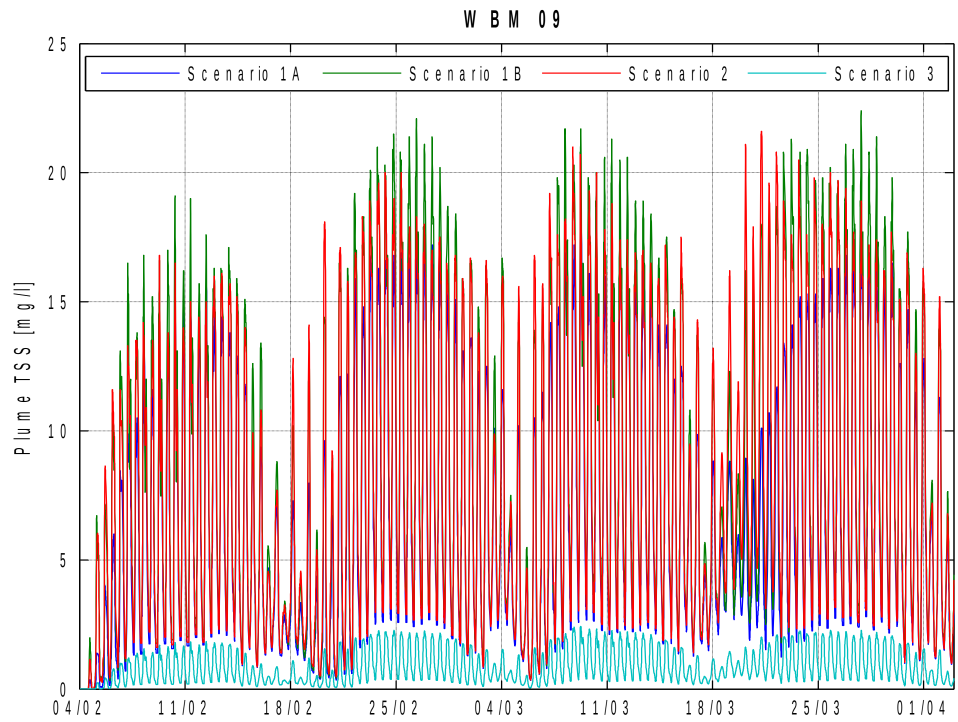


Figure E-9 Plume TSS Concentration Time Series – WBM 09

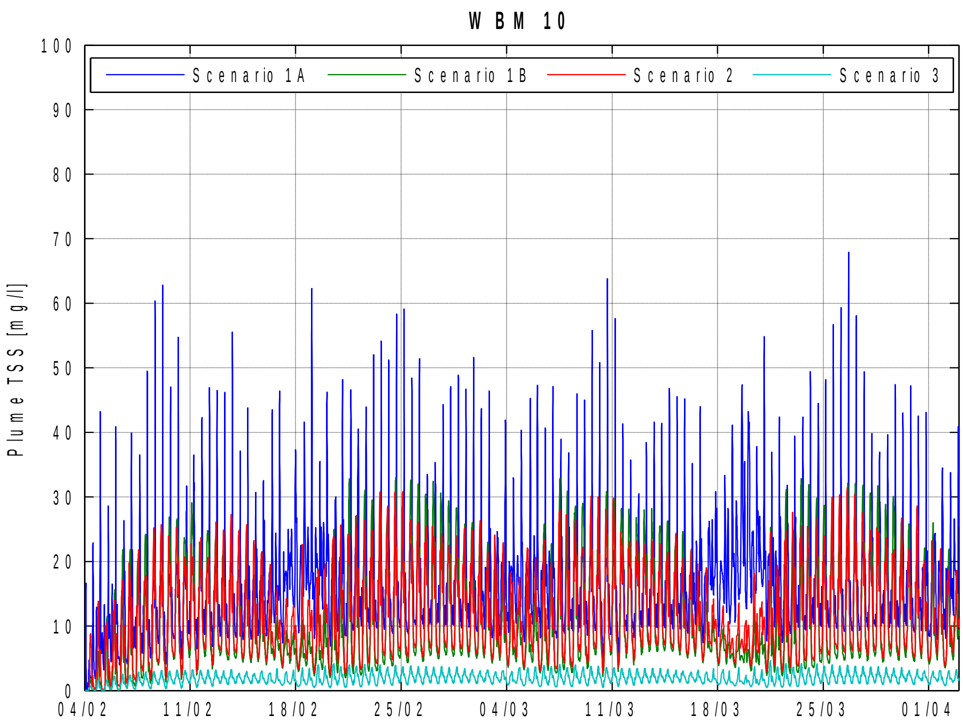


Figure E-10 Plume TSS Concentration Time Series – WBM 10

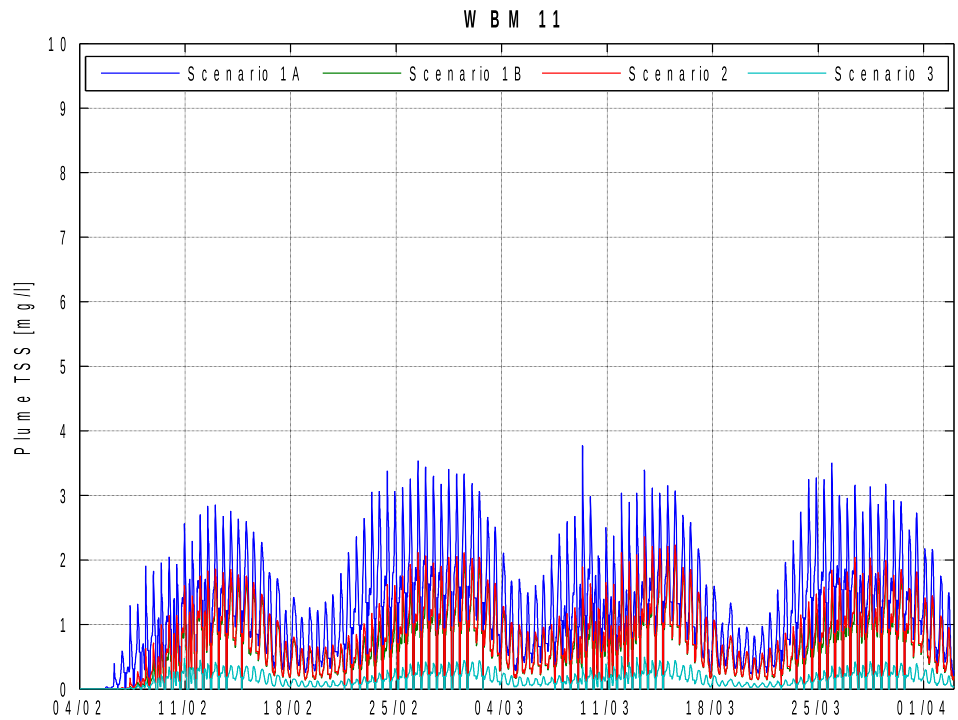


Figure E-11 Plume TSS Concentration Time Series – WBM 11

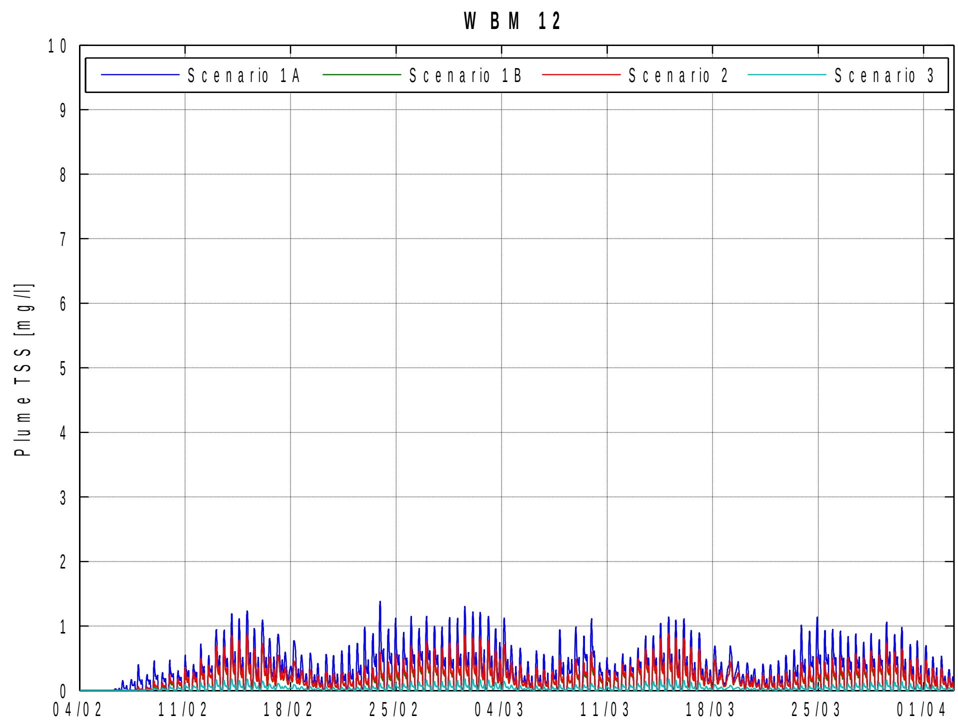
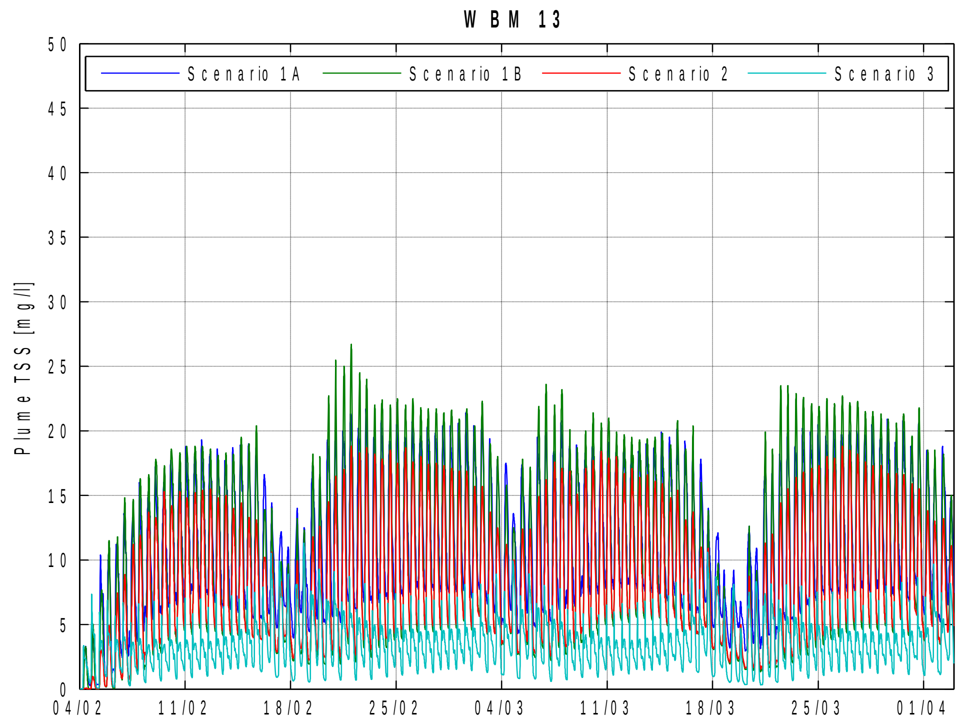


Figure E-12 Plume TSS Concentration Time Series – WBM 12



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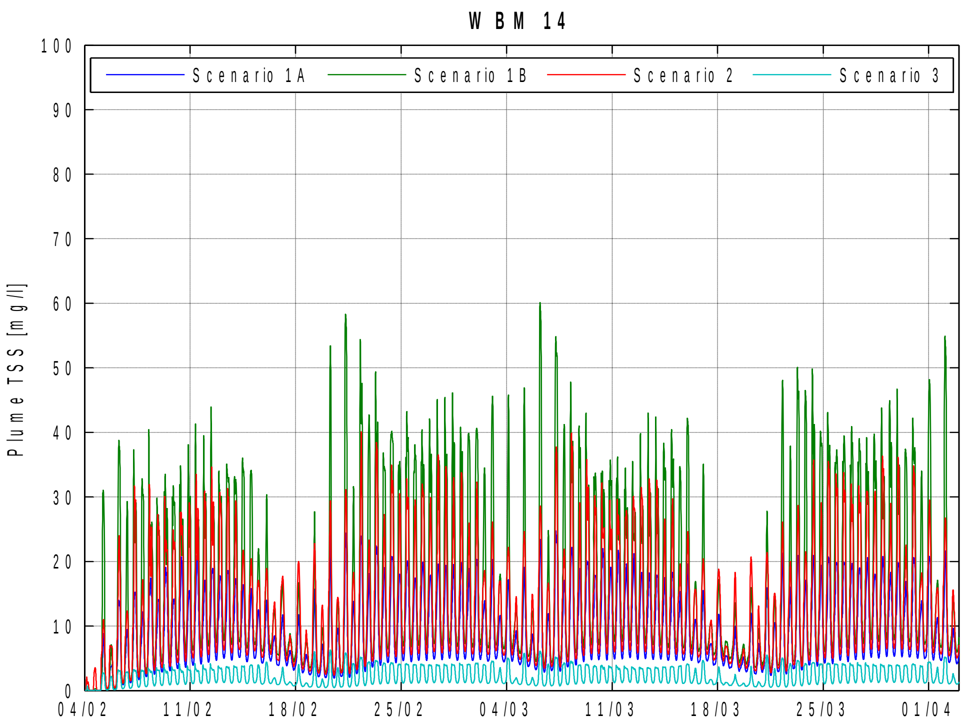


Figure E-14 Plume TSS Concentration Time Series – WBM 14

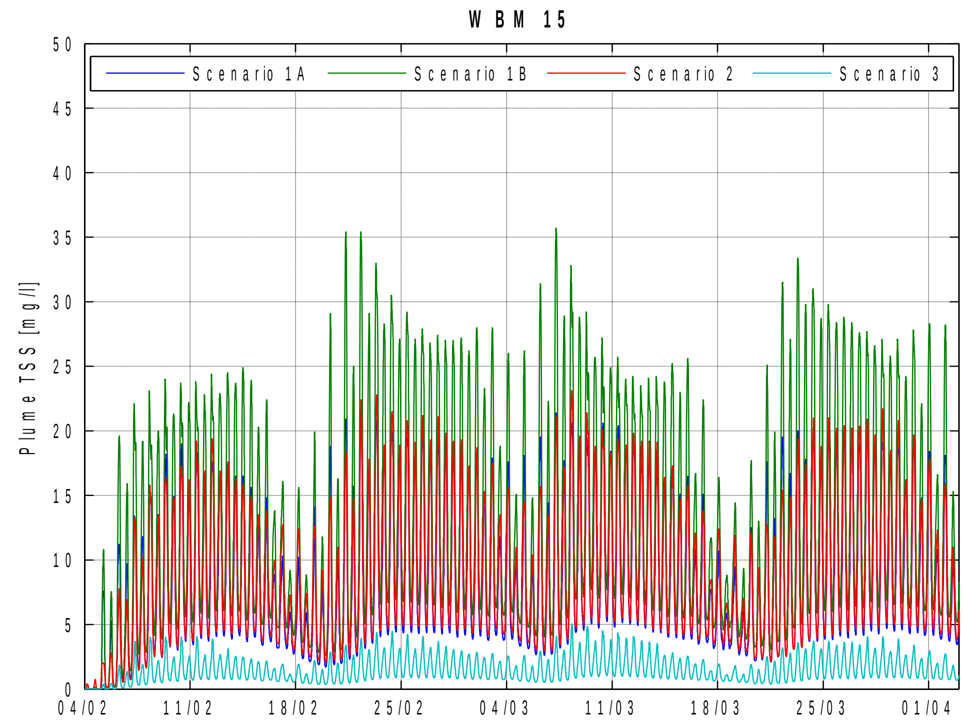
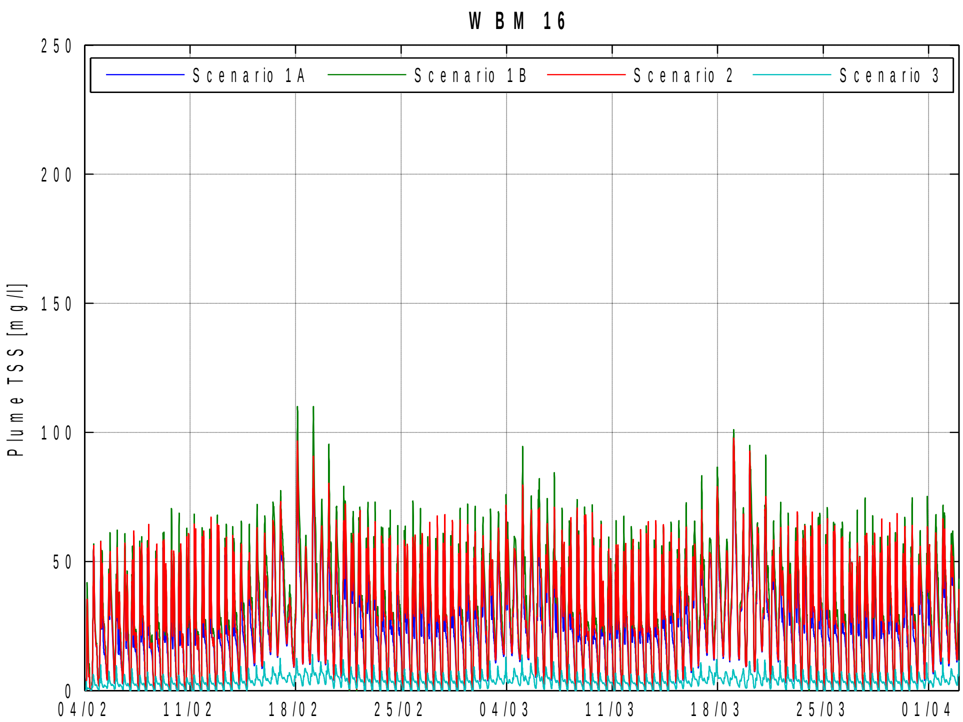


Figure E-15 Plume TSS Concentration Time Series – WBM 15



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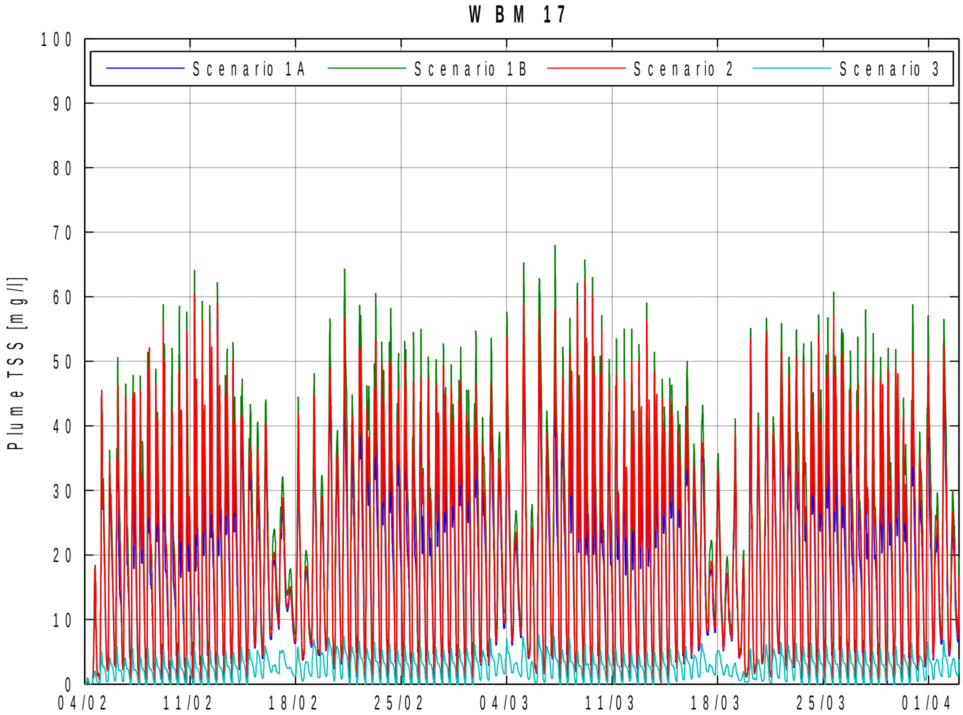


Figure E-17 Plume TSS Concentration Time Series – WBM 17

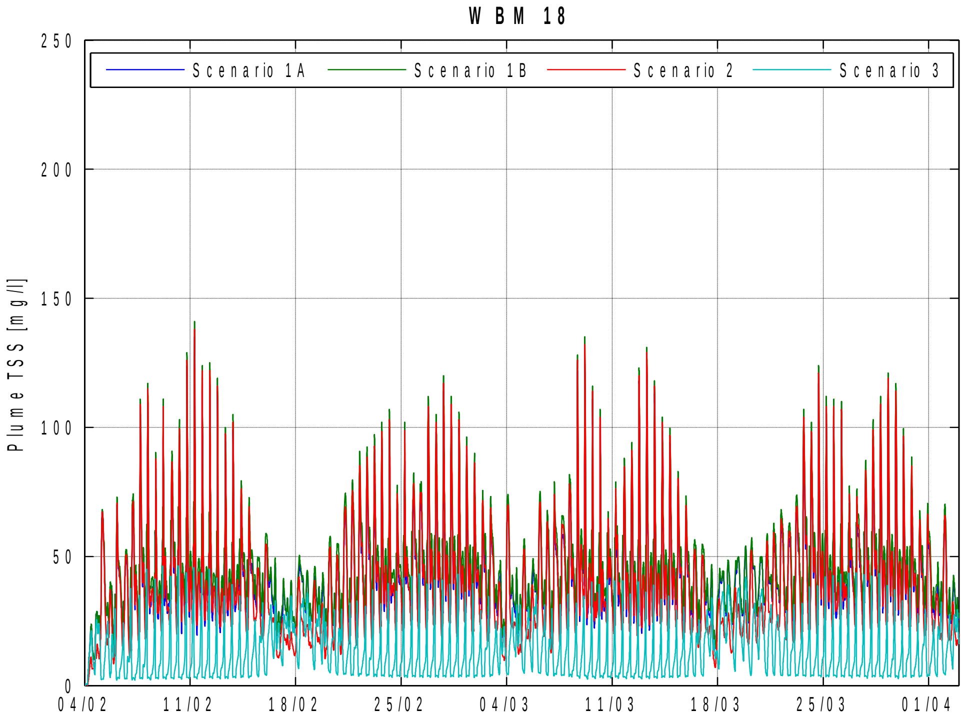


Figure E-18 Plume TSS Concentration Time Series – WBM 18

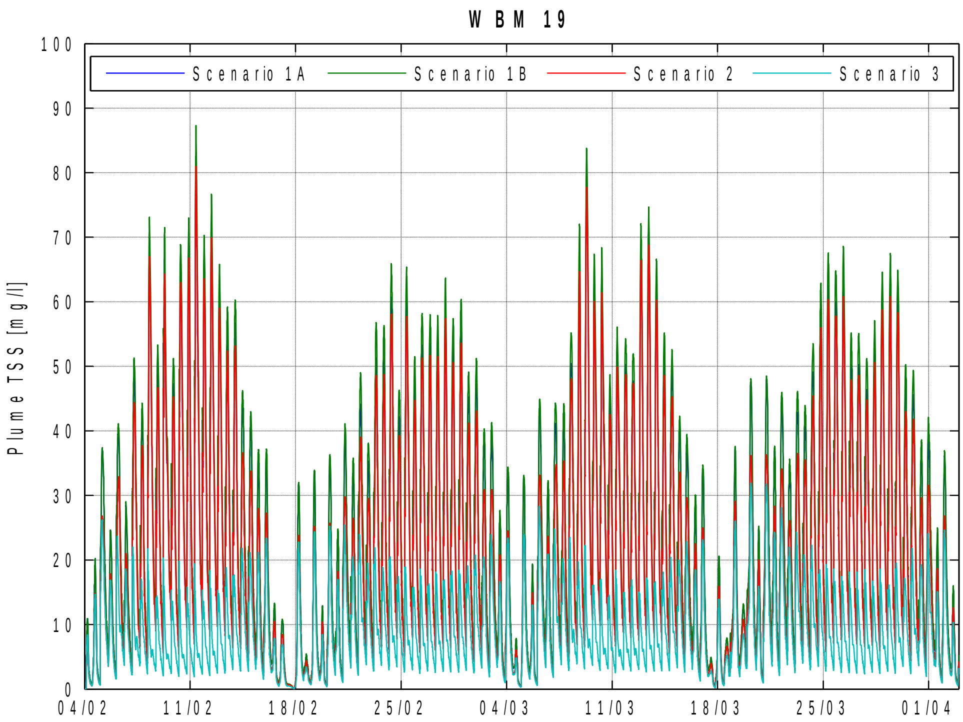
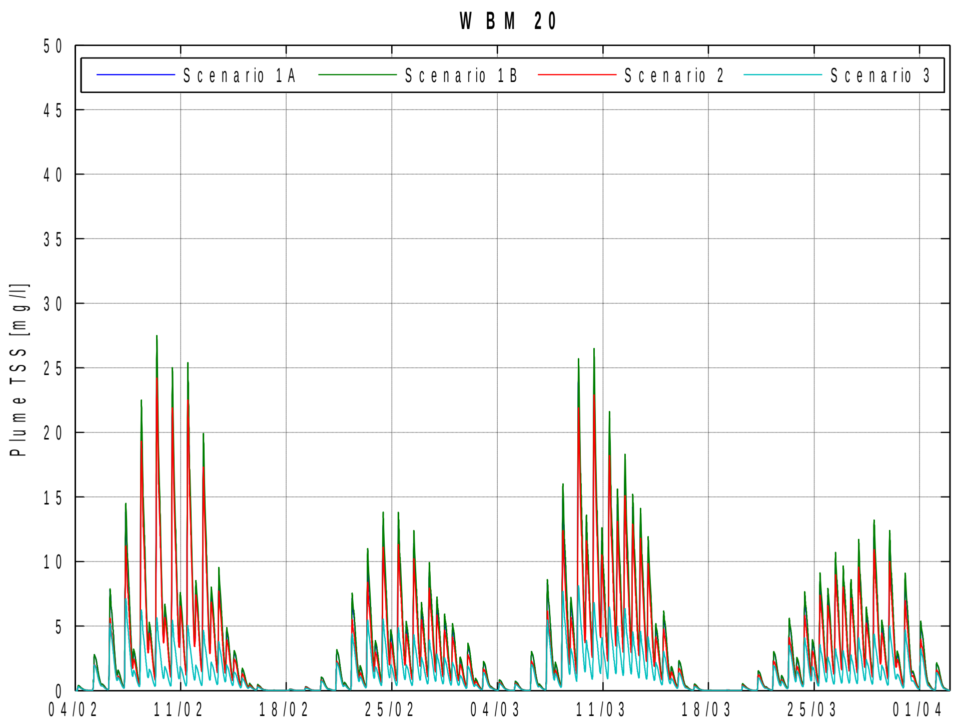


Figure E-19 Plume TSS Concentration Time Series – WBM 19



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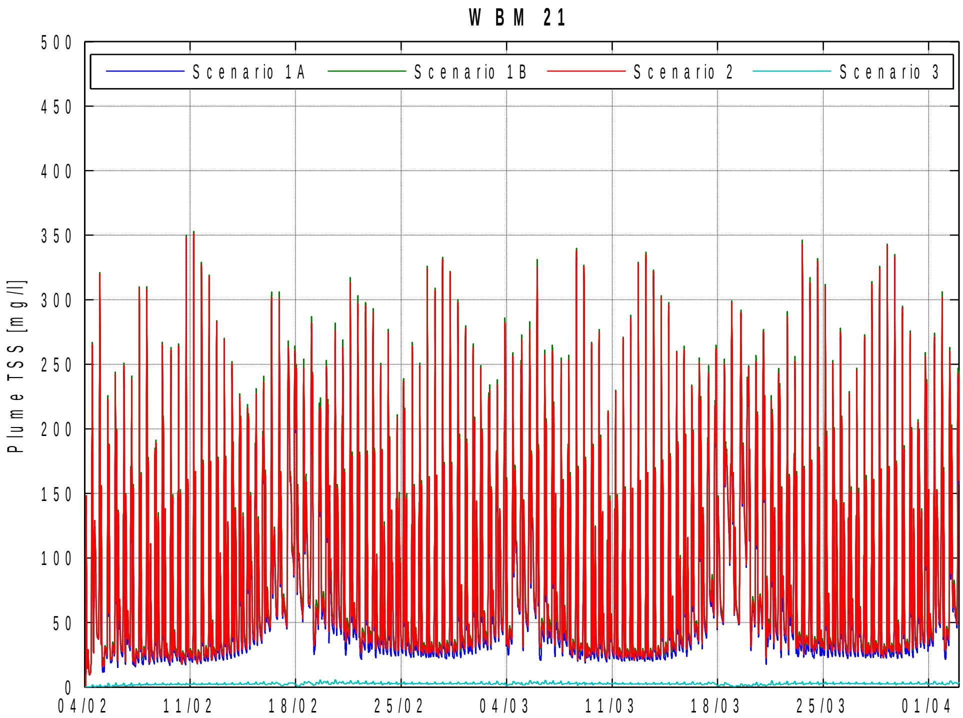

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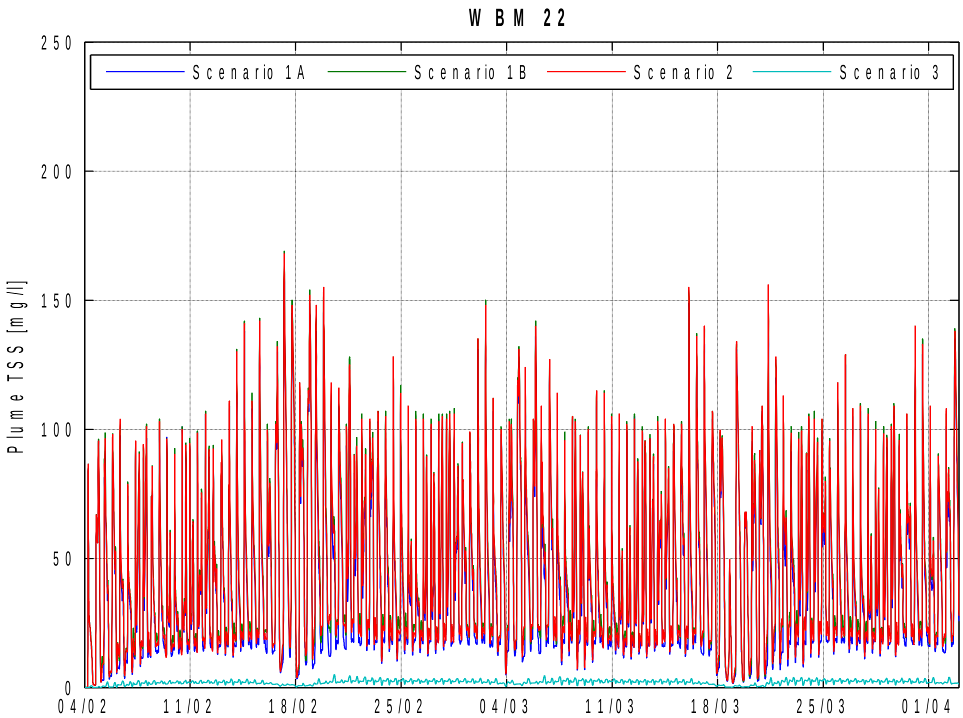


Figure E-22 Plume TSS Concentration Time Series – WBM 22

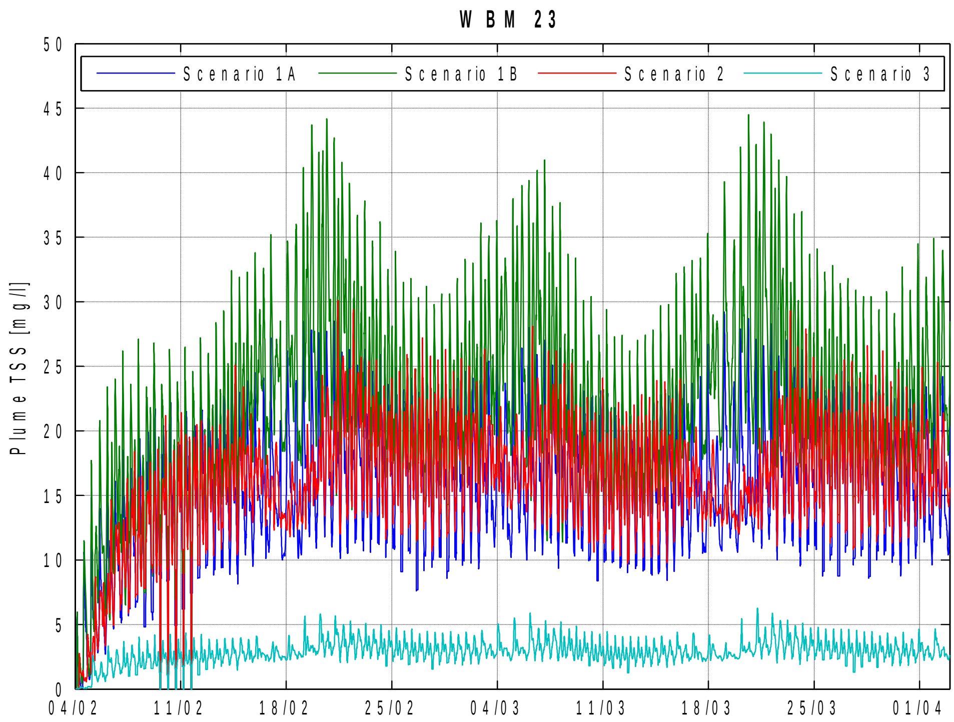


Figure E-23 Plume TSS Concentration Time Series – WBM 23

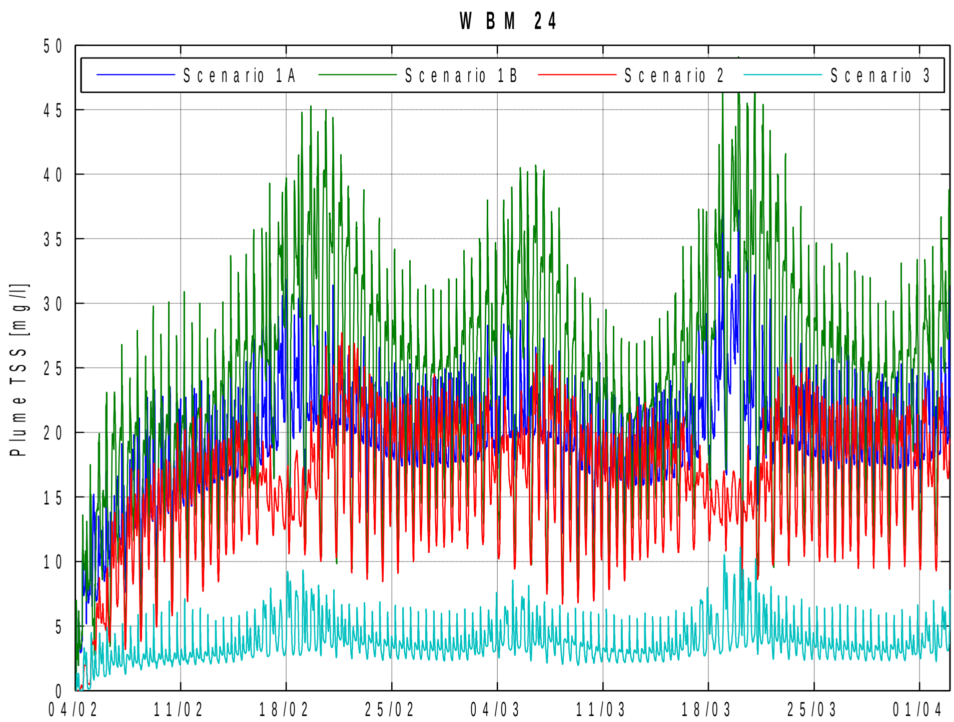


Figure E-24 Plume TSS Concentration Time Series – WBM 24

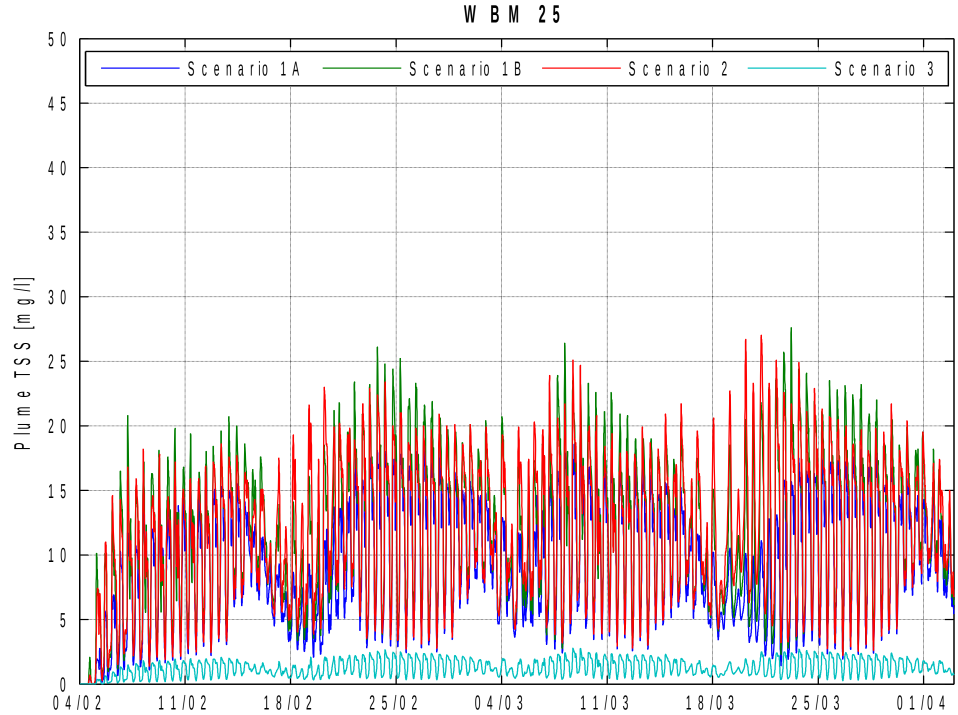


Figure E-25 Plume TSS Concentration Time Series – WBM 25

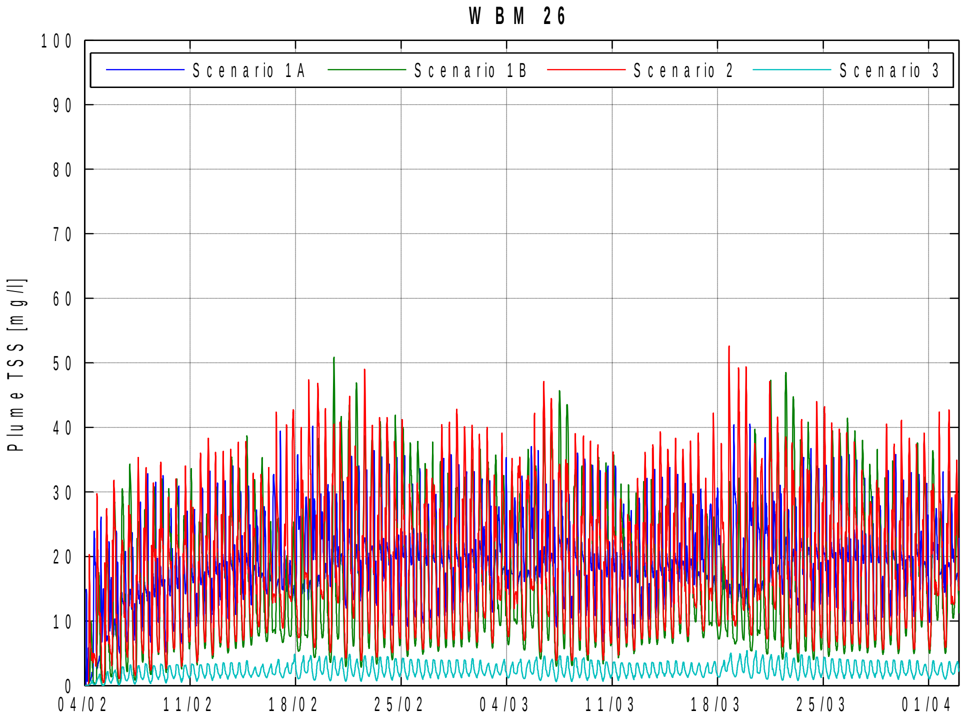


Figure E-26 Plume TSS Concentration Time Series – WBM 26

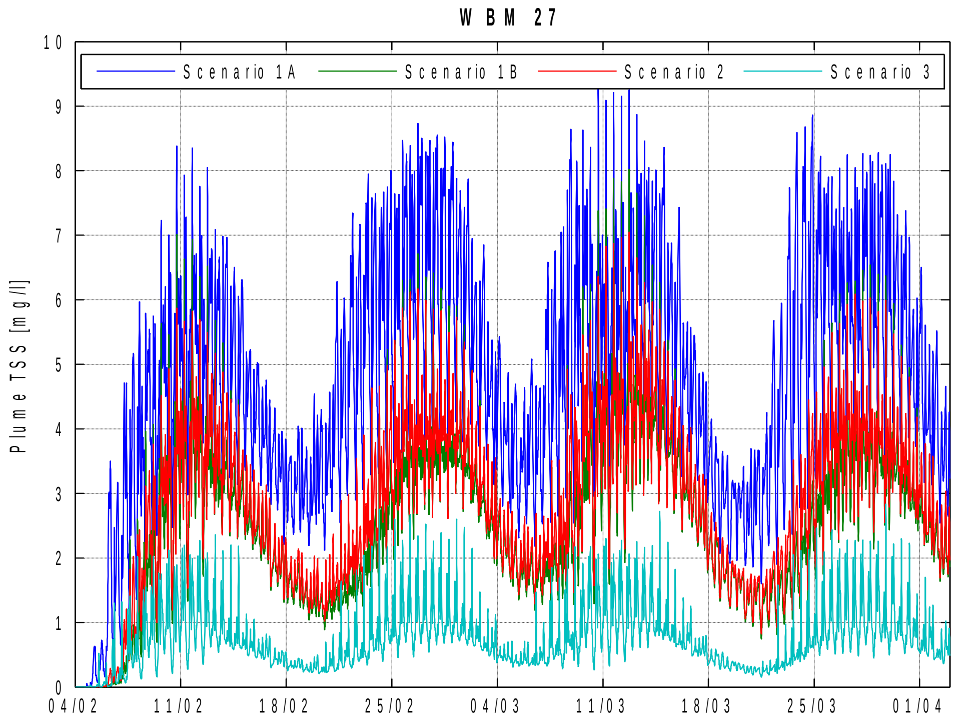


Figure E-27 Plume TSS Concentration Time Series – WBM 27

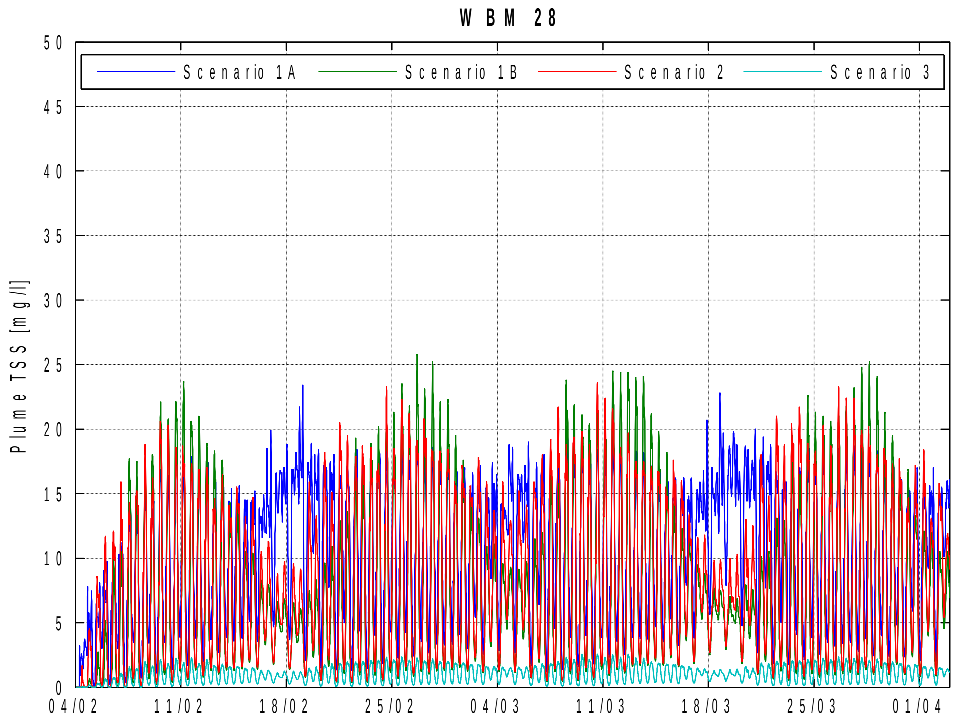


Figure E-28 Plume TSS Concentration Time Series – WBM 28

APPENDIX F: PLUME DEPOSITION TIME SERIES

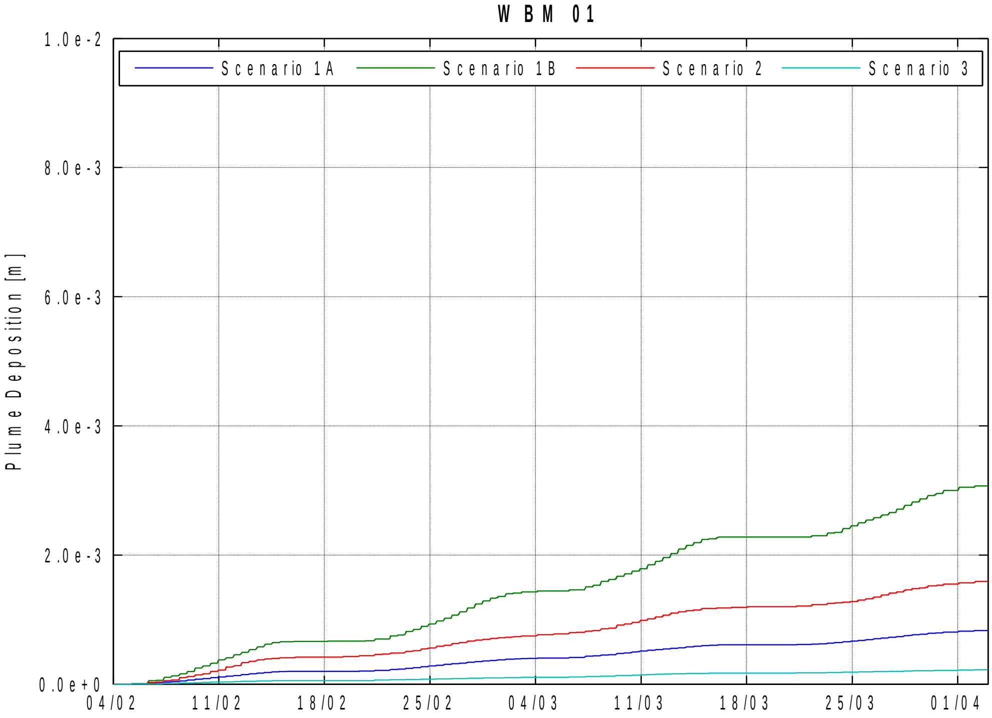


Figure F-1 Plume Deposition Time Series – WBM 01

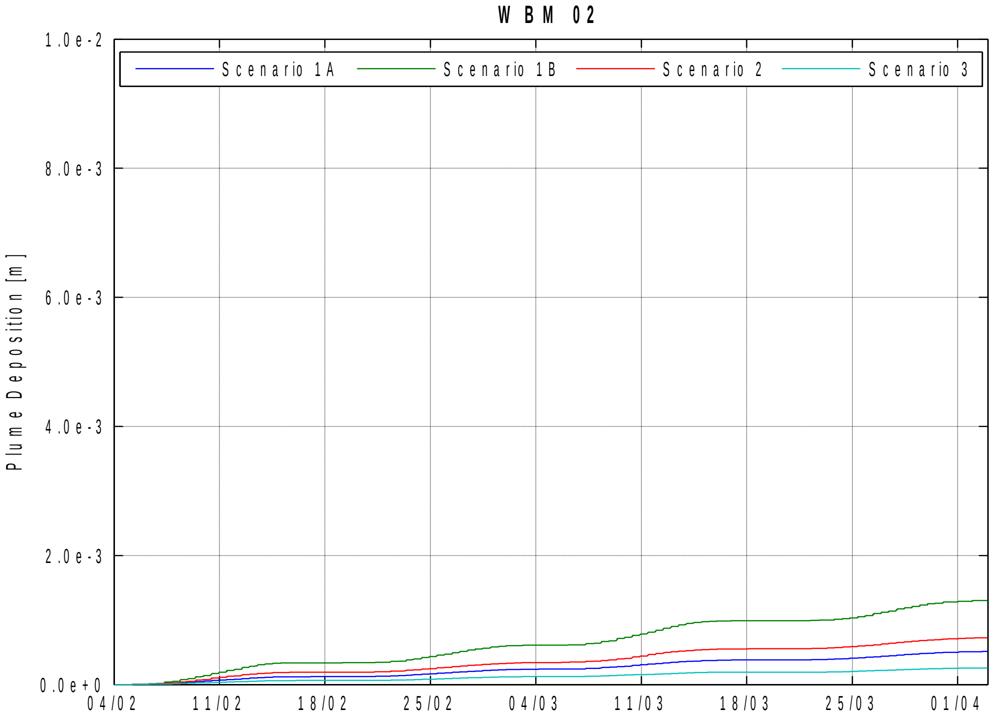


Figure F-2 Plume Deposition Time Series – WBM 02

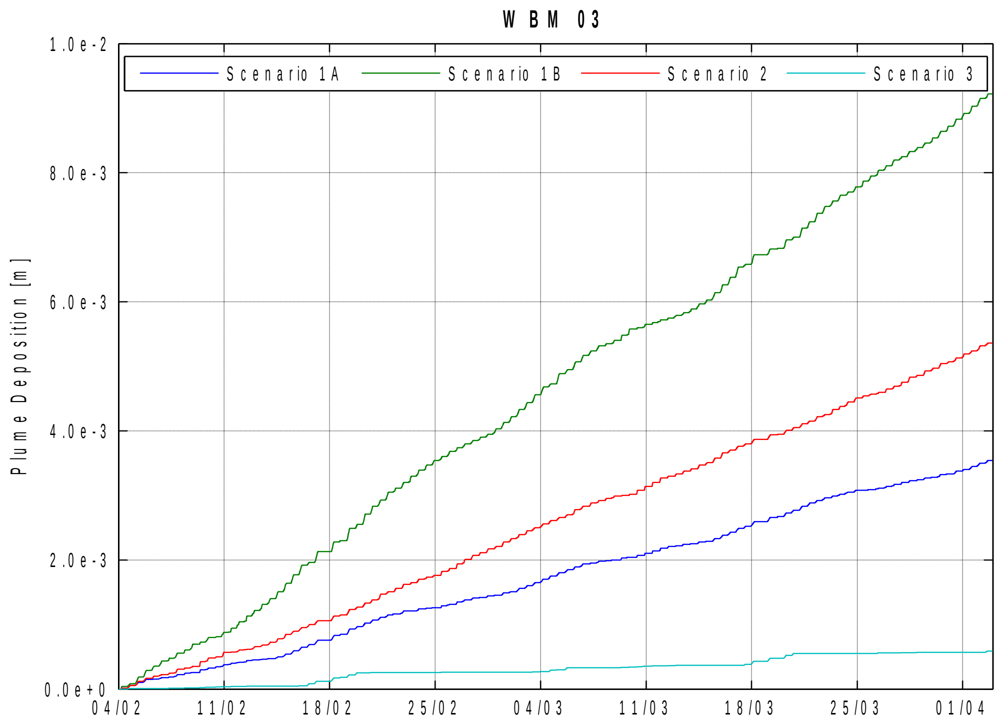


Figure F-3 Plume Deposition Time Series – WBM 03

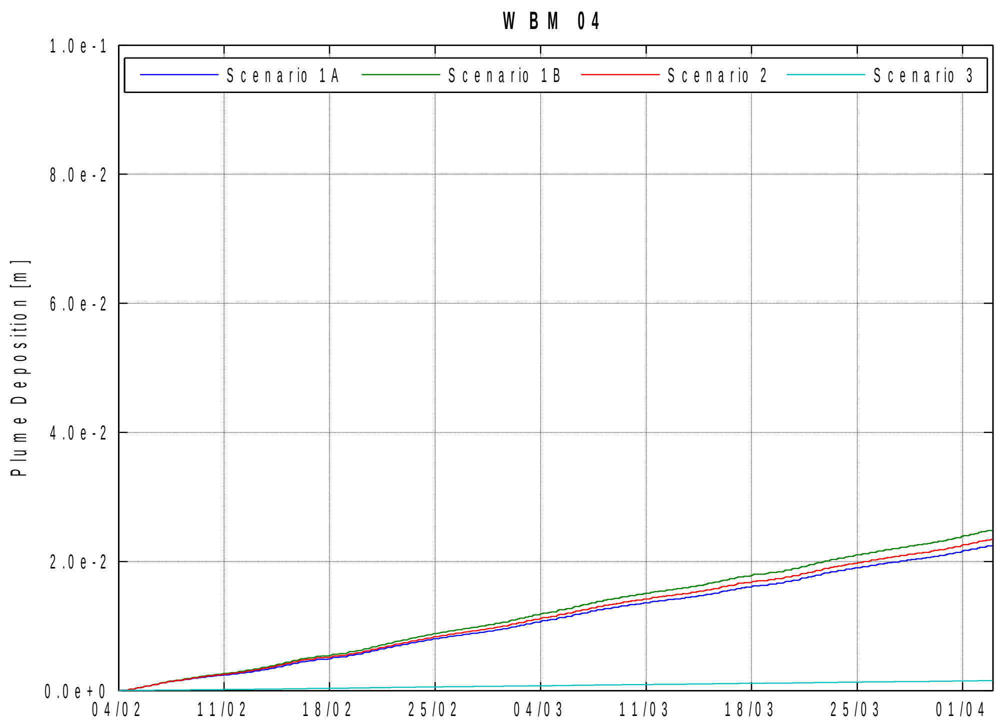


Figure F-4 Plume Deposition Time Series – WBM 04

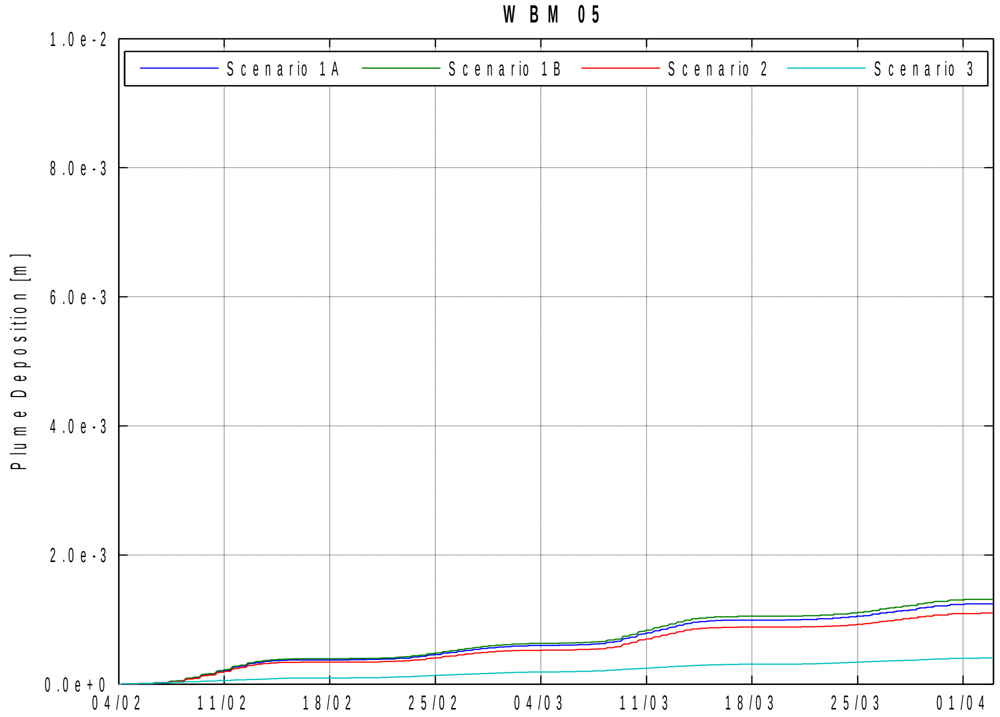


Figure F-5 Plume Deposition Time Series – WBM 05

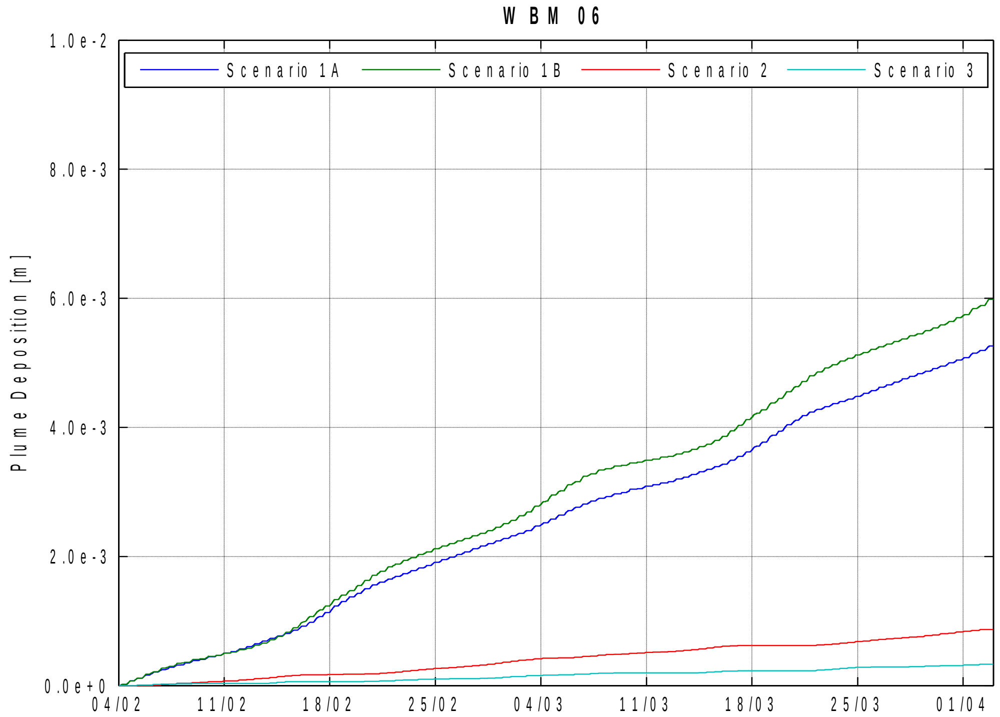


Figure F-6 Plume Deposition Time Series – WBM 06

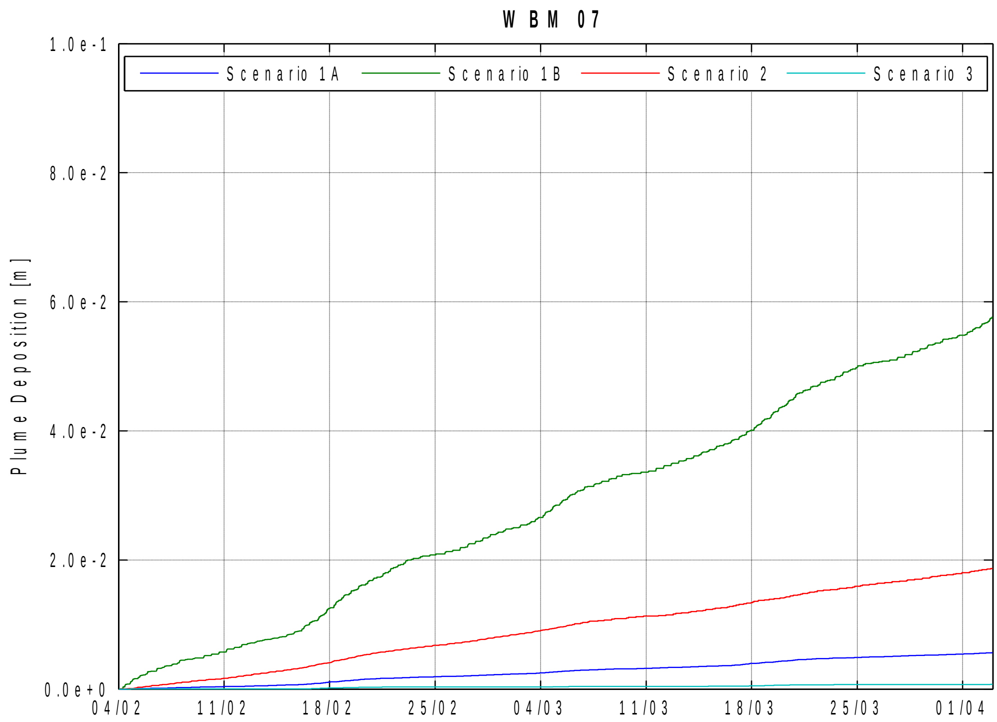


Figure F-7 Plume Deposition Time Series – WBM 07

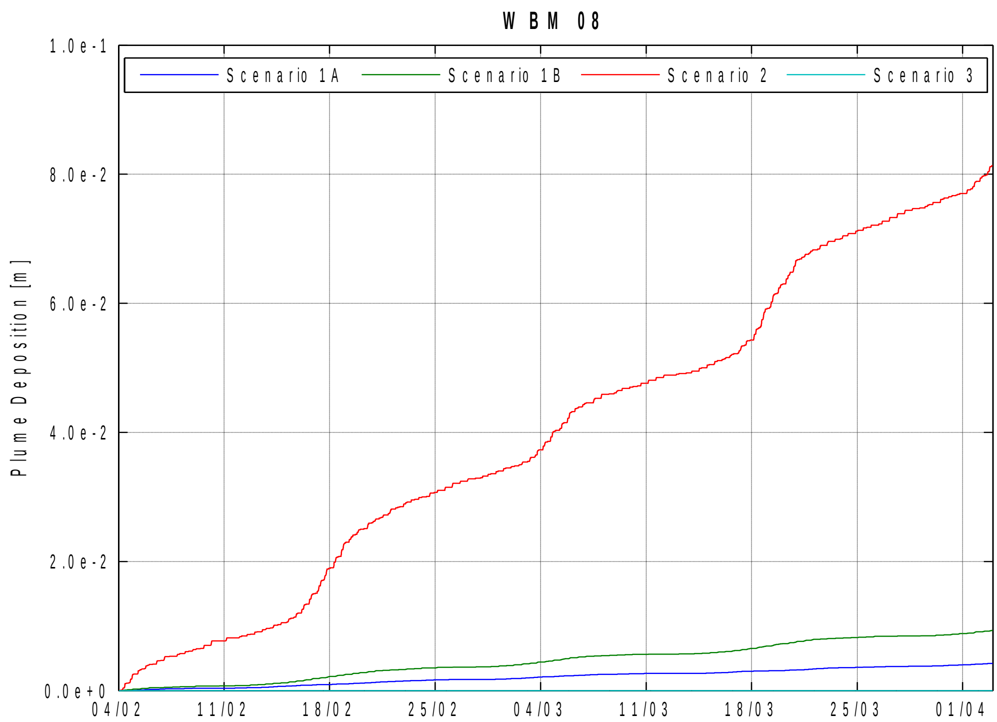


Figure F-8 Plume Deposition Time Series – WBM 08

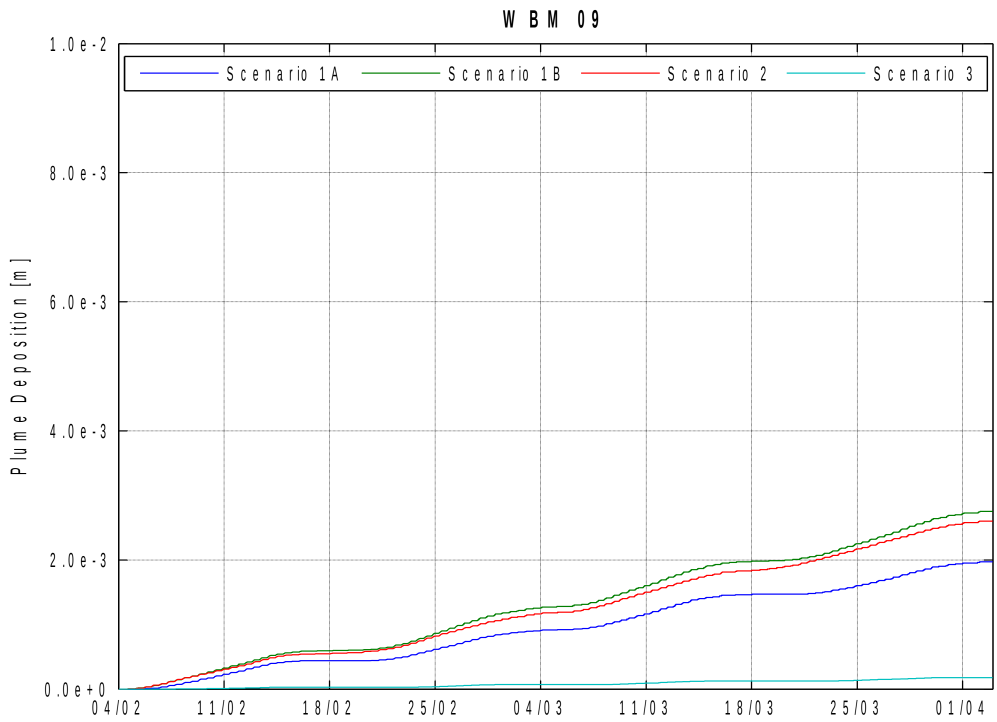


Figure F-9 Plume Deposition Time Series – WBM 09

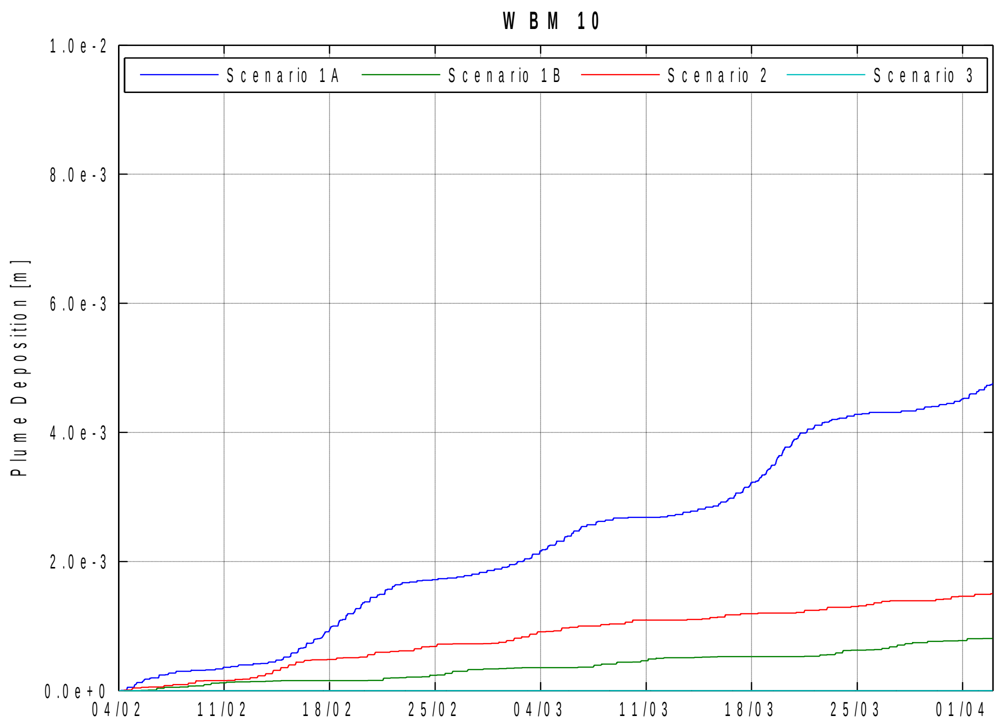


Figure F-10 Plume Deposition Time Series – WBM 10

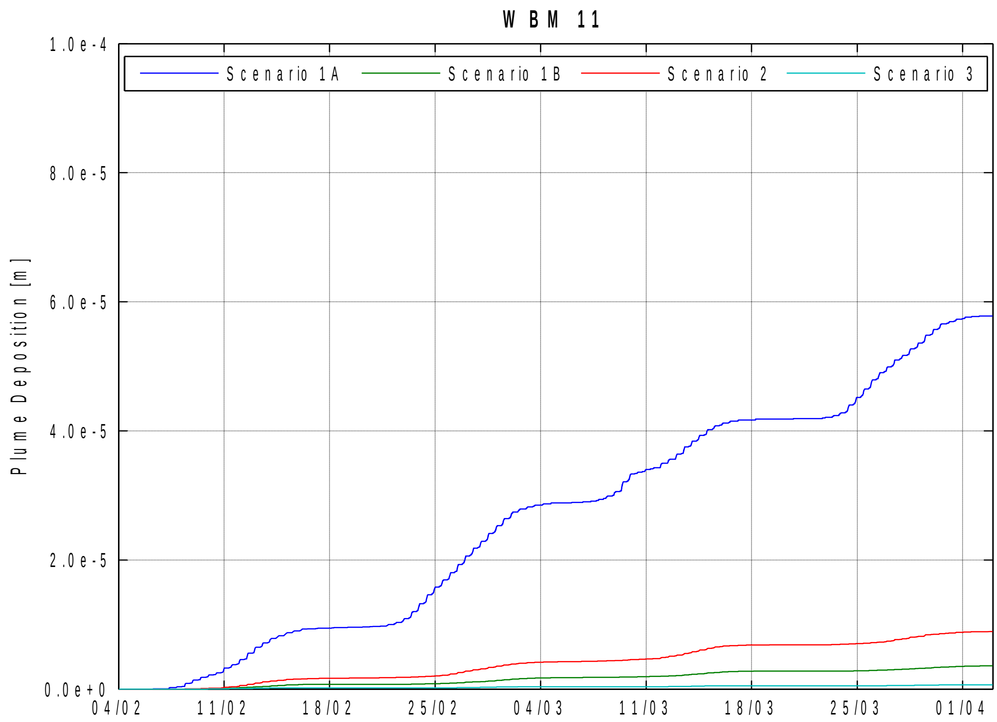


Figure F-11 Plume Deposition Time Series – WBM 11

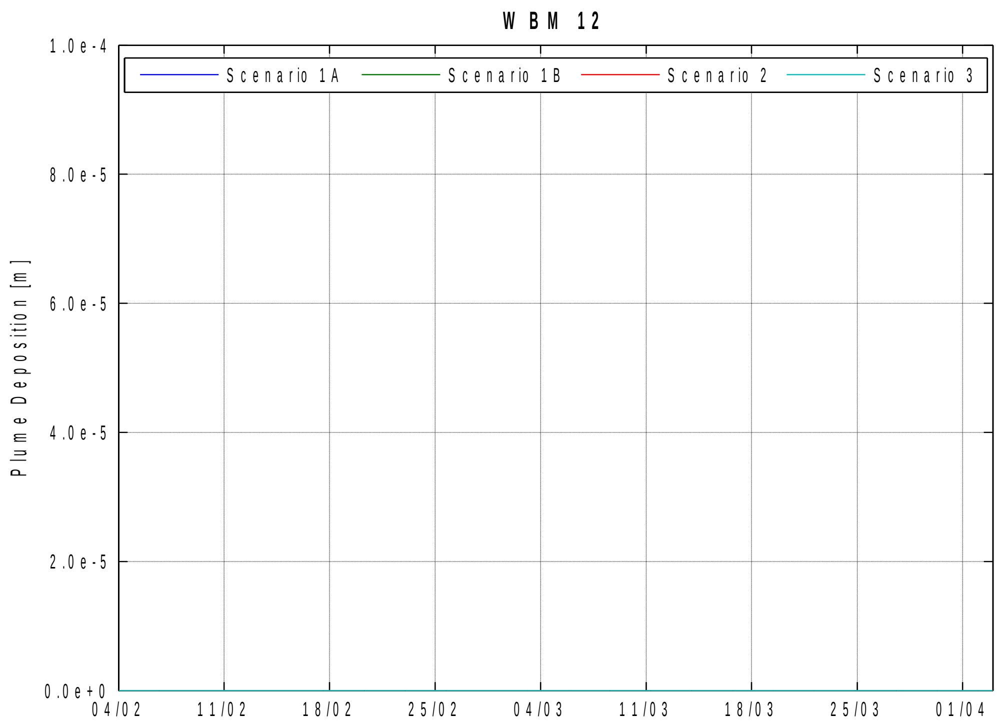


Figure F-12 Plume Deposition Time Series – WBM 12

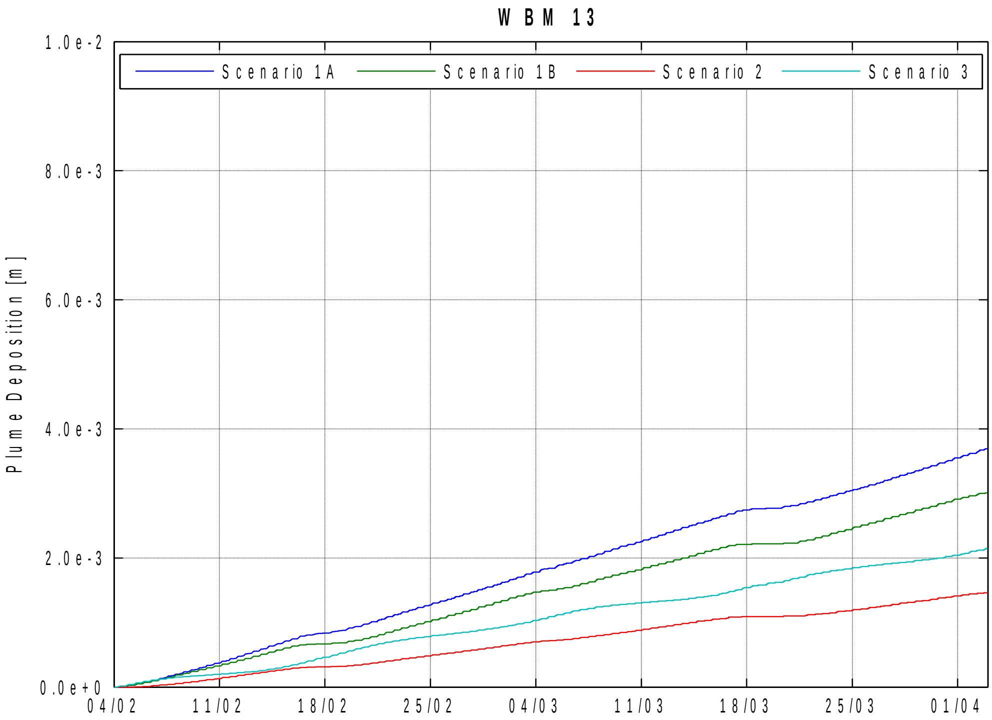


Figure F-13 Plume Deposition Time Series – WBM 13

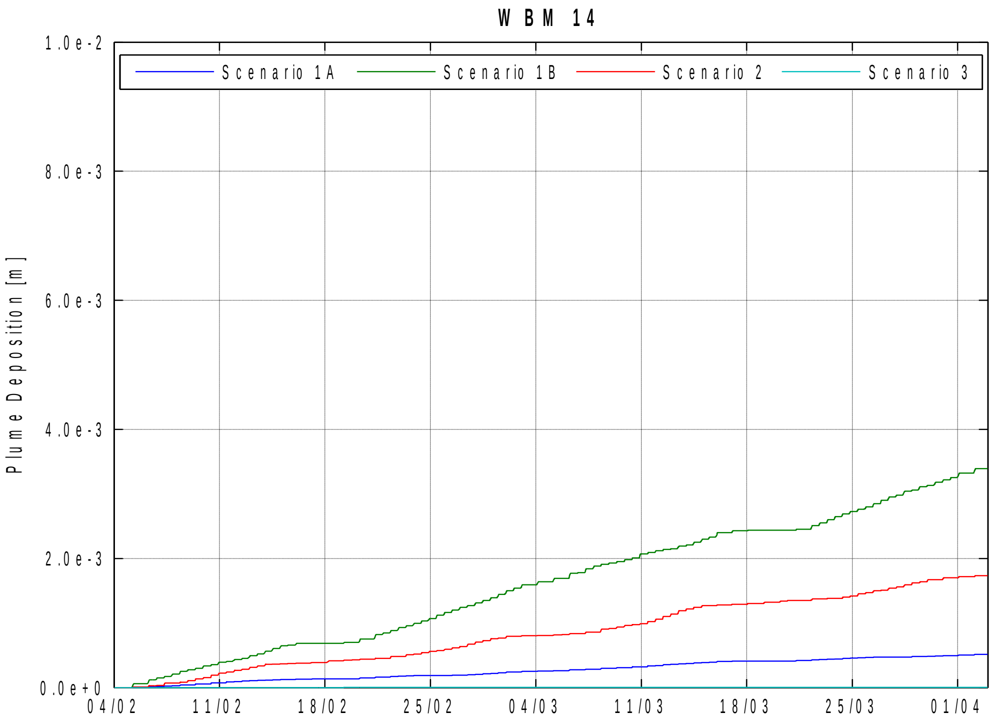


Figure F-14 Plume Deposition Time Series – WBM 14

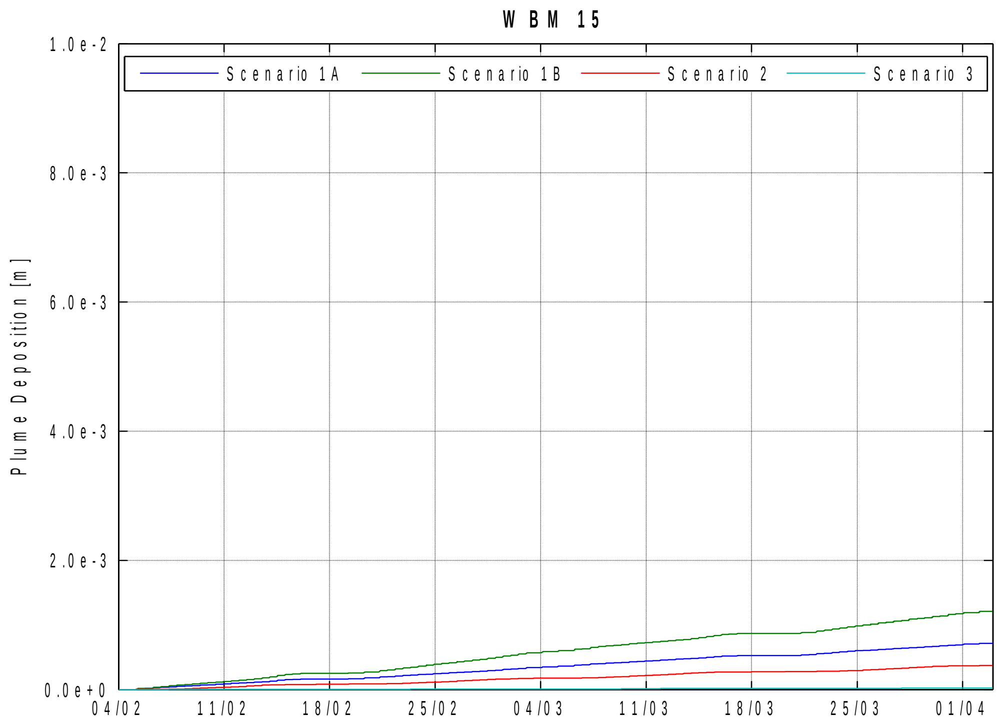


Figure F-15 Plume Deposition Time Series – WBM 15

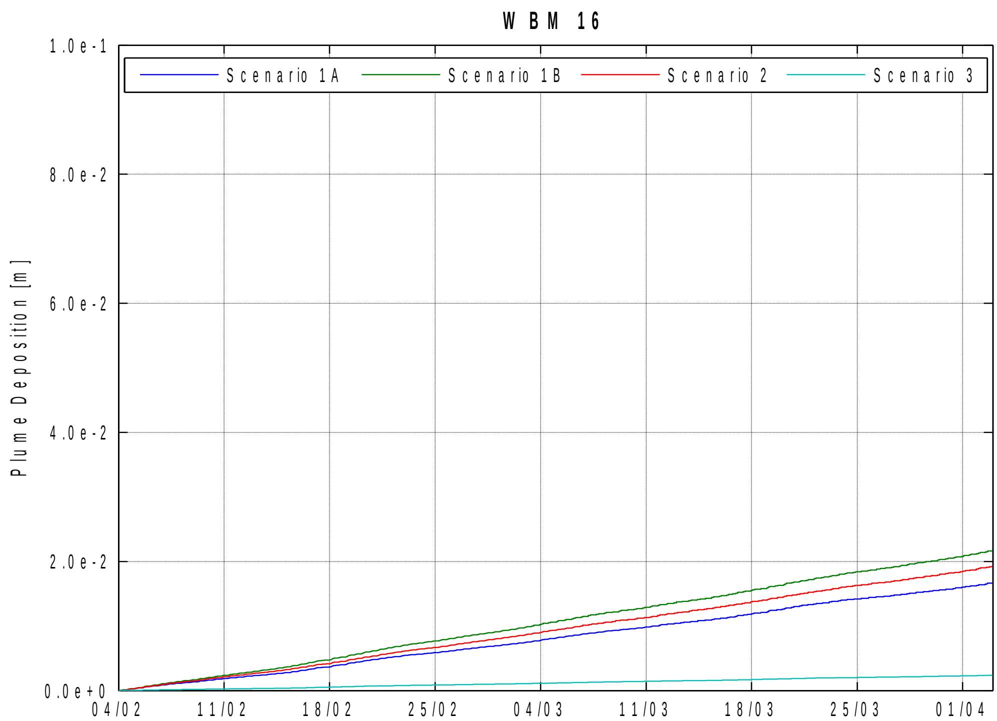


Figure F-16 Plume Deposition Time Series – WBM 16

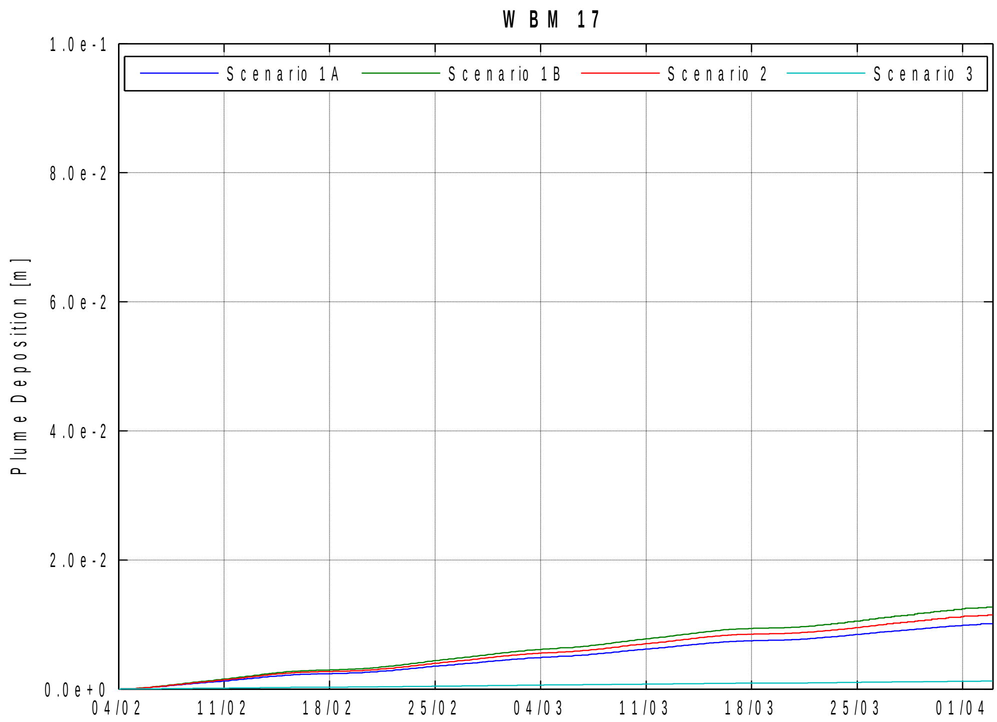


Figure F-17 Plume Deposition Time Series – WBM 17

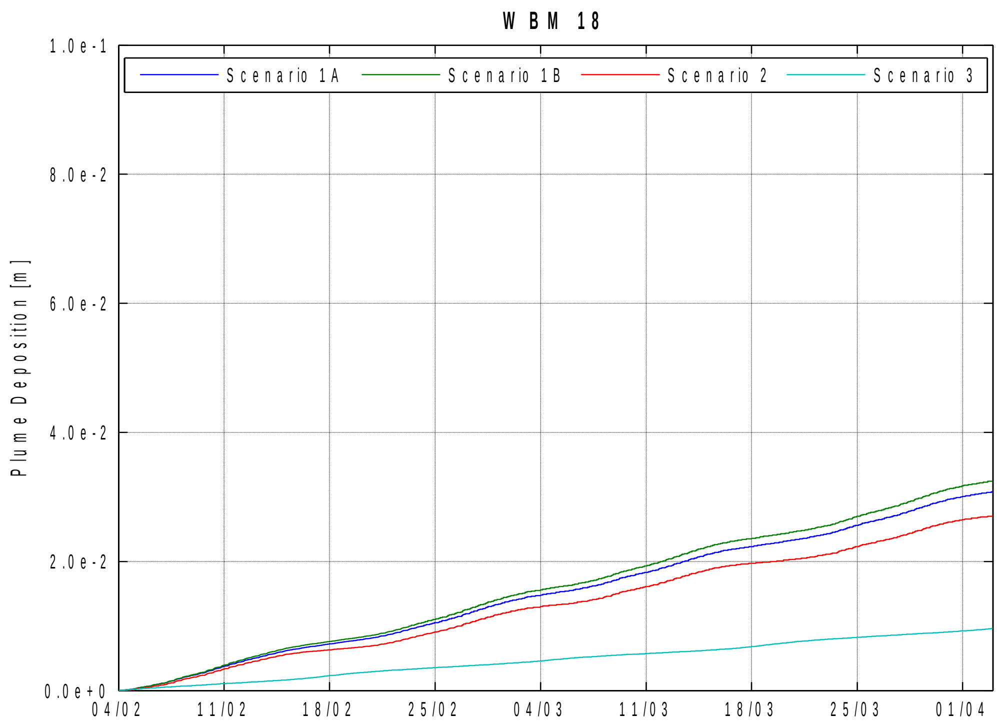


Figure F-18 Plume Deposition Time Series – WBM 18

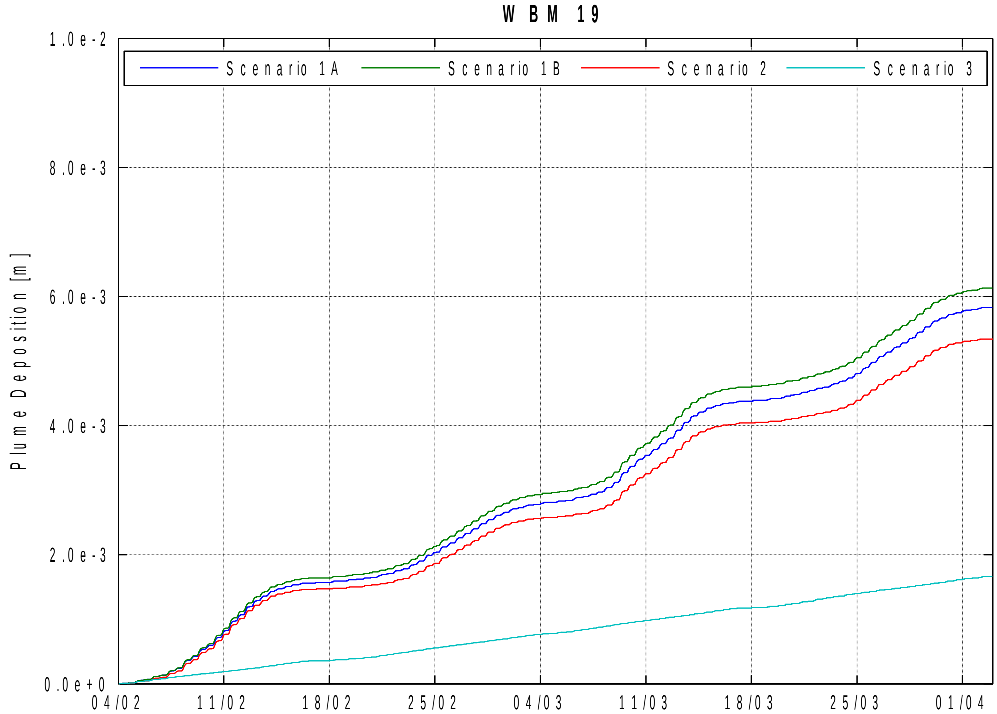


Figure F-19 Plume Deposition Time Series – WBM 19

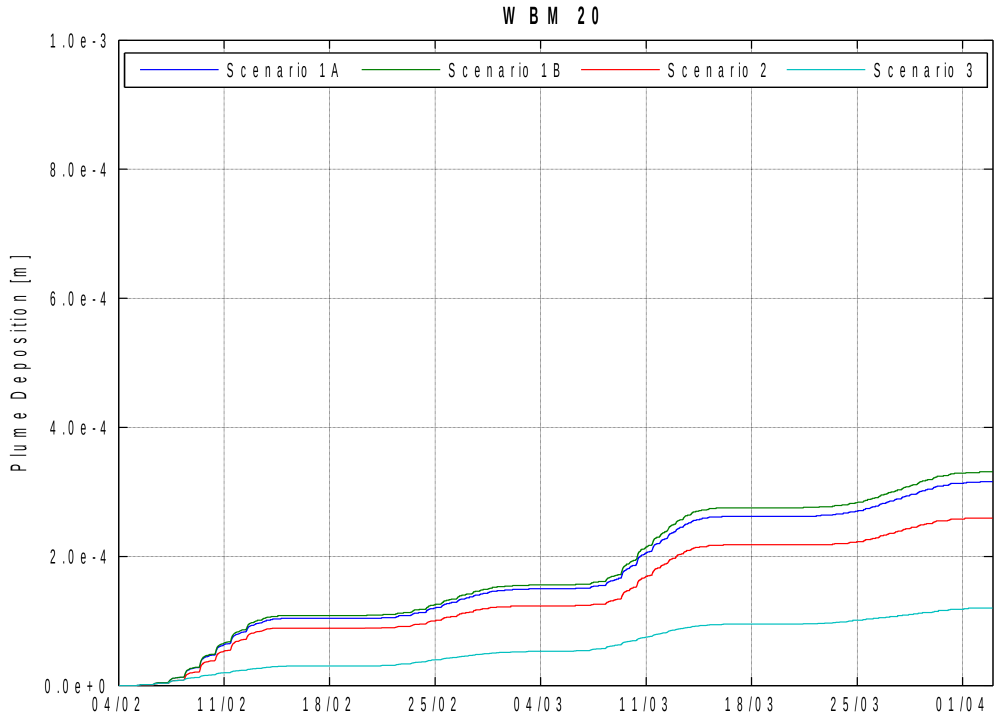


Figure F-20 Plume Deposition Time Series – WBM 20

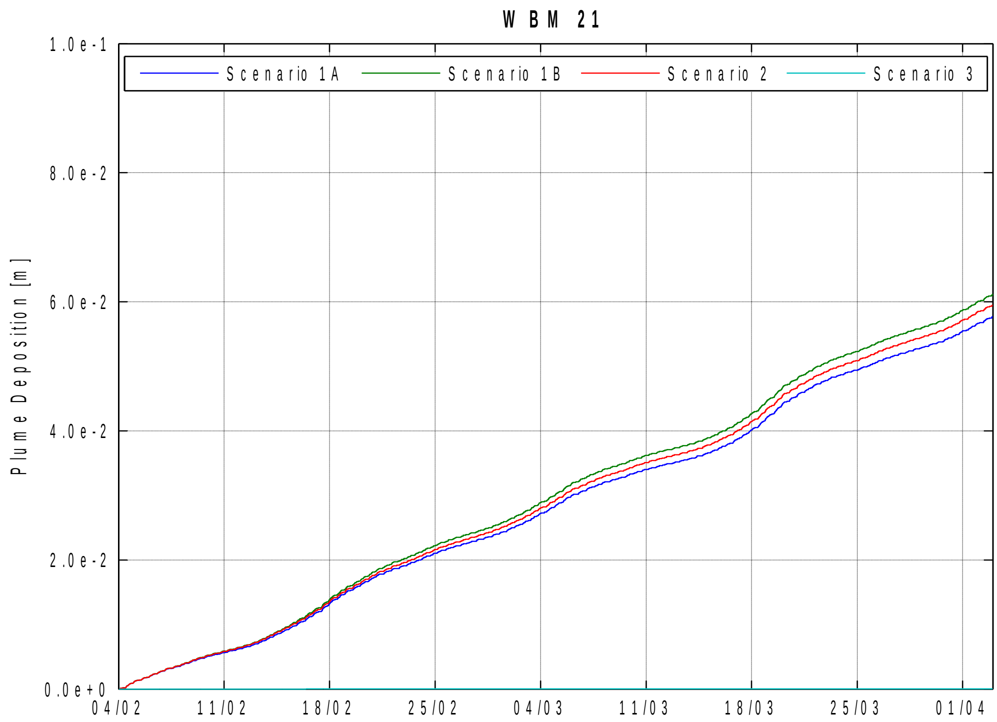


Figure F-21 Plume Deposition Time Series – WBM 21

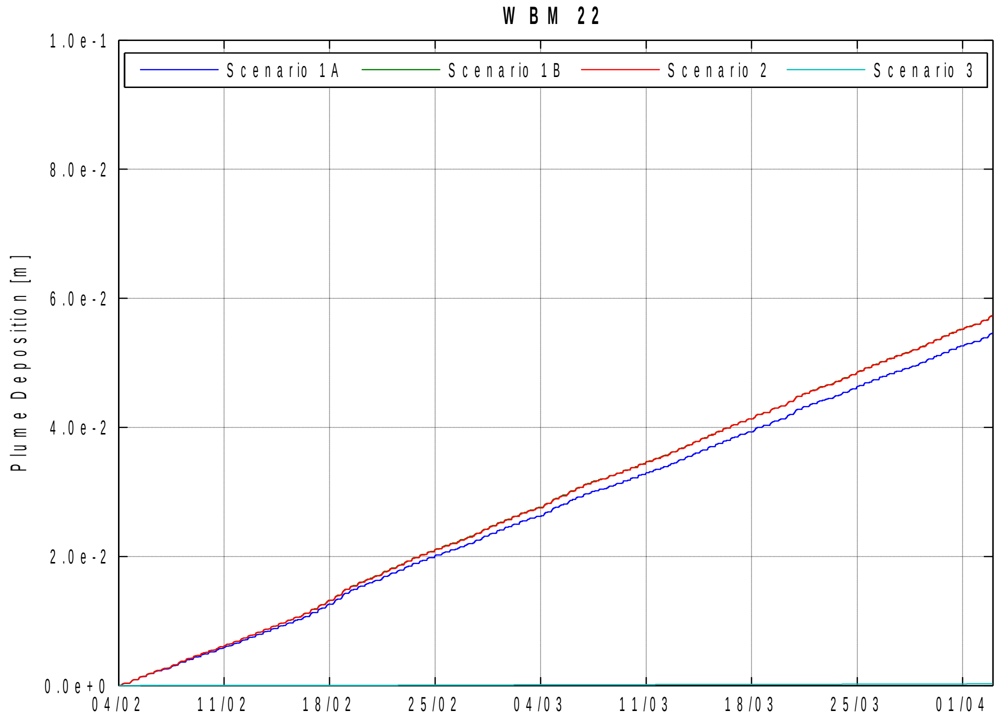


Figure F-22 Plume Deposition Time Series – WBM 22

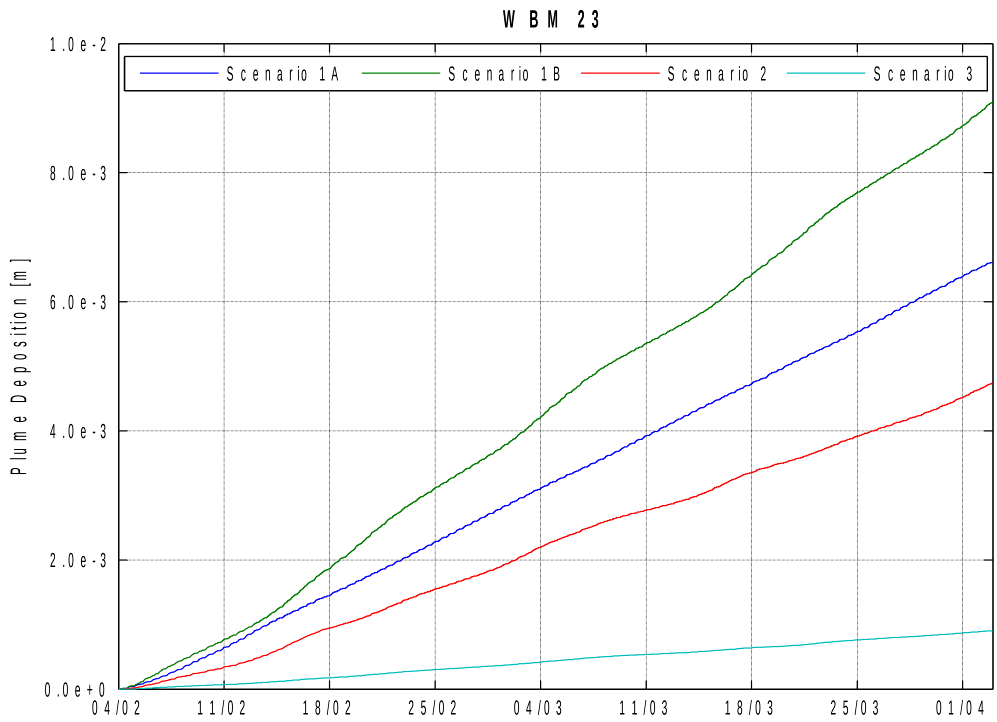


Figure F-23 Plume Deposition Time Series – WBM 23

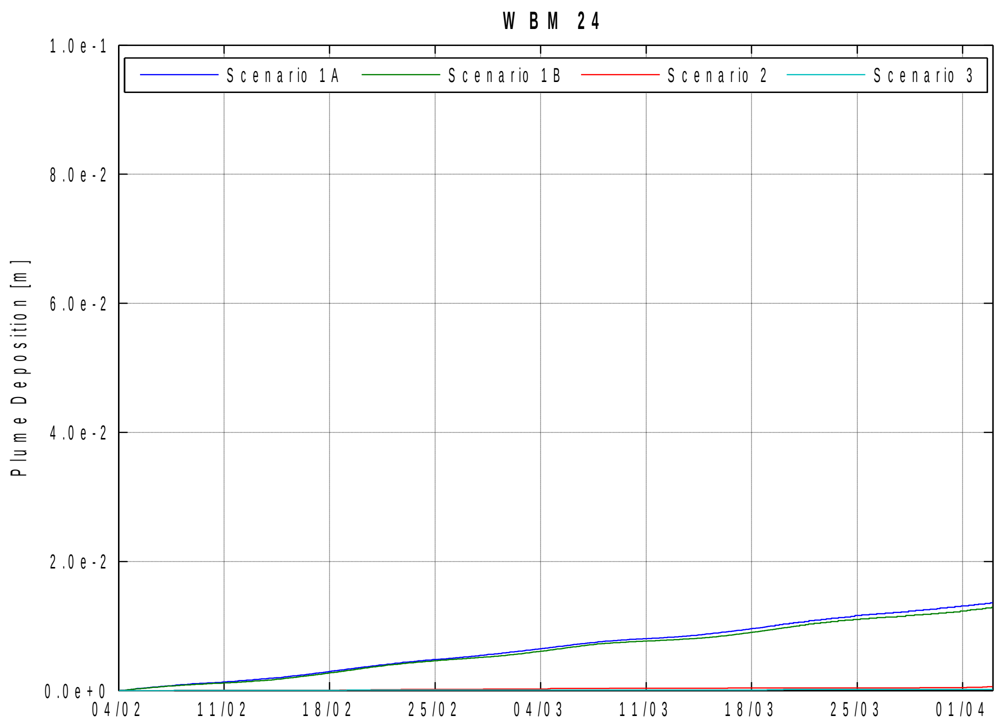


Figure F-24 Plume Deposition Time Series – WBM 24

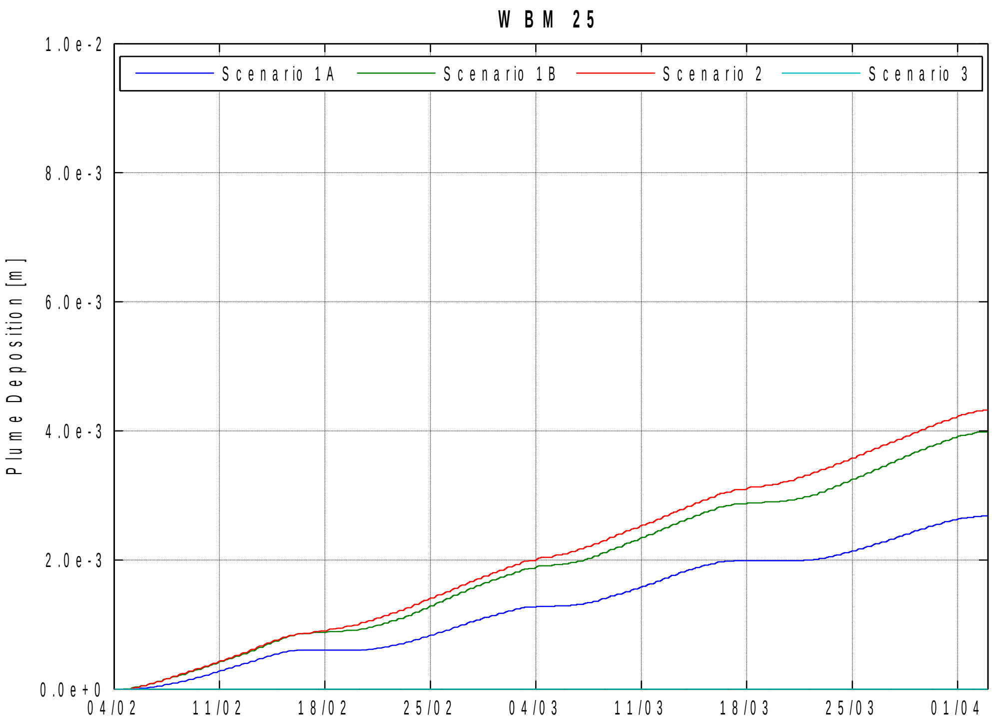


Figure F-25 Plume Deposition Time Series – WBM 25

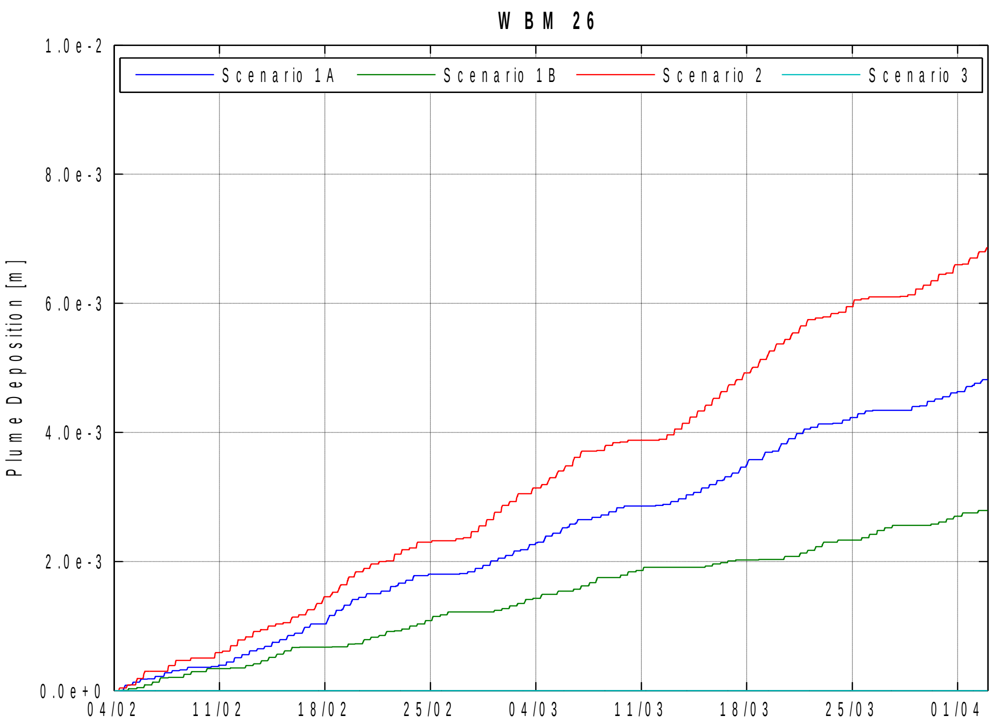


Figure F-26 Plume Deposition Time Series – WBM 26

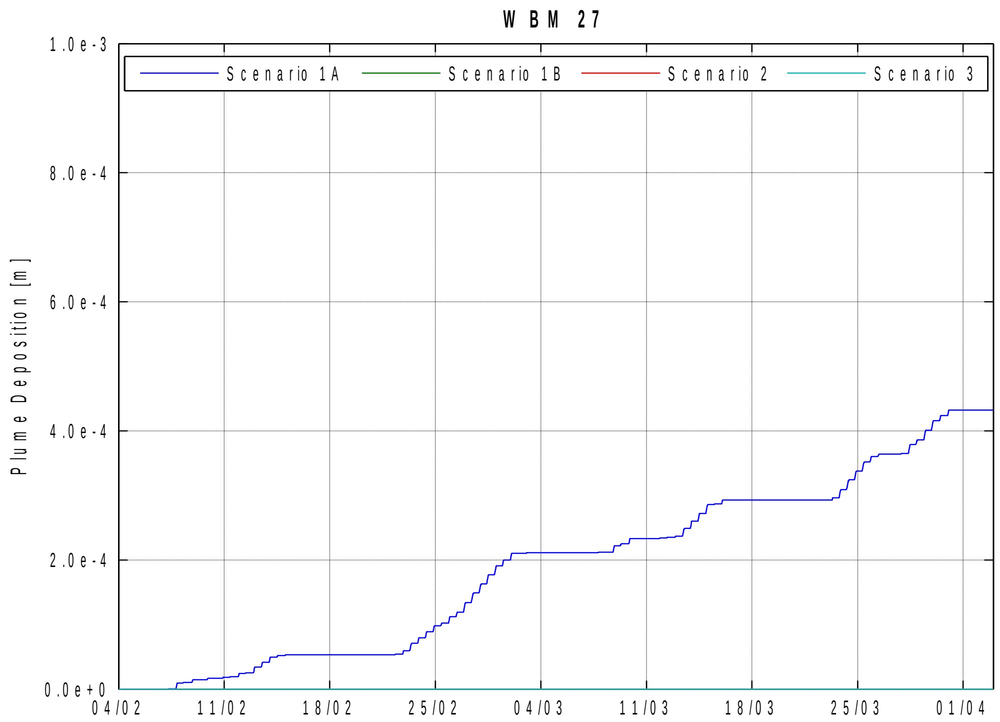


Figure F-27 Plume Deposition Time Series – WBM 27

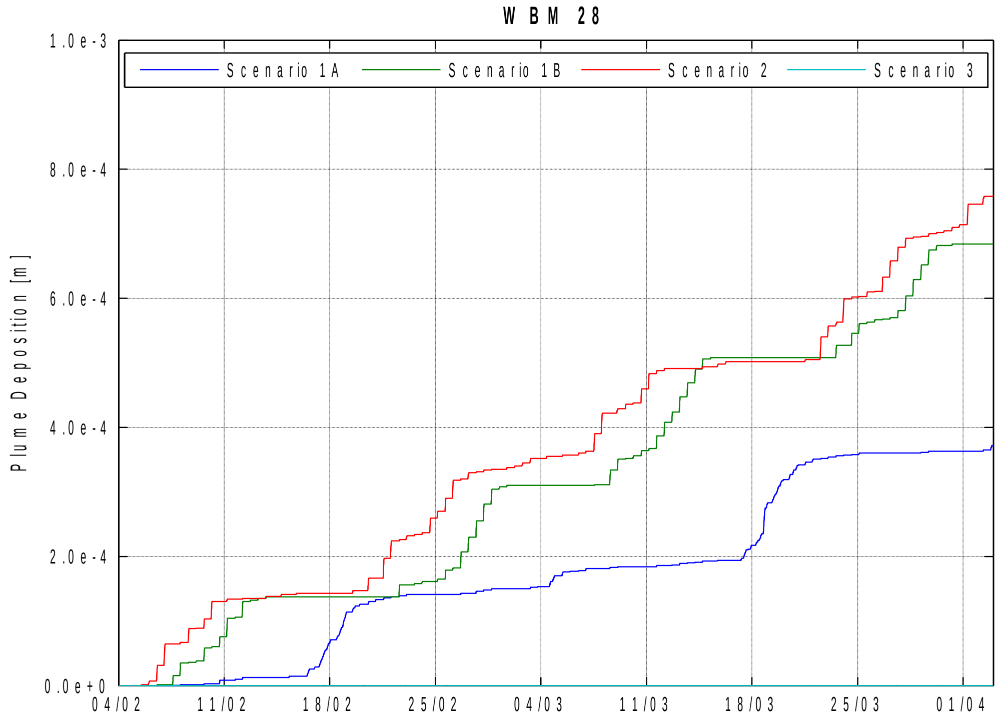


Figure F-28 Plume Deposition Time Series – WBM 28

APPENDIX G: EXTREME WAVE CONDITIONS

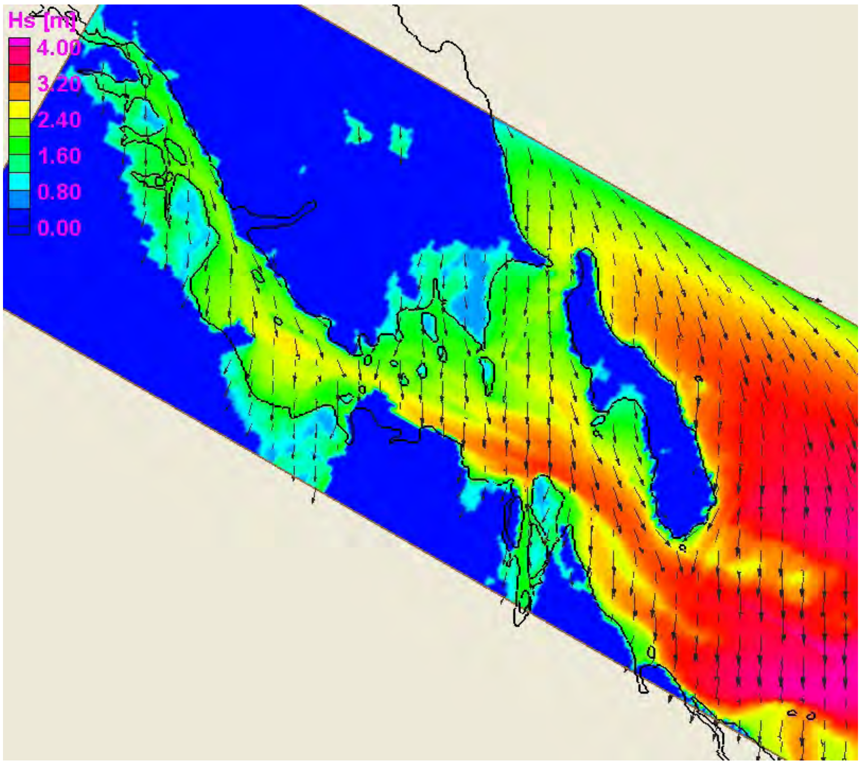


Figure G-1 Modelled Significant Wave Height for Extreme Wave Scenario 1 (Northerly Wind) - Base Case (Regional Model)

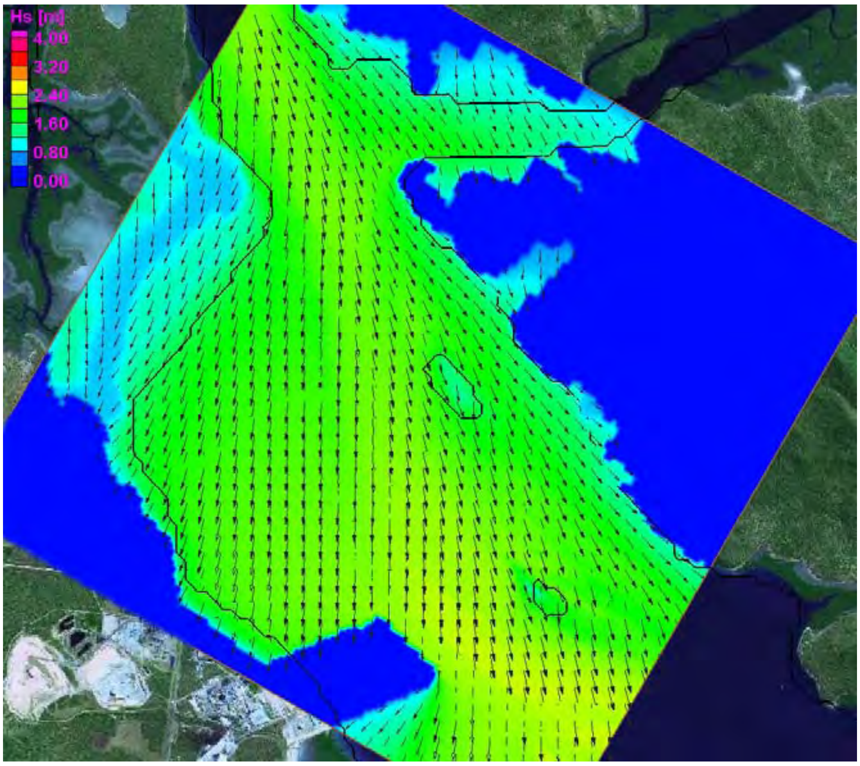


Figure G-2 Modelled Significant Wave Height for Extreme Wave Scenario 1 (Northerly Wind) - Base Case (Local Model)

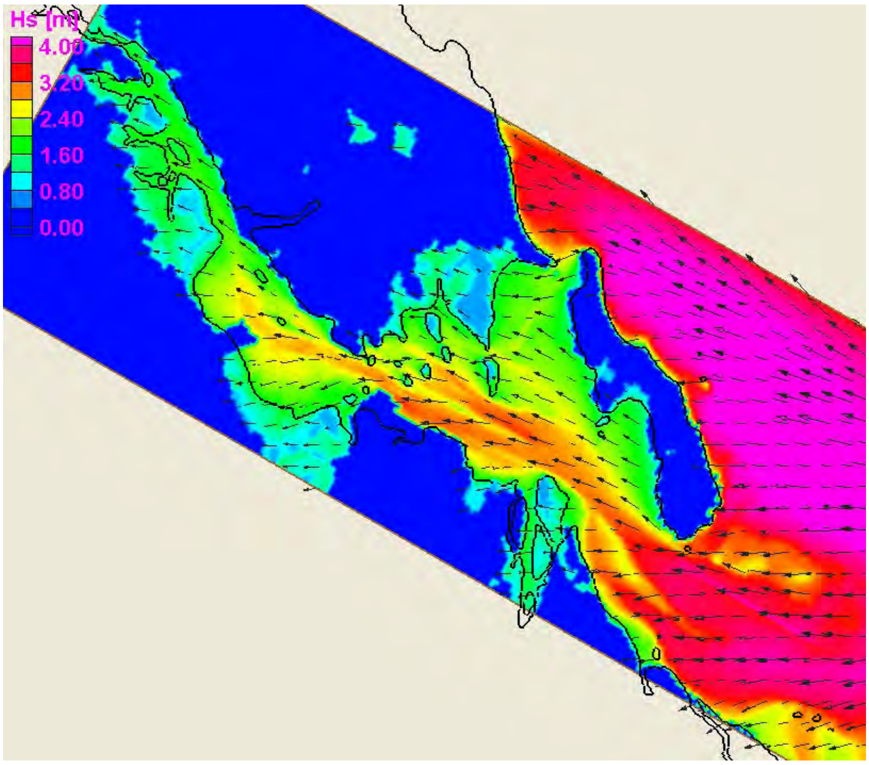


Figure G-3 Modelled Significant Wave Height for Extreme Wave Scenario 4 (Easterly Wind) - Base Case (Regional Model)

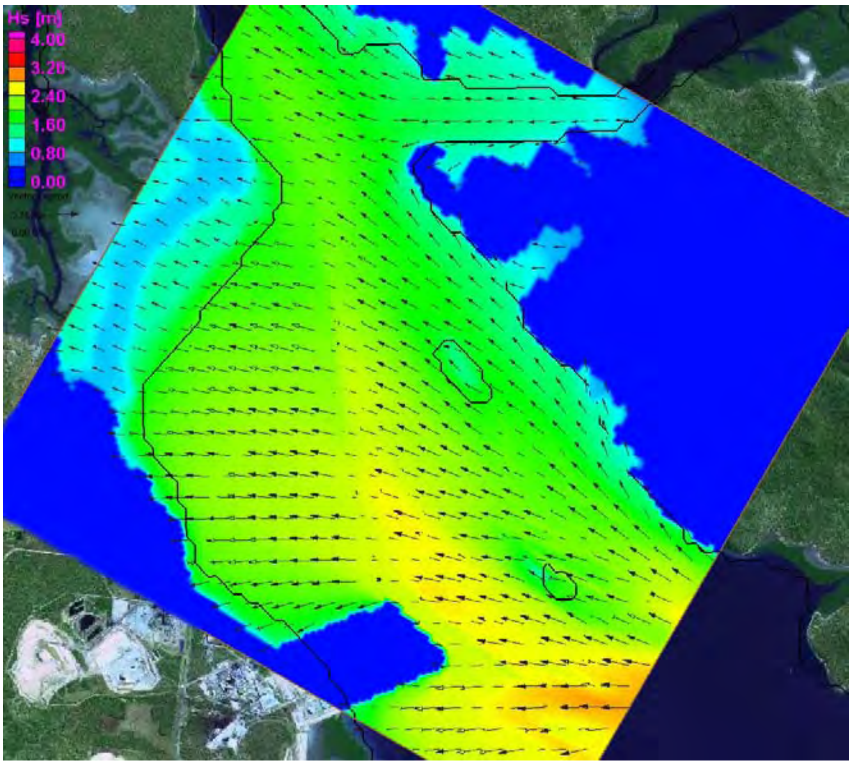


Figure G-4 Modelled Significant Wave Height for Extreme Wave Scenario 4 (Easterly Wind) - Base Case (Local Model)

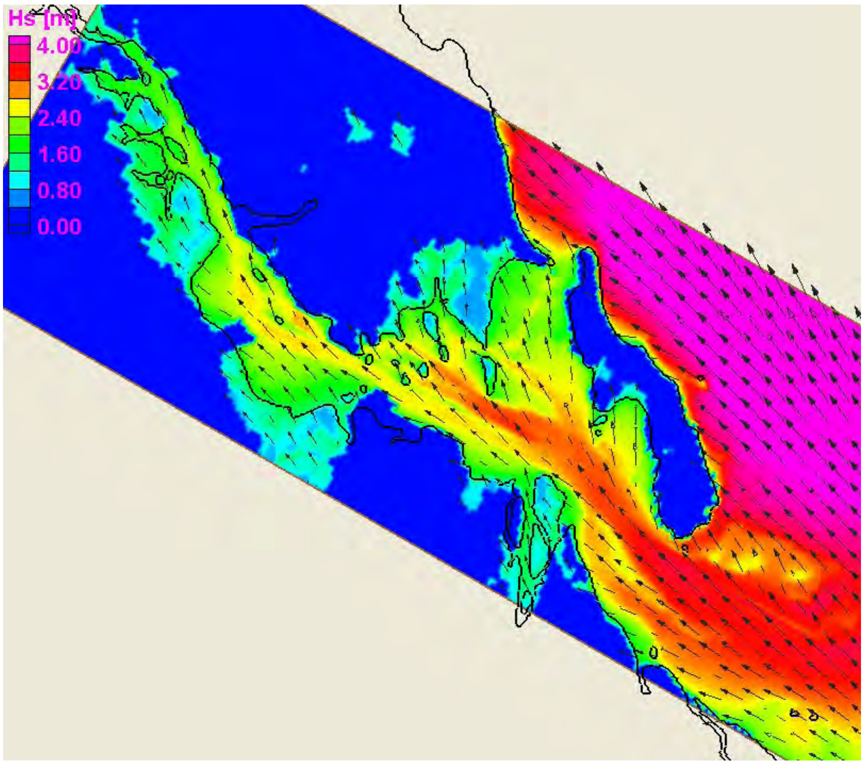


Figure G-5 Modelled Significant Wave Height for Extreme Wave Scenario 6 (Southeasterly Wind) - Base Case (Regional Model)

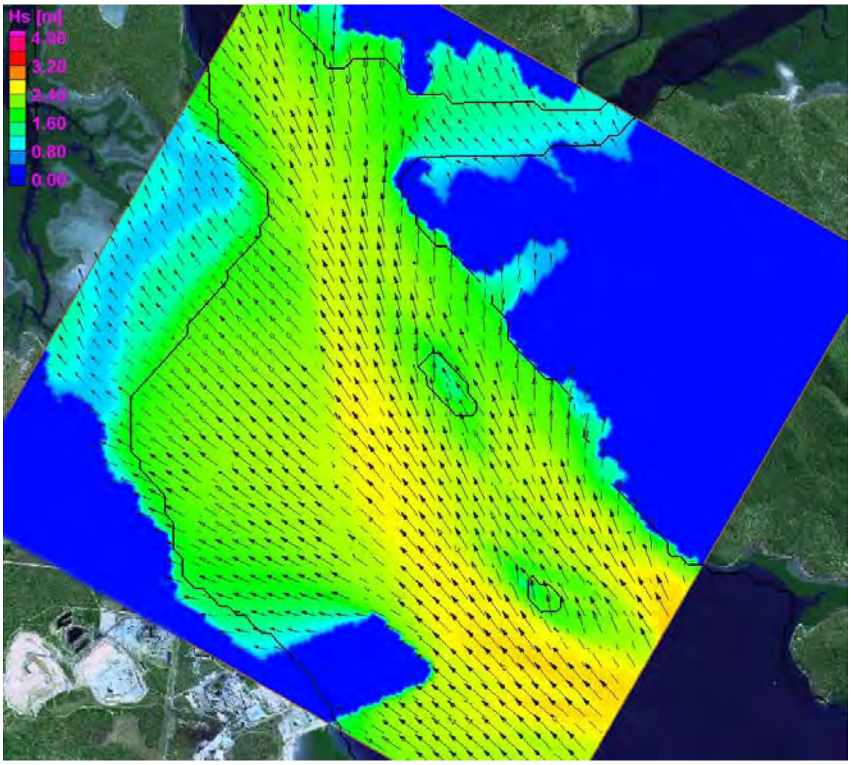


Figure G-6 Modelled Significant Wave Height for Extreme Wave Scenario 6 (Southeasterly Wind) - Base Case (Local Model)

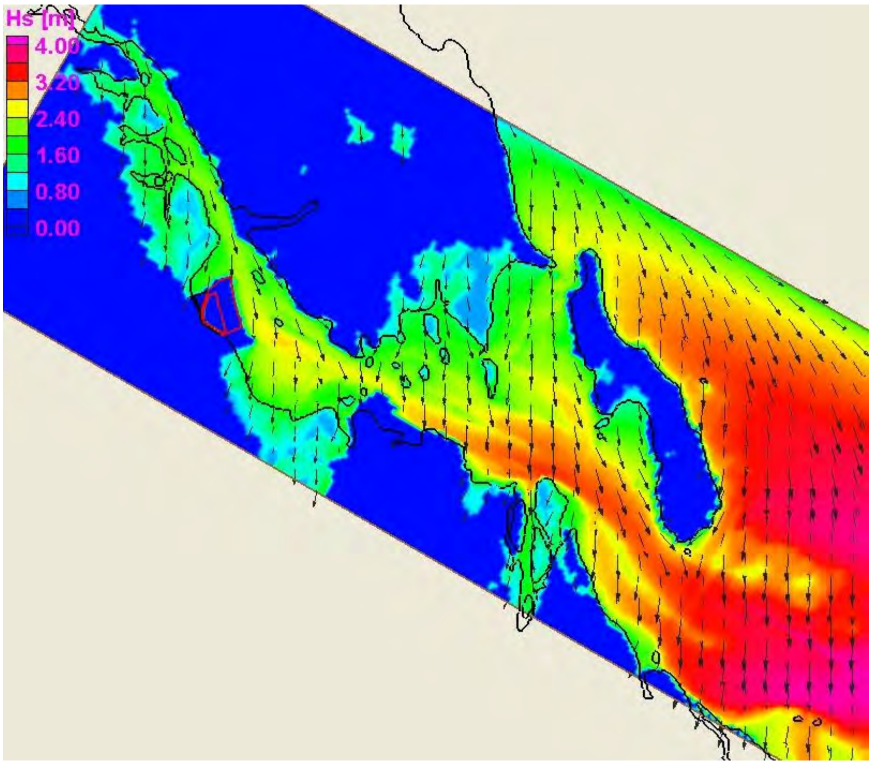


Figure G-7 Modelled Significant Wave Height for Extreme Wave Scenario 1 (Northerly Wind) – Development Scenario 3 (Regional Model)

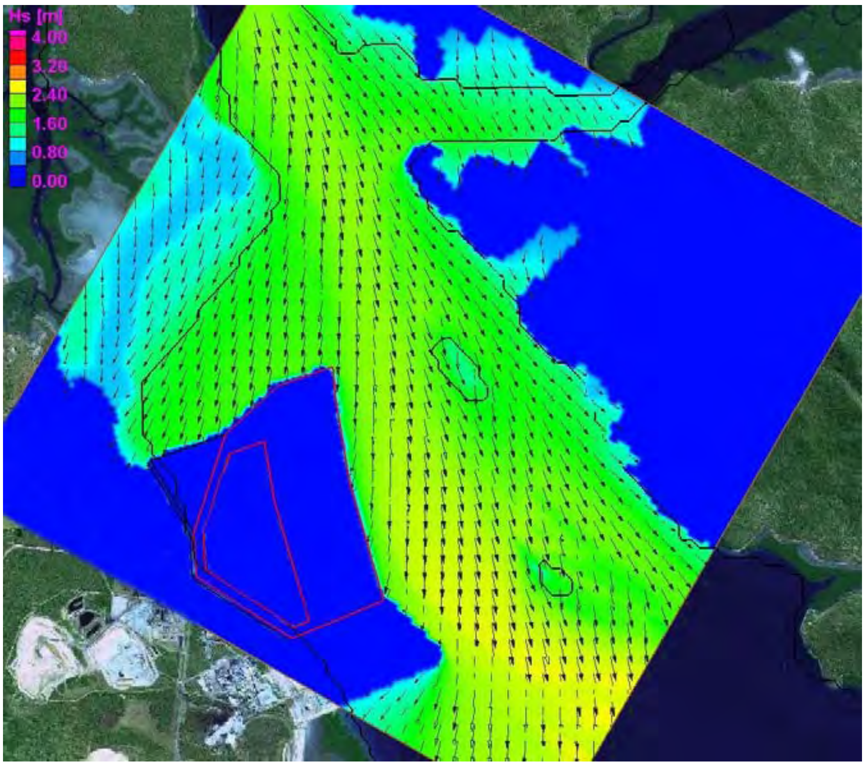


Figure G-8 Modelled Significant Wave Height for Extreme Wave Scenario 1 (Northerly Wind) - Development Scenario 3 (Local Model)

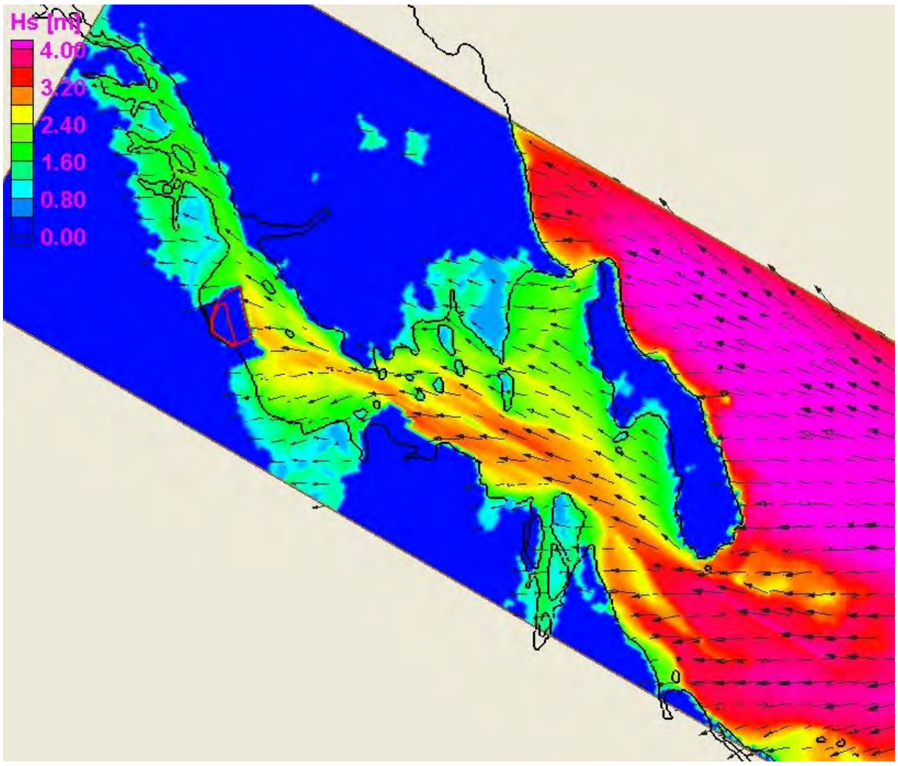


Figure G-9 Modelled Significant Wave Height for Extreme Wave Scenario 4 (Easterly Wind) - Development Scenario 3 (Regional Model)

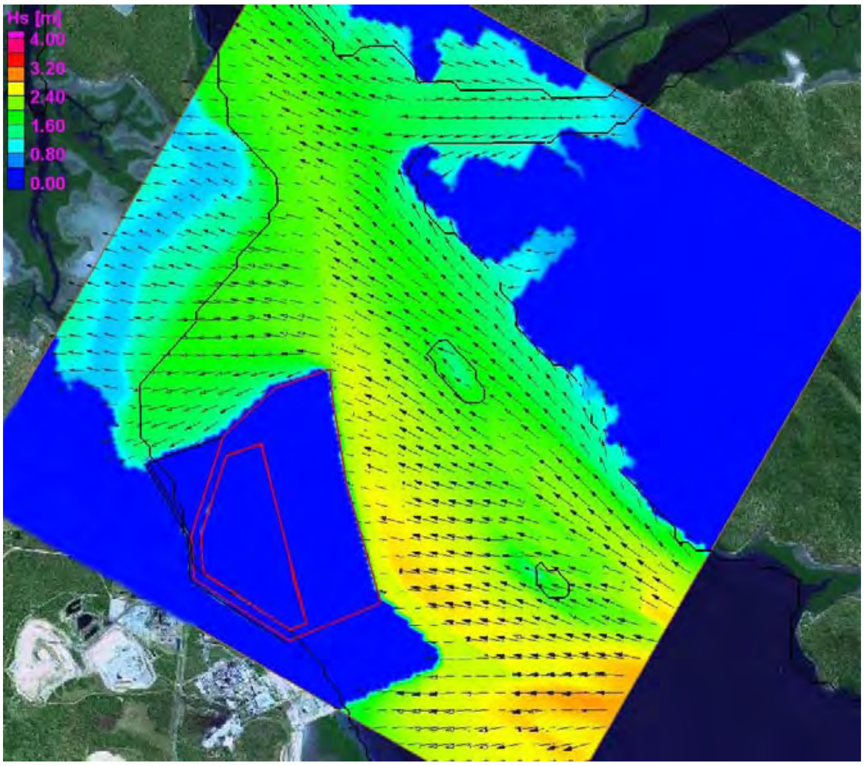


Figure G-10 Modelled Significant Wave Height for Extreme Wave Scenario 4 (Easterly Wind) - Development Scenario 3 (Local Model)

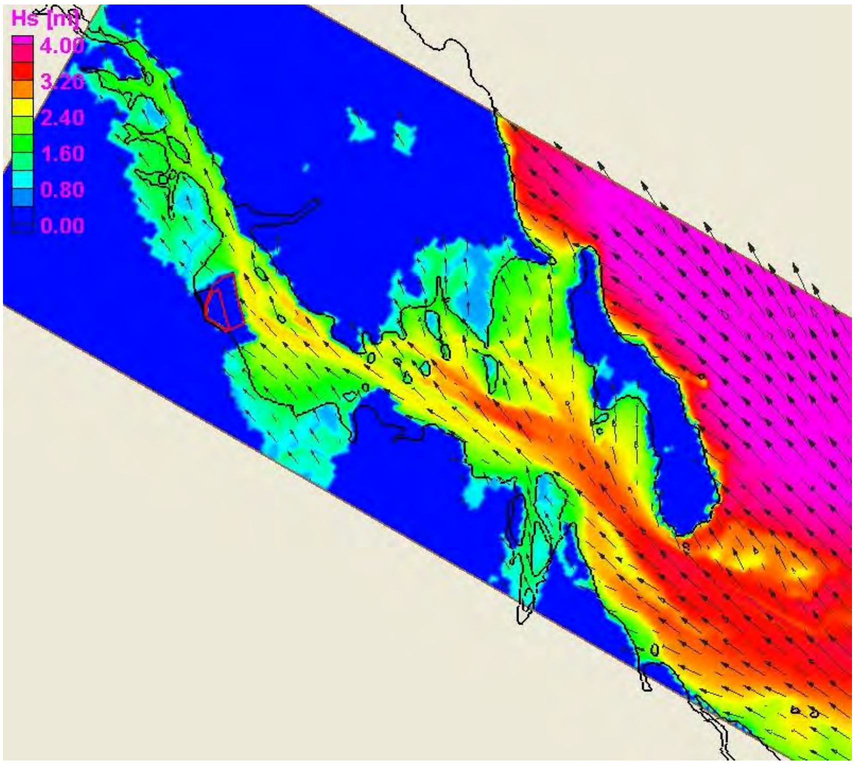


Figure G-11 Modelled Significant Wave Height for Extreme Wave Scenario 6 (Southeasterly Wind) - Development Scenario 3 (Regional Model)

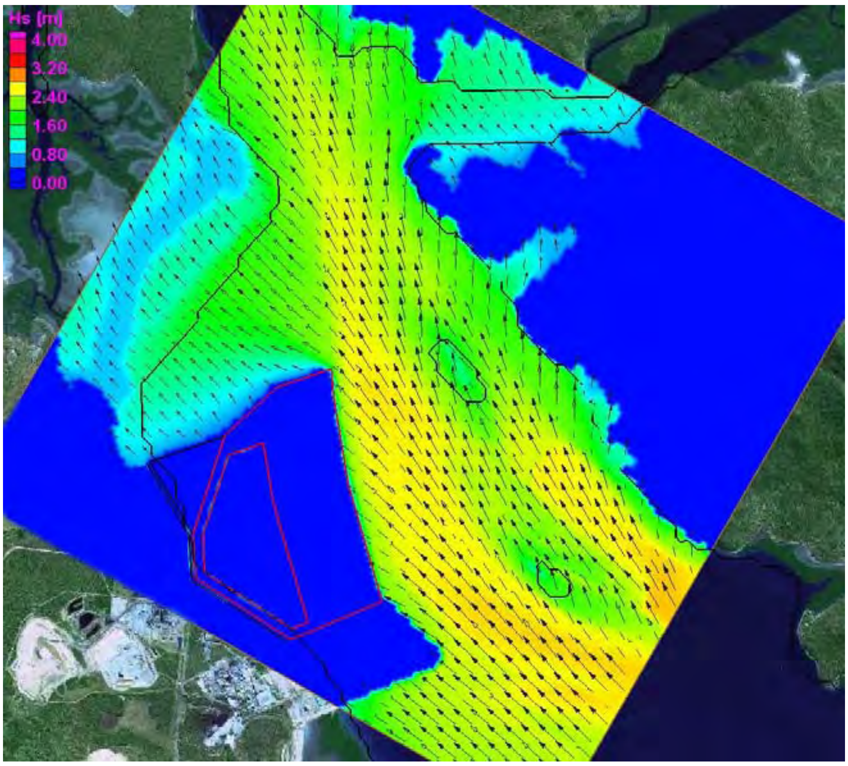


Figure G-12 Modelled Significant Wave Height for Extreme Wave Scenario 6 (Southeasterly Wind) - Development Scenario 3 (Local Model)

Table G-1 Waves during 100 year ARI Storm Conditions at Location 03

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53	1.90	4.8	356.2	1.97	4.8	355.9	1.97	4.8	355.9	1.97	4.8	355.9
2	34.5	30	3.53	1.75	3.9	22.3	1.78	3.9	22.4	1.78	3.9	22.4	1.78	3.9	22.4
3	34.5	60	3.53	1.64	3.8	62.3	1.64	3.8	62.6	1.64	3.8	62.5	1.64	3.8	62.6
4	34.5	90	3.53	1.89	4.2	109.1	1.87	4.2	109.9	1.87	4.2	110.1	1.91	4.2	110.0
5	34.5	120	3.53	2.12	4.9	131.5	2.13	4.9	131.4	2.13	4.9	131.5	2.15	4.9	131.9
6	34.5	150	3.53	2.12	5.0	148.5	2.13	5.0	147.0	2.13	5.0	147.1	2.15	5.0	147.3
7	34.5	180	3.53	2.05	4.8	167.3	2.06	4.9	165.1	2.05	4.8	165.3	2.07	4.9	165.1
8	34.5	210	3.53	1.97	4.5	189.7	1.96	4.3	189.8	1.95	4.2	190.2	1.96	4.3	189.8
9	34.5	240	3.53	1.77	4.1	220.2	1.74	4.0	223.7	1.74	4.0	223.7	1.74	4.0	223.7
10	34.5	270	3.53	1.73	3.8	272.3	1.74	3.9	272.5	1.74	3.9	272.5	1.74	3.9	272.5
11	34.5	300	3.53	1.83	4.4	316.3	1.89	4.5	319.7	1.89	4.5	319.7	1.89	4.5	319.7
12	34.5	330	3.53	1.85	4.8	336.2	1.92	4.8	338.5	1.92	4.8	338.5	1.95	4.8	339.2

Table G-2 Waves during 50 year ARI Storm Conditions at Location 03

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33	1.70	4.4	355.3	1.74	4.4	355.2	1.74	4.4	355.2	1.74	4.4	355.2
14	31.3	30	3.33	1.56	3.8	21.0	1.58	3.8	21.1	1.58	3.8	21.1	1.58	3.8	21.1
15	31.3	60	3.33	1.44	3.6	62.6	1.45	3.7	62.8	1.44	3.6	62.7	1.45	3.6	62.8
16	31.3	90	3.33	1.67	3.9	109.9	1.68	3.9	110.1	1.68	3.9	110.3	1.69	3.9	110.8
17	31.3	120	3.33	1.89	4.6	132.5	1.89	4.6	132.3	1.89	4.6	132.5	1.90	4.6	132.9
18	31.3	150	3.33	1.88	4.8	148.6	1.90	4.8	147.4	1.90	4.8	147.4	1.91	4.8	147.6
19	31.3	180	3.33	1.83	4.6	166.3	1.82	4.7	164.7	1.82	4.7	164.8	1.83	4.7	164.8
20	31.3	210	3.33	1.73	4.2	189.3	1.73	4.1	188.8	1.73	4.1	189.1	1.74	4.1	188.8
21	31.3	240	3.33	1.53	3.9	220.7	1.51	3.8	223.9	1.50	3.8	224.0	1.51	3.8	224.0
22	31.3	270	3.33	1.52	3.7	272.8	1.52	3.7	272.9	1.52	3.7	272.9	1.52	3.7	272.9
23	31.3	300	3.33	1.63	4.4	318.3	1.67	4.4	320.8	1.66	4.4	320.0	1.67	4.4	320.8
24	31.3	330	3.33	1.67	4.5	337.6	1.71	4.5	339.0	1.71	4.5	339.0	1.71	4.5	339.0

Table G-3 Waves during 100 year ARI Storm Conditions at Location 04

					BASE CASE				Development Scenario 1				Development Scenario 2				Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [degrees]		Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53		1.75	4.8	9.5		1.81	4.8	10.0		1.81	4.8	10.0		1.81	4.8	10.0
2	34.5	30	3.53		1.68	4.1	35.5		1.68	4.1	32.8		1.68	4.1	32.8		1.68	4.1	32.9
3	34.5	60	3.53		1.83	4.2	75.6		1.55	4.0	54.1		1.55	4.0	54.1		1.55	4.0	54.2
4	34.5	90	3.53		2.03	4.9	103.3		1.41	4.0	75.6		1.41	4.0	75.6		1.44	4.0	75.9
5	34.5	120	3.53		2.10	5.3	118.6		1.25	3.7	90.8		1.25	3.7	90.8		1.26	3.7	90.9
6	34.5	150	3.53		2.06	5.3	135.2		0.92	2.5	122.2		0.92	2.5	122.3		0.92	2.5	122.1
7	34.5	180	3.53		1.87	4.8	156.9		0.88	2.7	205.2		0.88	2.7	205.2		0.88	2.7	205.1
8	34.5	210	3.53		1.63	3.9	190.9		1.15	3.2	230.7		1.15	3.2	230.7		1.15	3.2	230.7
9	34.5	240	3.53		1.46	3.5	236.6		1.32	3.4	251.3		1.32	3.4	251.3		1.32	3.4	251.3
10	34.5	270	3.53		1.48	3.7	272.3		1.48	3.7	274.3		1.49	3.7	274.3		1.49	3.7	274.3
11	34.5	300	3.53		1.62	3.8	308.3		1.66	3.9	307.6		1.66	3.9	307.6		1.66	3.9	307.7
12	34.5	330	3.53		1.73	4.0	343.0		1.79	4.1	344.5		1.78	4.1	344.5		1.80	4.1	345.0

Table G-4 Waves during 50 year ARI Storm Conditions at Location 04

					BASE CASE				Development Scenario 1				Development Scenario 2				Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [degrees]		Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33		1.59	4.6	9.7		1.63	4.6	10.1		1.63	4.6	10.1		1.63	4.6	10.2
14	31.3	30	3.33		1.51	3.9	34.3		1.51	3.9	31.8		1.51	3.9	31.8		1.51	3.9	31.8
15	31.3	60	3.33		1.63	4.0	75.3		1.40	3.8	53.4		1.38	3.7	53.2		1.40	3.8	53.5
16	31.3	90	3.33		1.85	4.8	103.9		1.28	3.7	75.4		1.28	3.7	75.4		1.28	3.7	75.5
17	31.3	120	3.33		1.94	5.0	118.6		1.11	3.4	90.4		1.11	3.4	90.4		1.11	3.4	90.4
18	31.3	150	3.33		1.89	5.0	134.8		0.80	2.3	121.2		0.80	2.3	121.3		0.81	2.3	121.1
19	31.3	180	3.33		1.69	4.8	155.9		0.77	2.6	205.9		0.77	2.6	205.9		0.77	2.6	205.9
20	31.3	210	3.33		1.44	3.7	190.0		1.04	3.1	230.4		1.04	3.1	230.4		1.04	3.1	230.4
21	31.3	240	3.33		1.28	3.4	236.7		1.16	3.3	251.2		1.16	3.3	251.2		1.16	3.3	251.2
22	31.3	270	3.33		1.32	3.4	273.0		1.31	3.4	274.9		1.31	3.4	274.9		1.31	3.4	274.9
23	31.3	300	3.33		1.45	3.7	309.5		1.49	3.7	309.8		1.48	3.7	309.6		1.49	3.7	309.8
24	31.3	330	3.33		1.57	3.9	344.8		1.61	4.0	345.9		1.61	4.0	345.9		1.61	4.0	345.9

Table G-5 Waves during 100 year ARI Storm Conditions at Location 06

					BASE CASE				Development Scenario 1				Development Scenario 2				Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [degrees]		Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53		1.66	4.5	336.2		1.74	4.5	335.9		1.74	4.5	335.9		1.74	4.5	335.9
2	34.5	30	3.53		1.38	3.5	6.4		1.41	3.6	6.2		1.41	3.6	5.7		1.41	3.6	5.7
3	34.5	60	3.53		1.22	3.1	69.5		1.23	3.1	69.8		1.23	3.1	69.7		1.23	3.1	69.6
4	34.5	90	3.53		1.51	4.1	122.8		1.50	4.1	123.3		1.51	4.1	123.4		1.53	4.1	123.1
5	34.5	120	3.53		1.78	4.5	143.1		1.78	4.5	142.9		1.79	4.5	143.0		1.79	4.5	142.9
6	34.5	150	3.53		1.87	4.8	156.3		1.89	4.8	154.9		1.90	4.8	155.0		1.90	4.8	154.8
7	34.5	180	3.53		1.90	4.8	175.9		1.89	4.8	169.4		1.90	4.8	169.5		1.90	4.8	169.3
8	34.5	210	3.53		1.85	4.2	203.4		1.87	4.6	193.7		1.87	4.6	193.7		1.87	4.6	193.7
9	34.5	240	3.53		1.80	4.1	243.3		1.79	4.1	244.3		1.80	4.1	244.2		1.80	4.1	244.2
10	34.5	270	3.53		1.91	4.3	278.7		1.91	4.3	283.5		1.90	4.3	283.4		1.90	4.3	283.4
11	34.5	300	3.53		1.96	4.4	298.5		2.00	4.5	301.3		2.00	4.5	301.1		2.00	4.5	301.0
12	34.5	330	3.53		1.81	4.2	314.2		1.88	4.5	315.5		1.87	4.4	315.4		1.89	4.5	315.8

Table G-6 Waves during 50 year ARI Storm Conditions at Location 06

					BASE CASE				Development Scenario 1				Development Scenario 2				Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [deg]		Hs [m]	Tp [s]	Dir [degrees]		Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33		1.50	4.3	335.1		1.55	4.3	335.0		1.55	4.3	334.9		1.55	4.3	334.9
14	31.3	30	3.33		1.24	3.3	4.9		1.26	3.3	4.6		1.27	3.4	4.1		1.27	3.4	4.1
15	31.3	60	3.33		1.07	3.0	71.1		1.08	3.0	71.1		1.07	3.0	71.4		1.09	3.0	70.8
16	31.3	90	3.33		1.34	4.0	124.5		1.35	4.0	124.6		1.36	4.0	124.7		1.36	4.0	124.7
17	31.3	120	3.33		1.59	4.4	143.8		1.59	4.4	143.6		1.60	4.4	143.7		1.60	4.4	143.5
18	31.3	150	3.33		1.68	4.6	156.6		1.70	4.6	154.9		1.70	4.6	155.0		1.70	4.6	154.8
19	31.3	180	3.33		1.70	4.6	174.3		1.69	4.7	168.9		1.69	4.7	169.0		1.70	4.7	168.8
20	31.3	210	3.33		1.64	4.1	202.4		1.66	4.4	192.6		1.66	4.4	192.6		1.67	4.4	192.6
21	31.3	240	3.33		1.59	4.0	242.7		1.59	3.9	243.6		1.59	3.9	243.5		1.59	3.9	243.5
22	31.3	270	3.33		1.70	4.2	278.5		1.68	4.1	283.4		1.68	4.1	283.4		1.68	4.1	283.4
23	31.3	300	3.33		1.76	4.2	299.7		1.78	4.3	301.8		1.77	4.3	301.4		1.78	4.3	301.6
24	31.3	330	3.33		1.64	4.3	314.8		1.68	4.3	315.7		1.67	4.3	315.6		1.67	4.3	315.6

Table G-7 Waves during 100 year ARI Storm Conditions at Location 07

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53	2.21	4.8	351.6	2.30	4.9	354.0	2.30	4.9	353.7	2.32	4.9	352.8
2	34.5	30	3.53	2.01	4.4	22.9	2.03	4.4	21.7	2.04	4.4	21.6	2.05	4.4	21.0
3	34.5	60	3.53	2.28	4.8	80.3	2.28	4.8	79.7	2.28	4.8	79.4	2.29	4.8	79.4
4	34.5	90	3.53	2.40	5.3	102.3	2.39	5.3	101.8	2.40	5.3	101.4	2.43	5.3	101.0
5	34.5	120	3.53	2.50	5.1	119.4	2.51	5.1	118.7	2.52	5.1	118.3	2.53	5.1	118.2
6	34.5	150	3.53	2.47	5.0	139.4	2.51	5.0	138.6	2.52	5.0	138.3	2.53	5.0	138.1
7	34.5	180	3.53	2.25	4.9	163.5	2.30	4.9	164.0	2.31	4.9	163.8	2.31	4.9	163.8
8	34.5	210	3.53	2.01	4.6	192.0	2.10	4.8	188.6	2.11	4.8	188.4	2.11	4.8	188.4
9	34.5	240	3.53	1.86	4.2	233.0	1.71	4.3	214.0	1.71	4.3	214.0	1.71	4.3	214.0
10	34.5	270	3.53	1.99	4.4	288.4	1.69	3.8	288.2	1.69	3.8	287.9	1.70	3.8	288.4
11	34.5	300	3.53	2.20	4.8	315.7	2.09	4.8	326.9	2.08	4.8	326.6	2.12	4.9	326.5
12	34.5	330	3.53	2.25	4.9	332.5	2.25	4.9	341.2	2.25	4.9	341.0	2.31	4.9	339.9

Table G-8 Waves during 50 year ARI Storm Conditions at Location 07

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33	2.00	4.8	351.1	2.06	4.8	353.4	2.06	4.8	353.3	2.07	4.8	352.5
14	31.3	30	3.33	1.80	4.3	19.7	1.83	4.3	19.1	1.83	4.3	19.0	1.84	4.3	18.5
15	31.3	60	3.33	2.02	4.6	81.0	2.04	4.6	80.6	2.02	4.6	80.3	2.05	4.7	80.3
16	31.3	90	3.33	2.17	5.0	102.0	2.18	5.0	101.3	2.18	5.0	100.9	2.18	5.0	100.8
17	31.3	120	3.33	2.24	4.9	118.0	2.25	4.9	117.5	2.25	4.9	117.1	2.26	4.9	117.0
18	31.3	150	3.33	2.18	4.8	138.8	2.22	4.8	138.2	2.23	4.9	137.8	2.23	4.9	137.7
19	31.3	180	3.33	1.99	4.6	163.9	2.02	4.6	163.7	2.02	4.6	163.7	2.02	4.6	163.6
20	31.3	210	3.33	1.77	4.4	191.2	1.86	4.5	187.7	1.86	4.5	187.5	1.86	4.5	187.5
21	31.3	240	3.33	1.63	4.0	232.5	1.50	4.1	213.1	1.50	4.1	213.1	1.50	4.1	213.1
22	31.3	270	3.33	1.77	4.1	289.7	1.49	3.7	290.7	1.49	3.7	290.6	1.49	3.7	290.9
23	31.3	300	3.33	1.98	4.6	316.4	1.86	4.7	327.8	1.83	4.7	327.6	1.87	4.7	327.4
24	31.3	330	3.33	2.03	4.8	333.0	2.00	4.8	341.8	2.00	4.8	341.6	2.02	4.8	341.0

Table G-9 Waves during 100 year ARI Storm Conditions at Location 16

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53	1.69	4.8	9.9	1.74	4.8	10.8	1.74	4.8	10.8	1.74	4.8	10.8
2	34.5	30	3.53	1.60	4.0	31.3	1.62	4.0	31.3	1.62	4.0	31.3	1.62	4.0	31.3
3	34.5	60	3.53	1.61	3.8	69.1	1.62	3.8	69.4	1.62	3.8	69.5	1.62	3.8	69.9
4	34.5	90	3.53	1.82	4.5	104.5	1.81	4.6	104.6	1.81	4.7	104.7	1.84	4.8	104.7
5	34.5	120	3.53	1.92	5.0	121.3	1.92	5.0	120.2	1.92	5.0	120.0	1.93	5.0	120.2
6	34.5	150	3.53	1.92	5.3	137.9	1.91	5.3	133.6	1.91	5.3	133.4	1.92	5.3	133.4
7	34.5	180	3.53	1.85	4.7	161.8	1.78	5.0	155.5	1.78	5.0	155.7	1.79	5.0	155.4
8	34.5	210	3.53	1.76	4.5	189.8	1.68	4.0	192.2	1.67	4.0	192.7	1.68	4.0	192.5
9	34.5	240	3.53	1.60	4.0	228.9	1.51	3.9	237.5	1.51	3.9	237.6	1.51	3.9	237.7
10	34.5	270	3.53	1.55	3.9	265.7	1.56	3.9	266.4	1.56	3.9	266.4	1.56	3.9	266.4
11	34.5	300	3.53	1.65	4.0	308.0	1.69	4.1	309.4	1.69	4.1	309.5	1.69	4.1	309.5
12	34.5	330	3.53	1.68	4.0	343.5	1.72	4.8	346.2	1.73	4.8	346.3	1.74	4.8	347.1

Table G-10 Waves during 50 year ARI Storm Conditions at Location 16

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33	1.53	4.5	9.6	1.57	4.5	10.2	1.57	4.5	10.3	1.57	4.5	10.3
14	31.3	30	3.33	1.44	3.8	30.4	1.46	3.8	30.4	1.46	3.8	30.4	1.46	3.8	30.4
15	31.3	60	3.33	1.43	3.7	68.9	1.44	3.7	68.9	1.43	3.7	69.3	1.45	3.7	69.3
16	31.3	90	3.33	1.64	4.4	105.2	1.65	4.4	105.1	1.65	4.5	105.2	1.66	4.5	105.4
17	31.3	120	3.33	1.76	4.9	122.3	1.76	4.9	121.0	1.76	4.9	120.9	1.77	4.9	121.0
18	31.3	150	3.33	1.75	4.9	138.6	1.74	4.9	133.9	1.74	4.9	133.7	1.75	4.9	133.7
19	31.3	180	3.33	1.68	4.6	160.7	1.60	4.8	155.2	1.60	4.8	155.3	1.61	4.9	155.0
20	31.3	210	3.33	1.56	4.1	189.2	1.51	3.8	190.8	1.51	3.8	191.3	1.51	3.8	191.2
21	31.3	240	3.33	1.41	3.8	229.4	1.34	3.7	237.4	1.33	3.7	237.5	1.33	3.7	237.5
22	31.3	270	3.33	1.38	3.7	266.1	1.38	3.7	266.8	1.38	3.7	266.8	1.38	3.7	266.8
23	31.3	300	3.33	1.49	3.8	309.7	1.52	3.8	311.2	1.51	3.8	310.7	1.52	3.8	311.3
24	31.3	330	3.33	1.53	4.5	345.2	1.56	4.5	346.9	1.56	4.5	347.0	1.56	4.5	347.0

Table G-11 Waves during 100 year ARI Storm Conditions at Location 21

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53	1.88	4.2	3.4	1.63	4.8	17.9	1.63	4.7	17.9	1.63	4.5	18.6
2	34.5	30	3.53	1.80	4.1	30.6	1.69	4.1	37.6	1.69	4.1	37.6	1.69	4.1	38.2
3	34.5	60	3.53	1.98	4.2	75.6	1.93	4.2	77.2	1.91	4.2	76.0	1.92	4.2	76.7
4	34.5	90	3.53	2.25	5.1	103.2	2.19	5.1	102.8	2.14	5.0	101.6	2.18	5.0	101.6
5	34.5	120	3.53	2.39	5.3	118.2	2.31	5.3	116.3	2.26	5.2	115.6	2.27	5.2	115.4
6	34.5	150	3.53	2.28	5.3	132.0	2.15	5.3	126.1	2.11	5.3	126.1	2.11	5.3	125.8
7	34.5	180	3.53	1.95	4.9	155.2	1.71	5.0	137.6	1.69	5.0	138.0	1.67	5.0	138.0
8	34.5	210	3.53	1.73	3.8	194.2	1.30	4.8	151.5	1.31	4.8	151.2	1.28	4.6	151.7
9	34.5	240	3.53	1.61	3.8	241.4	0.65	3.0	186.3	0.65	3.0	185.9	0.64	3.0	186.7
10	34.5	270	3.53	1.76	4.0	276.8	0.55	2.0	308.4	0.55	2.0	308.4	0.55	2.0	308.6
11	34.5	300	3.53	1.91	4.2	311.3	1.06	4.8	351.8	1.06	4.8	352.1	1.06	4.8	352.5
12	34.5	330	3.53	1.93	4.3	337.5	1.39	4.8	5.5	1.39	4.8	5.6	1.41	4.7	6.3

Table G-12 Waves during 50 year ARI Storm Conditions at Location 21

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33	1.69	4.2	2.8	1.44	4.4	17.3	1.44	4.4	17.2	1.44	4.4	17.8
14	31.3	30	3.33	1.59	3.9	29.3	1.48	3.8	36.7	1.48	3.8	36.7	1.49	3.8	37.2
15	31.3	60	3.33	1.74	3.9	76.2	1.72	4.0	77.6	1.68	3.9	76.8	1.71	4.0	76.9
16	31.3	90	3.33	2.01	4.9	104.1	1.97	4.9	103.5	1.93	4.8	102.2	1.94	4.8	102.4
17	31.3	120	3.33	2.14	5.1	118.1	2.07	5.0	116.4	2.02	5.0	115.8	2.03	5.0	115.5
18	31.3	150	3.33	2.02	5.0	131.8	1.91	5.0	126.2	1.87	4.9	126.3	1.87	4.9	125.8
19	31.3	180	3.33	1.76	4.9	154.8	1.53	4.9	137.5	1.51	4.9	137.8	1.50	4.9	137.7
20	31.3	210	3.33	1.52	3.6	193.0	1.19	4.5	150.9	1.19	4.5	150.6	1.17	4.5	151.0
21	31.3	240	3.33	1.40	3.5	241.6	0.57	2.8	185.0	0.57	2.8	184.8	0.56	2.8	185.3
22	31.3	270	3.33	1.55	3.8	277.2	0.48	1.9	309.3	0.48	1.9	309.3	0.48	1.9	309.4
23	31.3	300	3.33	1.71	4.1	312.6	0.93	4.5	351.8	0.92	4.5	352.0	0.93	4.4	352.4
24	31.3	330	3.33	1.74	4.1	338.6	1.23	4.6	5.3	1.23	4.6	5.3	1.22	4.5	5.8

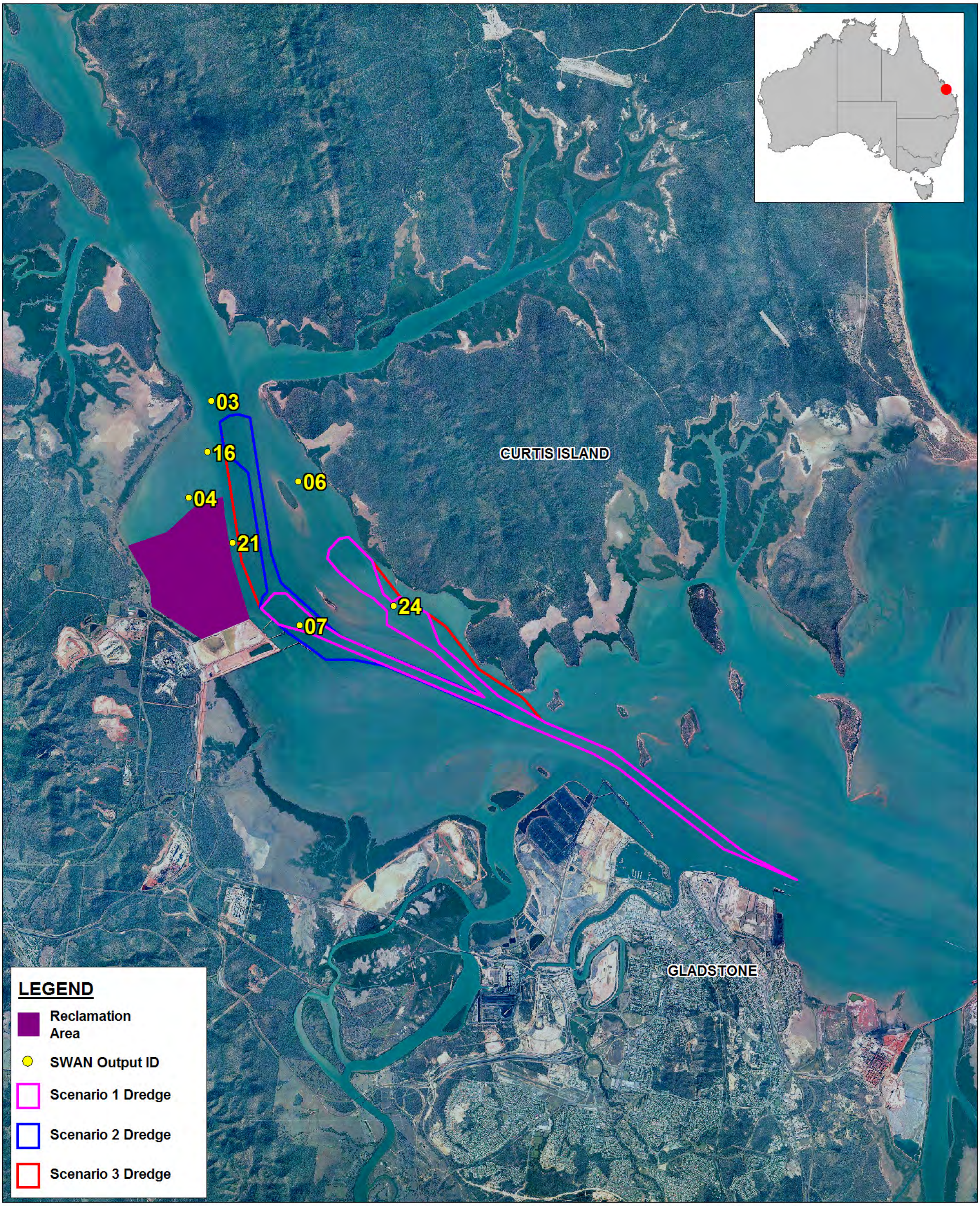
Table G-13 Waves during 100 year ARI Storm Conditions at Location 24

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
1	34.5	0	3.53	1.70	4.5	328.3	1.82	4.6	327.7	1.82	4.6	327.5	1.86	4.7	327.6
2	34.5	30	3.53	1.40	3.4	12.9	1.44	3.4	11.0	1.44	3.4	11.0	1.45	3.4	10.0
3	34.5	60	3.53	1.69	3.8	96.6	1.71	3.8	97.3	1.72	3.8	98.2	1.72	3.8	97.8
4	34.5	90	3.53	2.20	5.0	122.0	2.27	5.1	124.8	2.28	5.1	125.4	2.30	5.2	124.8
5	34.5	120	3.53	2.38	5.3	135.3	2.47	5.3	138.0	2.49	5.3	138.6	2.51	5.3	137.9
6	34.5	150	3.53	2.47	5.2	150.2	2.56	5.3	152.3	2.58	5.3	152.7	2.58	5.3	152.0
7	34.5	180	3.53	2.38	4.9	173.6	2.46	5.0	174.3	2.46	5.0	174.4	2.46	5.0	174.3
8	34.5	210	3.53	2.22	4.8	203.2	2.27	4.8	202.2	2.26	4.8	202.4	2.26	4.8	202.4
9	34.5	240	3.53	2.20	4.6	234.7	2.17	4.6	229.7	2.17	4.6	229.7	2.17	4.6	229.8
10	34.5	270	3.53	2.22	4.6	272.3	2.16	4.5	269.9	2.16	4.5	269.9	2.18	4.5	271.0
11	34.5	300	3.53	2.13	4.8	295.0	2.18	4.8	299.6	2.19	4.8	299.5	2.24	4.9	301.0
12	34.5	330	3.53	1.93	4.6	309.9	1.99	4.9	313.7	1.99	4.9	313.6	2.08	4.9	314.6

Table G-14 Waves during 50 year ARI Storm Conditions at Location 24

				BASE CASE			Development Scenario 1			Development Scenario 2			Development Scenario 3		
Extreme Wave Scenario	Wind_Speed	Wind_direction	Water Level [mAHD]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [deg]	Hs [m]	Tp [s]	Dir [degrees]	Hs [m]	Tp [s]	Dir [deg]
13	31.3	0	3.33	1.55	4.4	326.9	1.63	4.5	326.4	1.63	4.5	326.3	1.66	4.5	326.4
14	31.3	30	3.33	1.26	3.2	10.7	1.29	3.2	8.7	1.29	3.2	8.6	1.30	3.2	7.8
15	31.3	60	3.33	1.47	3.7	96.4	1.49	3.7	96.8	1.49	3.7	98.3	1.50	3.7	97.4
16	31.3	90	3.33	1.94	4.8	122.8	1.99	4.9	124.9	2.00	4.9	125.6	2.01	4.9	125.2
17	31.3	120	3.33	2.14	4.9	135.5	2.21	5.0	137.9	2.24	5.0	138.6	2.25	5.0	138.0
18	31.3	150	3.33	2.18	4.9	150.6	2.26	4.9	152.2	2.28	4.9	152.7	2.28	4.9	152.1
19	31.3	180	3.33	2.12	4.8	174.0	2.16	4.8	174.5	2.16	4.8	174.6	2.16	4.8	174.6
20	31.3	210	3.33	1.98	4.6	202.8	2.02	4.7	202.2	2.02	4.6	202.4	2.02	4.6	202.3
21	31.3	240	3.33	1.95	4.4	234.0	1.91	4.4	229.5	1.91	4.4	229.5	1.91	4.4	229.6
22	31.3	270	3.33	1.98	4.4	271.8	1.91	4.3	270.9	1.91	4.3	270.9	1.92	4.3	271.9
23	31.3	300	3.33	1.92	4.5	295.4	1.94	4.6	299.5	1.92	4.6	299.2	1.98	4.7	300.9
24	31.3	330	3.33	1.74	4.5	310.5	1.79	4.7	313.5	1.79	4.7	313.4	1.83	4.8	314.2

APPENDIX H: LOCAL WAVE CLIMATE THROUGHOUT PROJECT AREA



Title:

SWAN Wave Model Output Locations

Figure: **H-1**

Rev: **A**

BMT WBM
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Filepath : \\wbmfs2\drafting\B17382_I_clw_Glad Strategic\DRG\COA_012_090810_SWAN_Output_Locations.wor

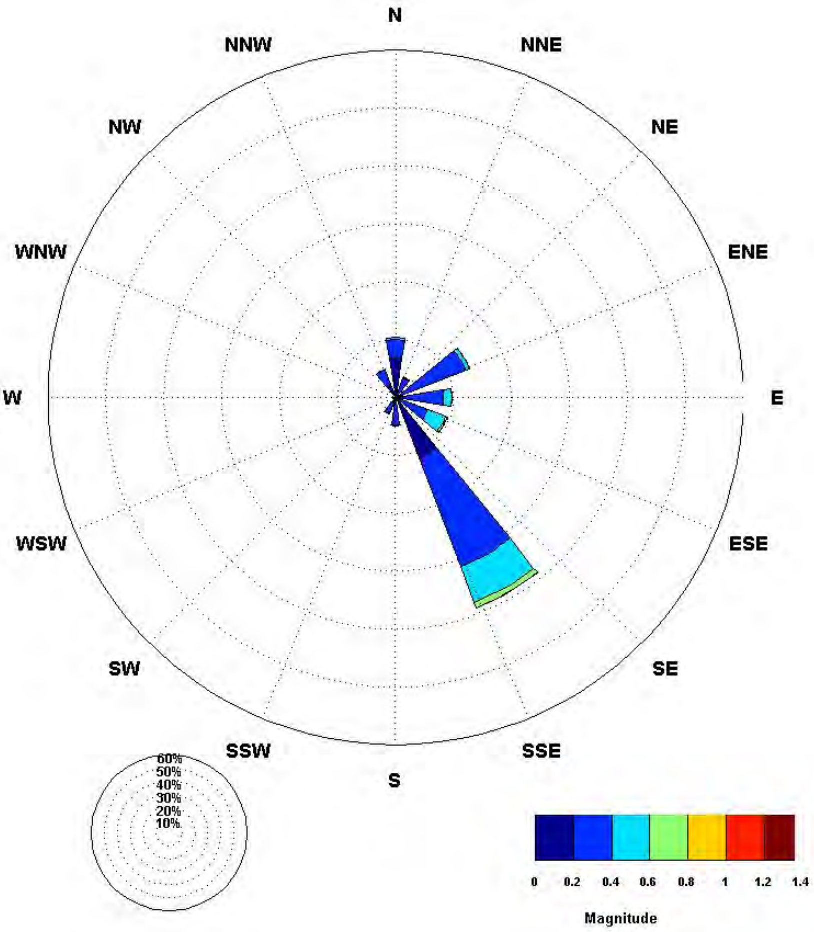

Figure H-2 Wave Recurrence Frequency Rose for Location 03 (Base Case)

Table H-1 Wave Climate at Location 03 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	3.1%	3.6%	13.0%	8.3%	5.9%	20.1%	4.1%	2.0%	0.3%	0.1%	0.1%	2.7%	**63.3%**
0.3 - 0.5	0.4%	0.2%	0.7%	1.4%	3.3%	6.6%	0.1%	0.1%		0.0%	0.0%	0.1%	**12.8%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.3%	1.0%	0.0%	0.0%		0.0%		0.0%	**1.3%**
0.7 - 0.9	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%							**0.1%**
0.9 - 1.1	0.0%			0.0%	0.0%	0.0%						0.0%	**0.0%**
1.1 - 1.3					0.0%	0.0%							**0.0%**
1.3 - 1.5						0.0%							**0.0%**
> 1.5						0.0%							**0.0%**
Total	**3.5%**	**3.8%**	**13.7%**	**9.7%**	**9.5%**	**27.7%**	**4.3%**	**2.1%**	**0.3%**	**0.1%**	**0.1%**	**2.8%**	**77.5%**

Calms (Hs < 0.1m): 22.5%

Table H-2 Wave Climate at Location 03 – Development Scenario 1

Wave height and Direction Recurrence frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	0	30	60	90	120	150	180	210	240	270	300	330	Total
0.1 - 0.3	3.1%	3.6%	13.0%	8.3%	5.9%	20.1%	3.4%	3.7%	0.3%	0.1%	0.1%	2.7%	64.3%
0.3 - 0.5	0.4%	0.2%	0.7%	2.7%	2.0%	6.6%	0.1%	0.1%		0.0%	0.0%	0.1%	12.8%
0.5 - 0.7	0.0%	0.0%	0.0%	0.1%	0.2%	1.0%	0.0%	0.0%		0.0%		0.0%	1.3%
0.7 - 0.9	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%							0.1%
0.9 - 1.1	0.0%			0.0%	0.0%	0.0%						0.0%	0.0%
1.1 - 1.3					0.0%	0.0%							0.0%
1.3 - 1.5						0.0%							0.0%
> 1.5						0.0%							0.0%
Total	3.5%	3.8%	13.7%	11.1%	8.2%	27.7%	3.5%	3.8%	0.3%	0.1%	0.1%	2.8%	78.5%

Calms (Hs < 0.1m): 21.5%

Table H-3 Wave Climate at Location 03 – Development Scenario 2

Wave height and Direction Recurrence frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	0	30	60	90	120	150	180	210	240	270	300	330	Total
0.1 - 0.3	3.1%	3.6%	13.0%	8.3%	5.0%	21.0%	3.4%	3.7%	0.3%	0.1%	0.1%	2.7%	64.3%
0.3 - 0.5	0.4%	0.2%	0.7%	2.7%	2.0%	6.6%	0.1%	0.1%		0.0%	0.0%	0.1%	12.8%
0.5 - 0.7	0.0%	0.0%	0.0%	0.1%	0.2%	1.0%	0.0%	0.0%		0.0%		0.0%	1.3%
0.7 - 0.9	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%							0.1%
0.9 - 1.1	0.0%			0.0%	0.0%	0.0%						0.0%	0.0%
1.1 - 1.3					0.0%	0.0%							0.0%
1.3 - 1.5						0.0%							0.0%
> 1.5						0.0%							0.0%
Total	3.5%	3.8%	13.7%	11.1%	7.2%	28.7%	3.5%	3.8%	0.3%	0.1%	0.1%	2.8%	78.5%

Calms (Hs < 0.1m): 21.5%

Table H-4 Wave Climate at Location 03 – Development Scenario 3

Wave height and Direction Recurrence frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	0	30	60	90	120	150	180	210	240	270	300	330	Total
0.1 - 0.3	3.1%	3.6%	13.0%	8.3%	5.0%	21.0%	3.4%	3.7%	0.3%	0.1%	0.1%	2.7%	64.3%
0.3 - 0.5	0.4%	0.2%	0.7%	2.7%	2.0%	6.6%	0.1%	0.1%		0.0%	0.0%	0.1%	12.8%
0.5 - 0.7	0.0%	0.0%	0.0%	0.1%	0.2%	1.0%	0.0%	0.0%		0.0%		0.0%	1.3%
0.7 - 0.9	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%							0.1%
0.9 - 1.1	0.0%			0.0%	0.0%	0.0%						0.0%	0.0%
1.1 - 1.3					0.0%	0.0%							0.0%
1.3 - 1.5						0.0%							0.0%
> 1.5						0.0%							0.0%
Total	3.5%	3.8%	13.7%	11.1%	7.2%	28.7%	3.5%	3.8%	0.3%	0.1%	0.1%	2.8%	78.5%

Calms (Hs < 0.1m): 21.5%

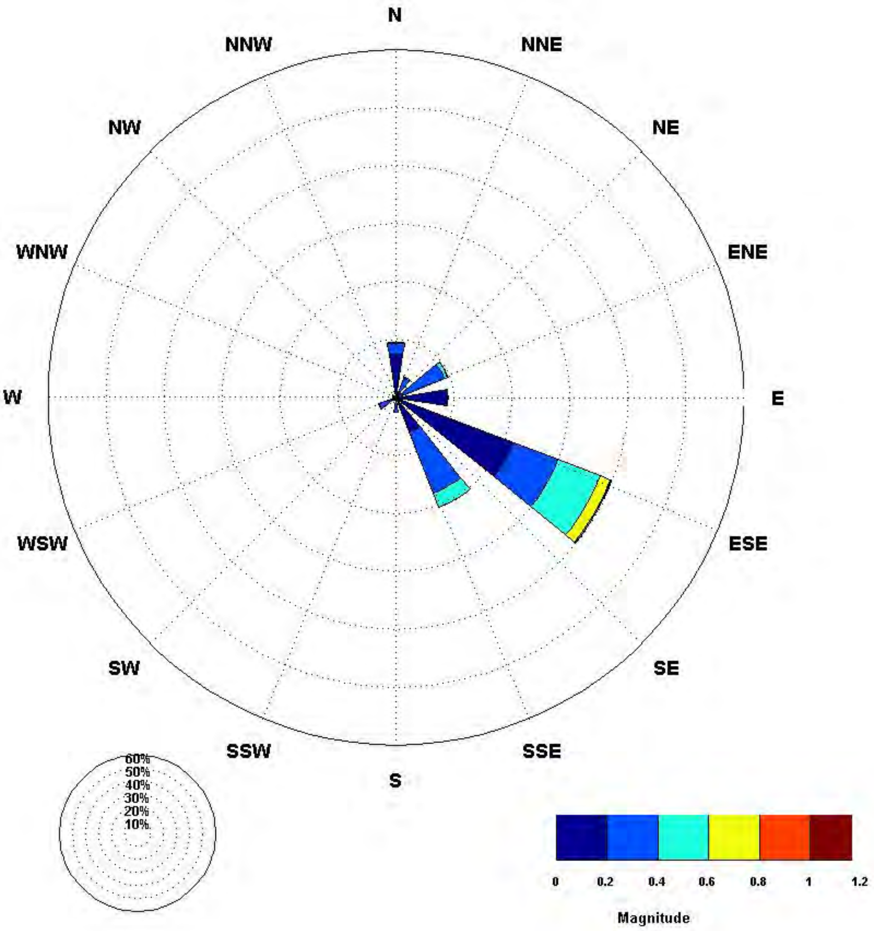

Figure H-3 Wave Recurrence Frequency Rose for Location 04 (Base Case)

Table H-5 Wave Climate at Location 04 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.8%	3.3%	8.5%	0.0%	8.2%	11.3%	2.1%	0.3%	3.0%	0.5%	0.6%	0.2%	**39.9%**
0.3 - 0.5	0.2%	0.2%	0.6%		7.8%	2.6%	0.0%		0.1%	0.0%	0.0%	0.0%	**11.5%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	1.9%	0.0%	0.0%		0.0%		0.0%	0.0%	**2.0%**
0.7 - 0.9		0.0%	0.0%	0.0%	0.2%	0.0%						0.0%	**0.2%**
0.9 - 1.1	0.0%				0.0%								**0.0%**
1.1 - 1.3				0.0%	0.0%								**0.0%**
> 1.3					0.0%								**0.0%**
Total	**2.0%**	**3.6%**	**9.1%**	**0.0%**	**18.1%**	**13.9%**	**2.2%**	**0.3%**	**3.0%**	**0.6%**	**0.6%**	**0.3%**	**53.6%**

Calms (Hs < 0.1m): 46.4%

Table H-6 Wave Climate at Location 04 – Development Scenario 1

Wave height and Direction Recurrence frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.8%	11.0%	7.6%	7.9%	1.0%	0.0%	0.0%	0.2%	5.9%	0.9%	0.6%	0.2%	**37.1%**
0.3 - 0.5	0.2%	0.2%	1.0%	0.8%	0.0%			0.0%	0.0%	0.0%	0.0%	0.0%	**2.2%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.0%				0.0%		0.0%	0.0%	**0.0%**
0.7 - 0.9		0.0%	0.0%	0.0%								0.0%	**0.0%**
> 0.9	0.0%												**0.0%**
Total	**2.0%**	**11.2%**	**8.6%**	**8.6%**	**1.1%**	**0.0%**	**0.0%**	**0.2%**	**5.9%**	**0.9%**	**0.6%**	**0.3%**	**39.4%**

Calms (Hs < 0.1m): 60.6%

Table H-7 Wave Climate at Location 04 – Development Scenario 2

Wave height and Direction Recurrence frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.8%	11.0%	7.6%	7.9%	1.0%	0.0%	0.0%	0.2%	5.9%	0.9%	0.6%	0.2%	**37.1%**
0.3 - 0.5	0.2%	0.2%	1.0%	0.8%	0.0%			0.0%	0.0%	0.0%	0.0%	0.0%	**2.2%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.0%				0.0%		0.0%	0.0%	**0.0%**
0.7 - 0.9		0.0%	0.0%	0.0%								0.0%	**0.0%**
> 0.9	0.0%												**0.0%**
Total	**2.0%**	**11.2%**	**8.6%**	**8.6%**	**1.1%**	**0.0%**	**0.0%**	**0.2%**	**5.9%**	**0.9%**	**0.6%**	**0.3%**	**39.4%**

Calms (Hs < 0.1m): 60.6%

Table H-8 Wave Climate at Location 04 – Development Scenario 3

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.8%	11.0%	7.6%	7.9%	1.0%	0.0%	0.0%	0.2%	5.9%	0.9%	0.6%	0.2%	**37.1%**
0.3 - 0.5	0.2%	0.2%	1.0%	0.8%	0.0%			0.0%	0.0%	0.0%	0.0%	0.0%	**2.2%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.0%				0.0%		0.0%	0.0%	**0.0%**
0.7 - 0.9		0.0%	0.0%	0.0%								0.0%	**0.0%**
> 0.9	0.0%												**0.0%**
Total	**2.0%**	**11.2%**	**8.6%**	**8.6%**	**1.1%**	**0.0%**	**0.0%**	**0.2%**	**5.9%**	**0.9%**	**0.6%**	**0.3%**	**39.4%**

Calms (Hs < 0.1m): 60.6%

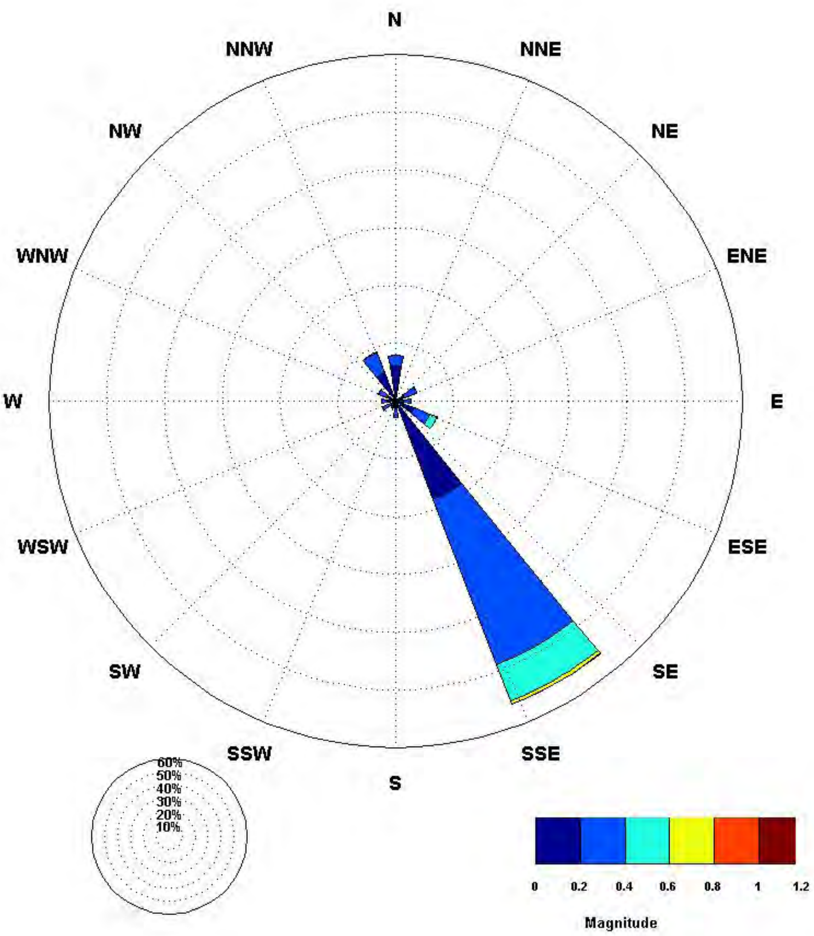

Figure H-4 Wave Recurrence Frequency Rose for Location 06 (Base Case)

Table H-9 Wave Climate at Location 06 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%		2.4%	2.6%	2.9%	30.6%	1.7%	1.0%	1.7%	0.9%	1.5%	3.7%	**50.8%**
0.3 - 0.5	0.0%		0.0%	0.0%	1.3%	6.7%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	**8.6%**
0.5 - 0.7	0.0%		0.0%		0.0%	0.6%	0.0%		0.0%	0.0%	0.0%	0.0%	**0.7%**
0.7 - 0.9					0.0%	0.0%	0.0%					0.0%	**0.0%**
0.9 - 1.1						0.0%					0.0%	0.0%	**0.0%**
1.1 - 1.3						0.0%					0.0%		**0.0%**
> 1.3						0.0%							**0.0%**
Total	**1.7%**	**0.0%**	**2.4%**	**2.6%**	**4.2%**	**38.0%**	**1.8%**	**1.1%**	**1.7%**	**1.0%**	**1.6%**	**3.9%**	**60.1%**

Calms (Hs < 0.1m): 39.9%

Table H-10 Wave Climate at Location 06 – Development Scenario 1

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%		3.3%	1.8%	2.9%	30.6%	2.7%		1.5%	1.1%	1.5%	3.7%	**50.8%**
0.3 - 0.5	0.0%		0.0%	0.0%	1.3%	6.7%	0.2%		0.1%	0.0%	0.1%	0.2%	**8.6%**
0.5 - 0.7	0.0%		0.0%		0.0%	0.6%	0.0%		0.0%		0.0%	0.0%	**0.7%**
0.7 - 0.9					0.0%	0.0%						0.0%	**0.0%**
0.9 - 1.1						0.0%					0.0%	0.0%	**0.0%**
1.1 - 1.3						0.0%					0.0%		**0.0%**
> 1.3						0.0%							**0.0%**
Total	**1.7%**	**0.0%**	**3.3%**	**1.8%**	**4.2%**	**38.0%**	**2.9%**	**0.0%**	**1.6%**	**1.1%**	**1.6%**	**3.9%**	**60.1%**

Calms (Hs < 0.1m): 39.9%

Table H-11 Wave Climate at Location 06 – Development Scenario 2

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%		3.3%	1.8%	2.9%	30.6%	2.7%		1.5%	1.1%	1.5%	3.7%	**50.8%**
0.3 - 0.5	0.0%		0.0%	0.0%	1.3%	6.7%	0.2%		0.1%	0.0%	0.1%	0.2%	**8.6%**
0.5 - 0.7	0.0%		0.0%		0.0%	0.6%	0.0%		0.0%		0.0%	0.0%	**0.7%**
0.7 - 0.9					0.0%	0.0%					0.0%	0.0%	**0.0%**
0.9 - 1.1						0.0%					0.0%	0.0%	**0.0%**
1.1 - 1.3						0.0%					0.0%		**0.0%**
> 1.3						0.0%							**0.0%**
Total	**1.7%**	**0.0%**	**3.3%**	**1.8%**	**4.2%**	**38.0%**	**2.9%**	**0.0%**	**1.6%**	**1.1%**	**1.6%**	**3.9%**	**60.1%**

Calms (Hs < 0.1m): 39.9%

Table H-12 Wave Climate at Location 06 – Development Scenario 3

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%		3.3%	1.8%	2.9%	30.6%	2.7%		1.5%	1.1%	1.5%	3.7%	**50.8%**
0.3 - 0.5	0.0%		0.0%	0.0%	1.3%	6.7%	0.2%		0.1%	0.0%	0.1%	0.2%	**8.6%**
0.5 - 0.7	0.0%		0.0%		0.0%	0.6%	0.0%		0.0%		0.0%	0.0%	**0.7%**
0.7 - 0.9					0.0%	0.0%					0.0%	0.0%	**0.0%**
0.9 - 1.1						0.0%					0.0%	0.0%	**0.0%**
1.1 - 1.3						0.0%					0.0%		**0.0%**
> 1.3						0.0%							**0.0%**
Total	**1.7%**	**0.0%**	**3.3%**	**1.8%**	**4.2%**	**38.0%**	**2.9%**	**0.0%**	**1.6%**	**1.1%**	**1.6%**	**3.9%**	**60.1%**

Calms (Hs < 0.1m): 39.9%

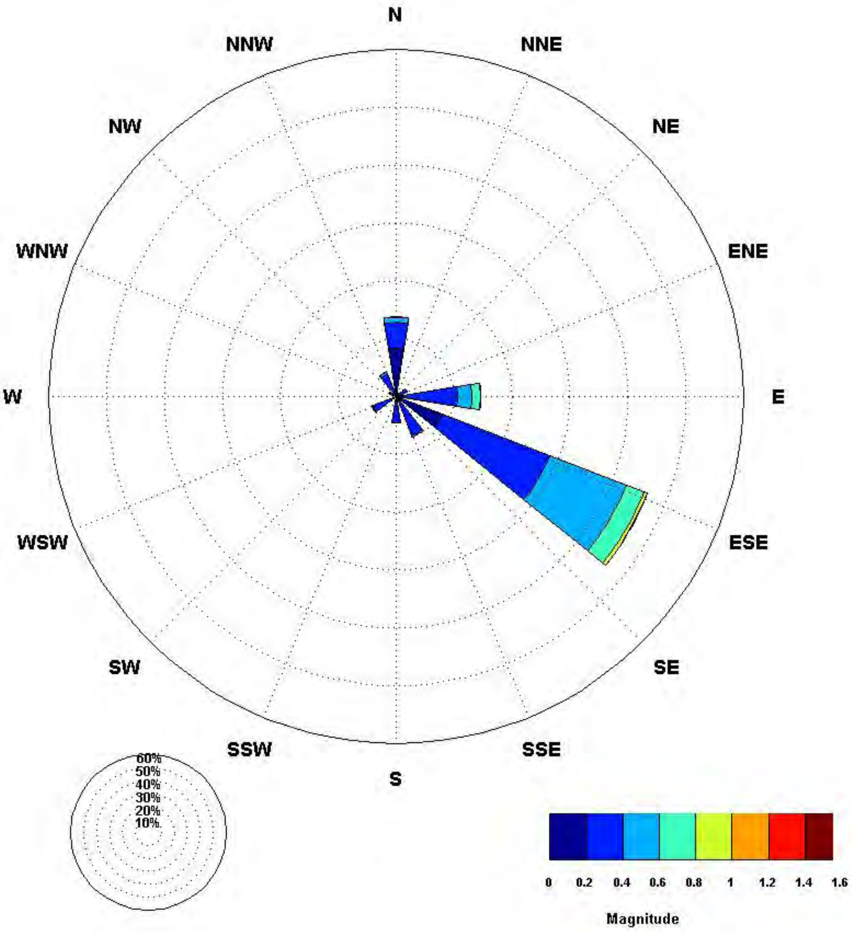

Figure H-5 Wave Recurrence Frequency Rose for Location 07 (Base Case)

Table H-13 Wave Climate at Location 07 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]											
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	4.4%	0.6%	1.8%	9.2%	19.8%	7.0%	4.5%		4.3%		1.3%	4.0%	**57.0%**
0.3 - 0.5	0.9%			2.5%	14.2%	0.2%	0.0%		0.2%		0.0%	0.4%	**18.5%**
0.5 - 0.7	0.0%			1.4%	3.3%	0.0%	0.0%		0.0%		0.0%	0.0%	**4.8%**
0.7 - 0.9	0.0%			0.1%	0.6%	0.0%			0.0%			0.0%	**0.7%**
0.9 - 1.1				0.0%	0.0%	0.0%							**0.1%**
1.1 - 1.3				0.0%	0.0%							0.0%	**0.0%**
1.3 - 1.5				0.0%	0.0%	0.0%						0.0%	**0.0%**
1.5 - 1.7					0.0%								**0.0%**
> 1.7						0.0%							**0.0%**
Total	**5.4%**	**0.6%**	**1.8%**	**13.2%**	**37.9%**	**7.2%**	**4.6%**	**0.0%**	**4.5%**	**0.0%**	**1.3%**	**4.4%**	**81.1%**

Calms (Hs < 0.1m): 18.9%

Table H-14 Wave Climate at Location 07 – Development Scenario 1

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	4.9%	0.6%	1.8%	9.2%	19.8%	7.0%	4.5%	1.4%			0.3%	3.6%	**53.3%**
0.3 - 0.5	0.9%			2.5%	14.2%	0.2%	0.0%	0.1%			0.0%	0.3%	**18.4%**
0.5 - 0.7	0.0%			1.4%	3.3%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	**4.8%**
0.7 - 0.9	0.0%			0.1%	0.6%	0.0%						0.0%	**0.7%**
0.9 - 1.1				0.0%	0.0%	0.0%							**0.1%**
1.1 - 1.3				0.0%	0.0%							0.0%	**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
1.5 - 1.7					0.0%	0.0%							**0.0%**
> 1.7						0.0%							**0.0%**
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**

Calms (Hs < 0.1m): 22.8%

Table H-15 Wave Climate at Location 07 – Development Scenario 2

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	4.9%	0.6%	1.8%	9.2%	19.8%	7.0%	4.5%	1.4%			0.3%	3.6%	**53.3%**
0.3 - 0.5	0.9%			2.5%	14.2%	0.2%	0.0%	0.1%			0.0%	0.3%	**18.4%**
0.5 - 0.7	0.0%			1.4%	3.3%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	**4.8%**
0.7 - 0.9	0.0%			0.1%	0.6%	0.0%						0.0%	**0.7%**
0.9 - 1.1				0.0%	0.0%	0.0%							**0.1%**
1.1 - 1.3				0.0%	0.0%							0.0%	**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
1.5 - 1.7					0.0%								**0.0%**
> 1.7						0.0%							**0.0%**
Total	**5.9%**	**0.6%**	**1.8%**	**13.2%**	**37.9%**	**7.2%**	**4.6%**	**1.6%**	**0.0%**	**0.0%**	**0.4%**	**3.9%**	**77.2%**

Calms (Hs < 0.1m): 22.8%

Table H-16 Wave Climate at Location 07 – Development Scenario 3

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	4.9%	0.6%	1.8%	9.2%	19.8%	7.0%	4.5%	1.4%			0.3%	3.6%	**53.3%**
0.3 - 0.5	0.9%			2.5%	14.2%	0.2%	0.0%	0.1%			0.0%	0.3%	**18.4%**
0.5 - 0.7	0.0%			1.4%	3.3%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	**4.8%**
0.7 - 0.9	0.0%			0.1%	0.6%	0.0%						0.0%	**0.7%**
0.9 - 1.1				0.0%	0.0%	0.0%							**0.1%**
1.1 - 1.3				0.0%	0.0%							0.0%	**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
1.5 - 1.7					0.0%								**0.0%**
> 1.7						0.0%							**0.0%**
Total	**5.9%**	**0.6%**	**1.8%**	**13.2%**	**37.9%**	**7.2%**	**4.6%**	**1.6%**	**0.0%**	**0.0%**	**0.4%**	**3.9%**	**77.2%**

Calms (Hs < 0.1m): 22.8%

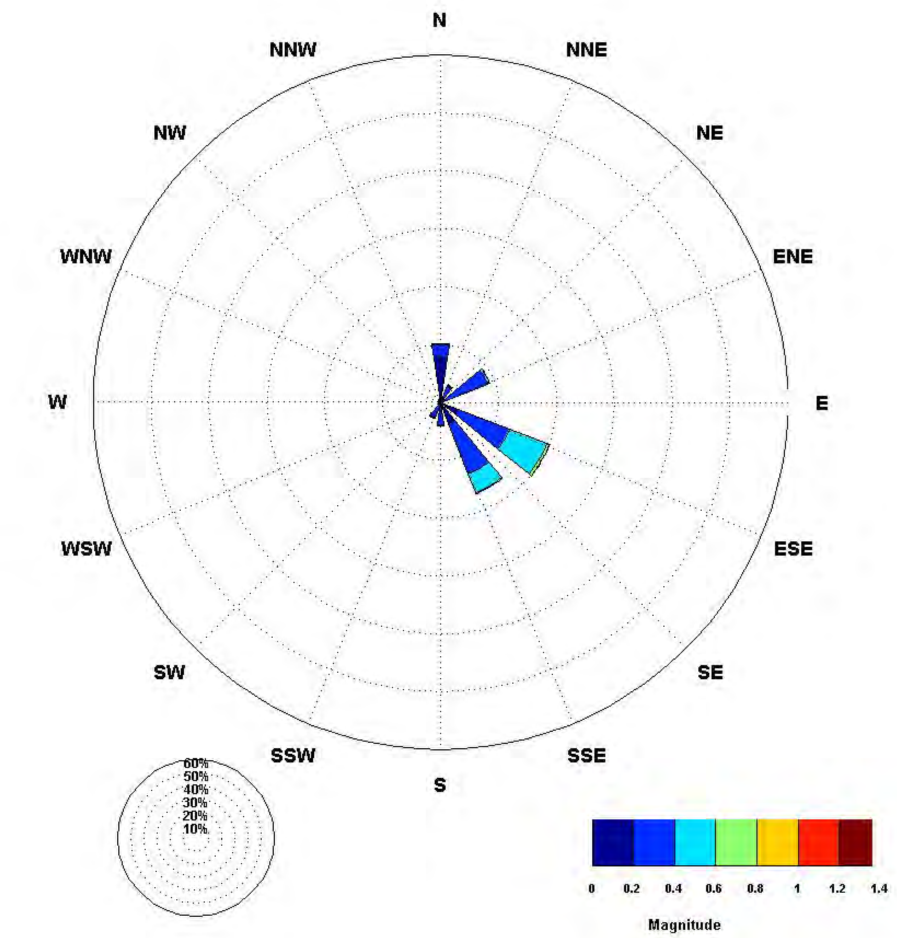

Figure H-6 Wave Recurrence Frequency Rose for Location 16 (Base Case)

Table H-17 Wave Climate at Location 16 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]														
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**dry**	**Total**
0.1 - 0.3	2.2%	3.0%	8.7%		9.5%	9.3%	4.0%	2.9%	0.4%	0.4%	0.5%	0.4%		**41.4%**
0.3 - 0.5	0.2%	0.2%	0.4%	0.1%	7.0%	3.5%	0.1%	0.1%	0.0%	0.0%		0.0%		**11.6%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	0.0%	0.0%		0.0%	0.0%	0.0%		**0.6%**
0.7 - 0.9	0.0%		0.0%		0.0%	0.0%						0.0%		**0.0%**
0.9 - 1.1				0.0%	0.0%	0.0%								**0.0%**
> 1.1						0.0%								**0.0%**
dry													31.3%	**31.3%**
Total	**2.4%**	**3.2%**	**9.1%**	**0.1%**	**17.0%**	**13.0%**	**4.1%**	**3.0%**	**0.4%**	**0.5%**	**0.5%**	**0.4%**	**31.3%**	**84.9%**

Calms (Hs < 0.1m): 15.1%

Table H-18 Wave Climate at Location 16 – Development Scenario 1

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**dry**	**Total**
0.1 - 0.3	2.2%	3.0%	8.7%		10.4%	9.4%	2.1%	2.4%	2.8%	0.4%	0.5%	0.4%		**42.5%**
0.3 - 0.5	0.2%	0.2%	0.4%	0.6%	6.1%	2.9%	0.0%	0.0%	0.1%	0.0%		0.0%		**10.4%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	0.0%		0.0%	0.0%	0.0%	0.0%		**0.6%**
0.7 - 0.9			0.0%		0.0%	0.0%								**0.0%**
0.9 - 1.1	0.0%			0.0%	0.0%							0.0%		**0.0%**
> 1.1					0.0%									**0.0%**
dry													31.3%	**31.3%**
Total	**2.4%**	**3.2%**	**9.1%**	**0.6%**	**17.0%**	**12.5%**	**2.1%**	**2.5%**	**2.9%**	**0.5%**	**0.5%**	**0.4%**	**31.3%**	**84.9%**

Calms (Hs < 0.1m): 15.1%

Table H-19 Wave Climate at Location 16 – Development Scenario 2

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**dry**	**Total**
0.1 - 0.3	2.2%	3.0%	8.7%		10.4%	9.4%	2.1%	2.4%	2.8%	0.4%	0.5%	0.4%		**42.5%**
0.3 - 0.5	0.2%	0.2%	0.4%	0.6%	6.1%	2.9%	0.0%	0.0%	0.1%	0.0%		0.0%		**10.4%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	0.0%		0.0%	0.0%	0.0%	0.0%		**0.6%**
0.7 - 0.9			0.0%		0.0%	0.0%								**0.0%**
0.9 - 1.1	0.0%			0.0%	0.0%							0.0%		**0.0%**
> 1.1					0.0%									**0.0%**
dry													31.3%	**31.3%**
Total	**2.4%**	**3.2%**	**9.1%**	**0.6%**	**17.0%**	**12.5%**	**2.1%**	**2.5%**	**2.9%**	**0.5%**	**0.5%**	**0.4%**	**31.3%**	**84.9%**

Calms (Hs < 0.1m): 15.1%

Table H-20 Wave Climate at Location 16 – Development Scenario 3

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**dry**	**Total**
0.1 - 0.3	2.2%	3.0%	8.7%		10.4%	9.4%	2.1%	2.4%	2.8%	0.4%	0.5%	0.4%		**42.5%**
0.3 - 0.5	0.2%	0.2%	0.4%	0.6%	6.1%	2.9%	0.0%	0.0%	0.1%	0.0%		0.0%		**10.4%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	0.0%		0.0%	0.0%	0.0%	0.0%		**0.6%**
0.7 - 0.9			0.0%		0.0%	0.0%								**0.0%**
0.9 - 1.1	0.0%			0.0%	0.0%							0.0%		**0.0%**
> 1.1					0.0%									**0.0%**
dry													31.3%	**31.3%**
Total	**2.4%**	**3.2%**	**9.1%**	**0.6%**	**17.0%**	**12.5%**	**2.1%**	**2.5%**	**2.9%**	**0.5%**	**0.5%**	**0.4%**	**31.3%**	**84.9%**

Calms (Hs < 0.1m): 15.1%

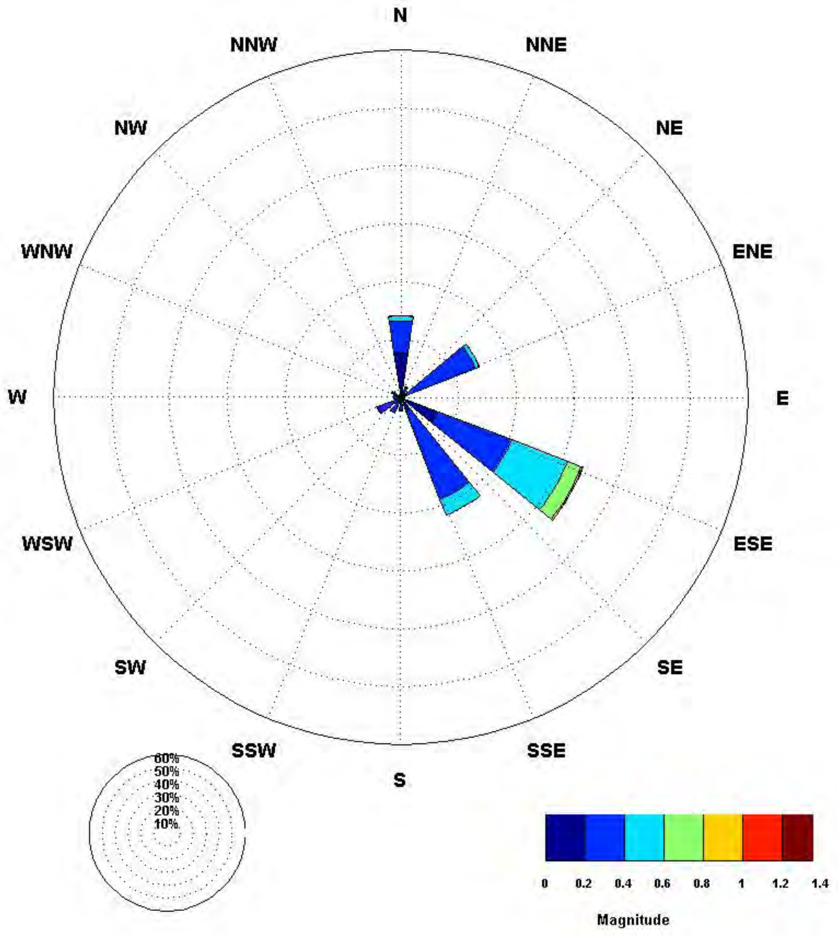

Figure H-7 Wave Recurrence Frequency Rose for Location 21 (Base Case)

Table H-21 Wave Climate at Location 21 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	5.5%	1.8%	13.0%		13.5%	16.3%	2.3%	2.9%	4.4%	1.3%	1.7%	0.2%	**62.8%**
0.3 - 0.5	0.9%	0.2%	0.7%		10.4%	3.0%	0.0%	0.0%	0.1%	0.0%		0.1%	**15.4%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	2.5%	0.0%	0.0%		0.0%	0.0%		0.0%	**2.6%**
0.7 - 0.9	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%						0.0%	**0.3%**
0.9 - 1.1	0.0%			0.0%	0.0%						0.0%	0.0%	**0.0%**
1.1 - 1.3				0.0%	0.0%								**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
> 1.5					0.0%								**0.0%**
Total	**6.4%**	**2.0%**	**13.7%**	**0.0%**	**26.8%**	**19.2%**	**2.3%**	**2.9%**	**4.5%**	**1.3%**	**1.7%**	**0.3%**	**81.1%**

Calms (Hs < 0.1m): 18.9%

Table H-22 Wave Climate at Location 21 – Development Scenario 1

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.5%	3.2%	9.4%	3.6%	26.5%	6.4%	0.2%					0.0%	**50.9%**
0.3 - 0.5	0.1%	0.2%	0.1%	0.6%	12.6%	0.1%							**13.6%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%							**2.3%**
0.7 - 0.9	0.0%			0.0%	0.1%	0.0%							**0.2%**
0.9 - 1.1				0.0%	0.0%								**0.0%**
1.1 - 1.3				0.0%	0.0%								**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
> 1.5					0.0%								**0.0%**
Total	**1.6%**	**3.4%**	**9.5%**	**4.2%**	**41.5%**	**6.5%**	**0.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**67.0%**

Calms (Hs < 0.1m): 33.0%

Table H-23 Wave Climate at Location 21 – Development Scenario 2

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.5%	3.2%	9.4%	3.6%	26.5%	6.4%	0.2%					0.0%	**50.9%**
0.3 - 0.5	0.1%	0.2%	0.1%	0.6%	12.6%	0.1%							**13.6%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%							**2.3%**
0.7 - 0.9	0.0%			0.0%	0.2%	0.0%							**0.2%**
0.9 - 1.1				0.0%	0.0%								**0.0%**
1.1 - 1.3				0.0%	0.0%								**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
> 1.5					0.0%								**0.0%**
Total	**1.6%**	**3.4%**	**9.5%**	**4.2%**	**41.5%**	**6.5%**	**0.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**67.0%**

Calms (Hs < 0.1m): 33.0%

Table H-24 Wave Climate at Location 21 – Development Scenario 3

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.5%	3.2%	9.4%	3.6%	26.5%	6.4%	0.2%					0.0%	**50.9%**
0.3 - 0.5	0.1%	0.2%	0.1%	0.6%	12.6%	0.1%							**13.6%**
0.5 - 0.7	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%							**2.3%**
0.7 - 0.9	0.0%			0.0%	0.2%	0.0%							**0.2%**
0.9 - 1.1				0.0%	0.0%								**0.0%**
1.1 - 1.3				0.0%	0.0%								**0.0%**
1.3 - 1.5				0.0%	0.0%								**0.0%**
> 1.5					0.0%								**0.0%**
Total	**1.6%**	**3.4%**	**9.5%**	**4.2%**	**41.5%**	**6.5%**	**0.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**67.0%**

Calms (Hs < 0.1m): 33.0%

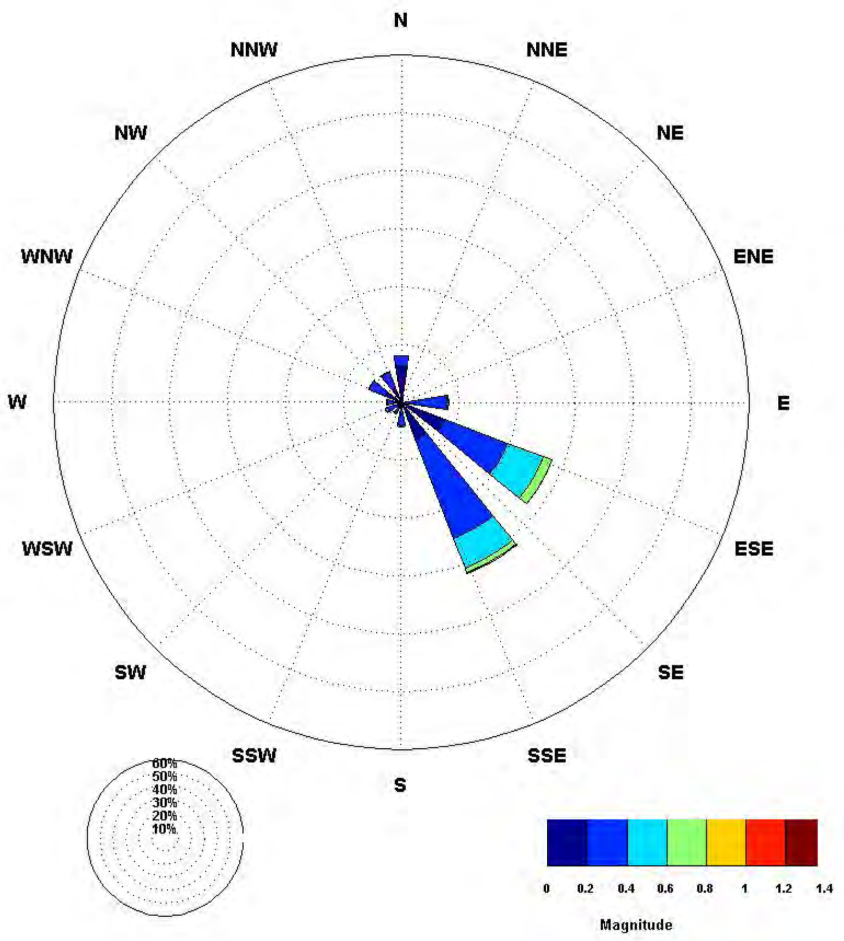

Figure H-8 Wave Recurrence Frequency Rose for Location 24 (Base Case)

Table H-25 Wave Climate at Location 24 – Base Case

Wave height and Direction Recurrence Frequency (% of year)

	Wave Direction [Degrees from North]												
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%	0.5%		7.9%	11.6%	18.4%	3.0%	2.0%	2.5%	1.3%	2.9%	2.9%	**54.8%**
0.3 - 0.5	0.0%			0.2%	6.6%	5.4%	0.2%	0.2%	0.4%	0.1%	0.2%	0.1%	**13.5%**
0.5 - 0.7	0.0%			0.0%	1.6%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**2.5%**
0.7 - 0.9				0.0%	0.1%	0.2%	0.0%		0.0%	0.0%	0.0%	0.0%	**0.3%**
0.9 - 1.1					0.0%	0.0%	0.0%				0.0%	0.0%	**0.0%**
1.1 - 1.3					0.0%	0.0%					0.0%		**0.0%**
1.3 - 1.5						0.0%							**0.0%**
1.5 - 1.7						0.0%							**0.0%**
> 1.7						0.0%							**0.0%**
Total	**1.7%**	**0.5%**	**0.0%**	**8.1%**	**19.8%**	**24.8%**	**3.2%**	**2.2%**	**3.0%**	**1.4%**	**3.1%**	**3.1%**	**71.0%**

Calms (Hs < 0.1m): 29.0%

Table H-26 Wave Climate at Location 24 – Development Scenario 1

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%	0.5%		7.9%	9.2%	18.3%	3.0%	2.0%	2.7%	1.3%	2.0%	3.6%	**52.2%**
0.3 - 0.5	0.0%			0.2%	6.5%	7.9%	0.2%	0.2%	0.3%	0.1%	0.1%	0.2%	**15.6%**
0.5 - 0.7	0.0%			0.0%	1.6%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**2.6%**
0.7 - 0.9				0.0%	0.1%	0.2%	0.0%		0.0%	0.0%	0.0%		**0.2%**
0.9 - 1.1					0.0%	0.0%	0.0%				0.0%	0.0%	**0.0%**
1.1 - 1.3					0.0%	0.0%					0.0%		**0.0%**
1.3 - 1.5					0.0%	0.0%							**0.0%**
1.5 - 1.7						0.0%							**0.0%**
> 1.8						0.0%							**0.0%**
Total	**1.7%**	**0.5%**	**0.0%**	**8.1%**	**17.4%**	**27.3%**	**3.2%**	**2.2%**	**3.0%**	**1.4%**	**2.1%**	**3.8%**	**70.7%**

Calms (Hs < 0.1m): 29.3%

Table H-27 Wave Climate at Location 24 – Development Scenario 2

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%	0.5%		7.9%	9.2%	18.3%	3.0%	2.0%	2.7%	1.3%	2.0%	3.6%	**52.2%**
0.3 - 0.5	0.0%			0.2%	6.5%	7.9%	0.2%	0.2%	0.3%	0.1%	0.1%	0.2%	**15.6%**
0.5 - 0.7	0.0%			0.0%	1.6%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**2.6%**
0.7 - 0.9				0.0%	0.1%	0.2%	0.0%		0.0%	0.0%	0.0%		**0.2%**
0.9 - 1.1					0.0%	0.0%	0.0%				0.0%	0.0%	**0.0%**
1.1 - 1.3					0.0%	0.0%					0.0%		**0.0%**
1.3 - 1.5					0.0%	0.0%							**0.0%**
1.5 - 1.7						0.0%							**0.0%**
> 1.7						0.0%							**0.0%**
Total	**1.7%**	**0.5%**	**0.0%**	**8.1%**	**17.4%**	**27.3%**	**3.2%**	**2.2%**	**3.0%**	**1.4%**	**2.1%**	**3.8%**	**70.7%**

Calms (Hs < 0.1m): 29.3%

Table H-28 Wave Climate at Location 24 – Development Scenario 3

Wave height and Direction Recurrence Frequency (% of year)

Wave Direction [Degrees from North]													
Hs [m]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
0.1 - 0.3	1.7%	0.5%		7.9%	9.2%	18.3%	3.0%	2.0%	2.7%	1.3%	1.9%	3.6%	**52.1%**
0.3 - 0.5	0.0%			0.2%	6.5%	7.9%	0.2%	0.2%	0.3%	0.1%	0.2%	0.2%	**15.7%**
0.5 - 0.7	0.0%			0.0%	1.6%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**2.6%**
0.7 - 0.9				0.0%	0.1%	0.2%	0.0%		0.0%	0.0%	0.0%		**0.2%**
0.9 - 1.1					0.0%	0.0%	0.0%				0.0%	0.0%	**0.0%**
1.1 - 1.3					0.0%	0.0%					0.0%		**0.0%**
1.3 - 1.5					0.0%	0.0%					0.0%		**0.0%**
1.5 - 1.7						0.0%							**0.0%**
> 1.7						0.0%							**0.0%**
Total	**1.7%**	**0.5%**	**0.0%**	**8.1%**	**17.4%**	**27.3%**	**3.2%**	**2.2%**	**3.0%**	**1.4%**	**2.1%**	**3.8%**	**70.7%**

Calms (Hs < 0.1m): 29.3%

APPENDIX I: BED SHEAR STRESS TIME SERIES

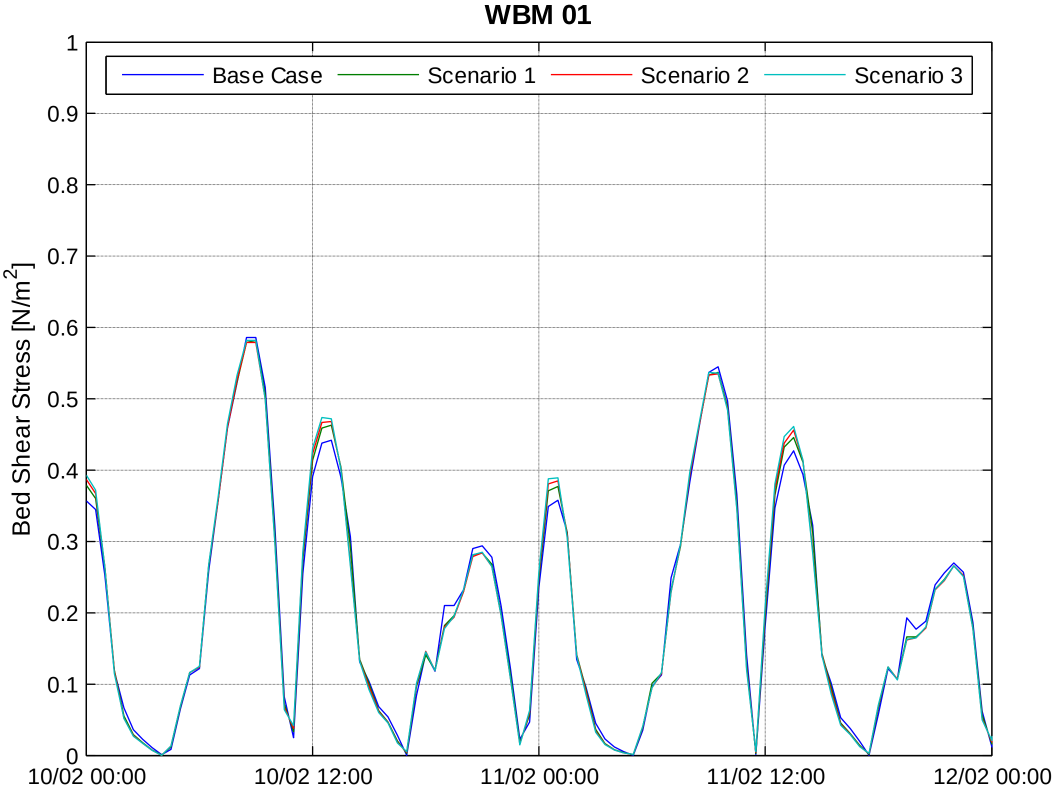

Figure I-1 Bed Shear Stress Time Series – WBM 01

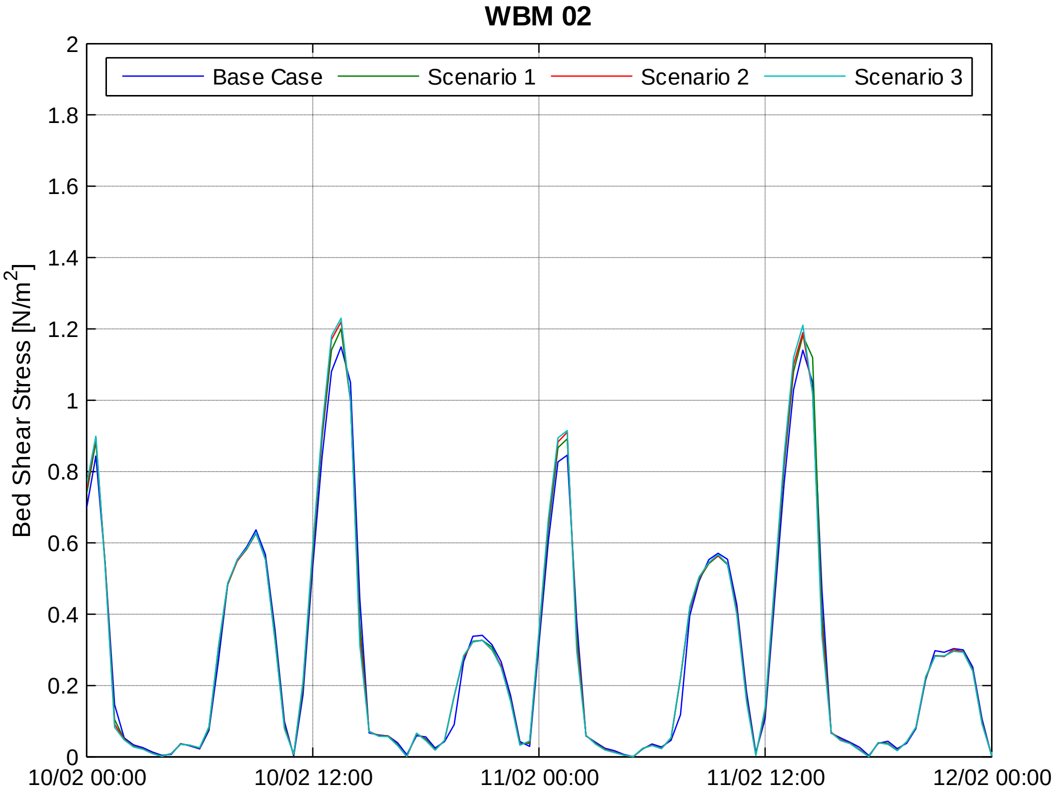

Figure I-2 Bed Shear Stress Time Series – WBM 02

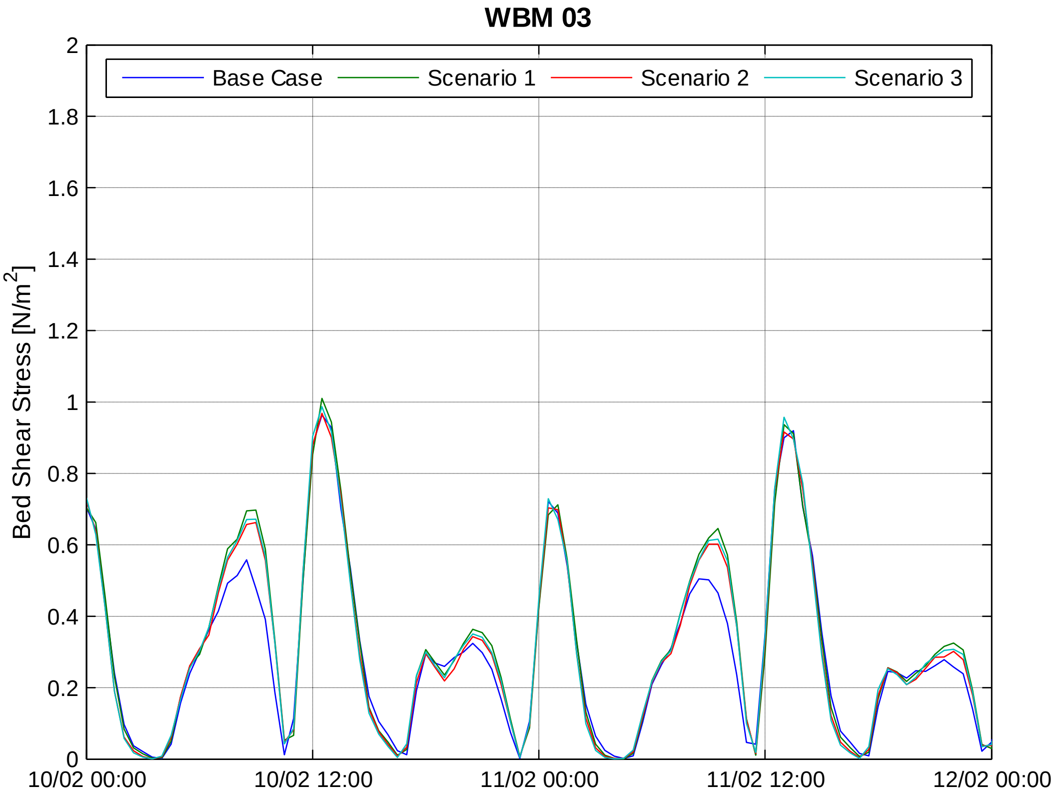

Figure I-3 Bed Shear Stress Time Series – WBM 03

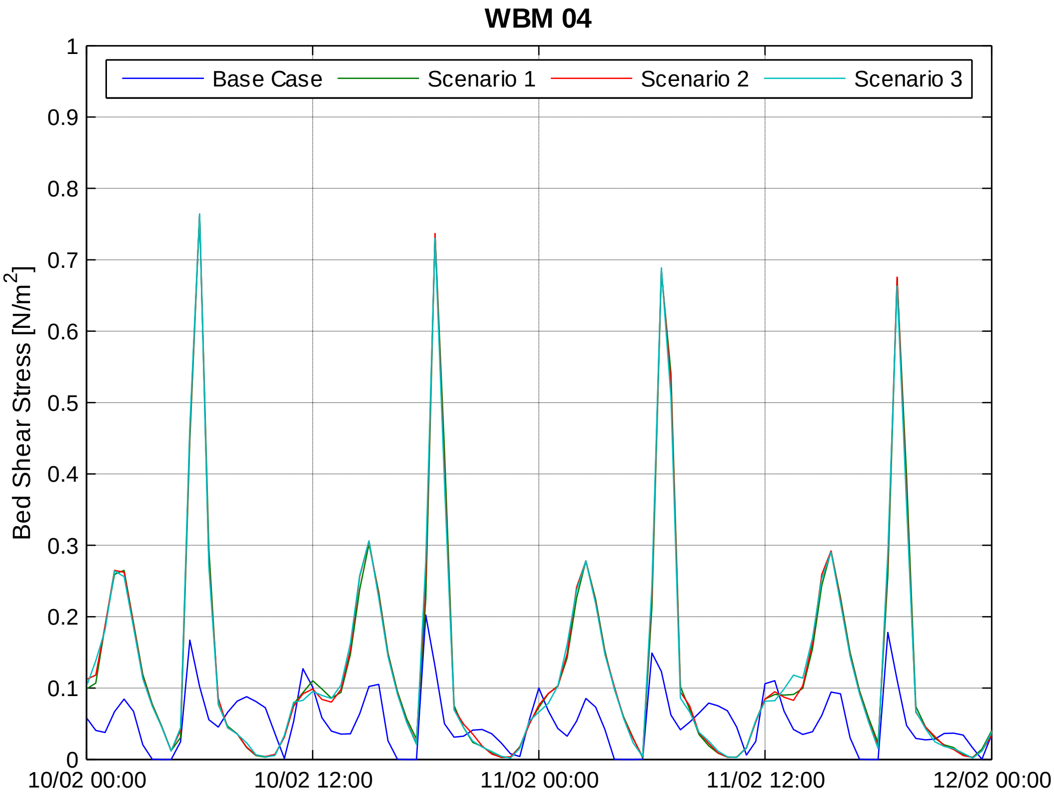

Figure I-4 Bed Shear Stress Time Series – WBM 04

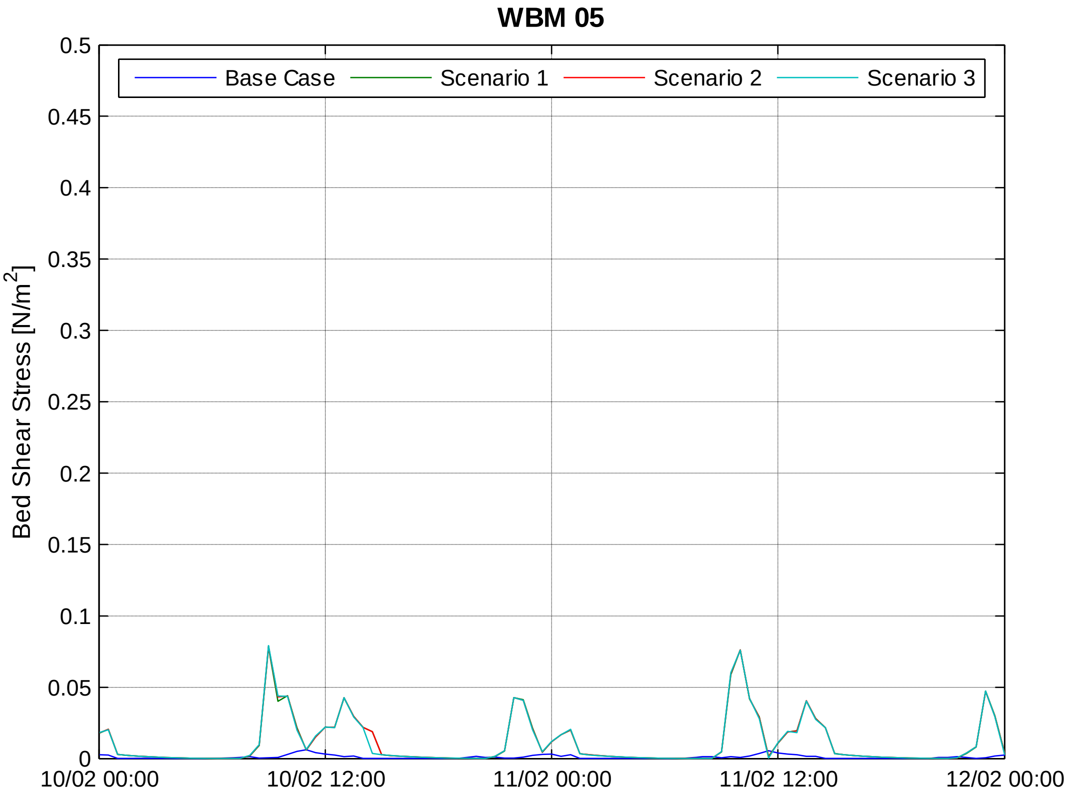

Figure I-5 Bed Shear Stress Time Series – WBM 05

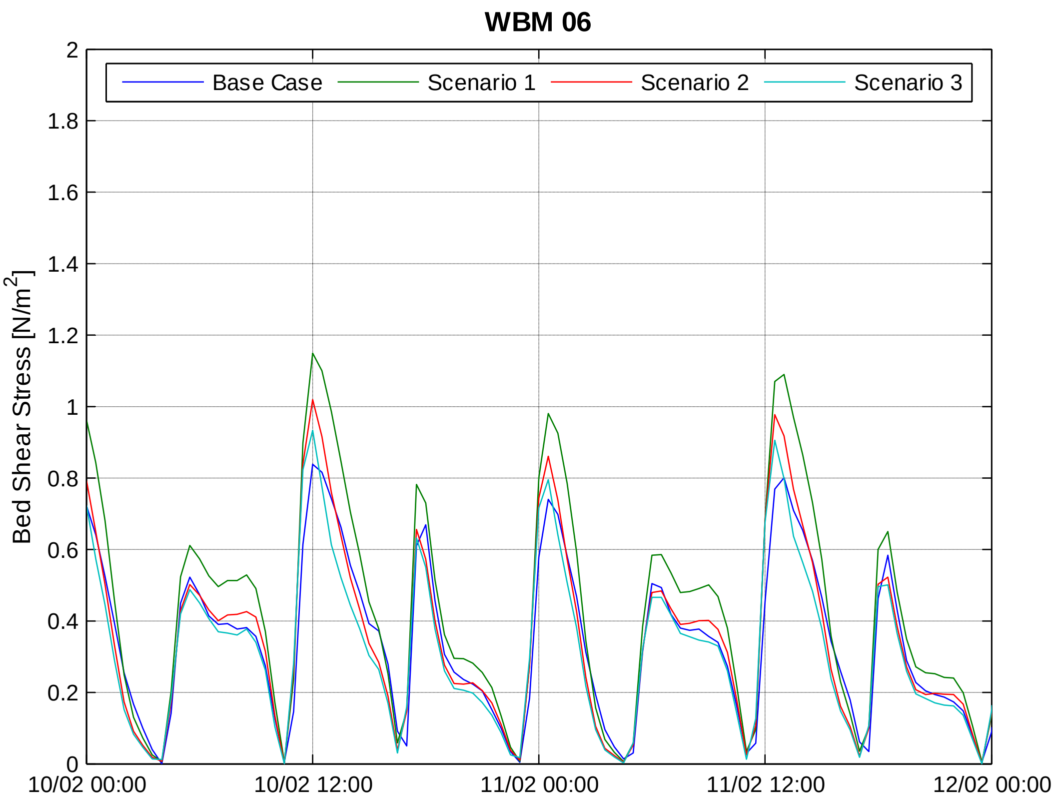

Figure I-6 Bed Shear Stress Time Series – WBM 06

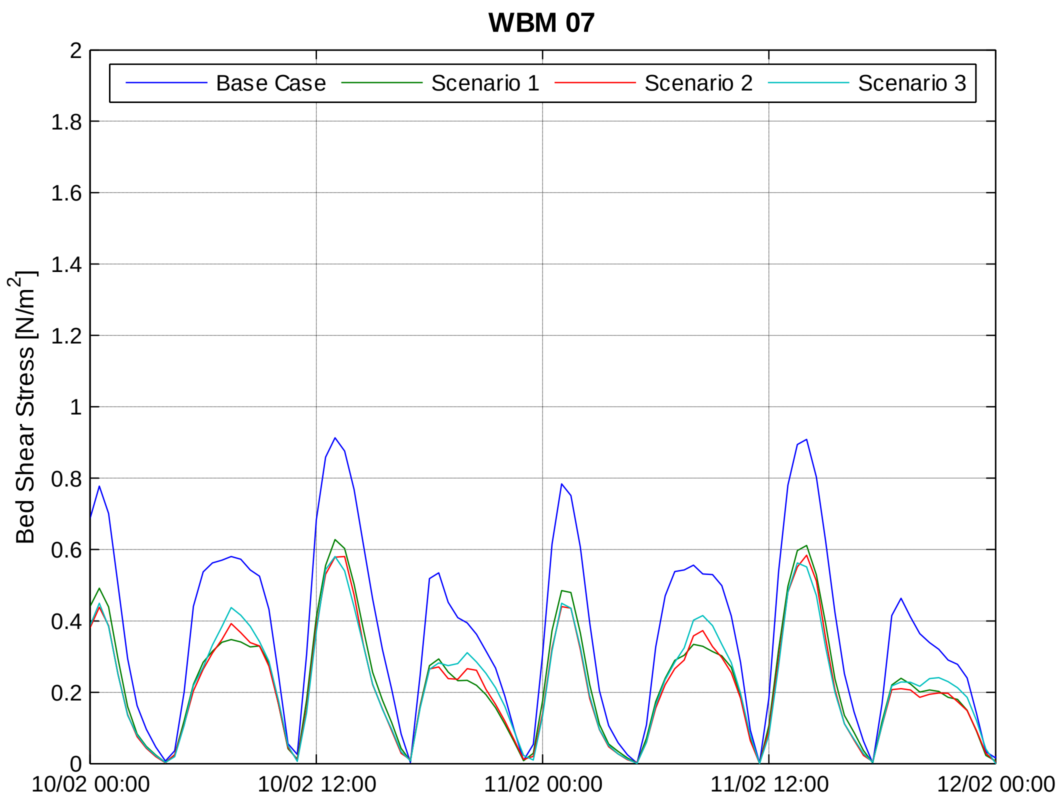

Figure I-7 Bed Shear Stress Time Series – WBM 07

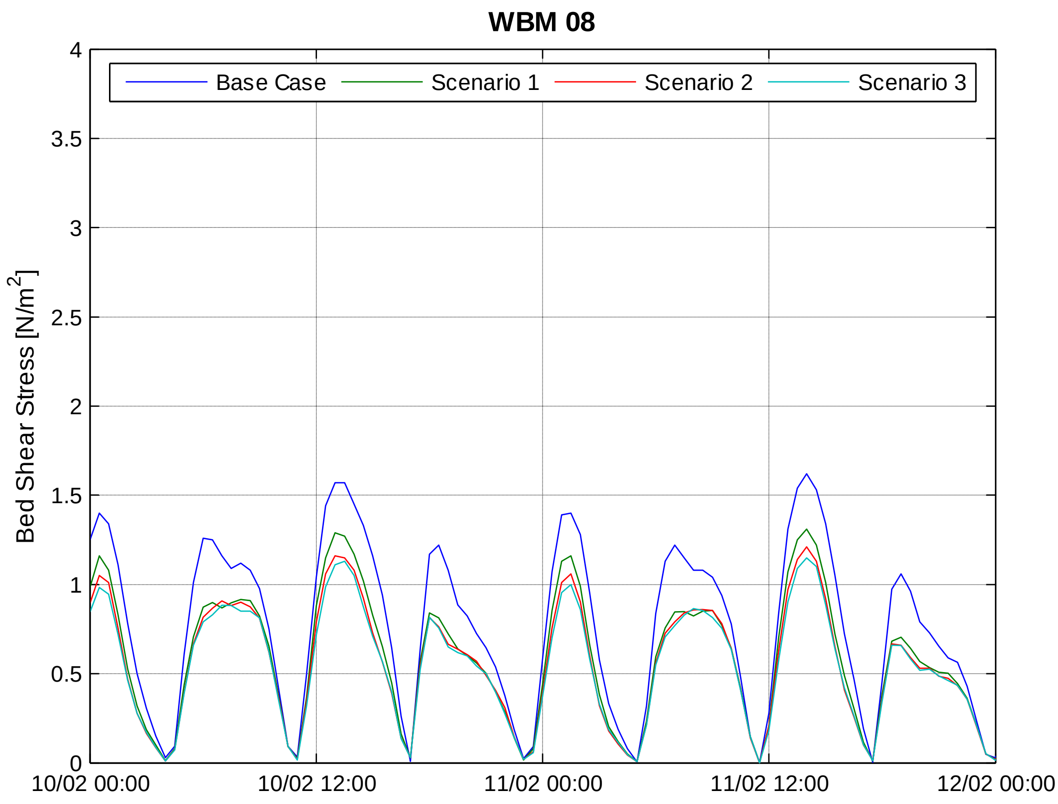

Figure I-8 Bed Shear Stress Time Series – WBM 08

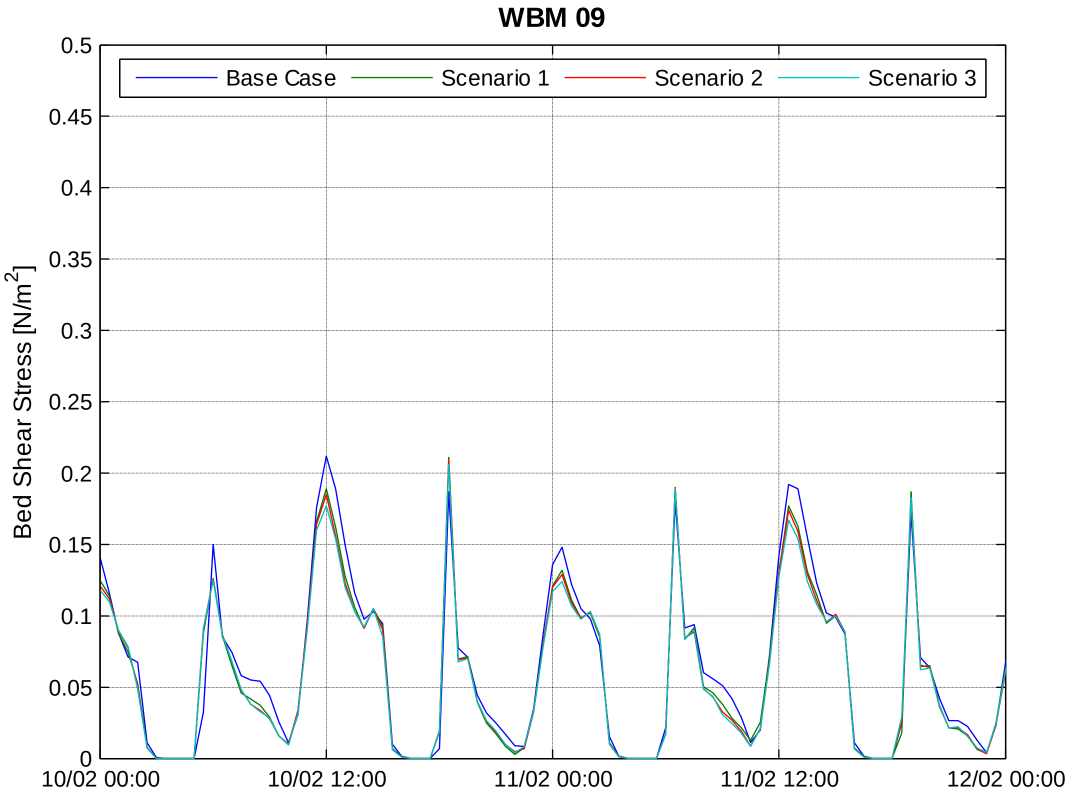

Figure I-9 Bed Shear Stress Time Series – WBM 09

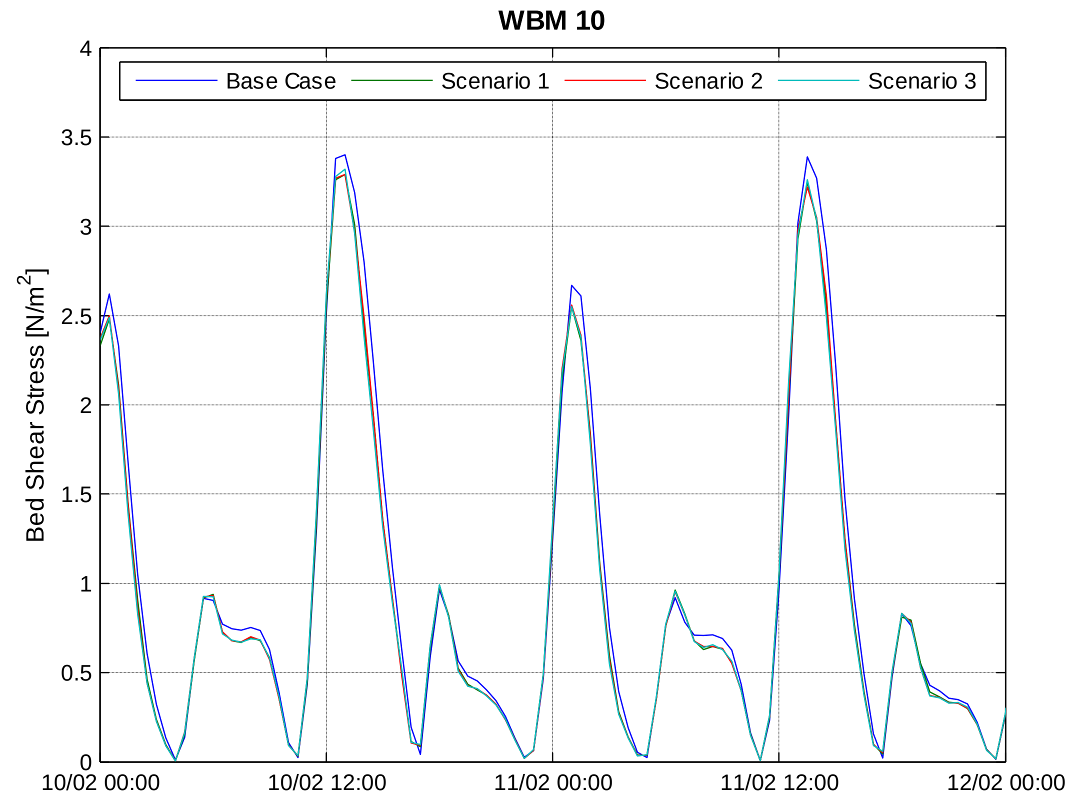

Figure I-10 Bed Shear Stress Time Series – WBM 10

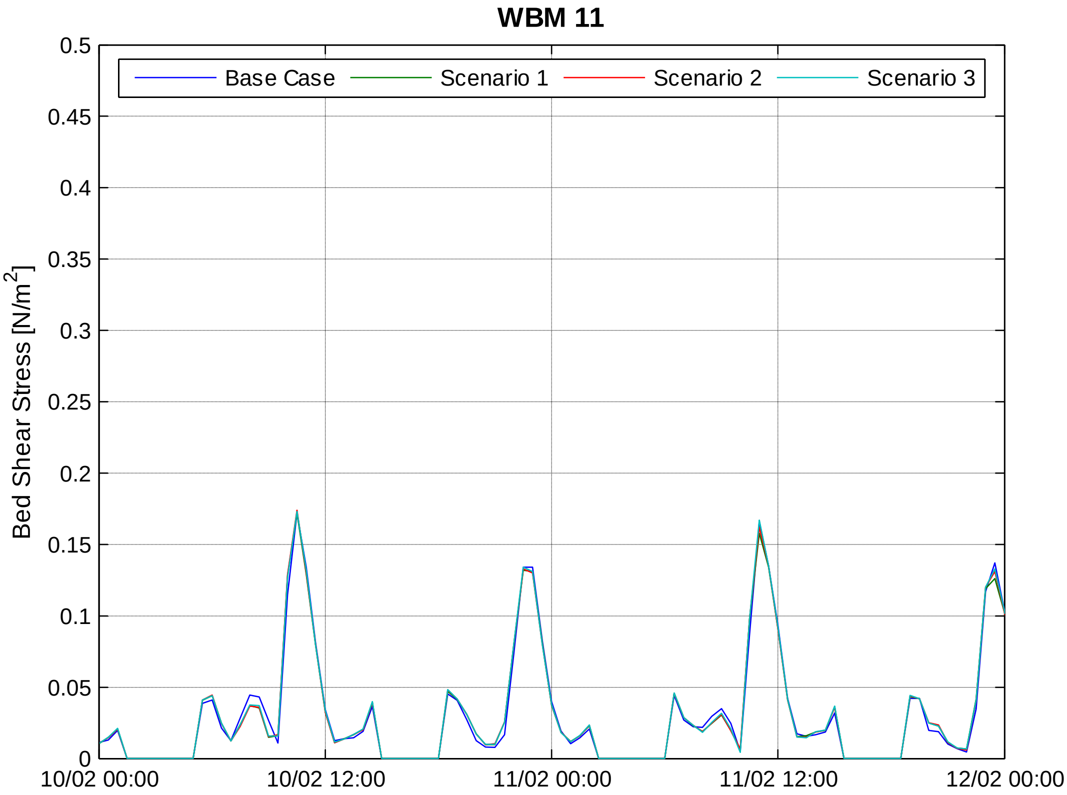

Figure I-11 Bed Shear Stress Time Series – WBM 11

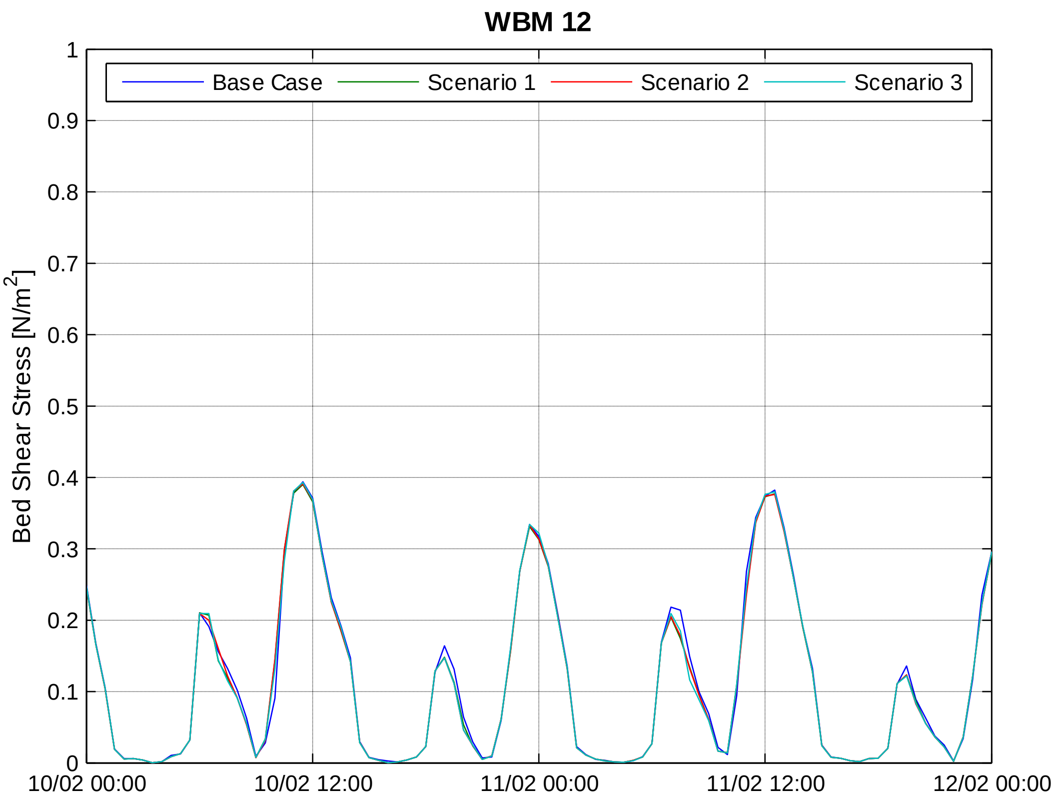

Figure I-12 Bed Shear Stress Time Series – WBM 12

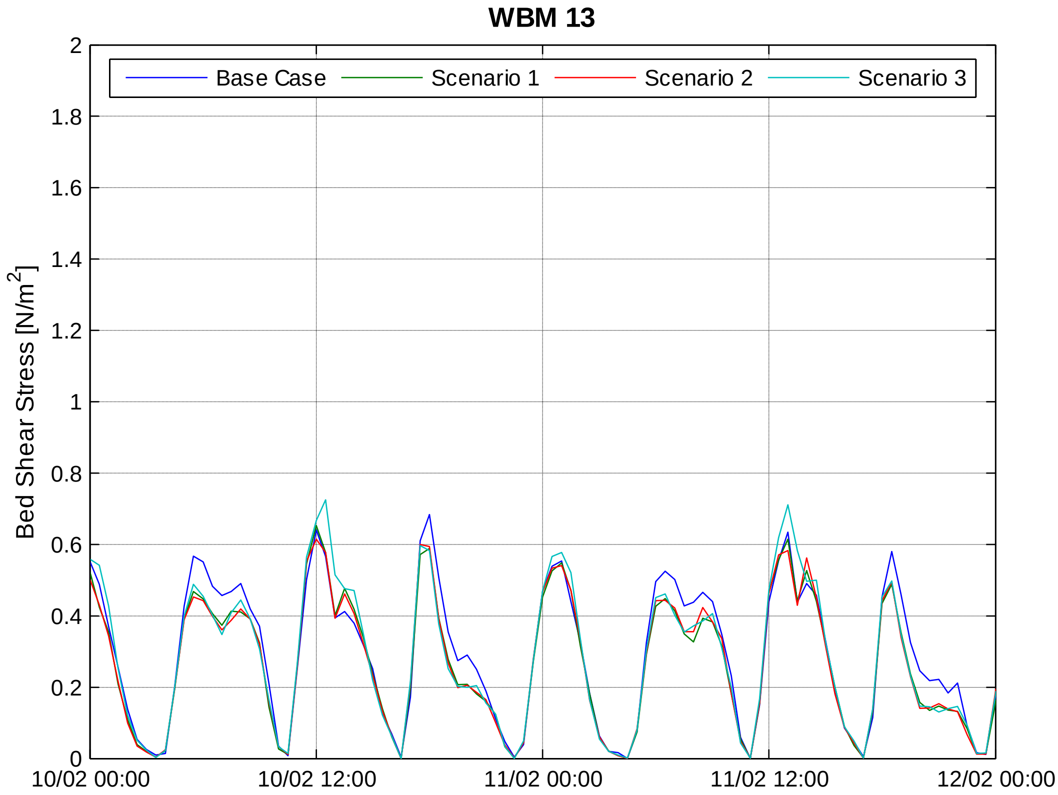

Figure I-13 Bed Shear Stress Time Series – WBM 13

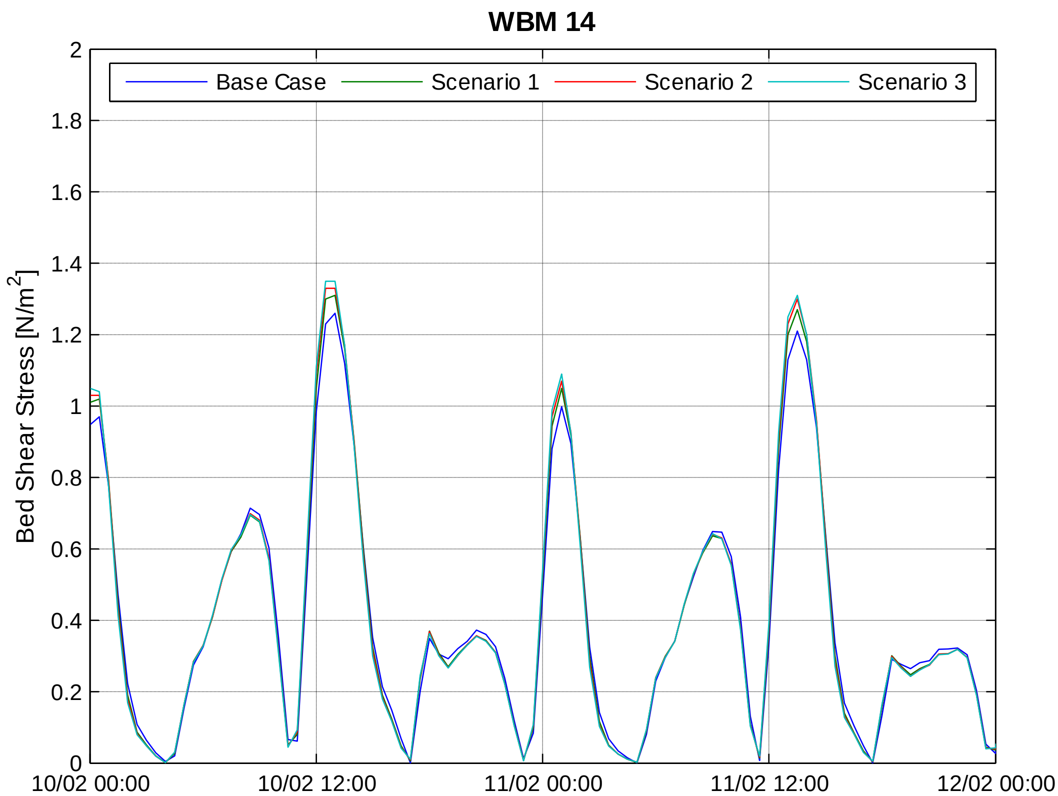

Figure I-14 Bed Shear Stress Time Series – WBM 14

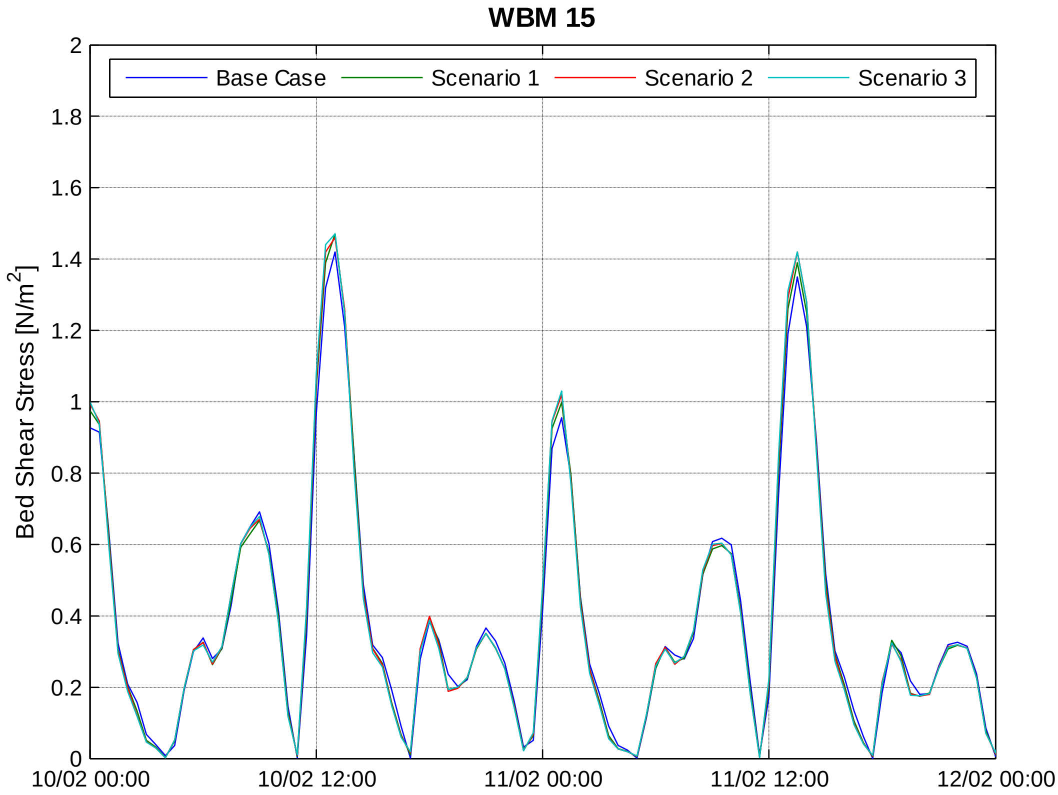

Figure I-15 Bed Shear Stress Time Series – WBM 15

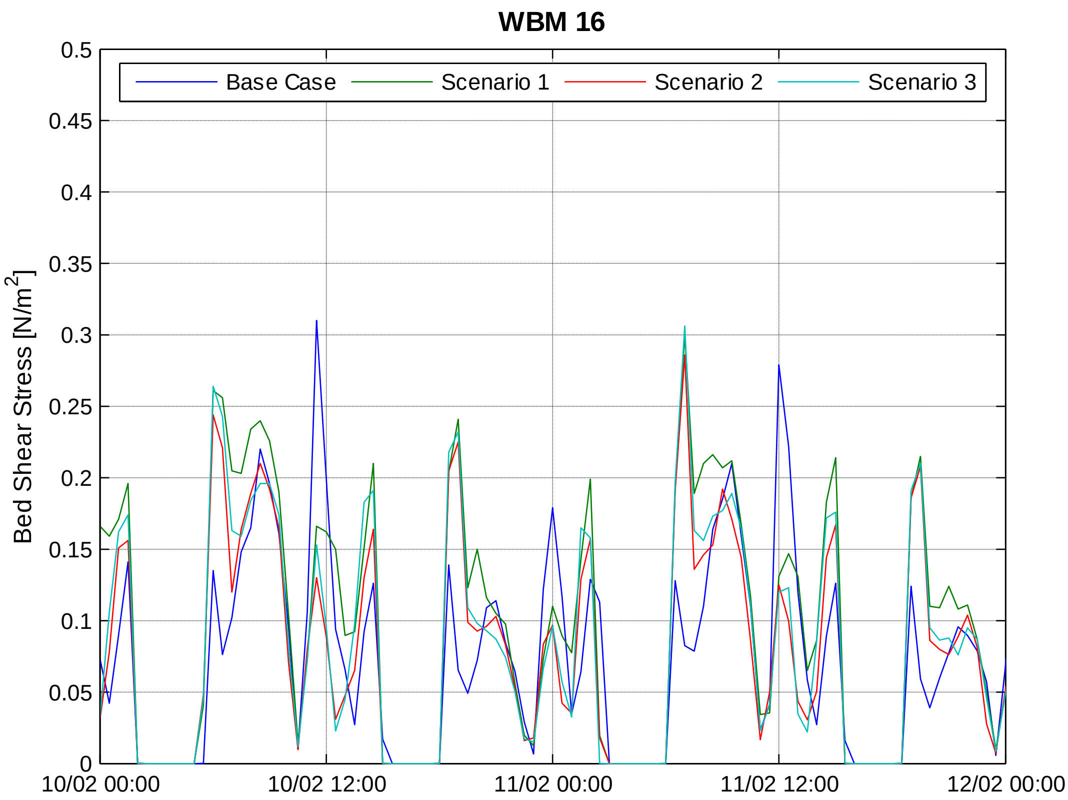

Figure I-16 Bed Shear Stress Time Series – WBM 16

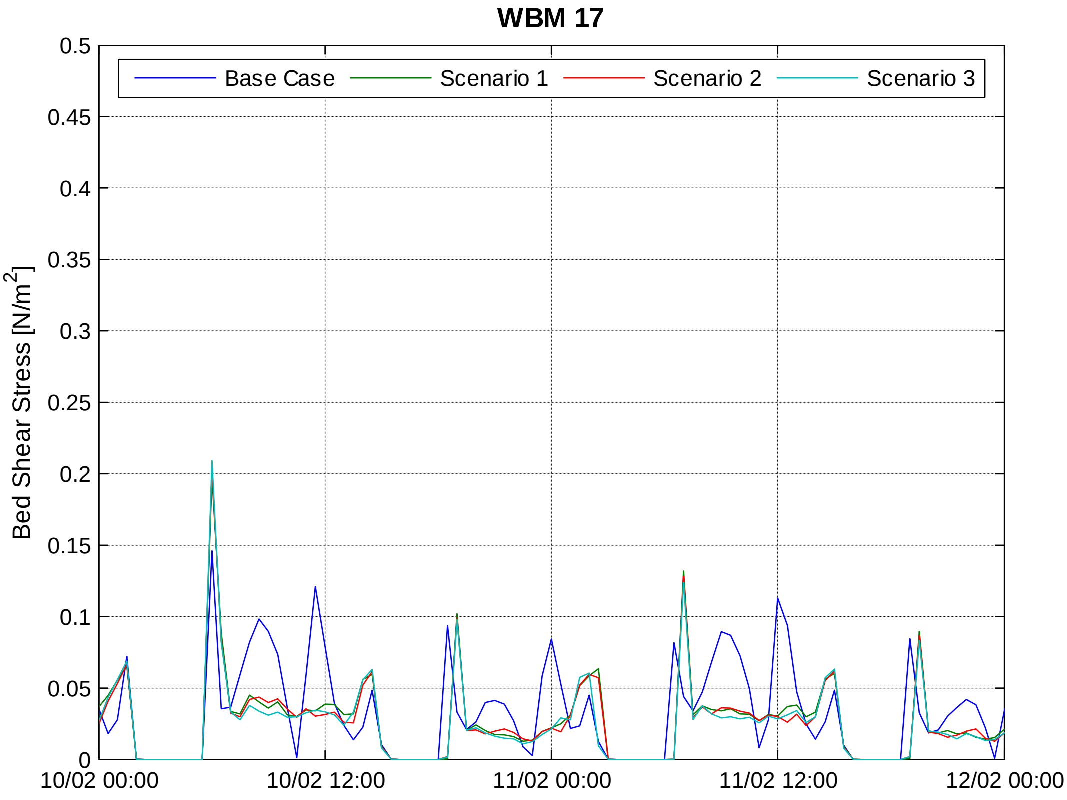

Figure I-17 Bed Shear Stress Time Series – WBM 17

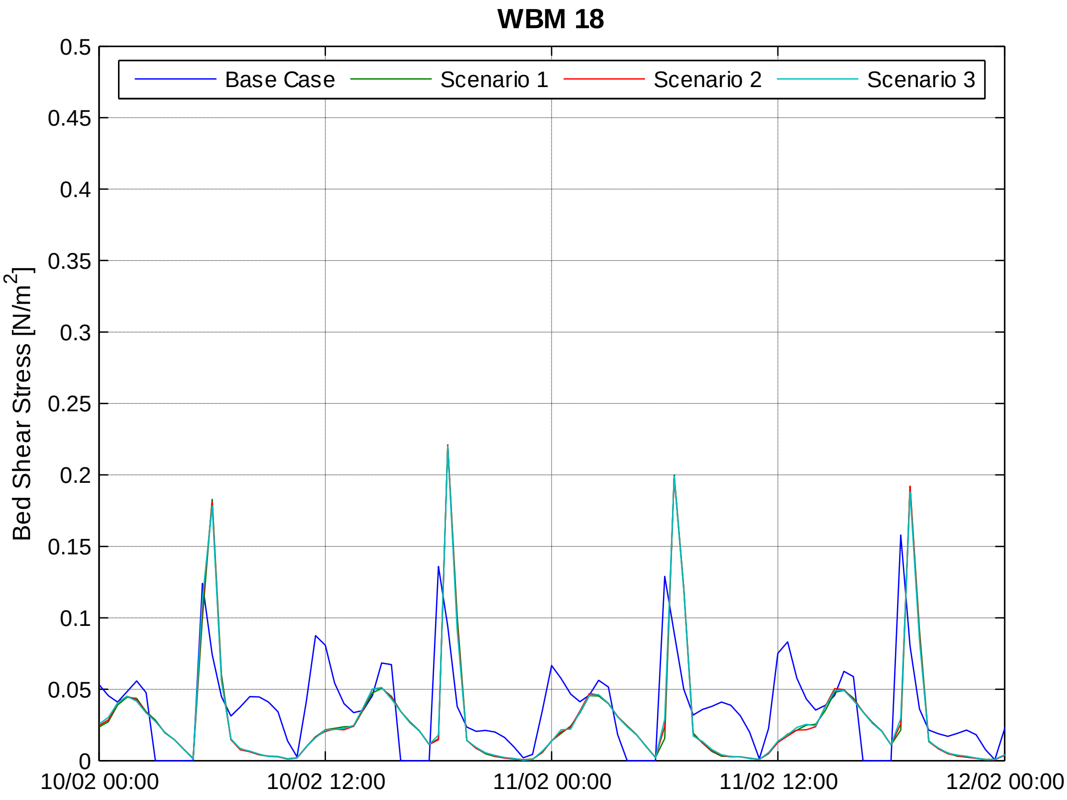

Figure I-18 Bed Shear Stress Time Series – WBM 18

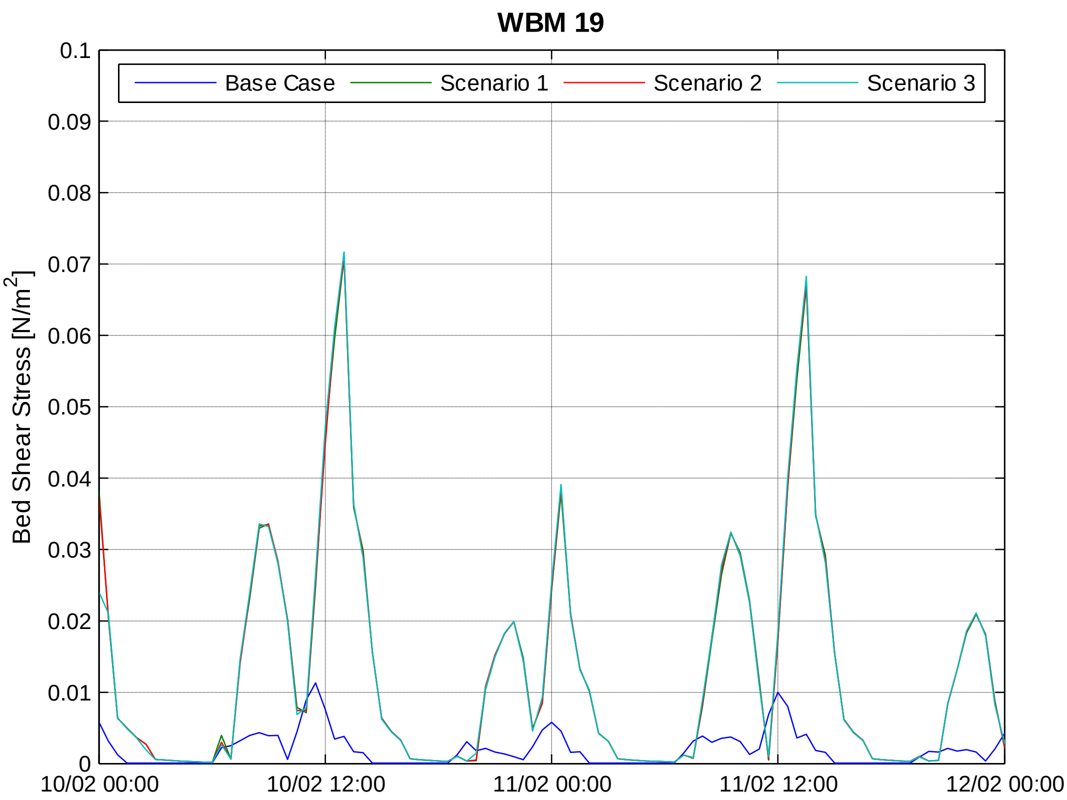

Figure I-19 Bed Shear Stress Time Series – WBM 19

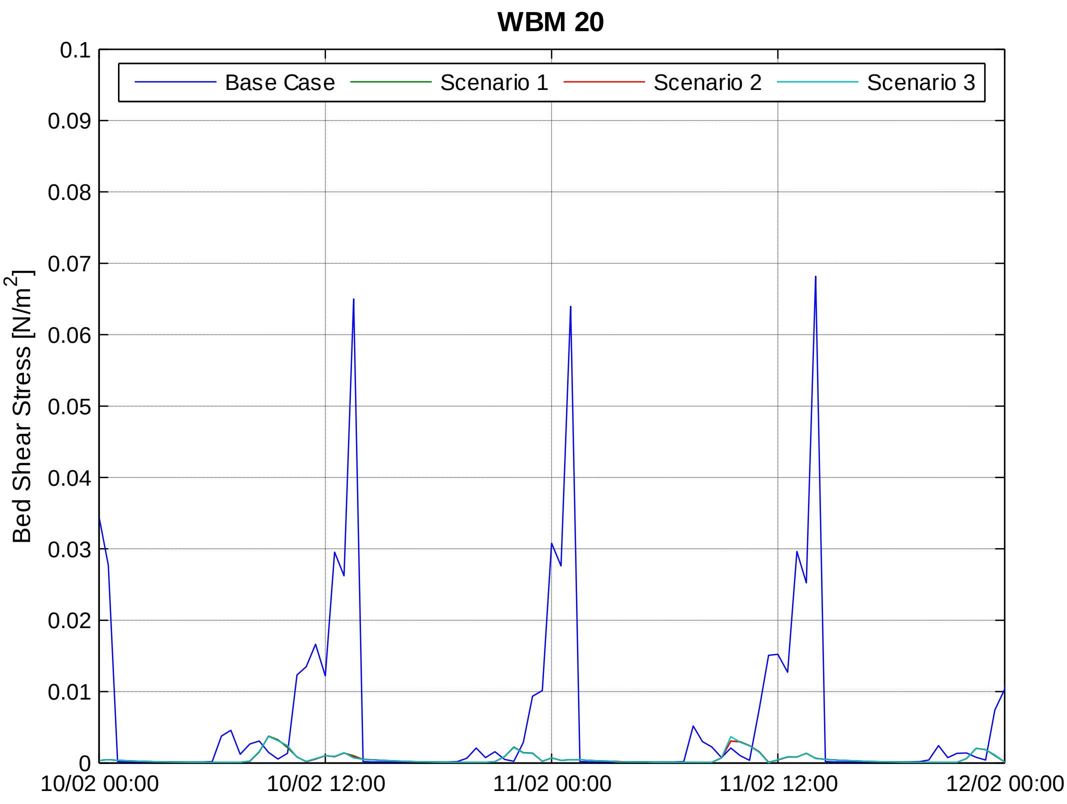

Figure I-20 Bed Shear Stress Time Series – WBM 20

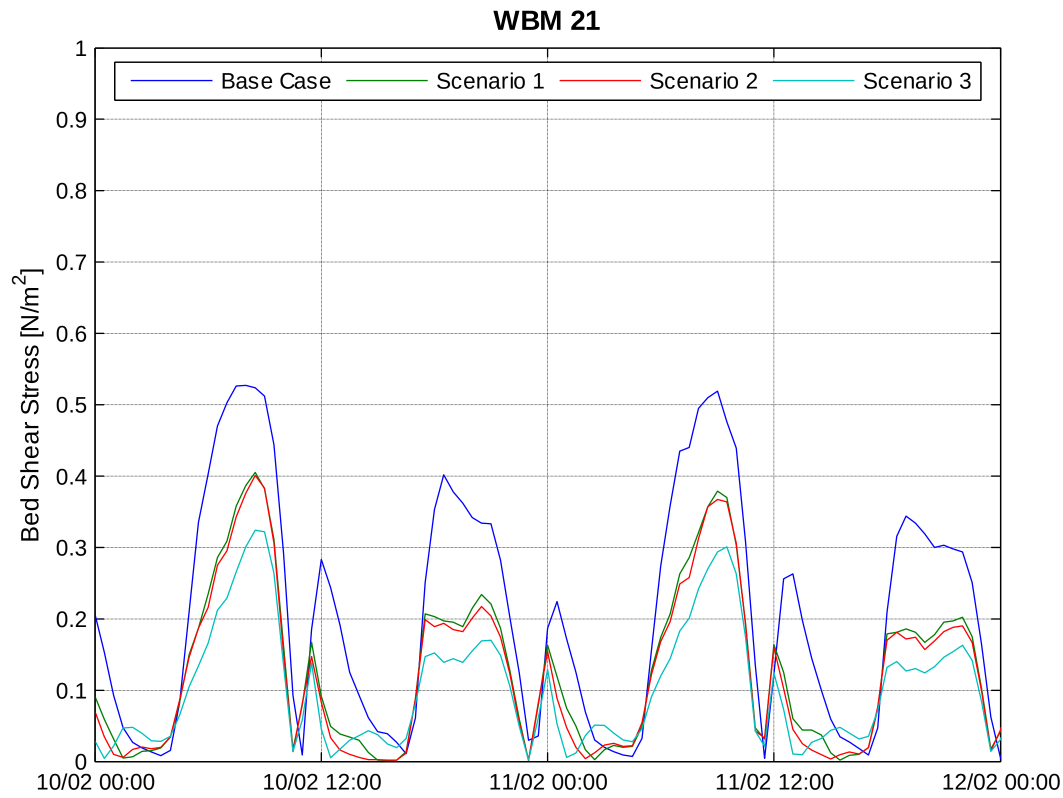

Figure I-21 Bed Shear Stress Time Series – WBM 21

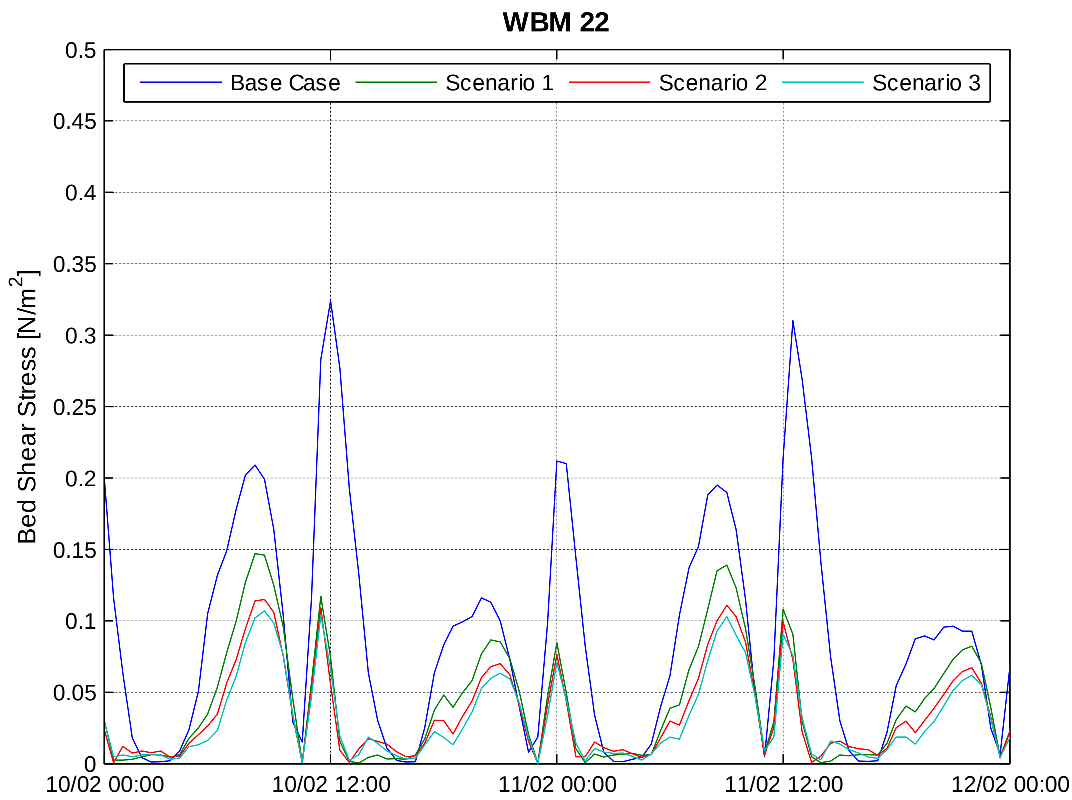

Figure I-22 Bed Shear Stress Time Series – WBM 22

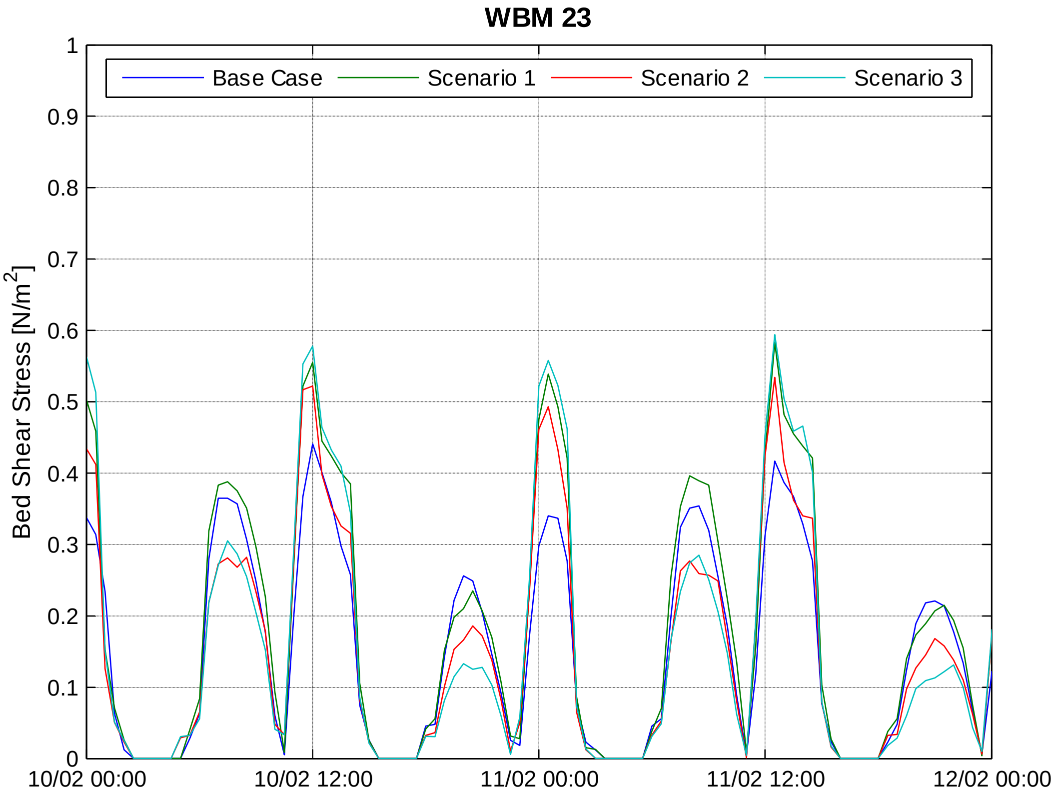

Figure I-23 Bed Shear Stress Time Series – WBM 23

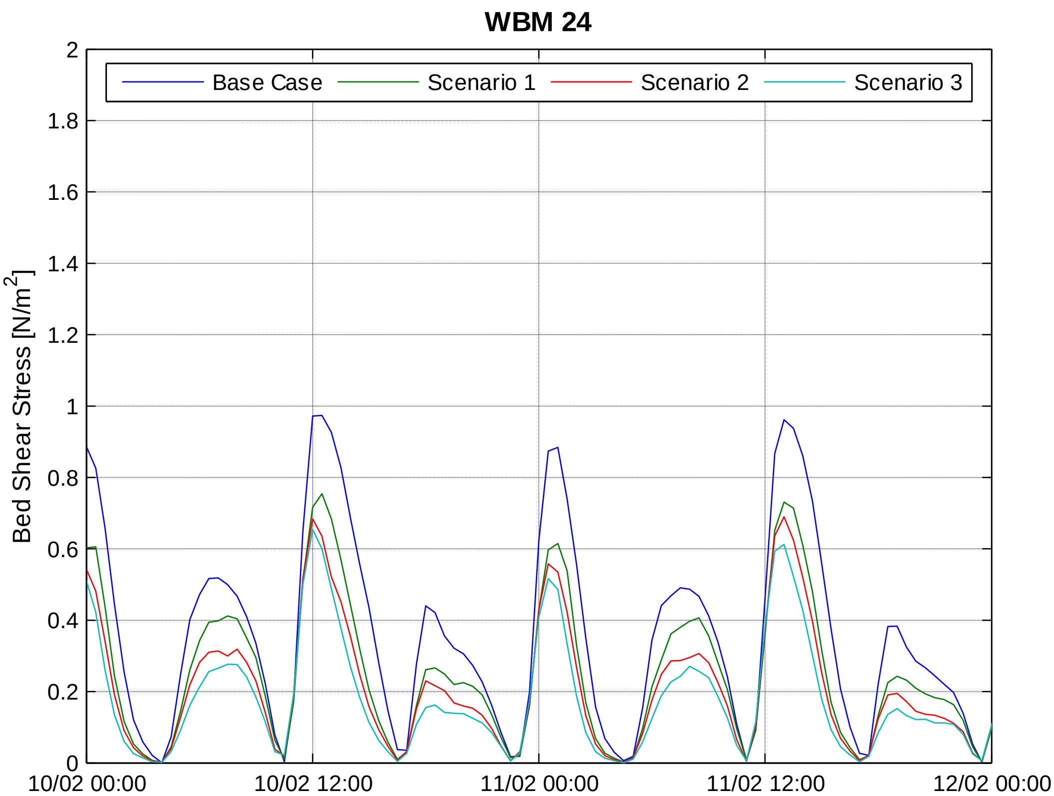

Figure I-24 Bed Shear Stress Time Series – WBM 24

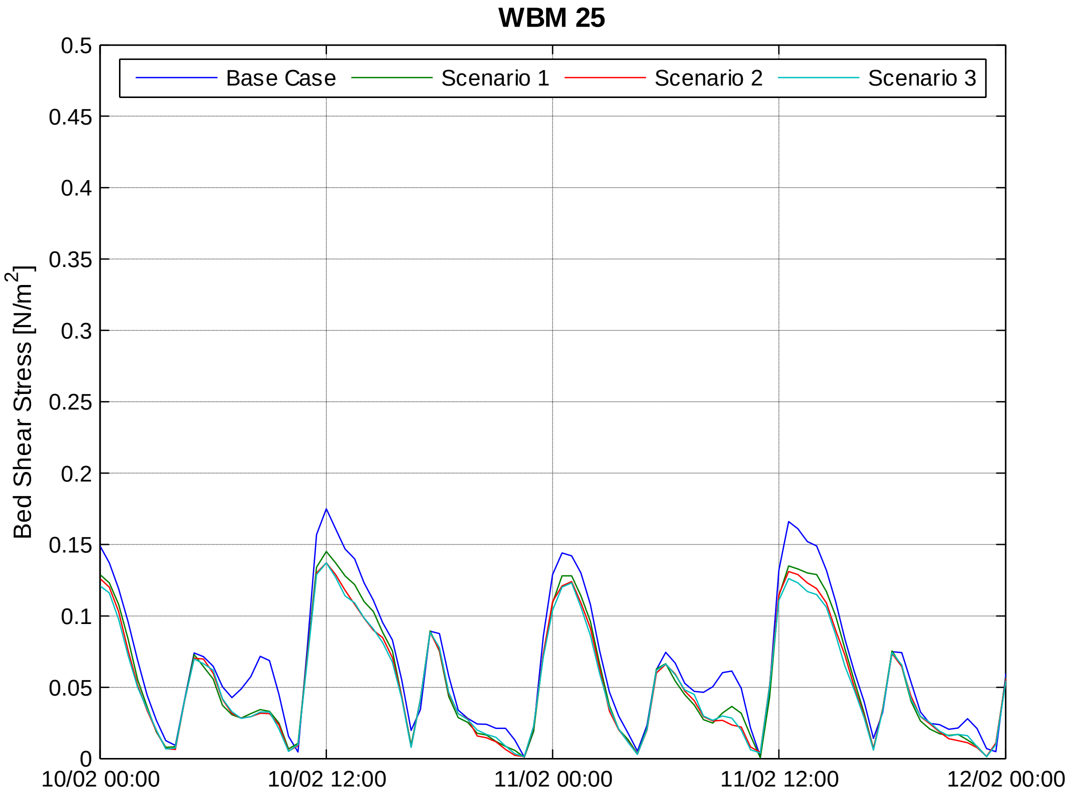

Figure I-25 Bed Shear Stress Time Series – WBM 25

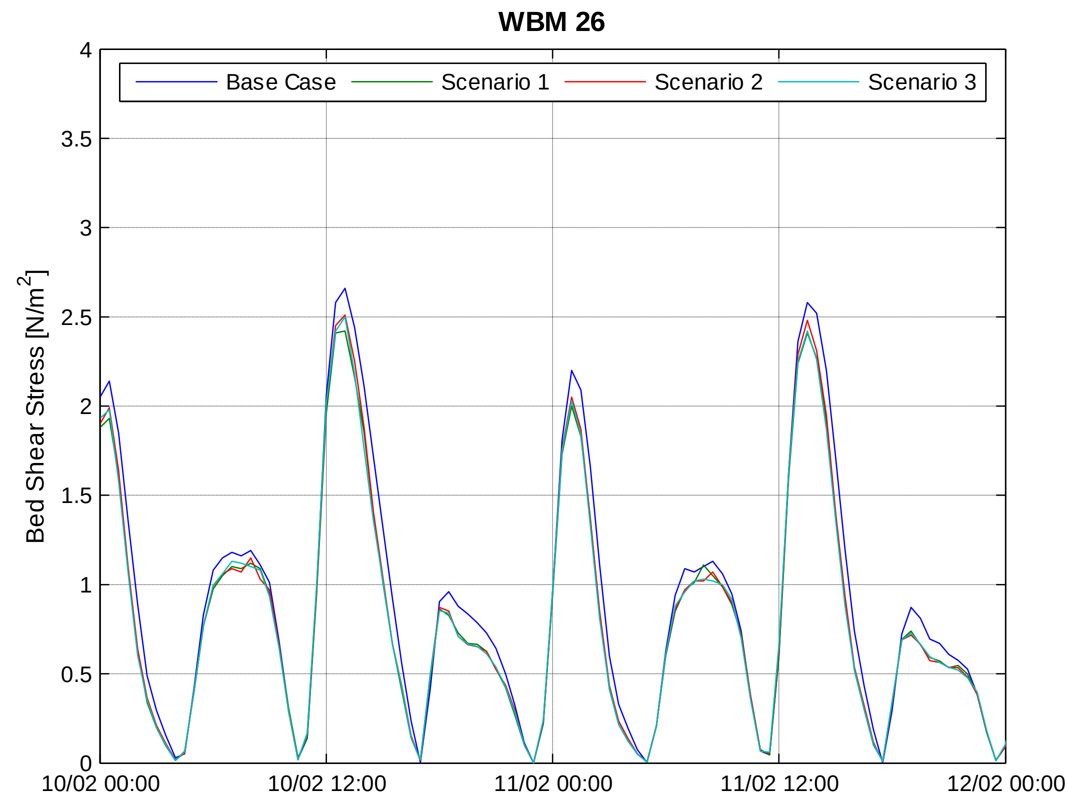

Figure I-26 Bed Shear Stress Time Series – WBM 26

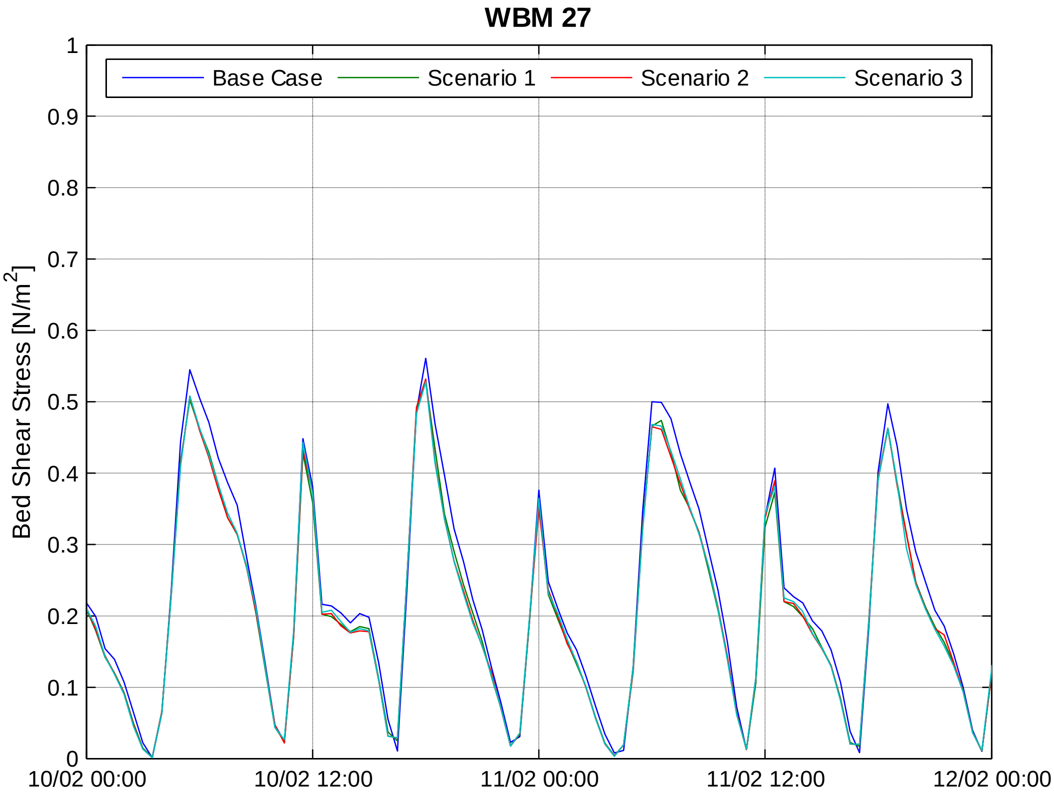

Figure I-27 Bed Shear Stress Time Series – WBM 27

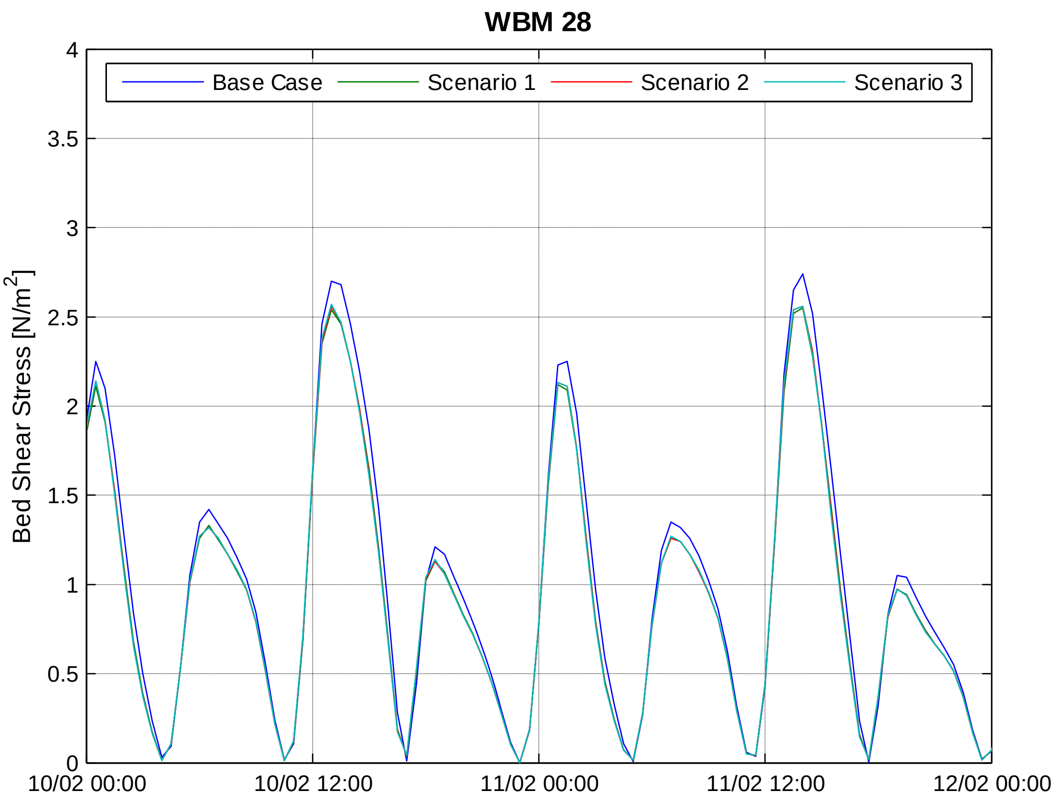

Figure I-28 Bed Shear Stress Time Series – WBM 28

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