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QCLNG Supplementary EIS – Hydrodynamics and Coastal Processes
FINAL Report

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QCLNG Supplementary EIS – Hydrodynamics and Coastal Processes FINAL Report

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Title :	QCLNG Supplementary EIS – Hydrodynamics and Coastal Processes – FINAL Report
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Synopsis :	This report documents numerical modelling undertaken for the QCLNG Project to determine individual and cumulative impacts on hydrodynamics and coastal processes within the Port of Gladstone resulting form the proposed works.

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1 INTRODUCTION

1.1 Background

This report details numerical modelling of Port Curtis undertaken by BMT WBM Pty Ltd (WBM) as part of the Queensland Curtis LNG Project (QCLNG) Supplementary EIS. The numerical models have been used as tools to assess the potential impacts of proposed dredging and reclamation works, both in terms of individual and cumulative impacts.

The modelling has focused on tidal hydrodynamics and flushing characteristics. The numerical model used in this study has been established and enhanced over many years by WBM and updated with further specific data collected for this project.

Previous hydrodynamics and marine water quality assessments were carried out as part of the EIS process and are reported in BMT WBM (2009c).

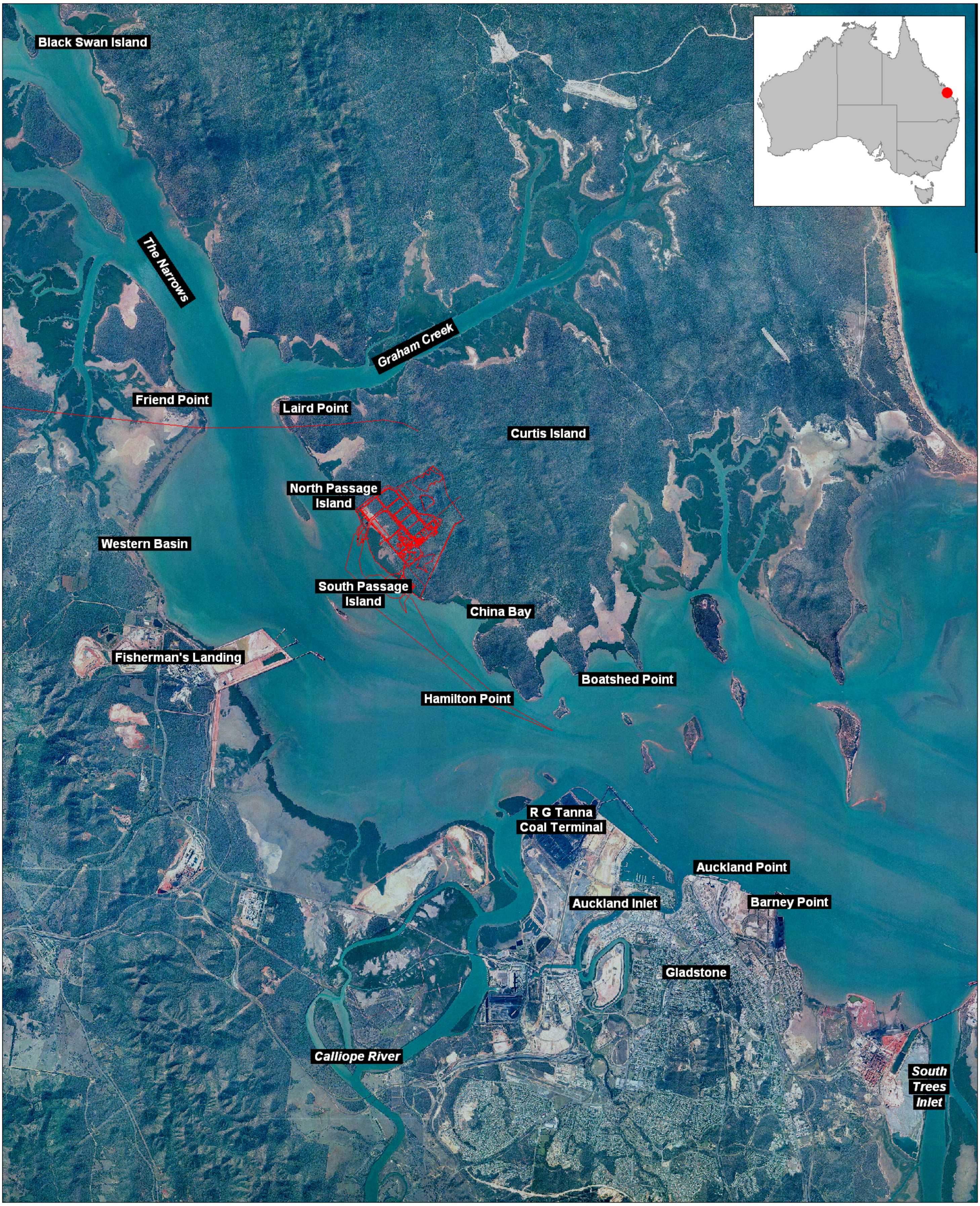
1.2 Site Description

The proposed QCLNG works are primarily located in the broad tidal basin between Curtis Island and the mainland. The locality and project area are shown in. Figure 1-1. 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.



Title:

Locality Plan

Figure: 1-1

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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 associated with the QCLNG Project on the hydrodynamic and flushing processes in Port Curtis. This has included the following tasks:

- **Data Collation and Review** – Collection of all relevant details of the proposed works to be assessed (including QCLNG Project and others). These details included the following elements:
  - Materials Offloading Facility (MOF);
  - LNG Jetty;
  - Pipeline crossing at the Narrows;
  - Various works for marine structures/loading unloading facilities, etc.
- **Model Refinement** – Refinement of the existing TUFLOW-FV model of Port Curtis mesh to update the existing bathymetry to incorporate recent dredging and to optimise the mesh for accurate representation of the developed scenario features that are being assessed.
- **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.

1.4 Scenarios Assessed

The details of the scenarios are as supplied by ERM. The modelling scenarios include an Existing Case and four developed scenarios as summarised in the following. Figure 1-2 to Figure 1-6 illustrate the bathymetry and the extent of dredging/reclamation in each of the scenarios. A brief description of each scenario is provided as follows:

- **Scenario 1 – Existing Environment:**

  This scenario represents existing conditions in Port Curtis, including the current Wombat dredging program.
- **Scenario 2a:**

  This scenario includes the temporary access works (coffer dams) associated with the construction of the proposed QCLNG pipeline across the Narrows.
- **Scenario 2b – Project Case:**

  This scenario includes all proposed features associated with the QCLNG project, as follows:
  - Maintenance Offloading Facility (MOF) and associated dredging at -7.5m LAT
  - Construction dock embayment near the southern LNG boundary, dredged at -3.8m LAT
  - QCLNG swing basin and approach channel, dredged at -13m LAT
  - RG Tanna vehicle ramp structure extending approximately 60m form the shoreline

- GPC offshore dredge spoil disposal (i.e. 2Mm3 deposited evenly in an area within a 500m border from the outer spoil ground boundary)

It is noted that the GPC offshore spoil ground area is outside of the existing TUFLOW-FV model used in these assessments. The extended model, with comprises the outer harbour, has thus been used to undertake the assessment of this offshore dredge disposal. This is described further in the following sections.

Scenario 2b also includes the Clinton Bypass channel dredging.

- **Scenario 3 – Project Cumulative:**

  This scenario includes all QCLNG features as described above, as well as the dredging works associated with the Wiggins Island Coal Terminal Project, the Santos (GLNG) swing basin and approach channel, and the Targinie Extension Stage 1B.

- **Scenario 4 – Full Cumulative:**

  This scenario is similar to Scenario 3, with the addition of the proposed Western Basin strategic dredging and disposal project.

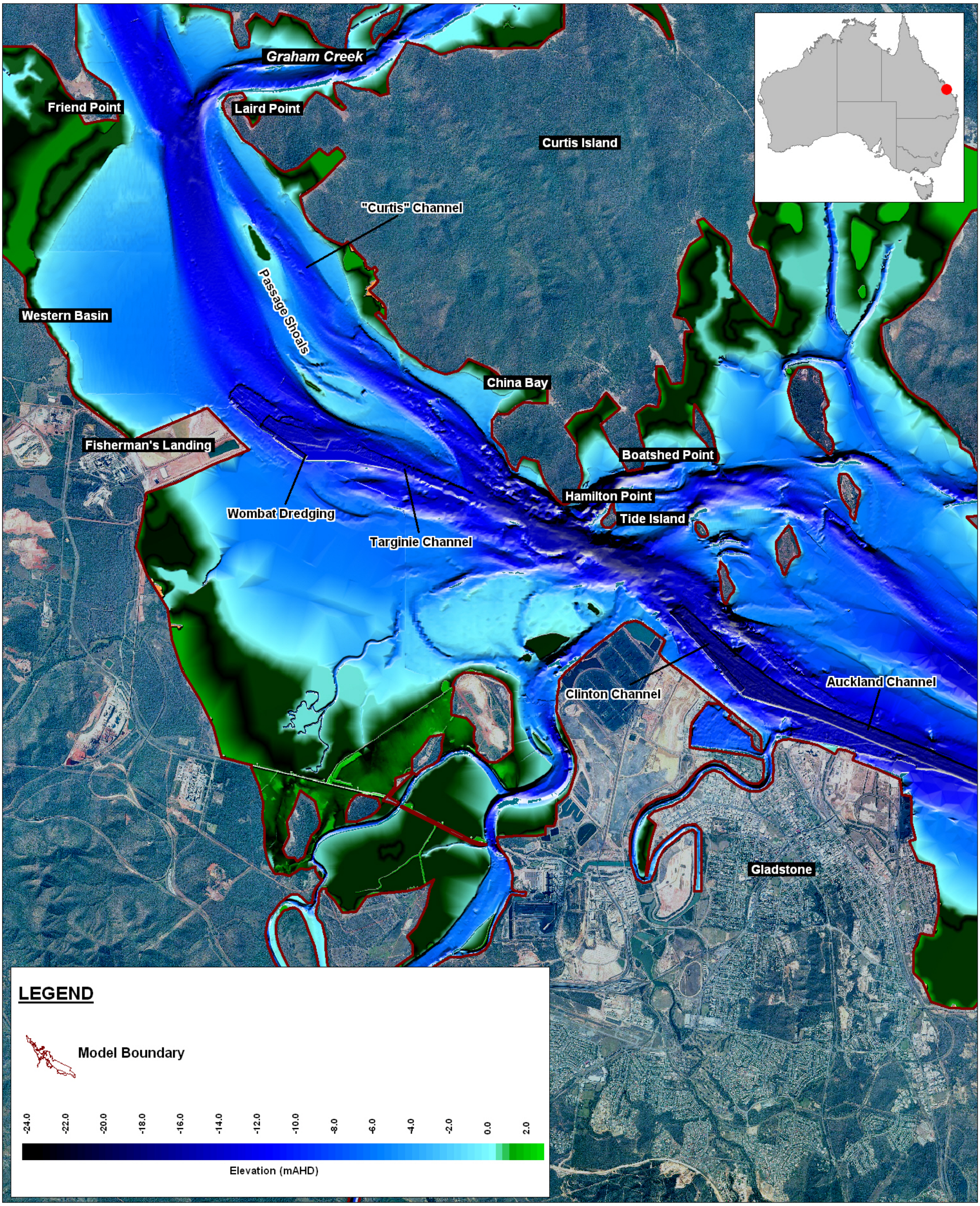
For all dredging scenarios, an over-dredging allowance of 0.3m has been included in the model simulations.

1.5 Pipeline Crossing Options

Scenario 2b, 3 and 4 were repeated with a different configuration of the rock armouring for the pipeline at the Narrows, as follows:

- *Option 1:* assuming a 2.5m high rock berm above the sea bed for the entire length of the pipeline between Laird Point and Friend Point;
- *Option 2:* assuming a 2.5m trench backfilled with rock in-situ material on the intertidal areas and with rock elsewhere; and
- *Option 3:* assuming a 2.5m trench backfilled with in-situ material on the intertidal areas and a 2.5m high rock berm above the seabed for the rest of the pipeline length.

These three options are reported in this report. It is noted that Option 1 is likely to have the worst impacts as the 2.5m high rock armouring above the sea bed effectively reduces the cross-sectional area available to flow at the pipeline crossing. This configuration also acts to block flow on the shallow areas either side of the main channel.



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Scenario 1 "Existing" Configuration

Figure: **1-2**

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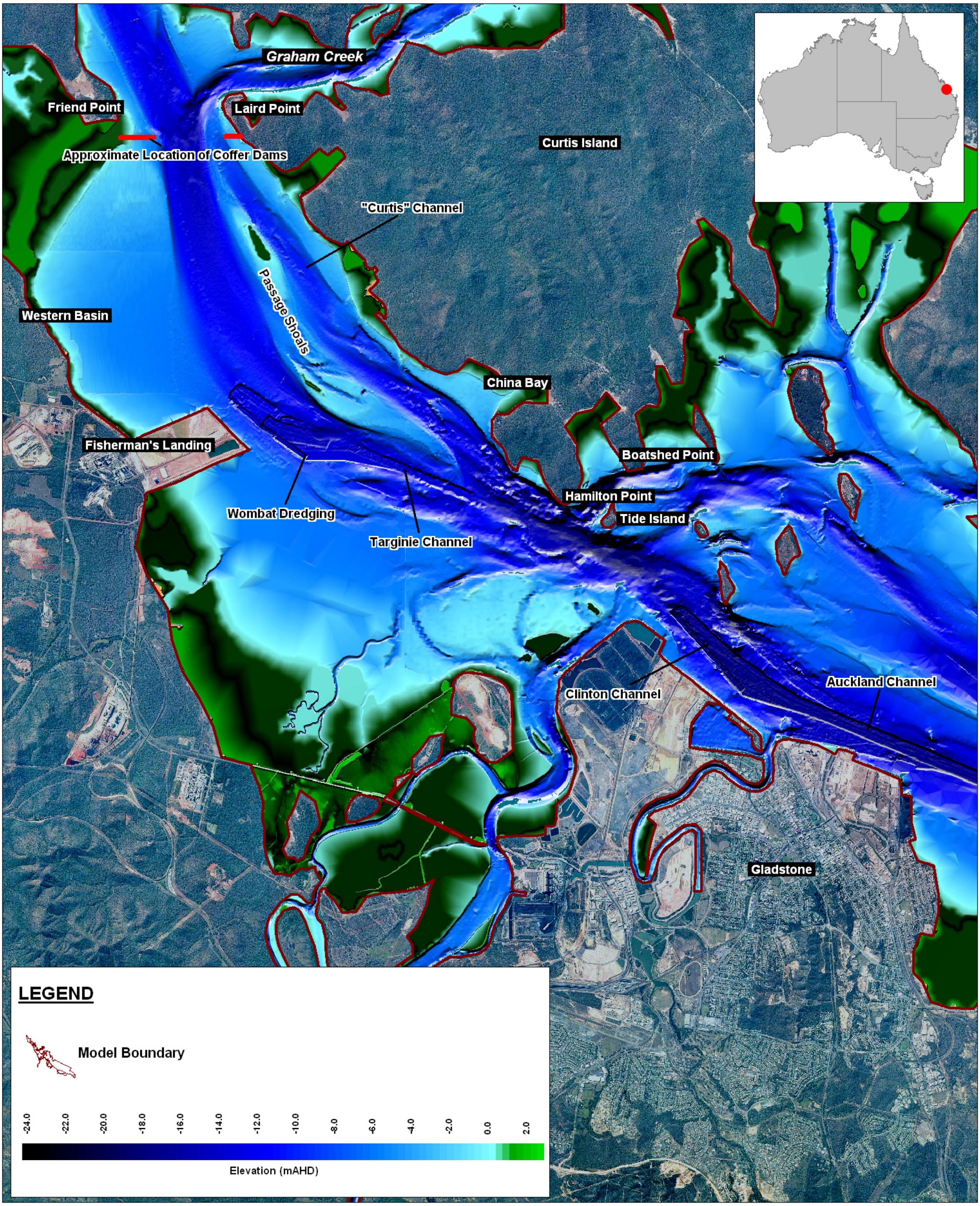

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Scenario 2a Configuration

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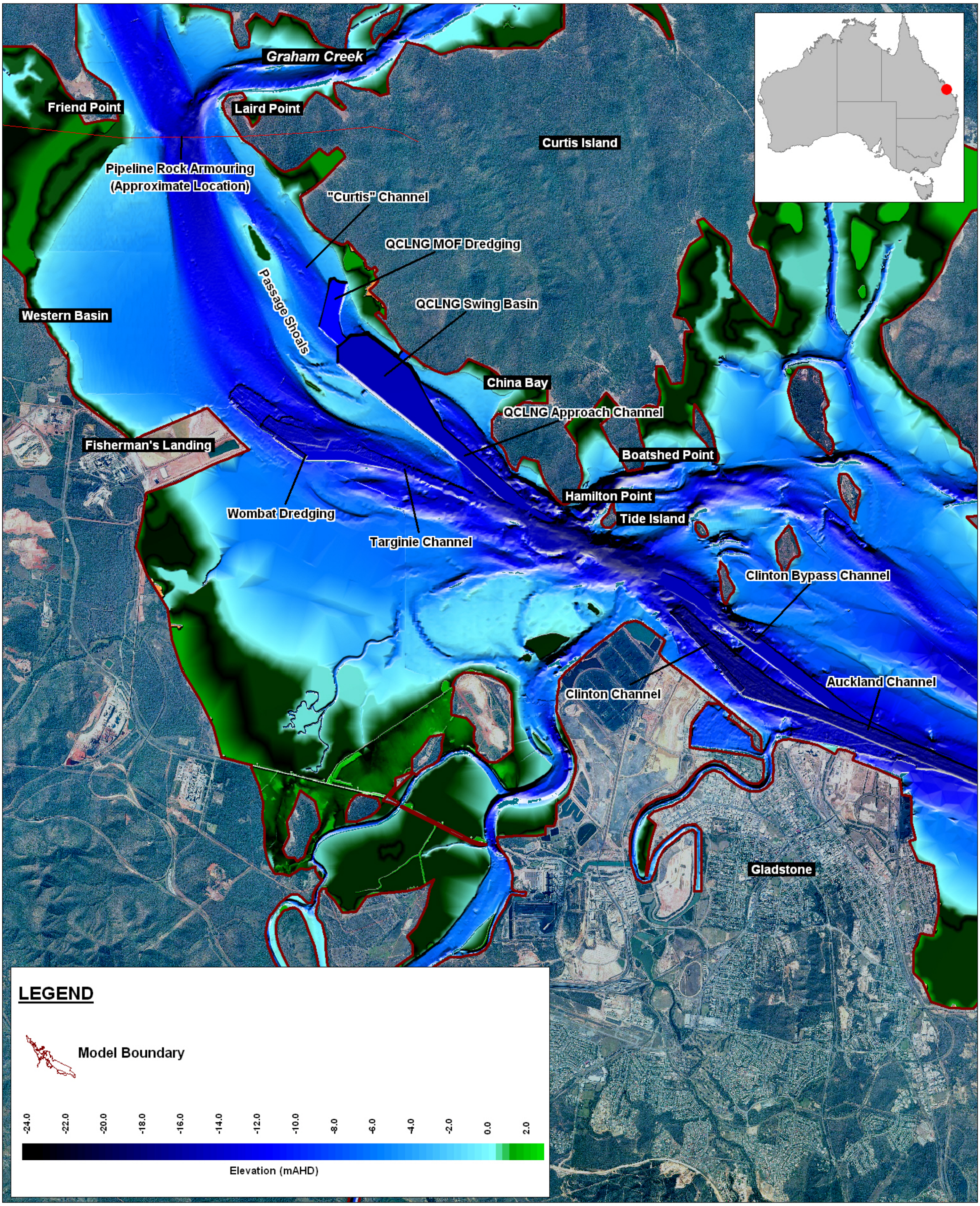

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Scenario 2b "Project Case" Configuration

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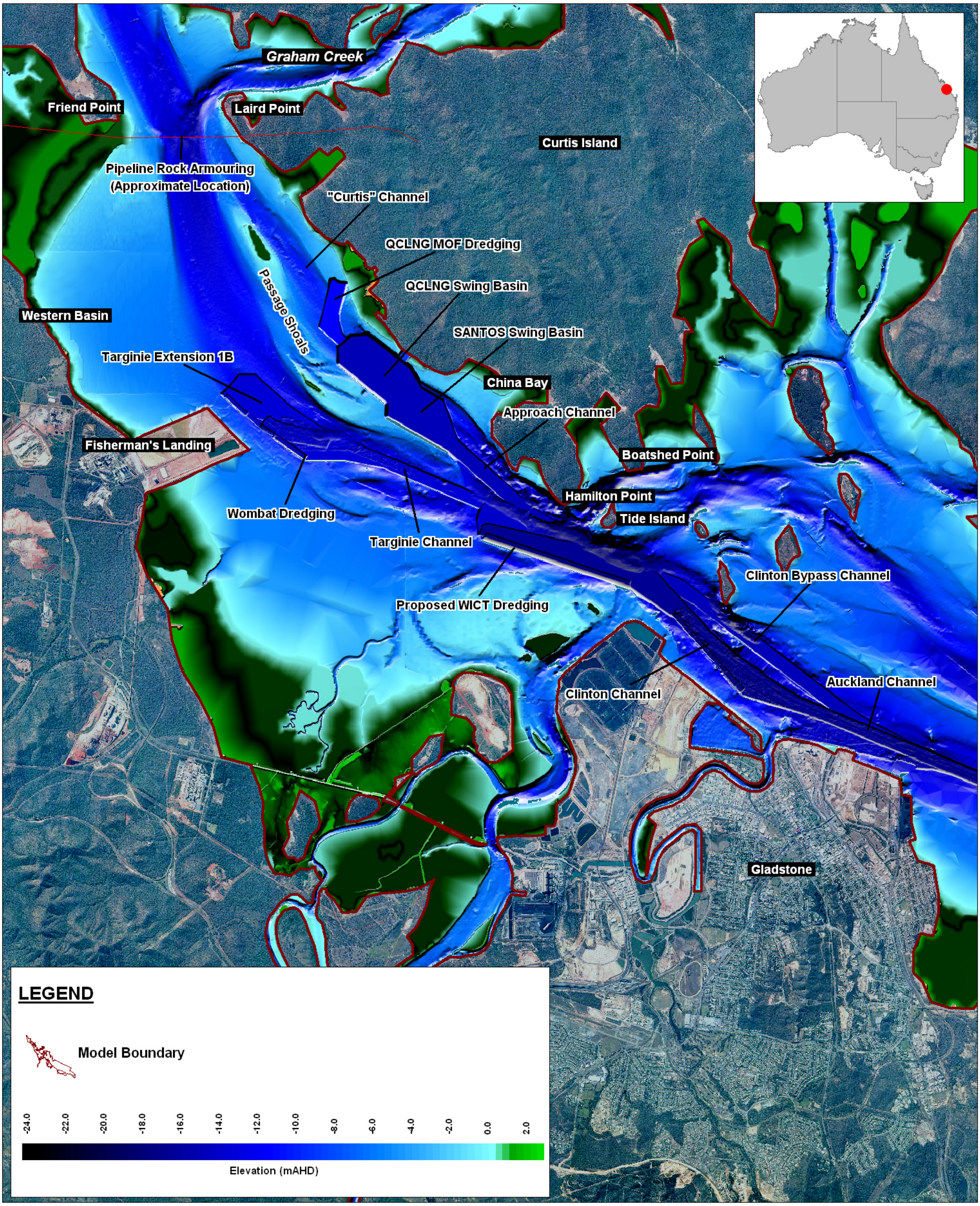

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Scenario 3 "Project Cumulative" Configuration

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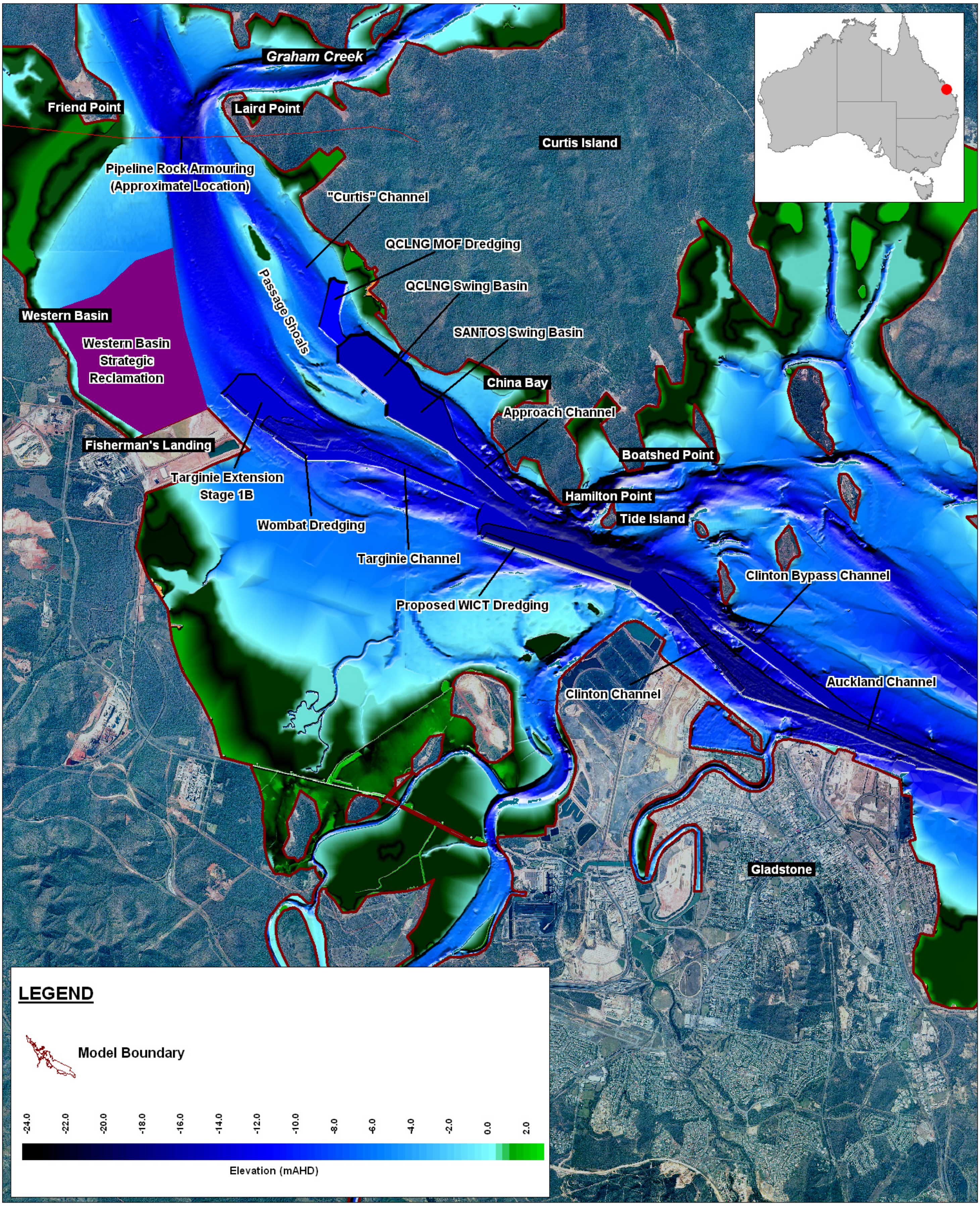

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Scenario 4 "Full Cumulative" Configuration

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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 on their websiteand are based on recent measurements and updates for the current Tidal Datum Epoch 1992-2011 (Maritime Safety Queensland, 2009). 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 and the mean neap tidal range is 1.54m. 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.

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.

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)	4.83	5.12	5.60	6.17
Mean High Water Springs (MHWS)	3.96	4.20	4.58	5.08
Mean High Water Neaps (MHWN)	3.11	3.30	3.59	4.01
Mean Level (ML)	2.34	2.41	2.68	3.01
Australian Height Datum (AHD)	2.268	2.43	-	-
Mean Low Water Neaps (MLWN)	1.57	1.66	1.79	2.07
Mean Low Water Springs (MLWS)	0.72	0.76	0.79	1.00
Lowest Astronomical Tide (LAT)	0.00	0.00	0.00	0.00

2.2 Methodology

The potential impacts of the proposed QCLNG 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 a separate model validation report (BMT WBM, 2009a).

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 existing case and the five 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 existing 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 areas. 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.

The extended model mesh, including the outer harbour is also presented in Figure 2-3. This extended model was used to investigate the impacts of the placement of dredge spoil within the existing GPC dredge disposal area within the outer harbour (i.e. as part of Scenario 2b).

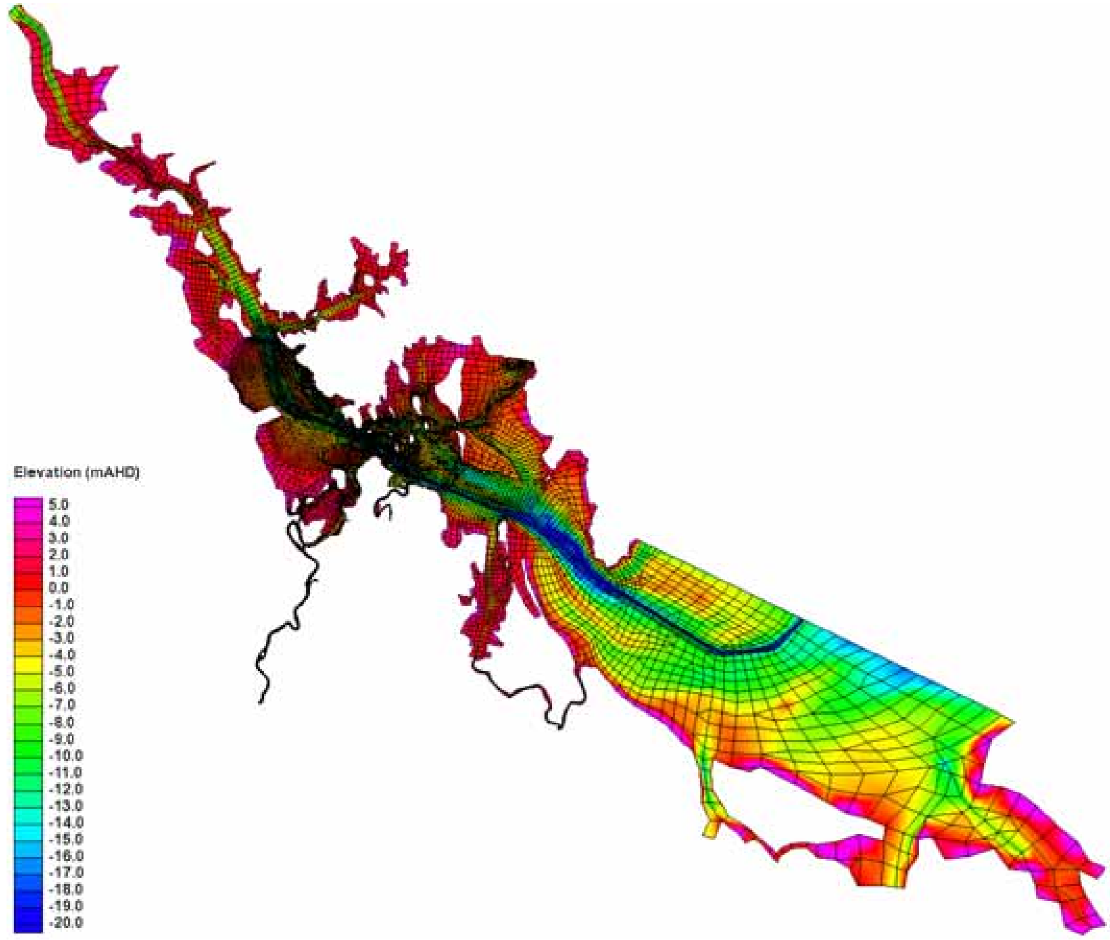

Figure 2-1 Overall Model Mesh

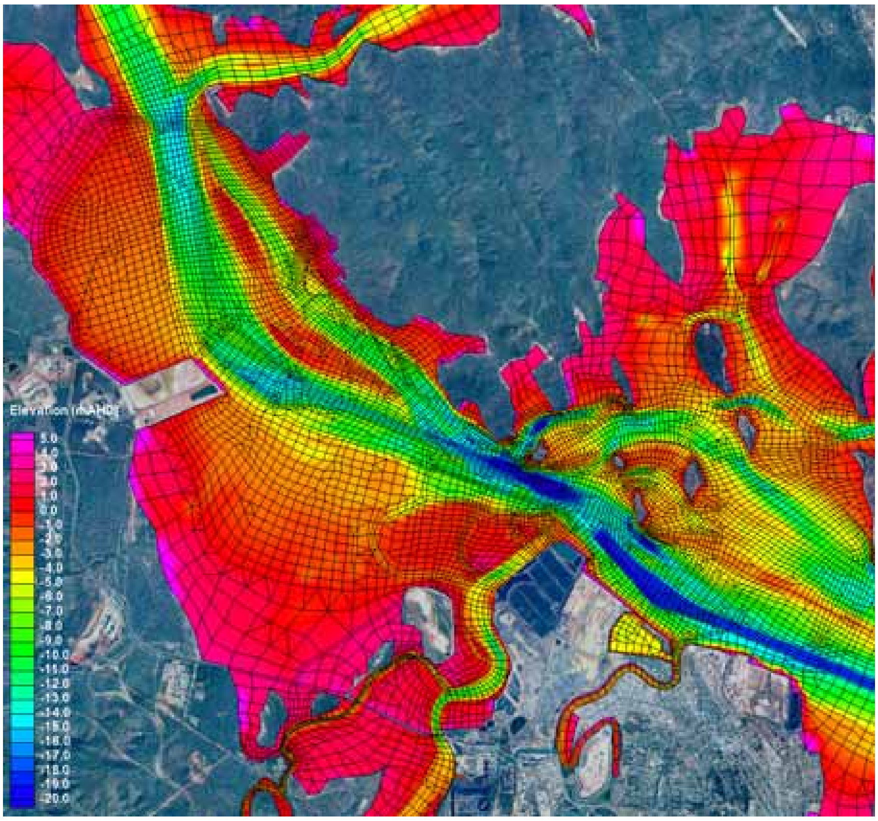

Figure 2-2 View of Model Mesh in the vicinity of the QCLNG project

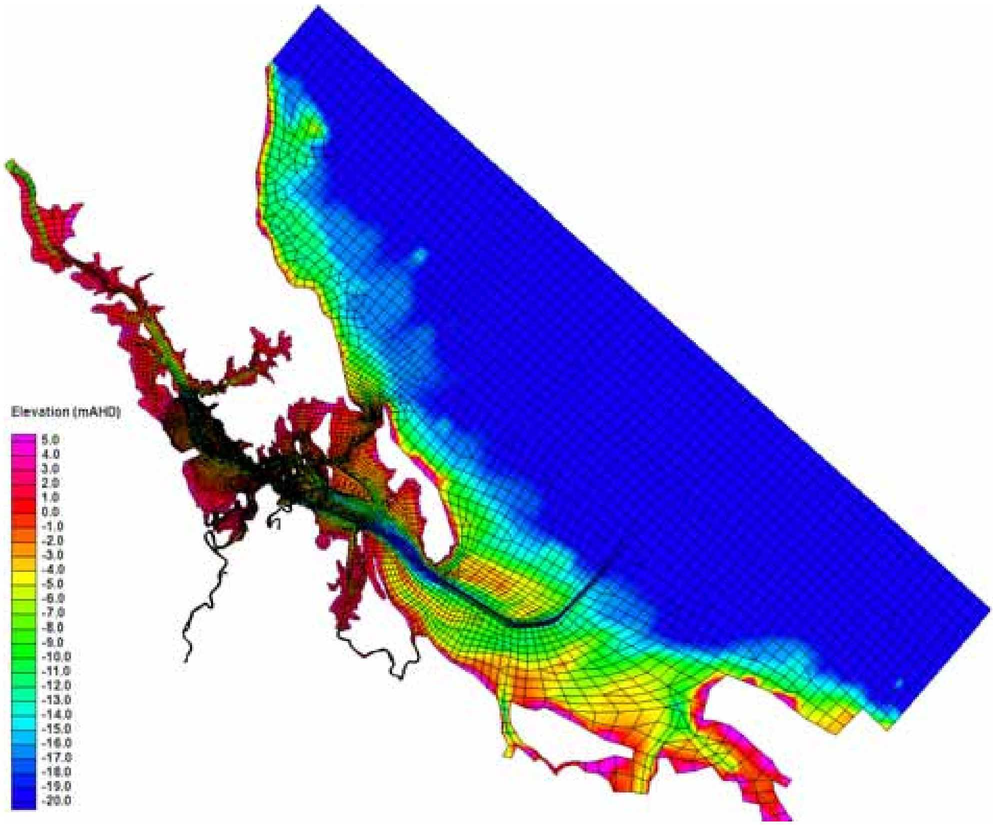

Figure 2-3 Extended Model Mesh

All simulations (except those involving the extended model – this is discussed further below) 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 2009a).

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 2-4. 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 2-5. 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.

Further details about the 2 month period selected for the impact assessments is provided in the Western Basin Dredging EIS prepared for Gladstone Port Corporation (BMT WBM 2009b).

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. The following table summarises the presentation of the results. These results are described in the following sections.

Table 2-2Results Presentation

Results	Pipeline Crossing Option 1	Pipeline Crossing Option 2	Pipeline Crossing Option 3
Water Level Timeseries	APPENDIX A:	APPENDIX G:	APPENDIX M:
Velocity Magnitude Timeseries	APPENDIX B:	APPENDIX H:	APPENDIX N:
Velocity Contours	APPENDIX C:	APPENDIX I:	APPENDIX O:
Tracer Concentration Timeseries	APPENDIX D:	APPENDIX J:	APPENDIX P:
Tracer Concentration Contours	APPENDIX E:	APPENDIX K:	APPENDIX Q:
e-Folding Time Contours	APPENDIX F:	APPENDIX L:	APPENDIX R:

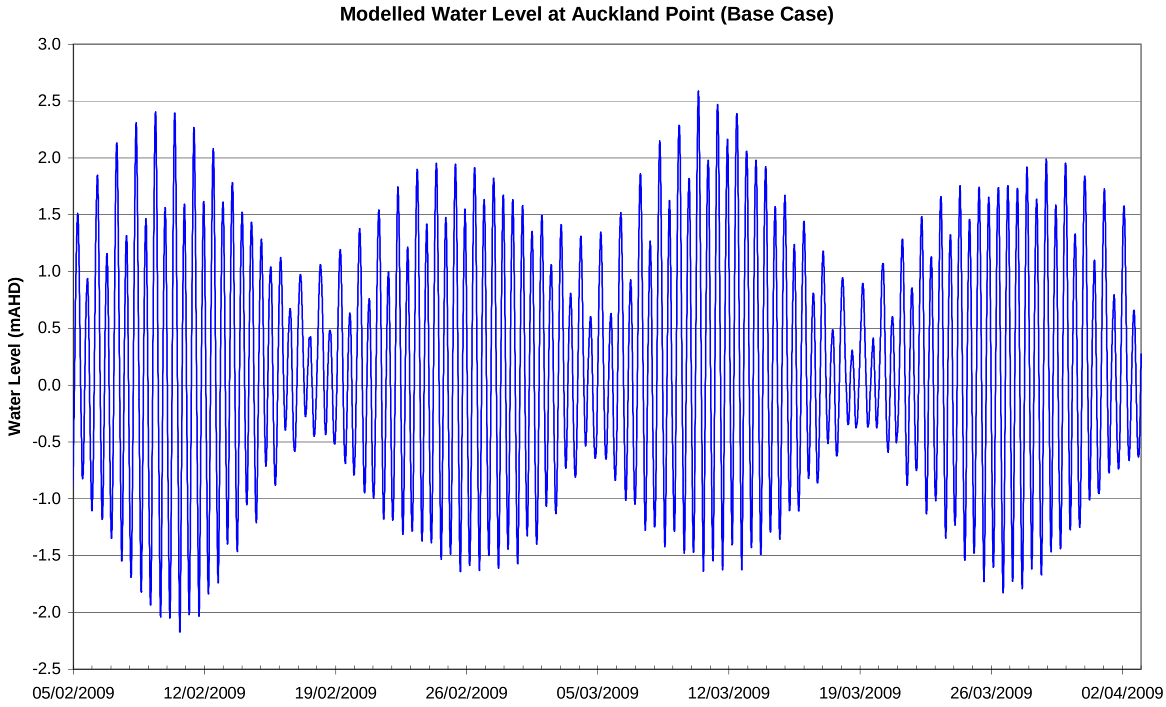

Figure 2-4 Simulation Period Water Levels – Auckland Point

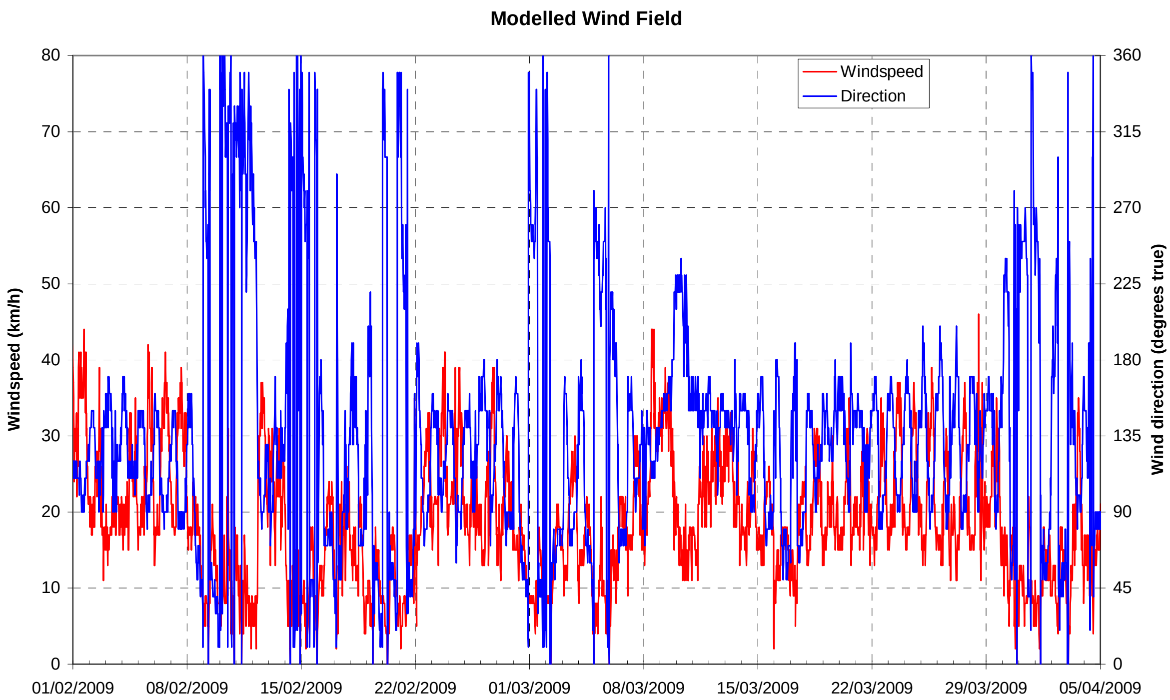

Figure 2-5 Simulation Period Wind Speed and Direction

2.3 Potential Tidal Hydraulic Impacts

2.3.1 Water Level Time Series

Time series of water level for all simulations were extracted at 11 locations as shown in Figure 2-6 below. Plots of the water level time series for all development scenarios as well as the existing case at each extraction location are presented in Appendix A for Option 1, Appendix B for Option 2 and Appendix C for Option 3. It is noted that the Western Basin extraction point is located in a shallow area, which dries at low tide as evidenced by the timeseries at this location being truncated at the bed elevation when the tide is below this level.

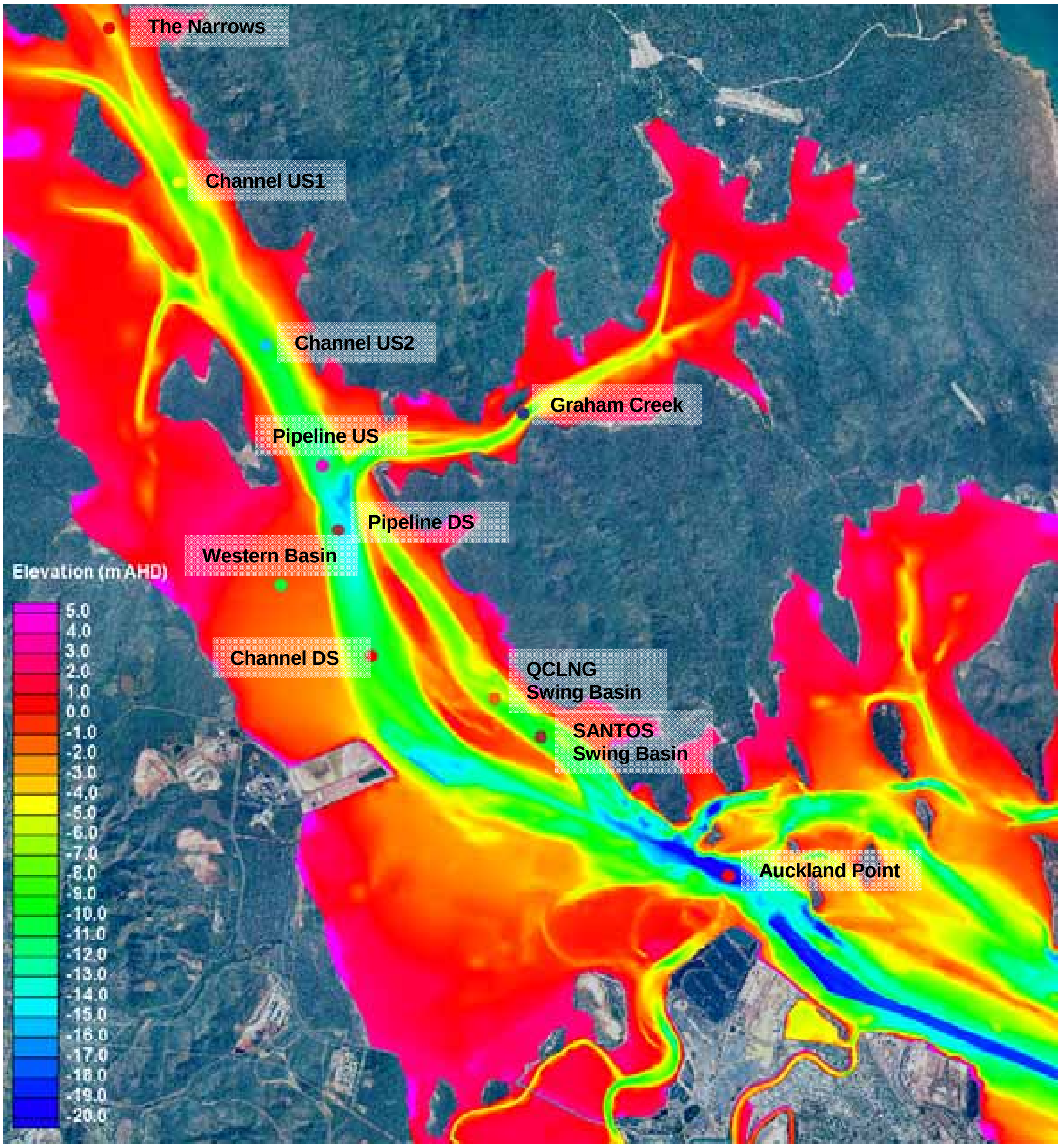

Figure 2-6 Time Series Extraction Location

2.3.2 Velocity Magnitude Timeseries

Time series of current speed for all simulations were extracted at the selected 11 locations shown in Figure 2-6. Plots of the velocity magnitude time series for each development scenarios compared to the existing case are presented in Appendix D for Pipeline Crossing Option 1, Appendix E for Option 2 and Appendix F for Option 3. Again, it is noted that the Western Basin extraction point is located in a shallow area which dries at low tide as evidenced by the extended periods with zero velocities.

2.3.3 Velocity Contours

Maps of typical large spring tide velocity patterns are presented below for the existing case (Scenario 1) and the design scenarios for Pipeline Crossing Option 1. Pipeline Crossing Option 2 contour plots are reported in Appendix G and Pipeline Crossing Option 3 contour plots are reported in Appendix H.

These figures depict the velocity magnitude with colour contours and velocity magnitude and direction with scaled vectors. The plots have been generated for two periods corresponding to approximately the time of peak flood velocities (10/02/2009 7:15) and peak ebb velocities(10/02/2009 12:45) in the main channel. 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 existing case magnitude at the selected time. The difference plots also include the developed case velocity vectors at that time for reference purposes.

For Scenario 2b Option 1, additional contour plots have also been provided for the extended model, in order to quantify the potential impacts on velocity magnitude generated by the disposal of dredged material in the outer harbour spoil ground area.

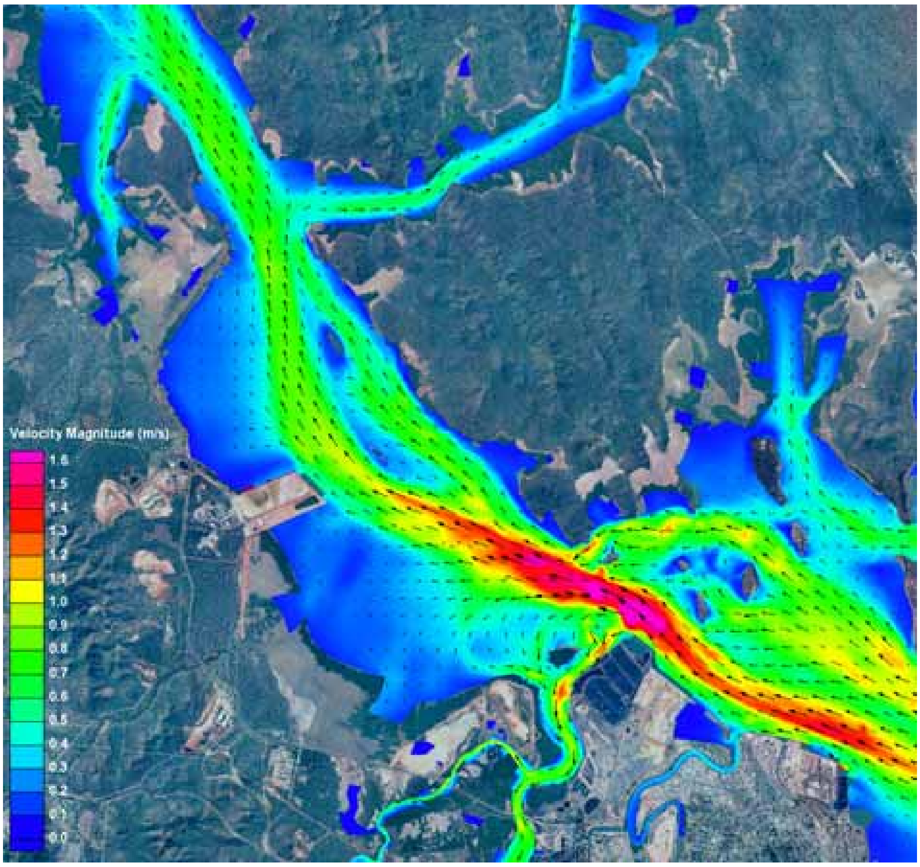

Figure 2-7 Scenario 1 (Existing) peak flood tide velocities

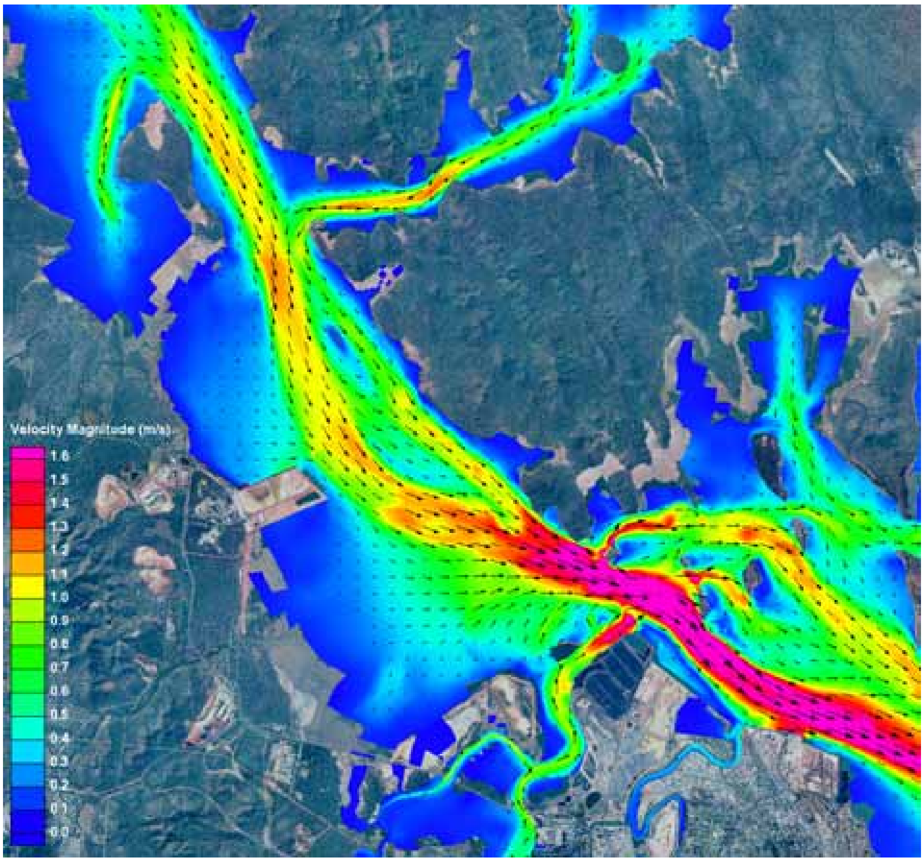

Figure 2-8 Scenario 1 (Existing) peak ebb tide velocities

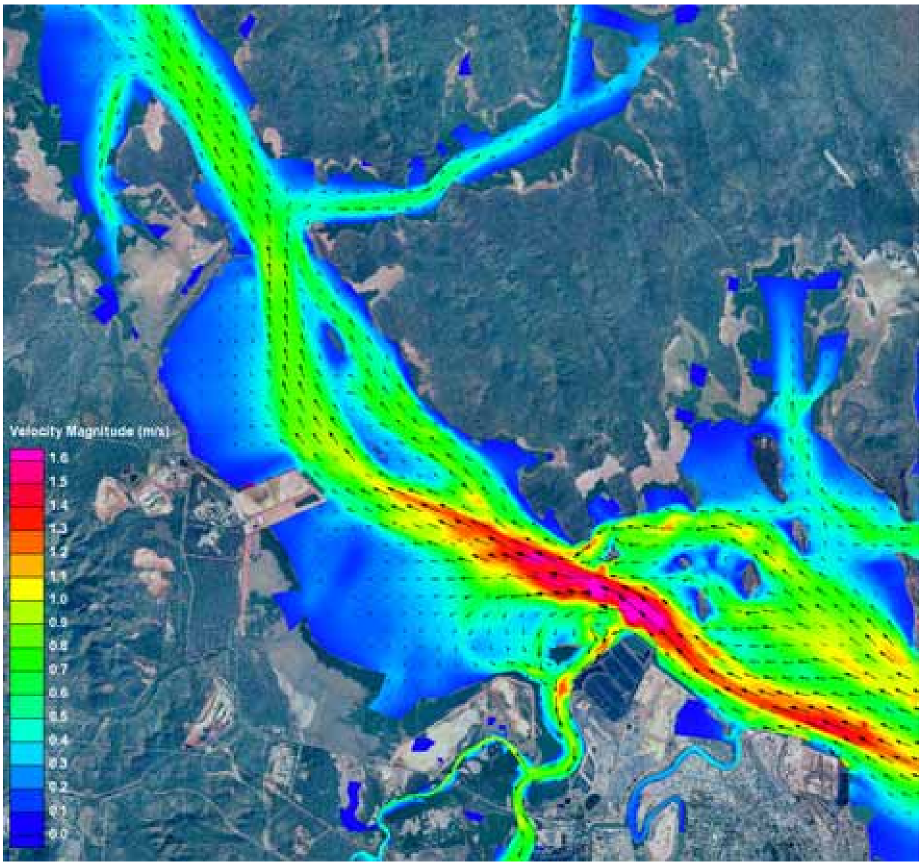

Figure 2-9 Scenario 2a peak flood tide velocities

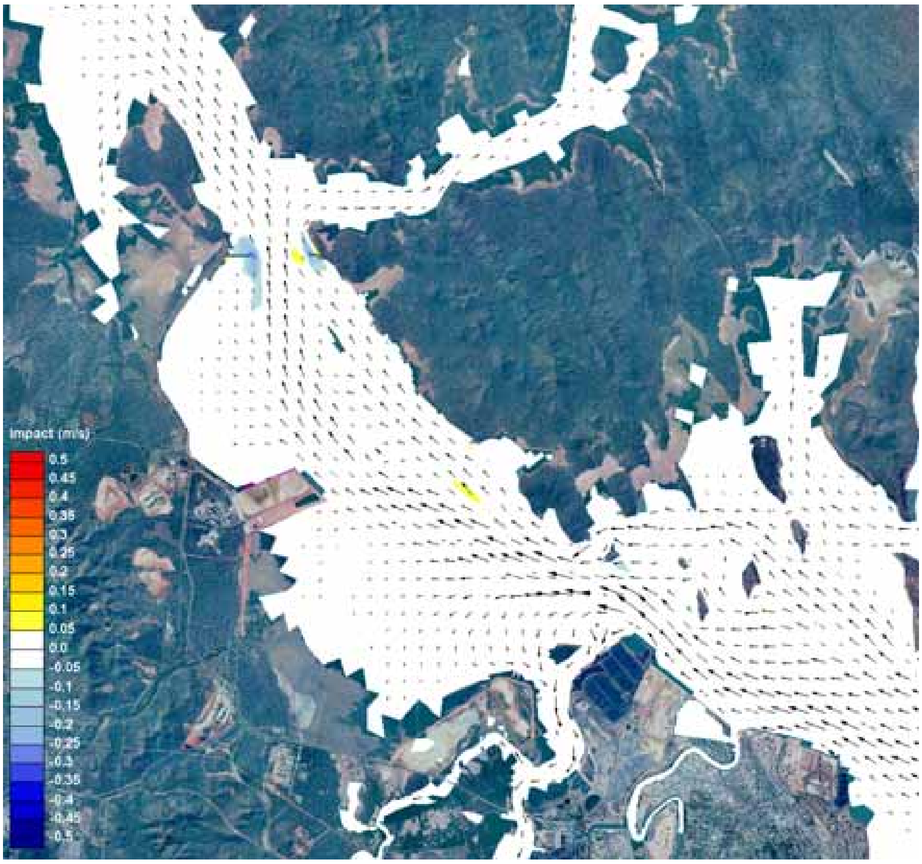

Figure 2-10 Scenario 2a peak flood tide velocity differences

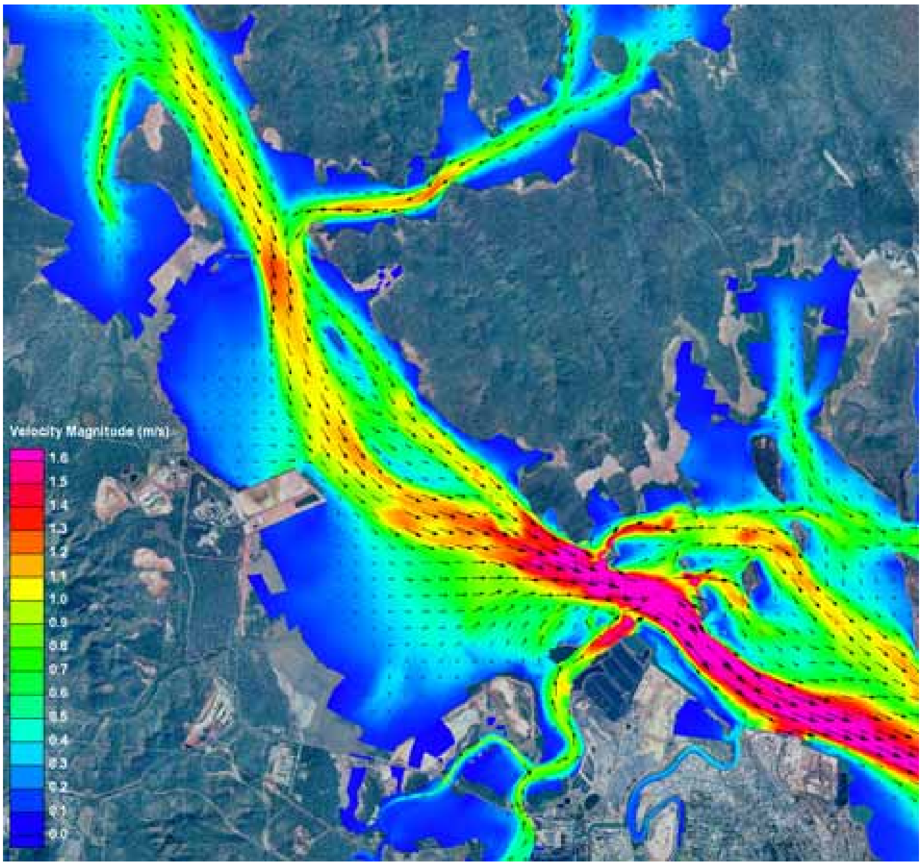

Figure 2-11 Scenario 2a peak ebb tide velocities

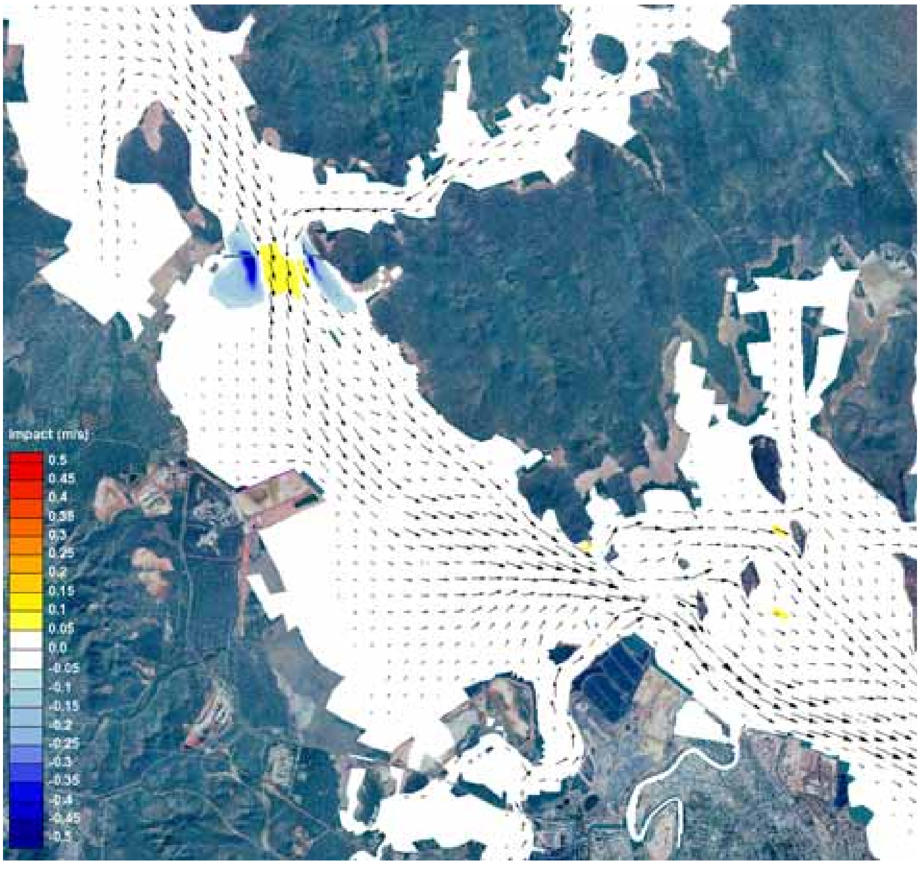

Figure 2-12 Scenario 2a peak ebb tide velocity differences

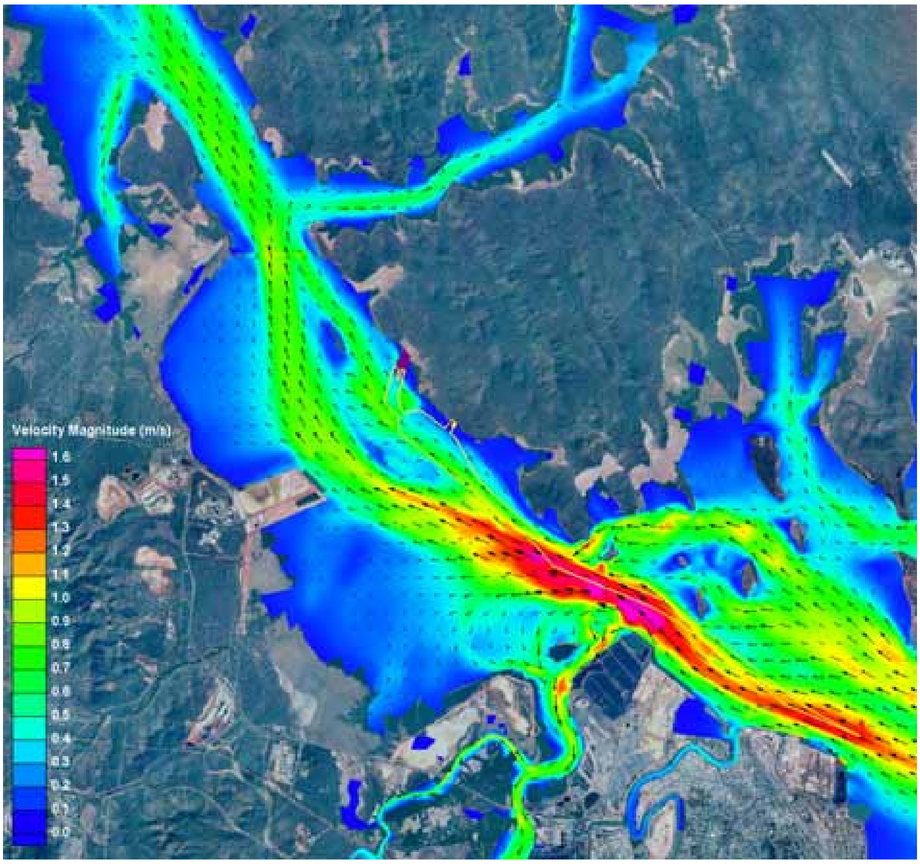

Figure 2-13 Scenario 2b peak flood tide velocities

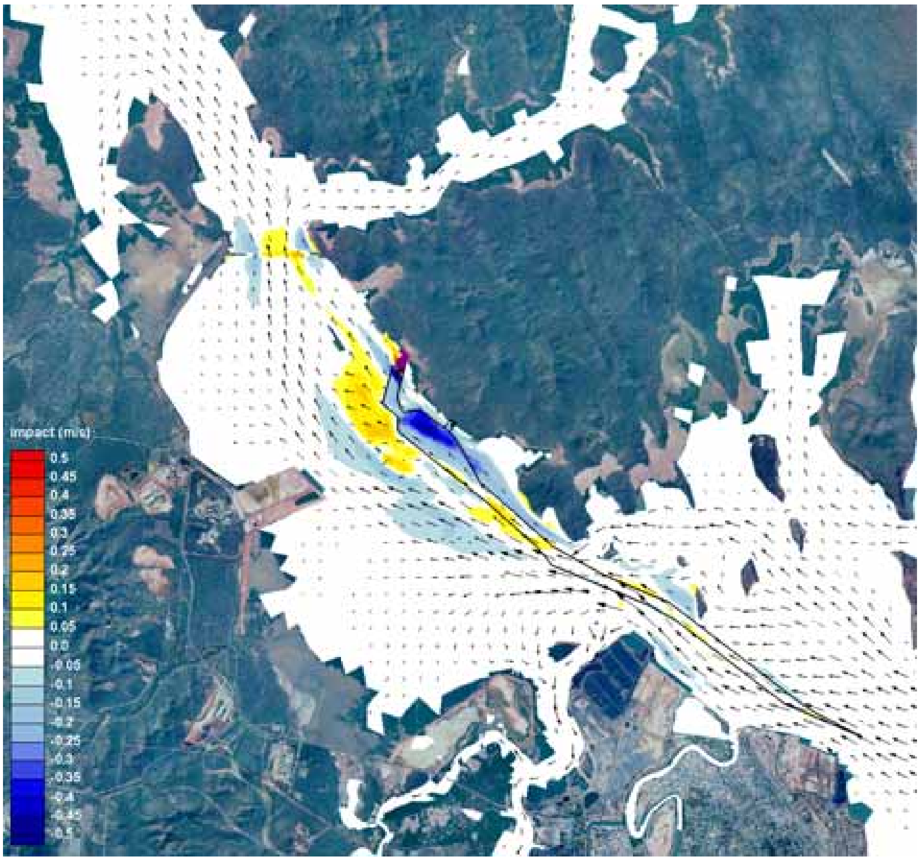

Figure 2-14 Scenario 2b peak flood tide velocity differences

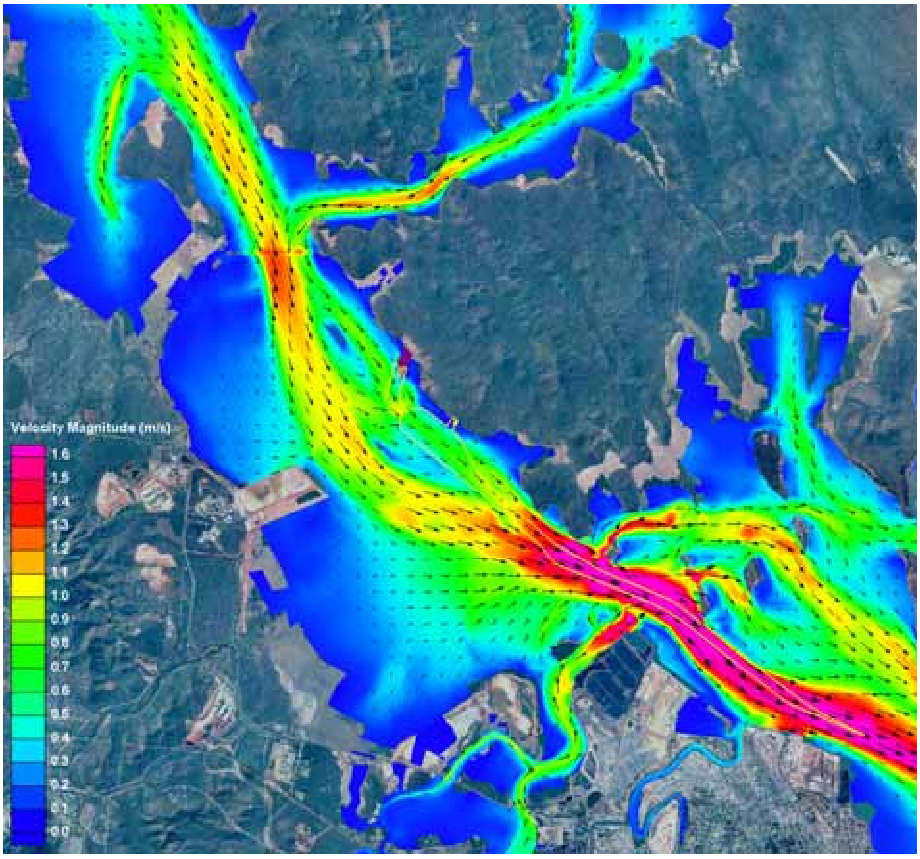

Figure 2-15 Scenario 2b peak ebb tide velocities

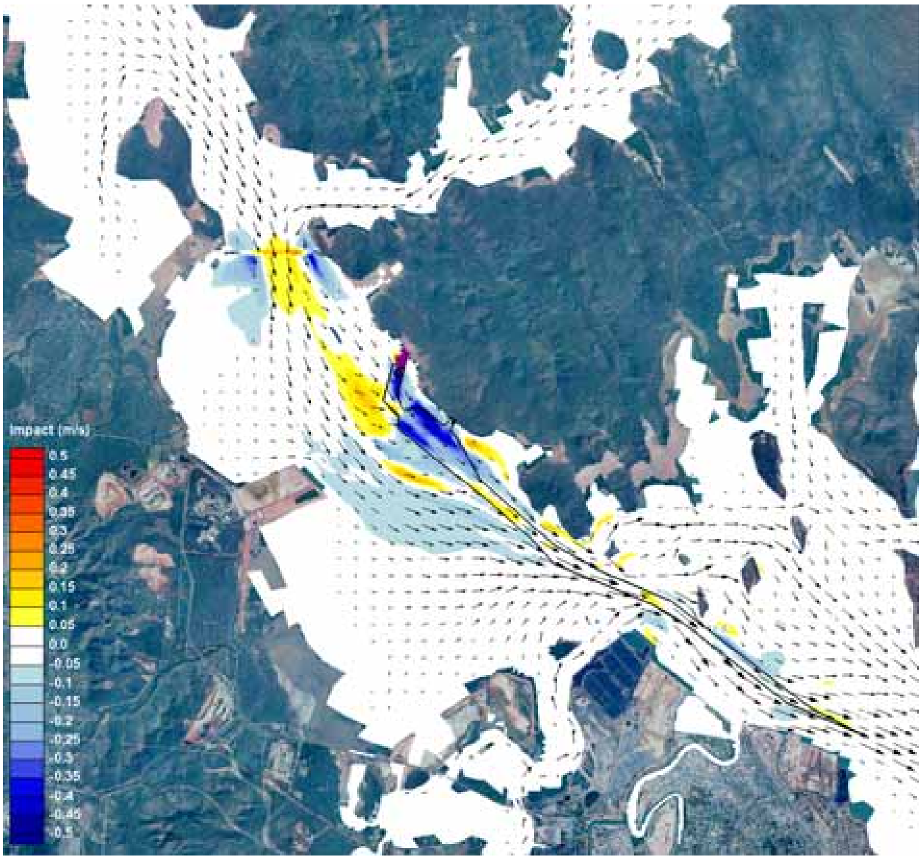

Figure 2-16 Scenario 2b peak ebb tide velocity differences

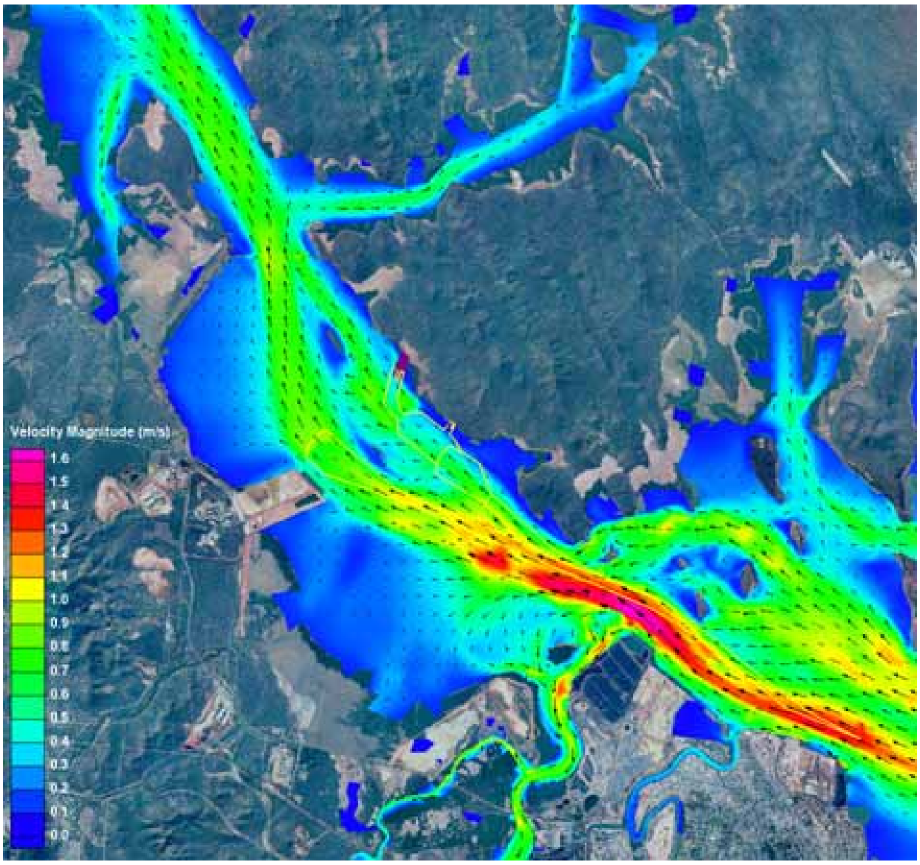

Figure 2-17 Scenario 3 peak flood tide velocities

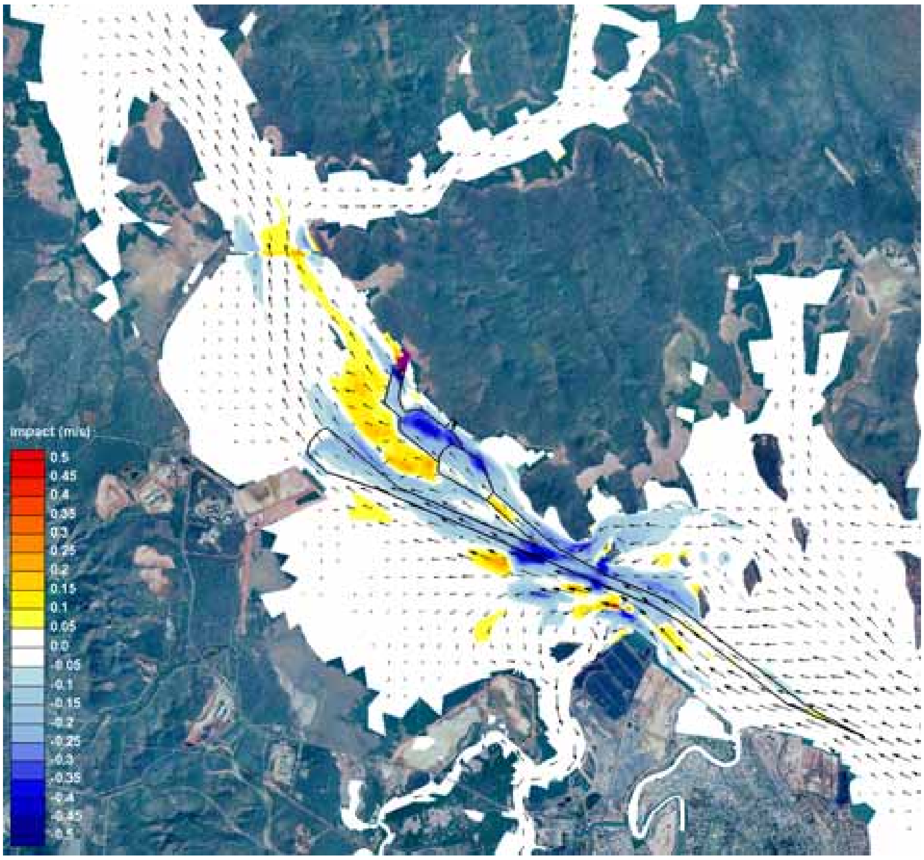

Figure 2-18 Scenario 3 peak flood tide velocity differences

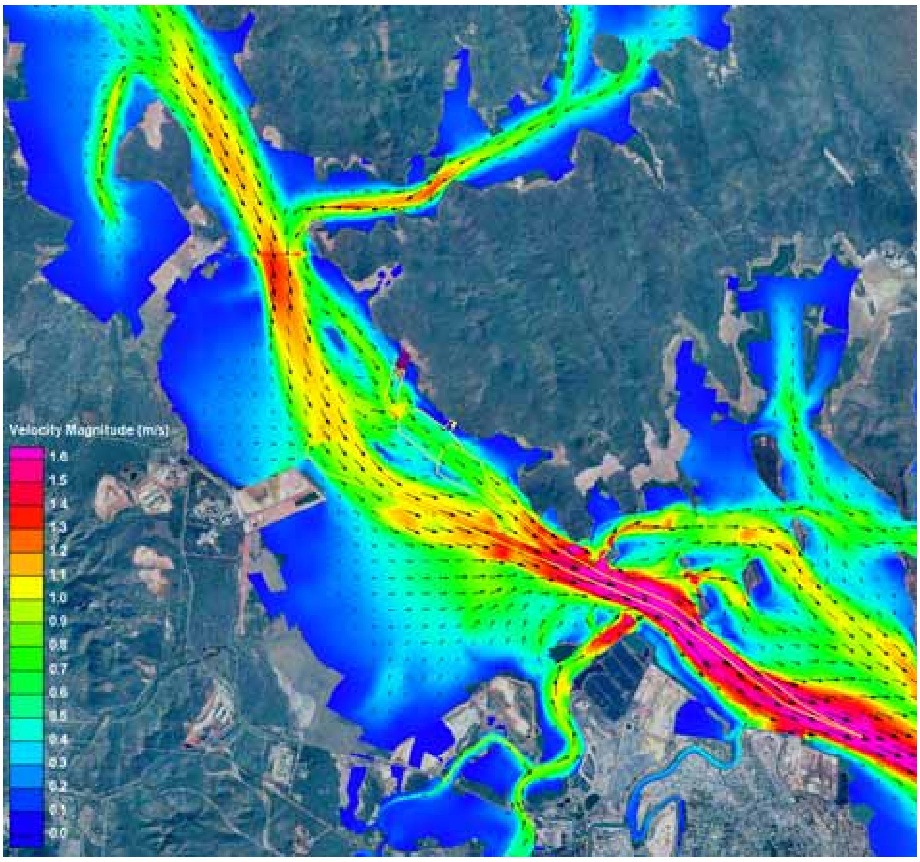

Figure 2-19 Scenario 3 peak ebb tide velocities

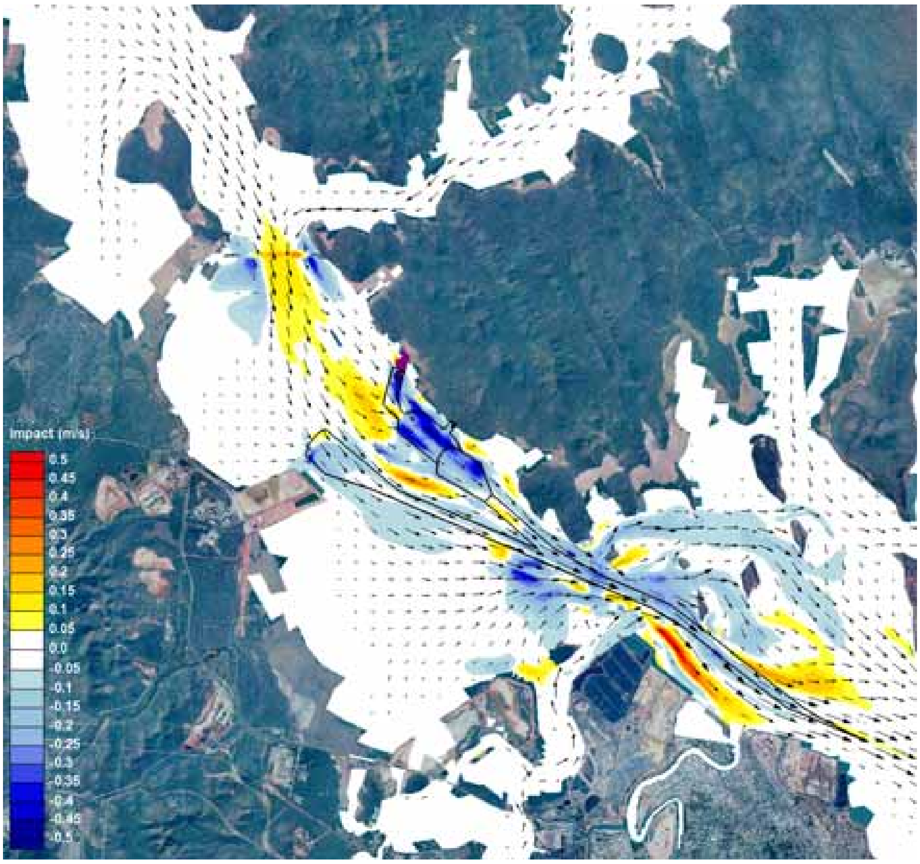

Figure 2-20 Scenario 3 peak ebb tide velocity differences

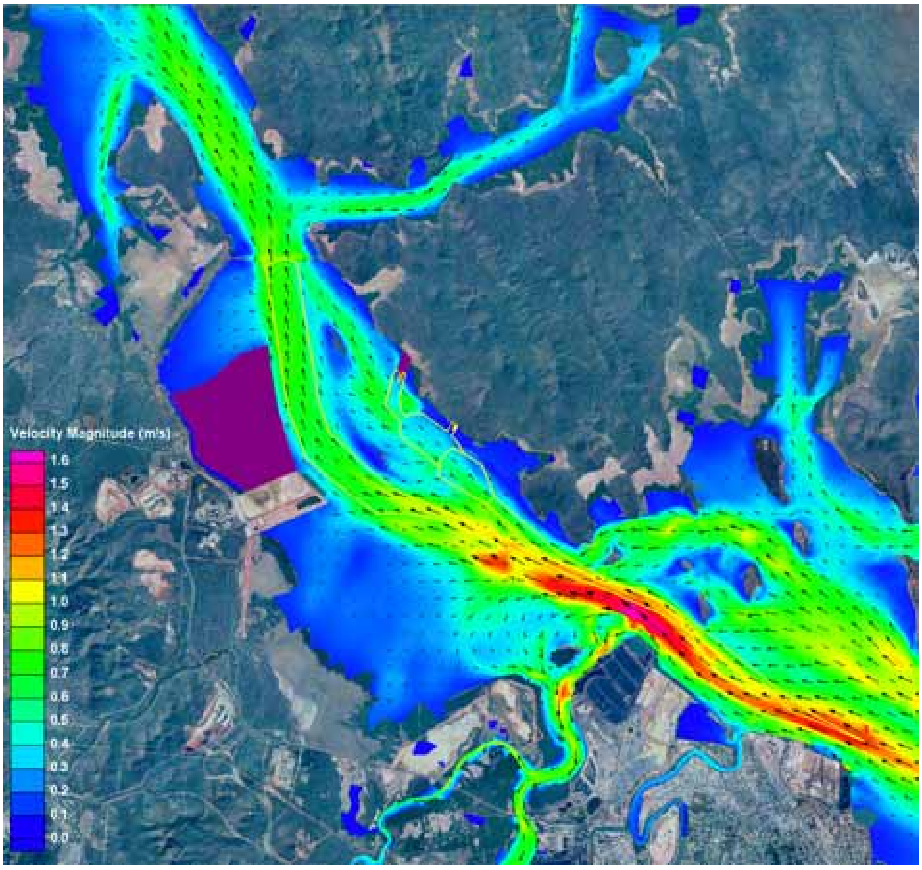

Figure 2-21 Scenario 4 peak flood tide velocities

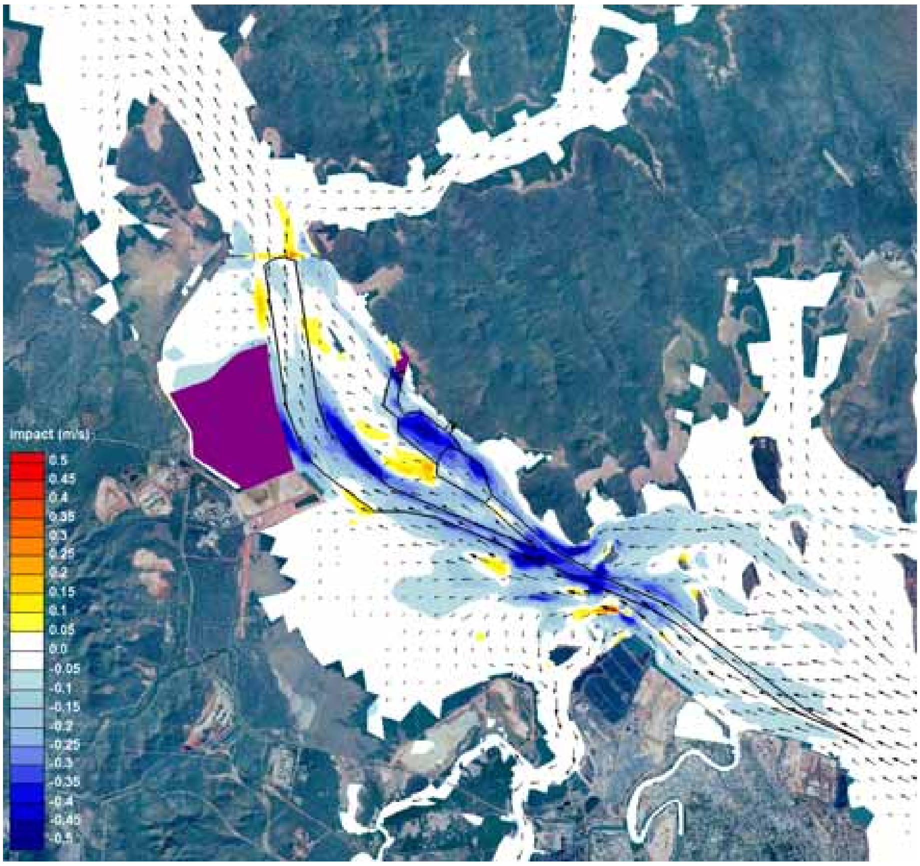

Figure 2-22 Scenario 4 peak flood tide velocity differences

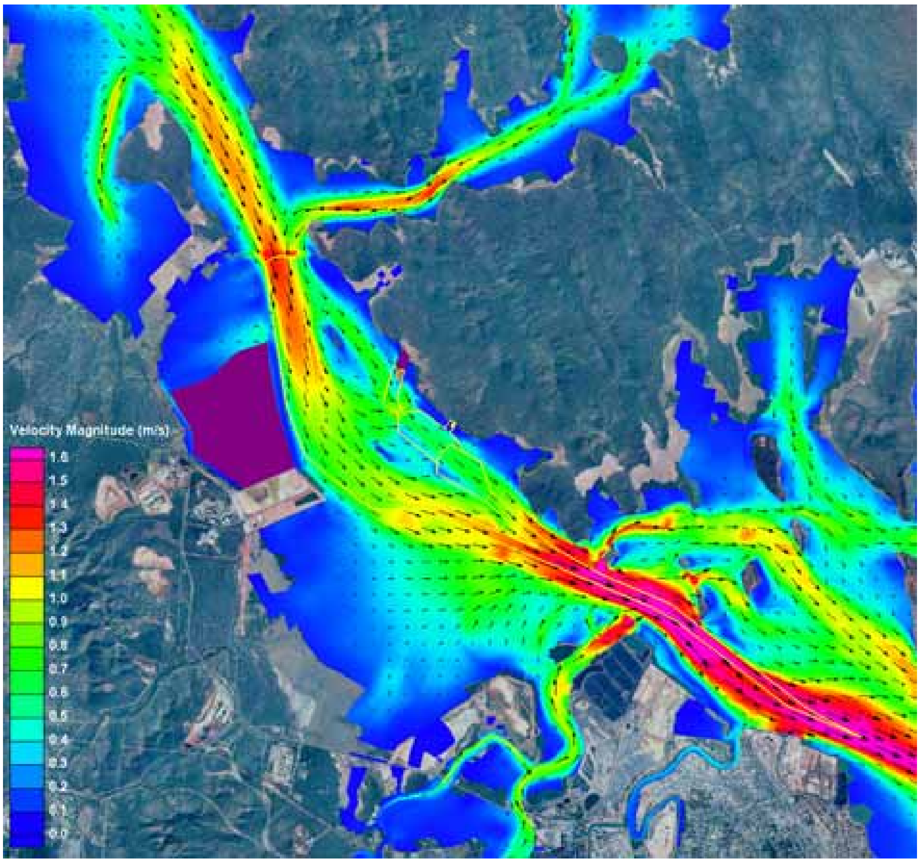

Figure 2-23 Scenario 4 peak ebb tide velocities

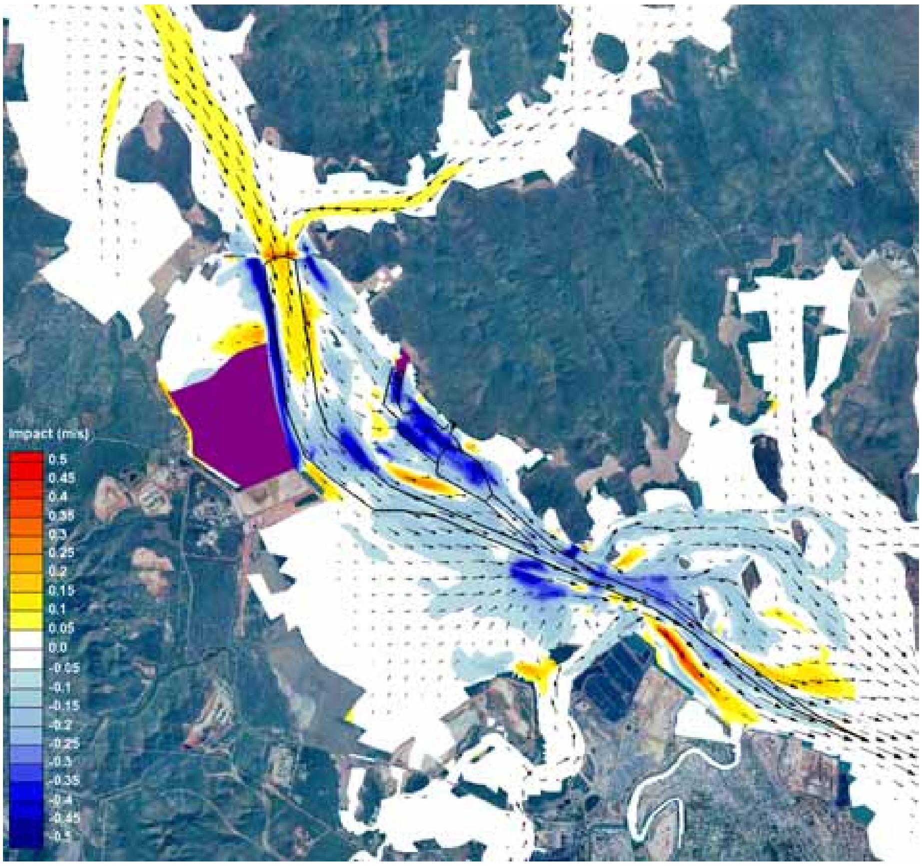

Figure 2-24 Scenario 4 peak ebb tide velocity differences

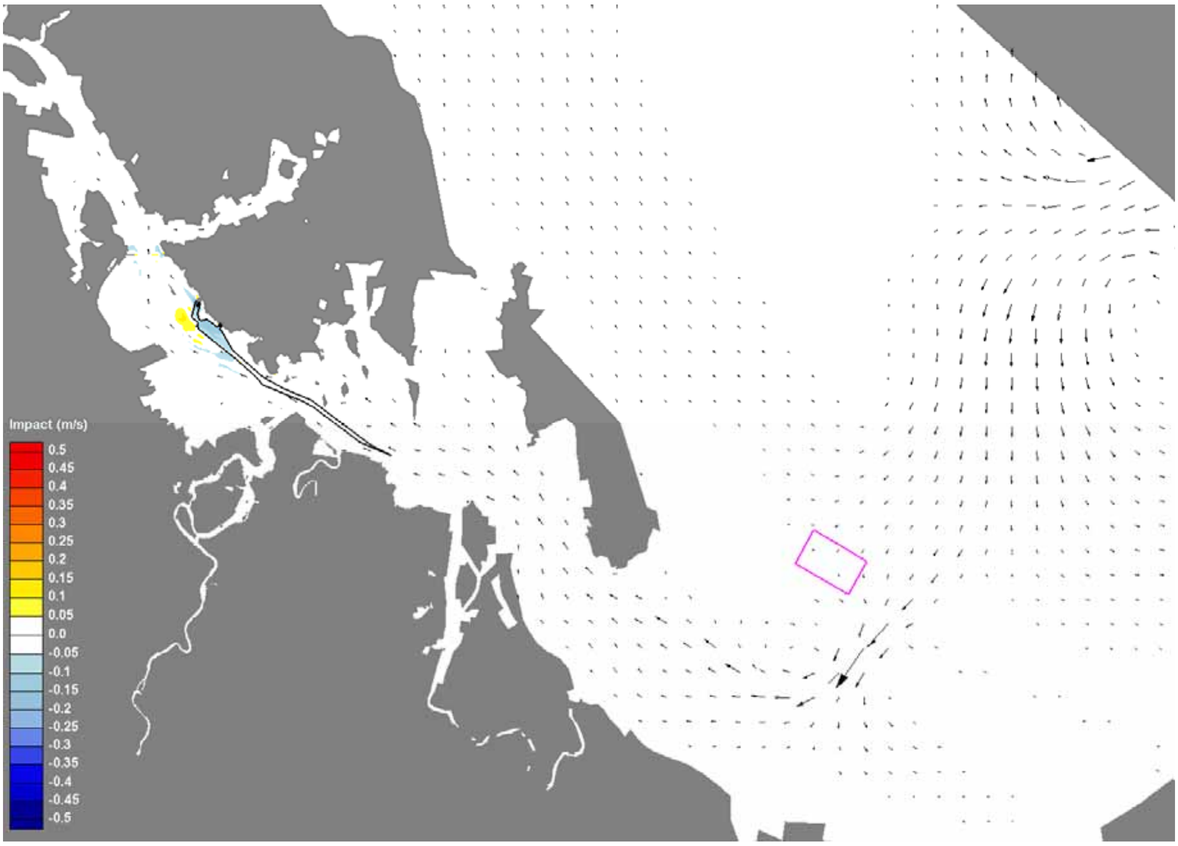

Figure 2-25 Extended Model - Scenario 2b peak flood tide velocity differences

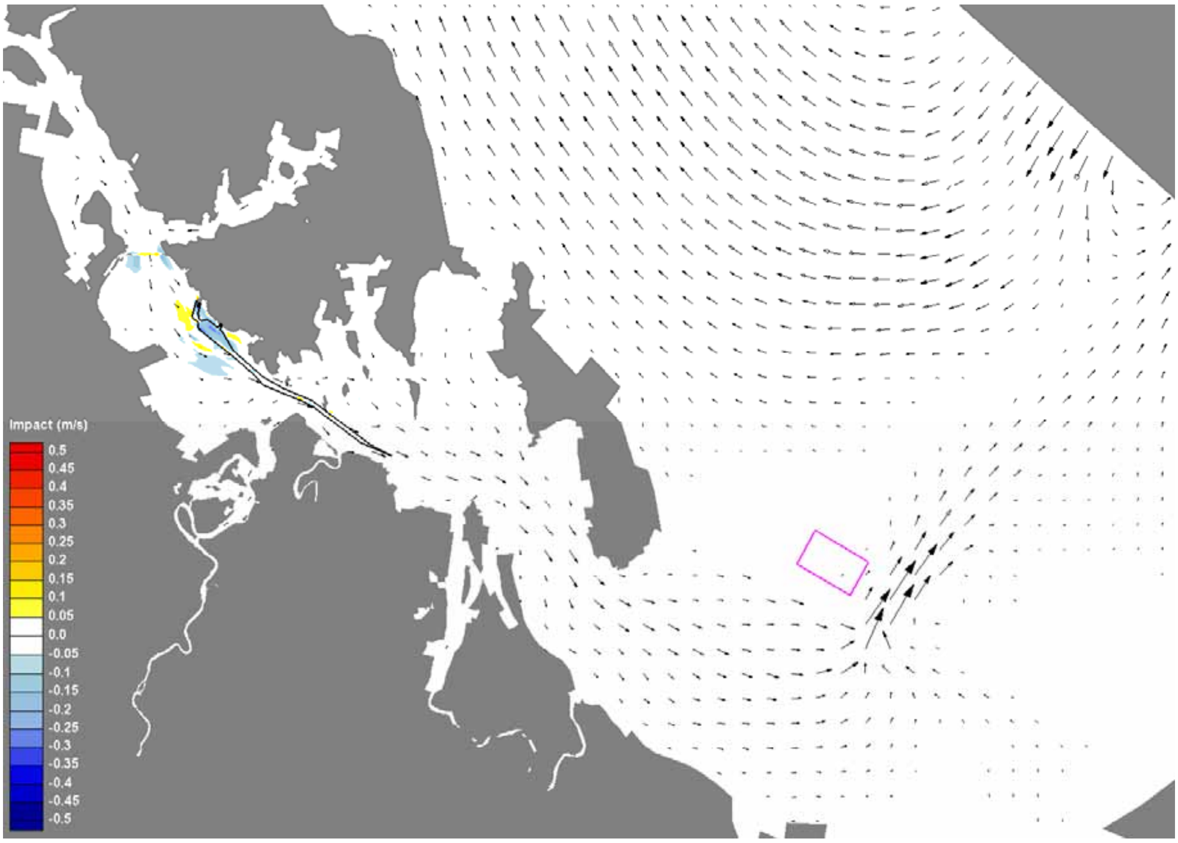

Figure 2-26 Extended Model - Scenario 2b peak ebb tide velocity differences

2.4 Discussion of Potential Impacts

The proposed dredging and reclamation works introduce various inter-related, additive and sometimes compensating effects to modify water levels, currents and flows making impact assessment complex.

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 MOF reclamation, Western Basin reclamation and temporary causeway structures at Laird Point can also act to modify velocities immediately upstream and downstream by confining and redirecting the flow.

2.4.1 Water Level Impacts

The water level time series results (see Appendices) indicate that the proposed QCLNG dredging and reclamation works alone will have negligible impact (1cm or less) on high and low tide levels throughout the area, for all pipeline construction options.

For scenario 3 and scenario 4, although high tide levels are predicted to remain globally unchanged (1cm or less impact), there are some changes to low tide levels, as detailed in Table 2-3.

Table 2-3 Spring Low Tide Level Impacts

Location	Scenario 2b	Scenario 3	Scenario 4
The Narrows	-1.4cm	+0.3cm	+4.7cm
QCLNG Swing Basin	+1.0cm	+2.1cm	+4.4cm
SANTOS Swing Basin	+0.4cm	+1.4cm	+3.6cm
Auckland Point	+0.2cm	+0.3cm	+2.2cm

Water level impacts are generally insensitive to the pipeline construction option, with comparable results predicted for all three options.

2.4.2 Velocity Impacts

Velocity 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 reported in Appendices. They can be summarised with reference to the spatial difference plots at about the time of peak flood and ebb spring tide currents as discussed below.

Scenario 2a Velocity Impacts

Scenario 2a simulated the impacts of the temporary coffer dams proposed for construction of the pipeline between Friend Point and Laird Point. The predicted impact of Scenario 2a on current velocities are generally localised within approximately 500m upstream (north) and 1km downstream (south) of the proposed pipeline crossing. These impacts are generally of bigger magnitude during ebb tide, with decreases of up to 0.4m/s predicted in the lee of the coffer dams, and increases in peak velocities of about 0.1m/s predicted in the main channel between those coffer dams.

Scenario 2b Velocity Impacts

The impacts on current velocities due to the features of the proposed QCLNG project other than the pipeline crossing (i.e. MOF, swing basin and approach channel dredging and reclamations) are similar for the three pipeline crossing options and are summarised as follows:

- Decreases in peak flood and peak ebb velocities of up to 0.4m/s are predicted within the proposed swing basin and MOF dredging;
- Increases in peak flood velocities of 0.2m/s are predicted. These are confined only to the west of the proposed dredging layout, but extend upstream to the Narrows;
- Increases in peak ebb velocities are of slightly higher magnitude (up to 0.3m/s). They extend upstream only to about the proposed MOF location. However, increases are also shown downstream of the swing basin to the east (i.e. over the SANTOS project area).

The proposed offloading of materials onto the outer harbour spoil ground disposal area is predicted to have negligible impact on current velocities (less than 0.05m/s).

Scenario 3 Velocity Impacts

Scenario 3 velocity impact patterns are very similar to Scenario 2b. Compared to Scenario 2b, additional impacts are generated by the additional dredging works simulated, in particular south of the approach channel and within Port Curtis beyond Auckland Point.

Scenario 4 Velocity Impacts

Scenario 4 generally shows more pronounced impacts on currents in Port Curtis, extending upstream into The Narrows. The proposed Western Basin reclamation extension results in a reduction of up to about 400ha of available tidal storage area at high tide levels (above 2.5m LAT). 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.

Pipeline Crossing Impacts

Three options for construction of the pipeline crossing between Friend Point and Laird Point have been considered in the modelled scenarios as detailed in Section

In the case of Pipeline Crossing Option 1, the proposed 2.5m cover (including armour layer and pipeline) over the sea bed effectively reduces the cross-sectional area available to flow at the pipeline crossing, thereby increasing velocities in the main channel. This configuration also acts to block flow on the shallow areas either side of the main channel (as per the coffer dams modelled in Scenario 2a), reducing velocities in this vicinity.

These impacts all but disappear in Pipeline Crossing Option 2, where the pipeline is constructed within a trench in the sea bed, thus resulting in no additional cover over the sea bed.

Option 3 is a hybrid configuration with a buried pipeline on the inter-tidal areas and an armoured pipeline above the sea bed across the channel. This configuration does not act to block flows on the shallow areas. However, increases in velocities are predicted within the main channel due to the 2.5m pipeline cover.

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.

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 (Scenarios 1 to 4) 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 existing flushing characteristics and impacts of the five development scenarios.

An Elder type model was used to represent the variation of horizontal dispersion with flow conditions (Fisher et al., 1979): $Dl = Klu^*h;\ Dt = Ktu^*h$

where Dl is the dispersion coefficient in the direction of the flow advection, u* is the friction velocity, h is the depth, Dt is the transverse dispersion coefficient and Kl, Kt are scaling coefficients. Based on a WBM dye release study conducted in Port Curtis several years ago, values of Kl=60 and Kt=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 Fushing Impacts

3.3.1 Time-Series Results

Time series of tracer concentration were extracted at the 11 locations shown in Figure 2-6. Plots of the time series results at each location are presented for the whole simulation period in Appendix I for Option 1, in Appendix J for Option 2 and in Appendix K for Option 3. Each plot illustrates the tracer concentration for the base case and the design scenarios at that location to allow direct comparison and visual assessment of impacts. The Western Basin extraction point is located in a shallow area which dries at low tide. This is illustrated by the tracer concentrations registering as zero 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 in Figure 3-1 to Figure 3-9 for the existing case (Scenario 1) and the design scenarios for Option 1 as well as the associated impacts of each design scenario (Option 1) relative to the existing case. All results (including for Option 2 and Option 3 of the pipeline crossing configuration) are reported in the appendices as per Table 2-2**Error! Reference source not found.**.

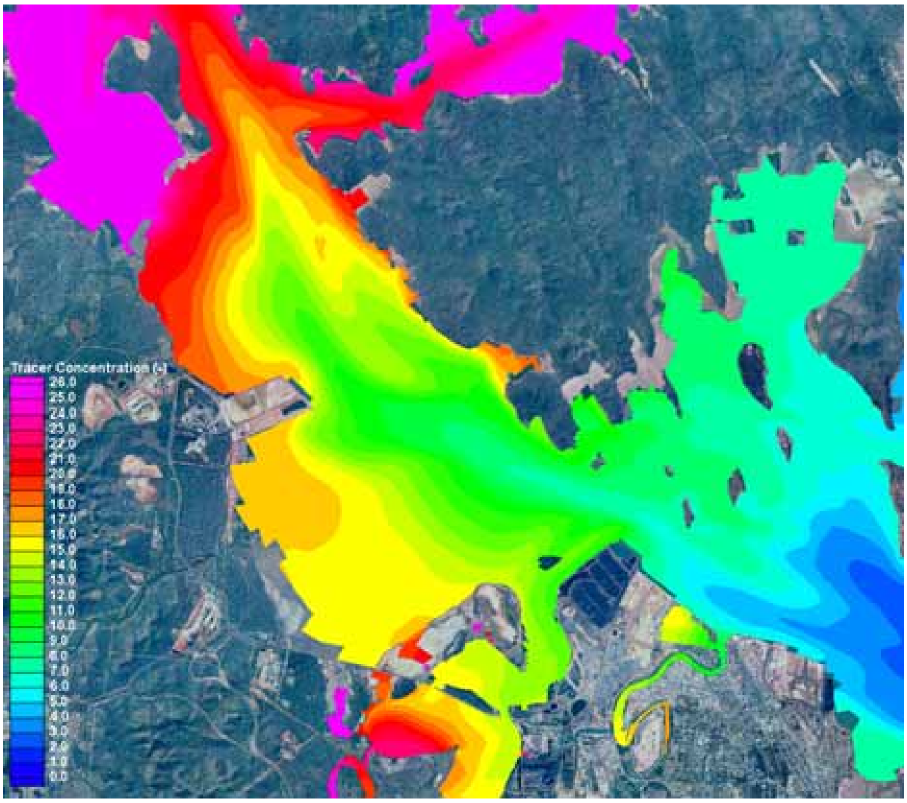

Figure 3-1 Scenario 1 (Existing) tracer concentration

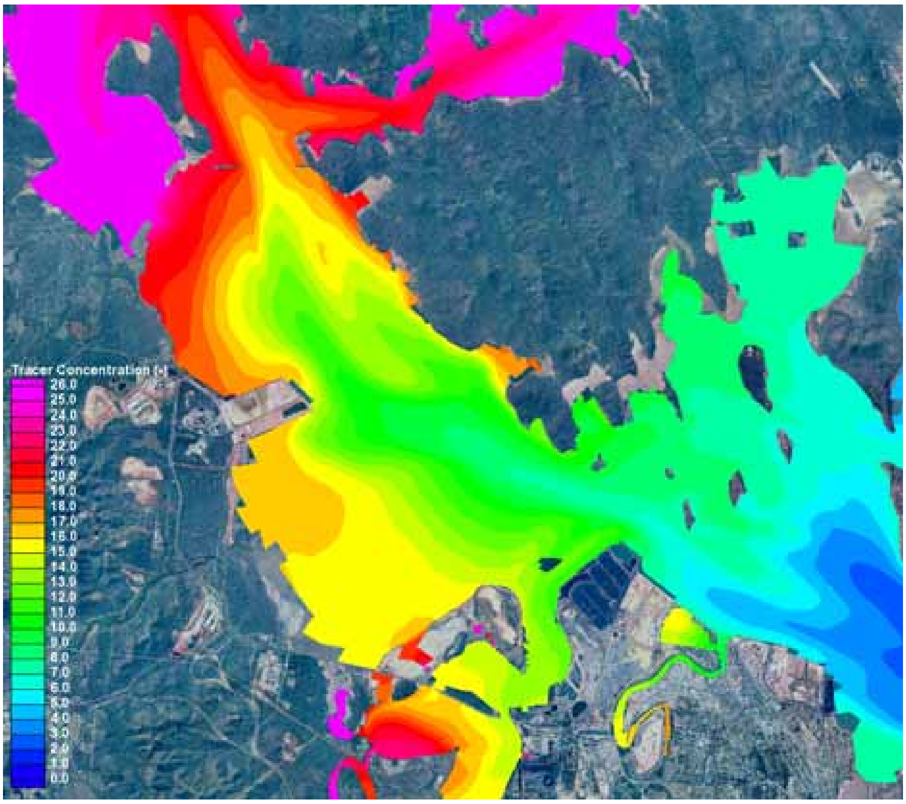

Figure 3-2 Scenario 2a tracer concentration

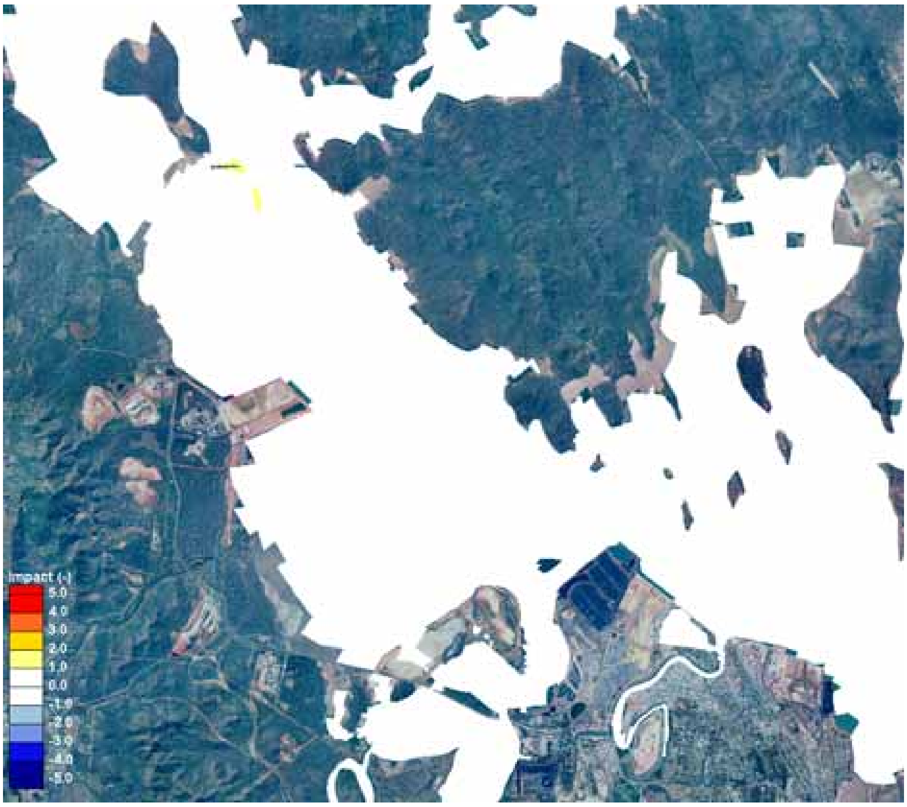

Figure 3-3 Scenario 2a tracer concentration differences

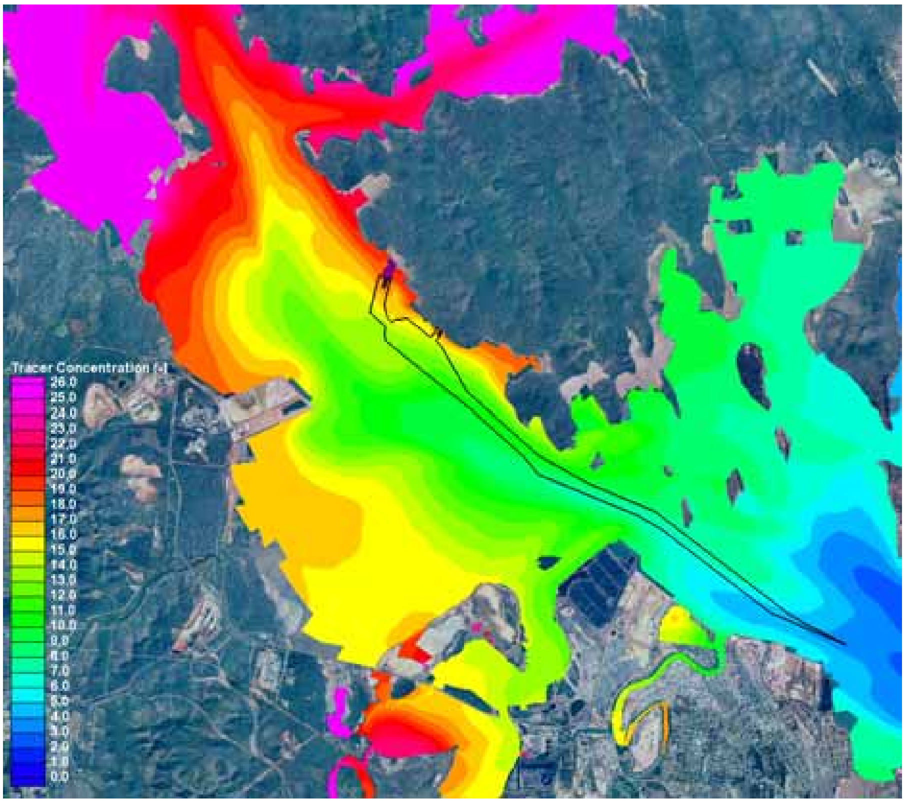

Figure 3-4 Scenario 2b tracer concentration

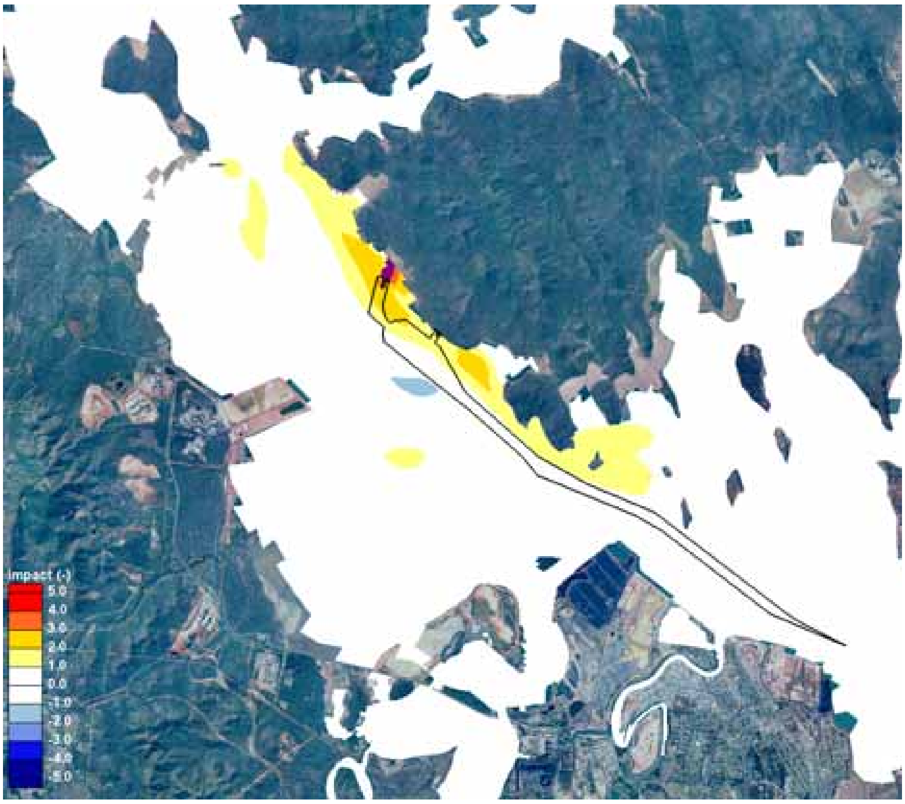

Figure 3-5 Scenario 2b tracer concentration differences

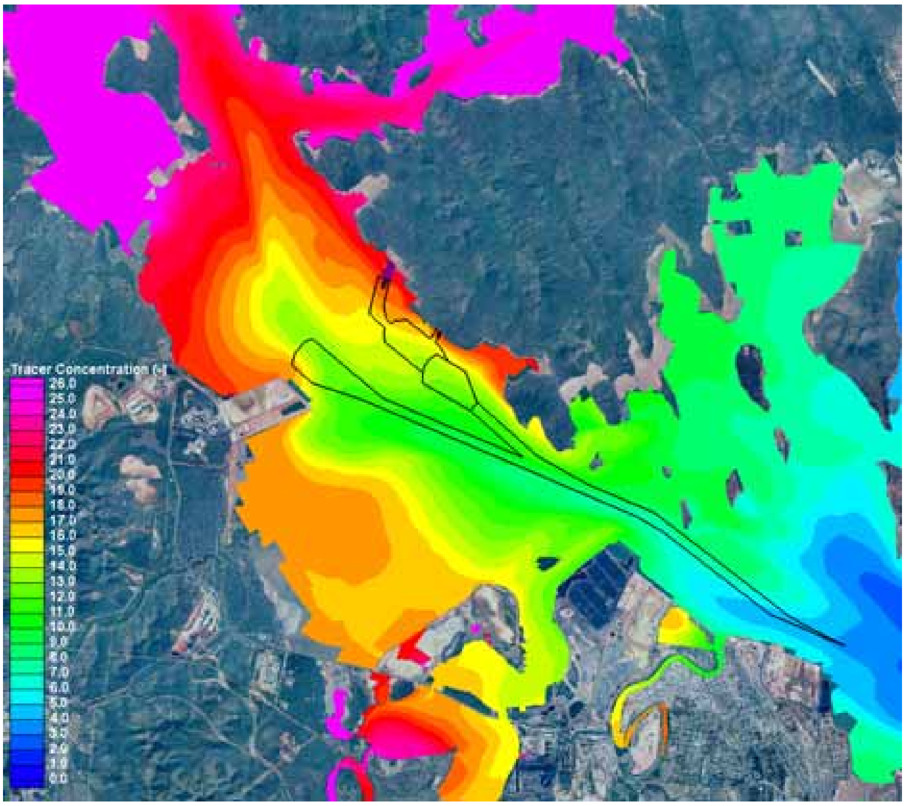

Figure 3-6 Scenario 3 tracer concentration

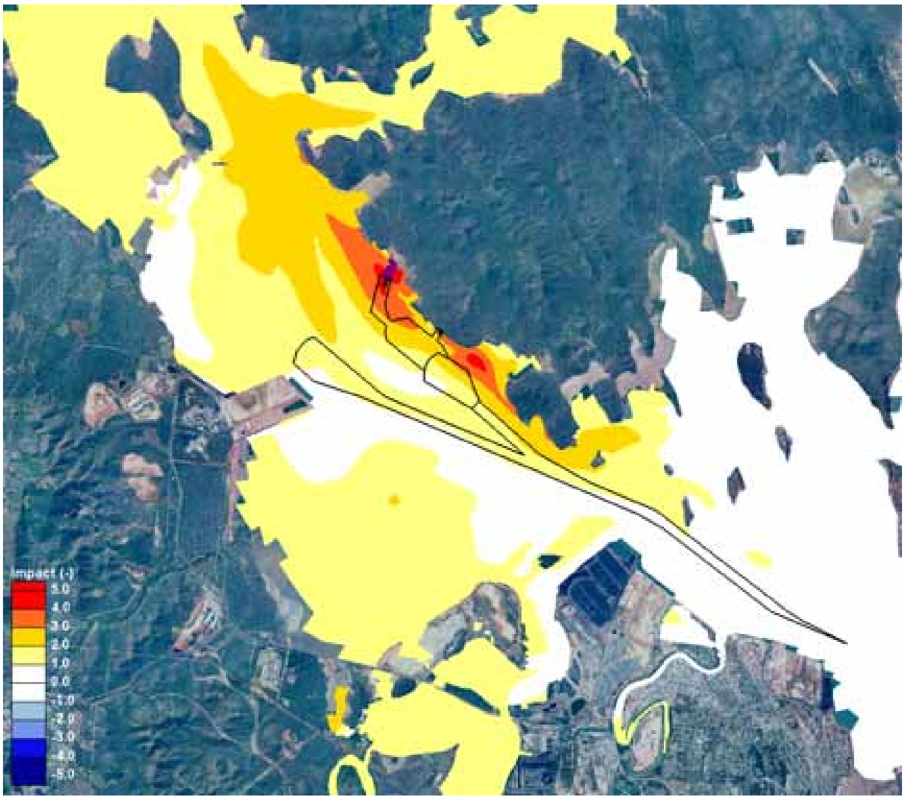

Figure 3-7 Scenario 3 tracer concentration differences

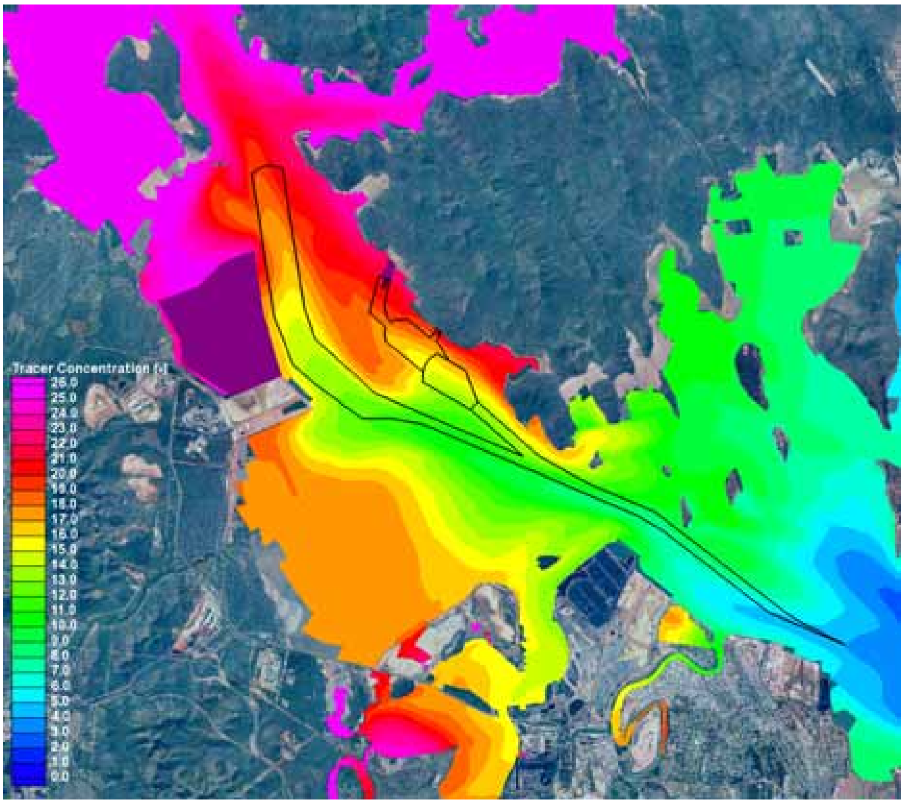

Figure 3-8 Scenario 4 tracer concentration

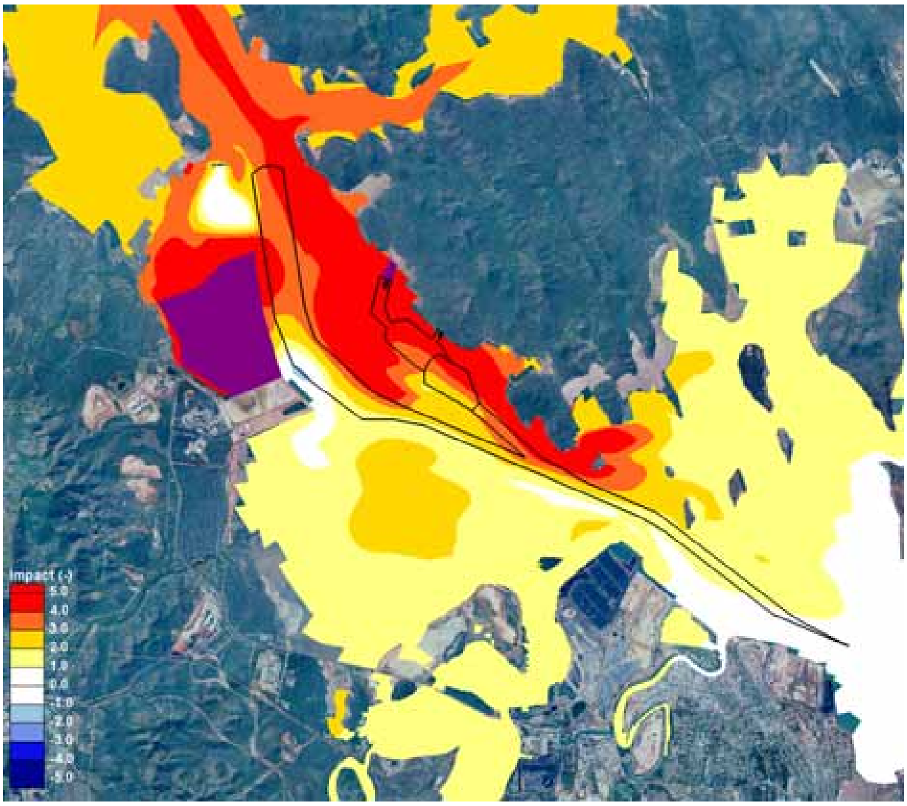

Figure 3-9 Scenario 4 tracer concentration differences

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 3-10 illustrates the method. The red curve is the fitted exponential.

Direct use of the 25-hr moving average concentration for calculation of the e-folding time 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.

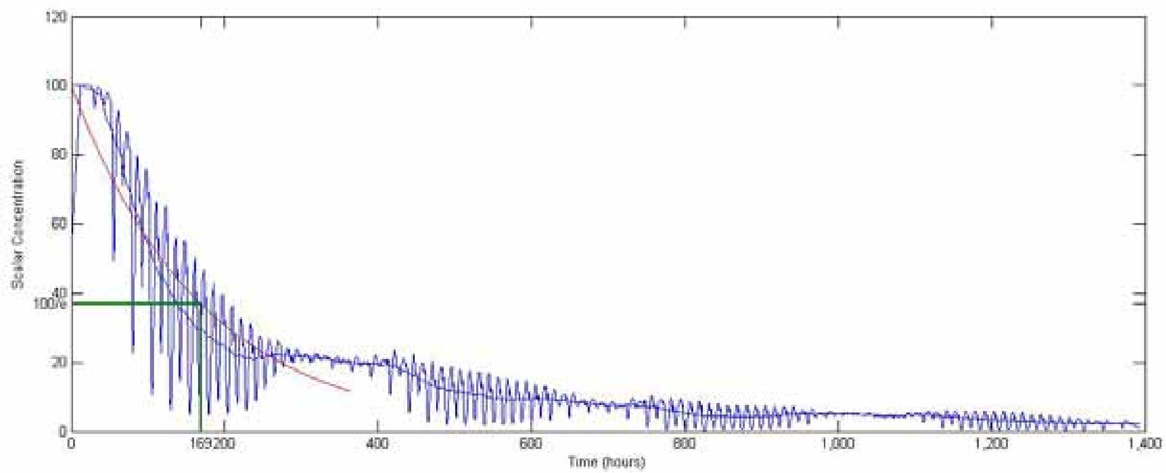

Figure 3-10 e-Folding Time Calculation

Spatial plots of the e-folding time for the existing case (Scenario 1) and the design scenarios as well as the associated impacts relative to the existing case are presented below for Option 1. All results (including for Option 2 and Option 3) are reported in the appendices as per Table 2-2.

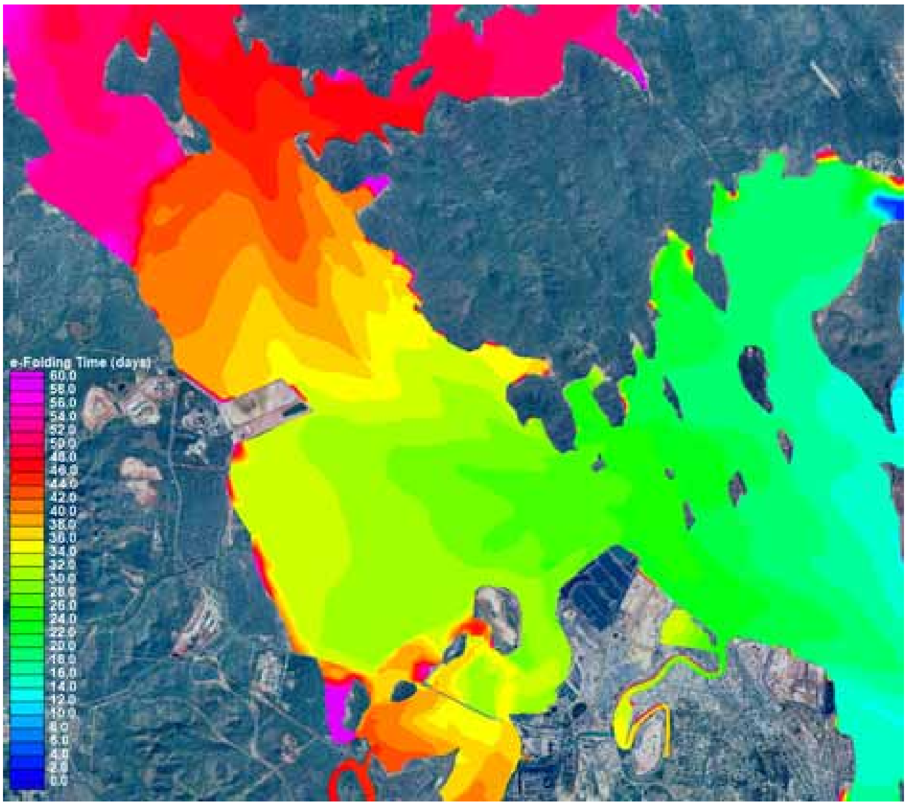

Figure 3-11 Scenario 1 (Existing) e-folding time

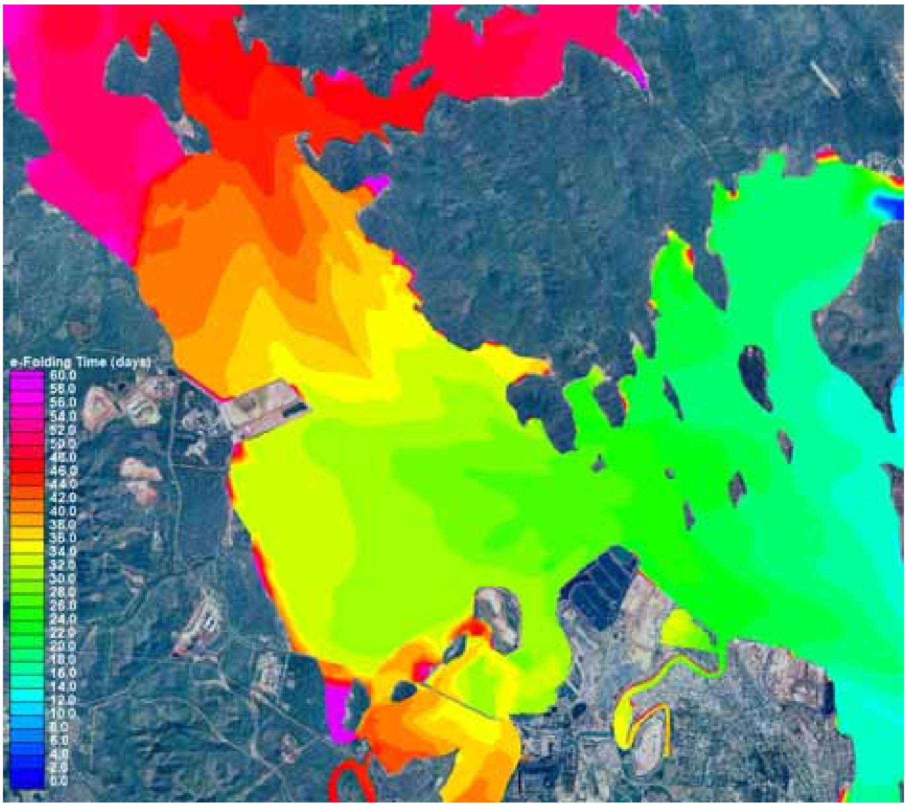

Figure 3-12 Scenario 2a e-folding time

Figure 3-13 Scenario 2a e-folding time differences

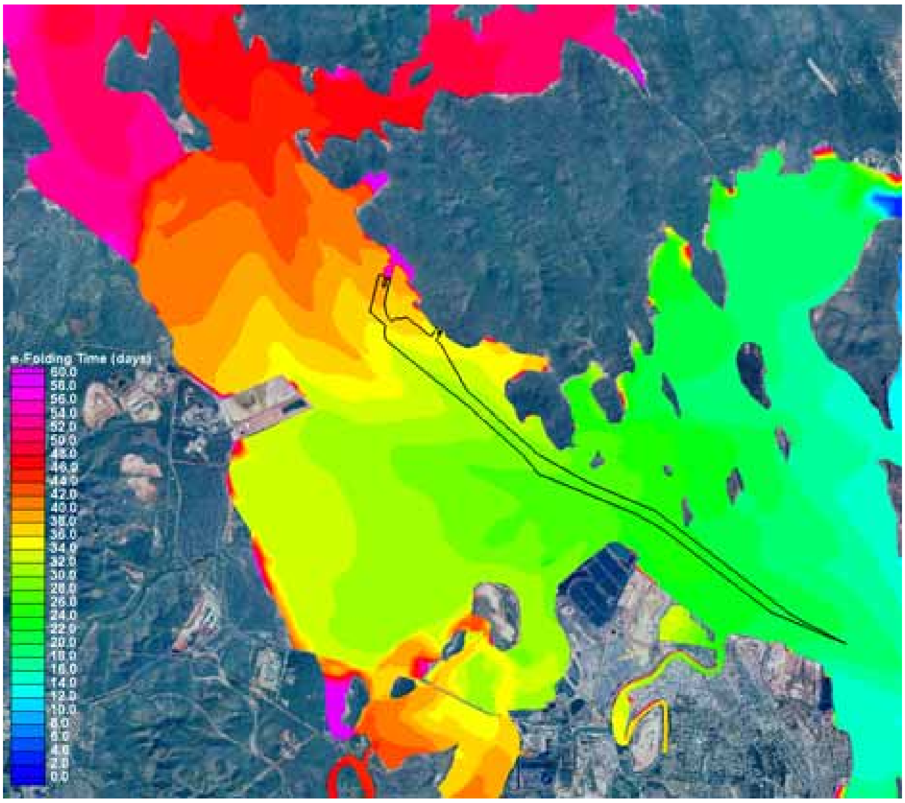

Figure 3-14 Scenario 2b e-folding time

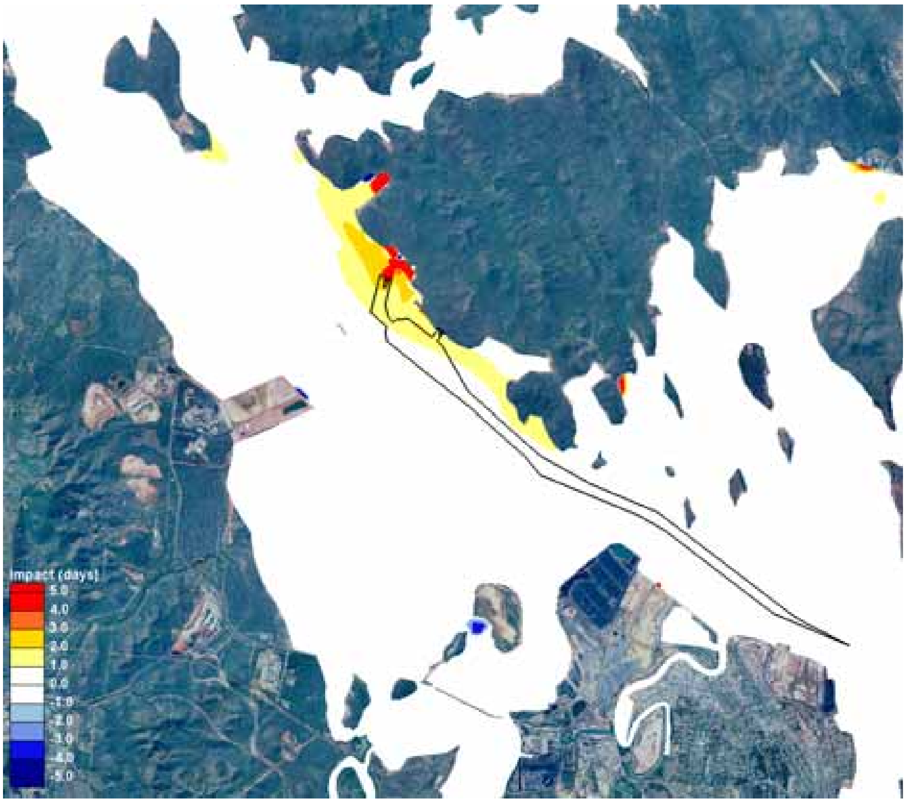

Figure 3-15 Scenario 2b e-folding time differences

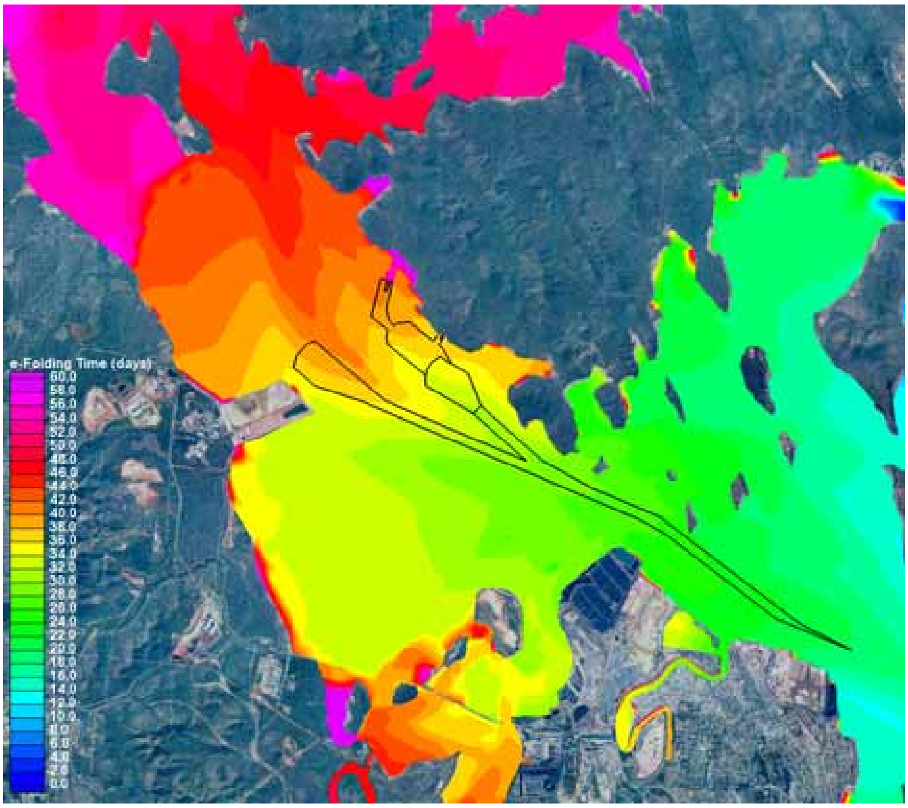

Figure 3-16 Scenario 3 e-folding time

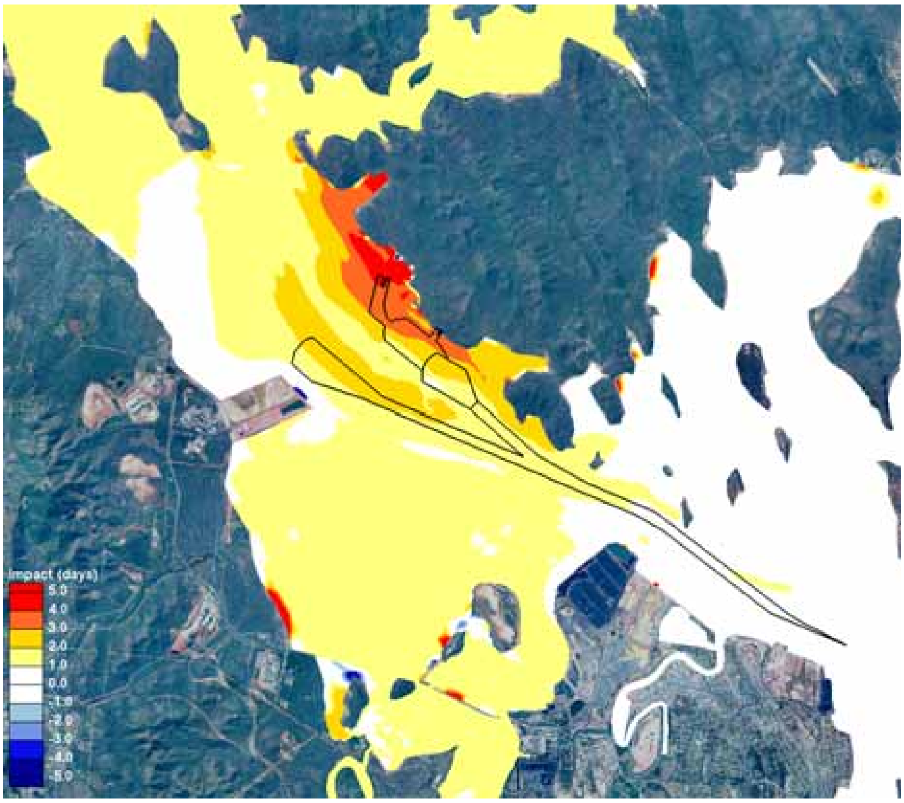

Figure 3-17 Scenario 3 e-folding time differences

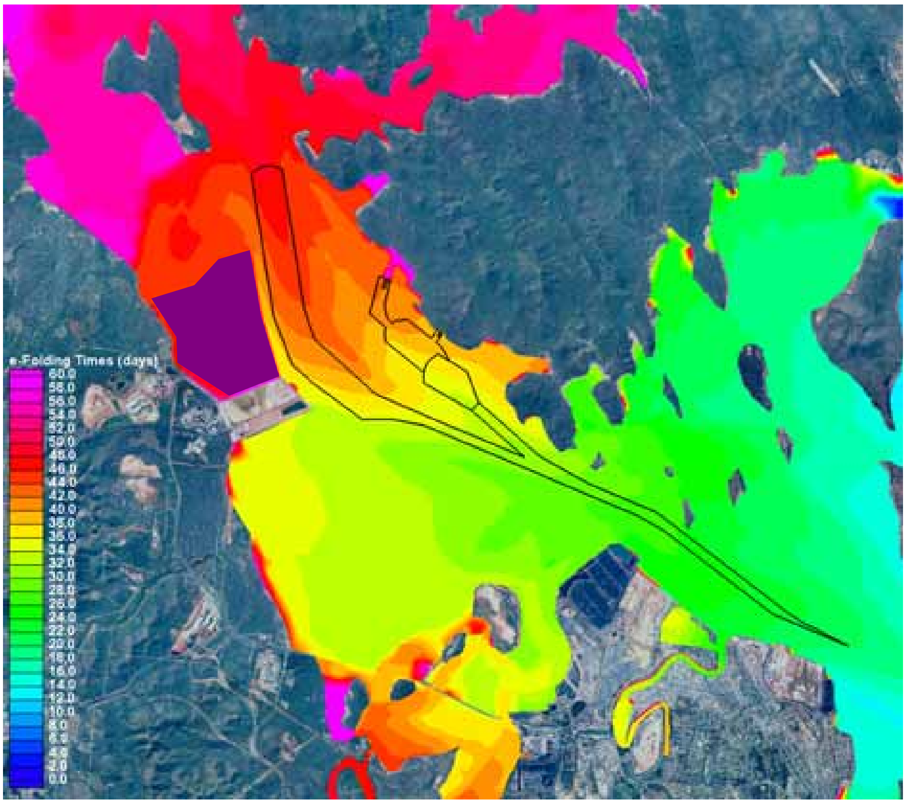

Figure 3-18 Scenario 4 e-folding time

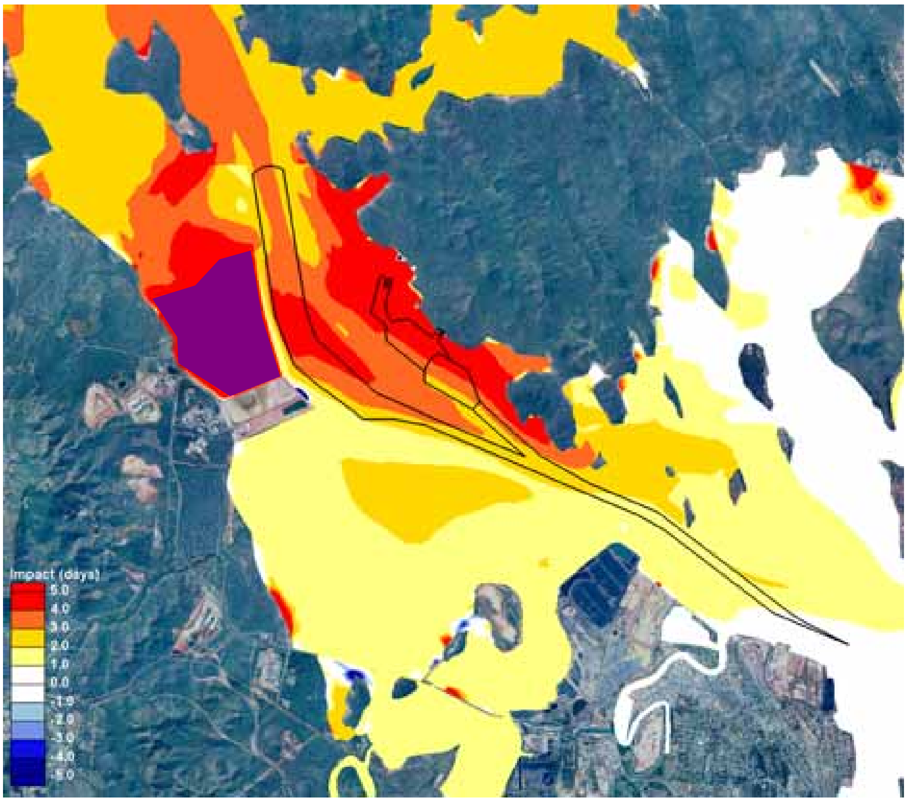

Figure 3-19 Scenario 4 e-folding time differences

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.

The predicted impacts are discussed as follows for all Option 1 design scenarios, compared to the existing case (Scenario 1):

- Scenario 2a has a minimal impact on tracer concentrations (increases by a couple of units) only locally in the vicinity of the temporary coffer dams;
- The QCLNG project case (Scenario 2b) generates further impacts, located principally along the Curtis Island shoreline from Laird Point to approximately Boatshed Point. In this scenario, the highest impacts (increase in tracer concentration by 4 units) are localised in the shadow of the proposed MOF;
- Scenario 3 (project cumulative) shows more generalised impacts throughout Port Curtis from Auckland Point upstream, and specifically upstream of the existing Fisherman's Landing reclamation; and
- Scenario 4 (full cumulative) generates the highest impacts out of all scenarios. Increases in tracer concentration of more than 5 units are predicted to the north of the proposed channel dredging line in Port Curtis from approximately Boatshed Point, as well as within the main channel upstream towards the Narrows.

In the existing case, e-folding times range from around 30 days in the proposed approach channel area, to around 38 days at the proposed MOF location. Upstream in the Narrows and Graham Creek, e-Folding times range upward from 45 days.

The flushing impact of the four scenarios is quite different in magnitude and spatial distribution, with Scenario 4 generating the highest impacts. This indicates that the Western Basin reclamation and associated loss of inter-tidal storage is the major broad-scale hydrodynamic perturbation to the system. The impacts of dredging and reclamation configurations associated with the QCLNG project are generally localised between Curtis Island shoreline and the dredging outline. Additional dredging configurations within the Port also generate further impacts on net-circulation patterns, which is also contributing to the hydrodynamic and flushing impacts on the system.

The broad scale flushing impacts are generally insensitive to the pipeline construction configuration. Differences in tracer concentration and e-folding times between the three pipeline crossing options are most likely due to a modelling artefact where the diffusion coefficient is proportional to friction velocities. These friction velocities are specifically modified in the vicinity of the pipeline crossing due to the change in depth in particular in option 1, thus modifying the diffusion in the area and consequently e-folding times.

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APPENDIX A: WATER LEVEL TIME SERIES – PIPELINE CROSSING OPTION 1

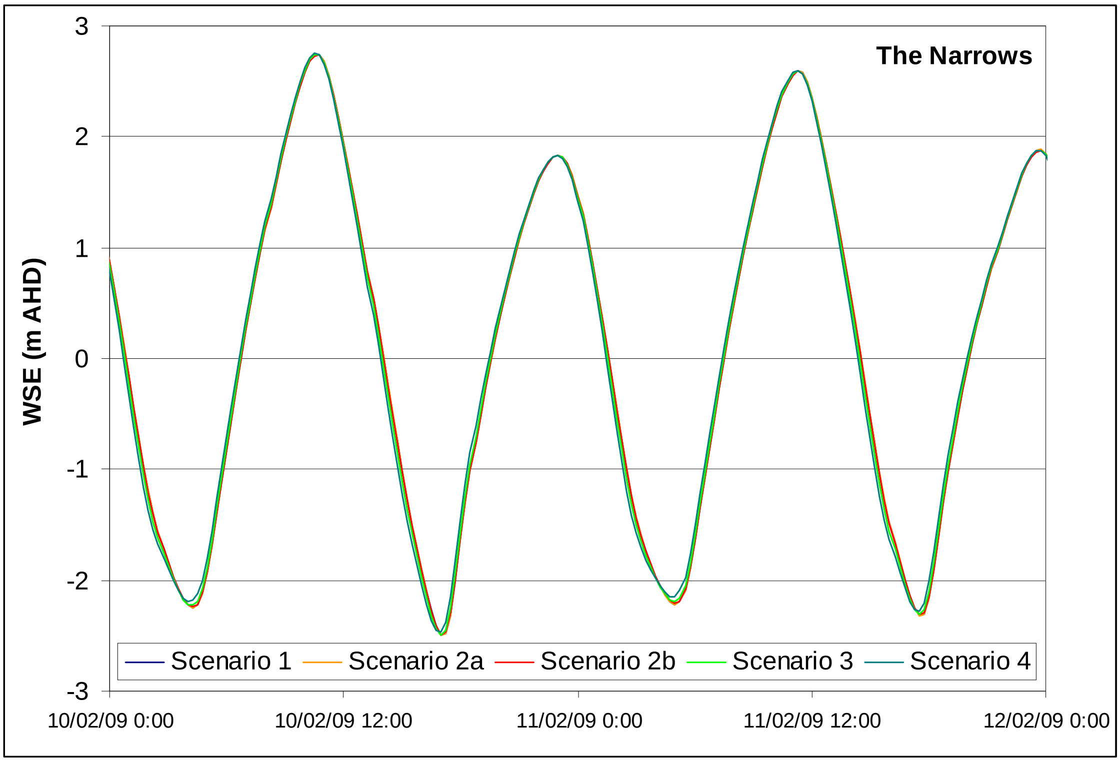

Figure A-1 Water Level Time Series – The Narrows

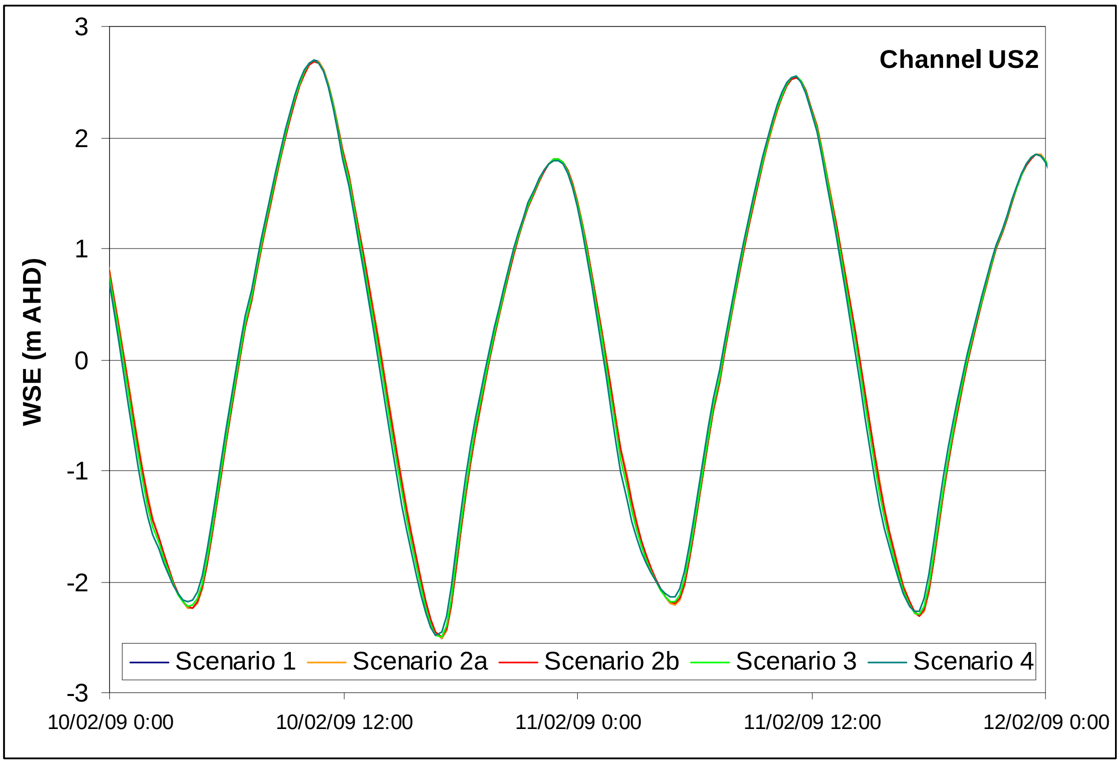

Figure A-2 Scenario 4 e-folding time differences

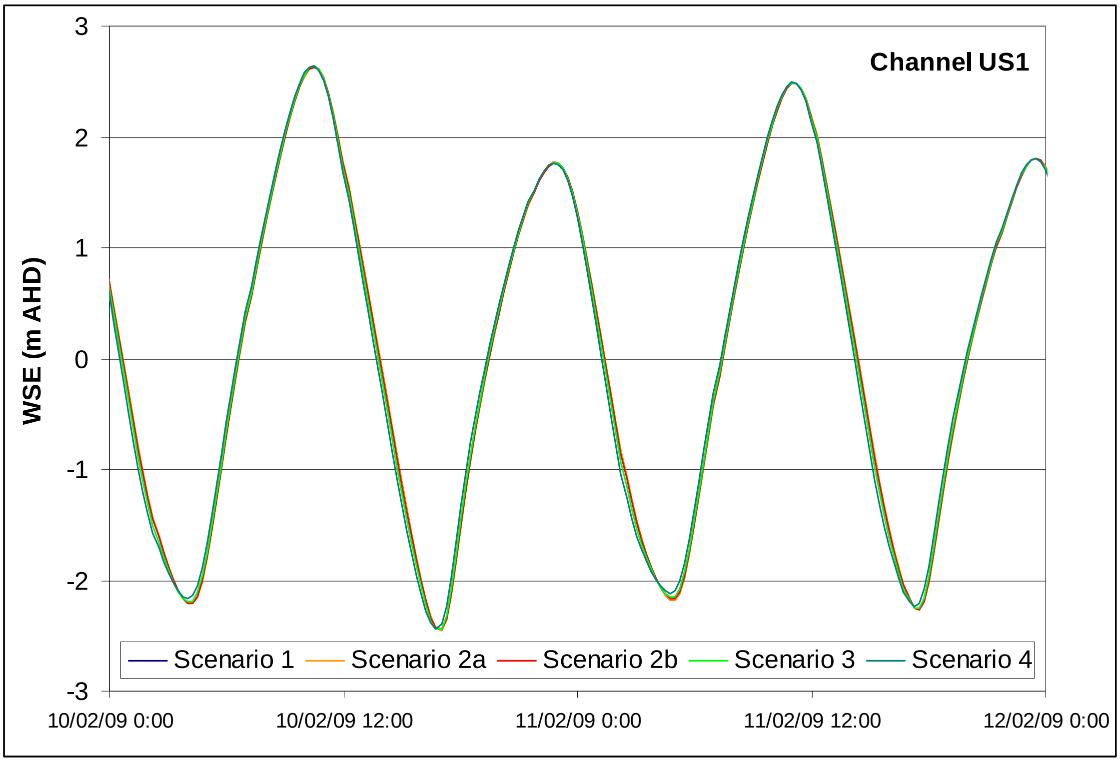

Figure A-3 Water Level Time Series – Channel US1

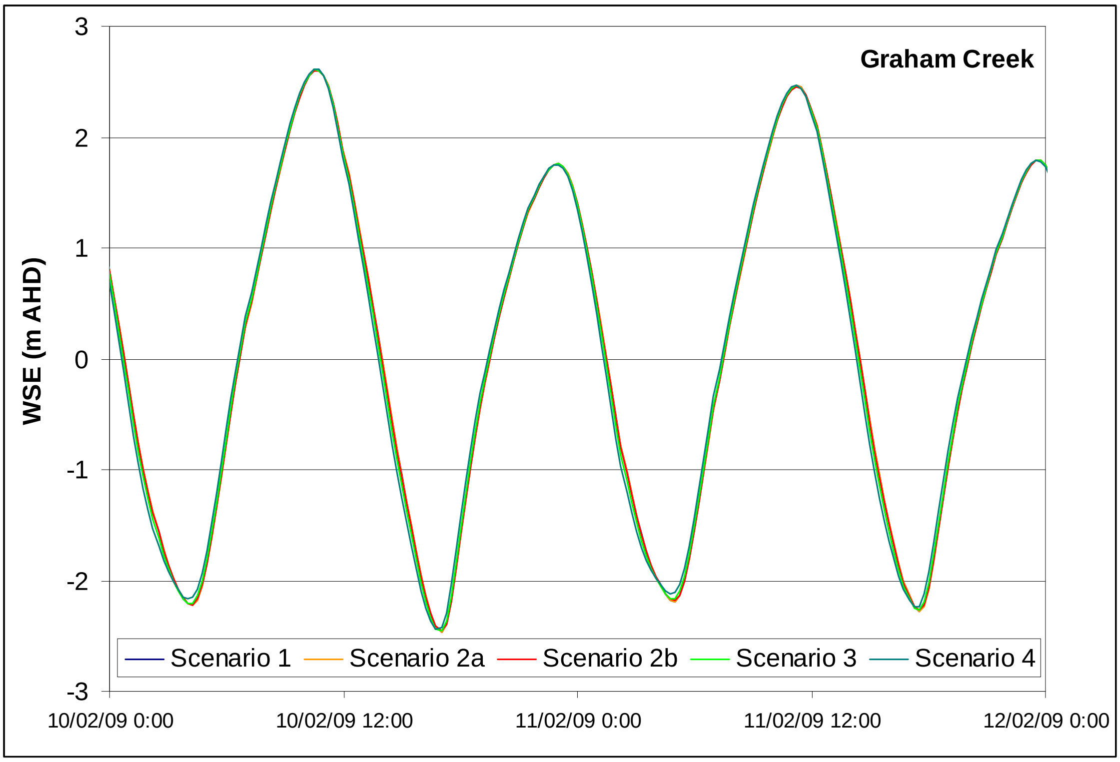

Figure A-4 Water Level Time Series – Graham Creek

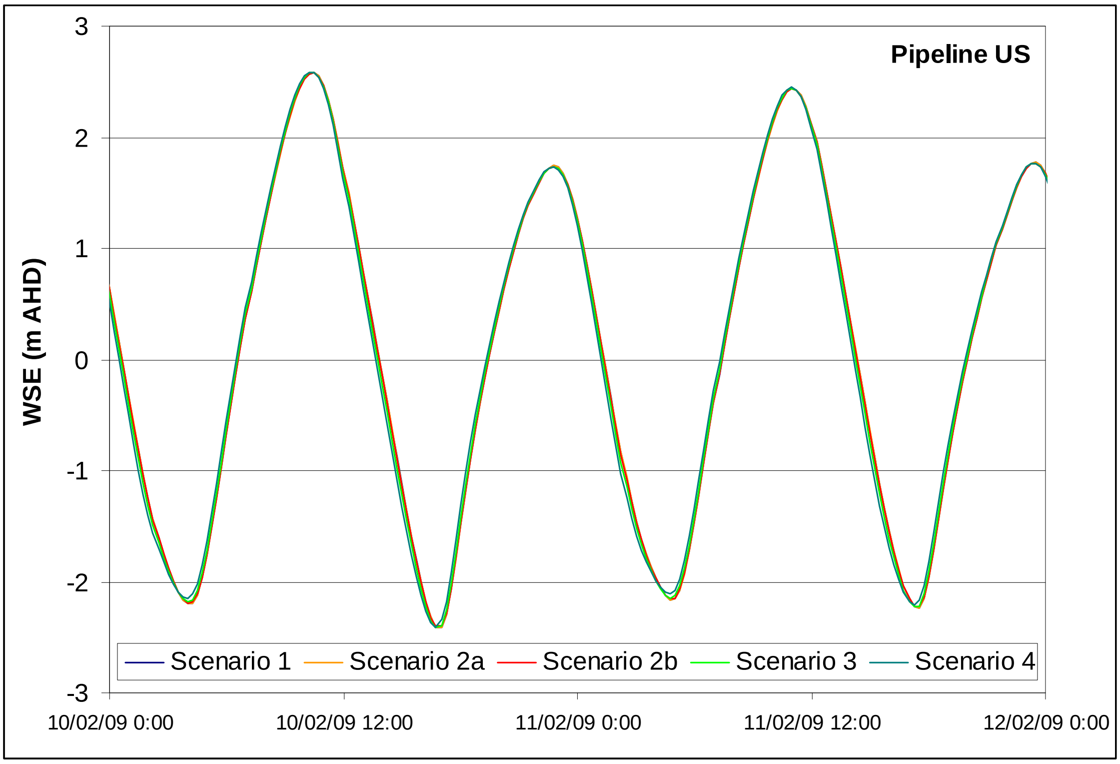

Figure A-5 Water Level Time Series – Pipeline US

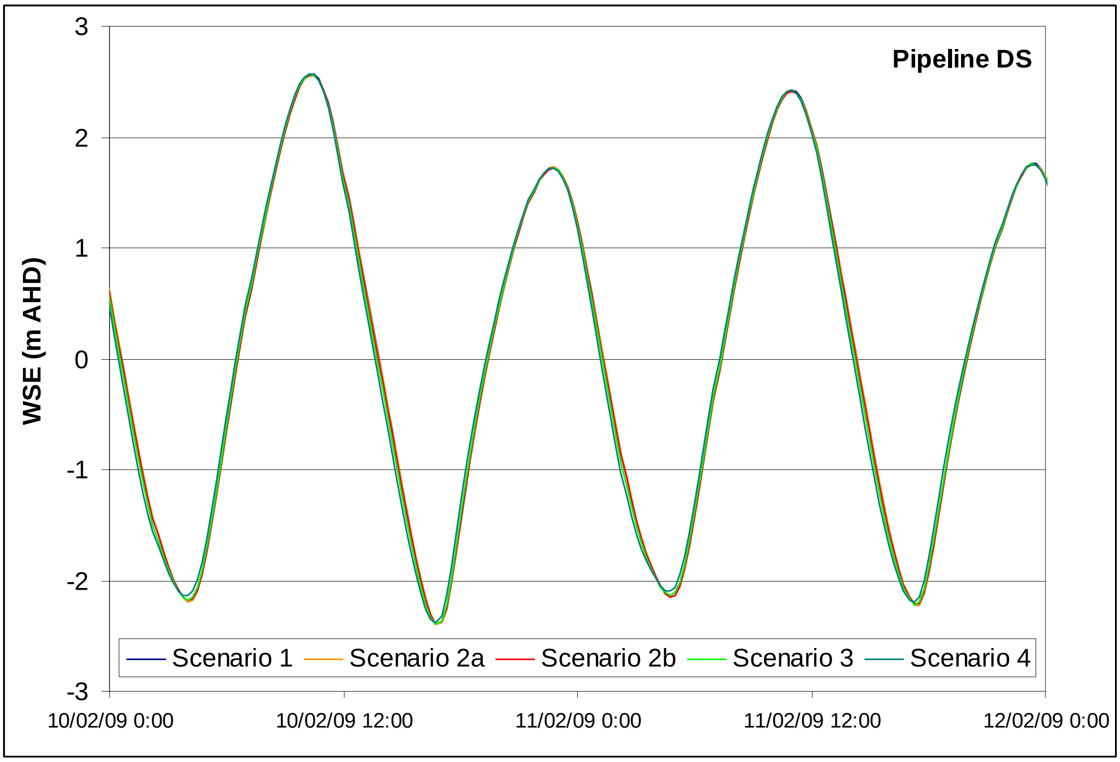

Figure A-6 Water Level Time Series – Pipeline DS

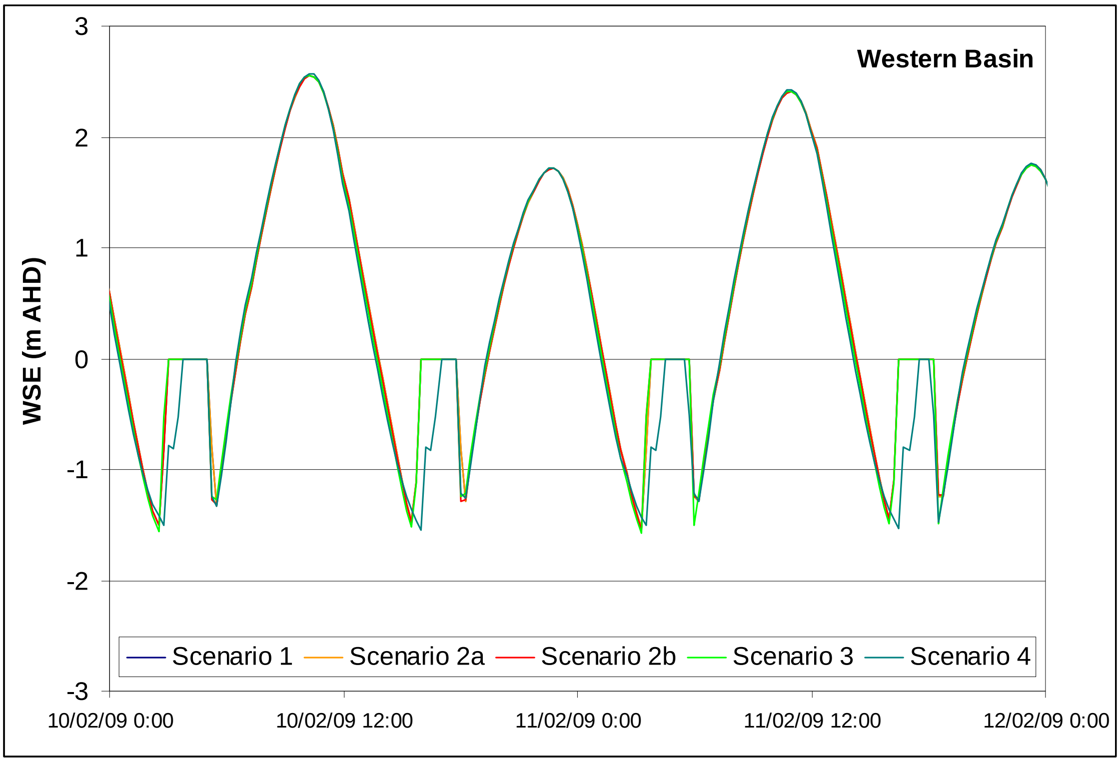

Figure A-7 Water Level Time Series – Western Basin

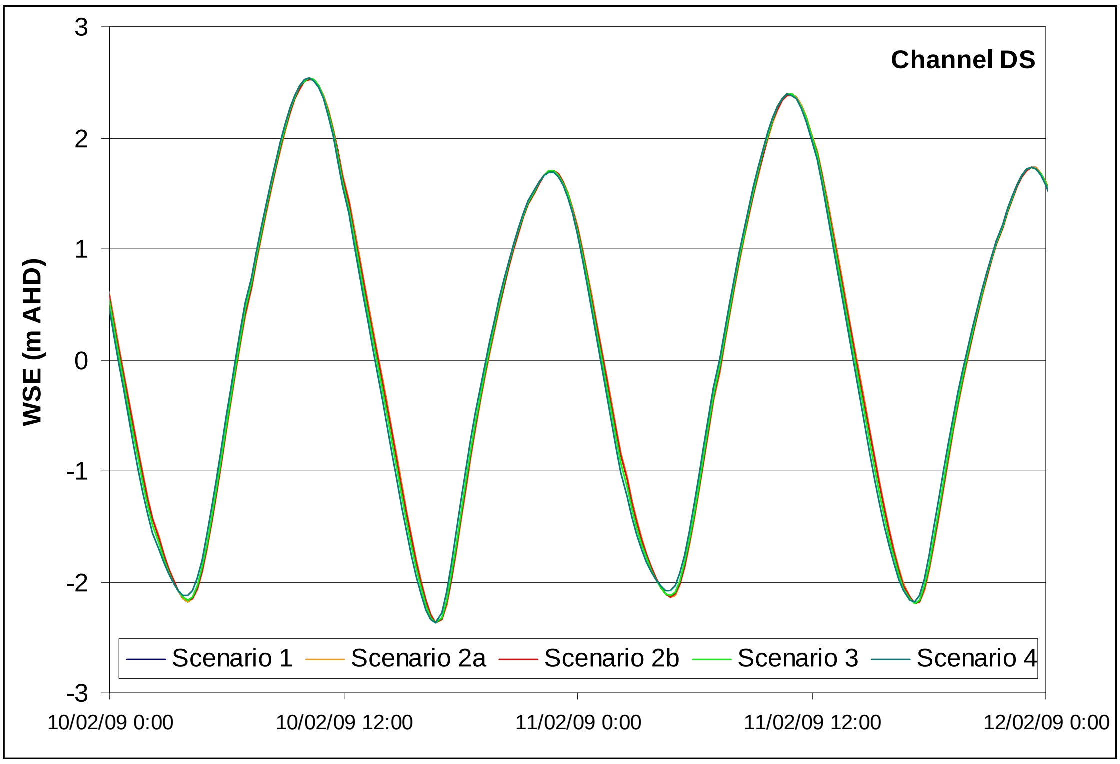

Figure A-8 Water Level Time Series – Channel DS

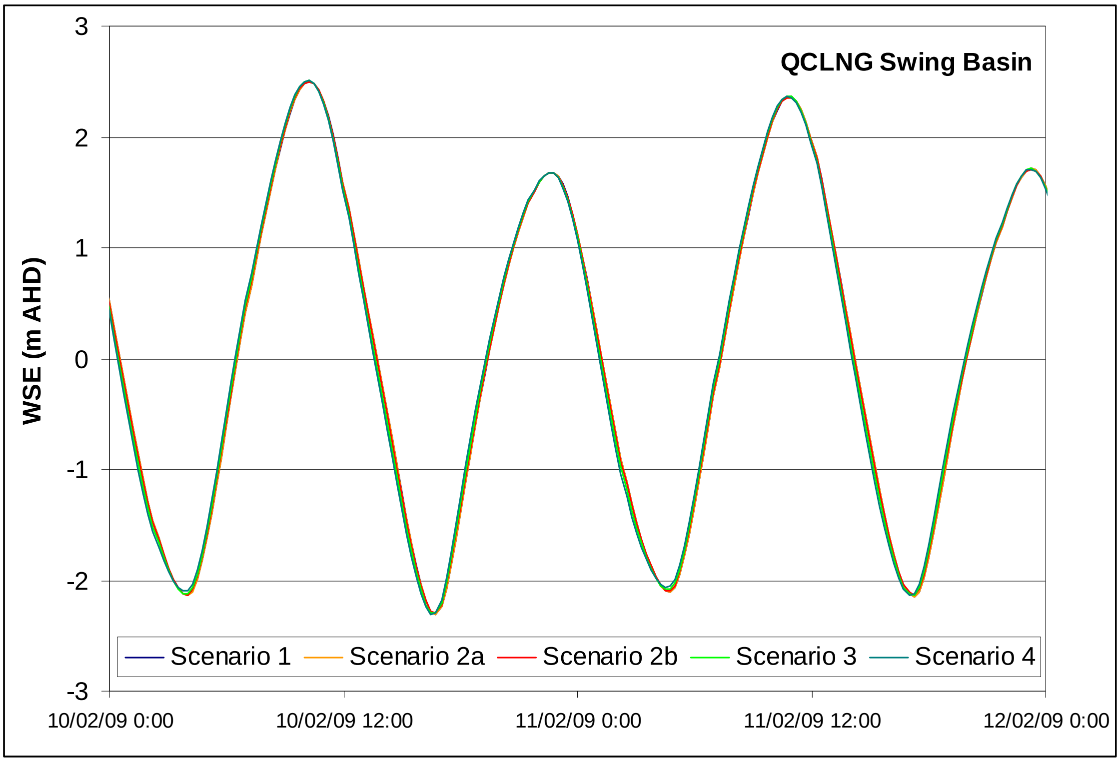

Figure A-9 Water Level Time Series – QCLNG Swing Basin

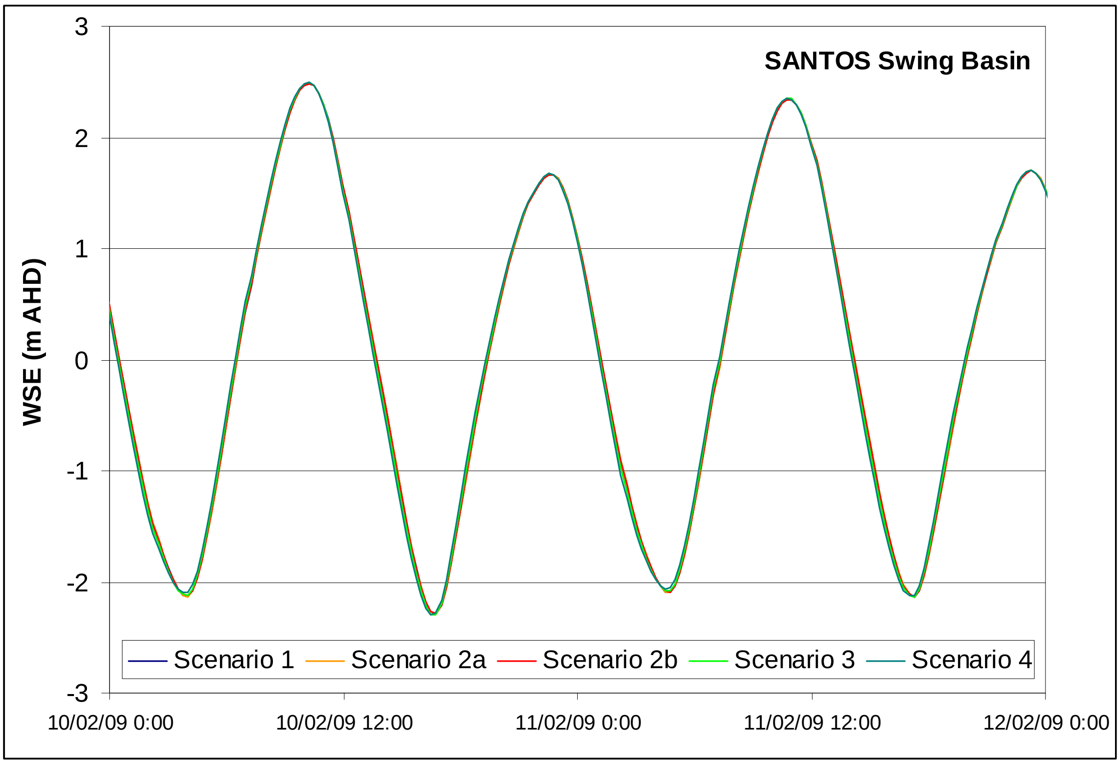

Figure A-10 Water Level Time Series – SANTOS Swing Basin

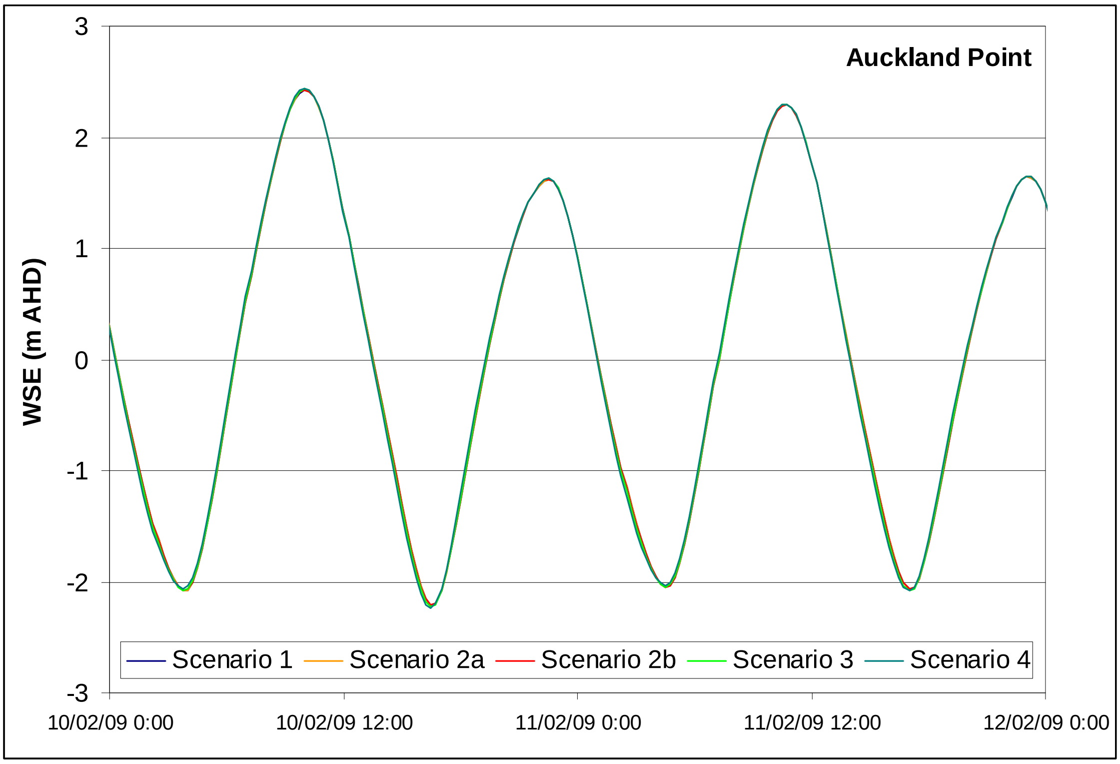

Figure A-11 Water Level Time Series – Auckland Point

APPENDIX B: VELOCITY MAGNITUDE TIME SERIES – PIPELINE CROSSING OPTION 1

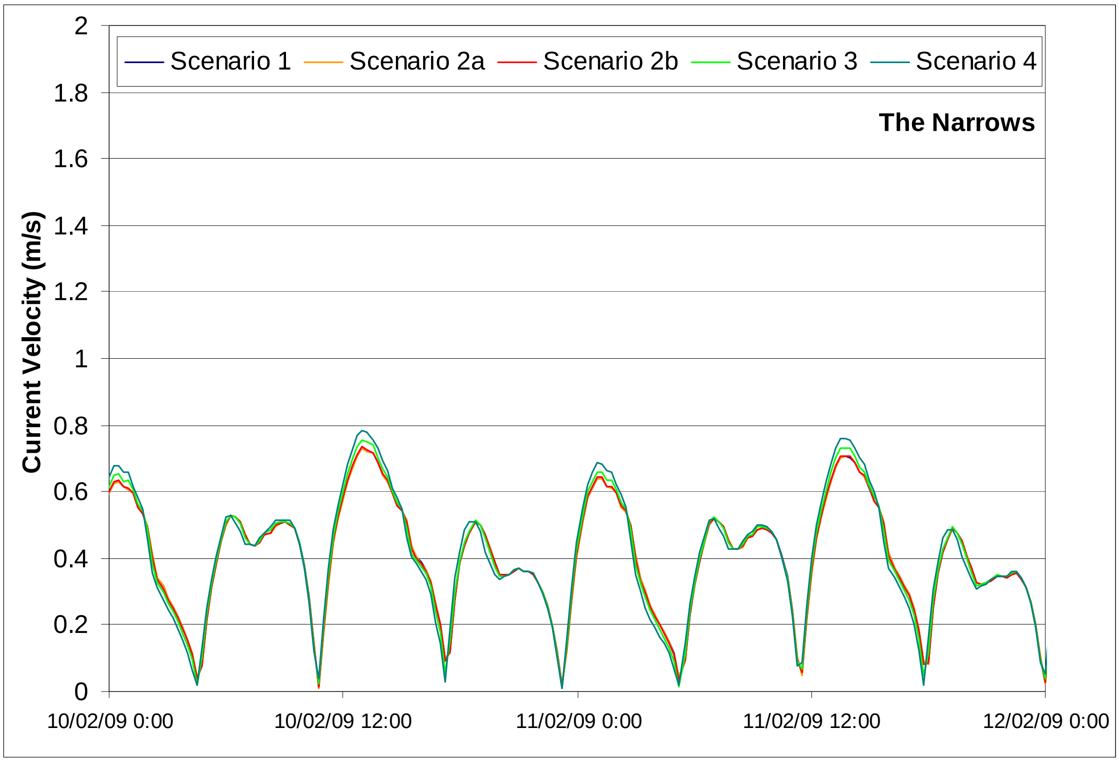

Figure B-1 Velocity Magnitude Time Series – The Narrows

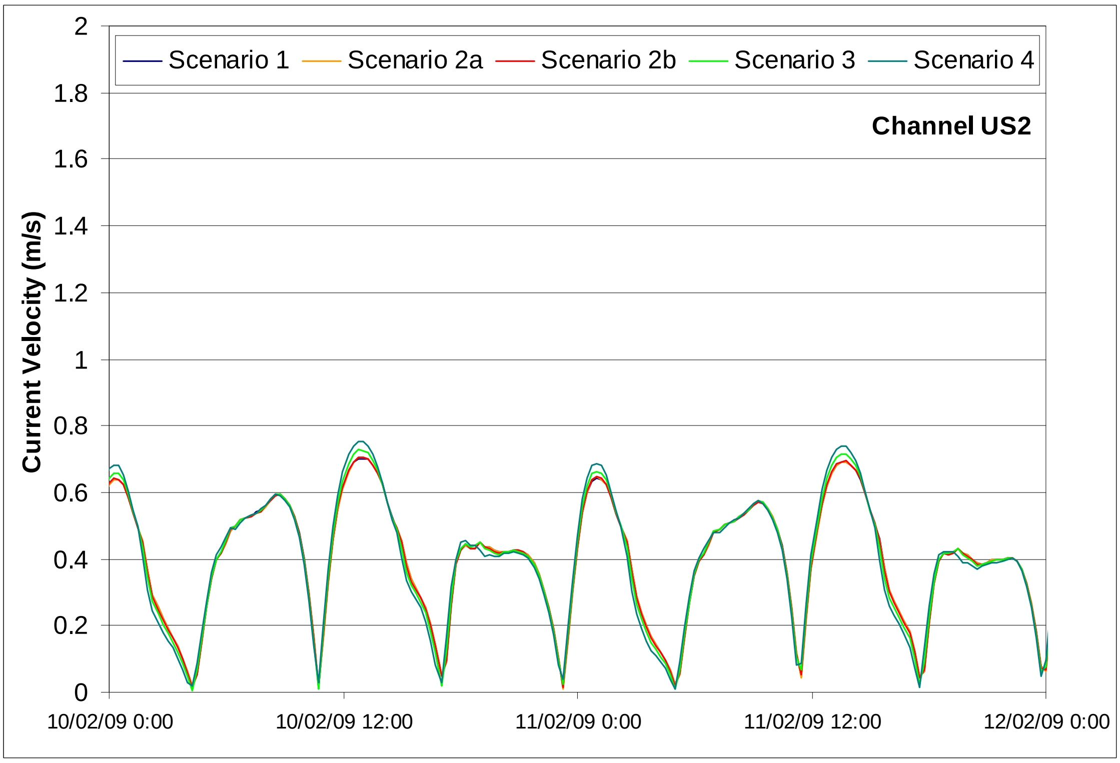

Figure B-2 Velocity Magnitude Time Series – Channel US2

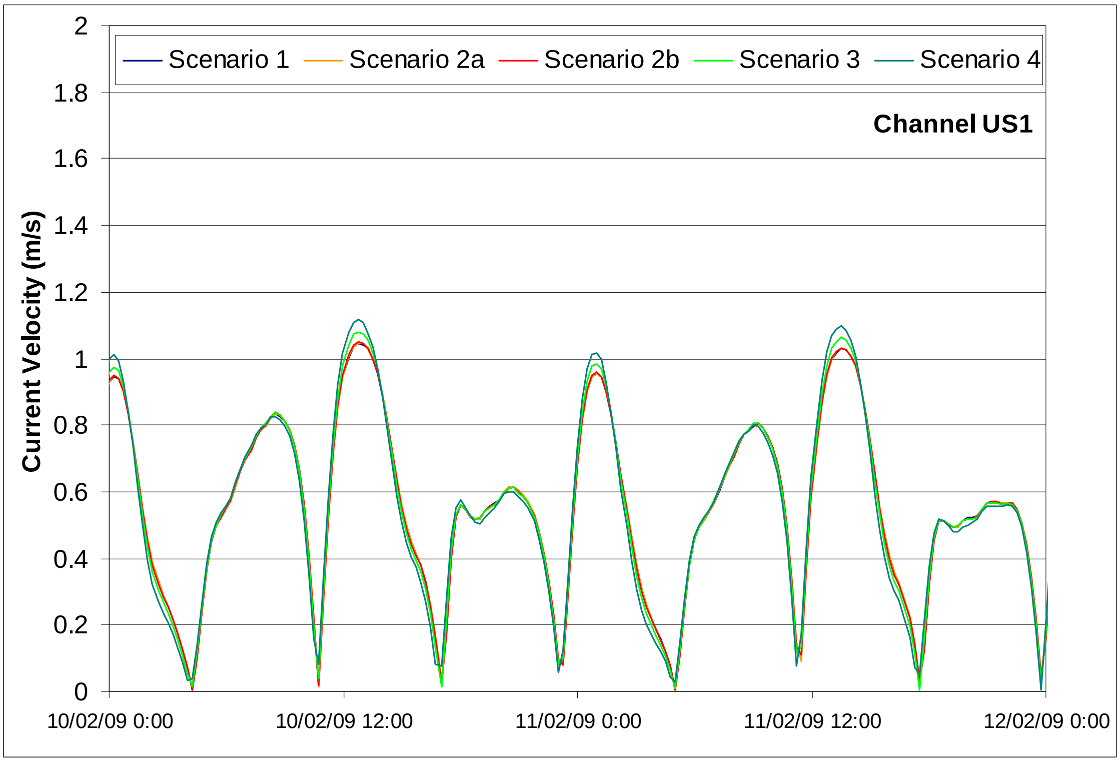

Figure B-3 Velocity Magnitude Time Series – Channel US1

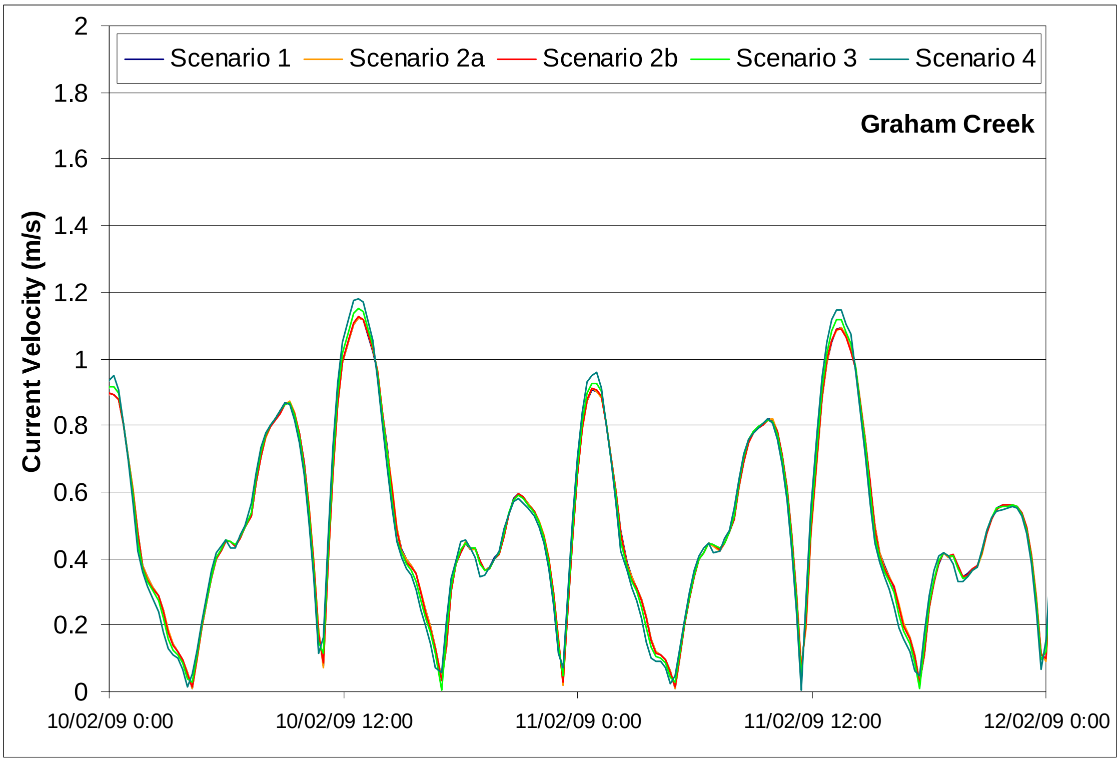

Figure B-4 Velocity Magnitude Time Series – Graham Creek

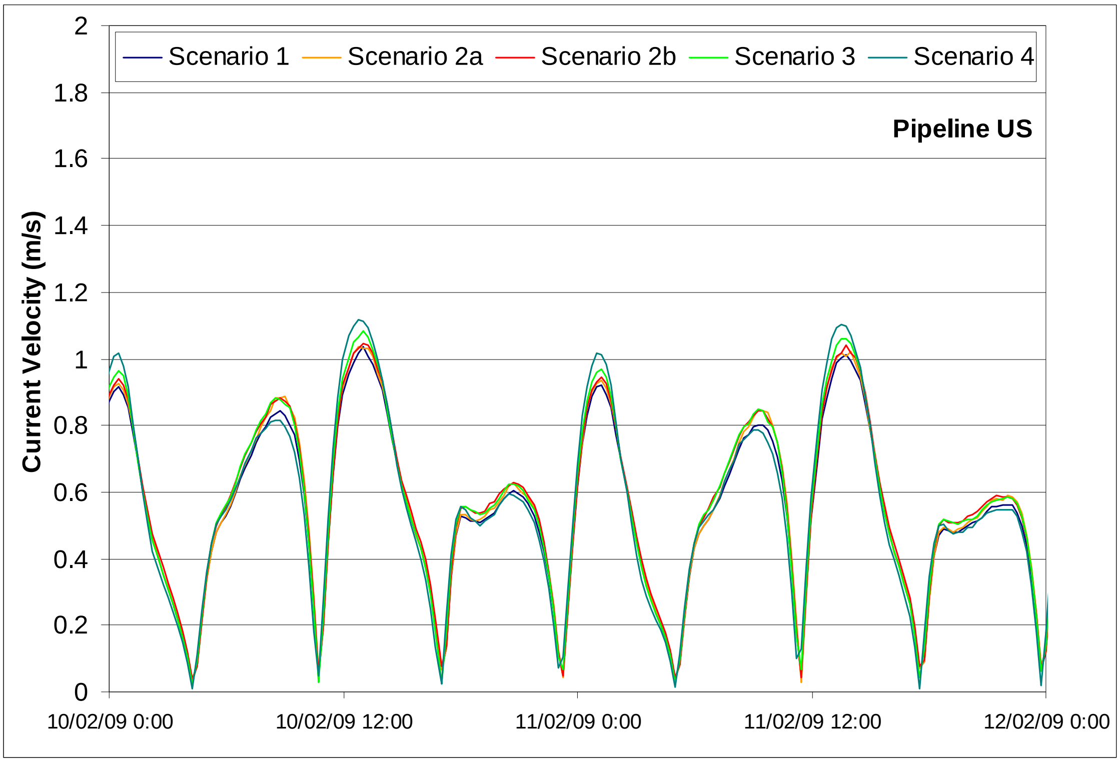

Figure B-5 Velocity Magnitude Time Series – Pipeline US

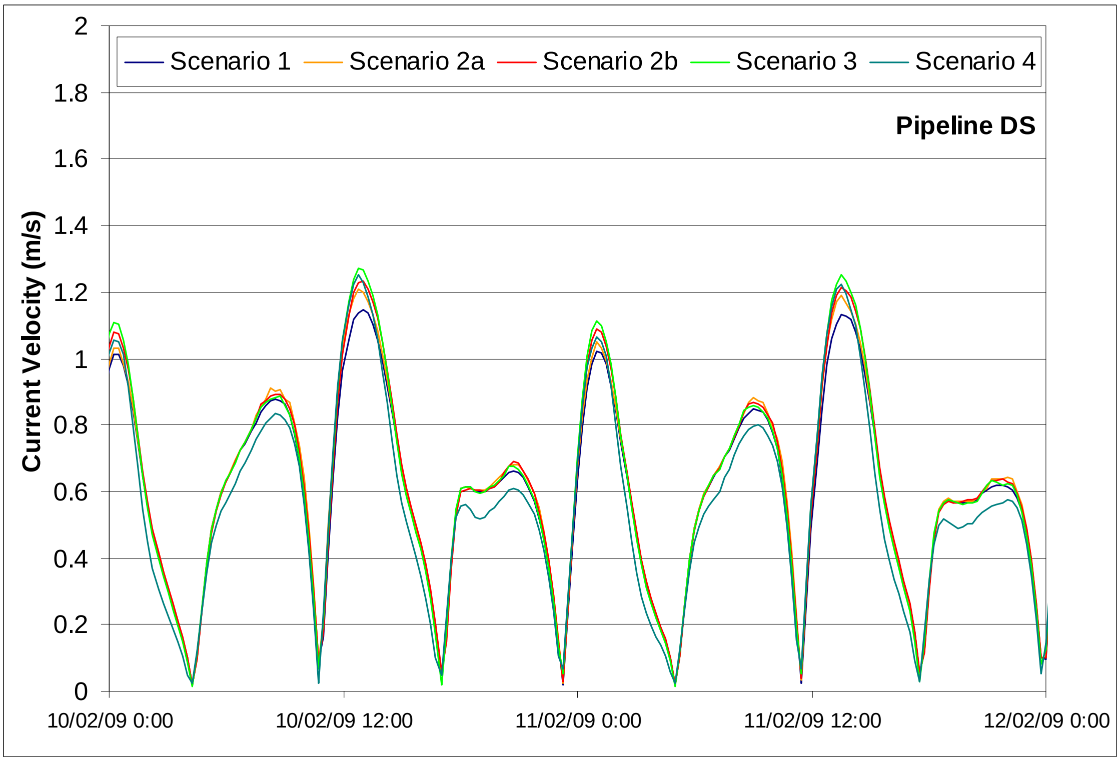

Figure B-6 Velocity Magnitude Time Series – Pipeline DS

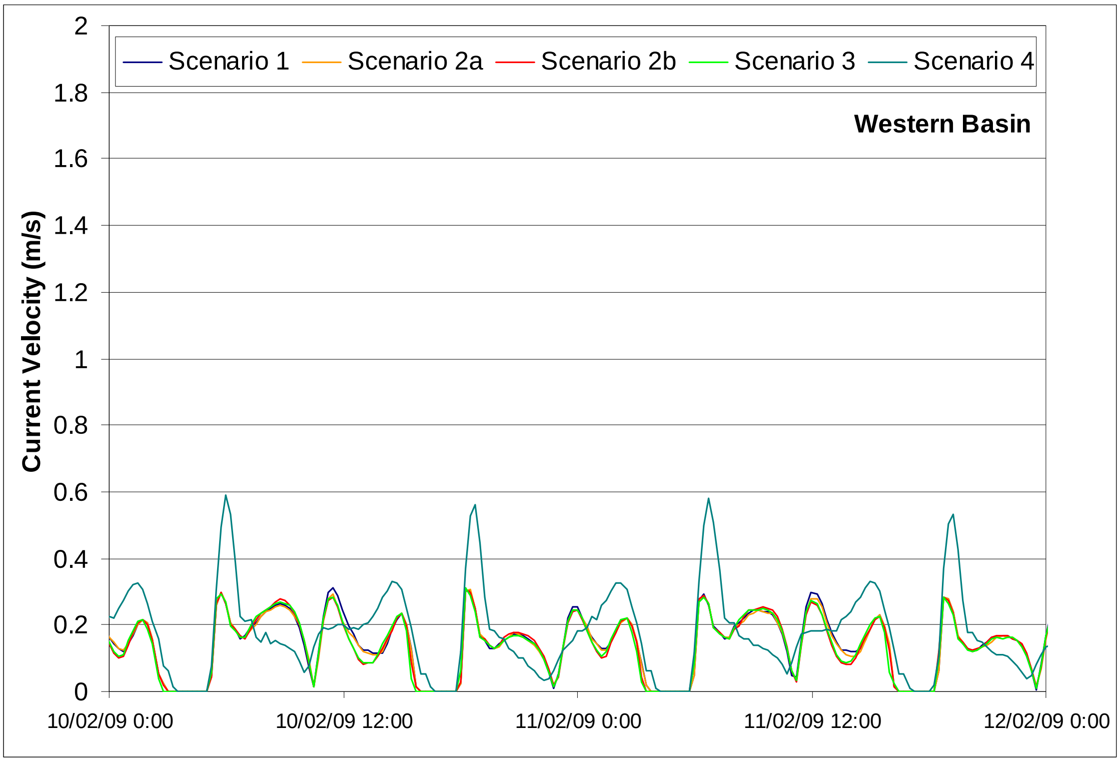

Figure B-7 Velocity Magnitude Time Series – Western Basin

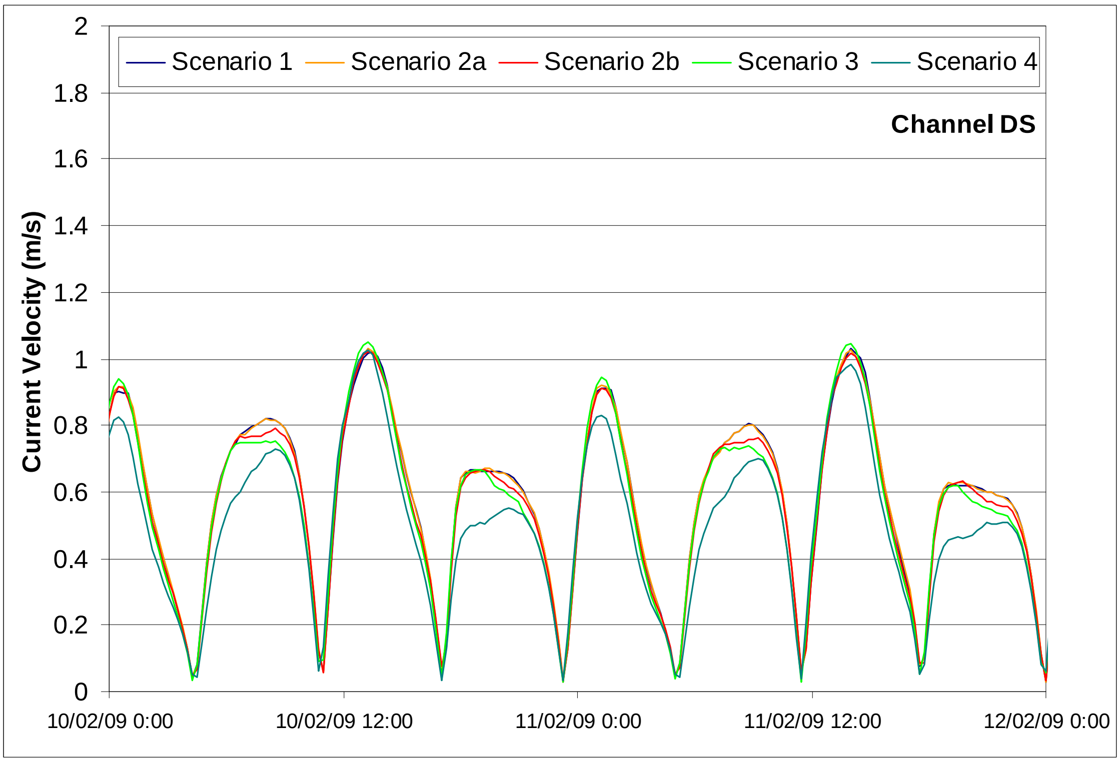

Figure B-8 Velocity Magnitude Time Series – Channel DS

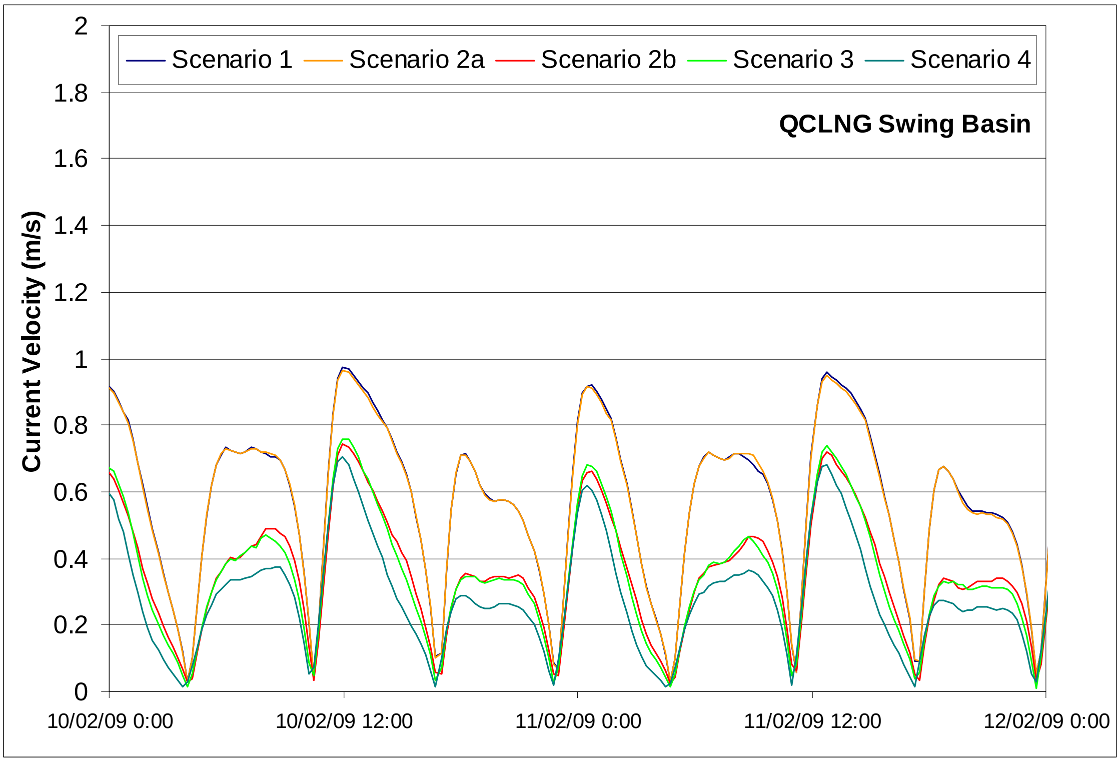

Figure B-9 Velocity Magnitude Time Series – QCLNG Swing Basin

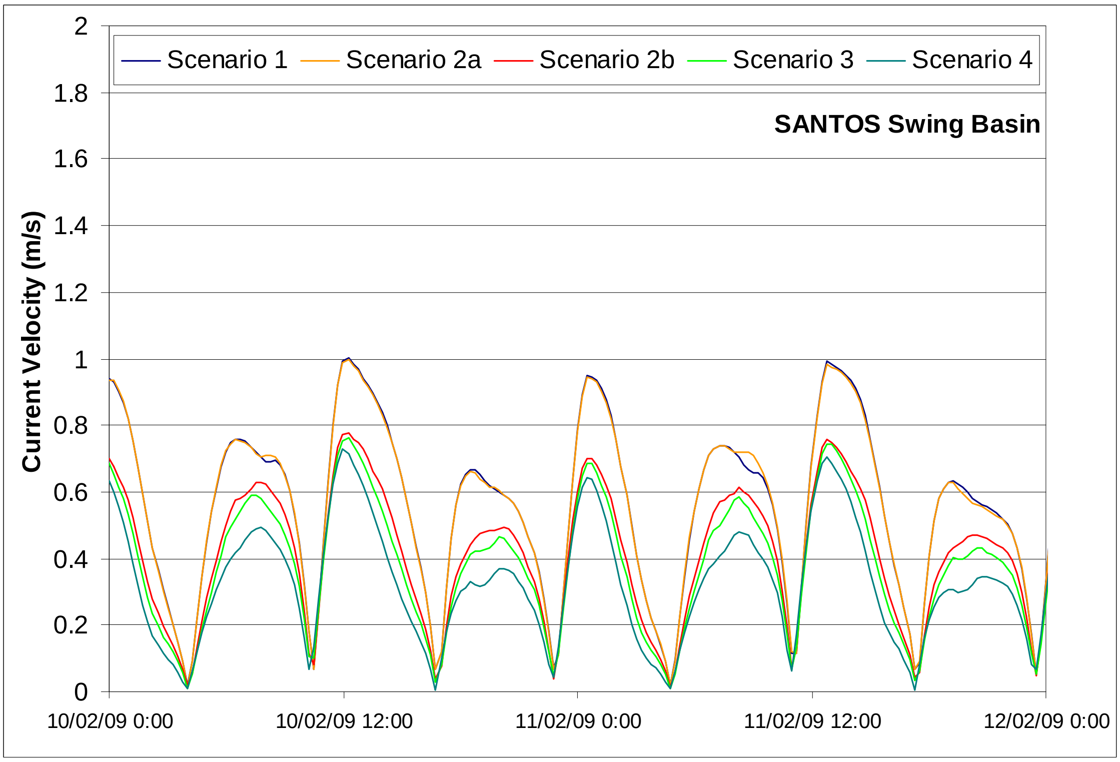

Figure B-10 Velocity Magnitude Time Series – SANTOS Swing Basin

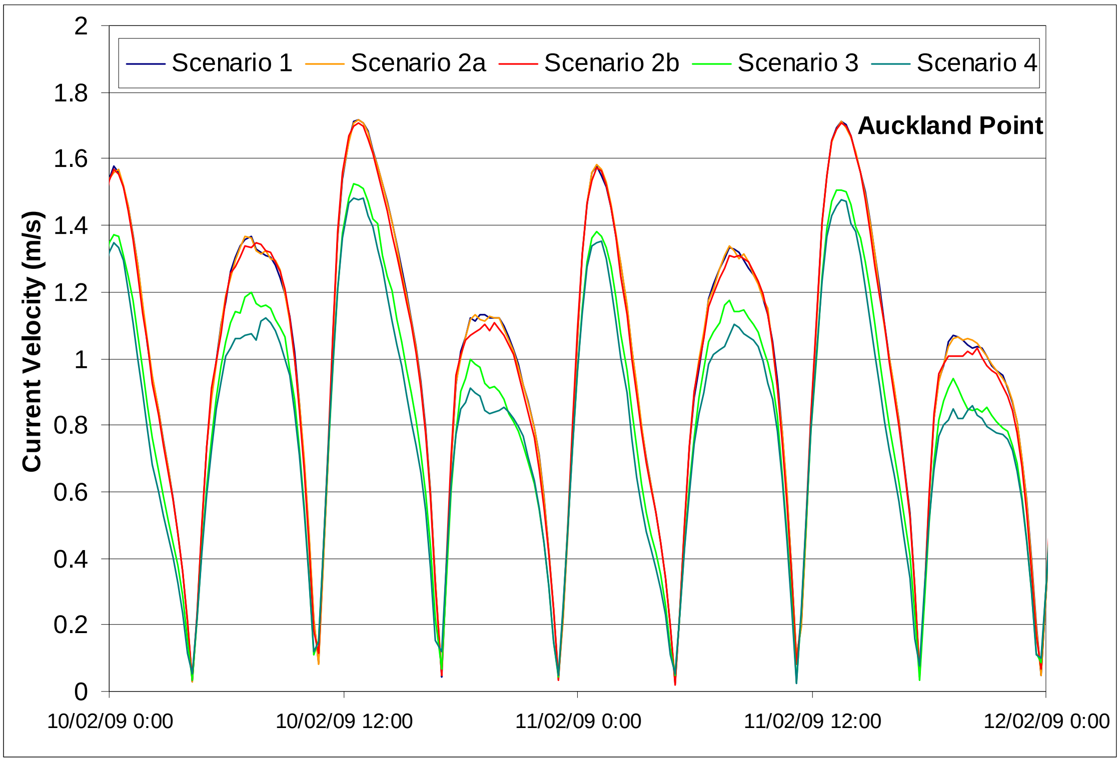

Figure B-11 Velocity Magnitude Time Series – Auckland Point

APPENDIX C: VELOCITY CONTOURS – PIPELINE CROSSING OPTION 1

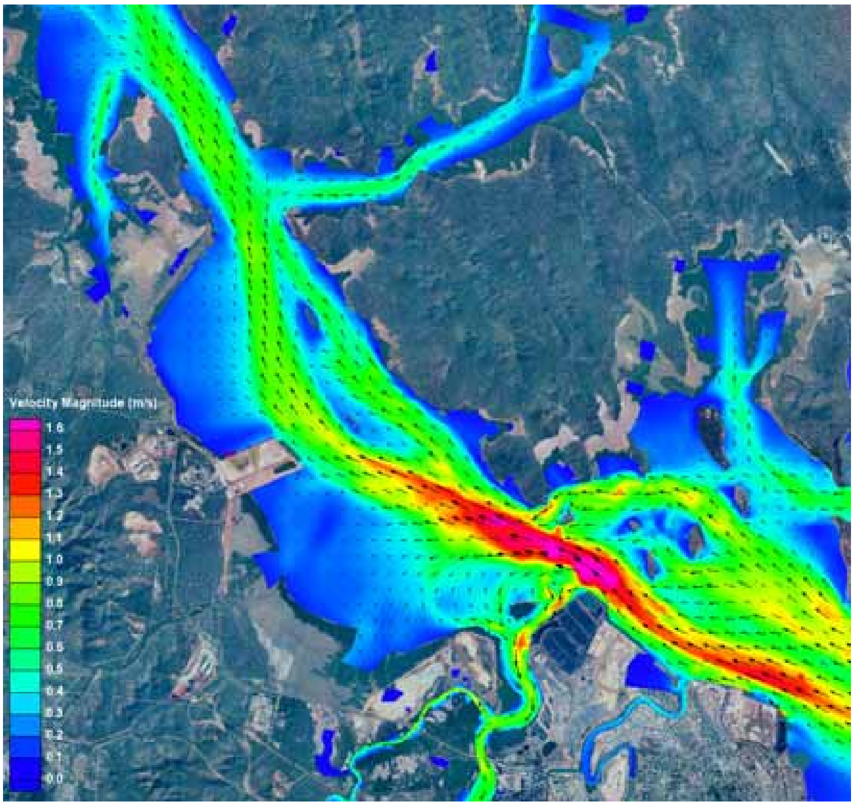

Figure C-1 Scenario 1 (Existing) peak flood tide velocities

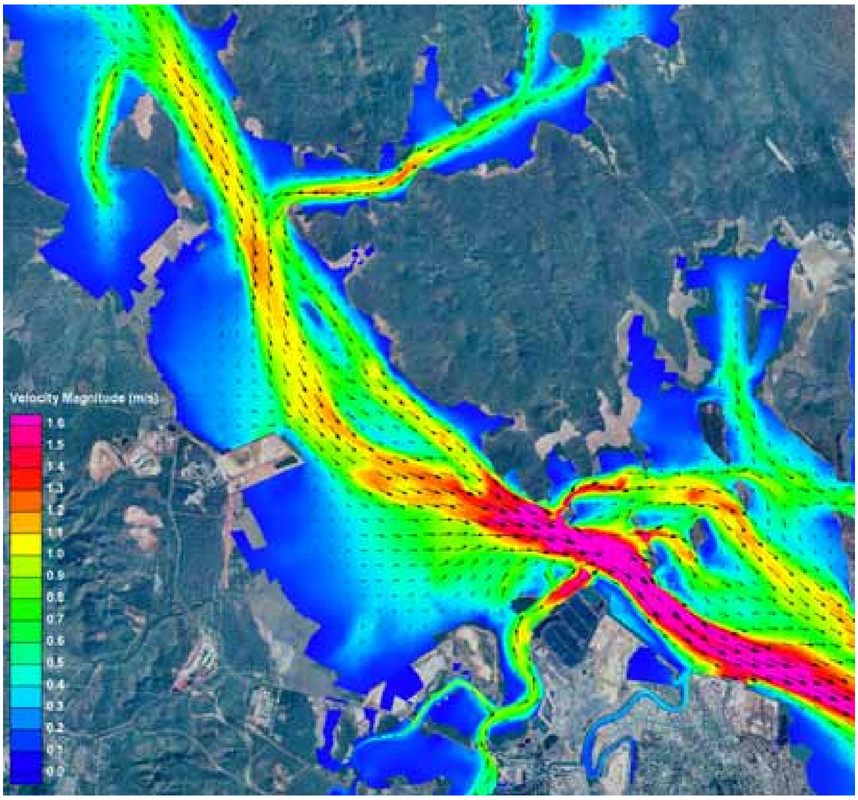

Figure C-2 Scenario 1 (Existing) peak ebb tide velocities

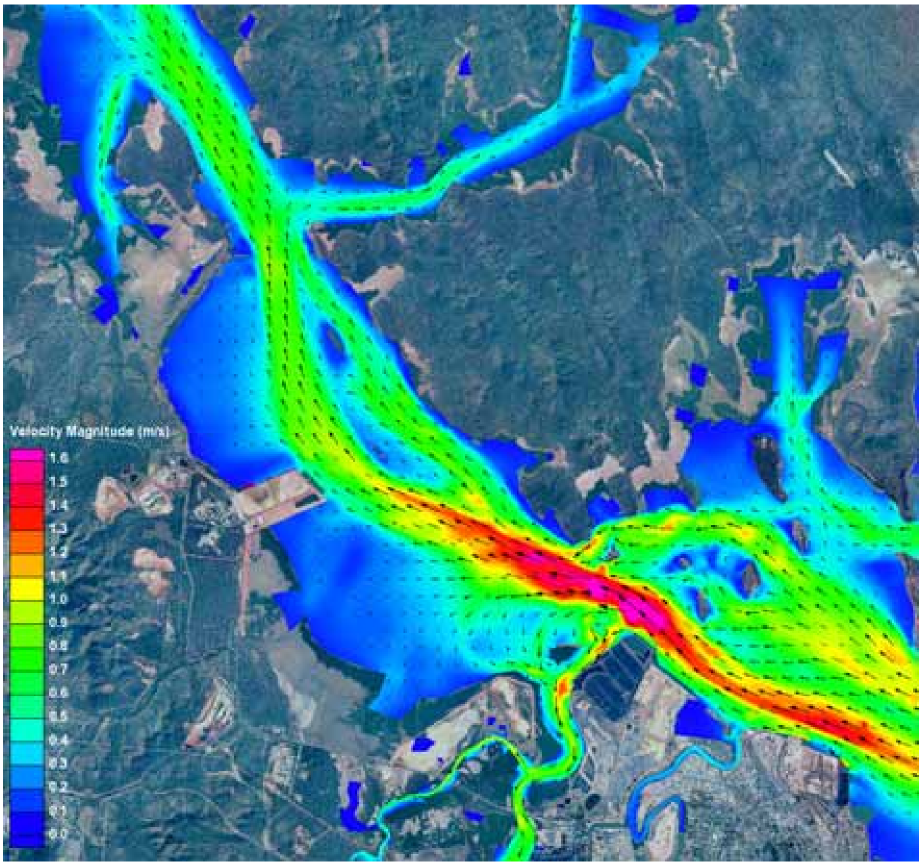

Figure C-3 Scenario 2a peak flood tide velocities

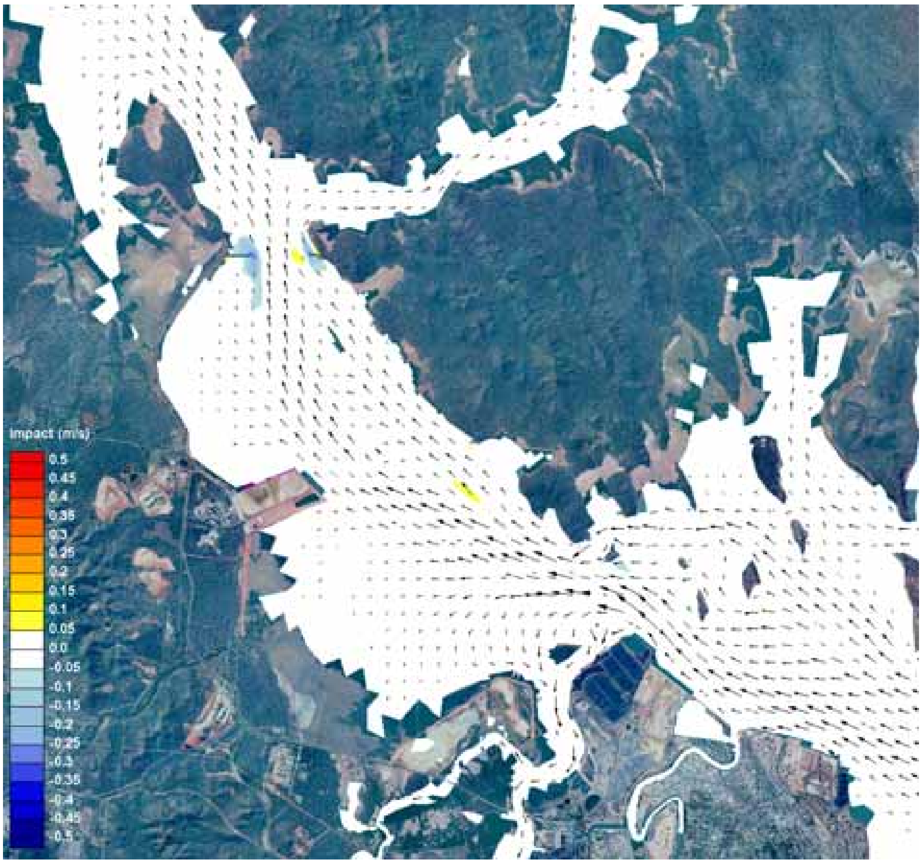

Figure C-4 Scenario 2a peak flood tide velocity differences

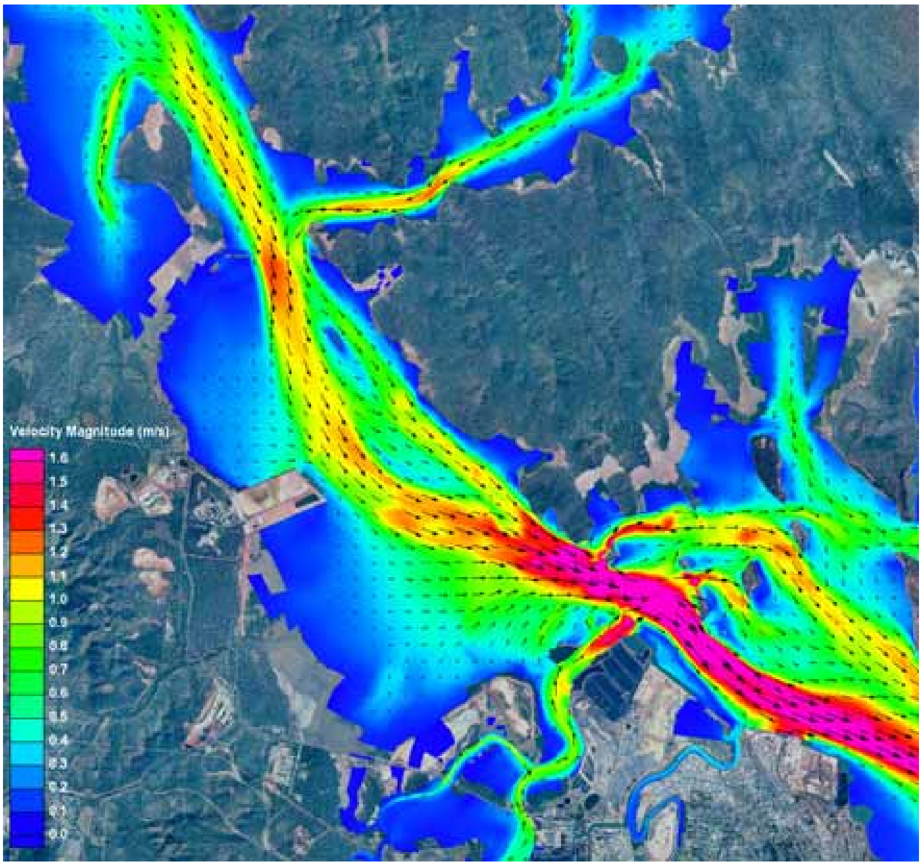

Figure C-5 Scenario 2a peak ebb tide velocities

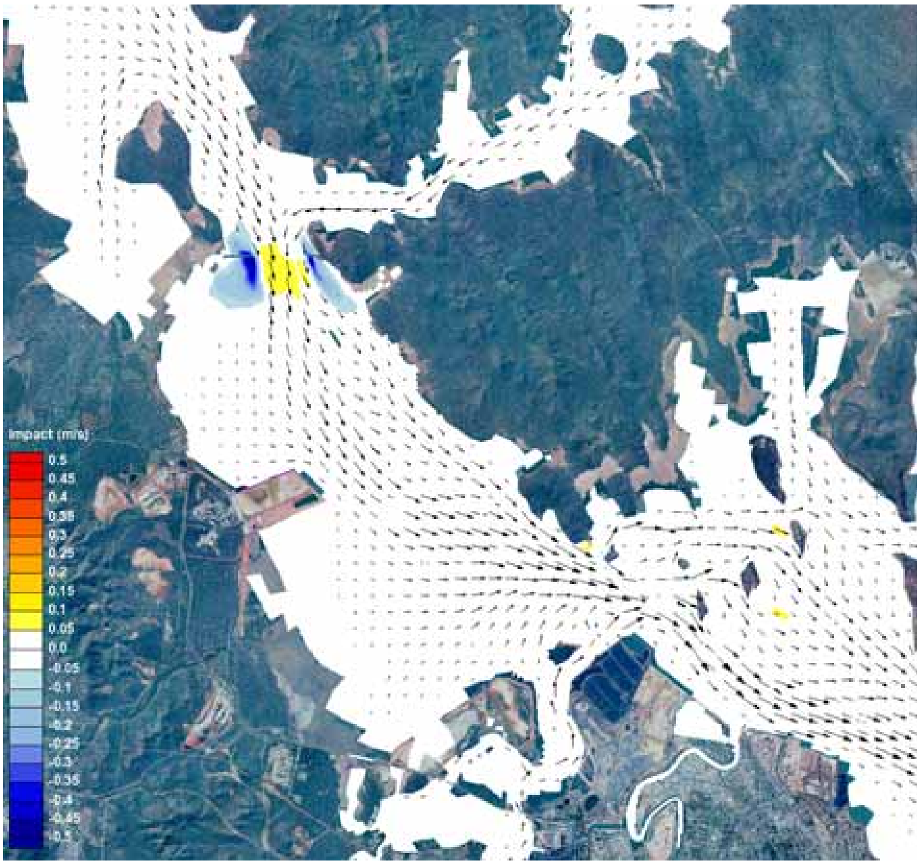

Figure C-6 Scenario 2a peak ebb tide velocity differences

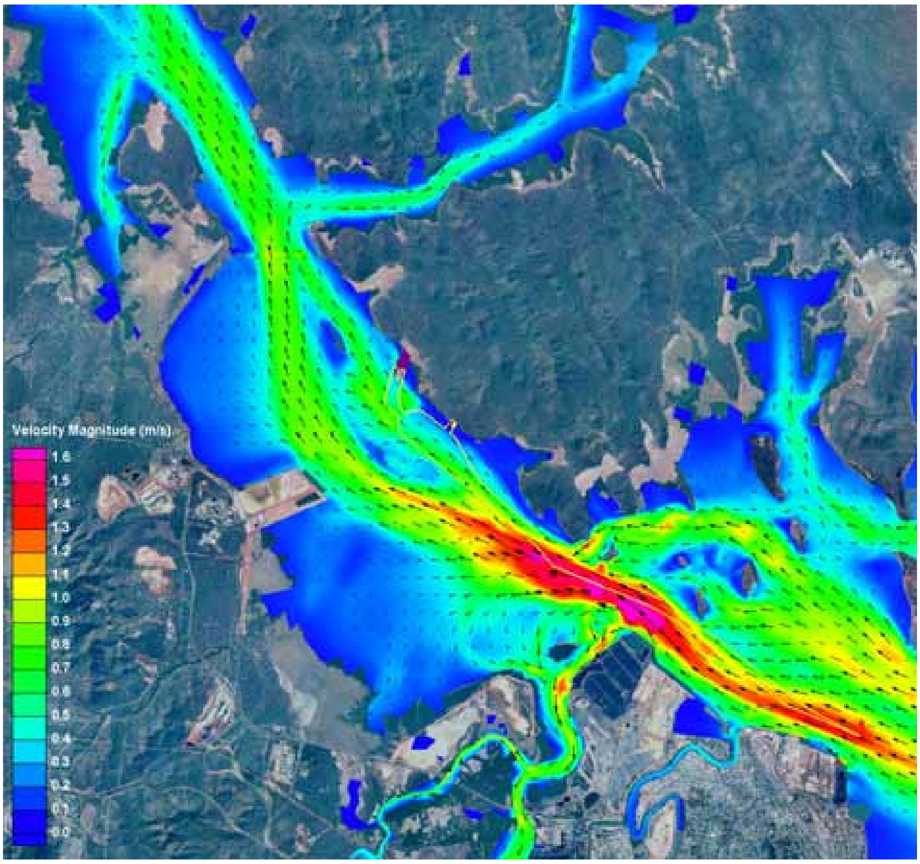

Figure C-7 Scenario 2b peak flood tide velocities

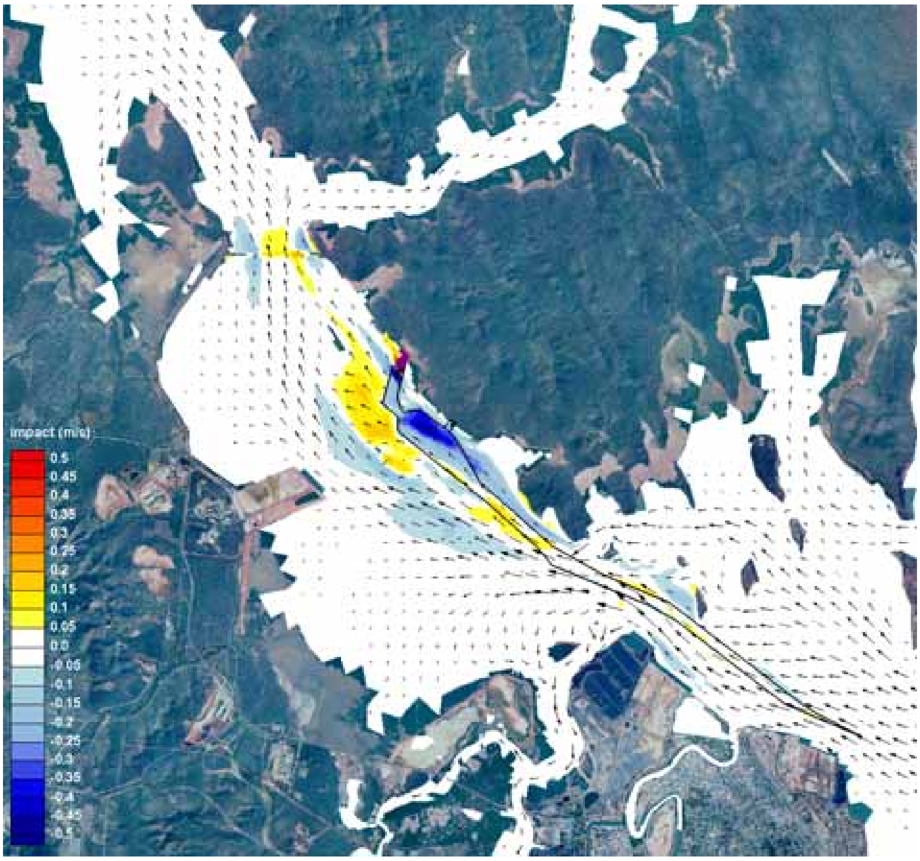

Figure C-8 Scenario 2b peak flood tide velocity differences

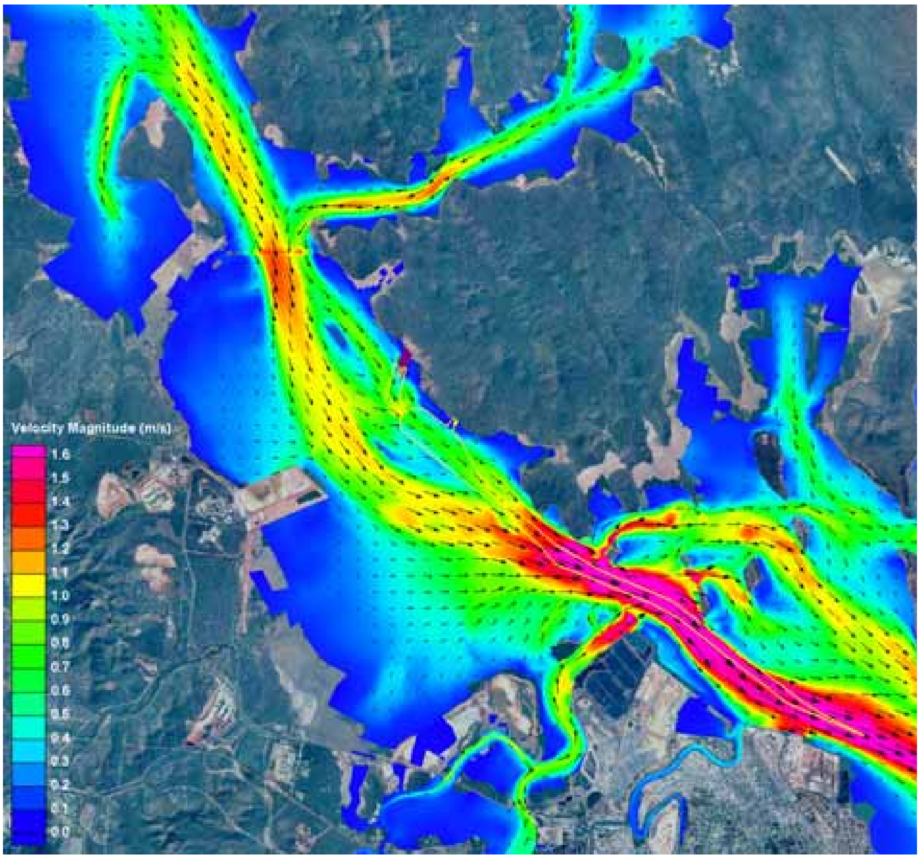

Figure C-9 Scenario 2b peak ebb tide velocities

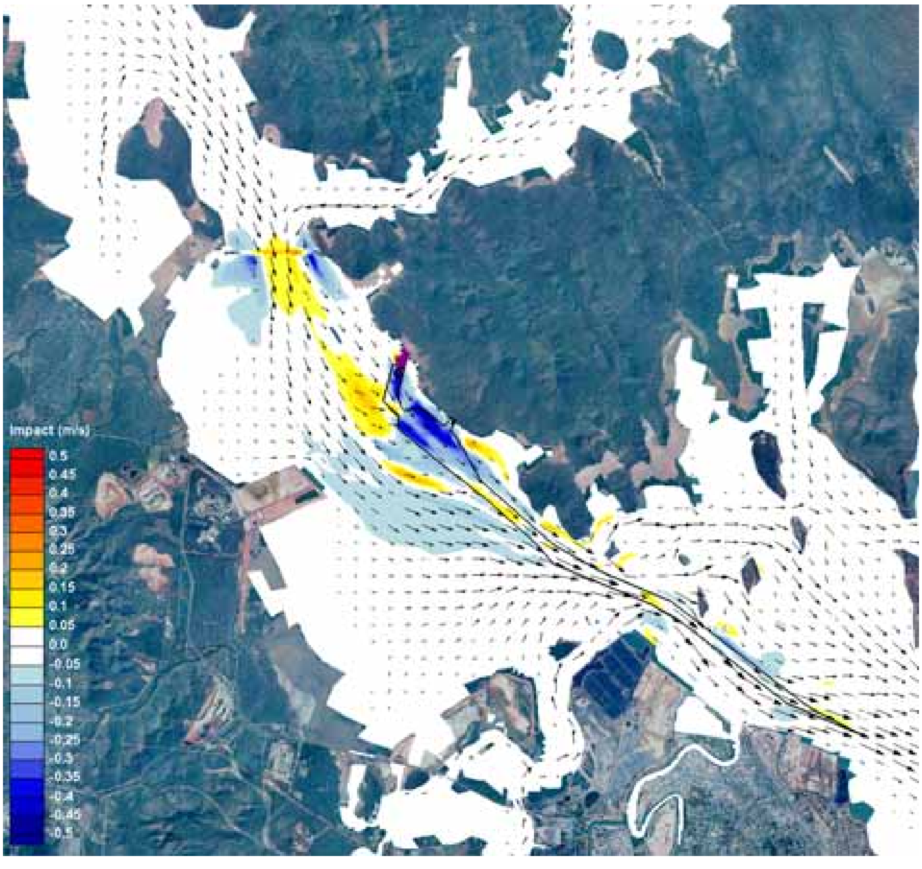

Figure C-10 Scenario 2b peak ebb tide velocity differences

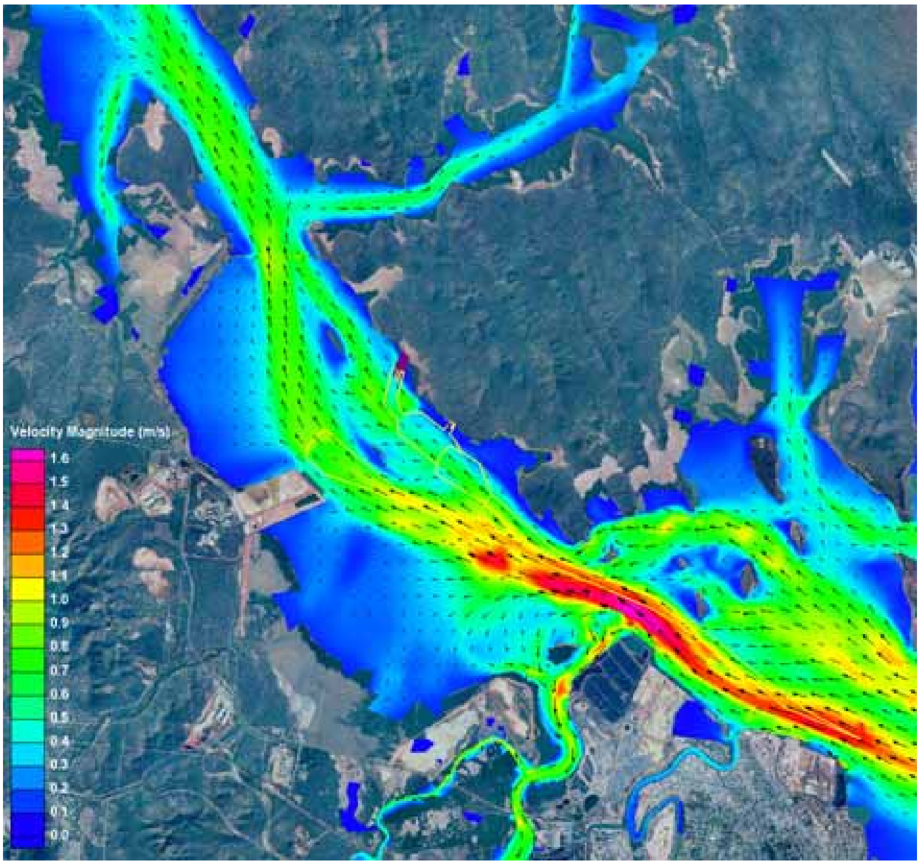

Figure C-11 Scenario 3 peak flood tide velocities

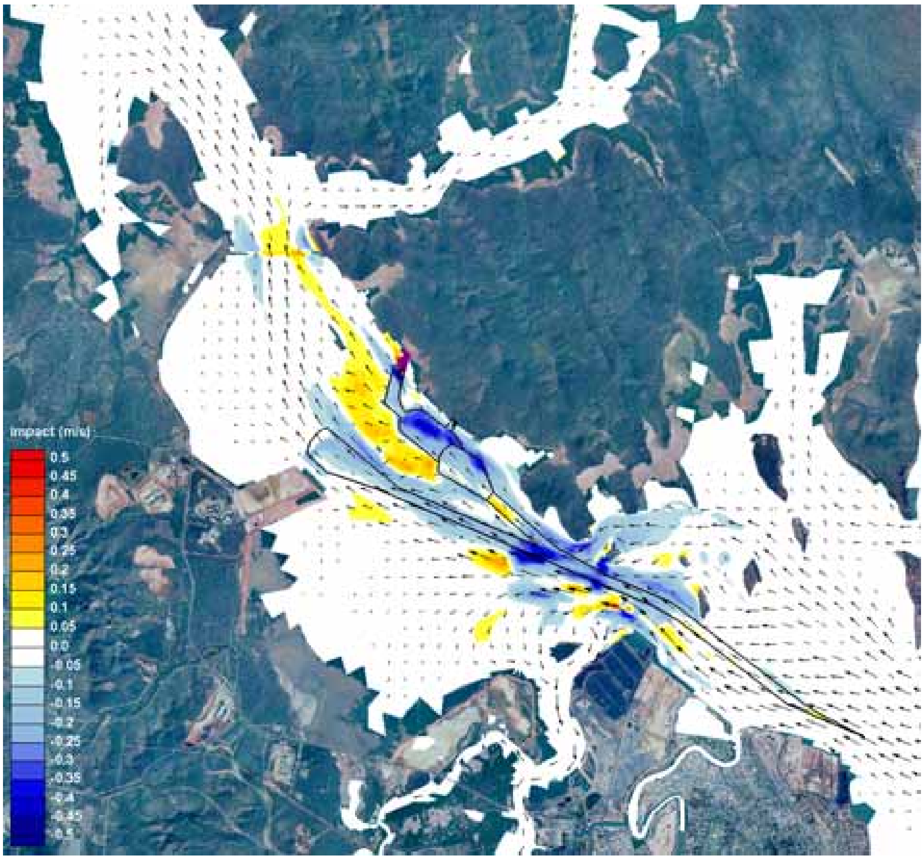

Figure C-12 Scenario 3 peak flood tide velocity differences

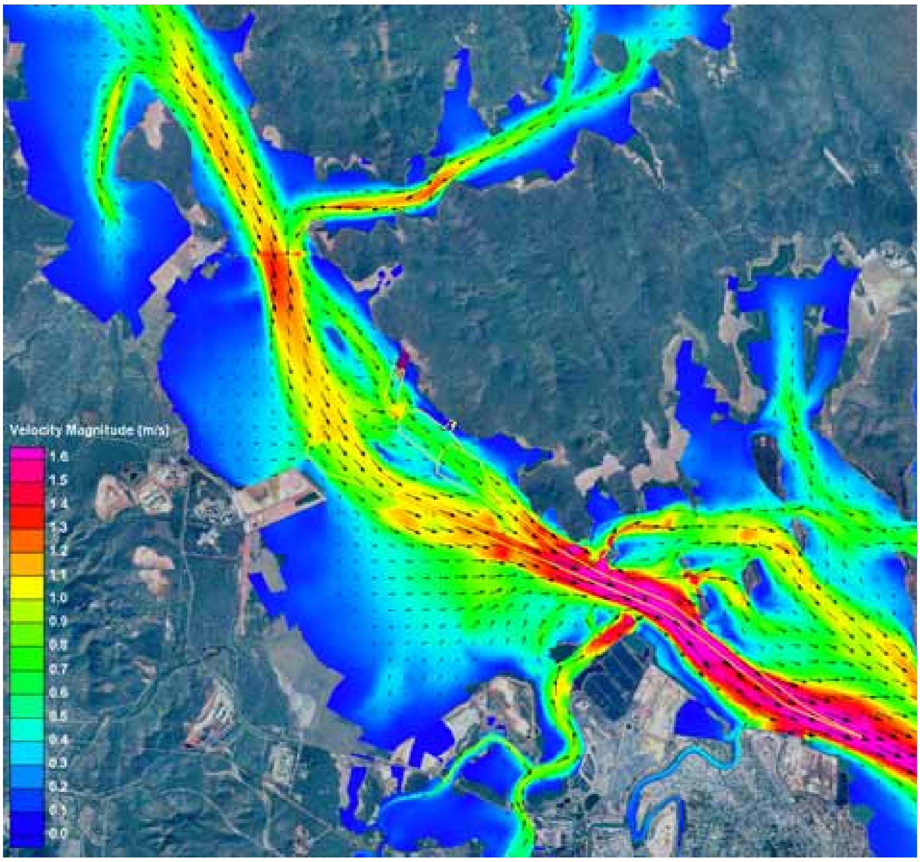

Figure C-13 Scenario 3 peak ebb tide velocities

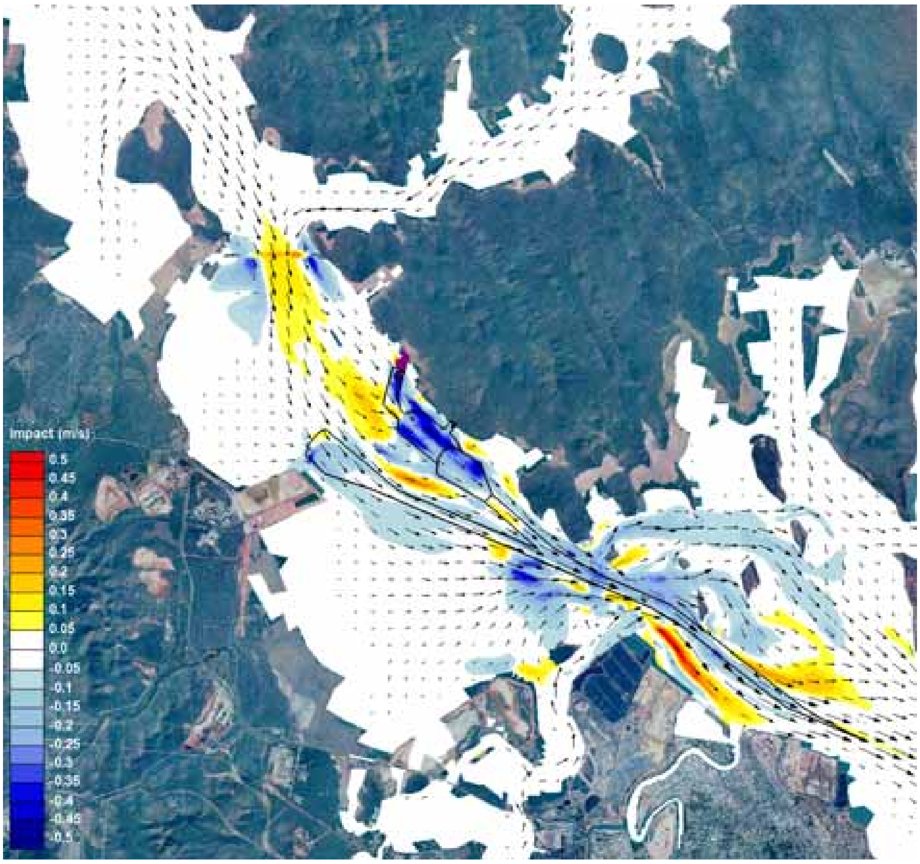

Figure C-14 Scenario 3 peak ebb tide velocity differences

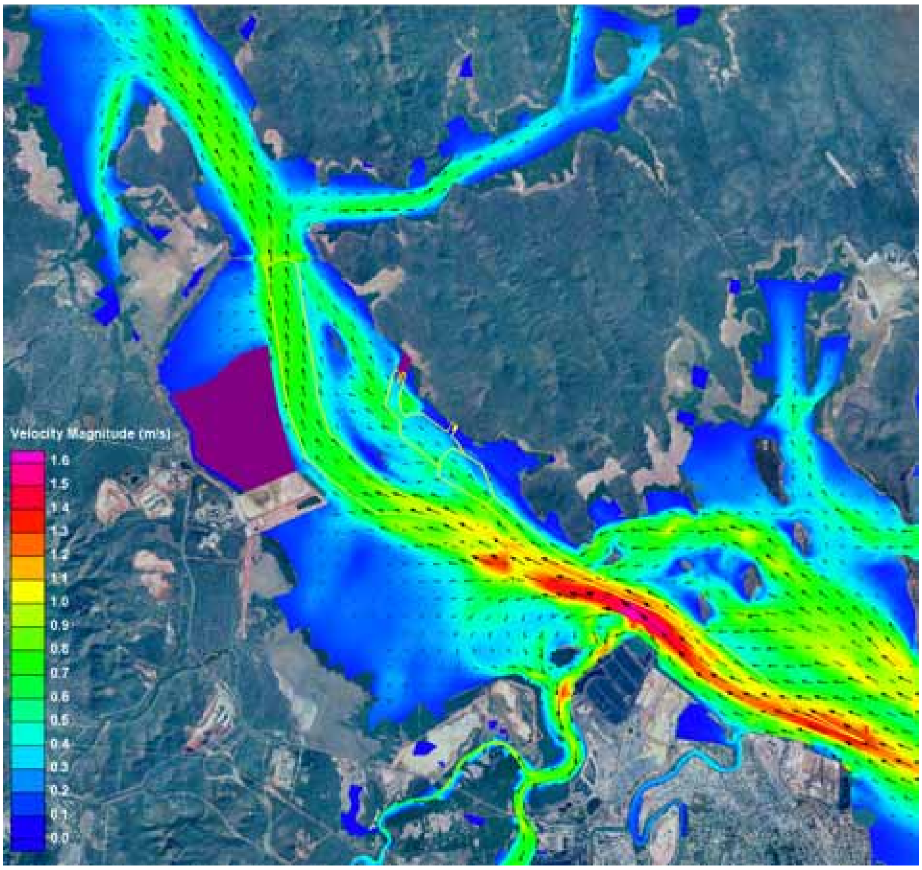

Figure C-15 Scenario 4 peak flood tide velocities

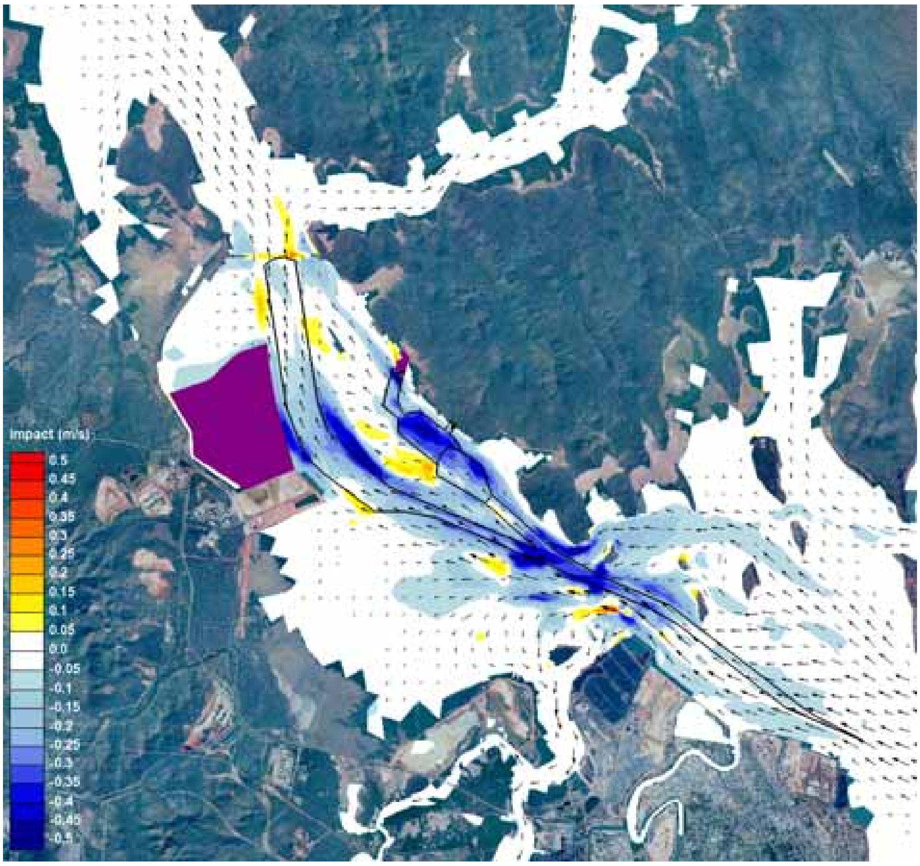

Figure C-16 Scenario 4 peak flood tide velocity differences

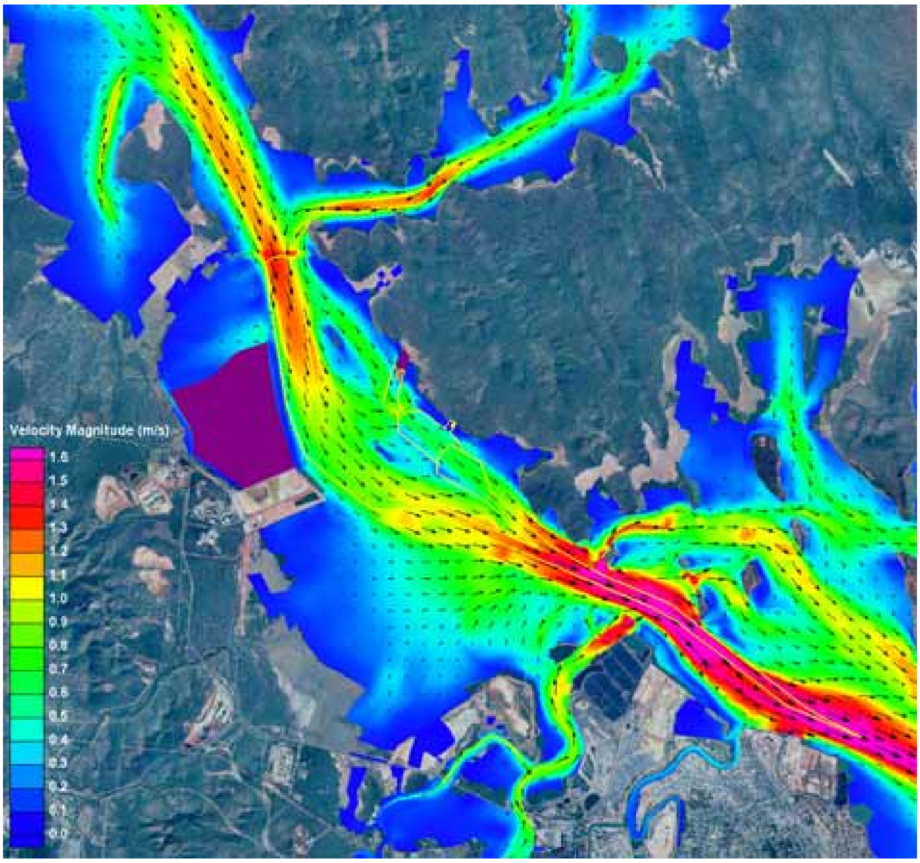

Figure C-17 Scenario 4 peak ebb tide velocities

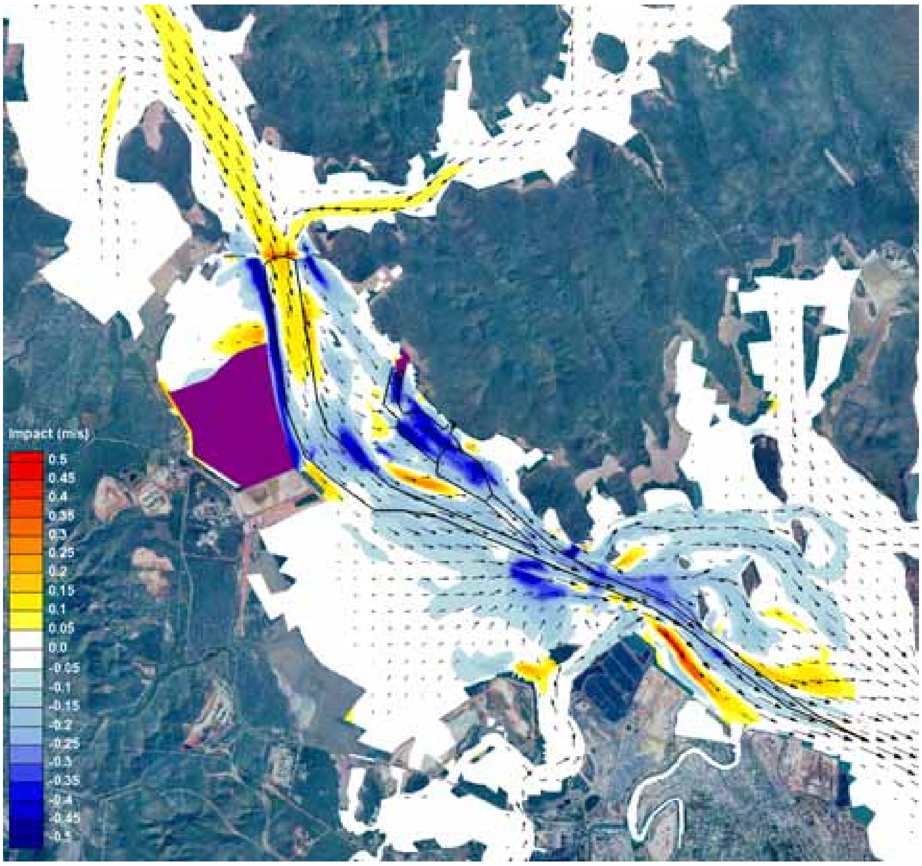

Figure C-18 Scenario 4 peak ebb tide velocity differences

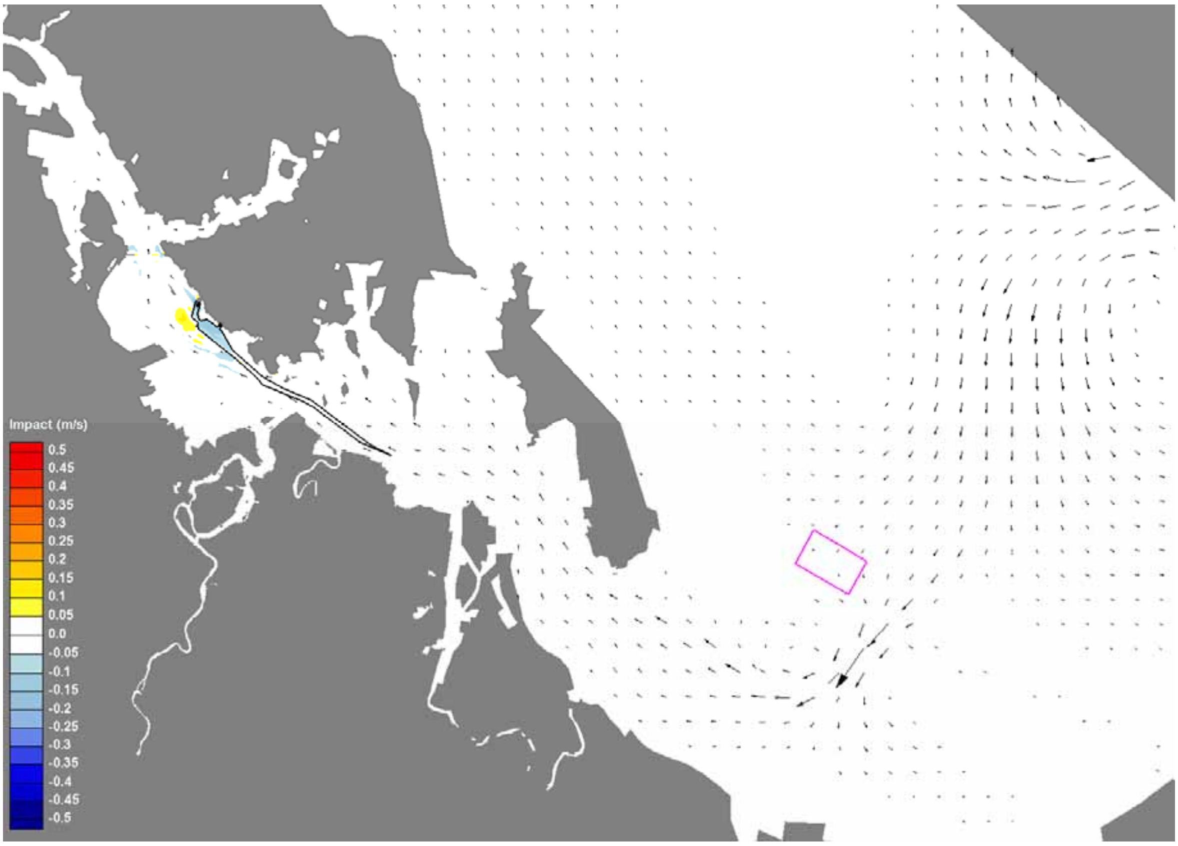

Figure C-19 Extended Model - Scenario 2b peak flood tide velocity differences

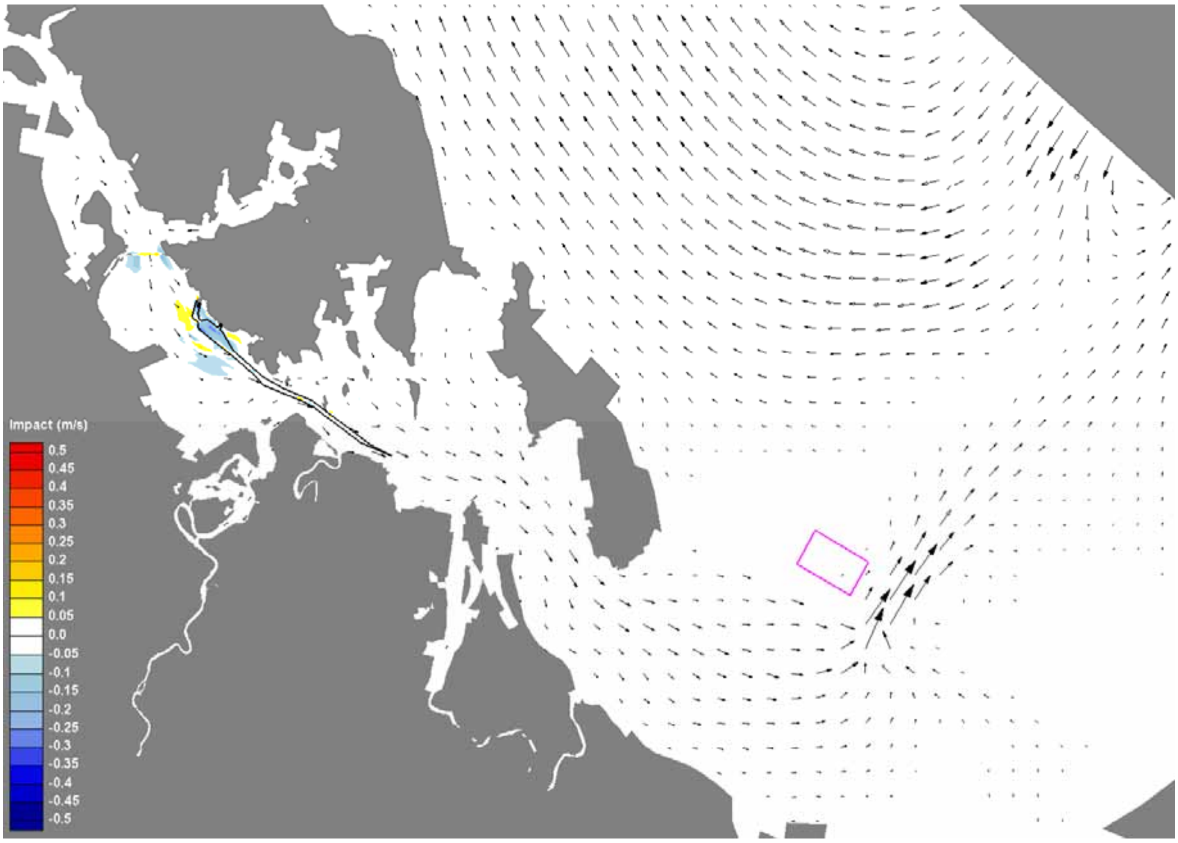

Figure C-20 Extended Model - Scenario 2b peak ebb tide velocity differences

APPENDIX D: TRACER CONCENTRATION TIME SERIES - PIPELINE CROSSING OPTION 1

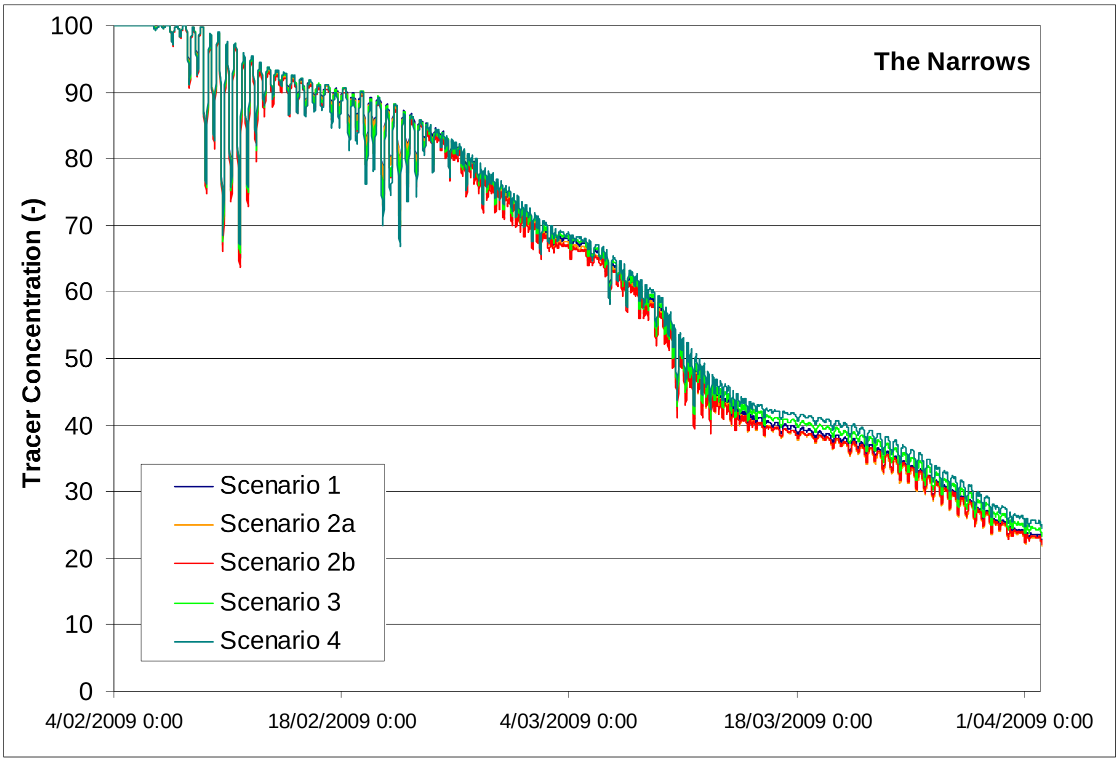

Figure D-1 Tracer Concentration Time Series – The Narrows

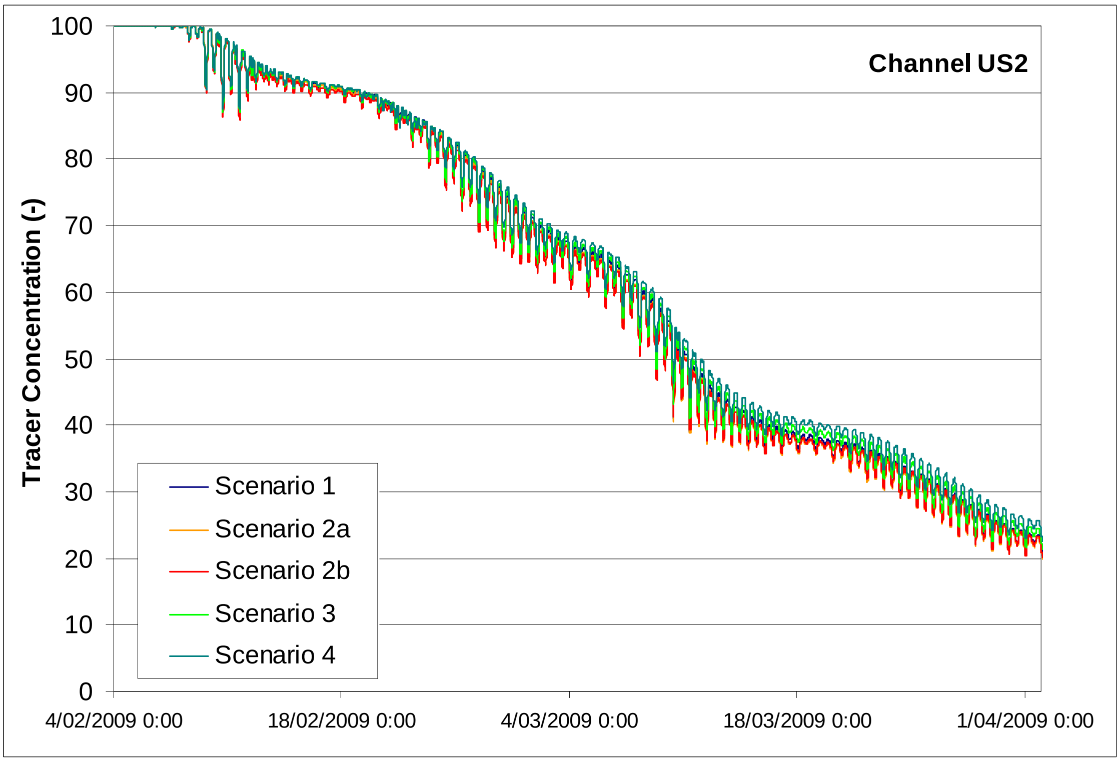

Figure D-2 Tracer Concentration Time Series – Channel US2

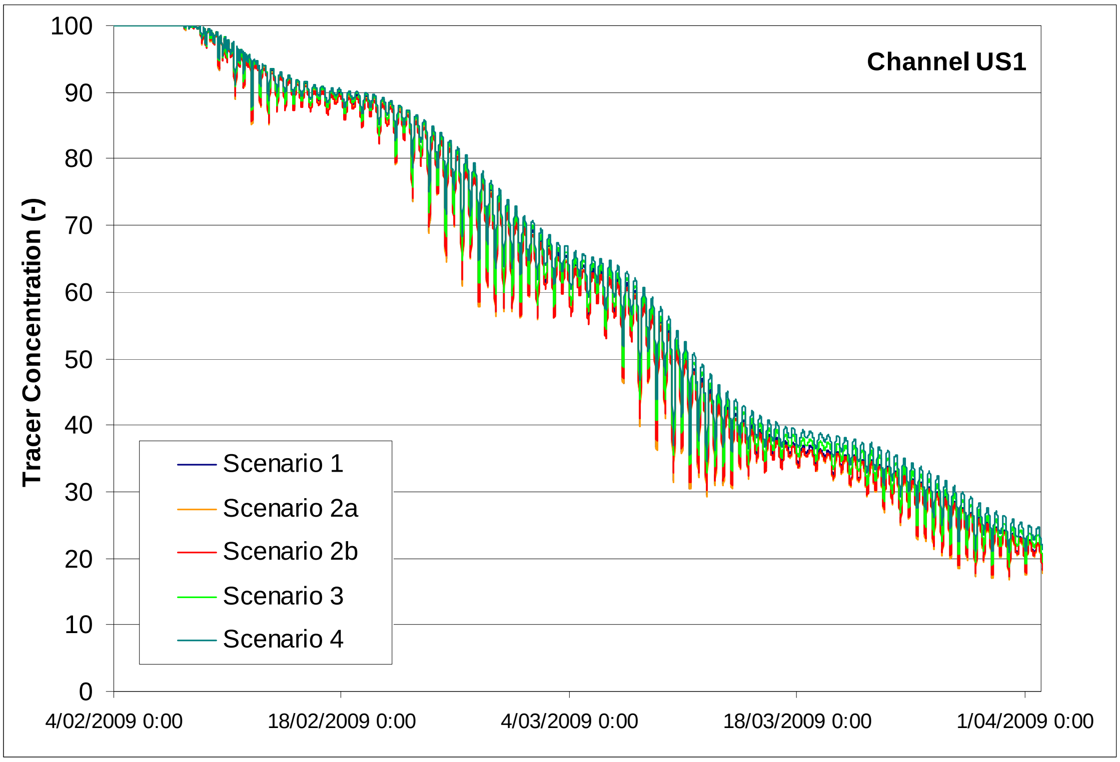

Figure D-3 Tracer Concentration Time Series – Channel US1

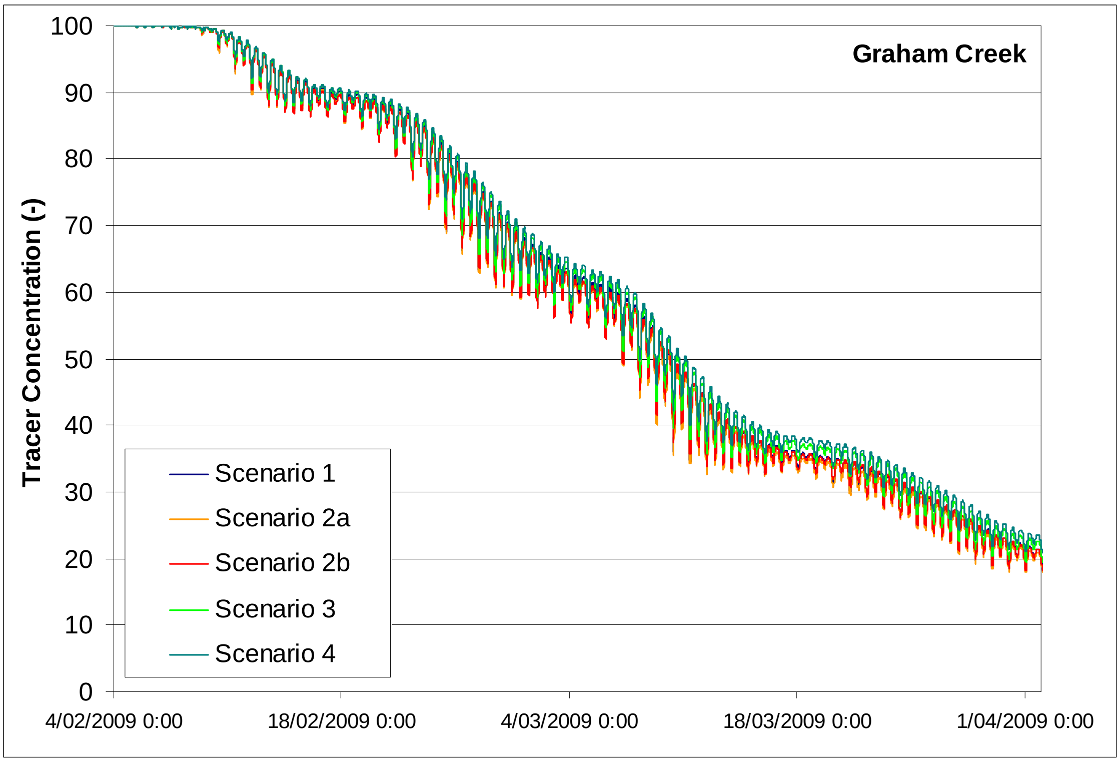

Figure D-4 Tracer Concentration Time Series – Graham Creek

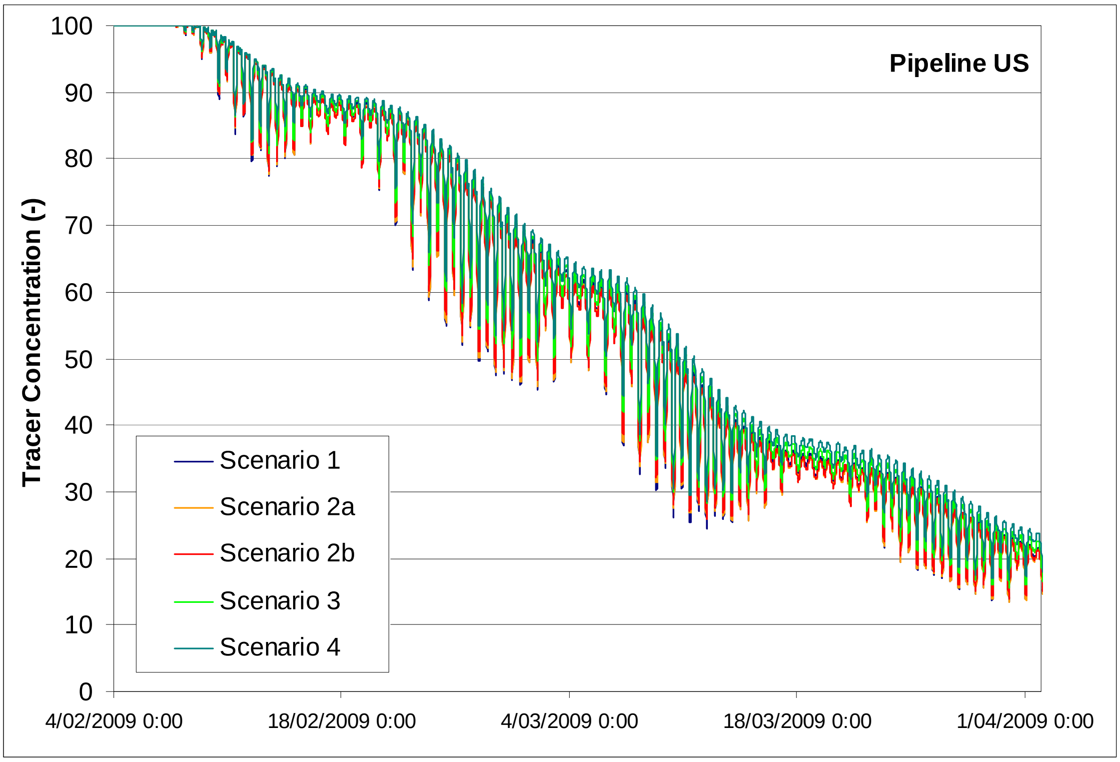

Figure D-5 Tracer Concentration Time Series – Pipeline US

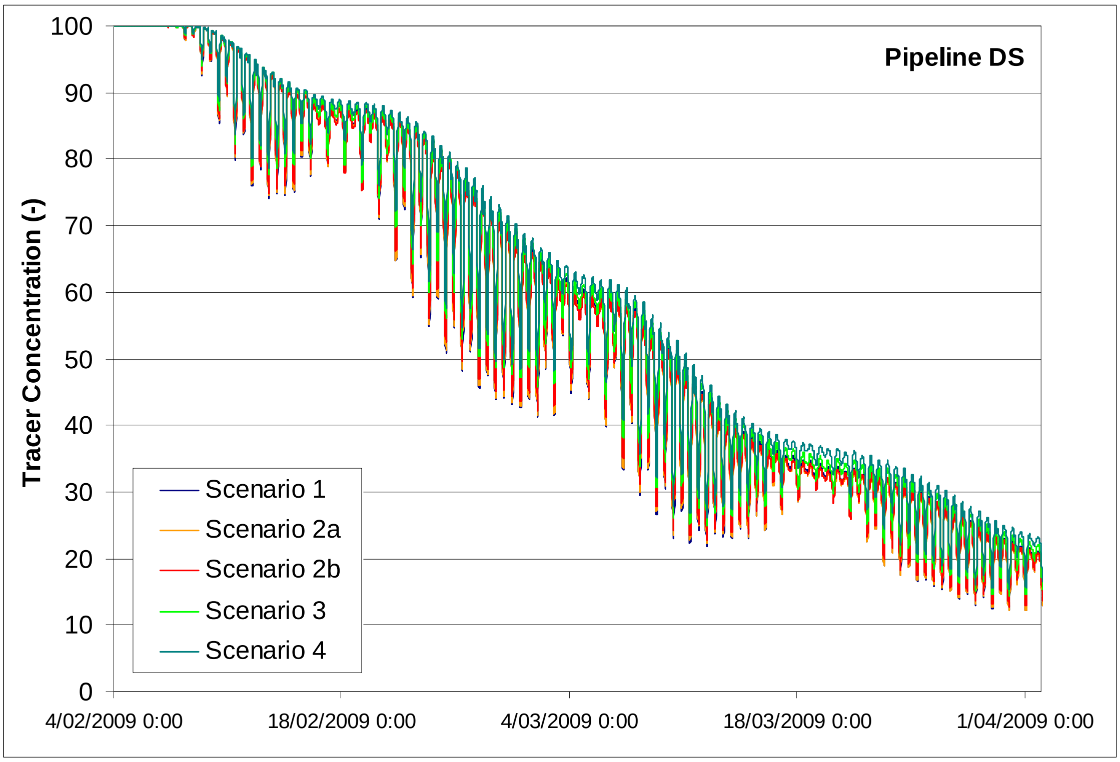

Figure D-6 Tracer Concentration Time Series – Pipeline DS

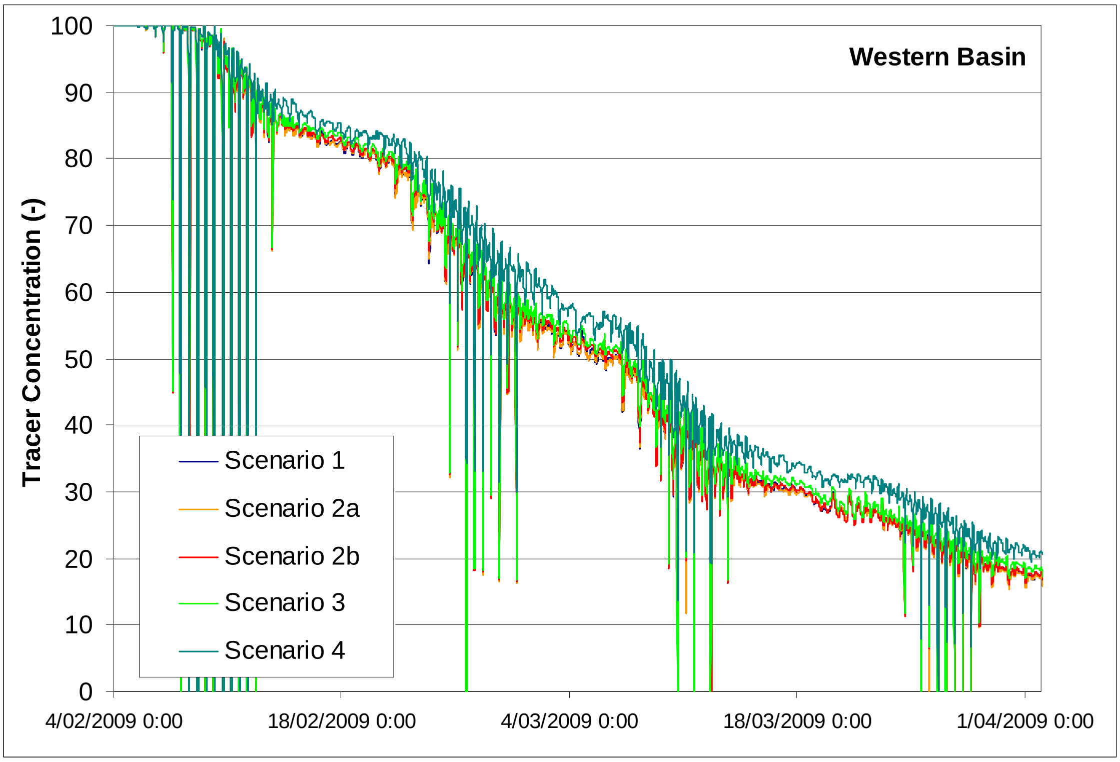

Figure D-7 Tracer Concentration Time Series – Western Basin

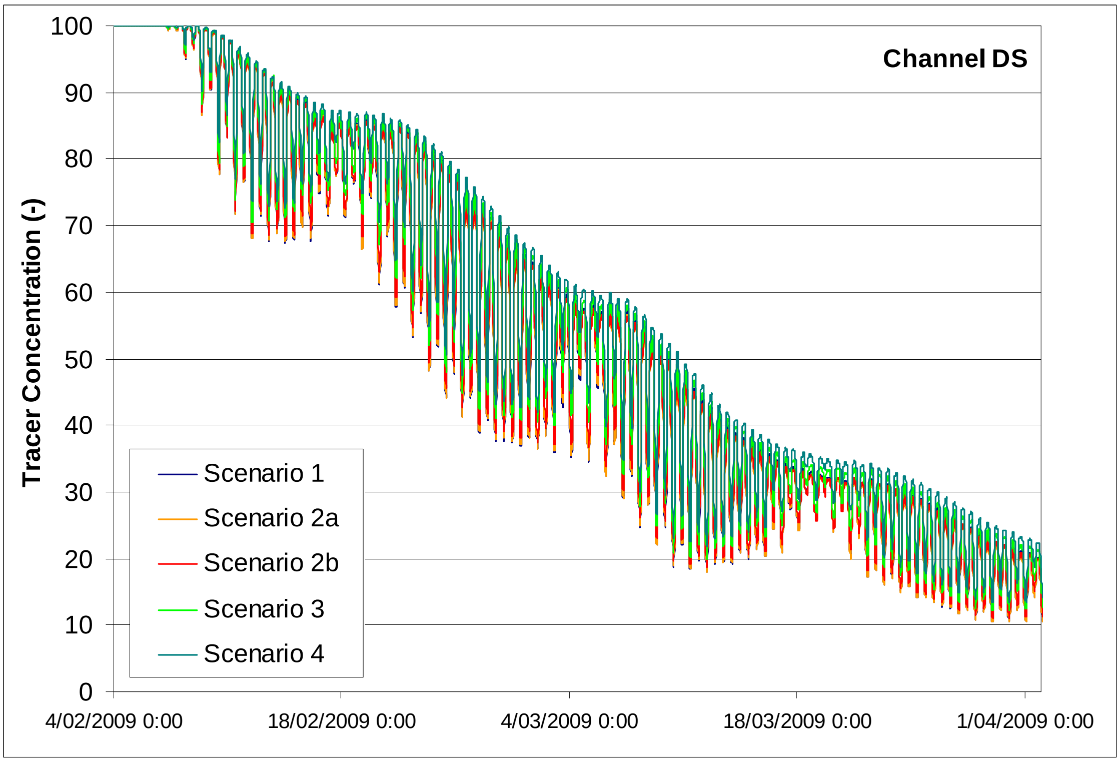

Figure D-8 Tracer Concentration Time Series – Channel DS

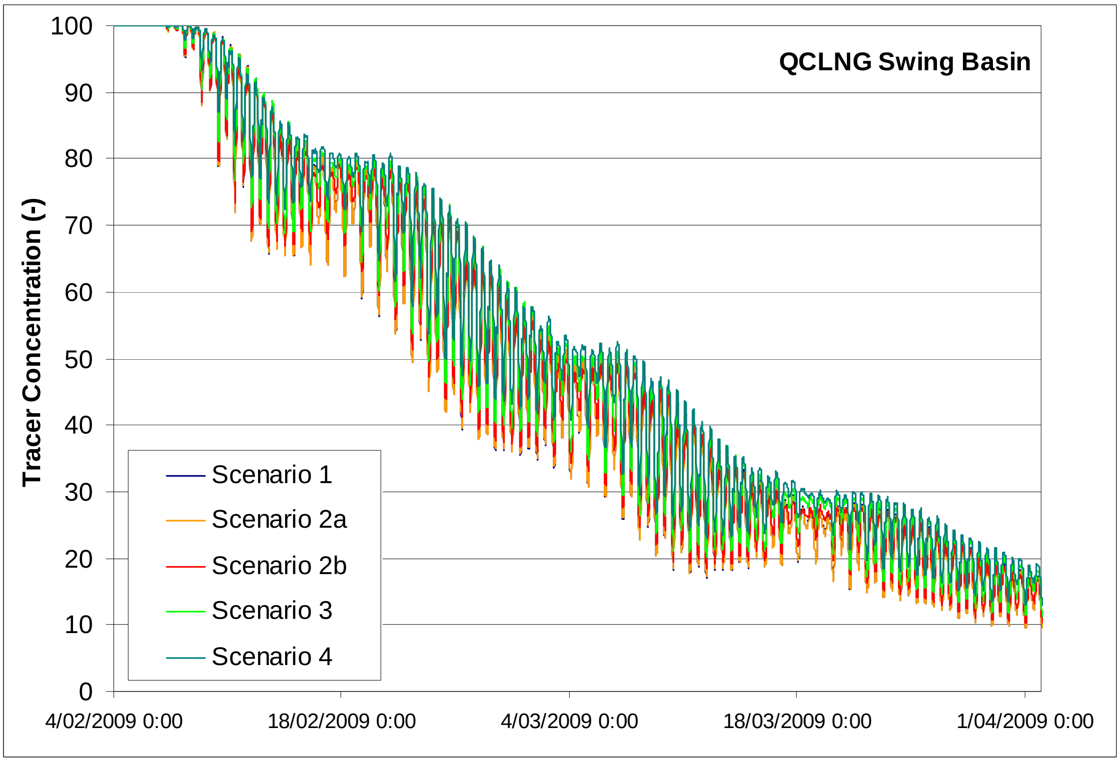

Figure D-9 Tracer Concentration Time Series – QCLNG Swing Basin

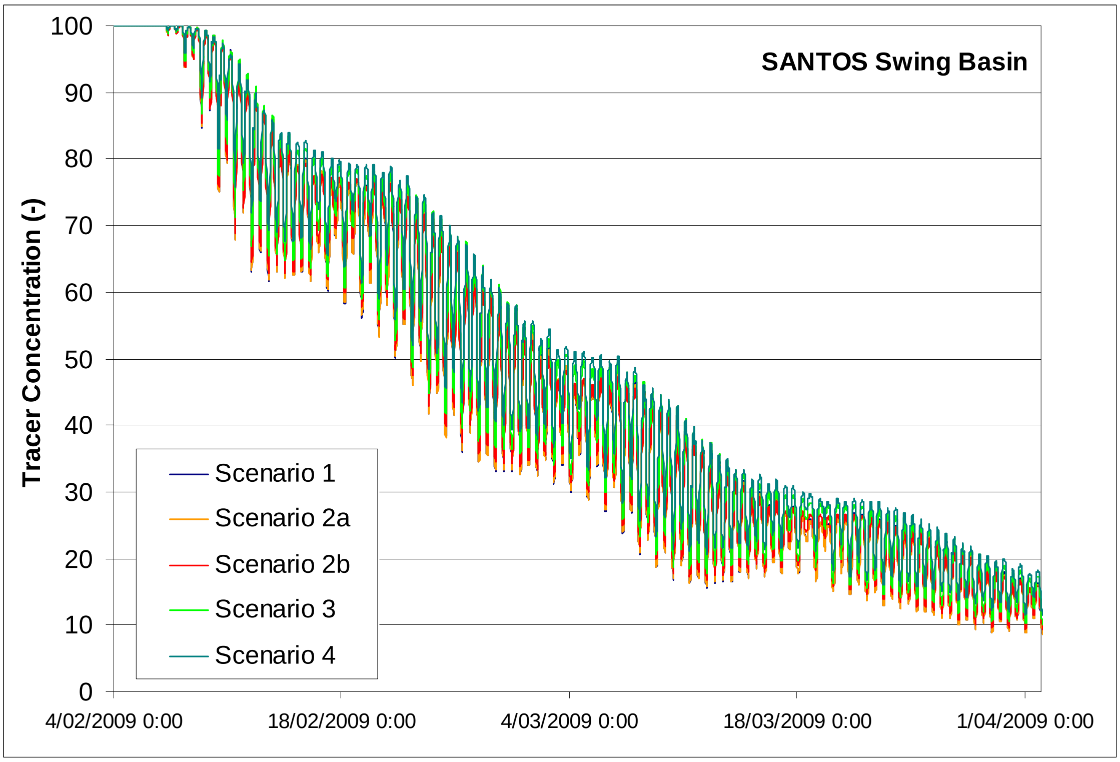

Figure D-10 Tracer Concentration Time Series – SANTOS Swing Basin

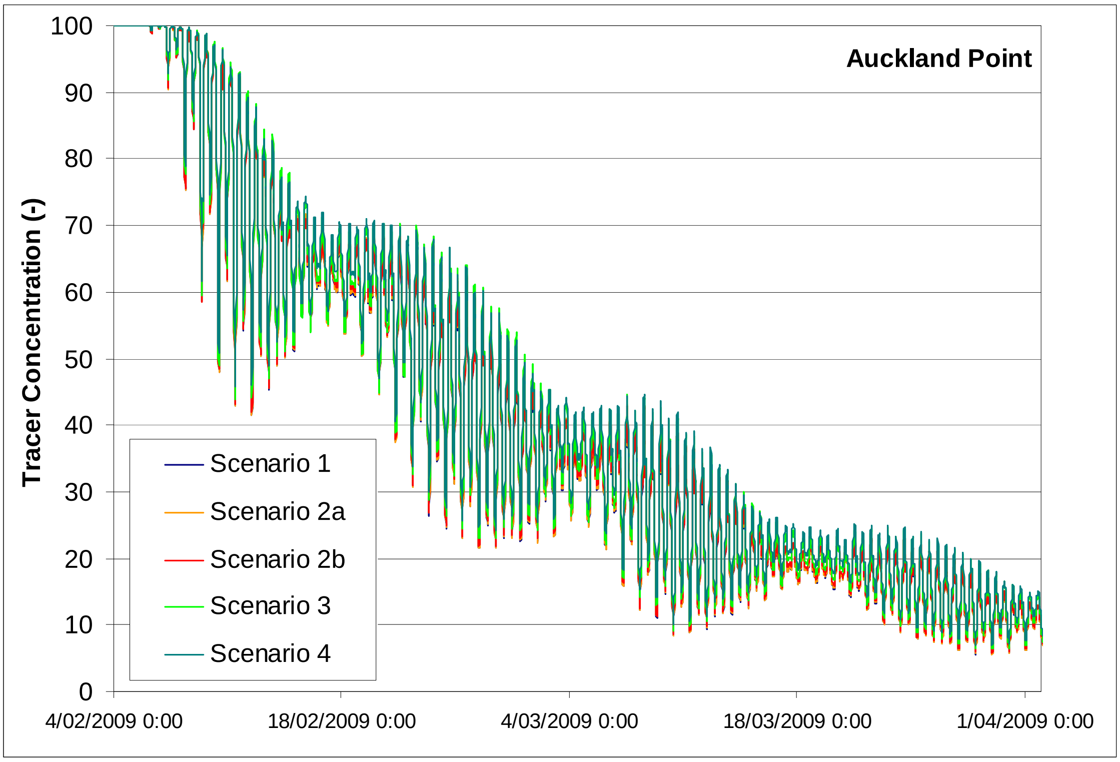

Figure D-11 Tracer Concentration Time Series – Auckland Point

APPENDIX E: TRACER CONCENTRATION CONTOURS – PIPELINE CROSSING OPTION 1

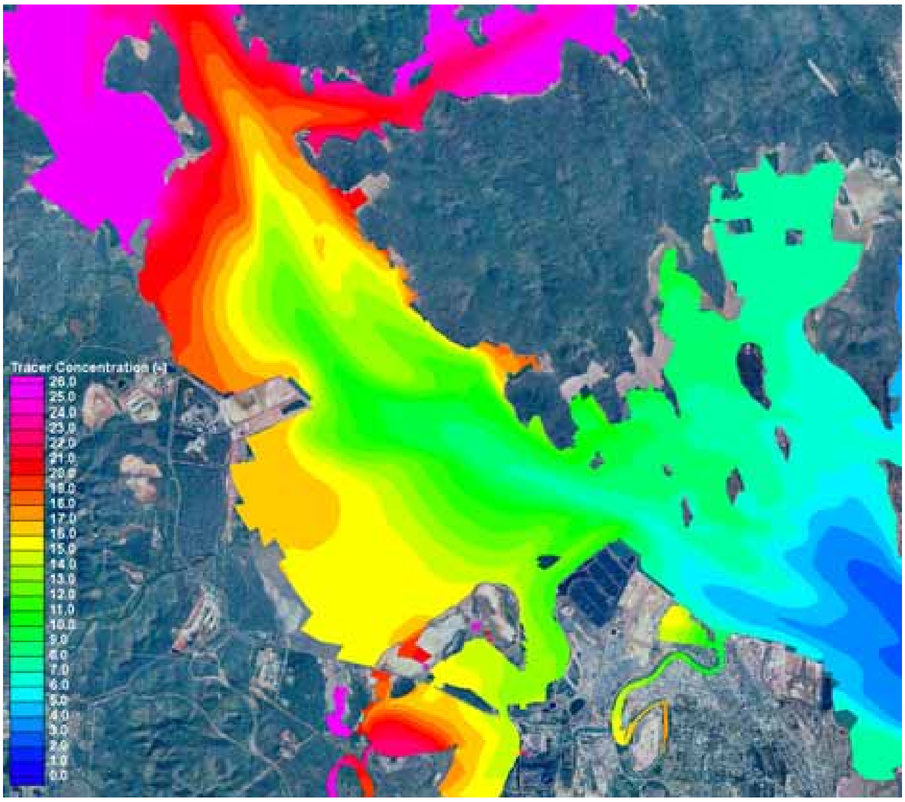

Figure E-1 Scenario 1 (Existing) tracer concentration

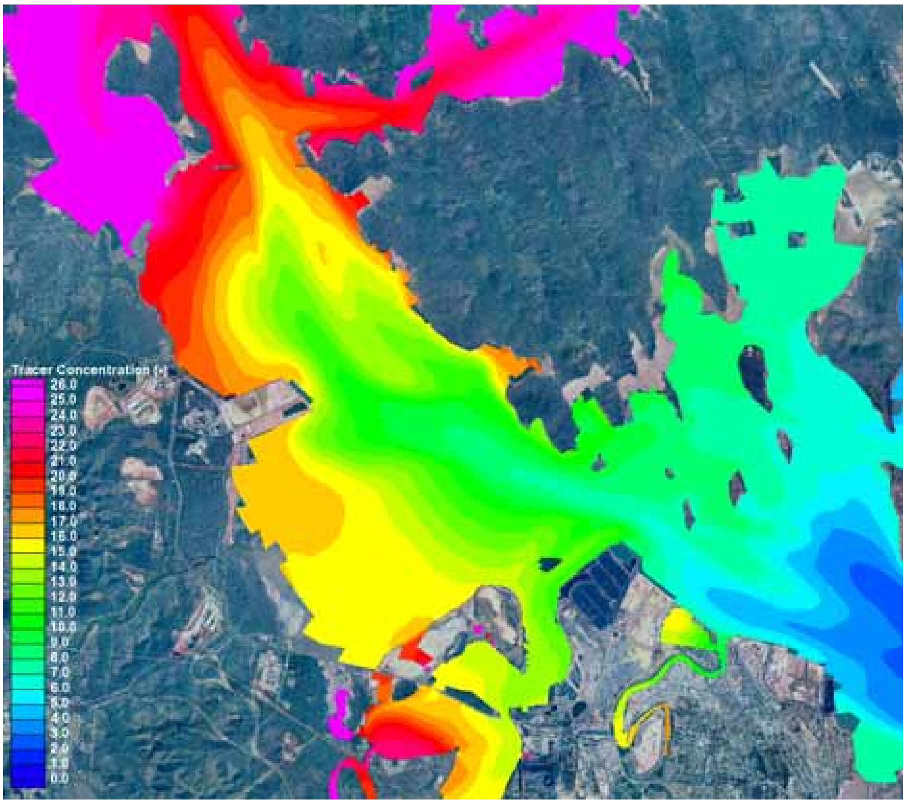

Figure E-2 Scenario 2a tracer concentration

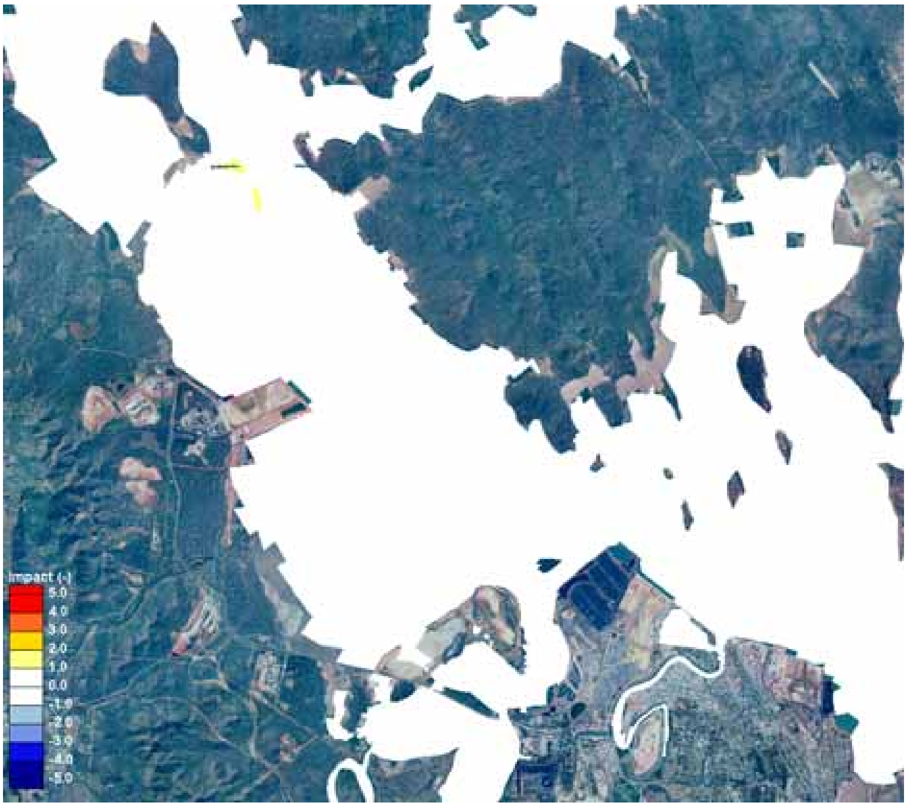

Figure E-3 Scenario 2a tracer concentration differences

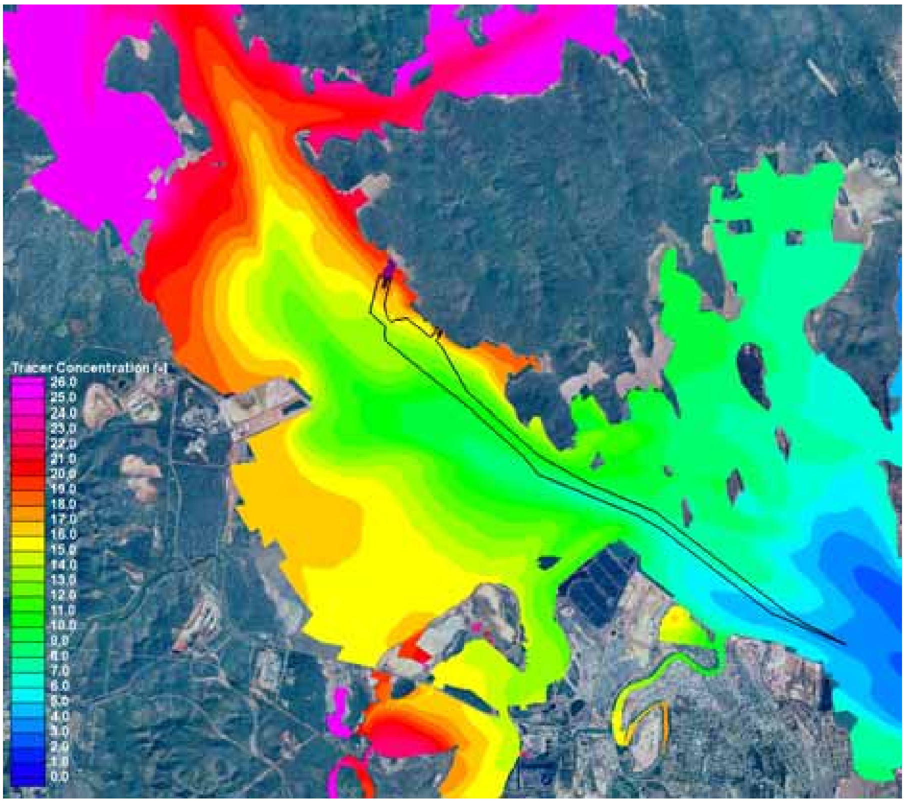

Figure E-4 Scenario 2b tracer concentration

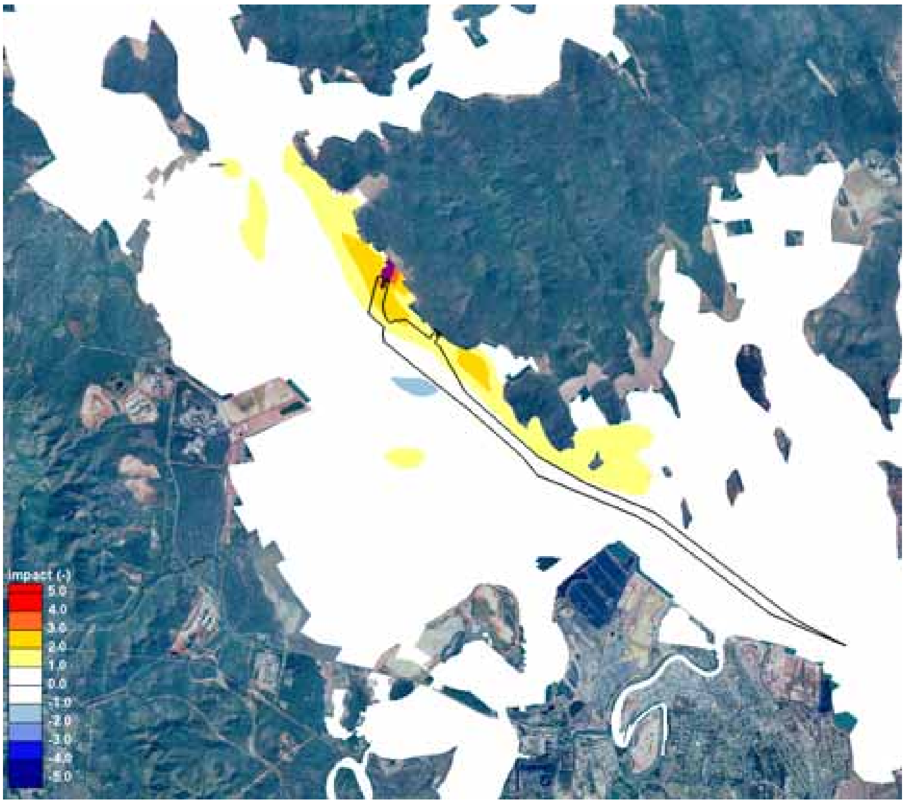

Figure E-5 Scenario 2b tracer concentration differences

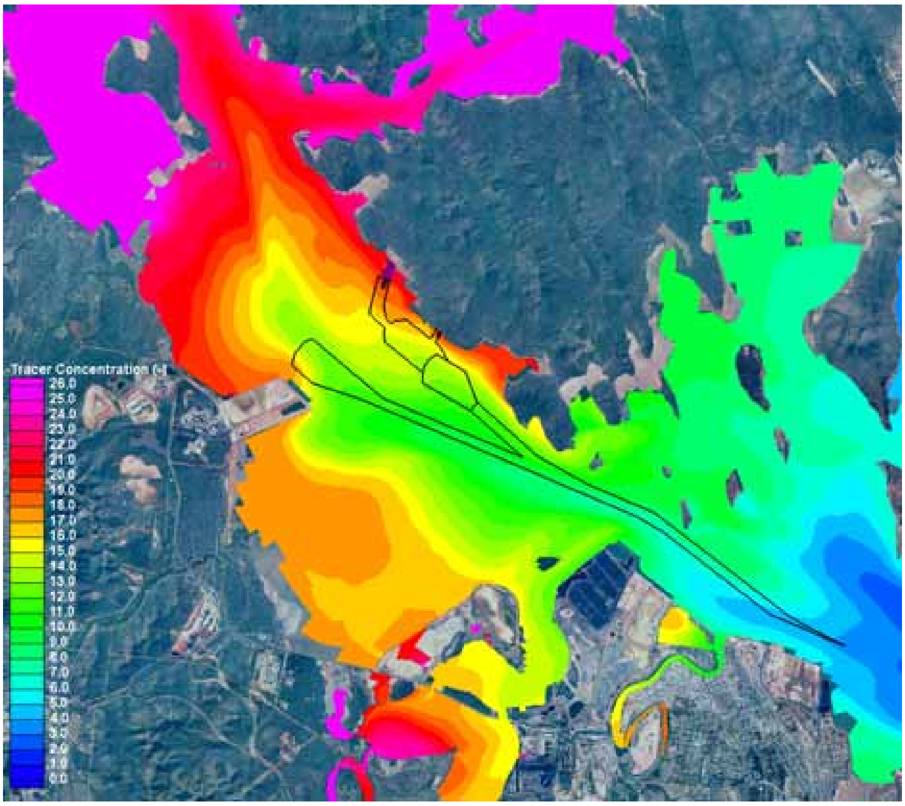

Figure E-6 Scenario 3 tracer concentration

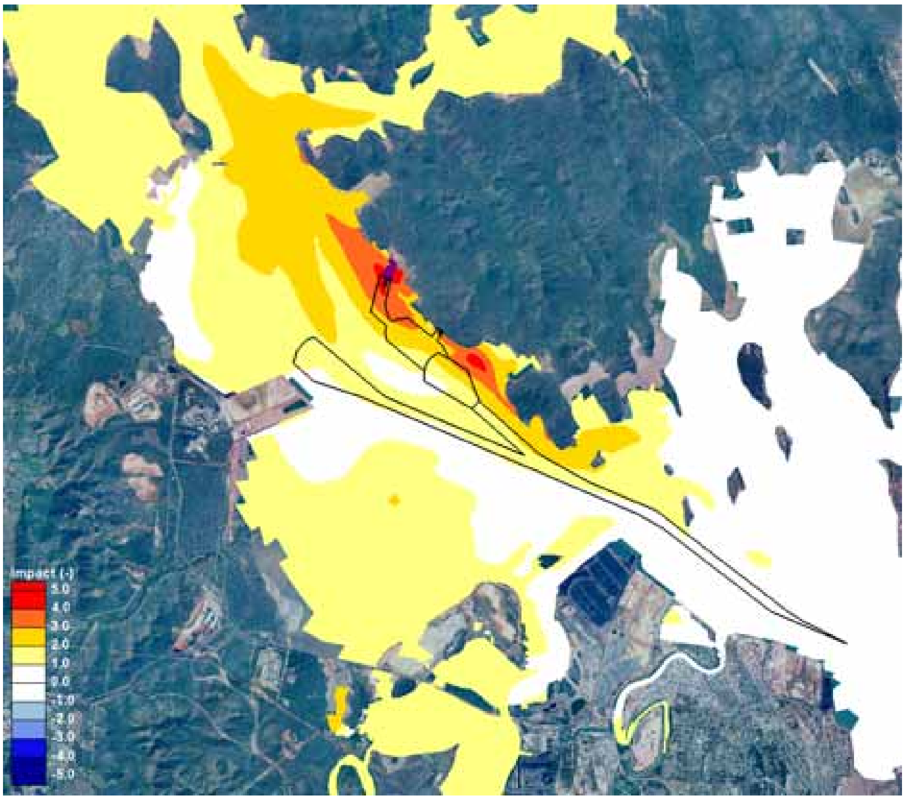

Figure E-7 Scenario 3 tracer concentration differences

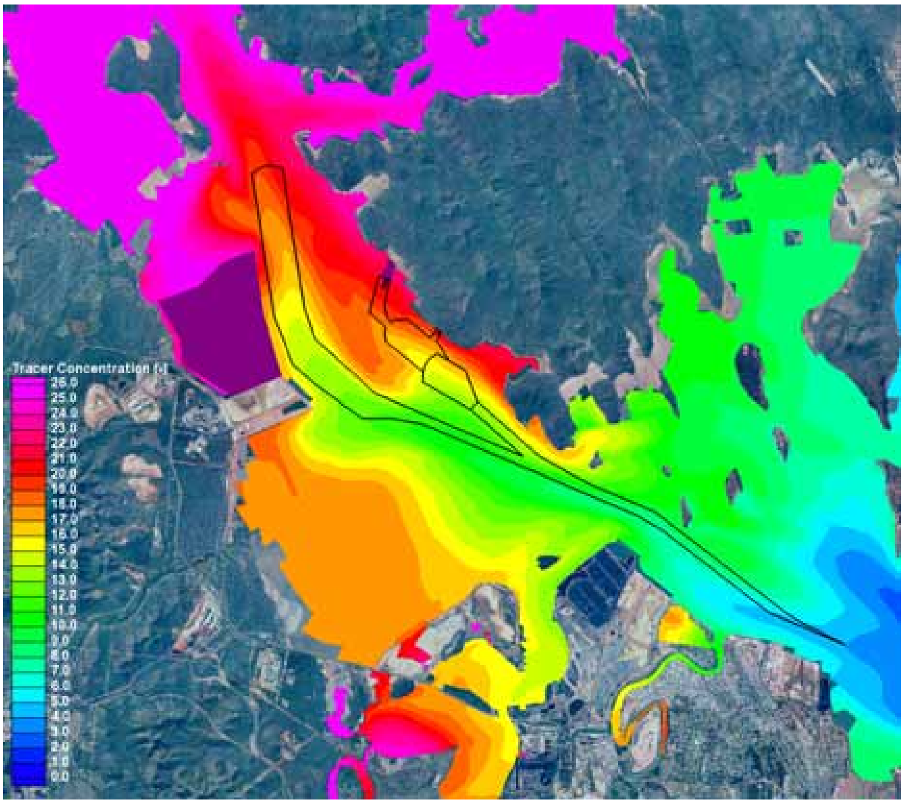

Figure E-8 Scenario 4 tracer concentration

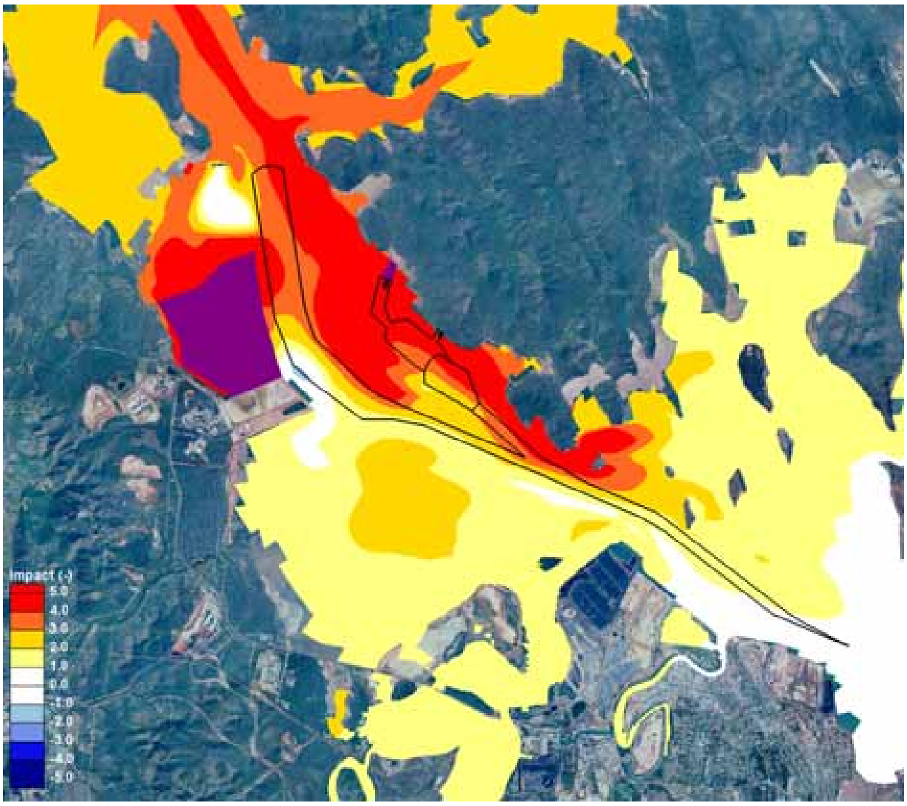

Figure E-9 Scenario 4 tracer concentration differences

APPENDIX F: E-FOLDING TIME CONTOURS – PIPELINE CROSSING OPTION 1

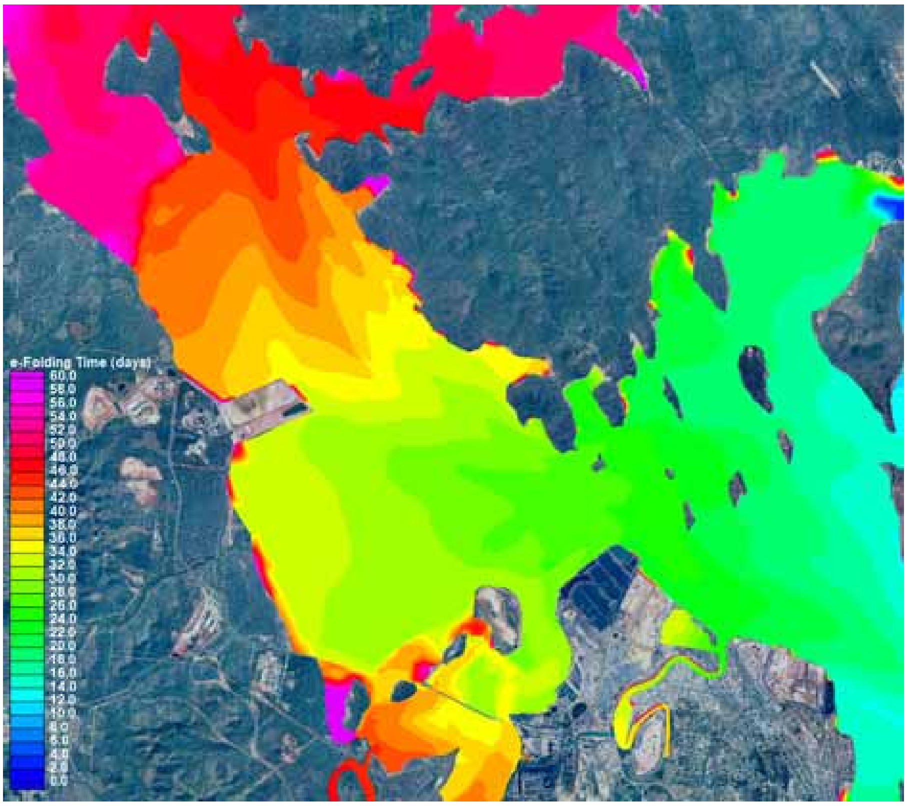

Figure F-1 Scenario 1 (Existing) e-folding time

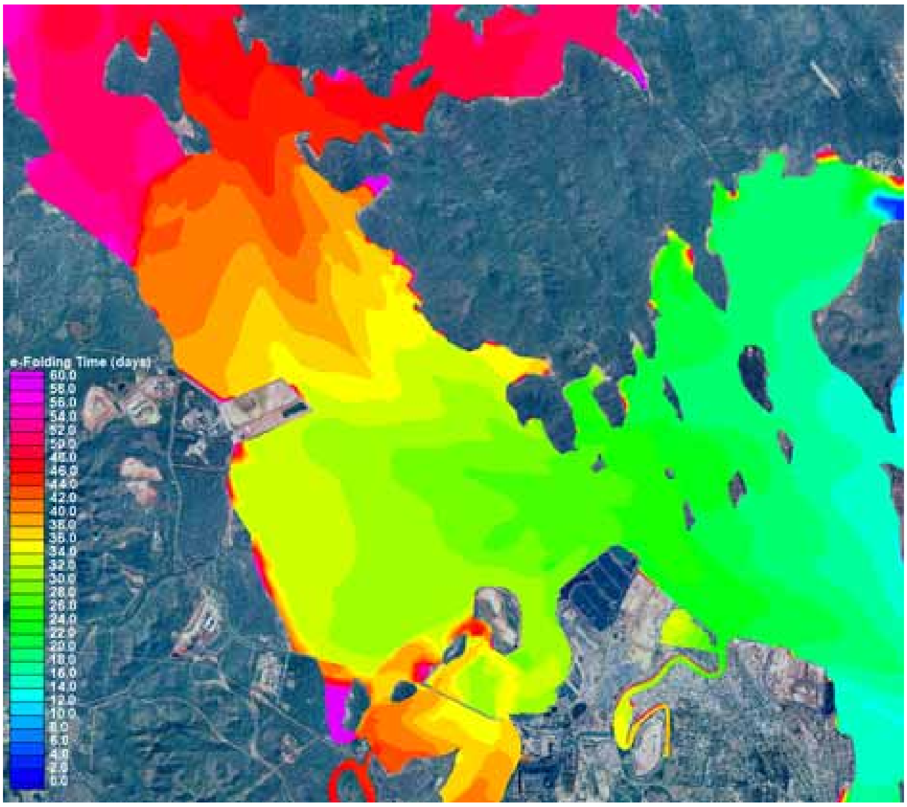

Figure F-2 Scenario 2a e-folding time

Figure F-3 Scenario 2a e-folding time differences

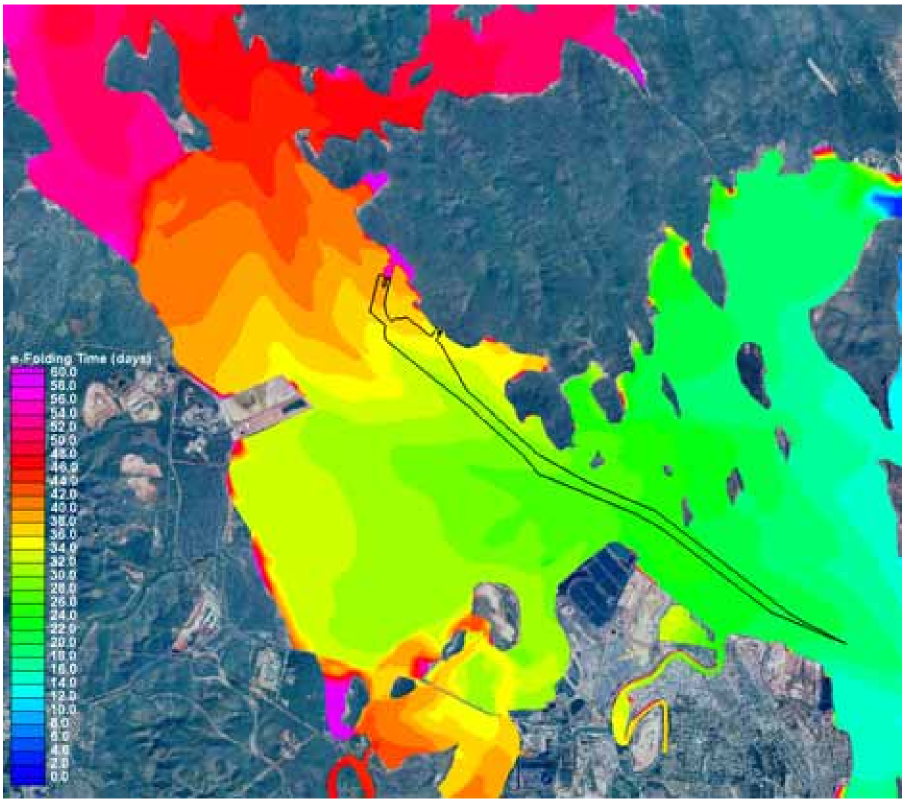

Figure F-4 Scenario 2b e-folding time

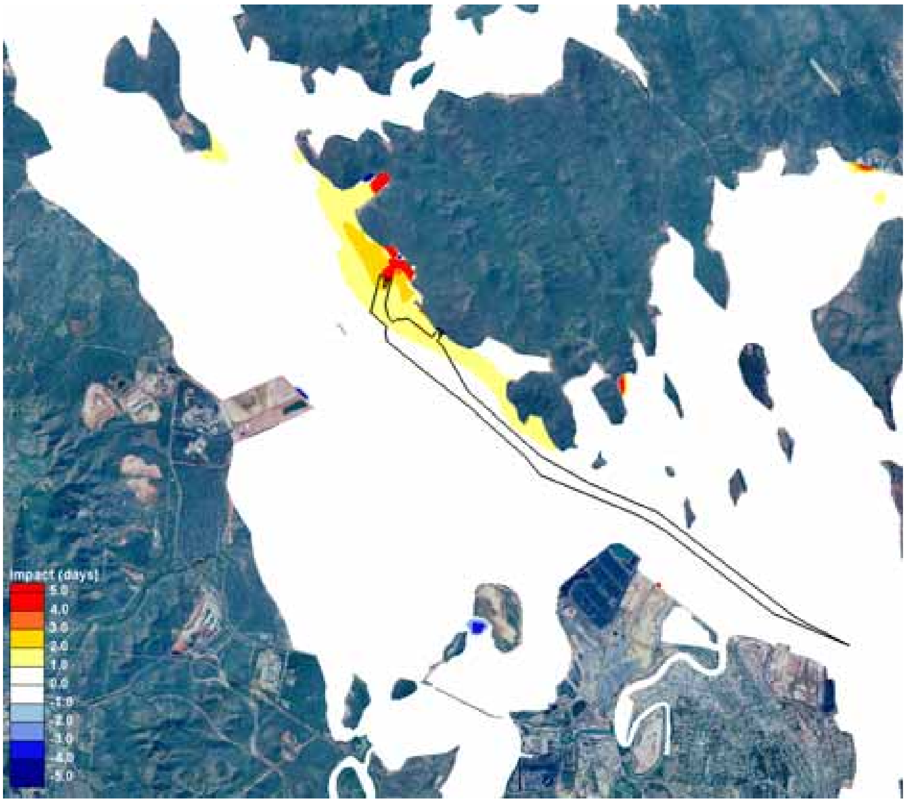

Figure F-5 Scenario 2b e-folding time differences

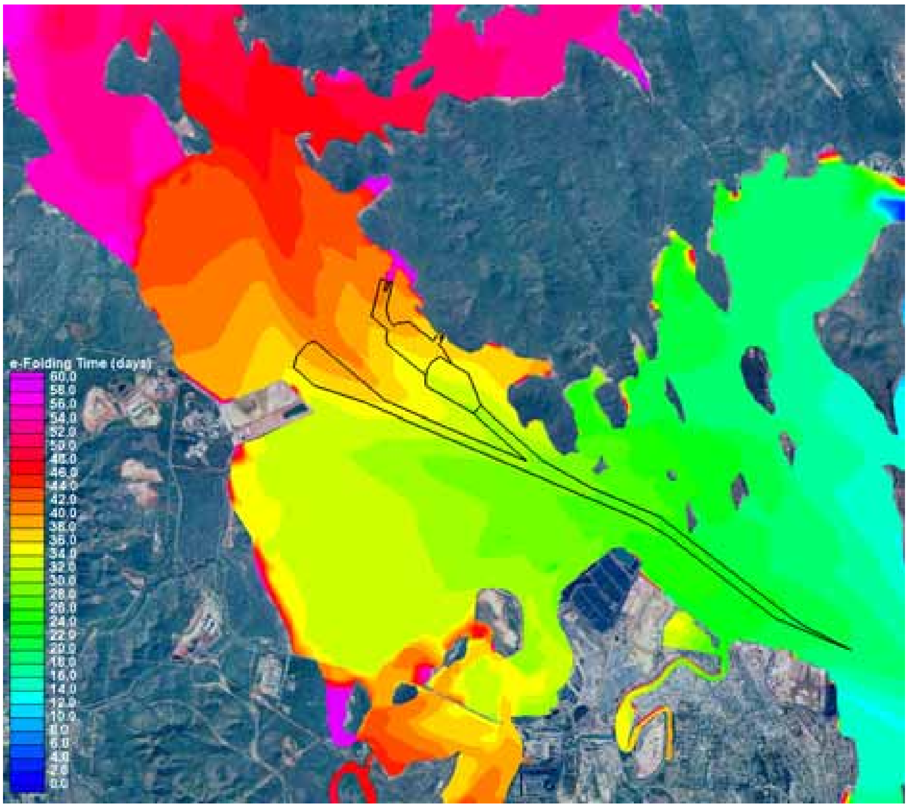

Figure F-6 Scenario 3 e-folding time

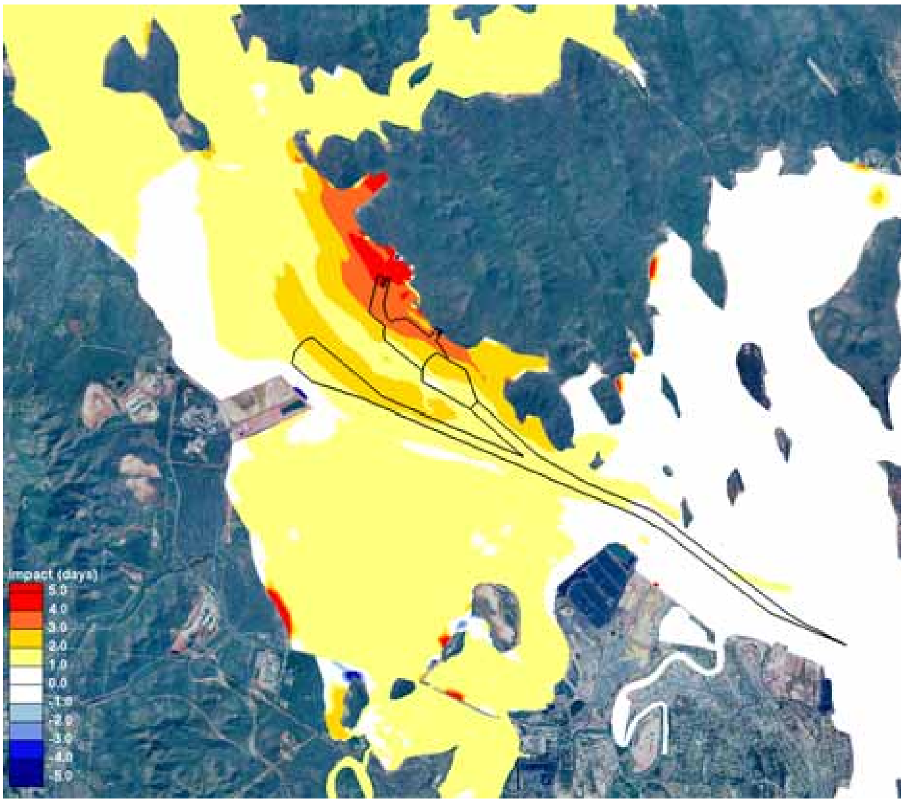

Figure F-7 Scenario 3 e-folding time differences

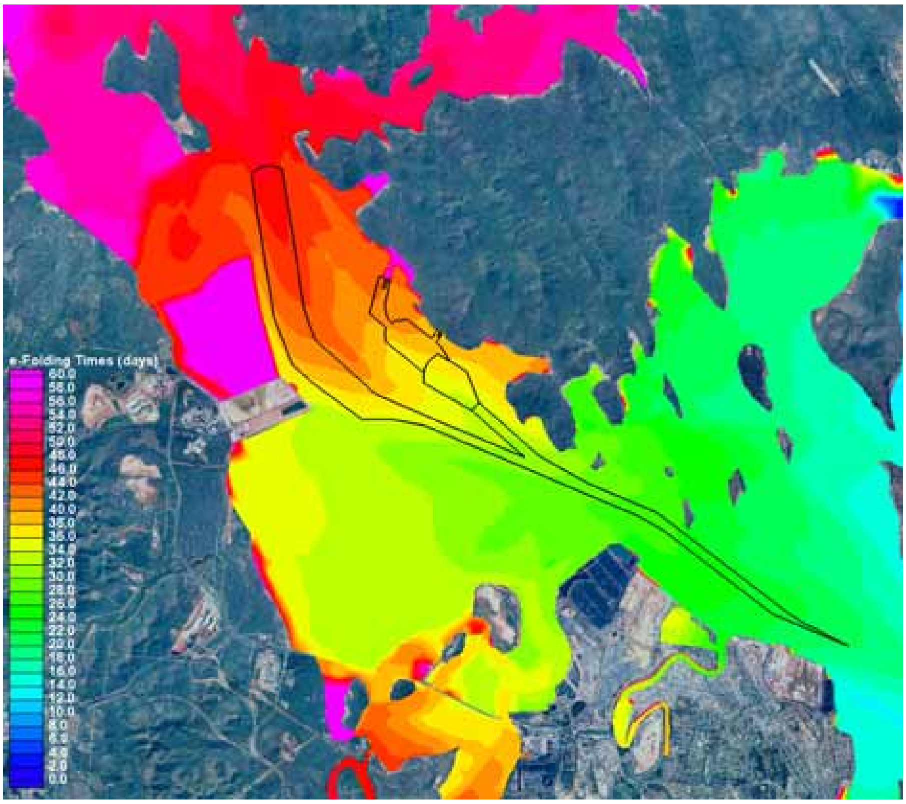

Figure F-8 Scenario 4 e-folding time

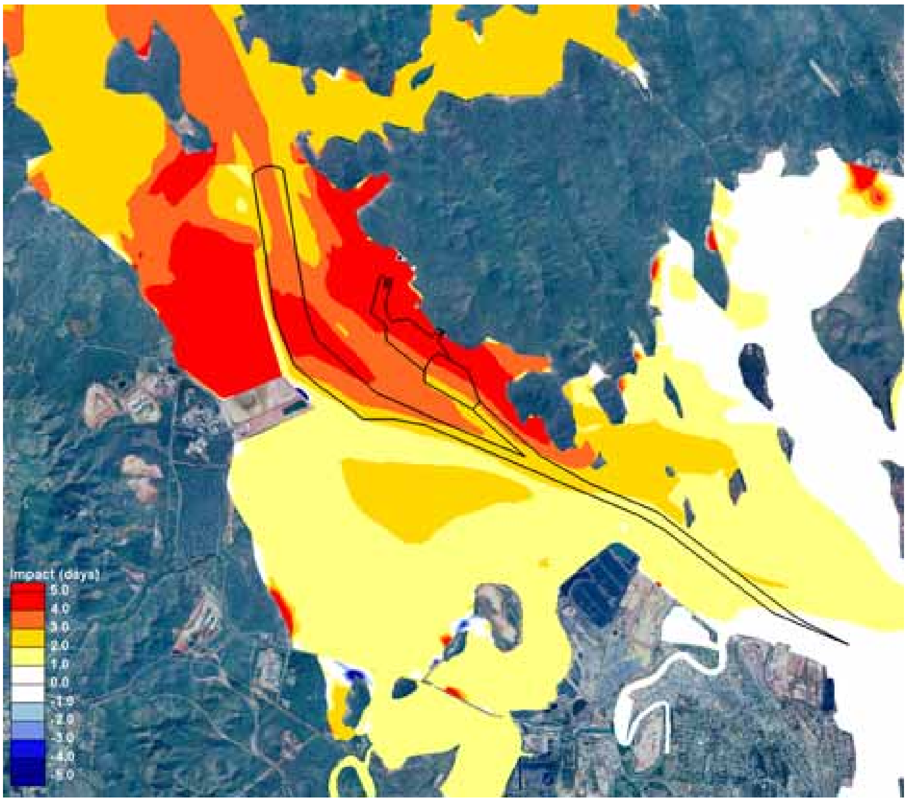

Figure F-9 Scenario 4 e-folding time differences

APPENDIX G: OPTION 2 WATER LEVEL TIME SERIES – PIPELINE CROSSING OPTION 2

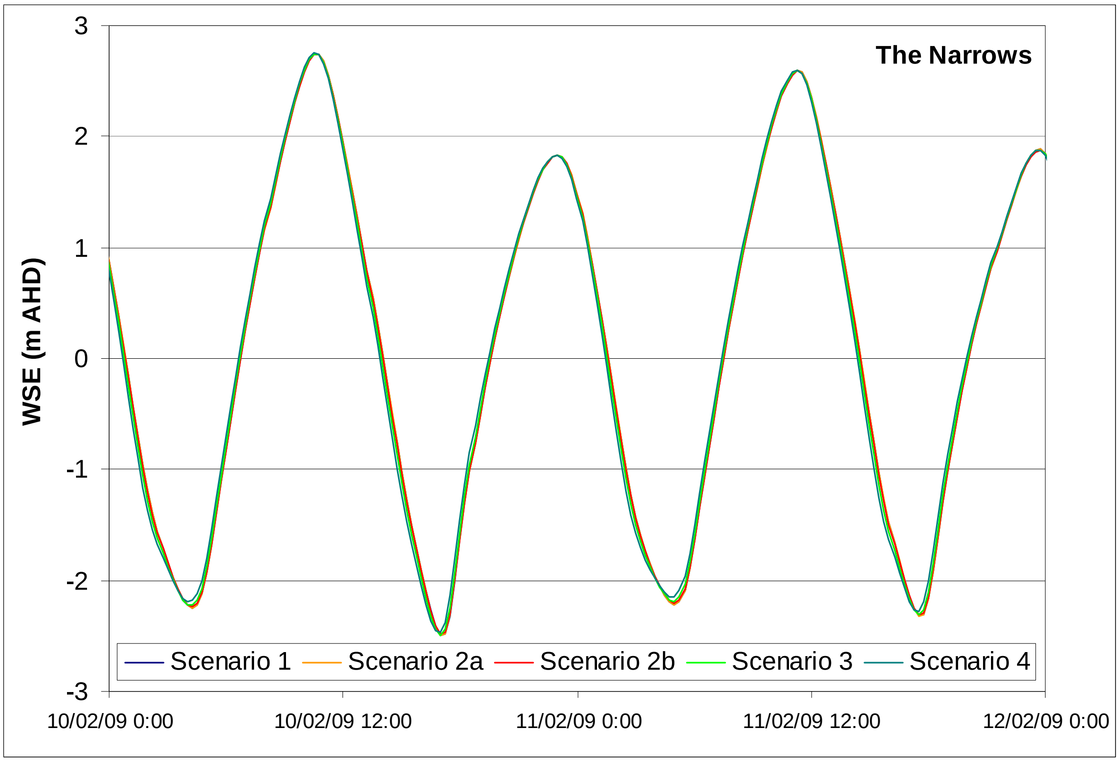

Figure G-1 Water Level Time Series – The Narrows

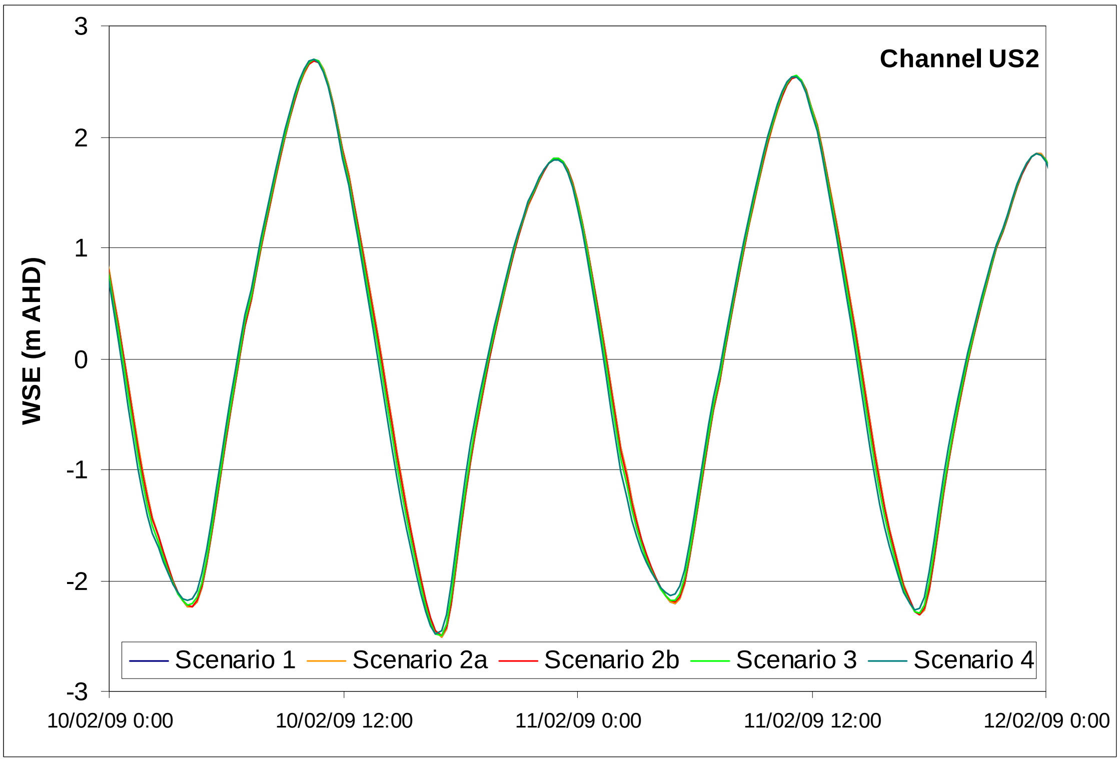

Figure G-2 Water Level Time Series – Channel US2

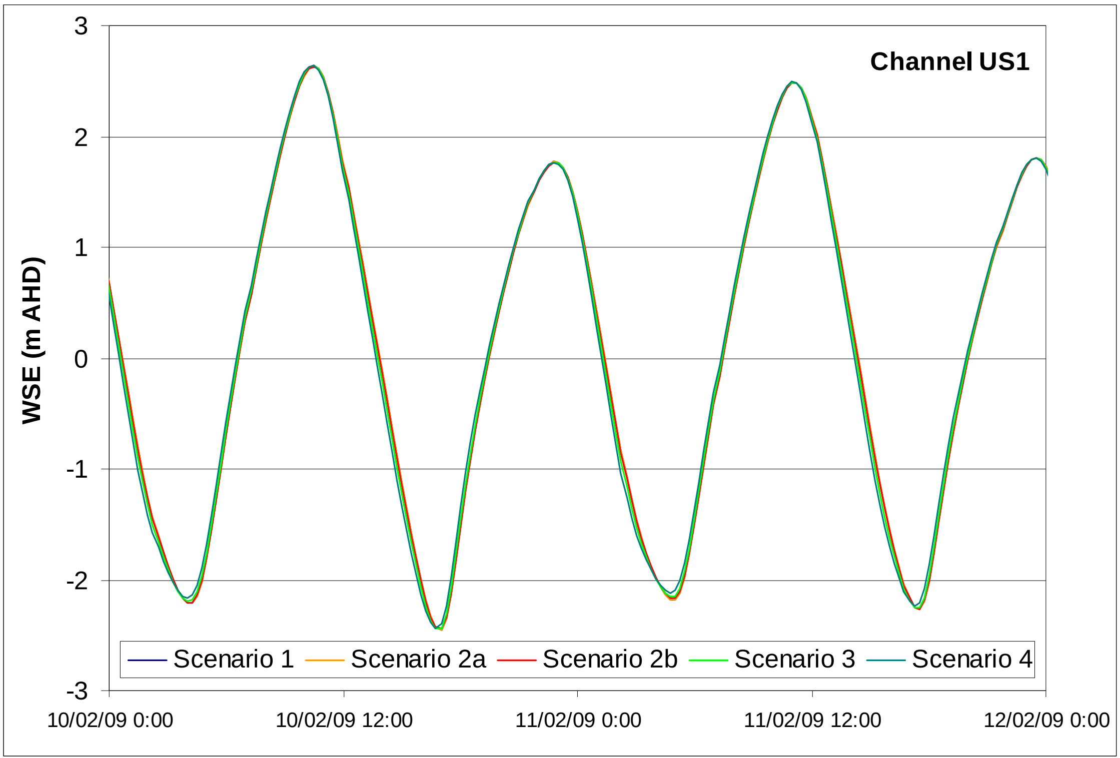

Figure G-3 Water Level Time Series – Channel US1

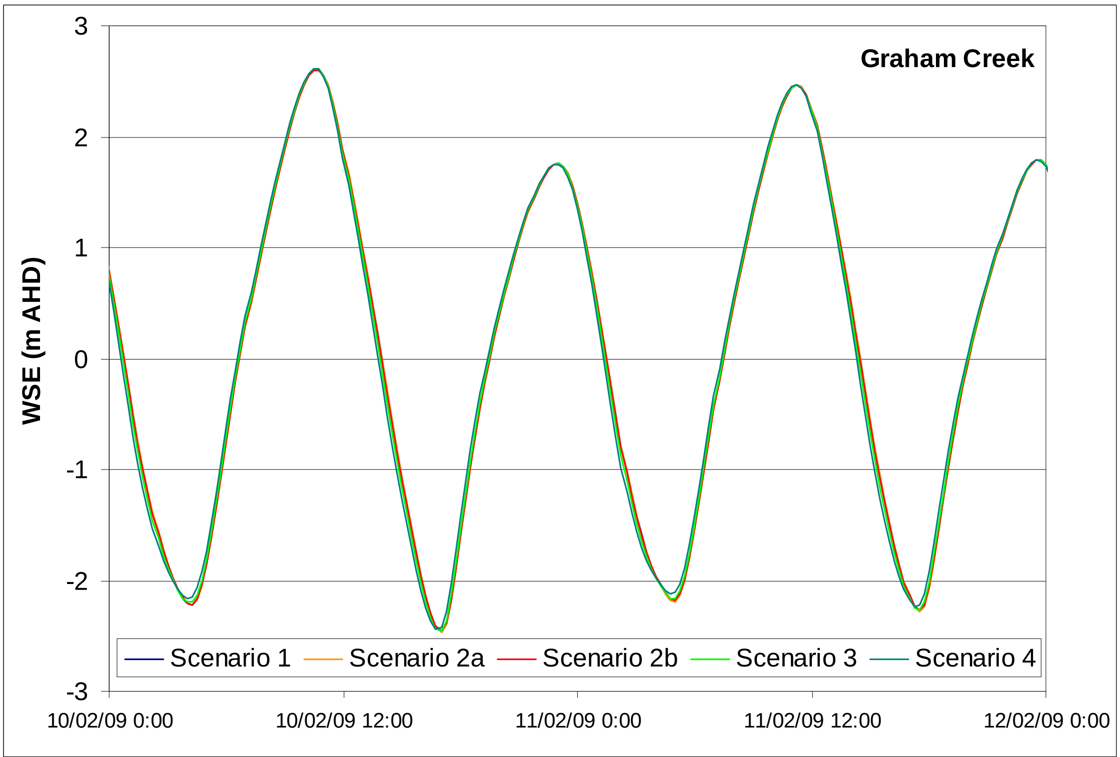

Figure G-4 Water Level Time Series – Graham Creek

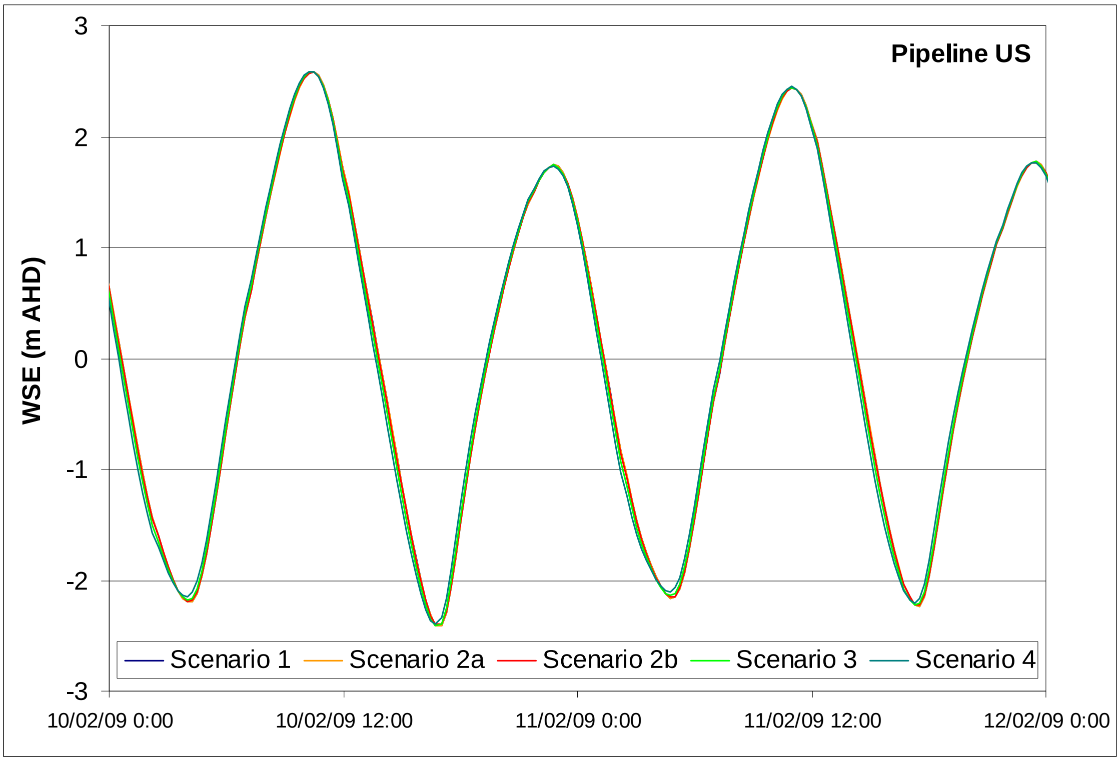

Figure G-5 Water Level Time Series – Pipeline US

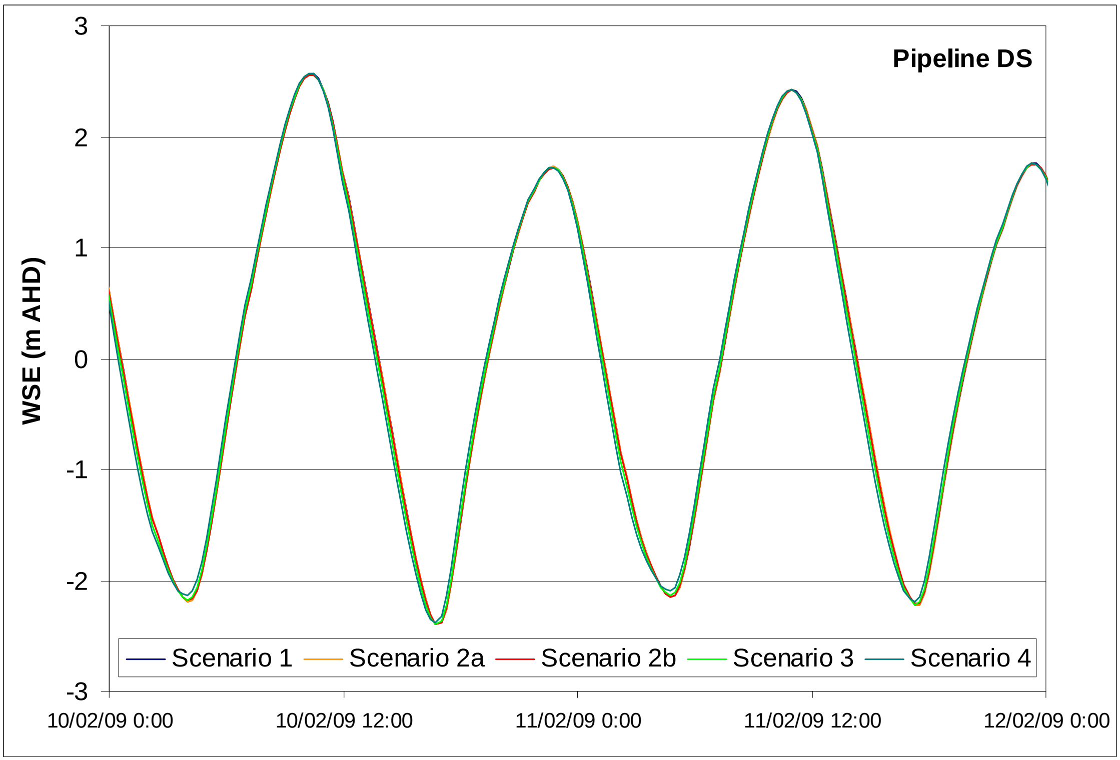

Figure G-6 Water Level Time Series – Pipeline DS

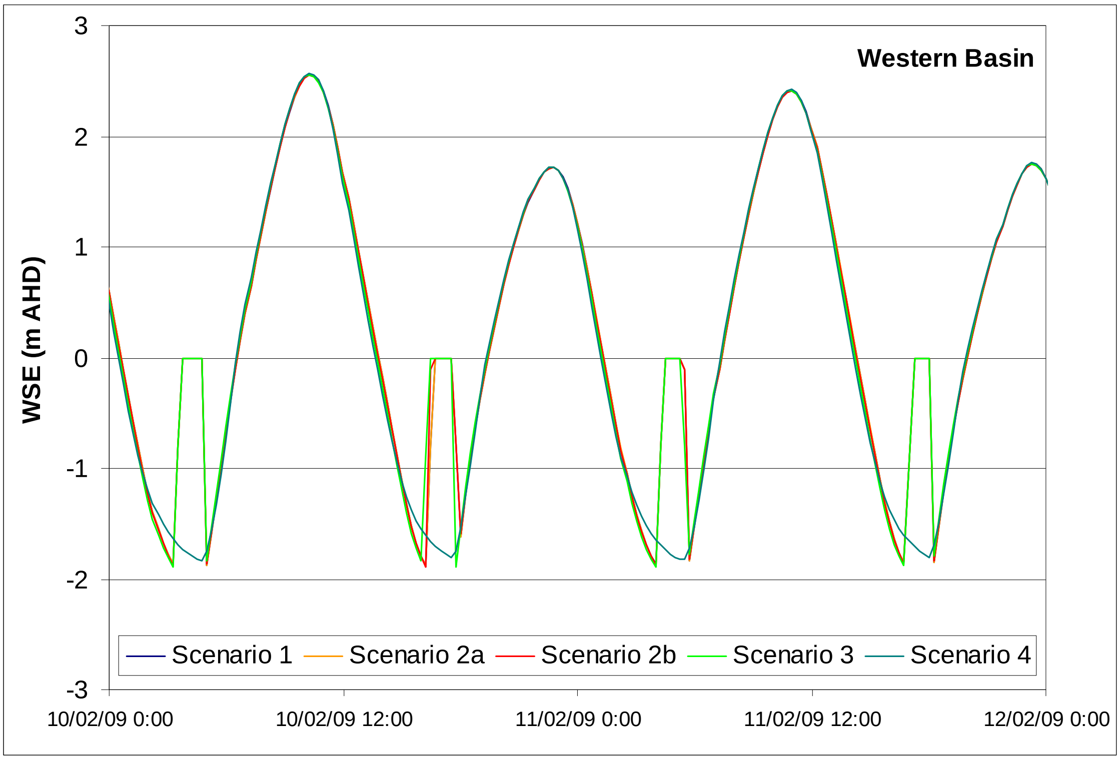

Figure G-7 Water Level Time Series – Western Basin

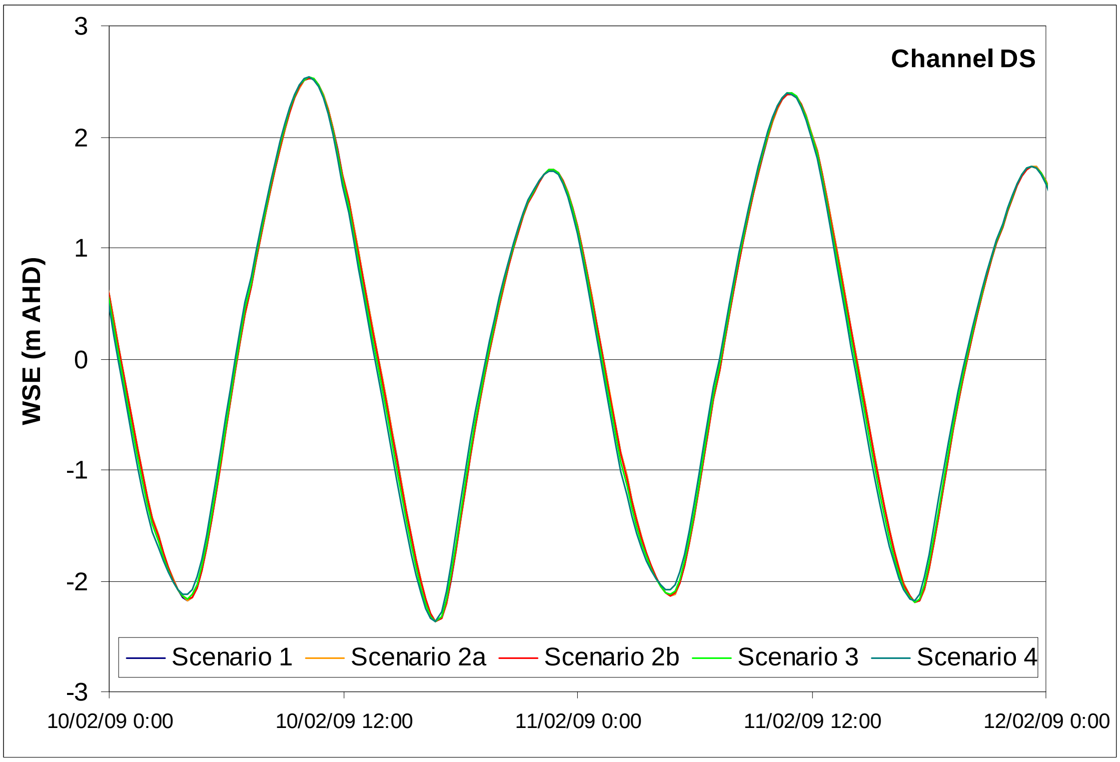

Figure G-8 Water Level Time Series – Channel DS

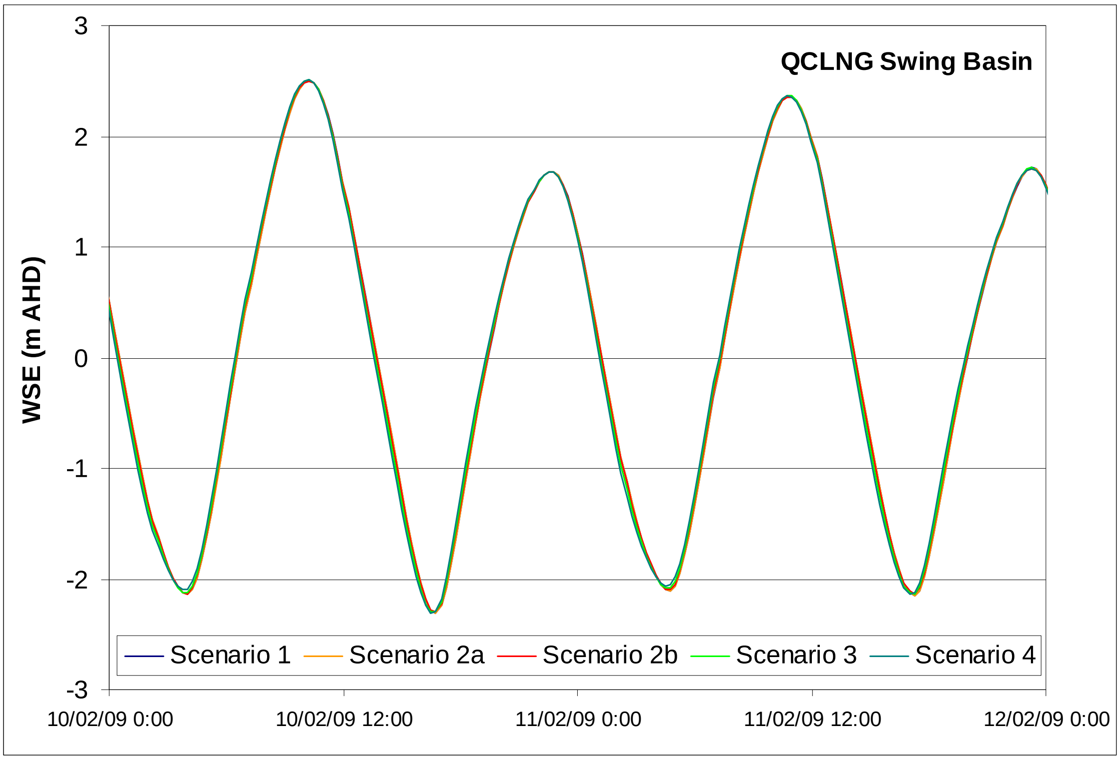

Figure G-9 Water Level Time Series – QCLNG Swing Basin

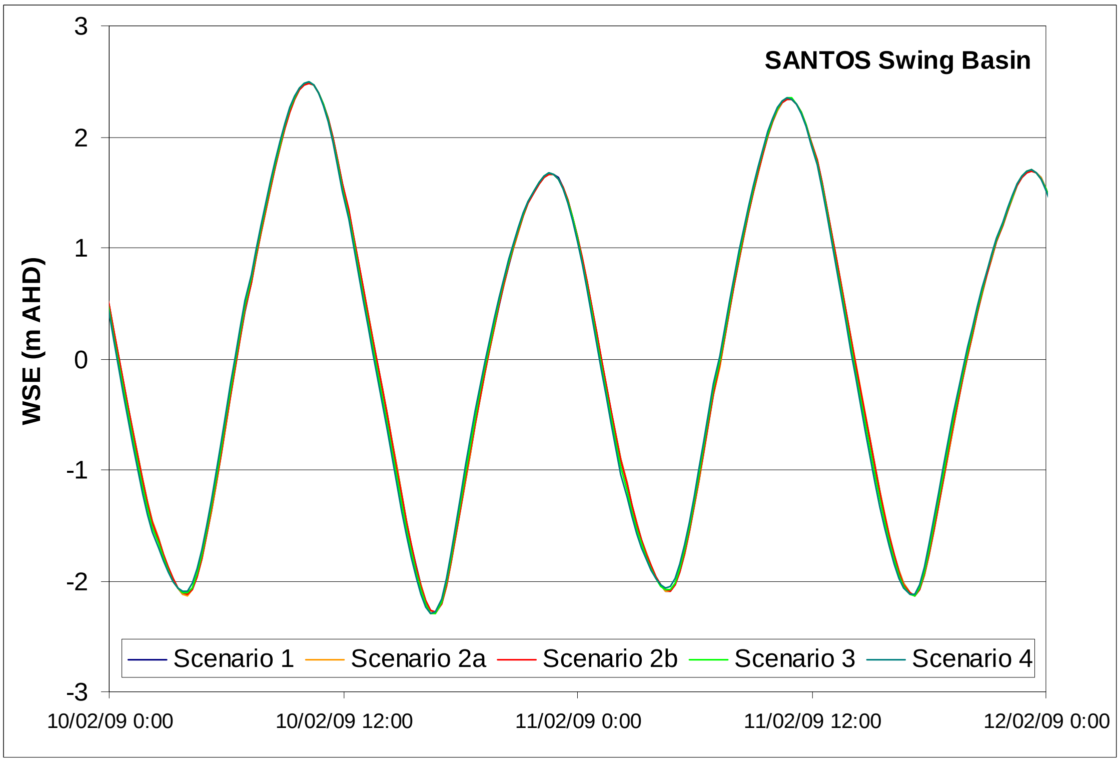

Figure G-10 Water Level Time Series – SANTOS Swing Basin

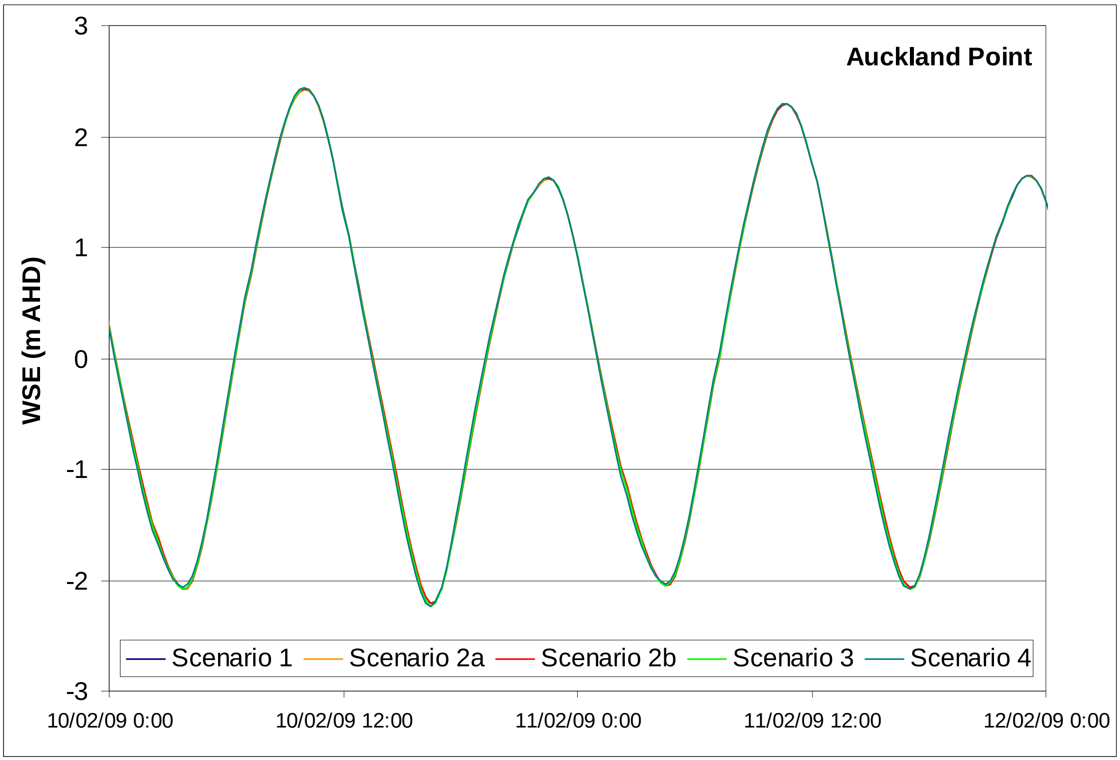

Figure G-11 Water Level Time Series – Auckland Point

APPENDIX H: VELOCITY MAGNITUDE TIME SERIES – PIPELINE CROSSING OPTION 2

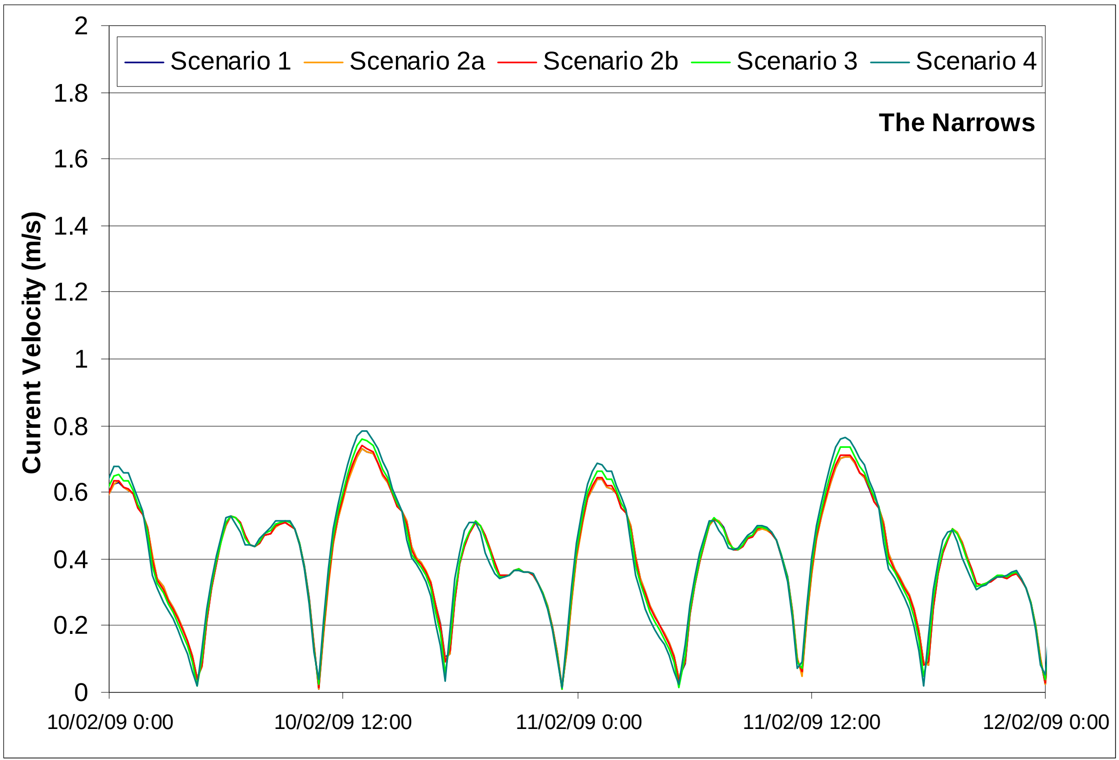

Figure H-1 Velocity Magnitude Time Series – The Narrows

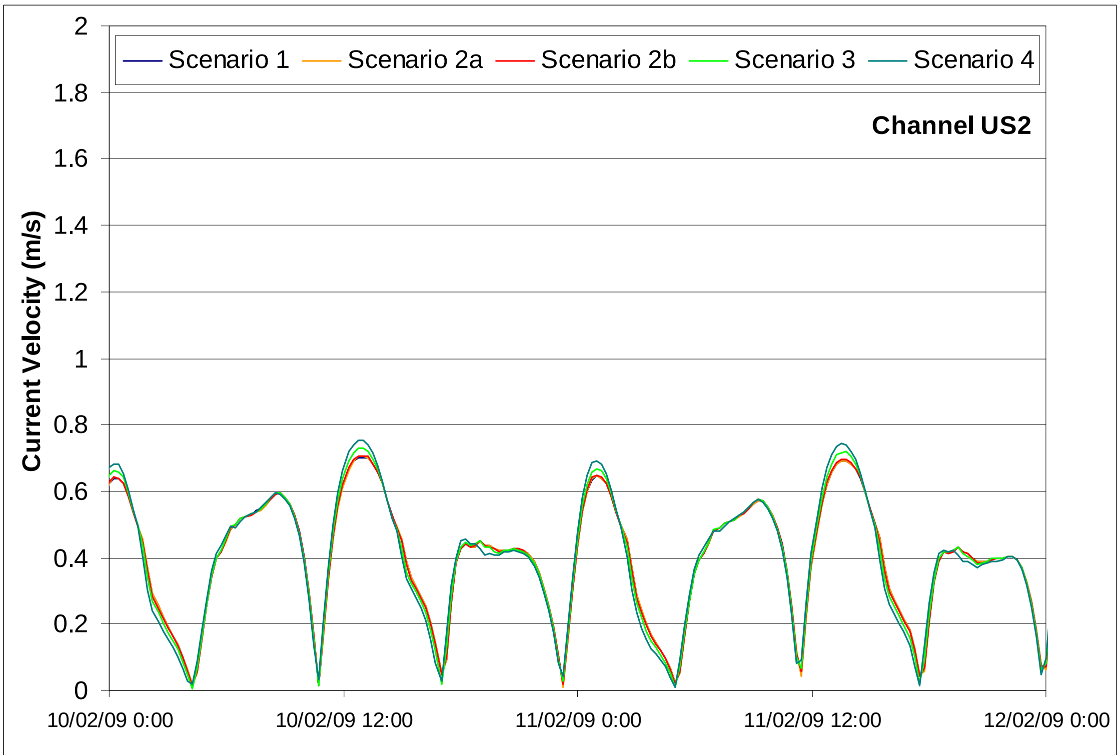

Figure H-2 Velocity Magnitude Time Series – Channel US2

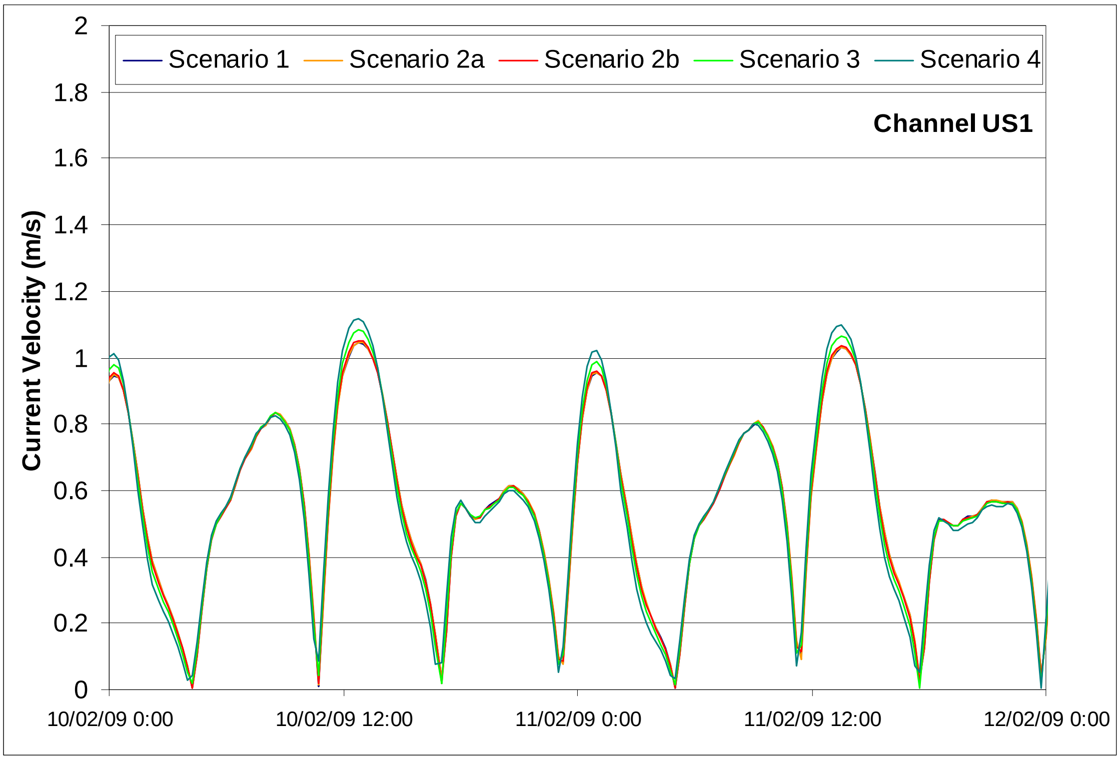

Figure H-3 Velocity Magnitude Time Series – Channel US1

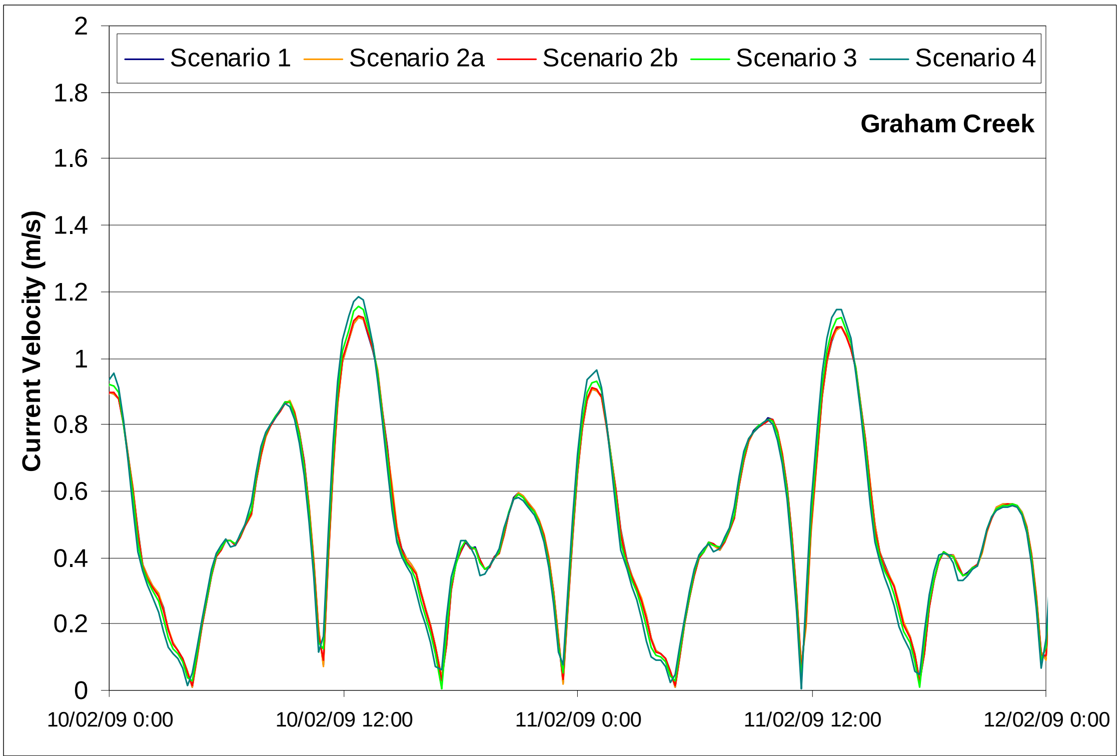

Figure H-4 Velocity Magnitude Time Series – Graham Creek

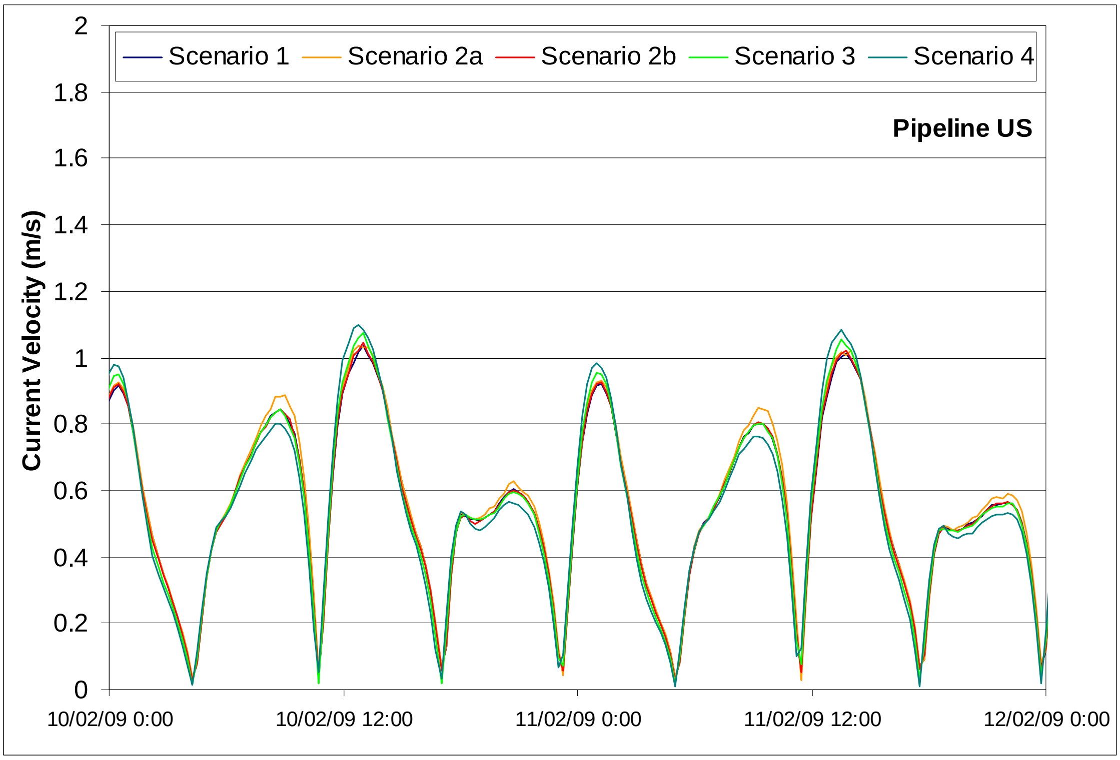

Figure H-5 Velocity Magnitude Time Series – Pipeline US

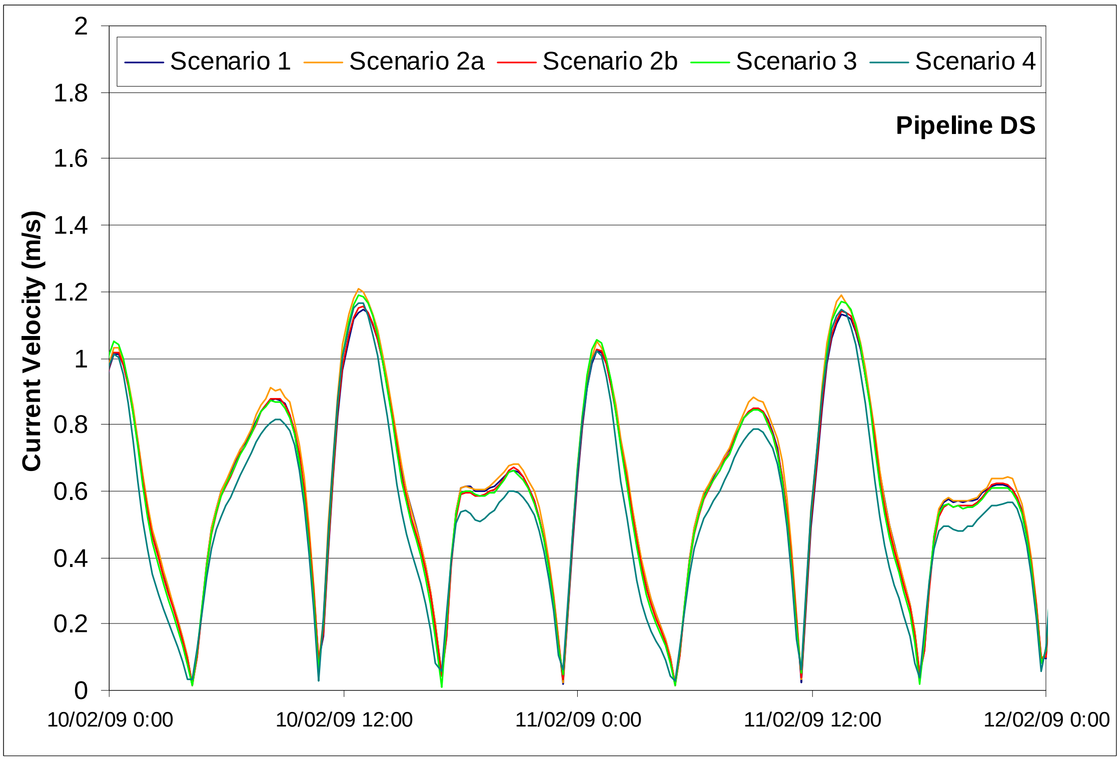

Figure H-6 Velocity Magnitude Time Series – Pipeline DS

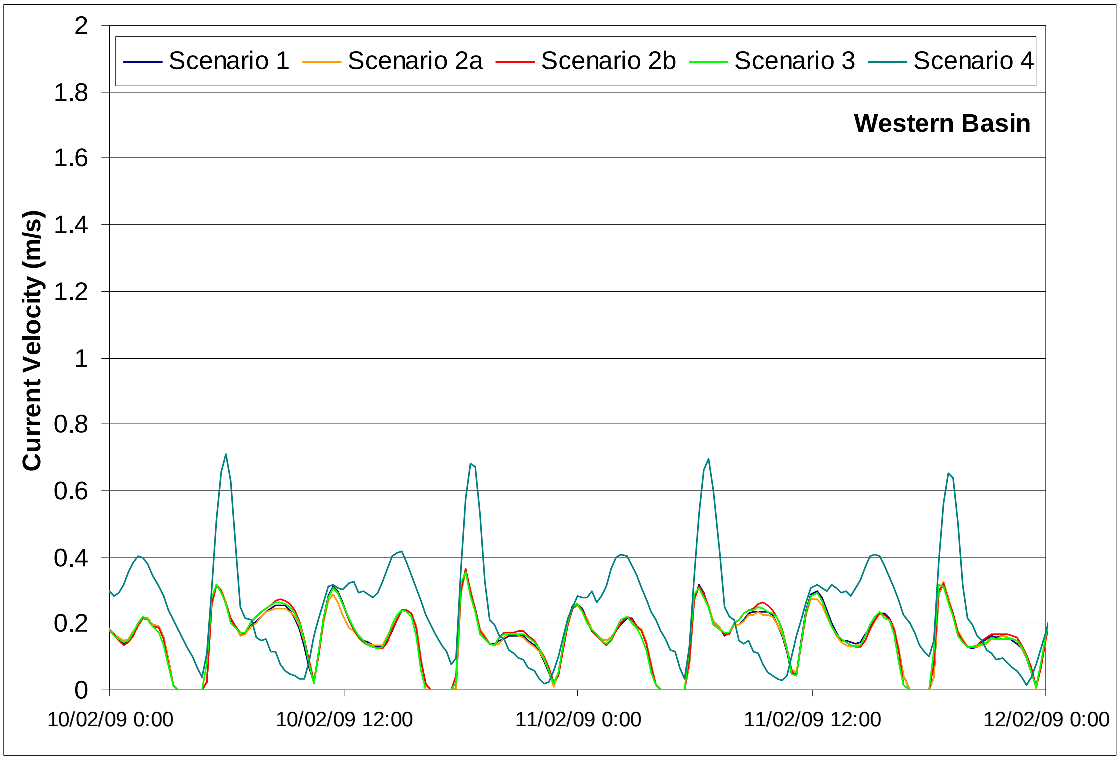

Figure H-7 Velocity Magnitude Time Series – Western Basin

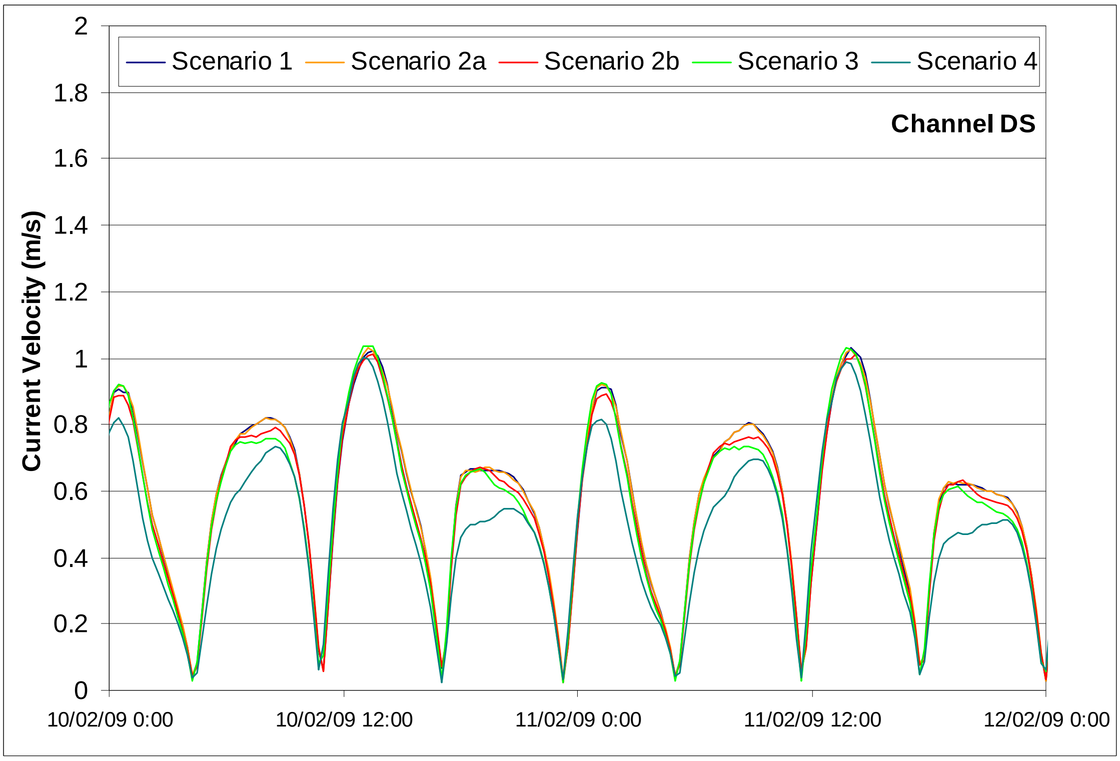

Figure H-8 Velocity Magnitude Time Series – Channel DS

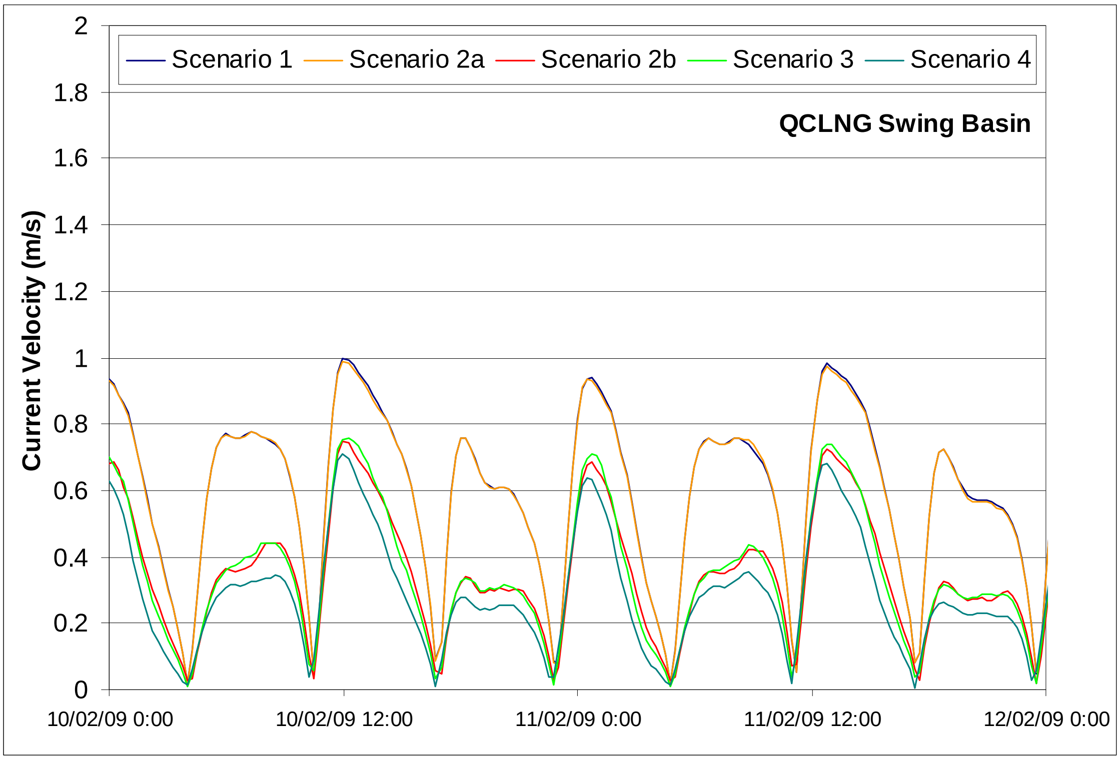

Figure H-9 Velocity Magnitude Time Series – QCLNG Swing Basin

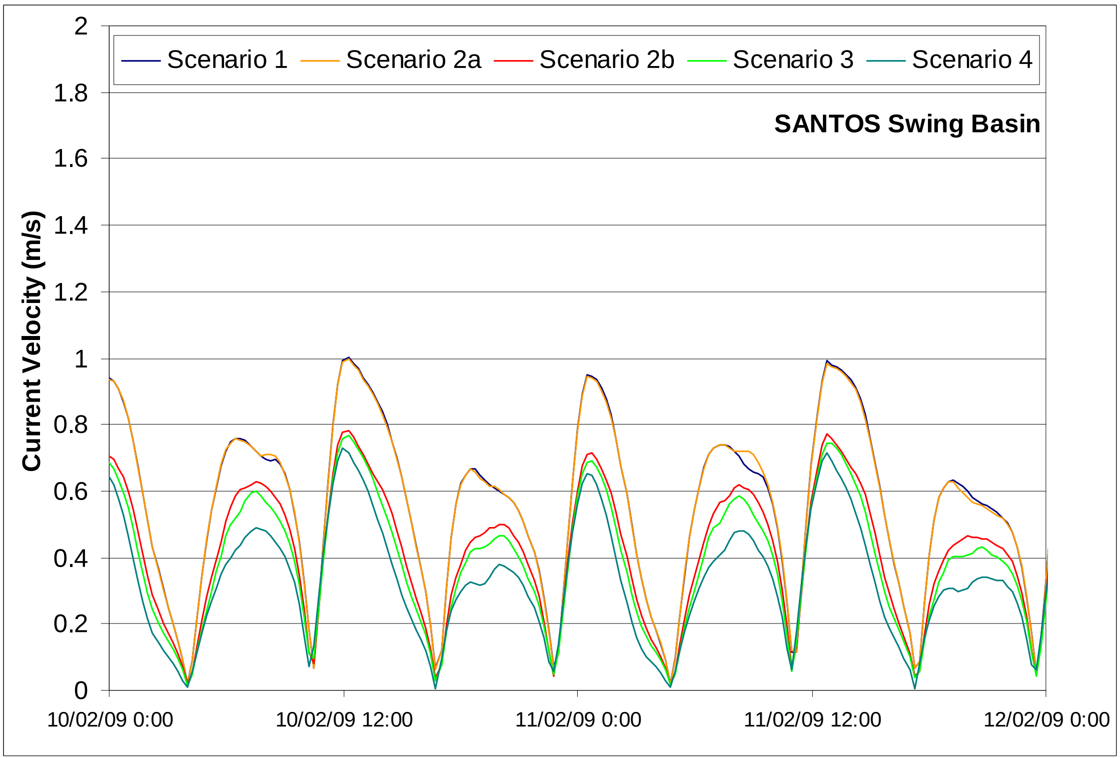

Figure H-10 Velocity Magnitude Time Series – SANTOS Swing Basin

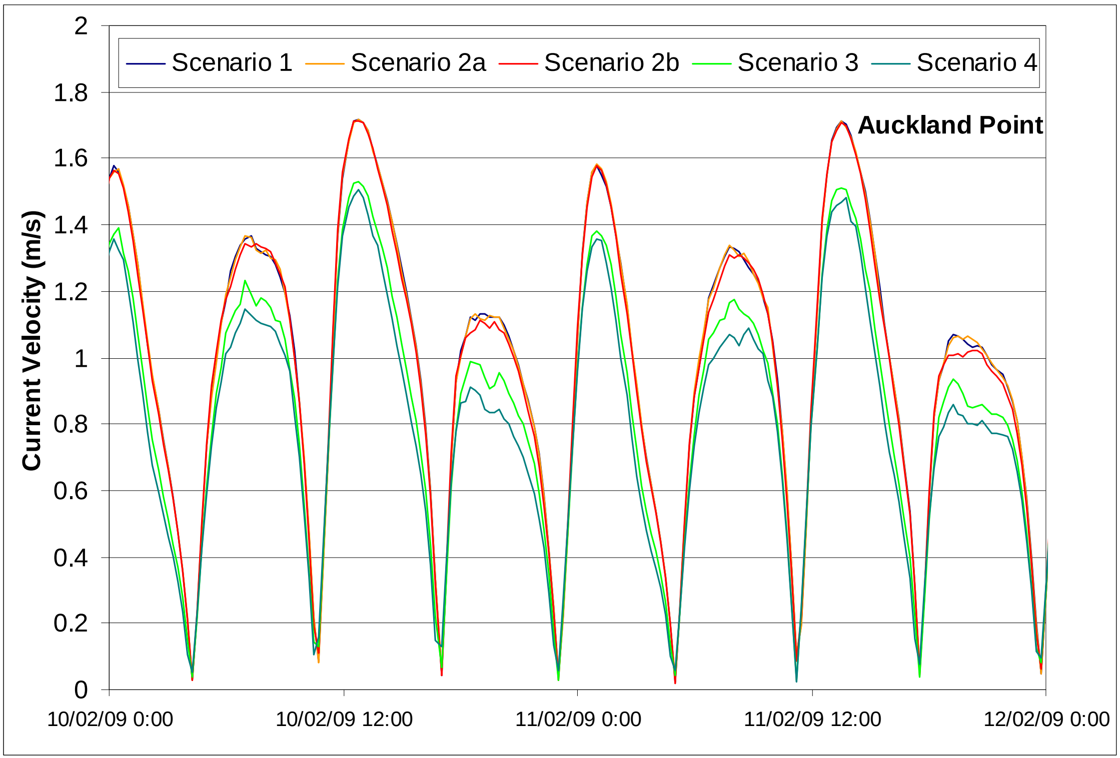

Figure H-11 Velocity Magnitude Time Series – Auckland Point

APPENDIX I: VELOCITY CONTOURS – PIPELINE CROSSING OPTION 2

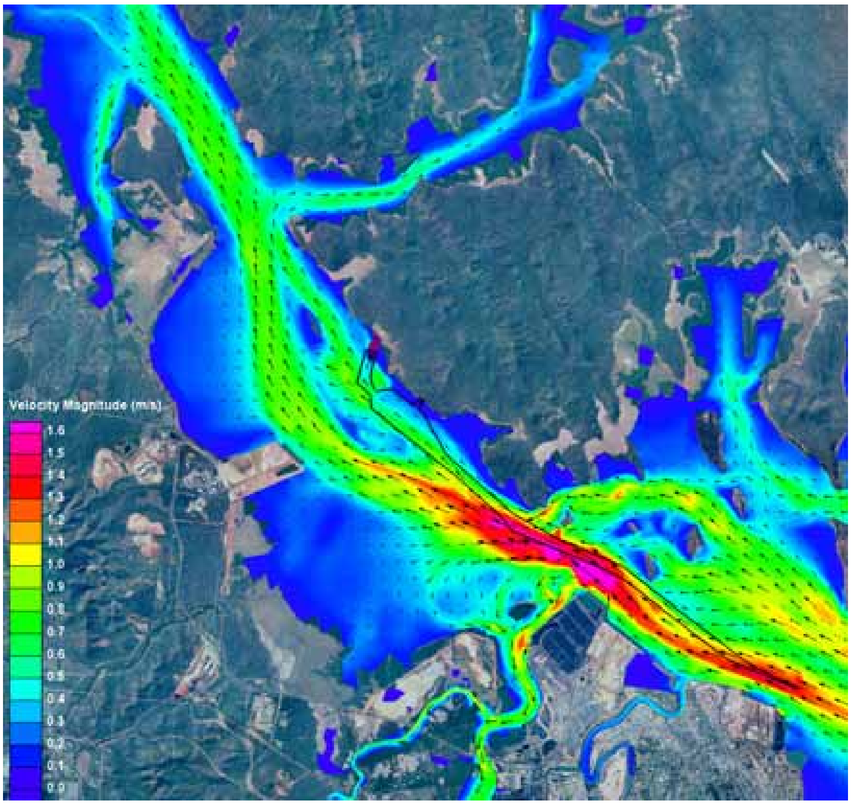

Figure I-1 Scenario 2b peak flood tide velocities

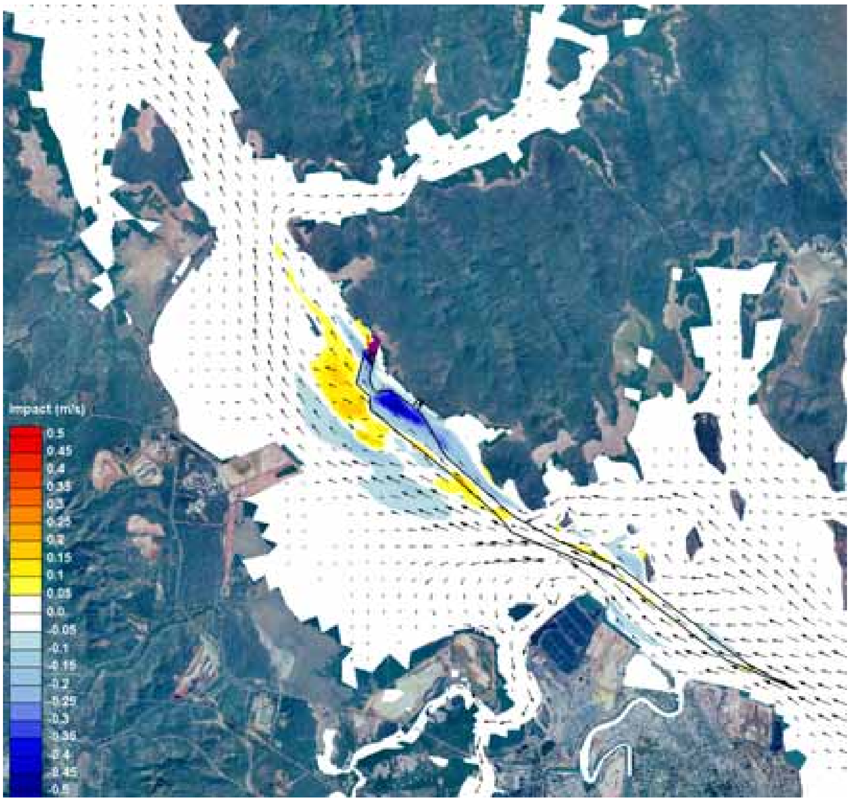

Figure I-2 Scenario 2b peak flood tide velocity differences

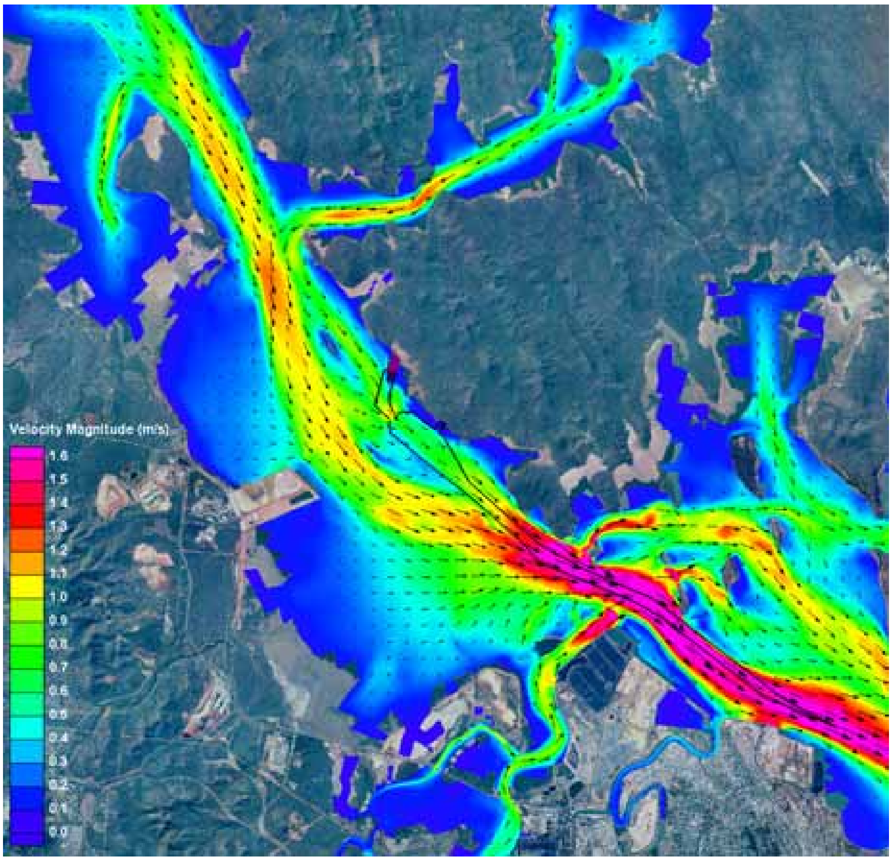

Figure I-3 Scenario 2b peak ebb tide velocities

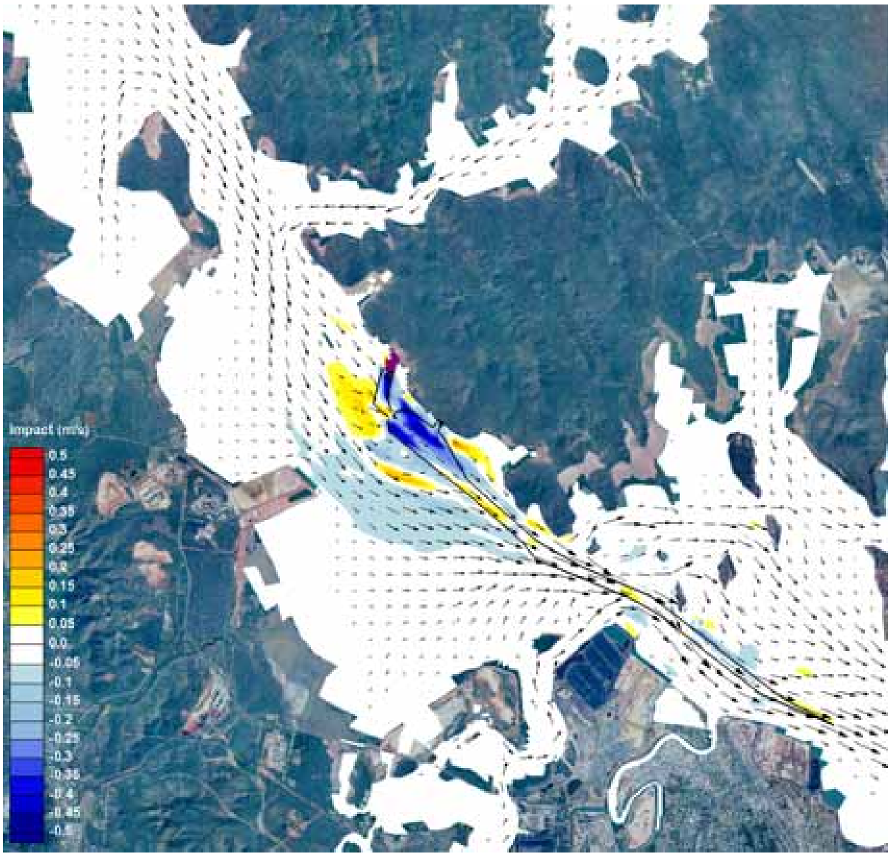

Figure I-4 Scenario 2b peak ebb tide velocity differences

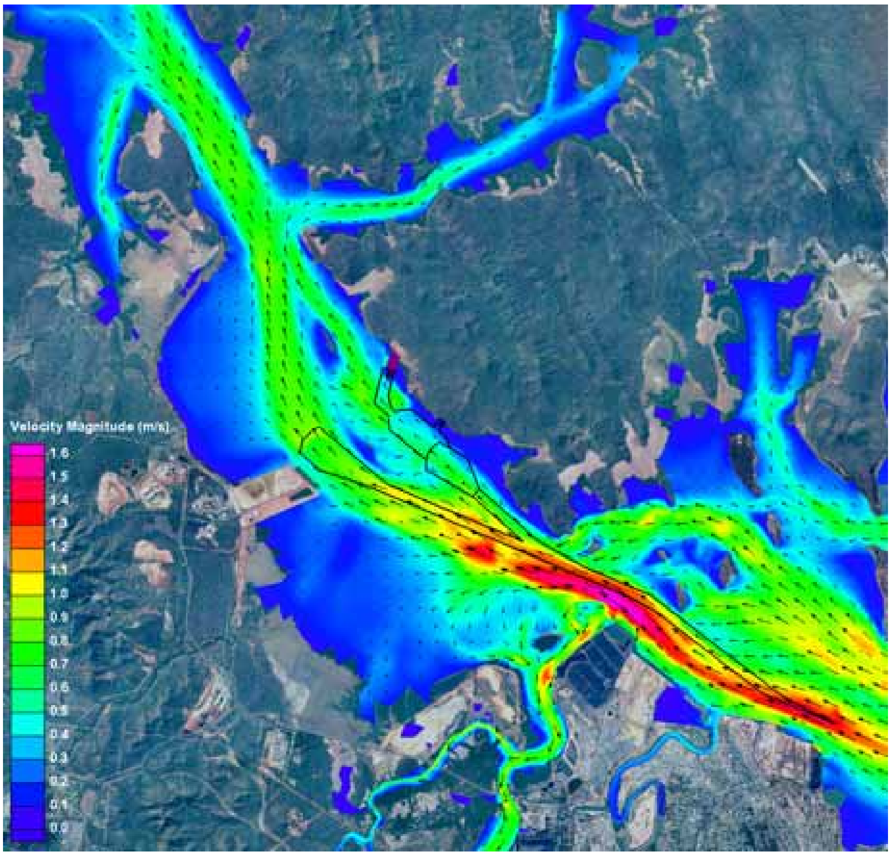

Figure I-5 Scenario 3 peak flood tide velocities

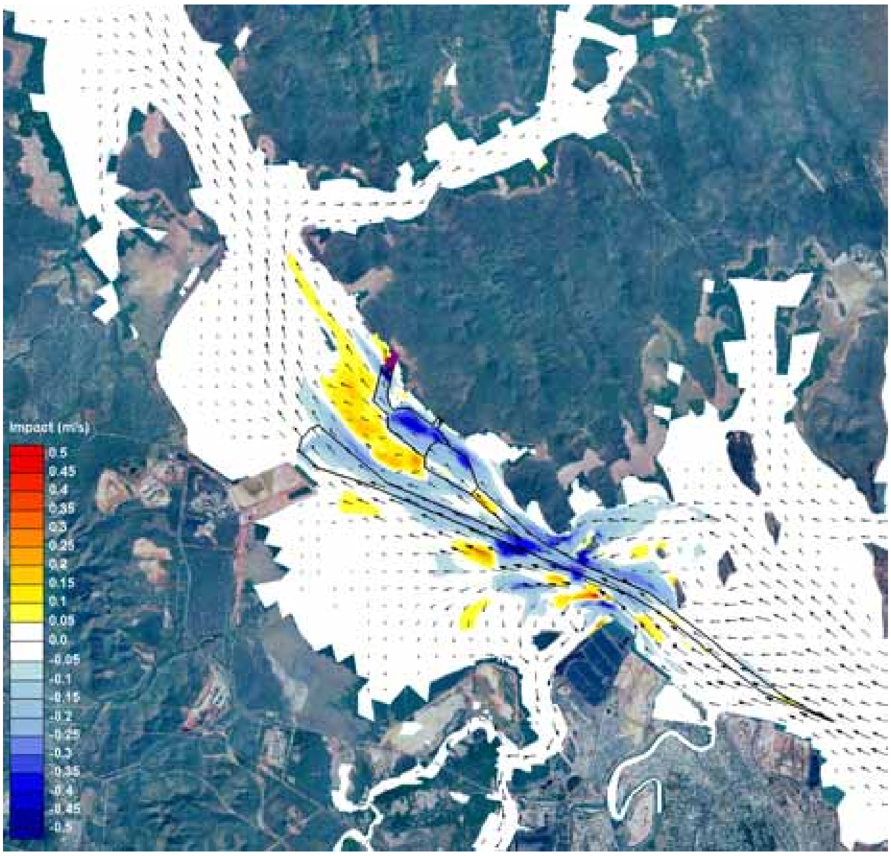

Figure I-6 Scenario 3 peak flood tide velocity differences

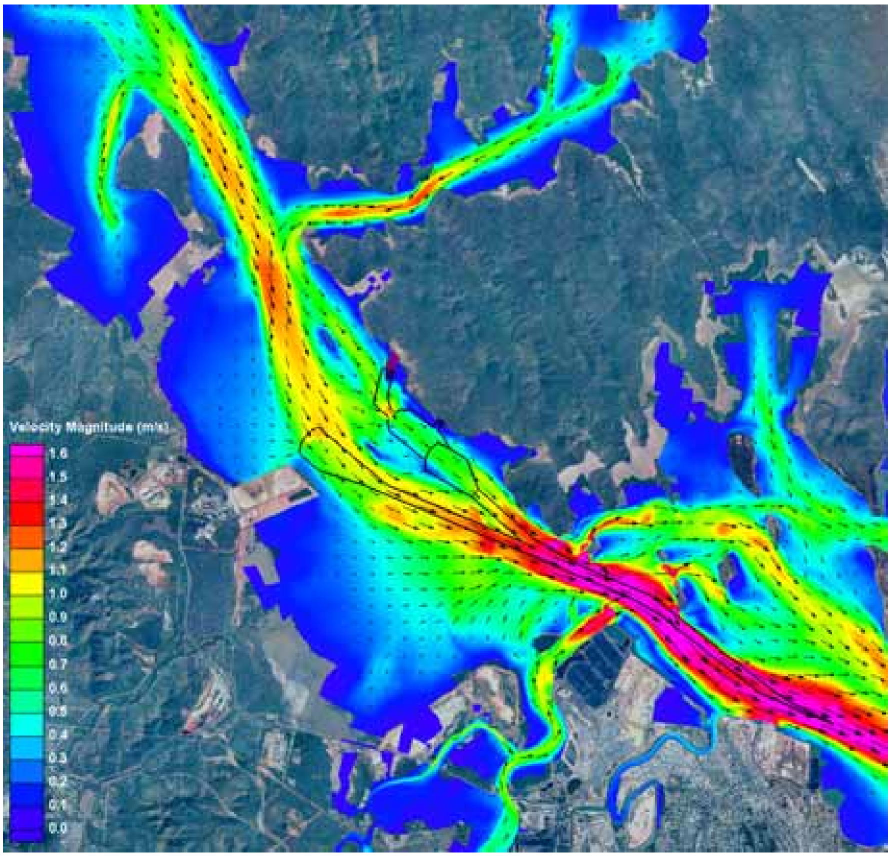

Figure I-7 Scenario 3 peak ebb tide velocities

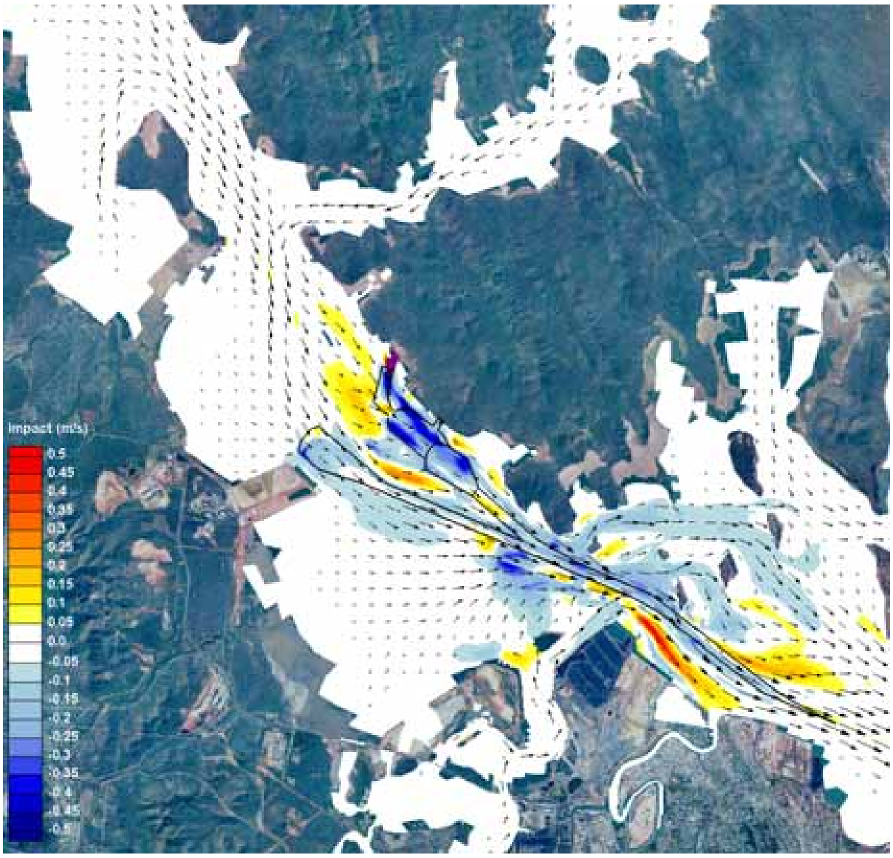

Figure I-8 Scenario 3 peak ebb tide velocity differences

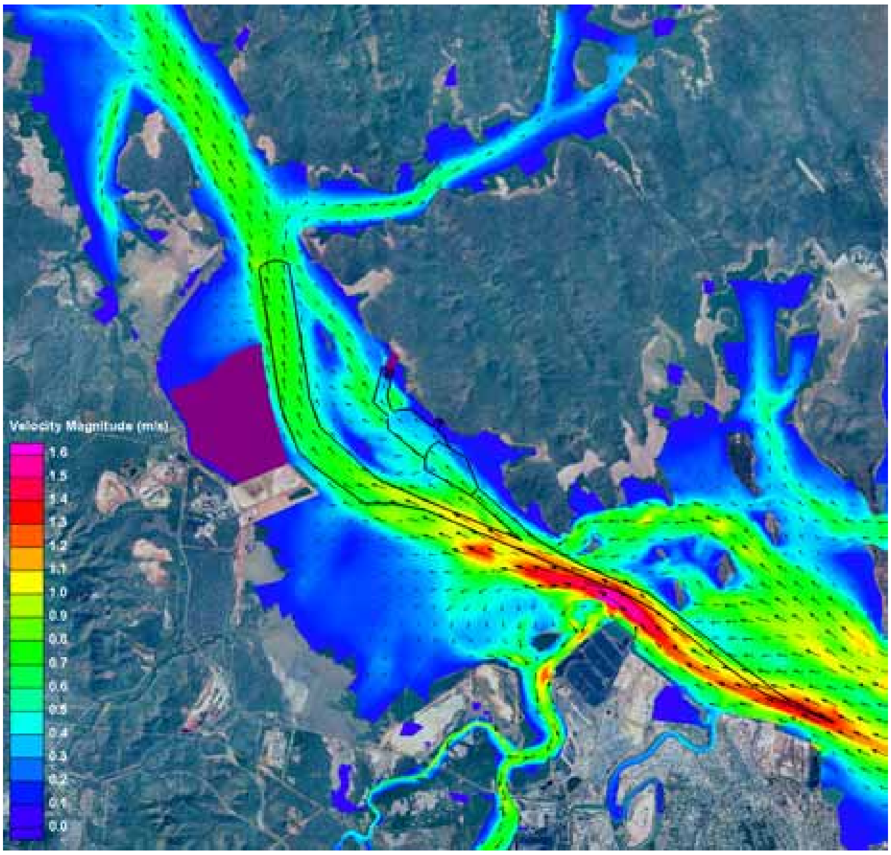

Figure I-9 Scenario 4 peak flood tide velocities

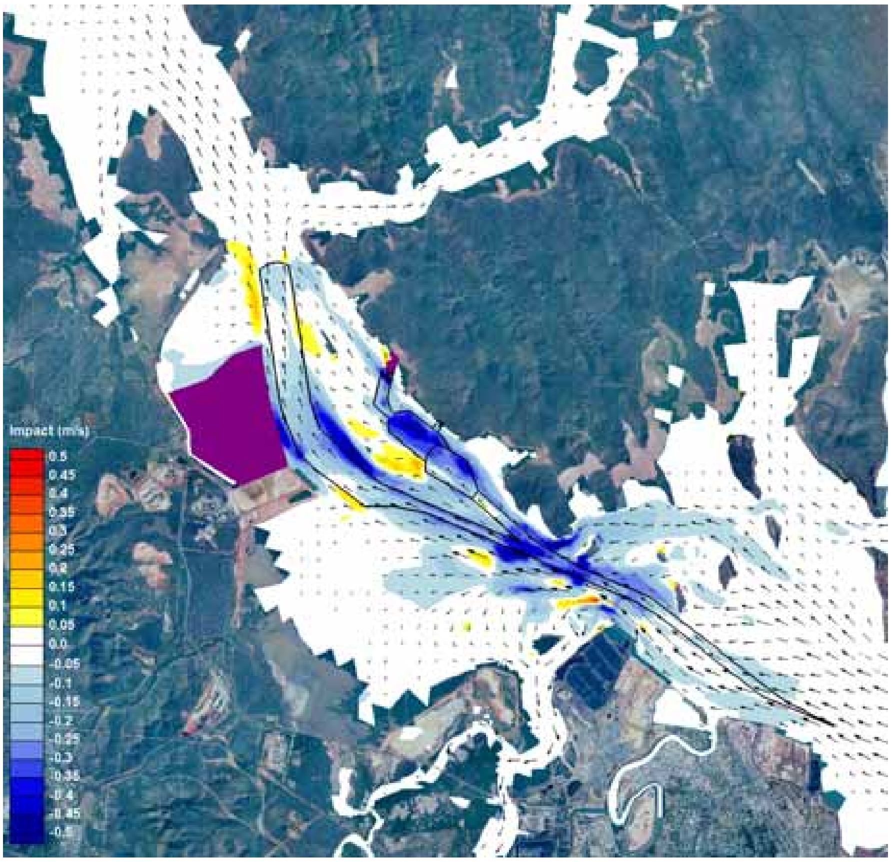

Figure I-10 Scenario 4 peak flood tide velocity differences

BMT WBM

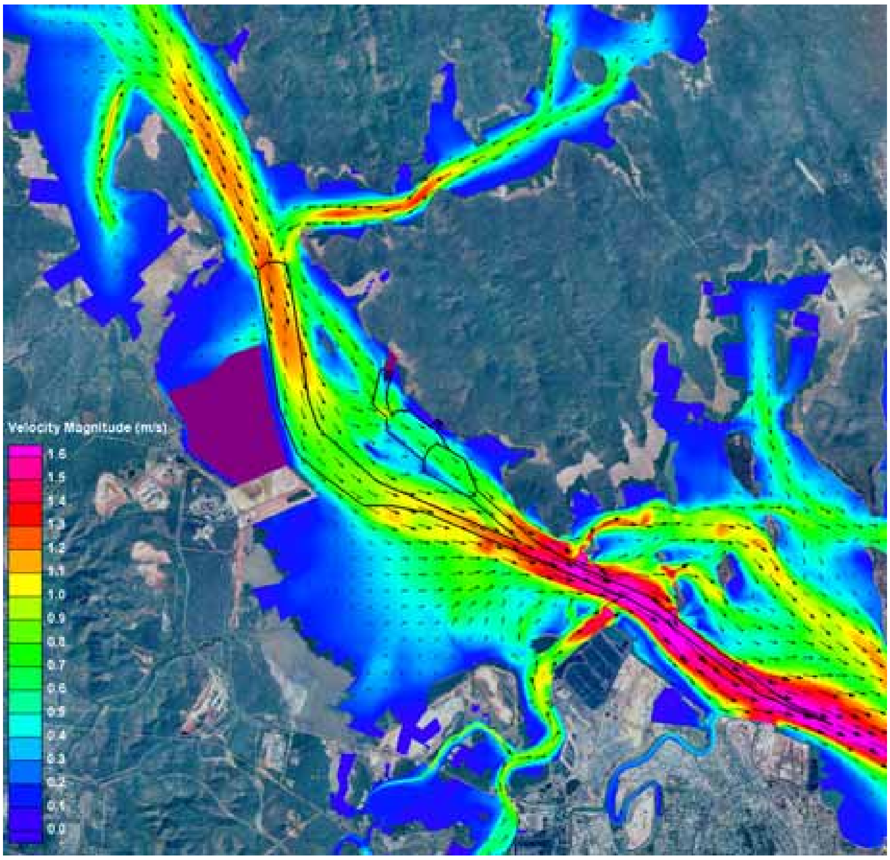

Figure I-11 Scenario 4 peak ebb tide velocities

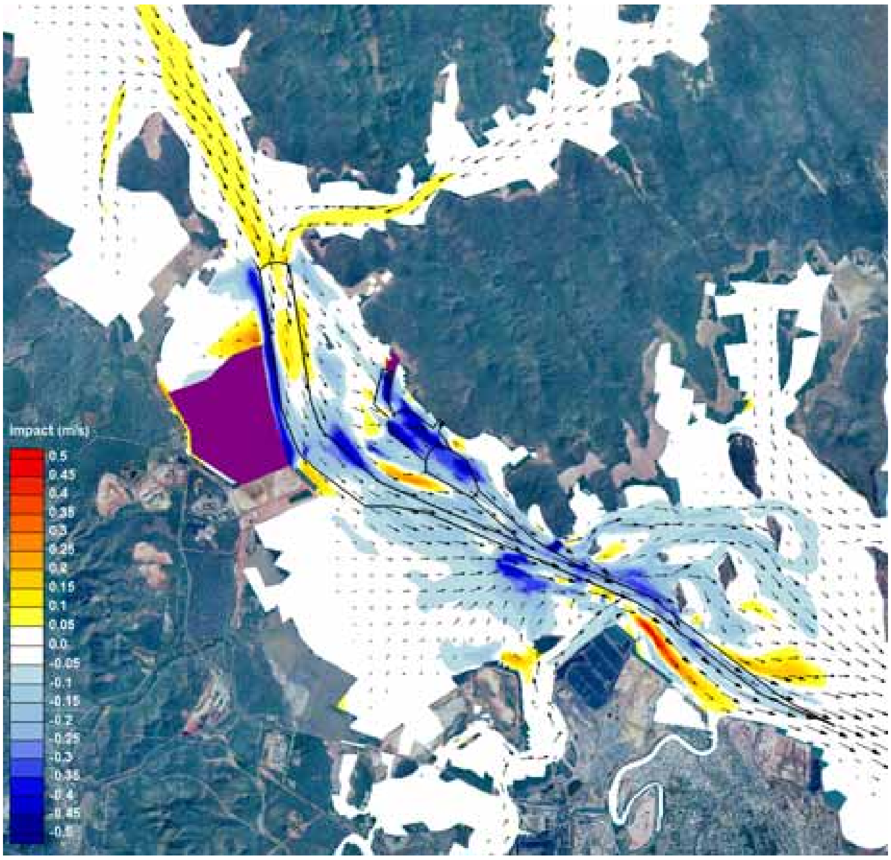

Figure I-12 Scenario 4 peak ebb tide velocity differences

APPENDIX J: TRACER CONCENTRATION TIME SERIES - PIPELINE CROSSING OPTION 2

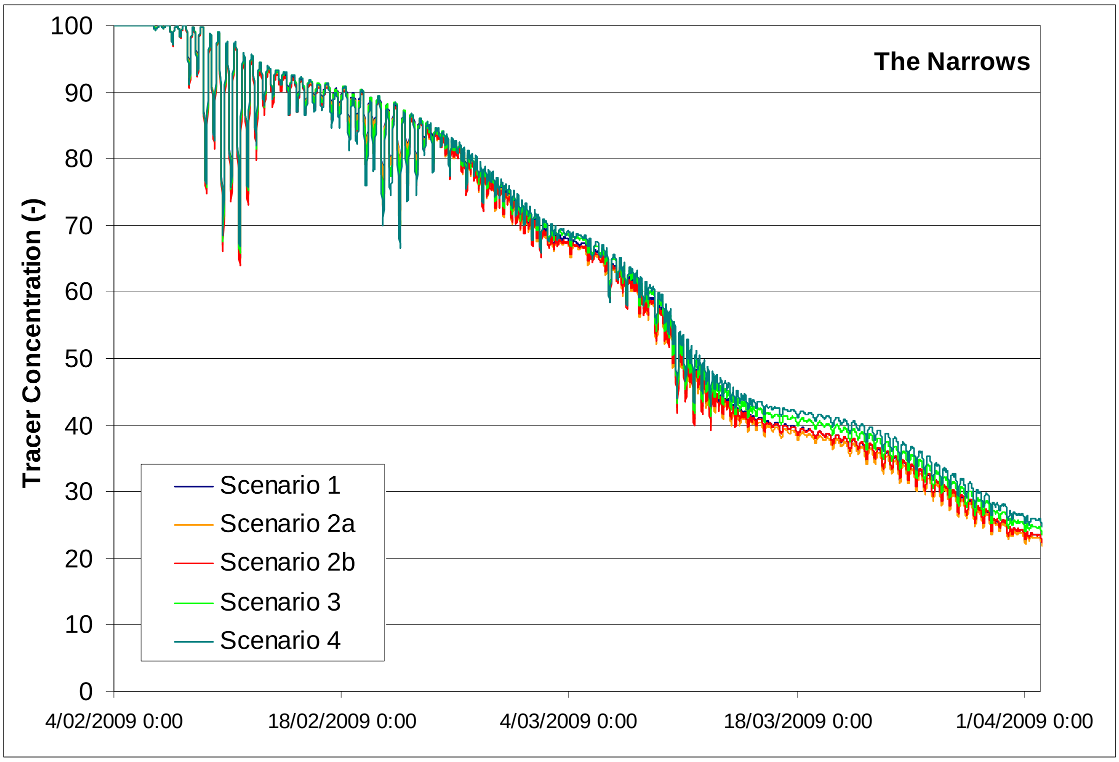

Figure J-1 Tracer Concentration Time Series – The Narrows

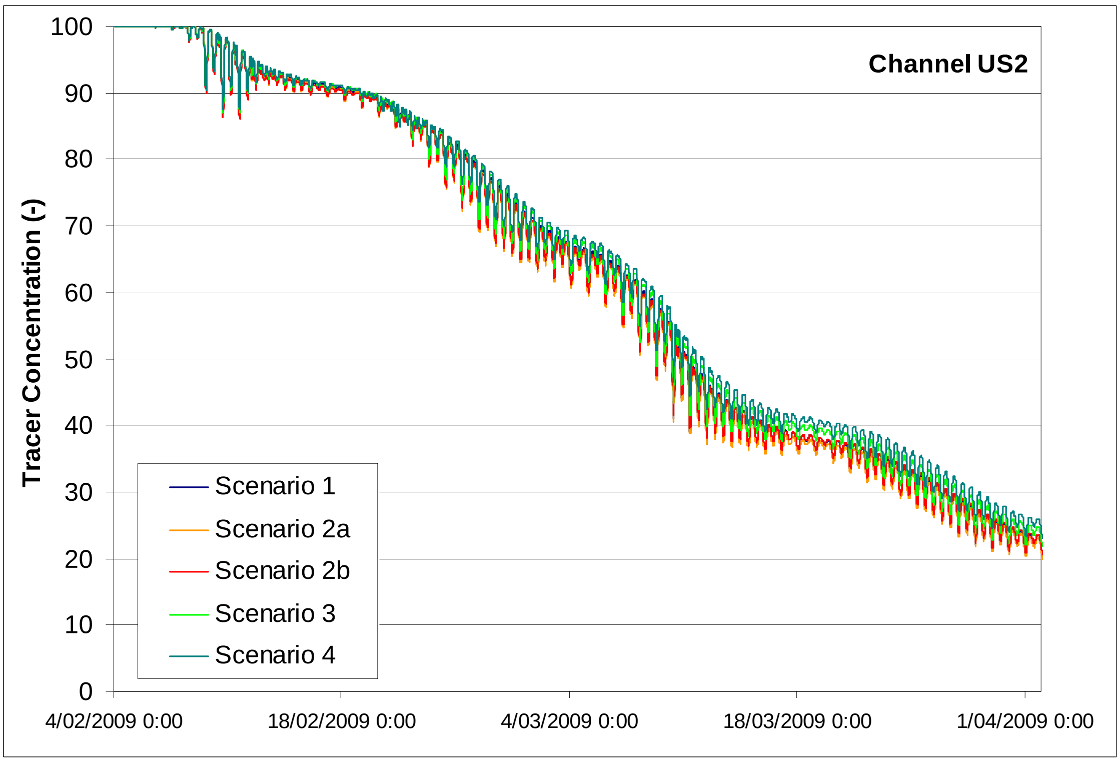

Figure J-2 Tracer Concentration Time Series – Channel US2

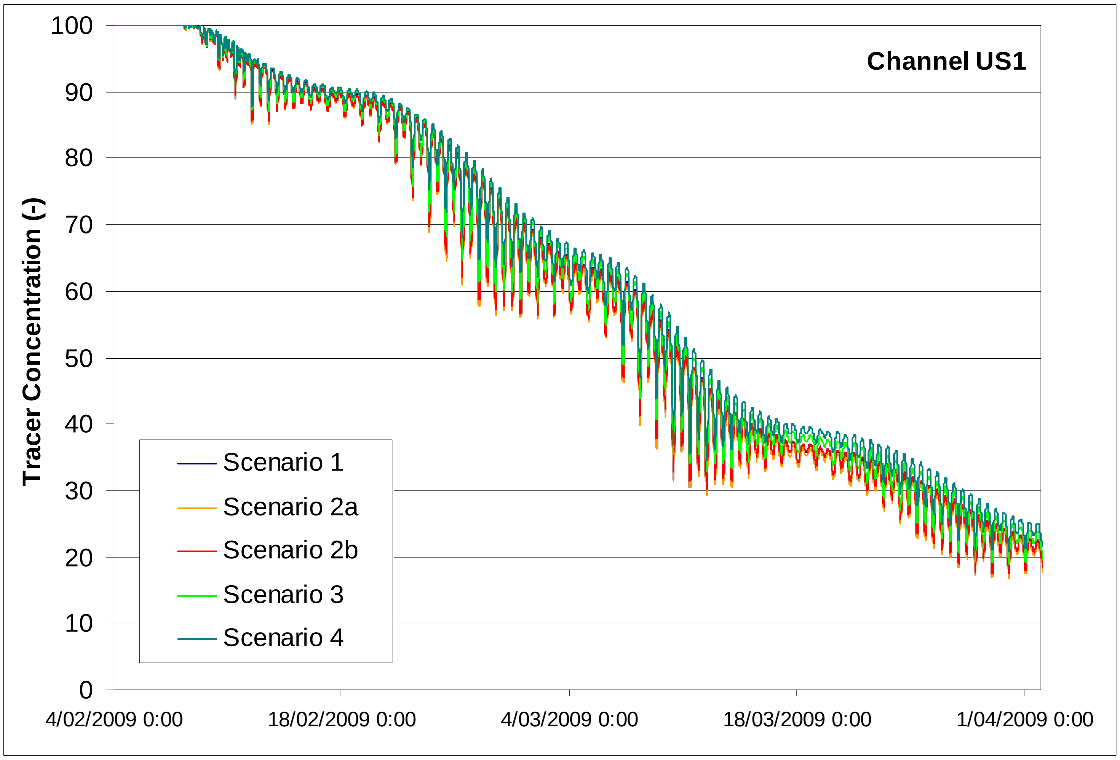

Figure J-3 Tracer Concentration Time Series – Channel US1

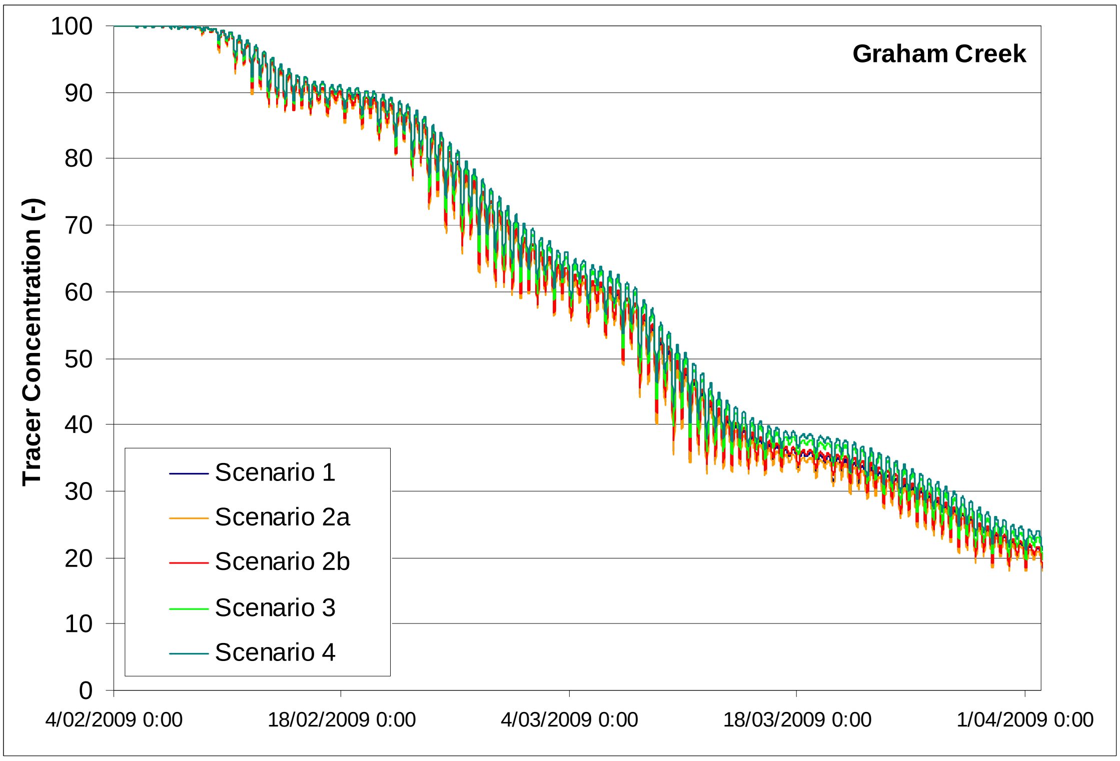

Figure J-4 Tracer Concentration Time Series – Graham Creek

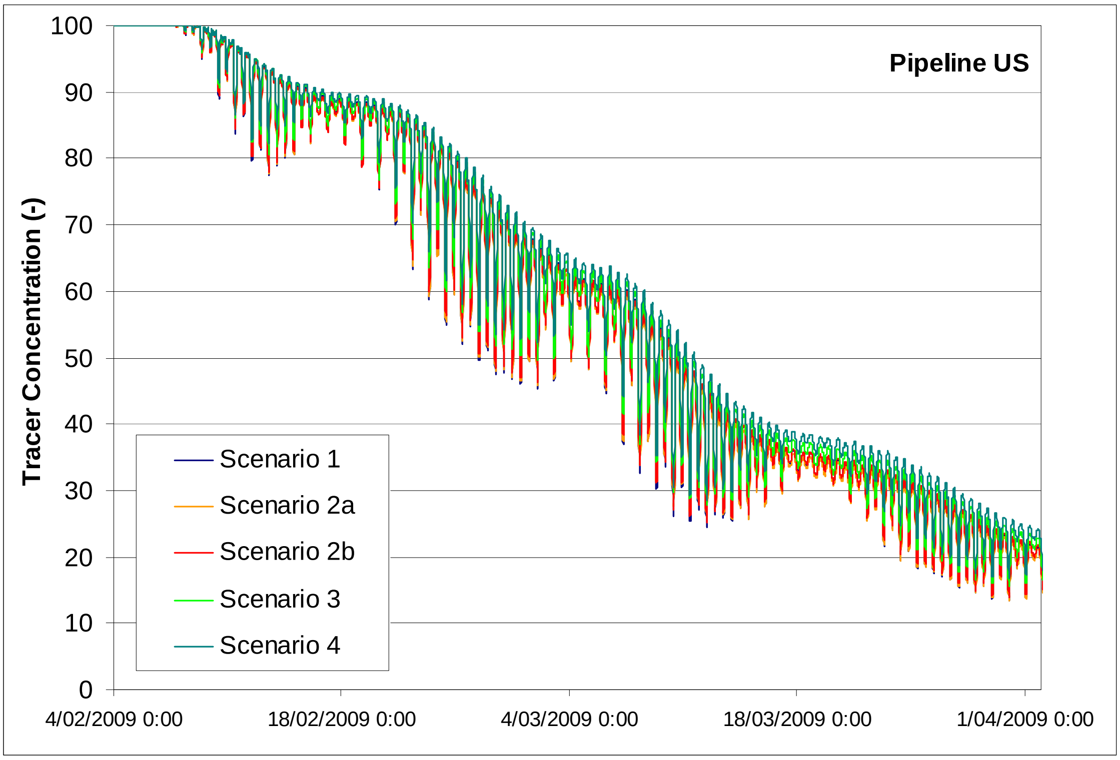

Figure J-5 Tracer Concentration Time Series – Pipeline US

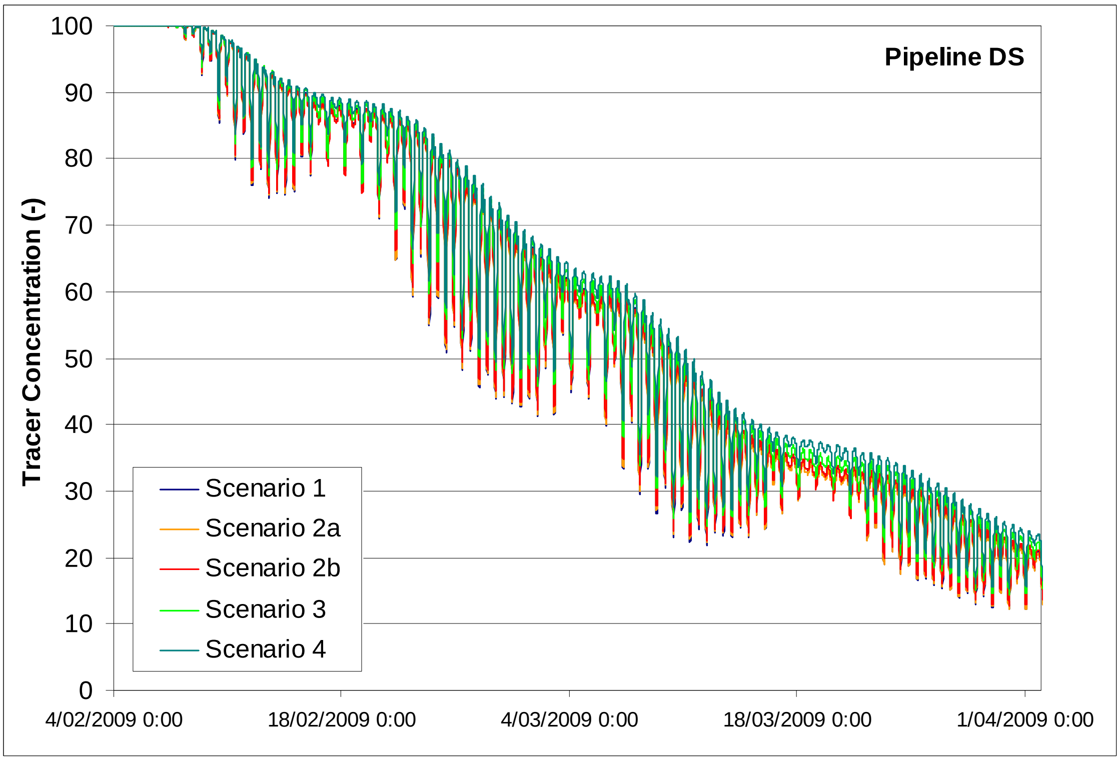

Figure J-6 Tracer Concentration Time Series – Pipeline DS

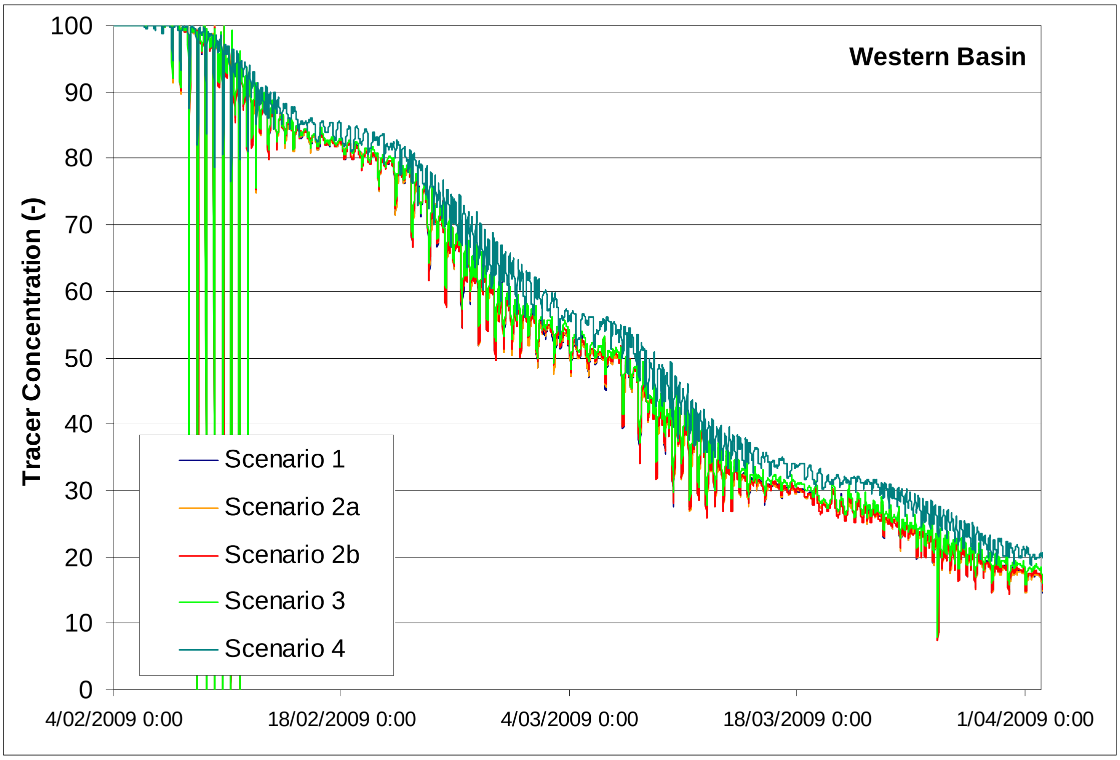

Figure J-7 Tracer Concentration Time Series – Western Basin

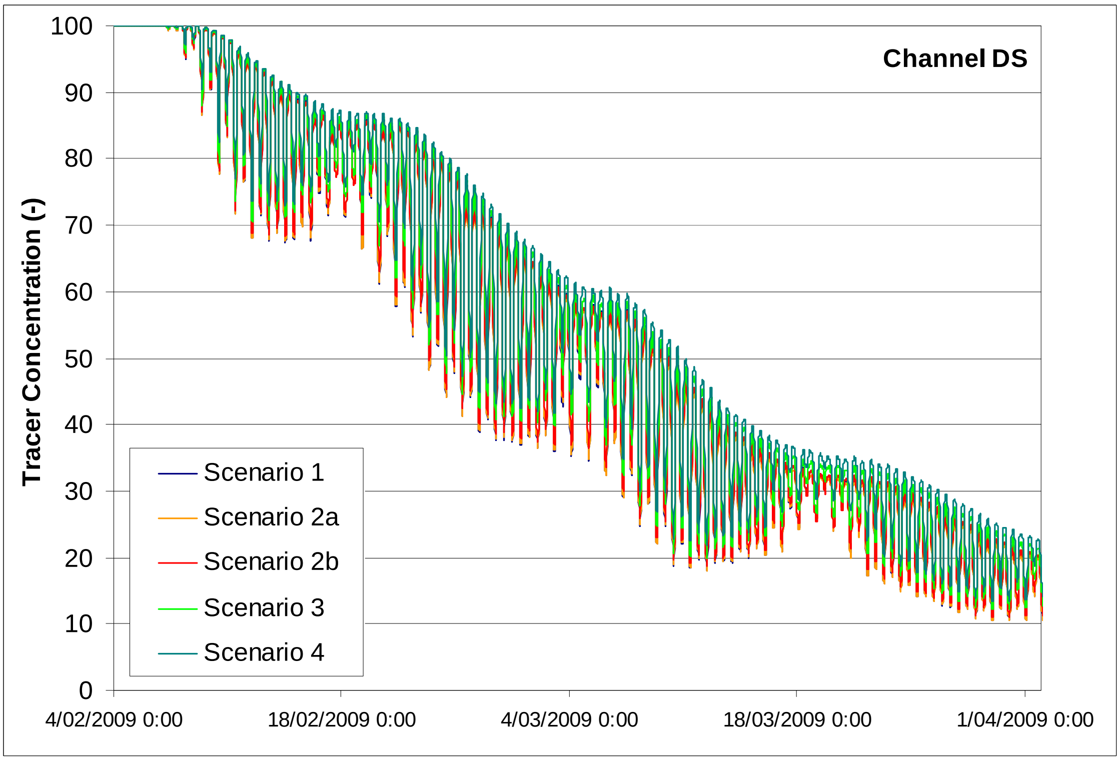

Figure J-8 Tracer Concentration Time Series – Channel DS

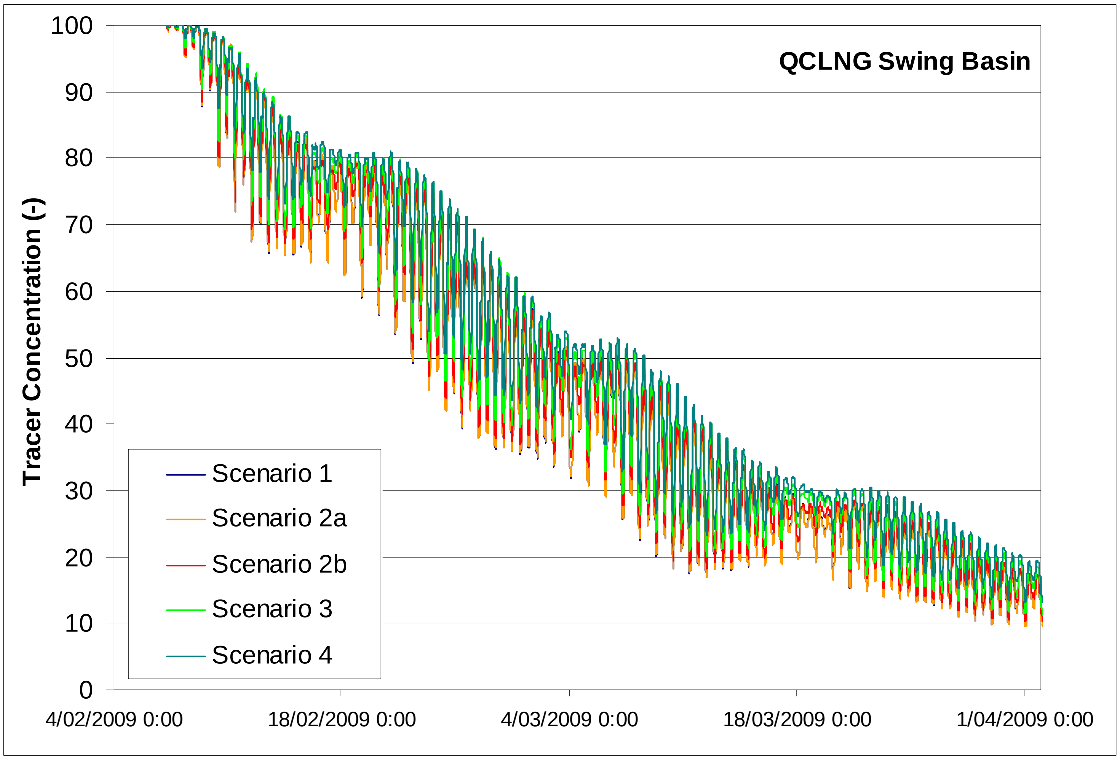

Figure J-9 Tracer Concentration Time Series – QCLNG Swing Basin

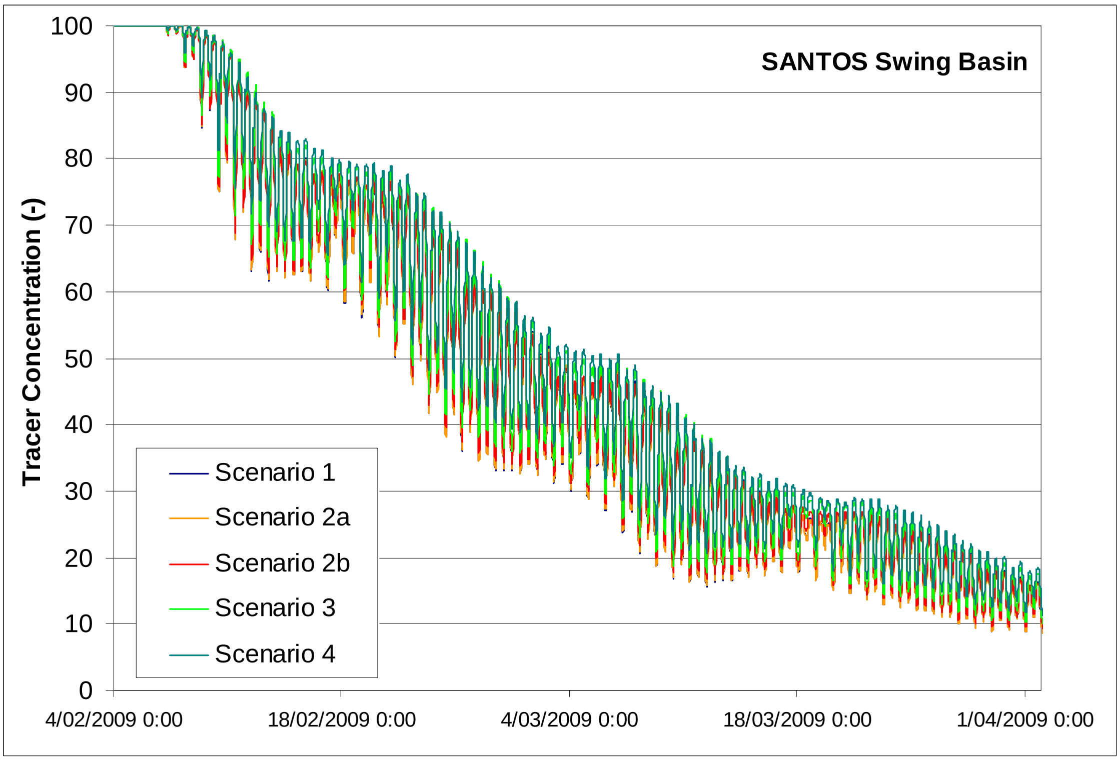

Figure J-10 Tracer Concentration Time Series – SANTOS Swing Basin

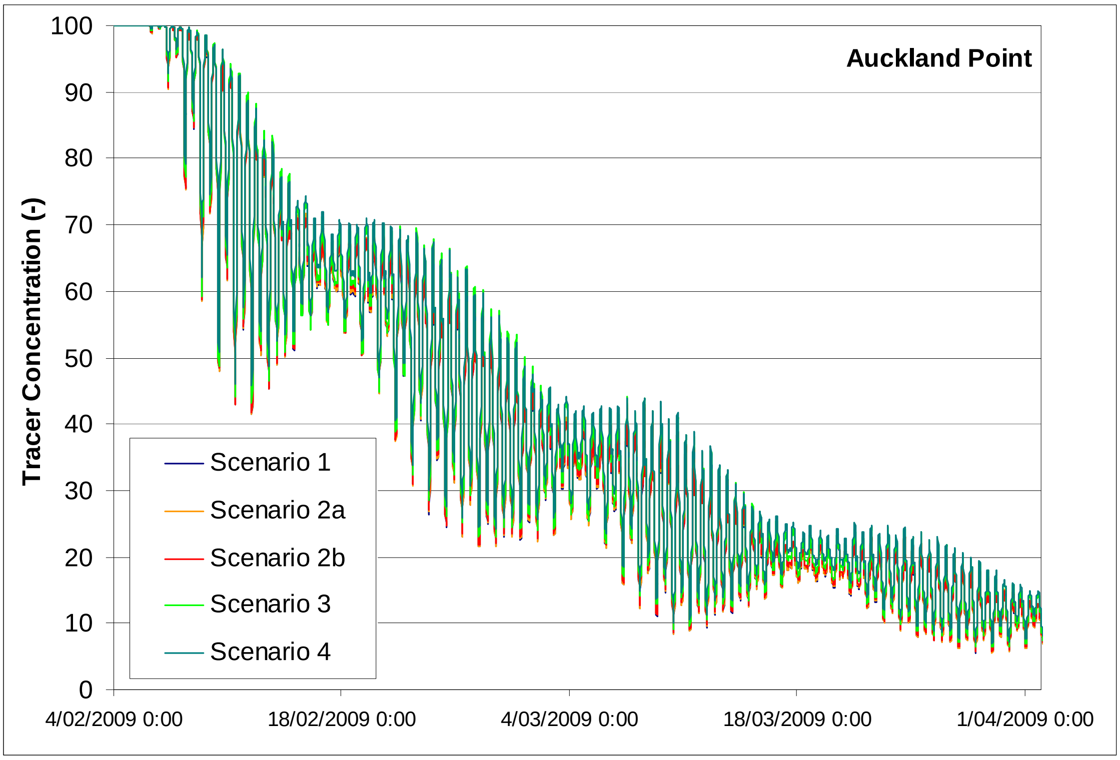

Figure J-11 Tracer Concentration Time Series – Auckland Point

APPENDIX K: TRACER CONCENTRATION CONTOURS - PIPELINE CROSSING OPTION 2

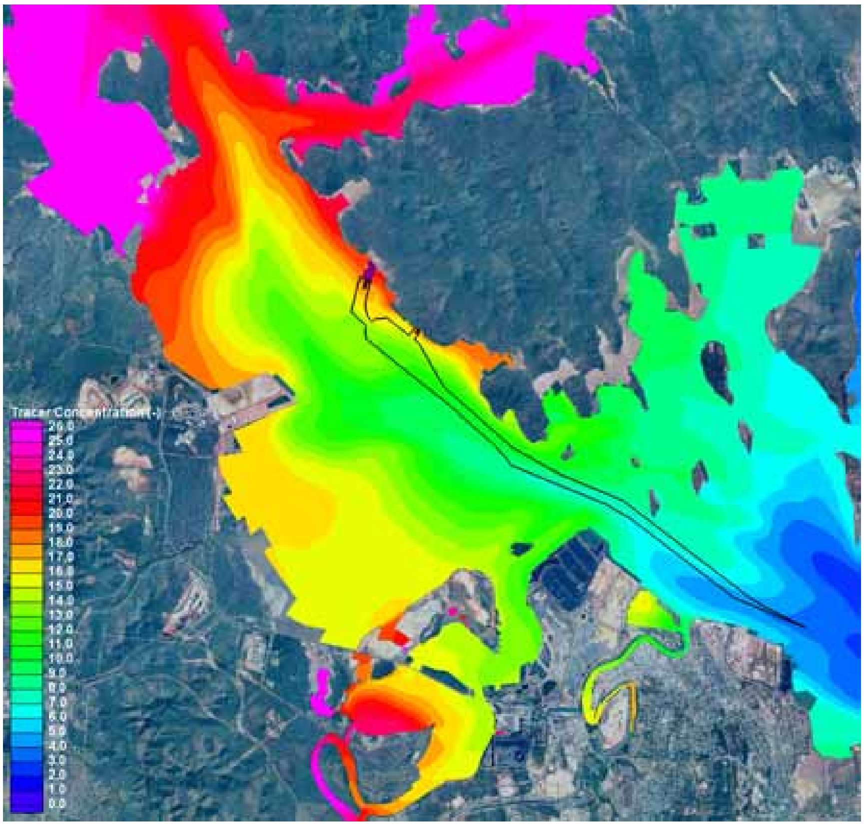

Figure K-1 Scenario 2b tracer concentration

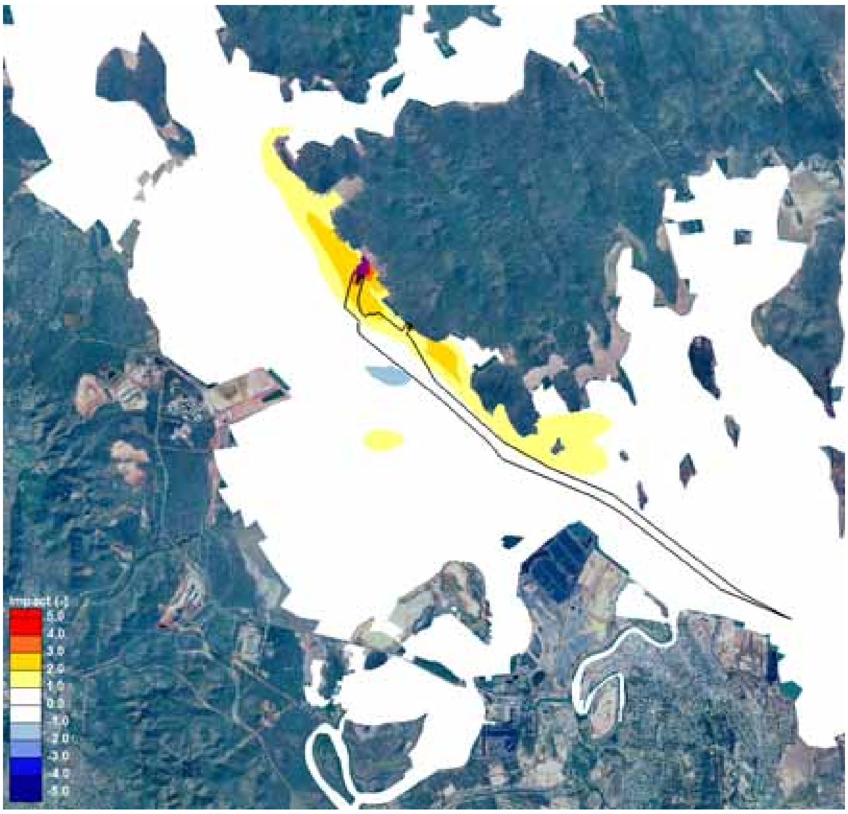

Figure K-2 Scenario 2b tracer concentration differences

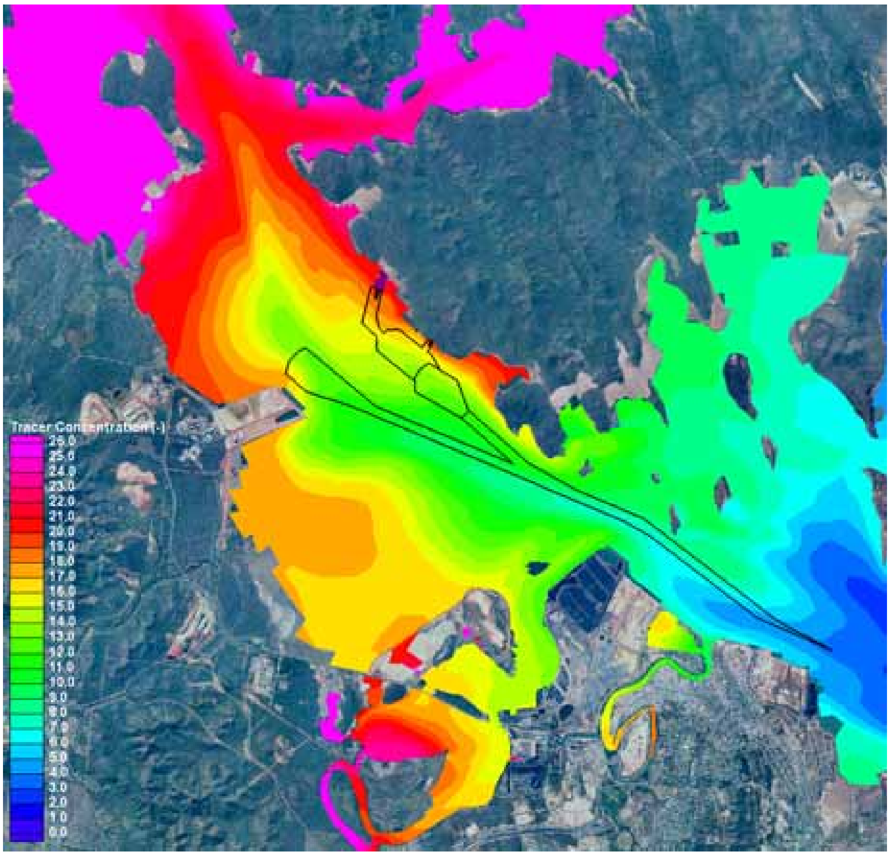

Figure K-3 Scenario 3 tracer concentration

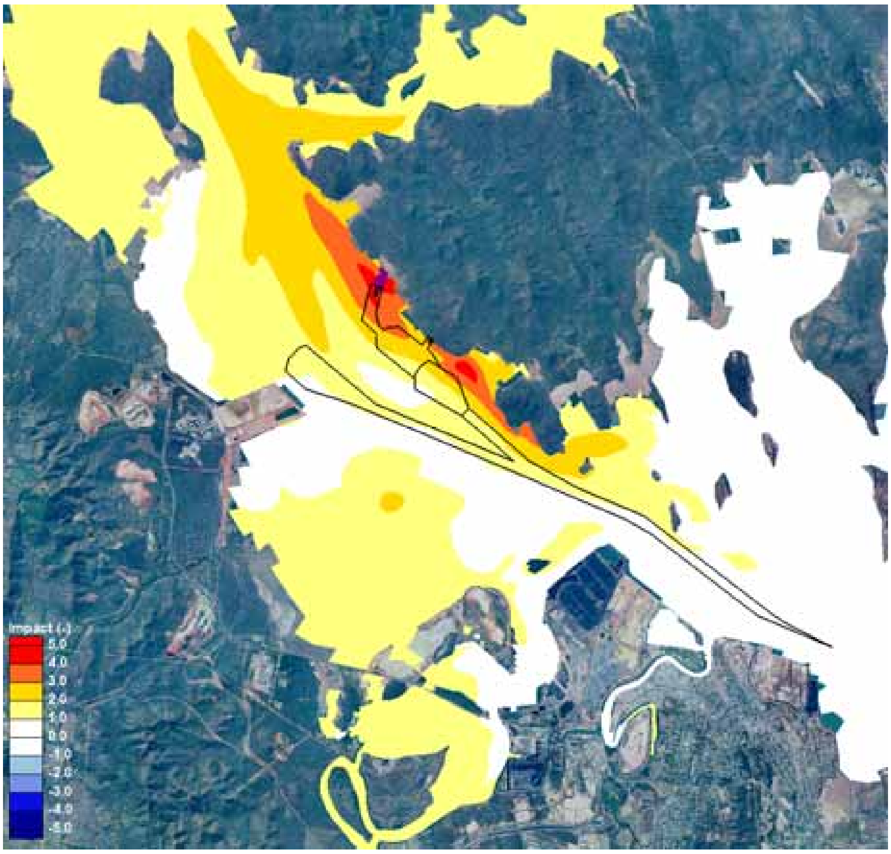

Figure K-4 Scenario 3 tracer concentration differences

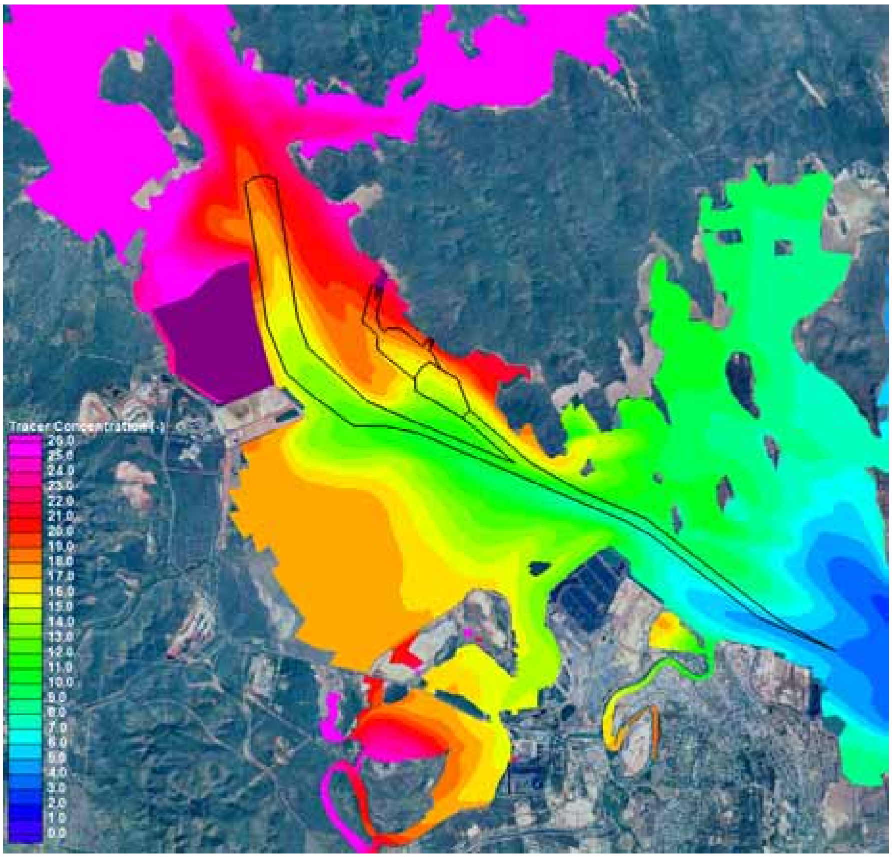

Figure K-5 Scenario 4 tracer concentration

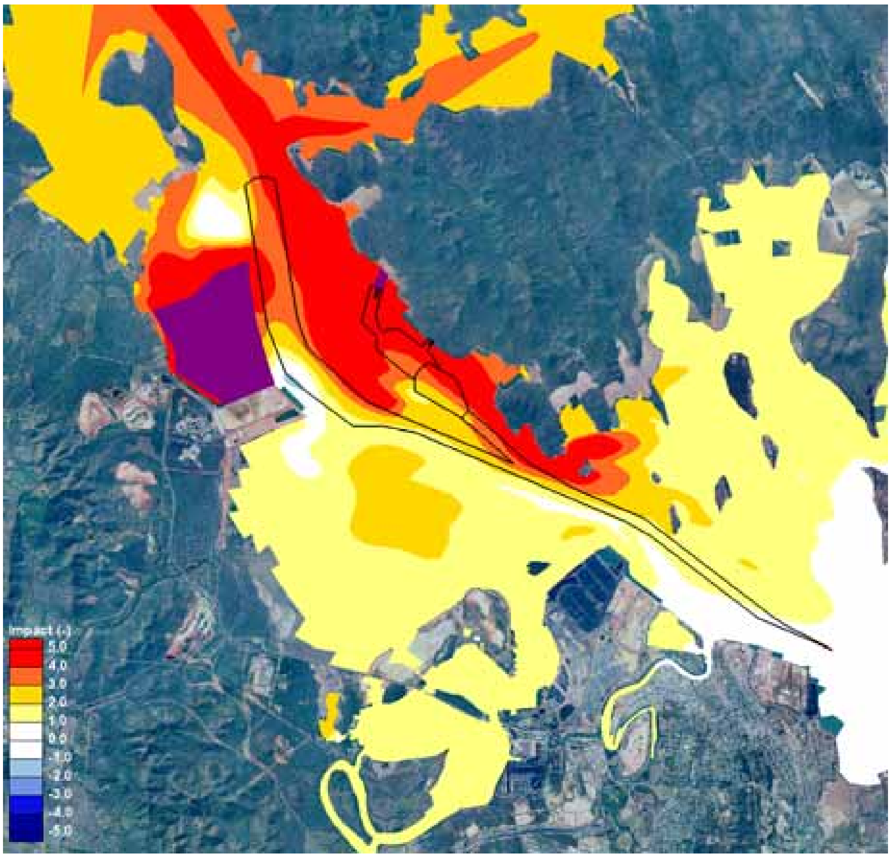

Figure K-6 Scenario 4 tracer concentration differences

APPENDIX L: E-FOLDING TIME CONTOURS – PIPELINE CROSSING OPTION 2

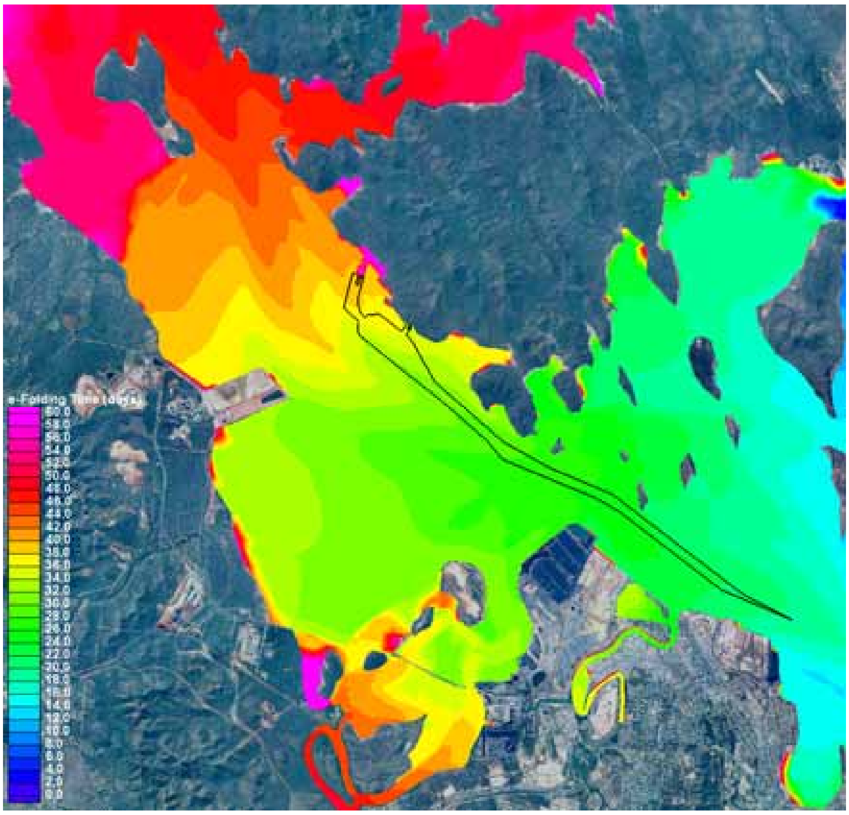

Figure L-1 Scenario 2b e-folding time

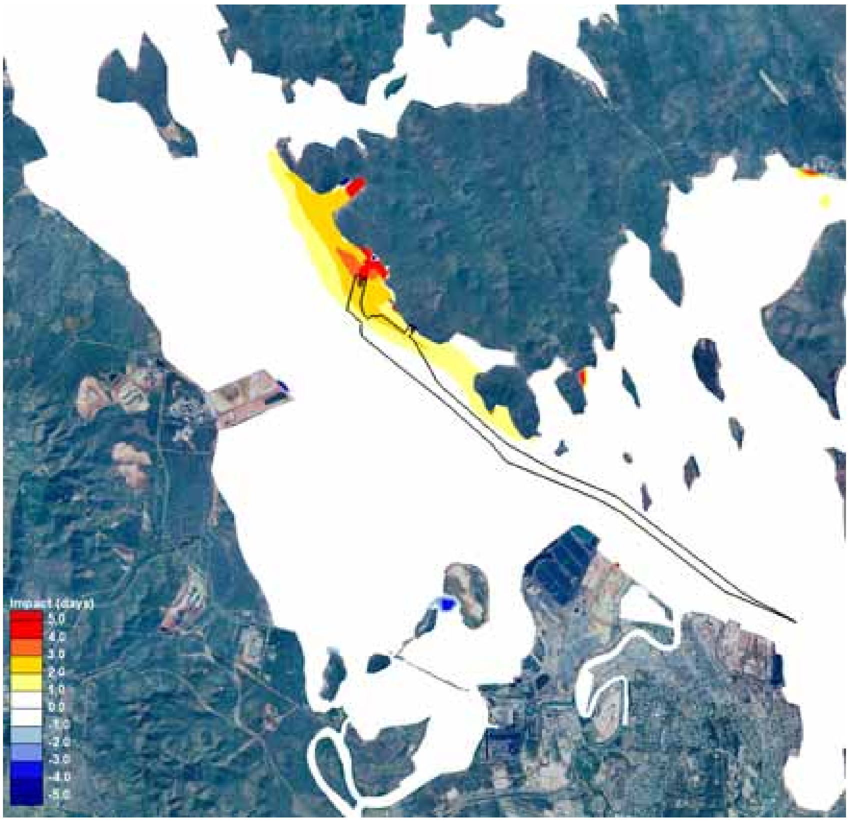

Figure L-2 Scenario 2b e-folding time differences

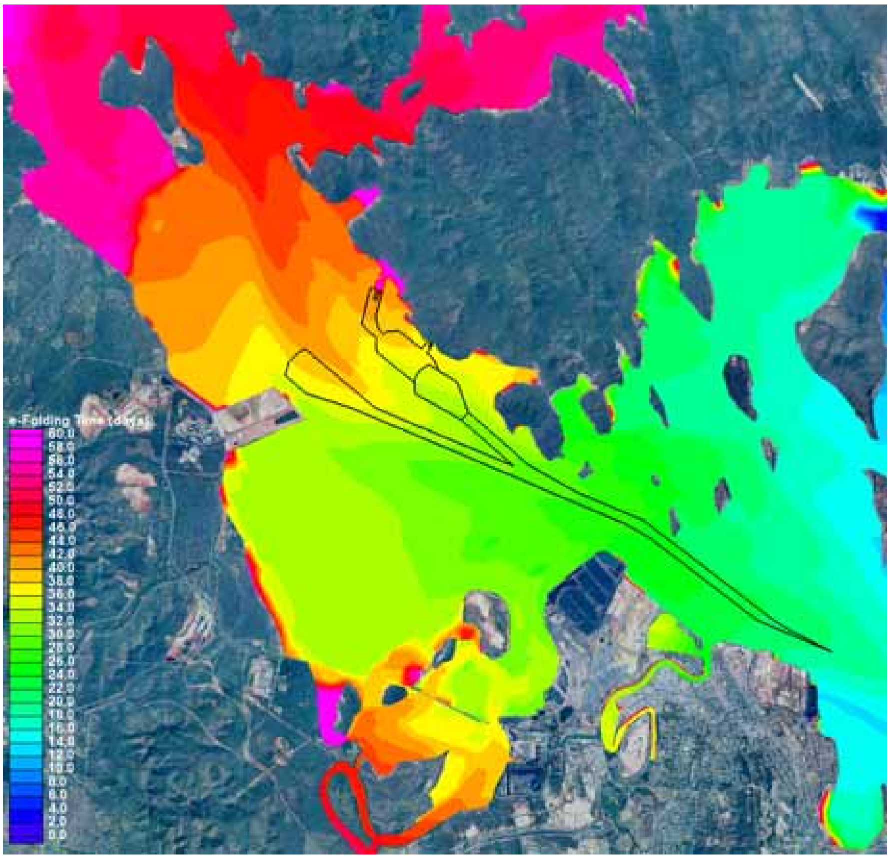

Figure L-3 Scenario 3 e-folding time

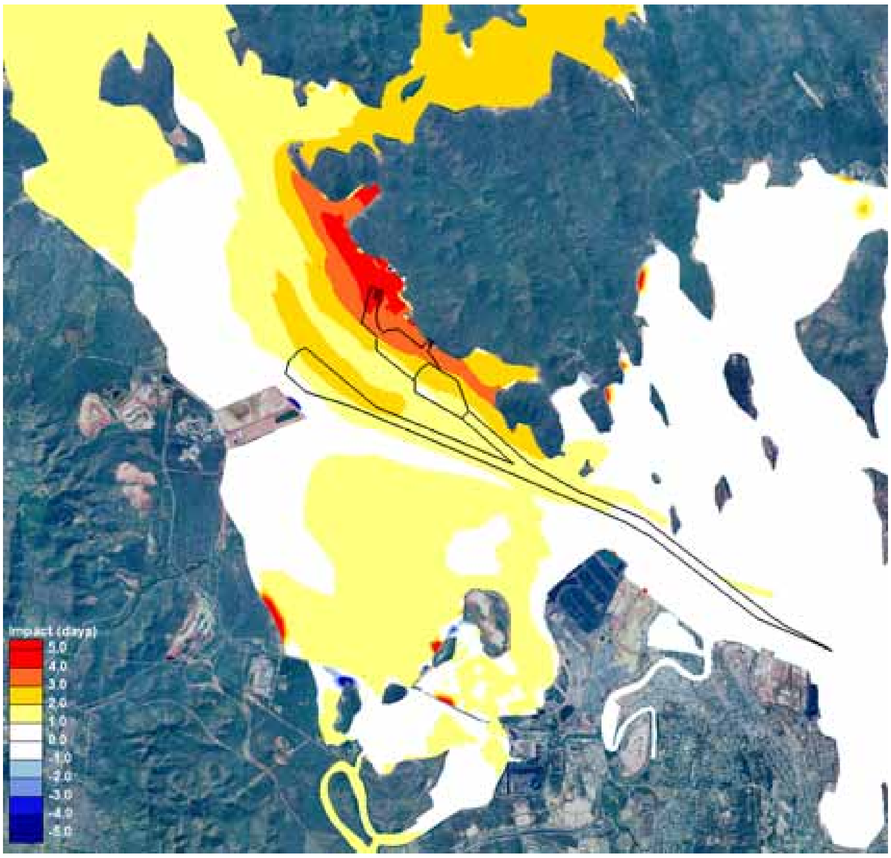

Figure L-4 Scenario 3 e-folding time differences

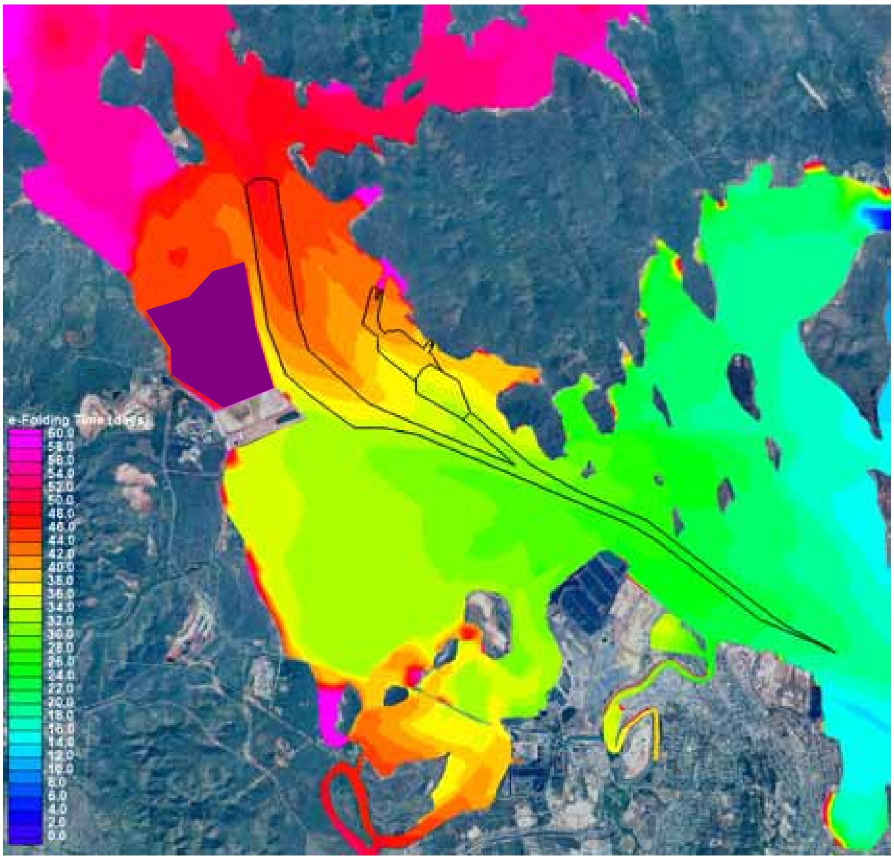

Figure L-5 Scenario 4 e-folding time

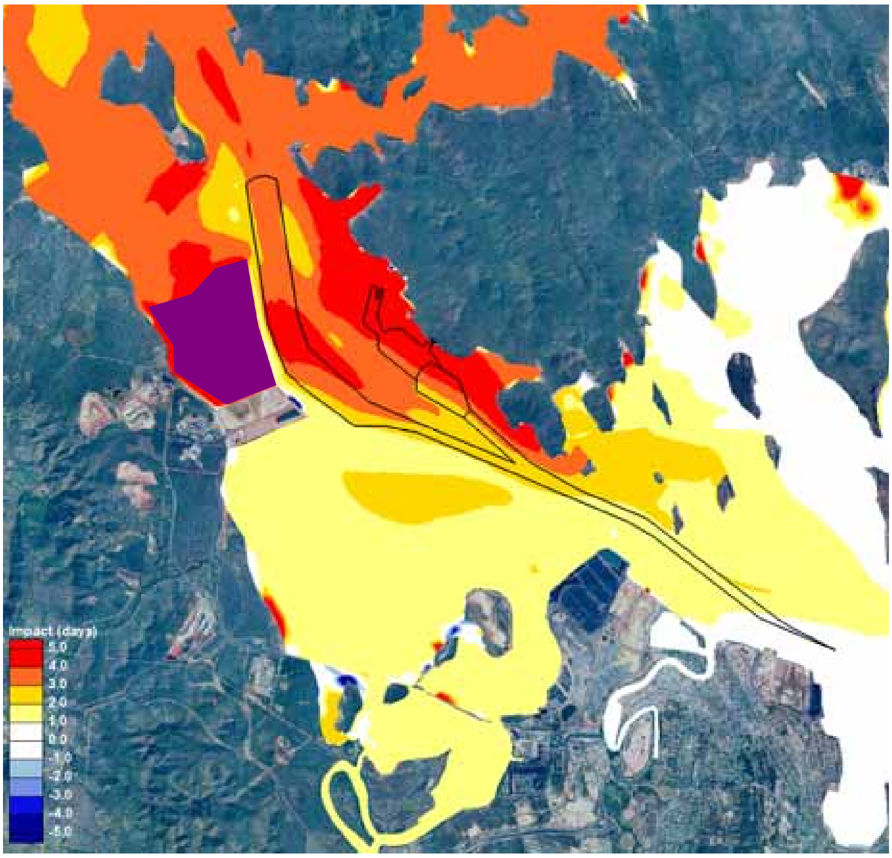

Figure L-6 Scenario 4 e-folding time differences

APPENDIX M: WATER LEVEL TIME SERIES PLOTS – PIPELINE CROSSING OPTION 3

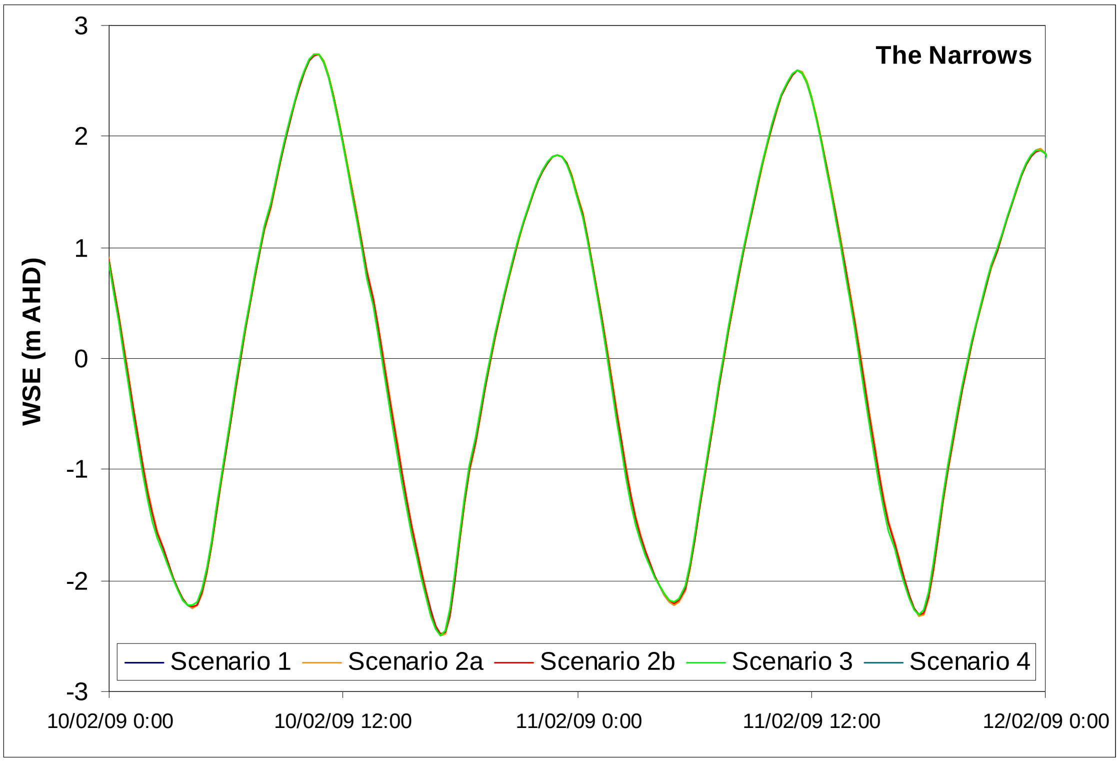

Figure M-1 Water Level Time Series – The Narrows

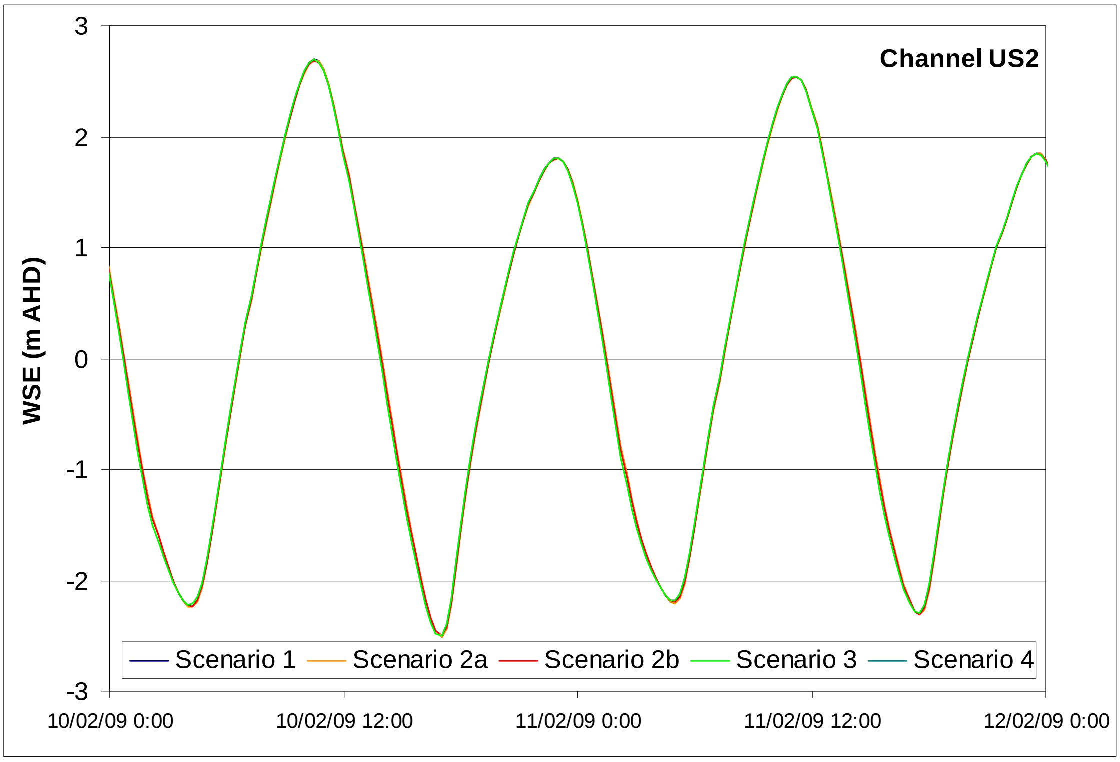

Figure M-2 Water Level Time Series – Channel US2

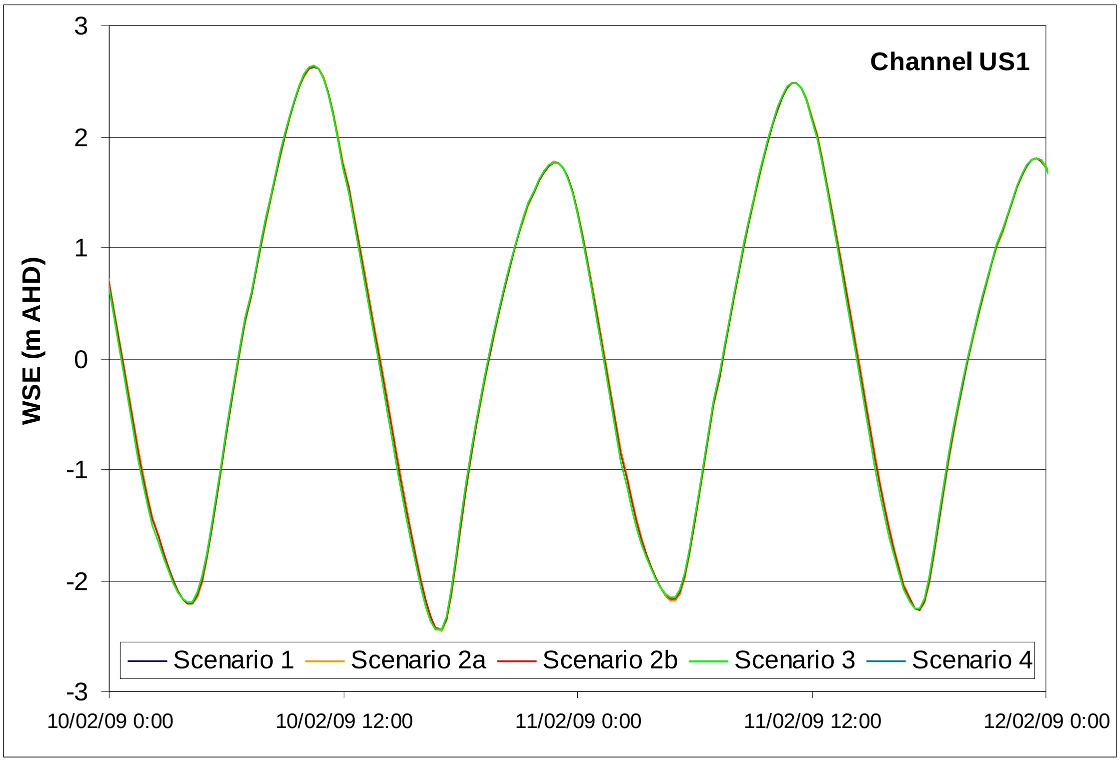

Figure M-3 Water Level Time Series – Channel US1

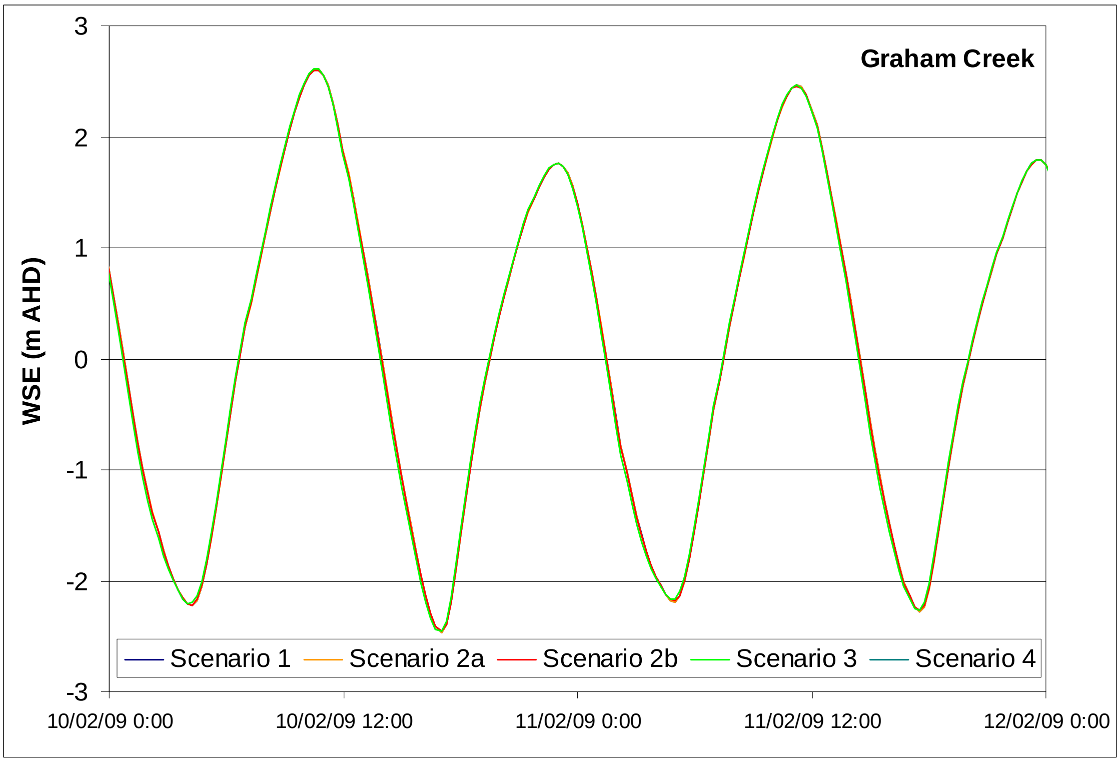

Figure M-4 Water Level Time Series – Graham Creek

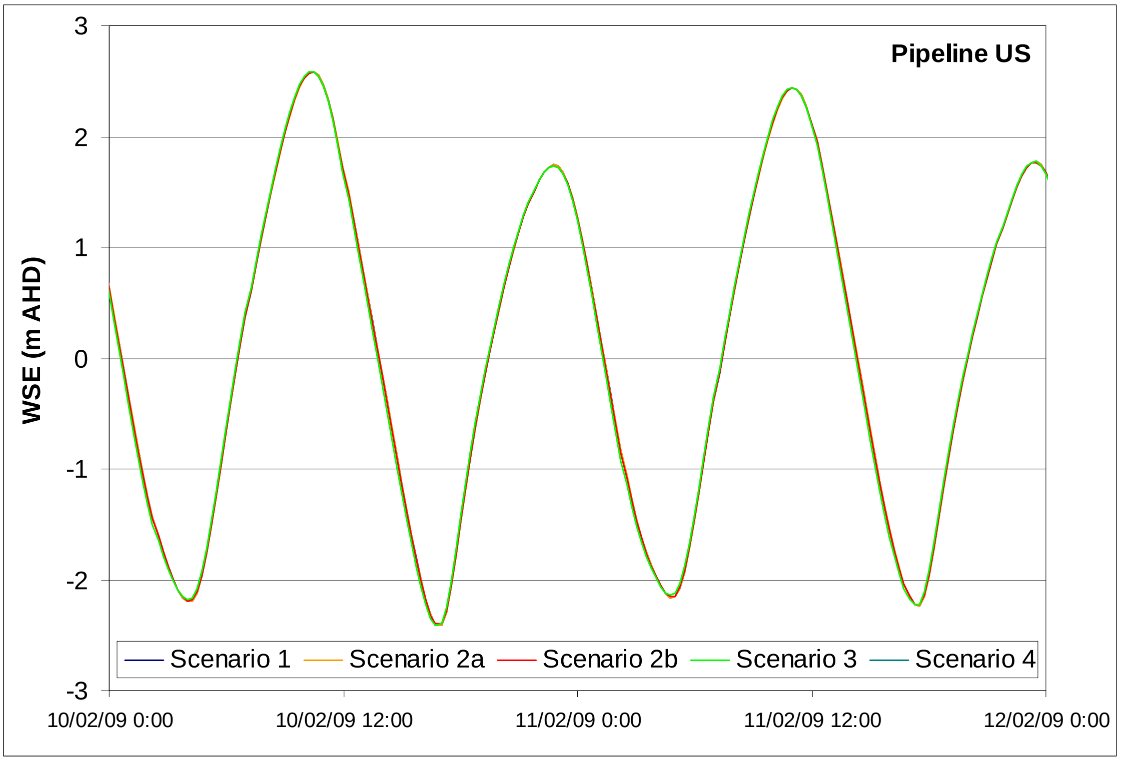

Figure M-5 Water Level Time Series – Pipeline US

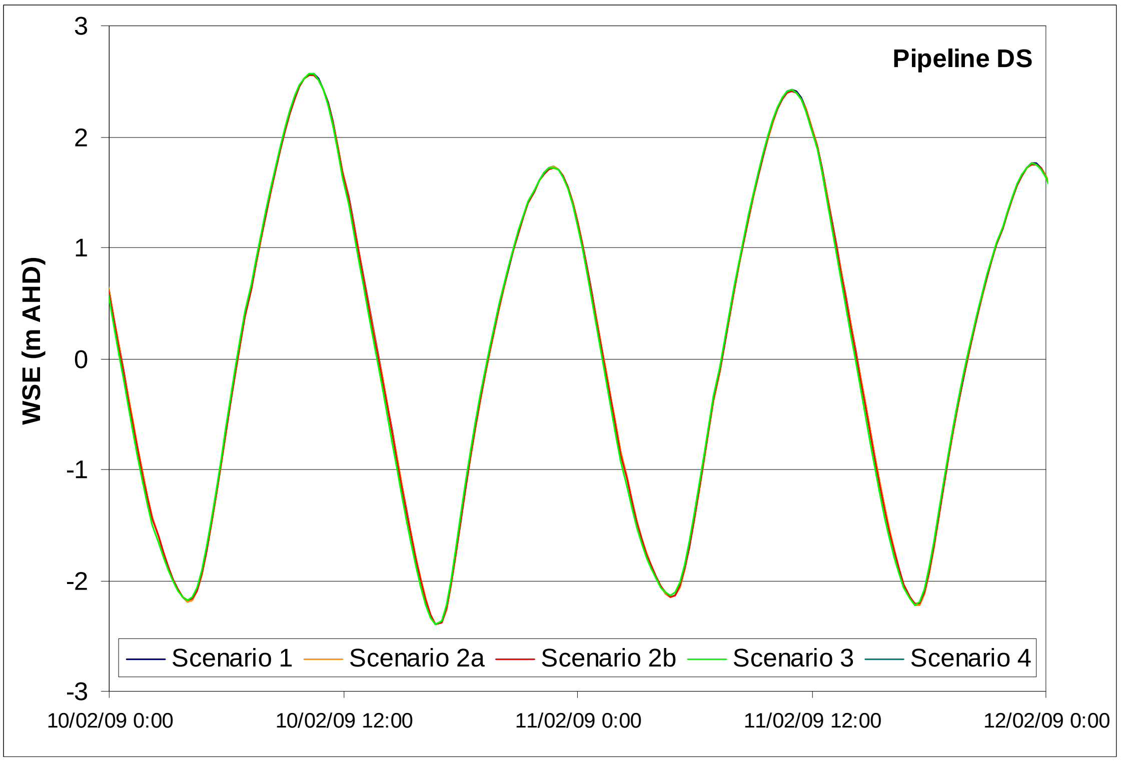

Figure M-6 Water Level Time Series – Pipeline DS

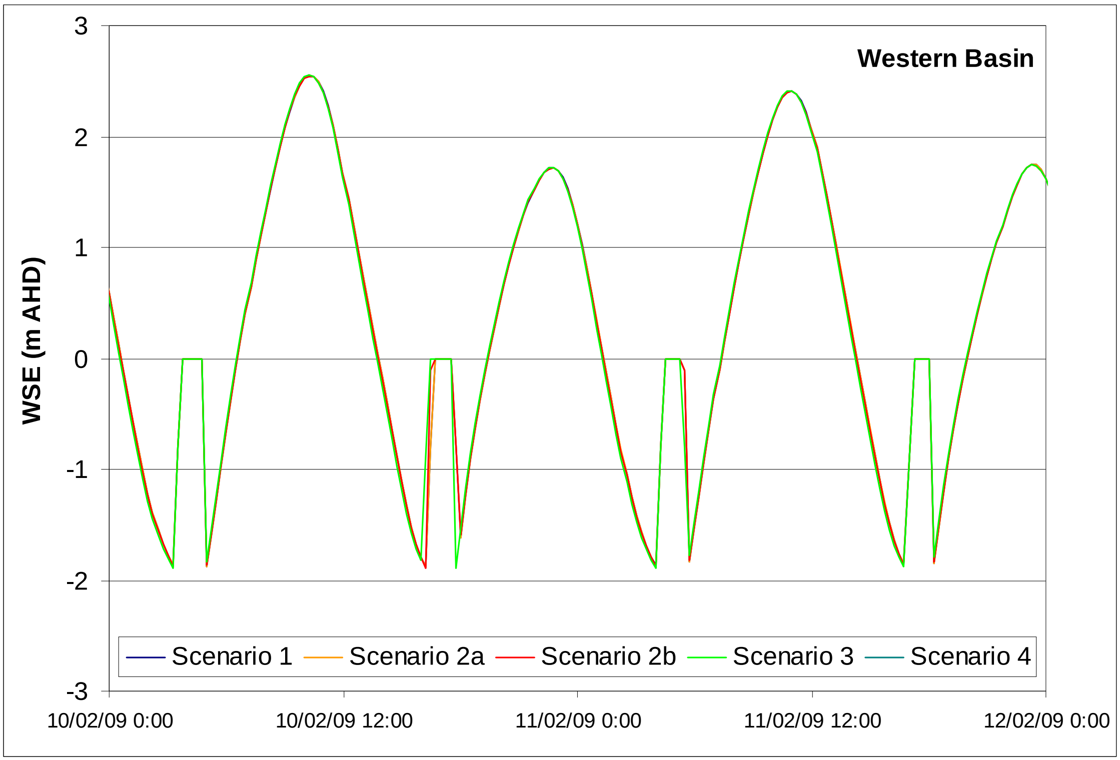

Figure M-7 Water Level Time Series – Western Basin

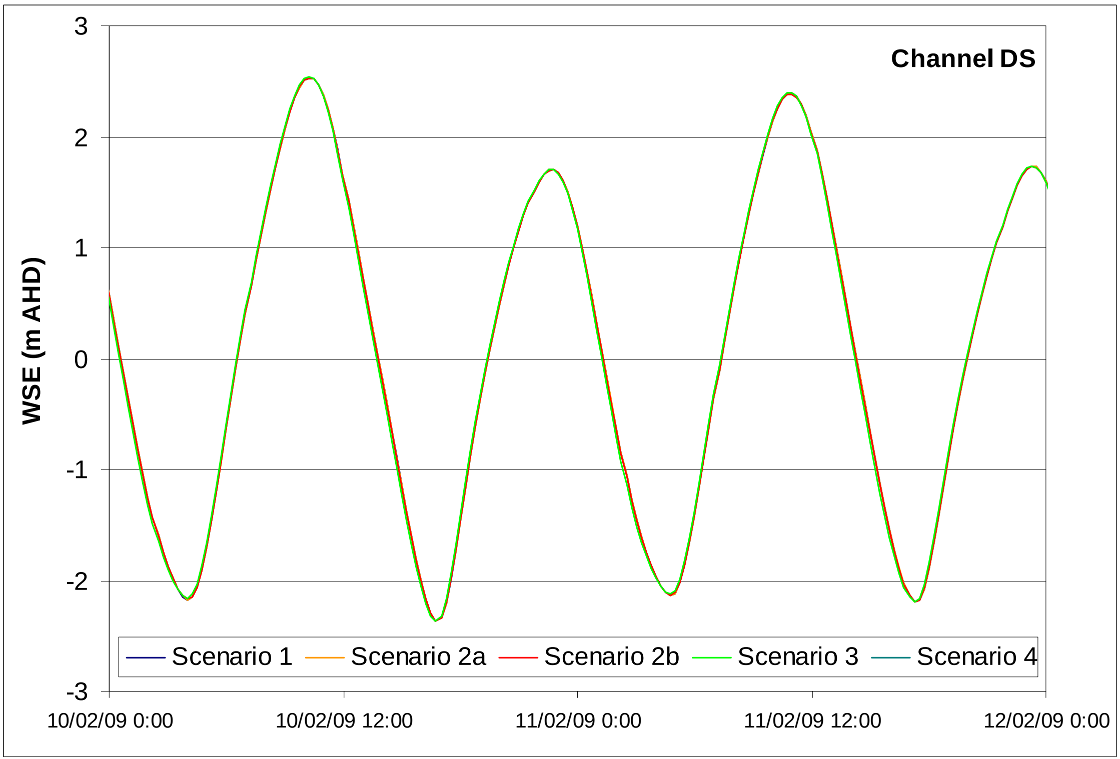

Figure M-8 Water Level Time Series – Channel DS

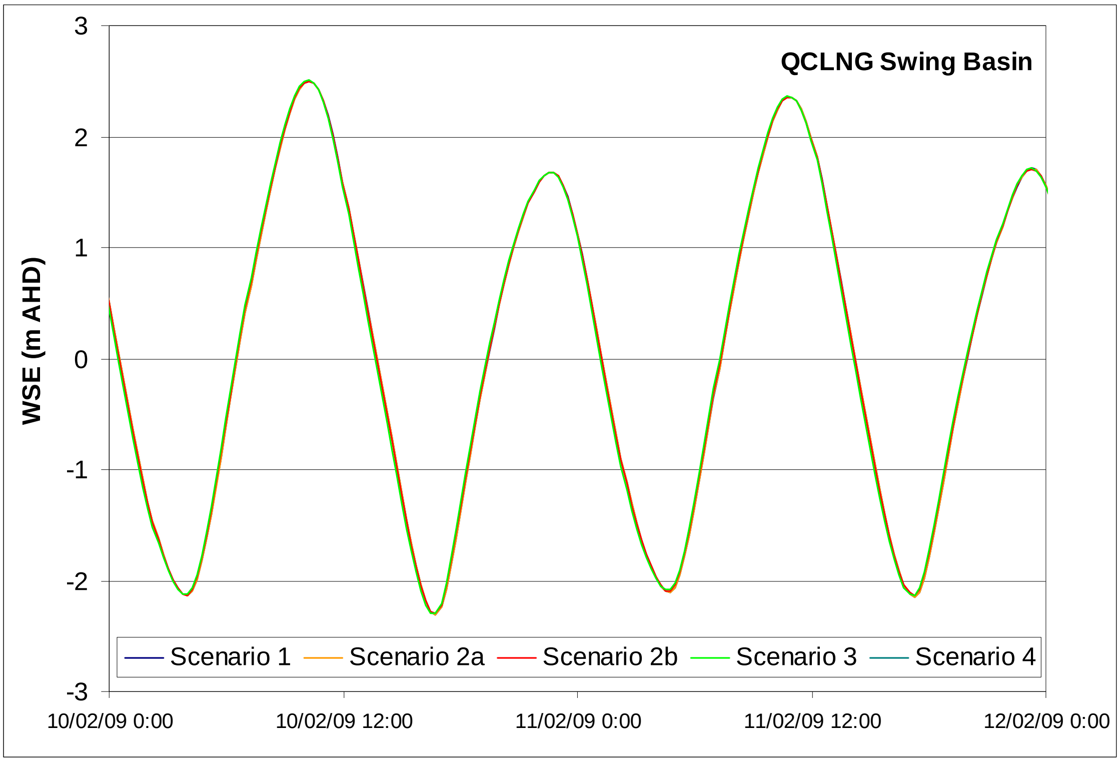

Figure M-9 Water Level Time Series – QCLNG Swing Basin

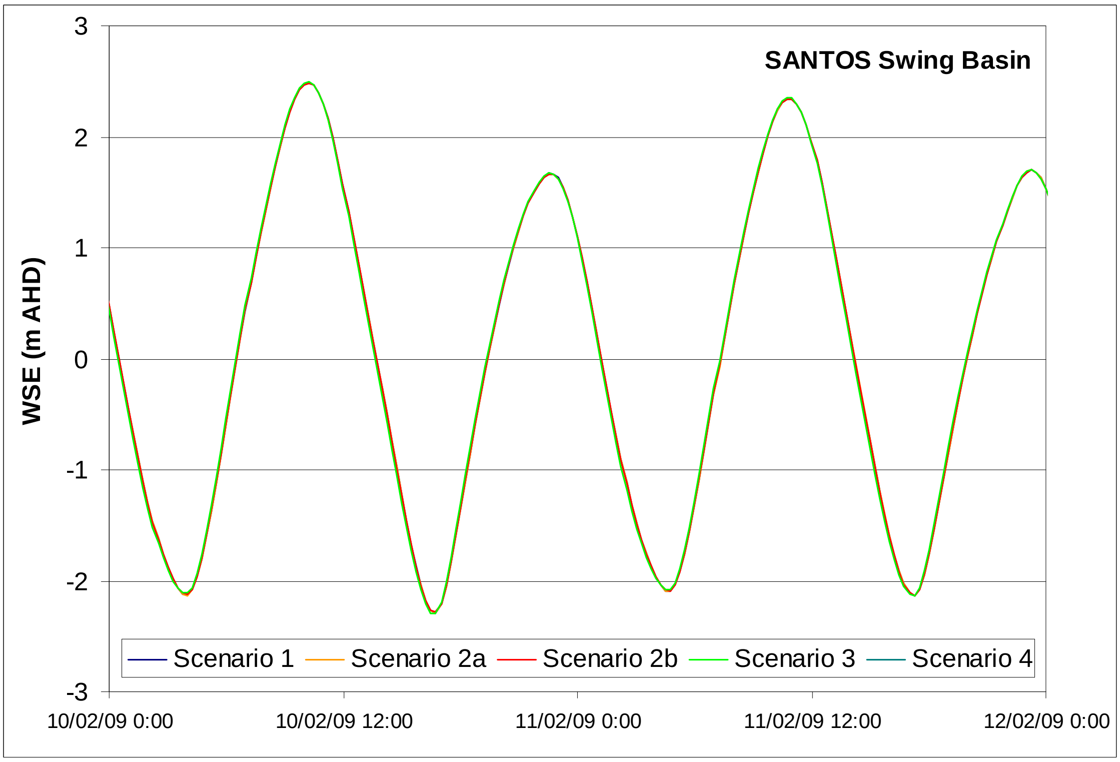

Figure M-10 Water Level Time Series – SANTOS Swing Basin

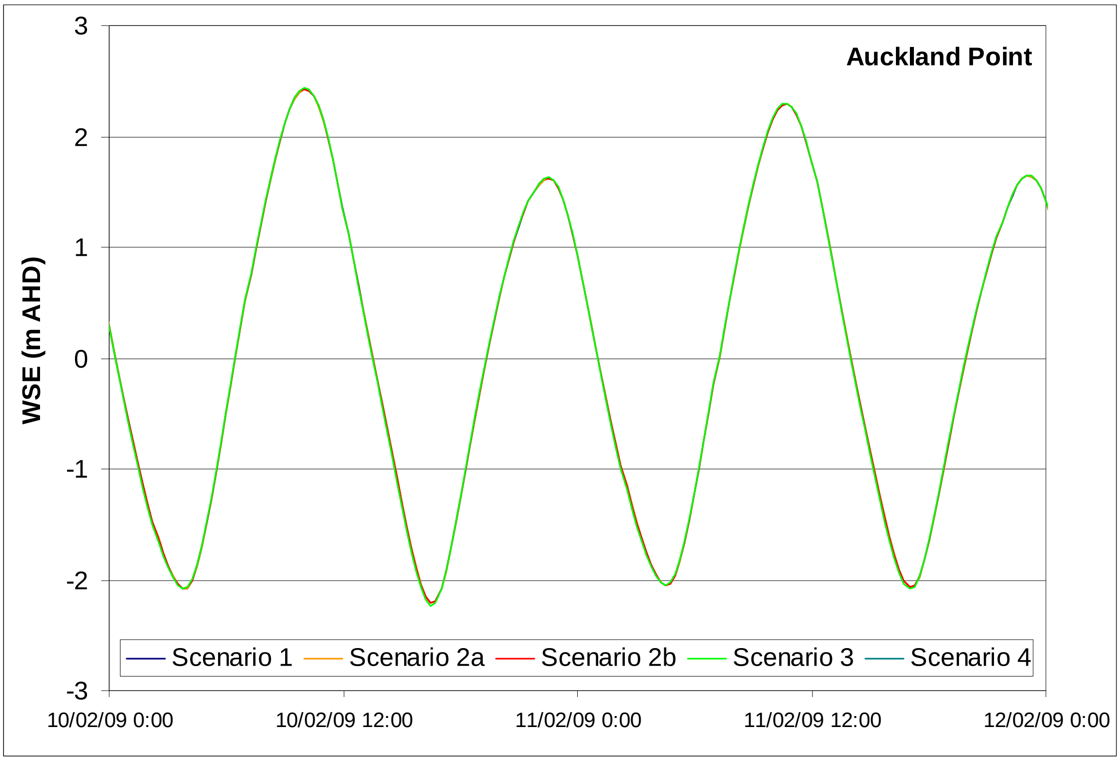

Figure M-11 Water Level Time Series – Auckland Point

APPENDIX N: VELOCITY MAGNITUDE TIME SERIES – PIPELINE CROSSING OPTION 3

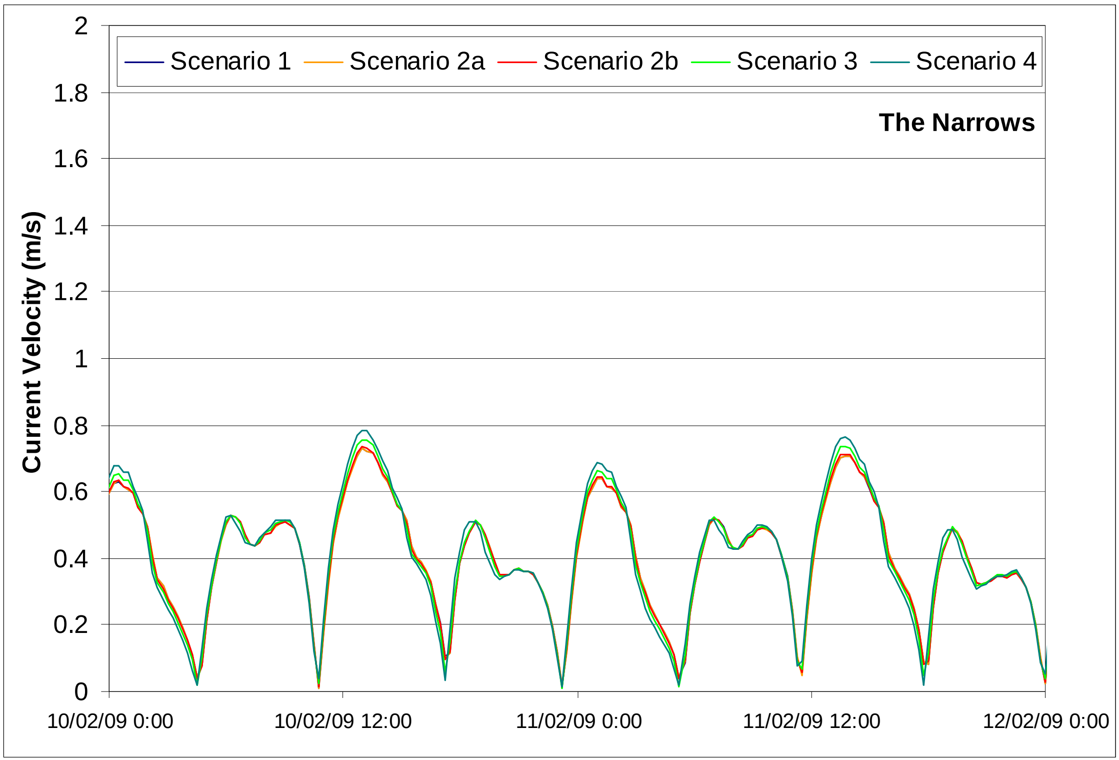

Figure N-1 Velocity Magnitude Time Series – The Narrows

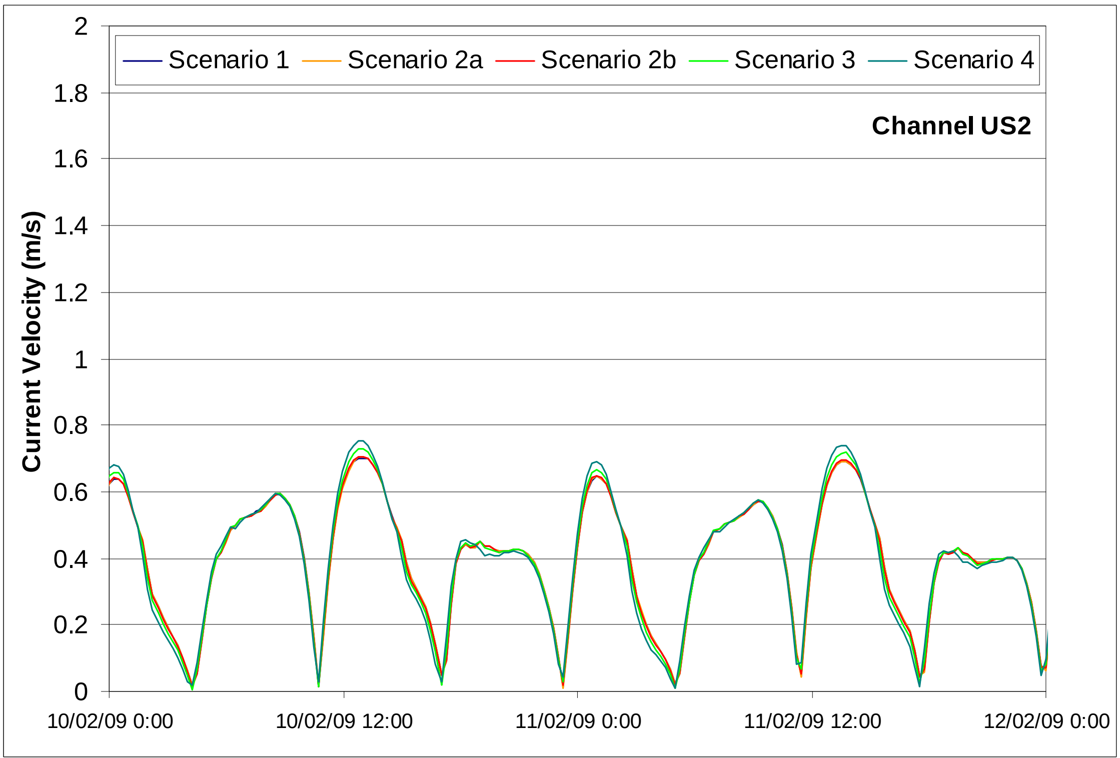

Figure N-2 Velocity Magnitude Time Series – Channel US2

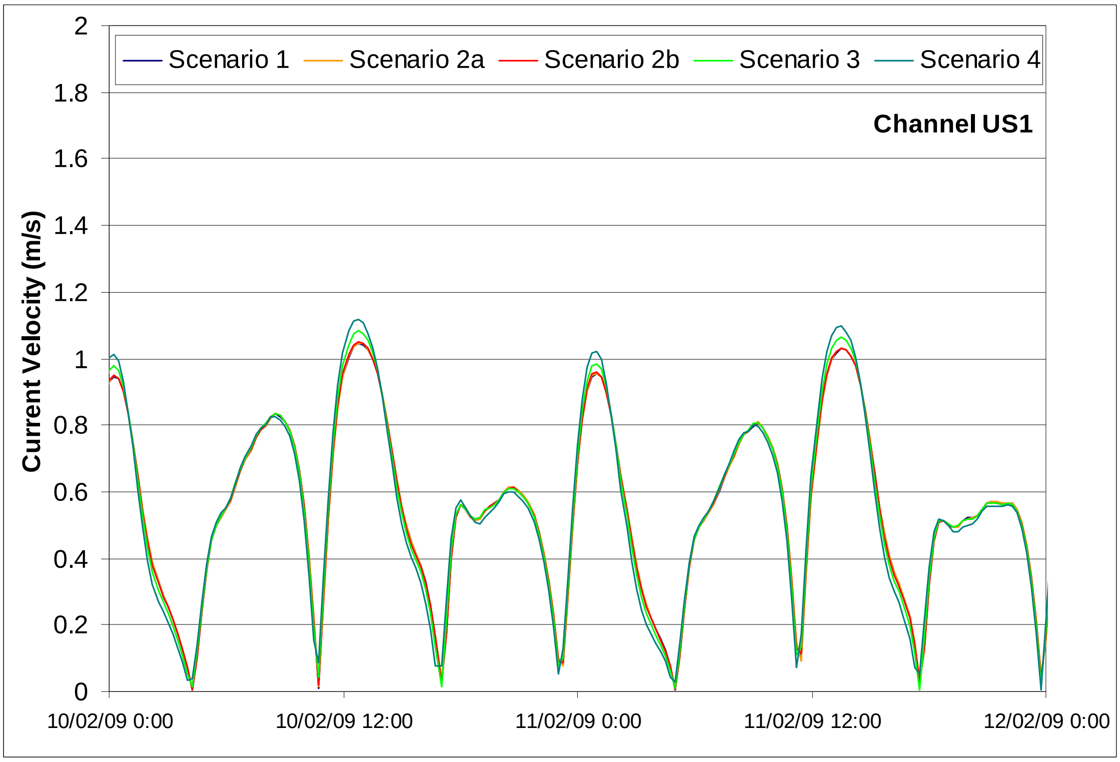

Figure N-3 Velocity Magnitude Time Series – Channel US1

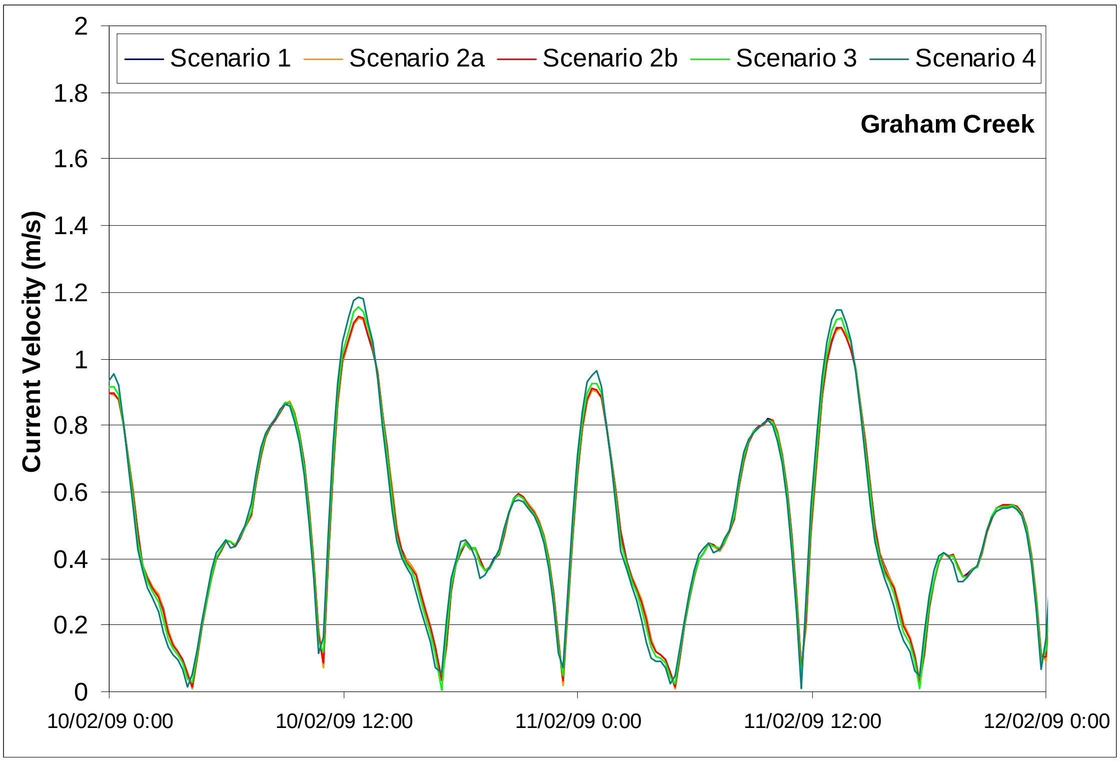

Figure N-4 Velocity Magnitude Time Series – Graham Creek

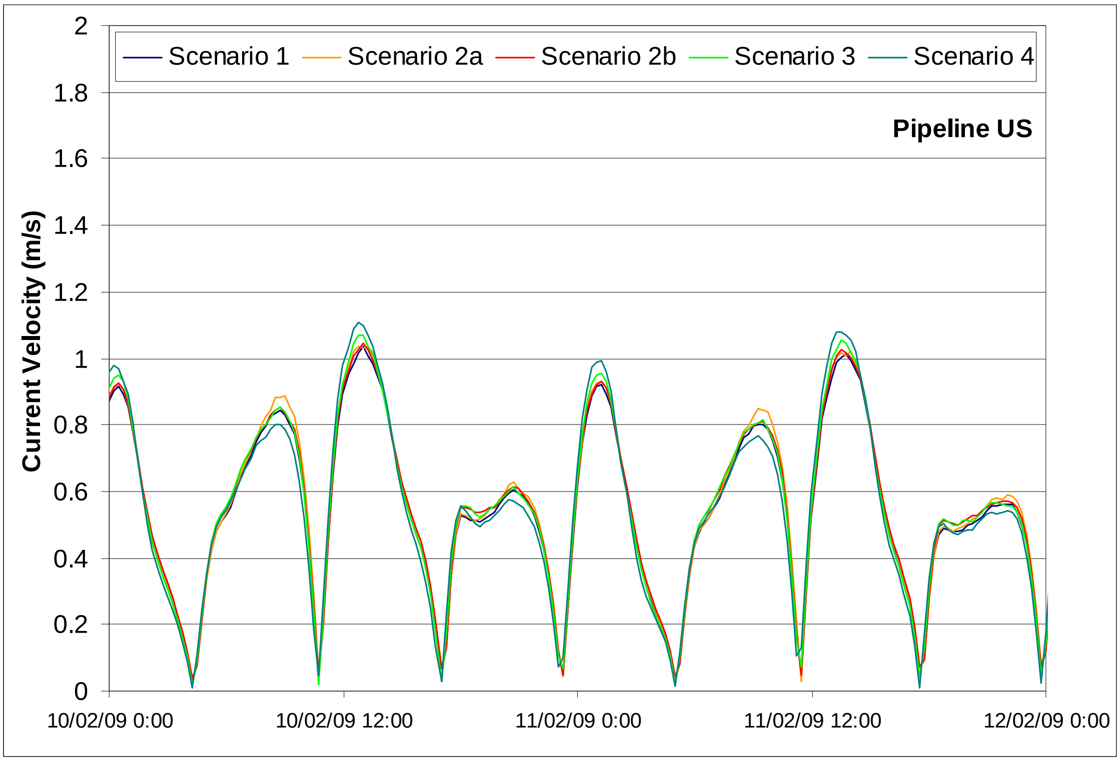

Figure N-5 Velocity Magnitude Time Series – Pipeline US

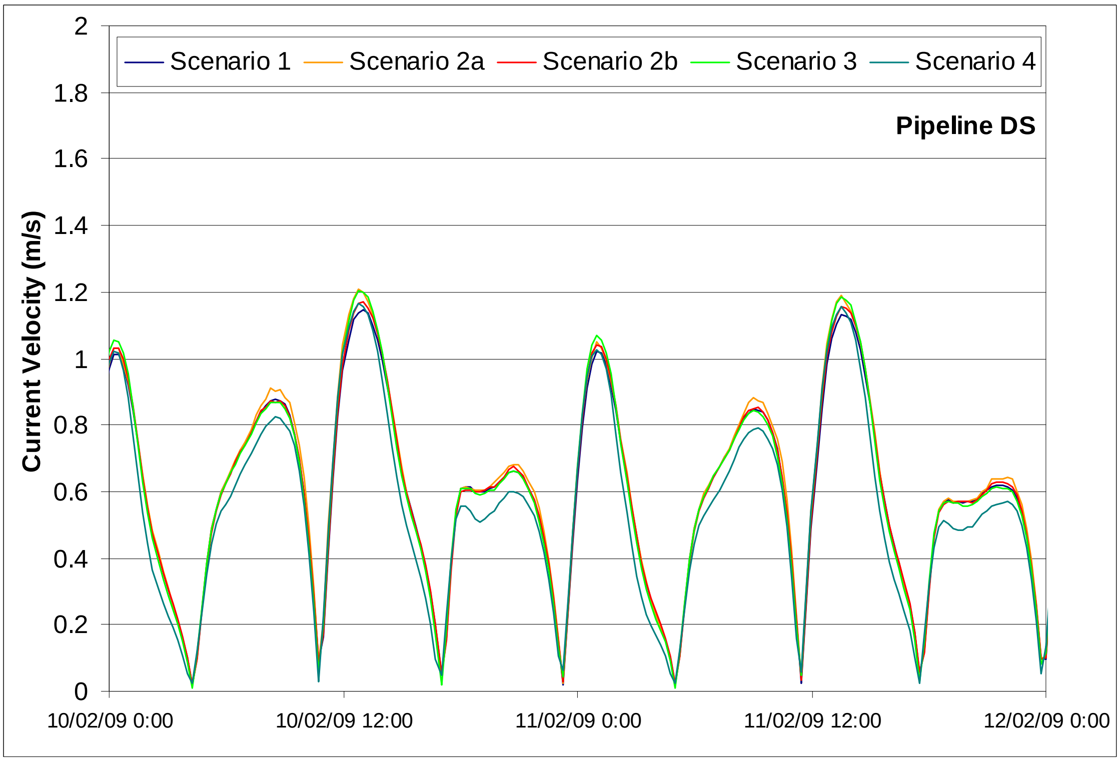

Figure N-6 Velocity Magnitude Time Series – Pipeline DS

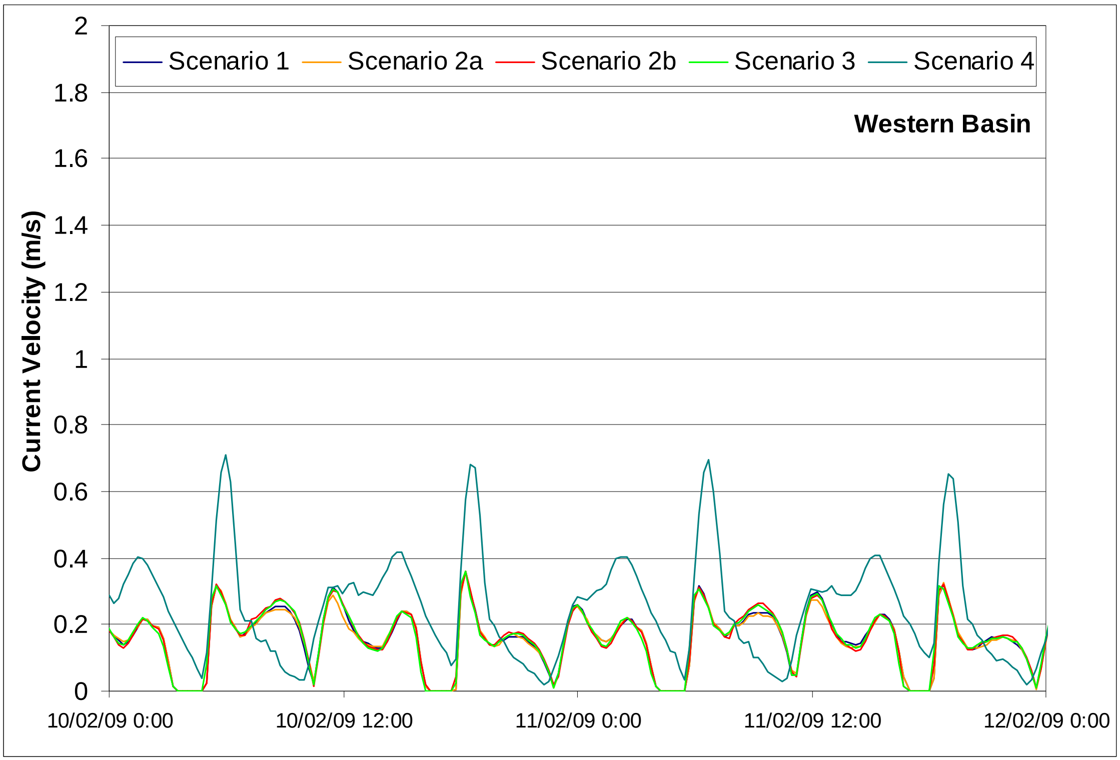

Figure N-7 Velocity Magnitude Time Series – Western Basin

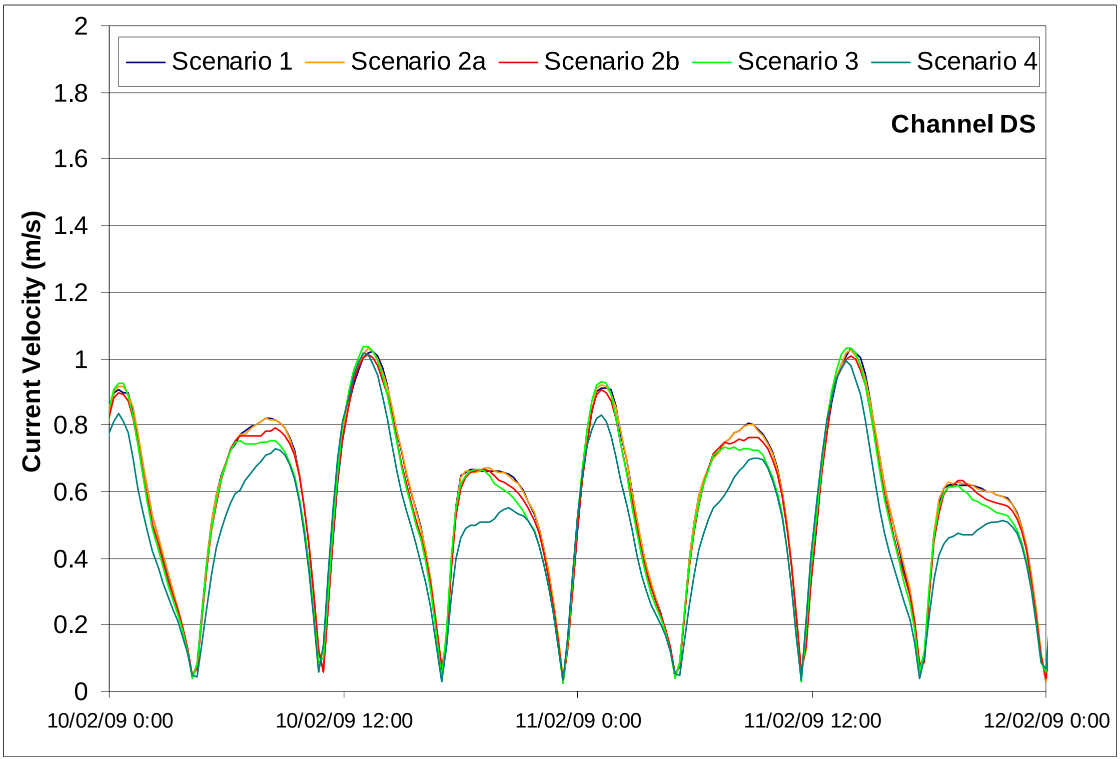

Figure N-8 Velocity Magnitude Time Series – Channel DS

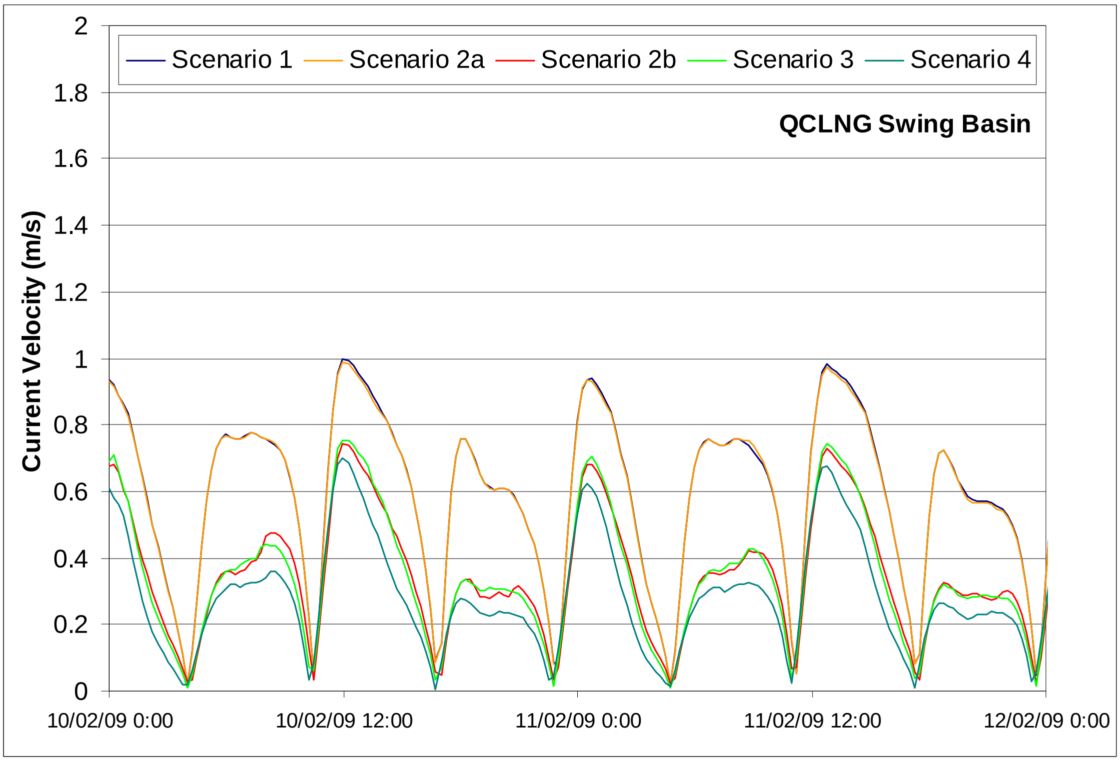

Figure N-9 Velocity Magnitude Time Series – QCLNG Swing Basin

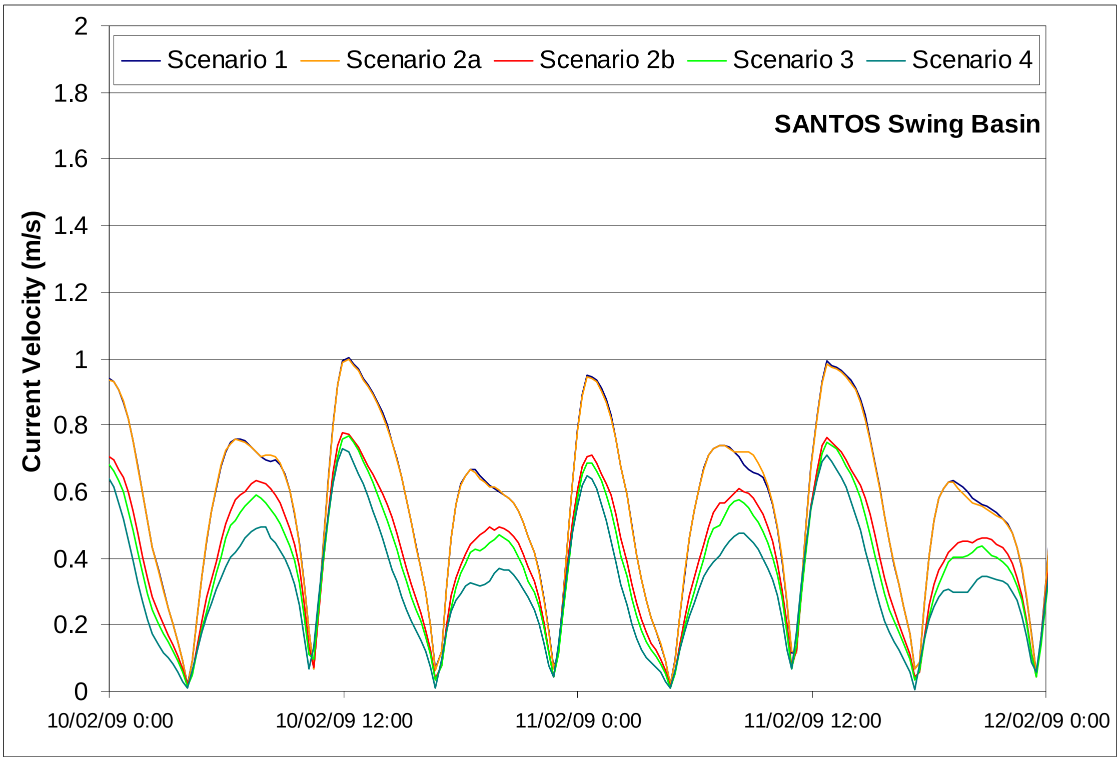

Figure N-10 Velocity Magnitude Time Series – SANTOS Swing Basin

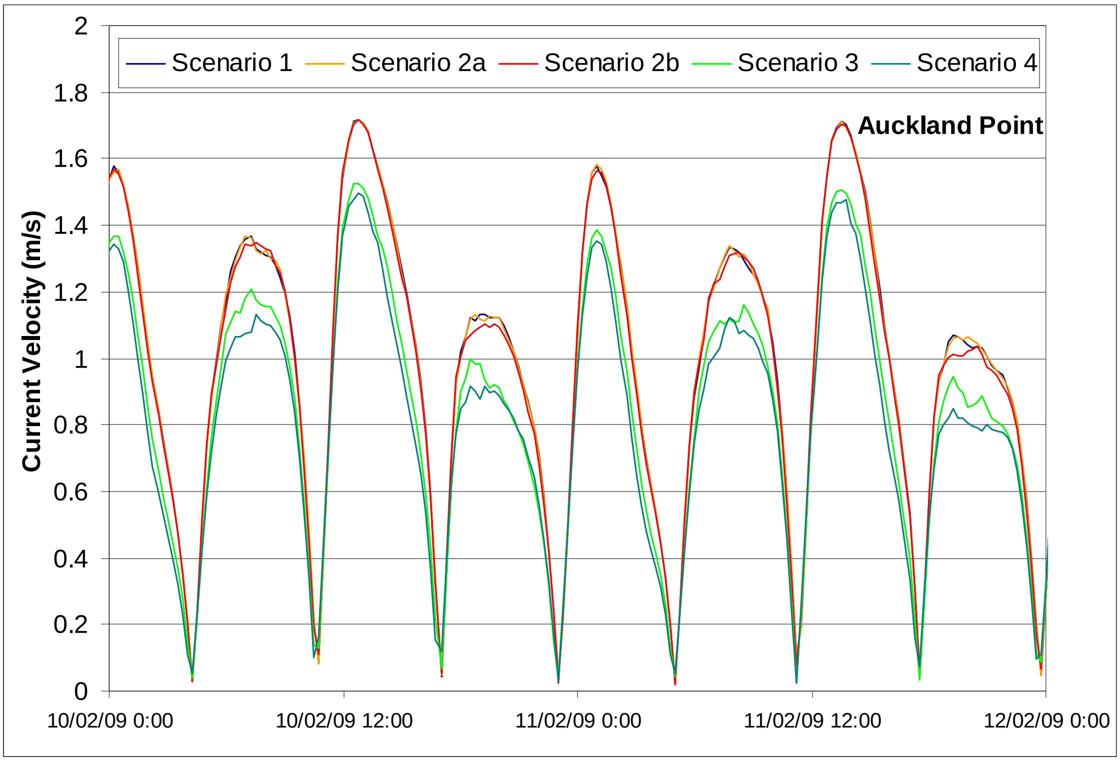

Figure N-11 Velocity Magnitude Time Series – Auckland Point

APPENDIX O: VELOCITY CONTOURS – PIPELINE CROSSING OPTION 3

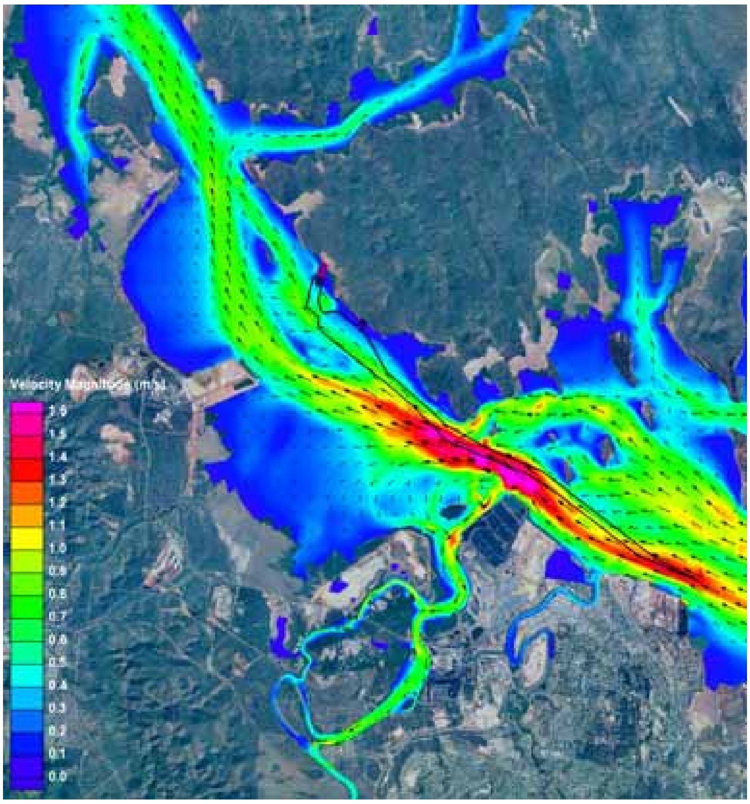

Figure O-1 Scenario 2b peak flood tide velocities

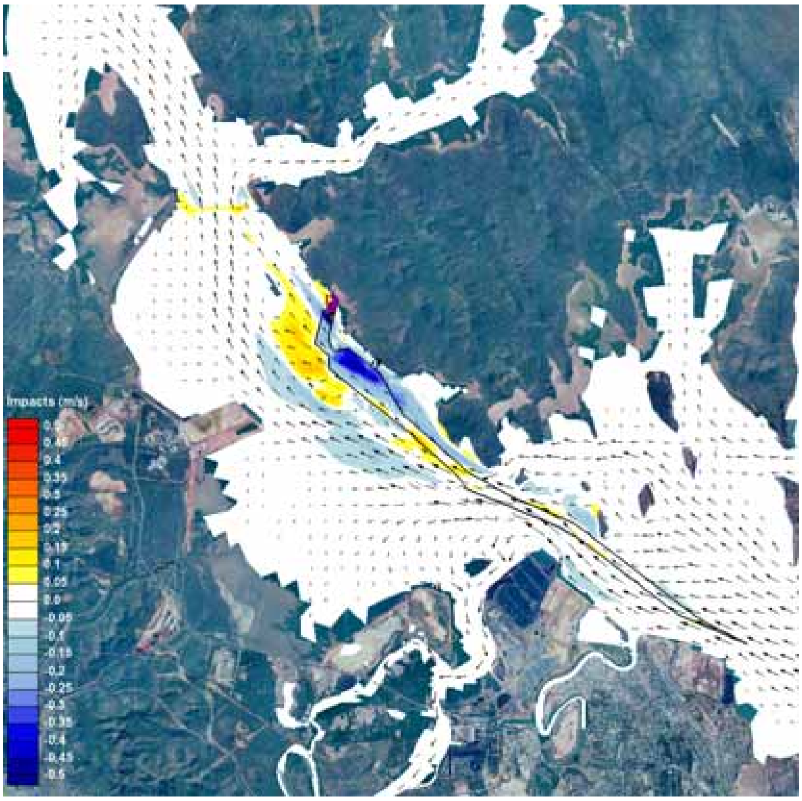

Figure O-2 Scenario 2b peak flood tide velocity differences

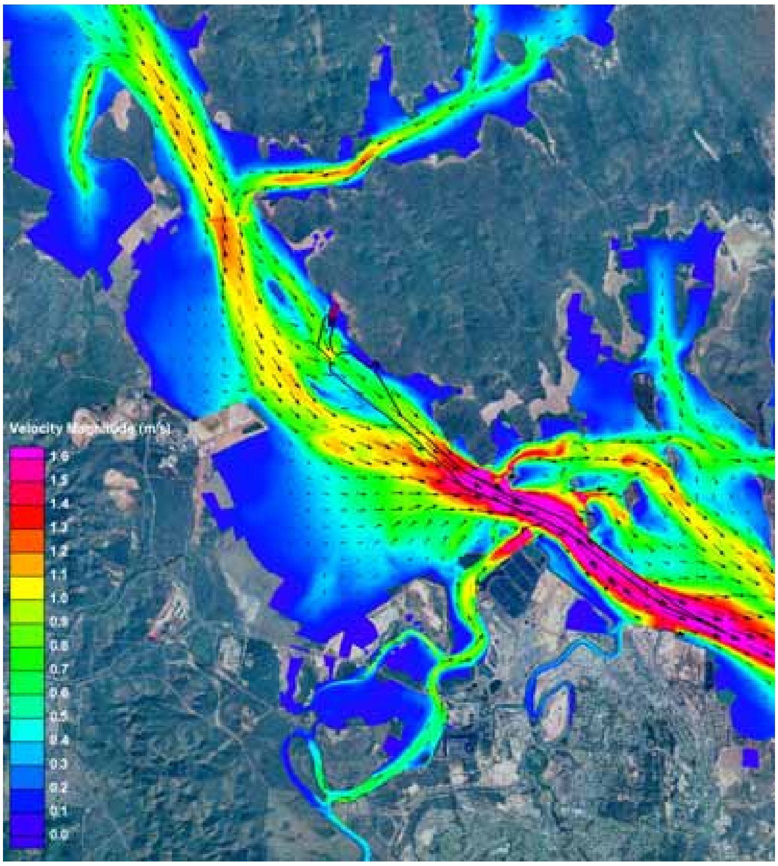

Figure O-3 Scenario 2b peak ebb tide velocities

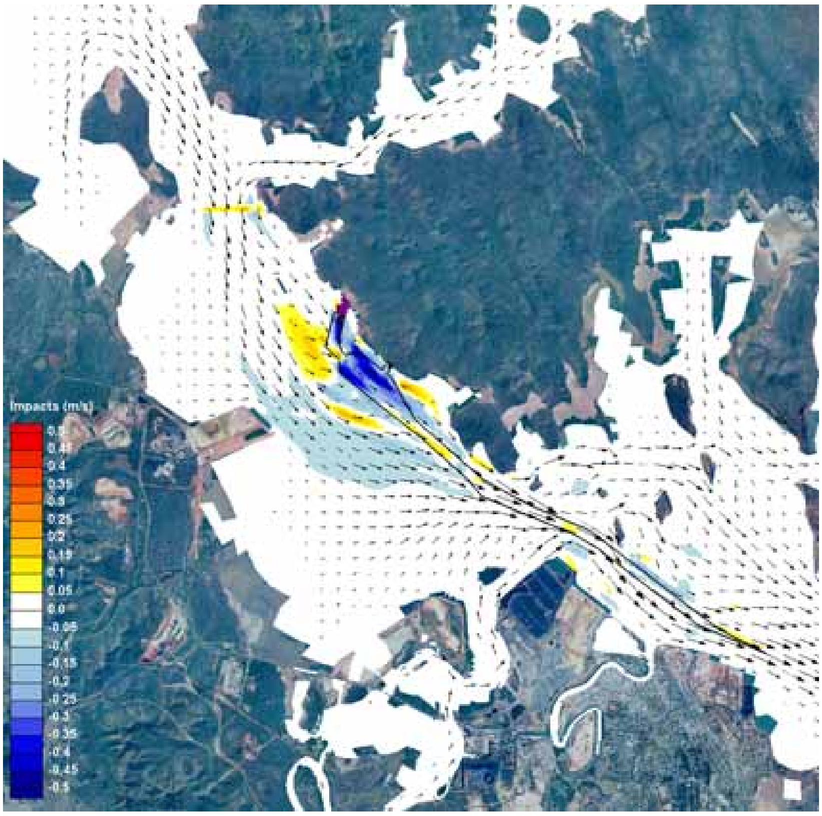

Figure O-4 Scenario 2b peak ebb tide velocity differences

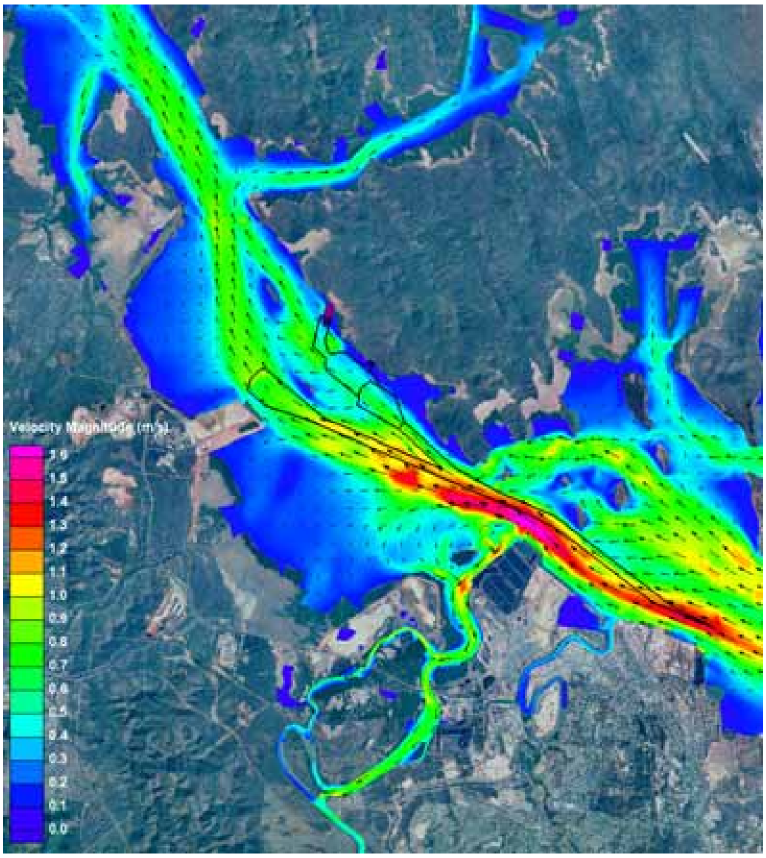

Figure O-5 Scenario 3 peak flood tide velocities

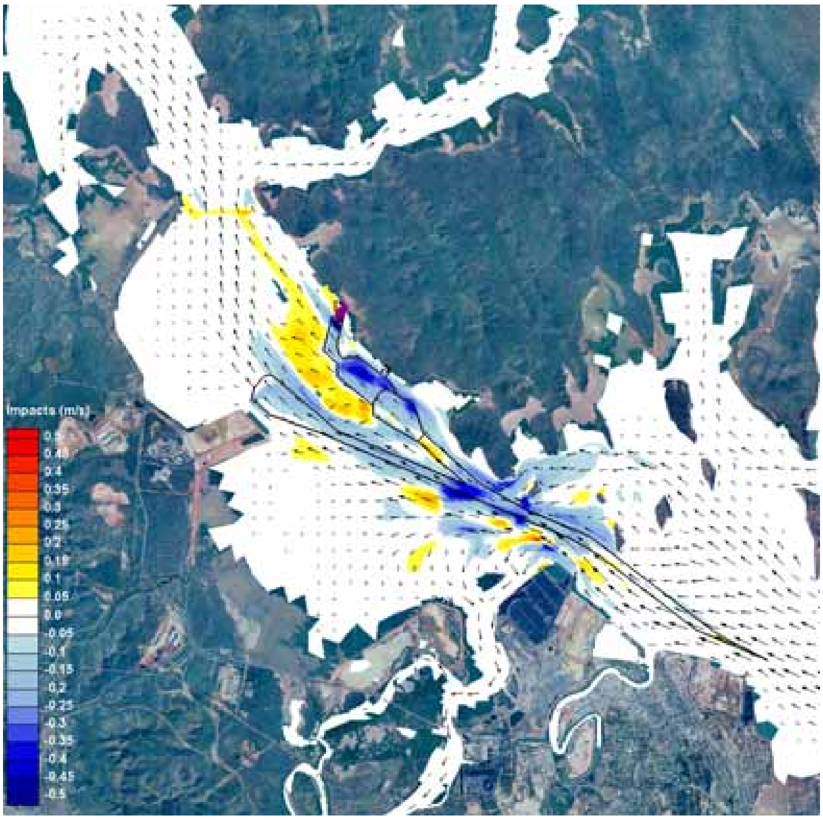

Figure O-6 Scenario 3 peak flood tide velocity differences

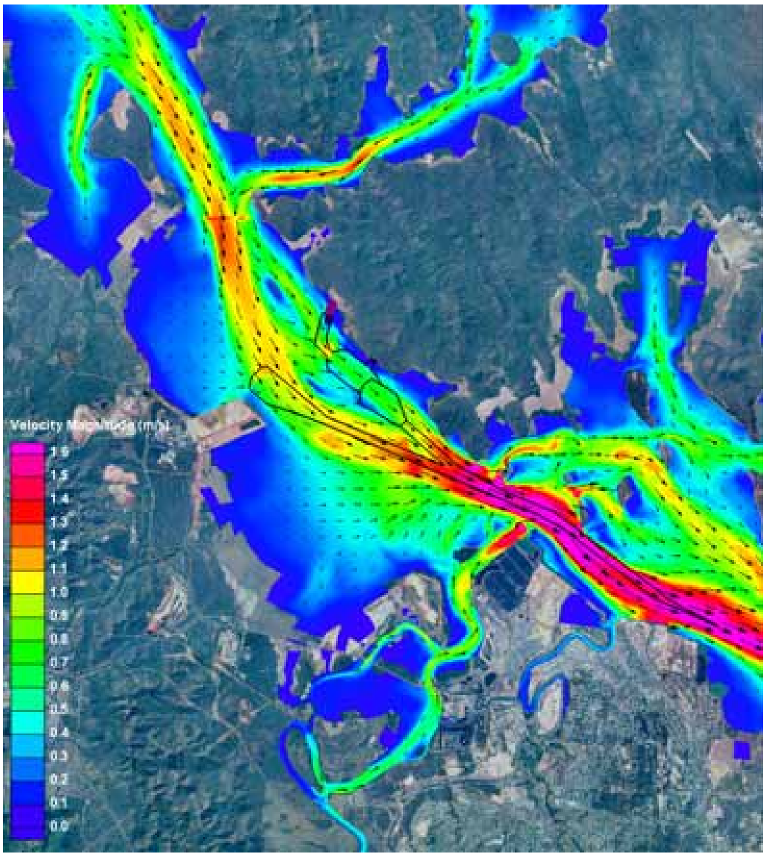

Figure O-7 Scenario 3 peak ebb tide velocities

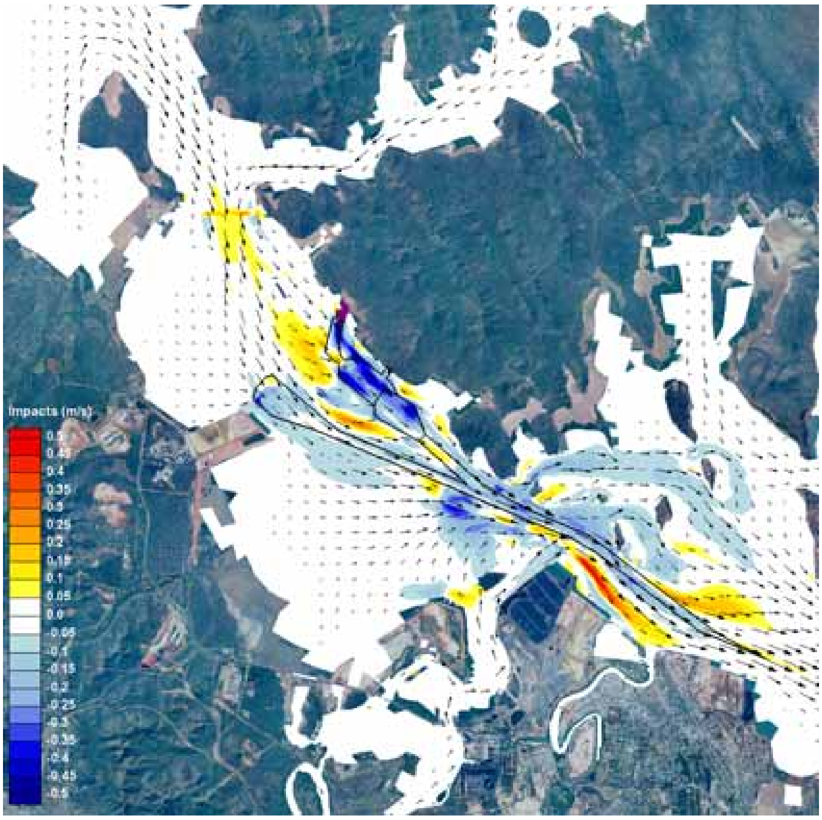

Figure O-8 Scenario 3 peak ebb tide velocity differences

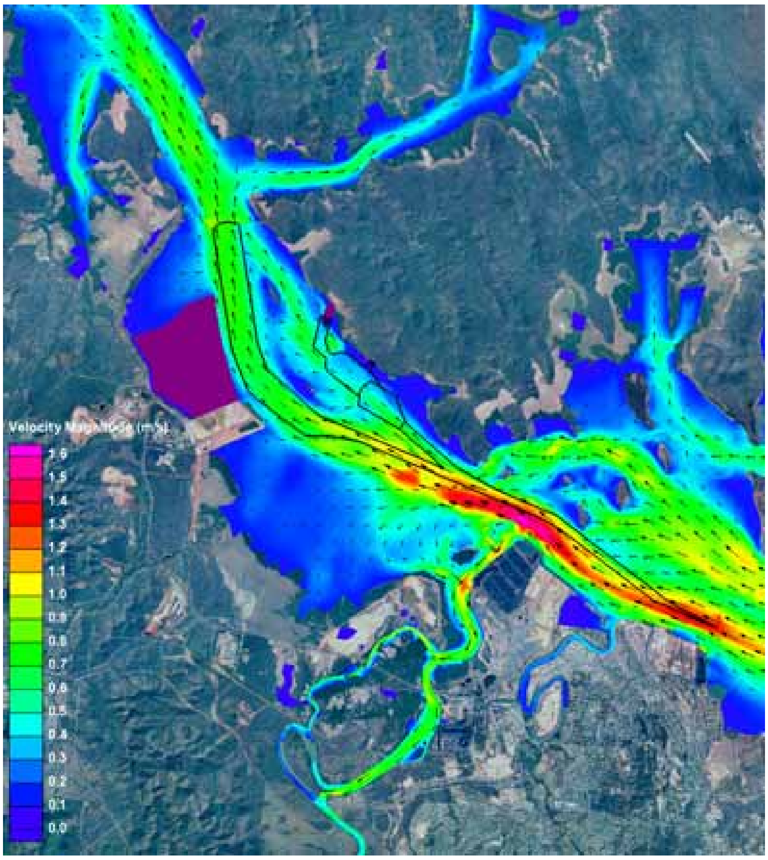

Figure O-9 Scenario 4 peak flood tide velocities

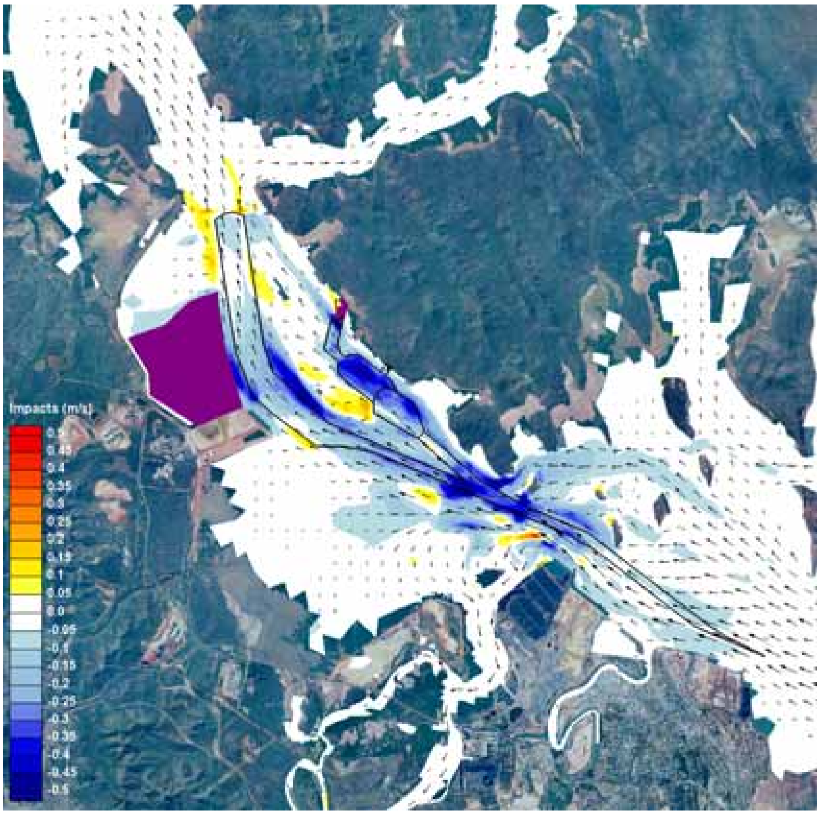

Figure O-10 Scenario 4 peak flood tide velocity differences

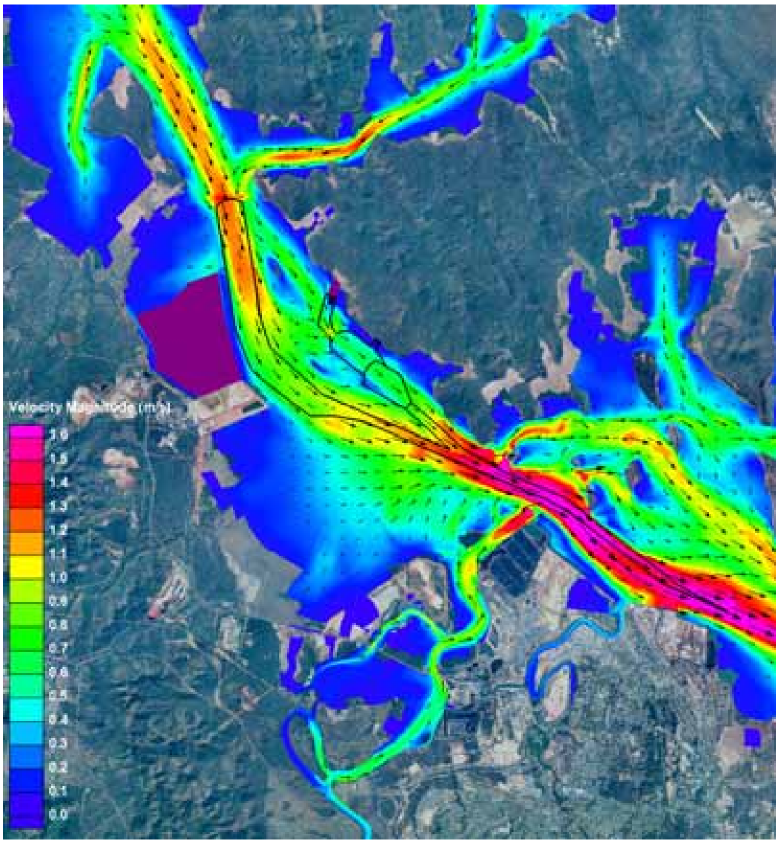

Figure O-11 Scenario 4 peak ebb tide velocities

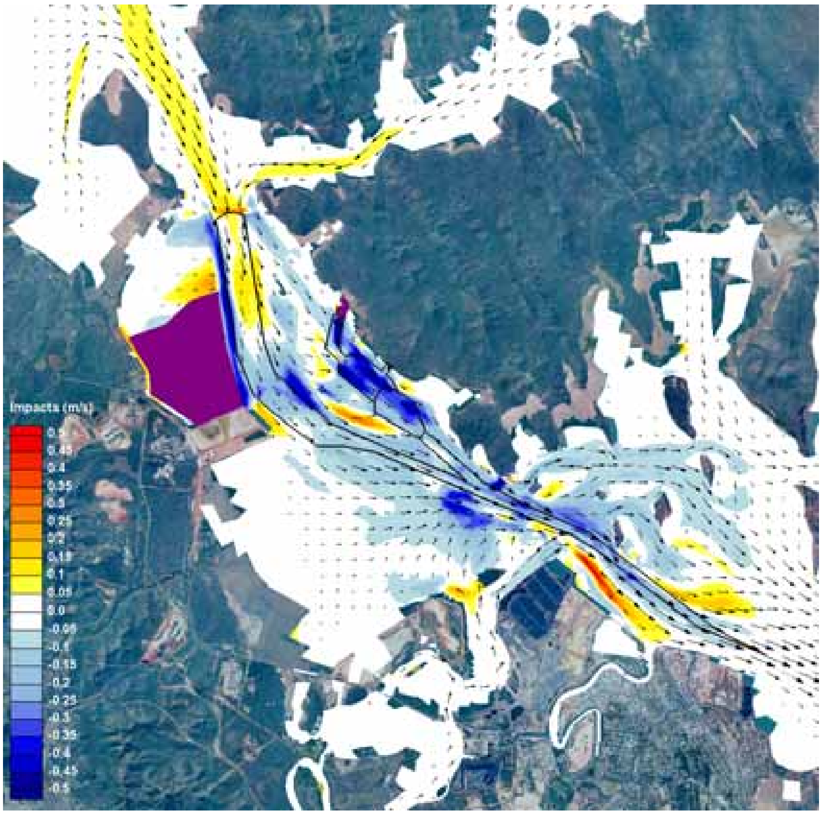

Figure O-12 Scenario 4 peak ebb tide velocity differences

APPENDIX P: TRACER CONCENTRATION TIME SERIES - PIPELINE CROSSING OPTION 3

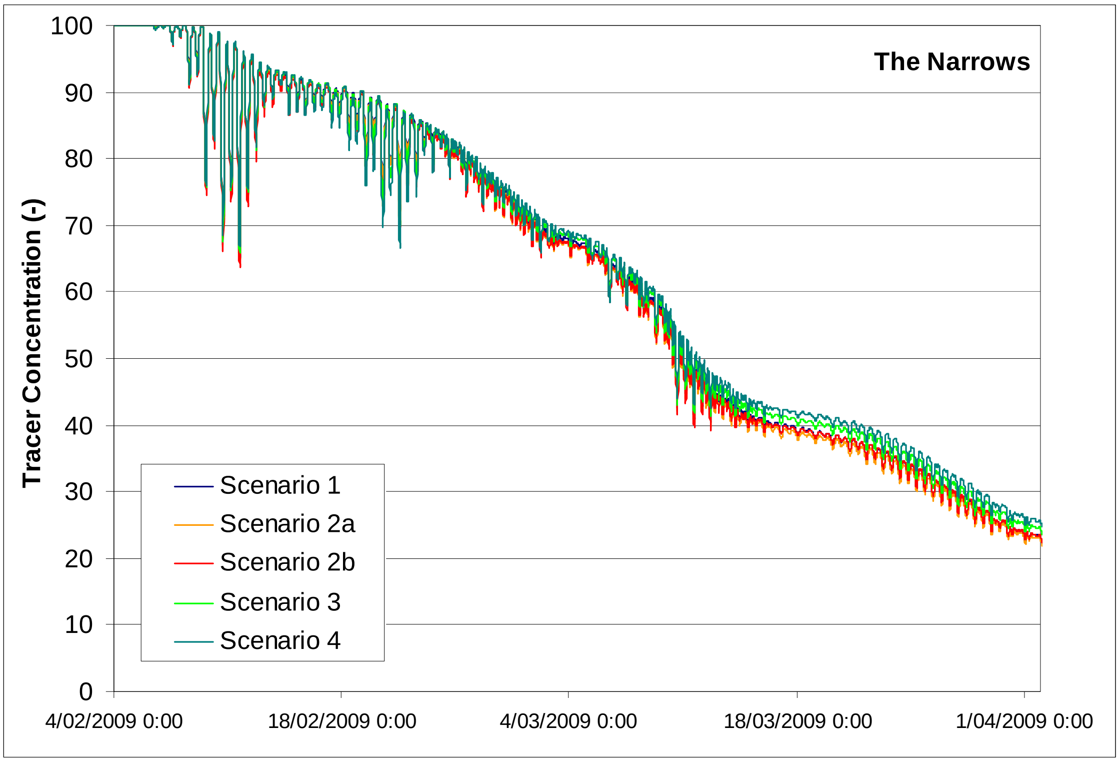

Figure P-1 Tracer Concentration Time Series – The Narrows

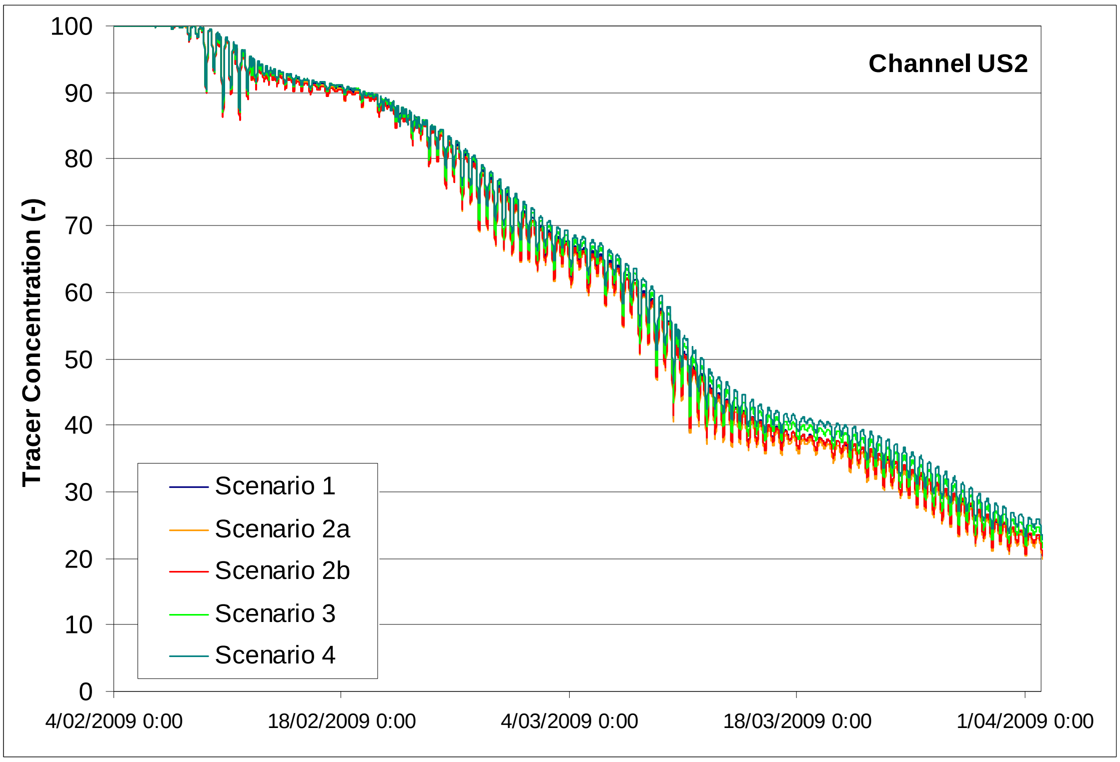

Figure P-2 Tracer Concentration Time Series – Channel US2

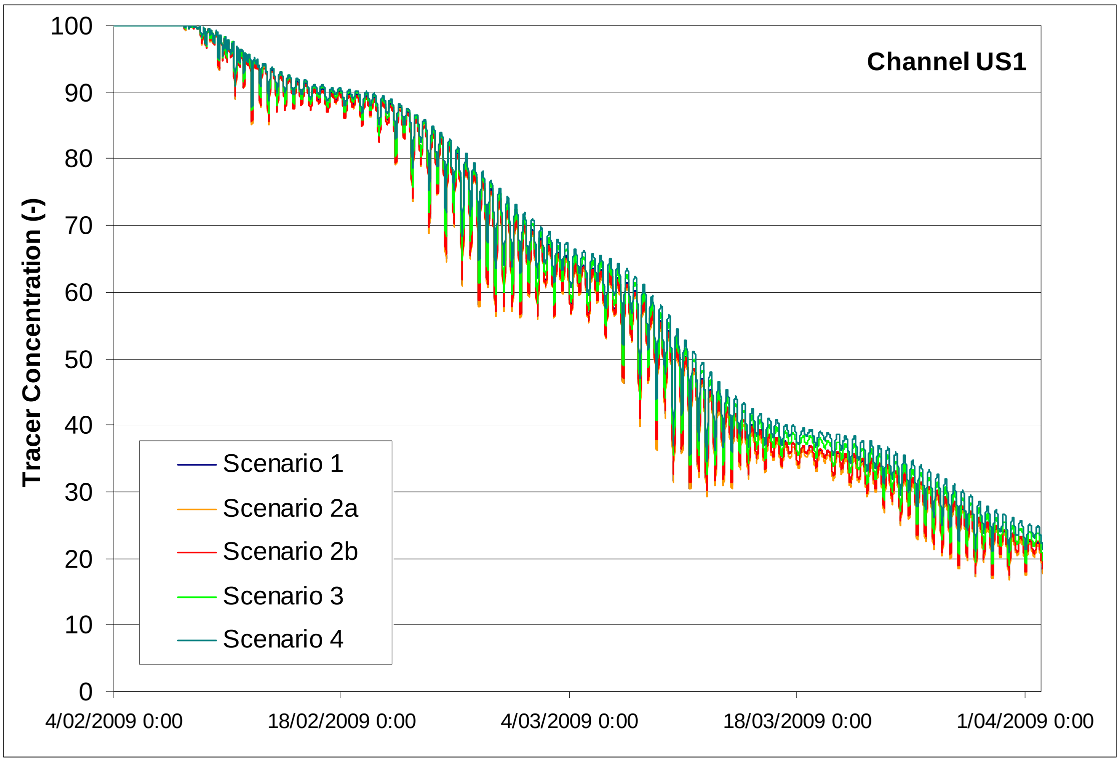

Figure P-3 Tracer Concentration Time Series – Channel US1

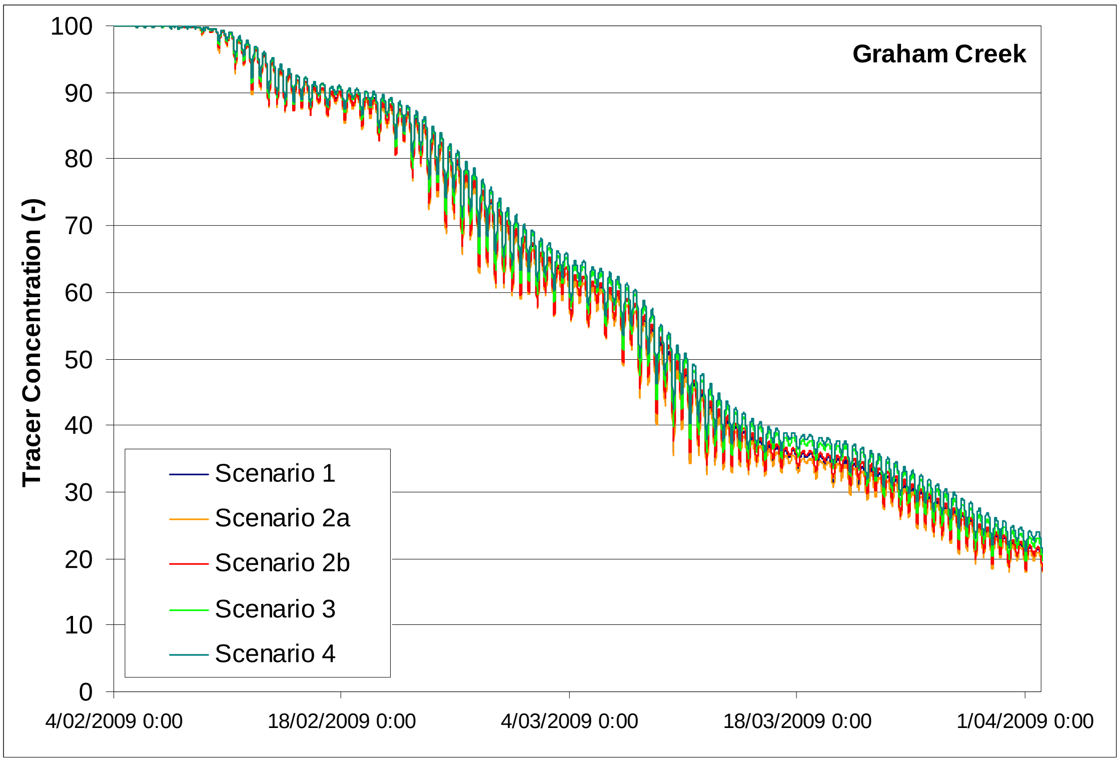

Figure P-4 Tracer Concentration Time Series – Graham Creek

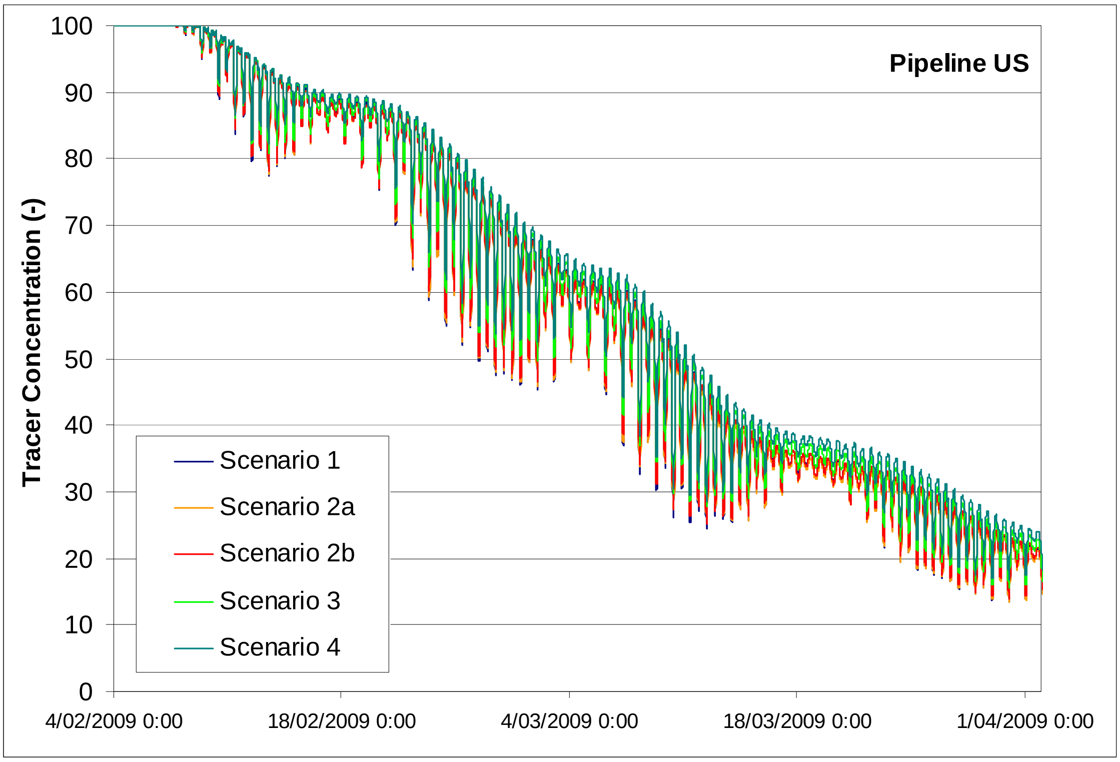

Figure P-5 Tracer Concentration Time Series – Pipeline US

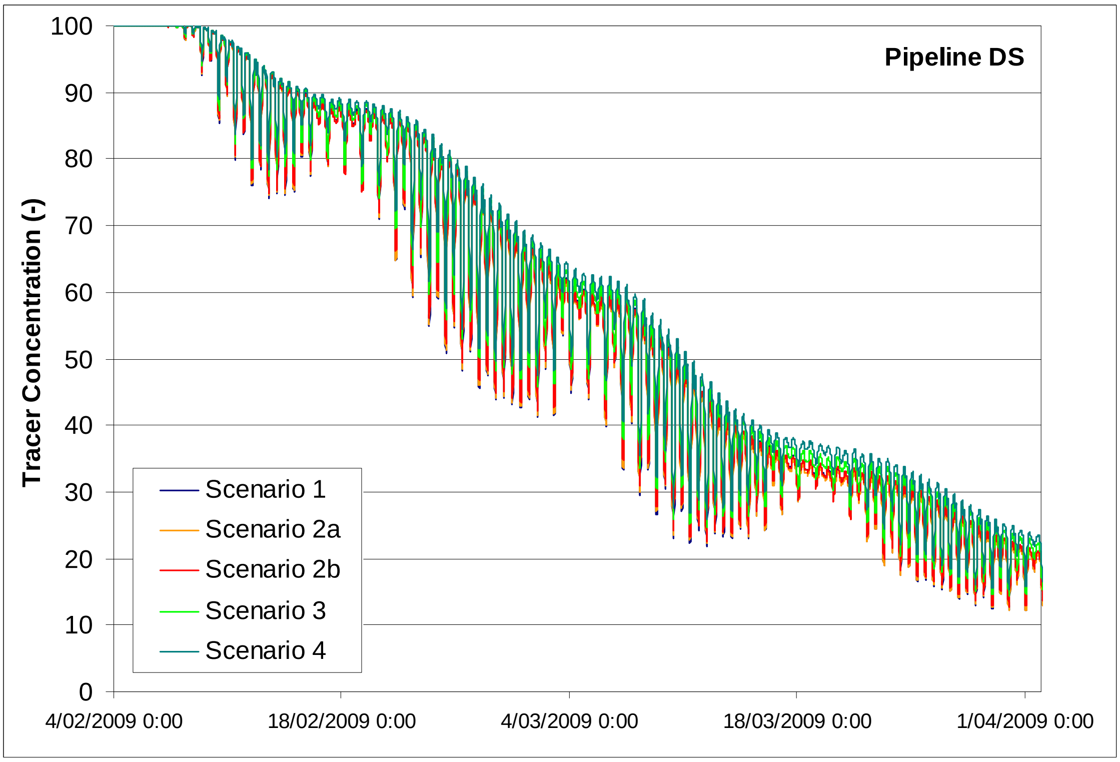

Figure P-6 Tracer Concentration Time Series – Pipeline DS

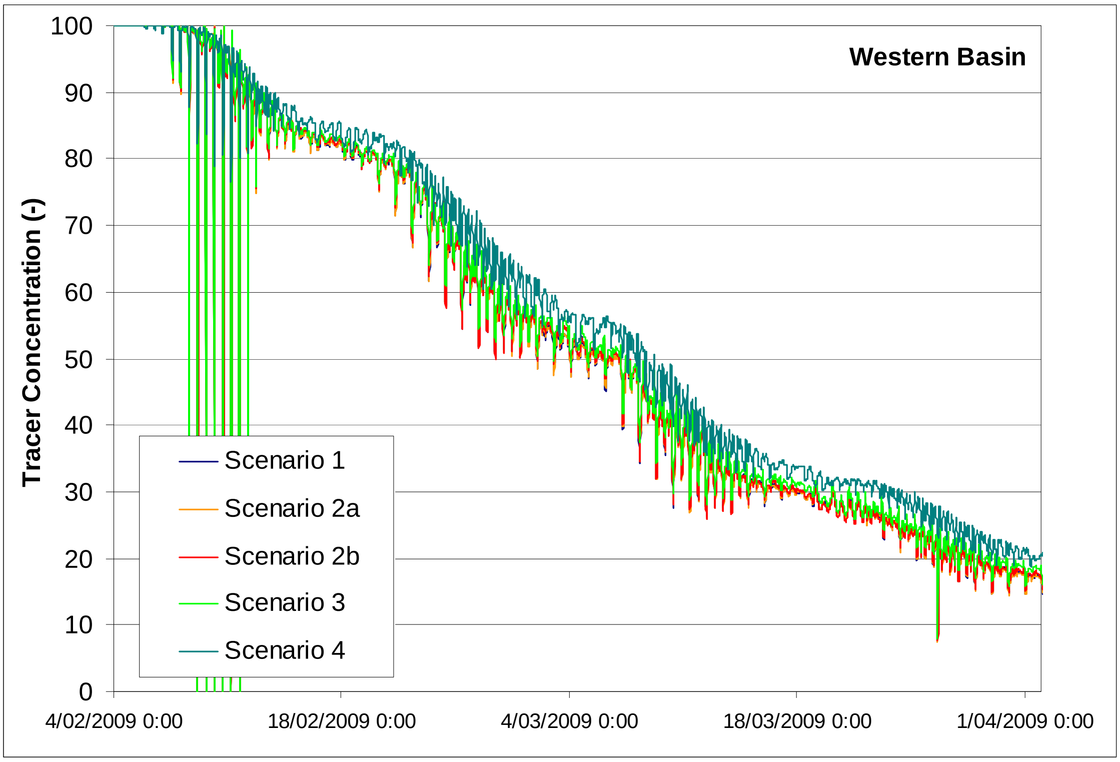

Figure P-7 Tracer Concentration Time Series – Western Basin

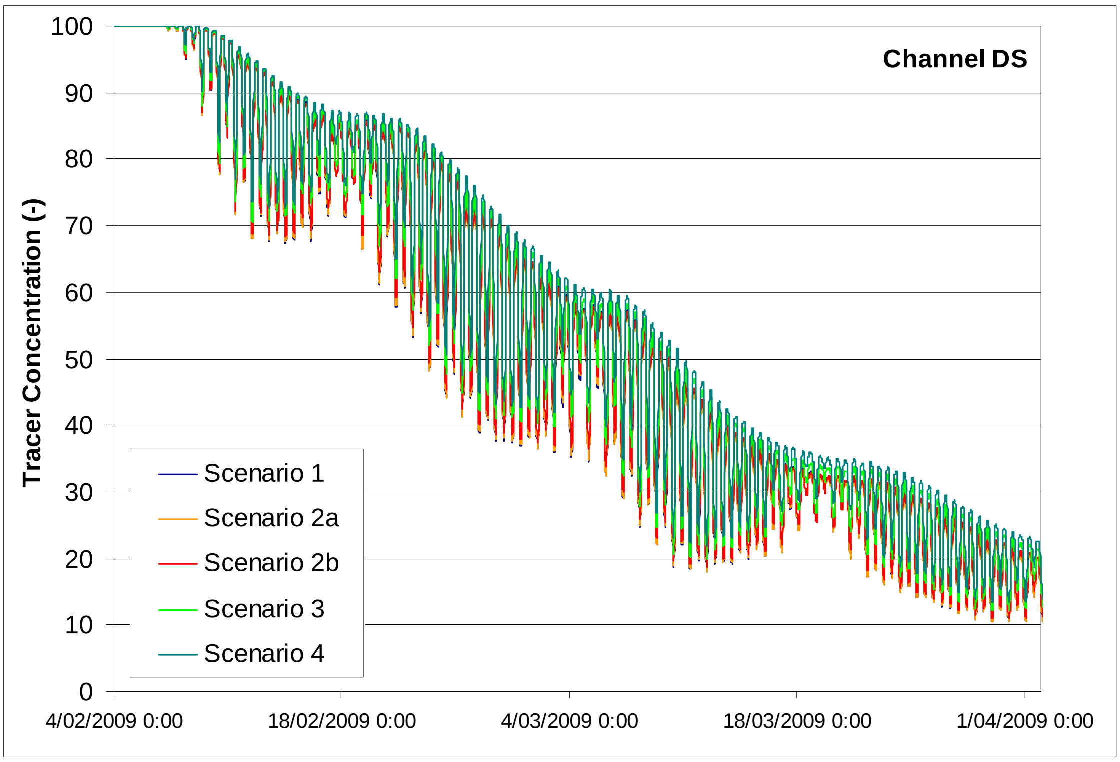

Figure P-8 Tracer Concentration Time Series – Channel DS

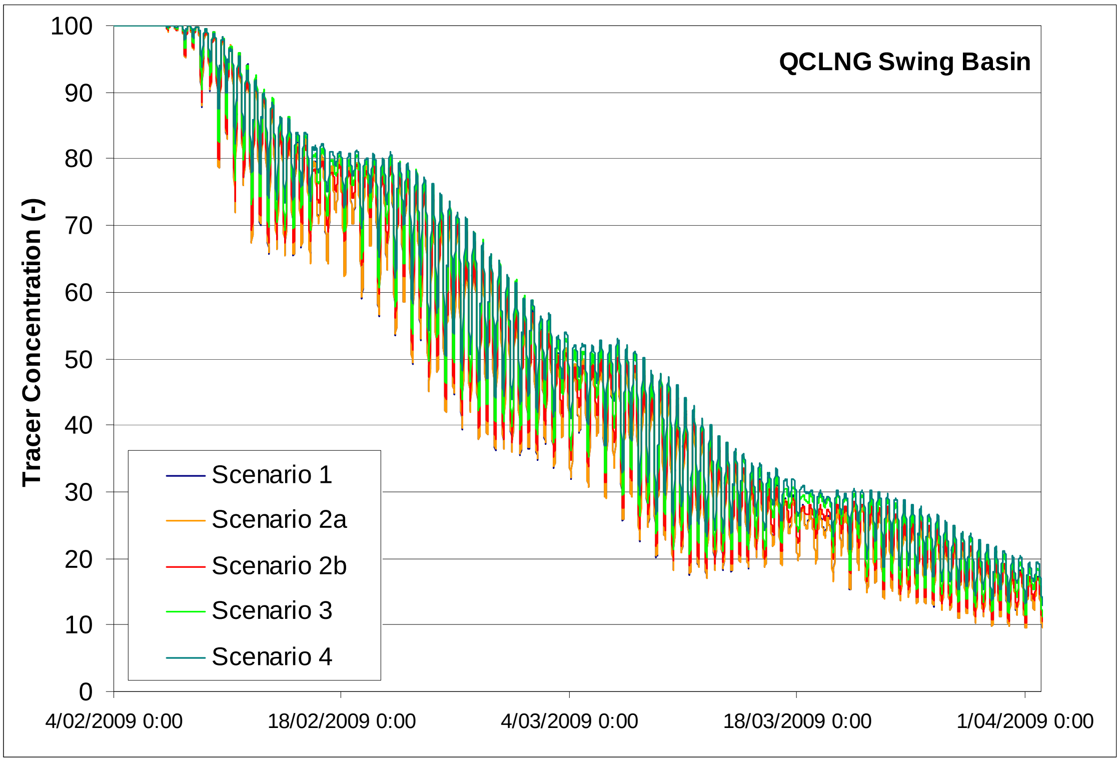

Figure P-9 Tracer Concentration Time Series – QCLNG Swing Basin

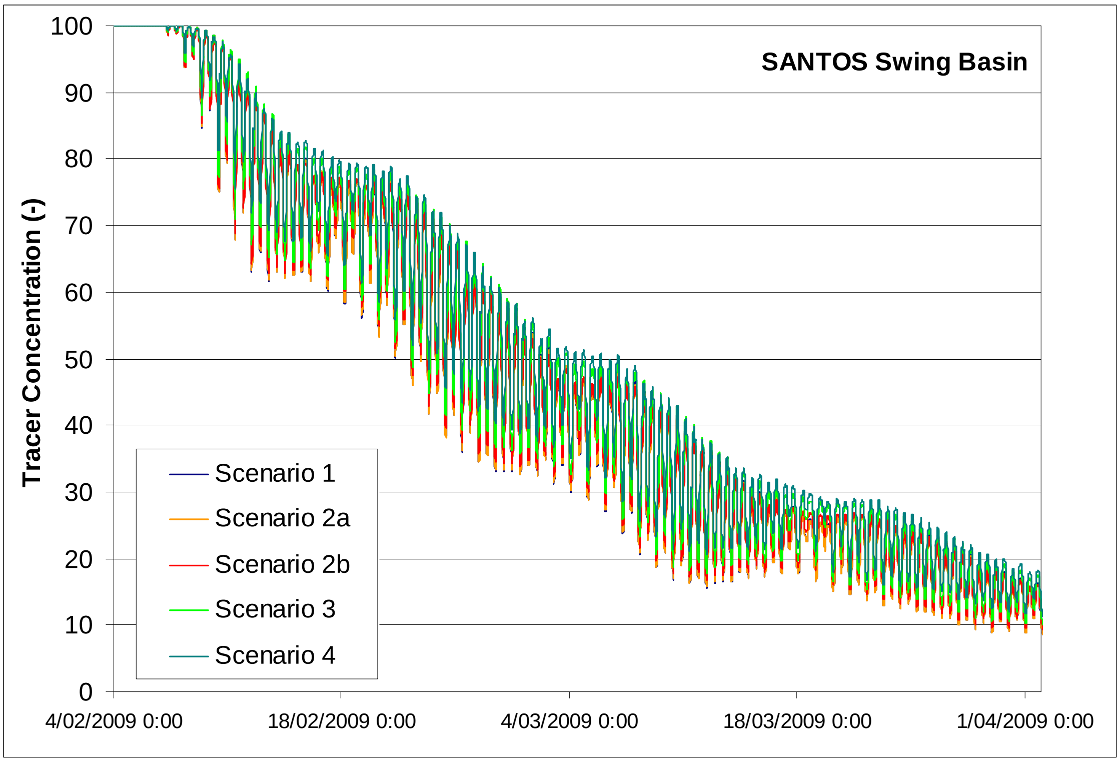

Figure P-10 Tracer Concentration Time Series – SANTOS Swing Basin

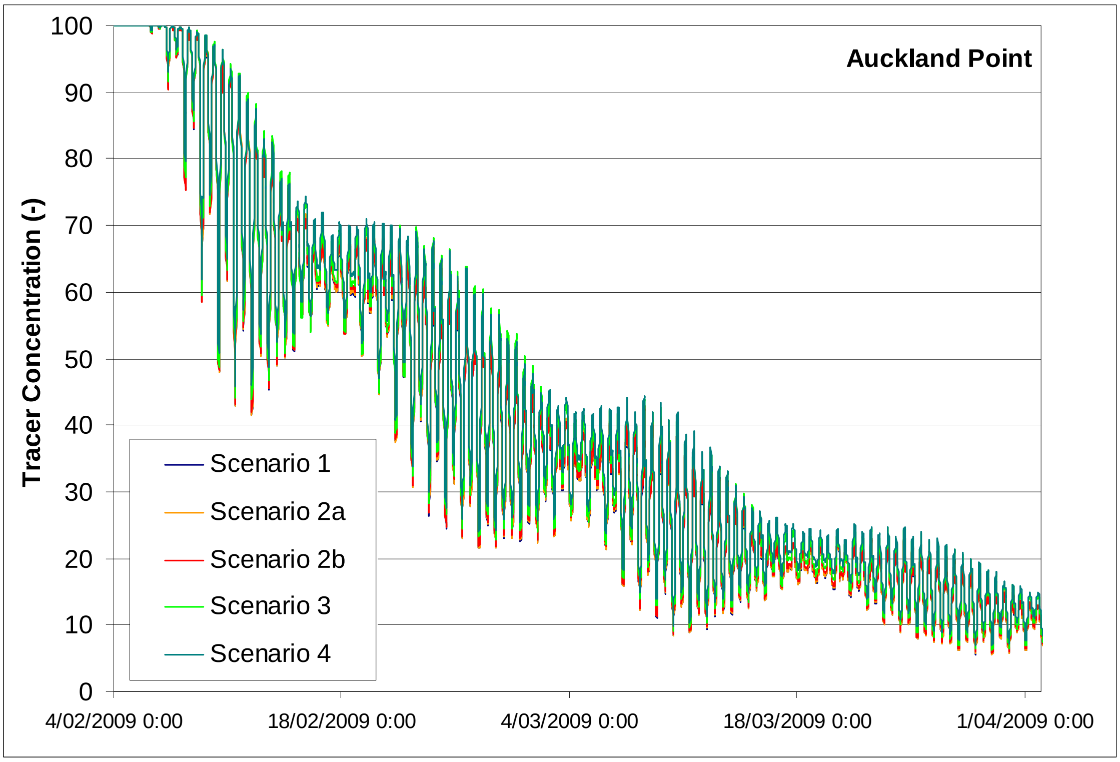

Figure P-11 Tracer Concentration Time Series – Auckland Point

APPENDIX Q: TRACER CONCENTRATION CONTOURS - PIPELINE CROSSING OPTION 3

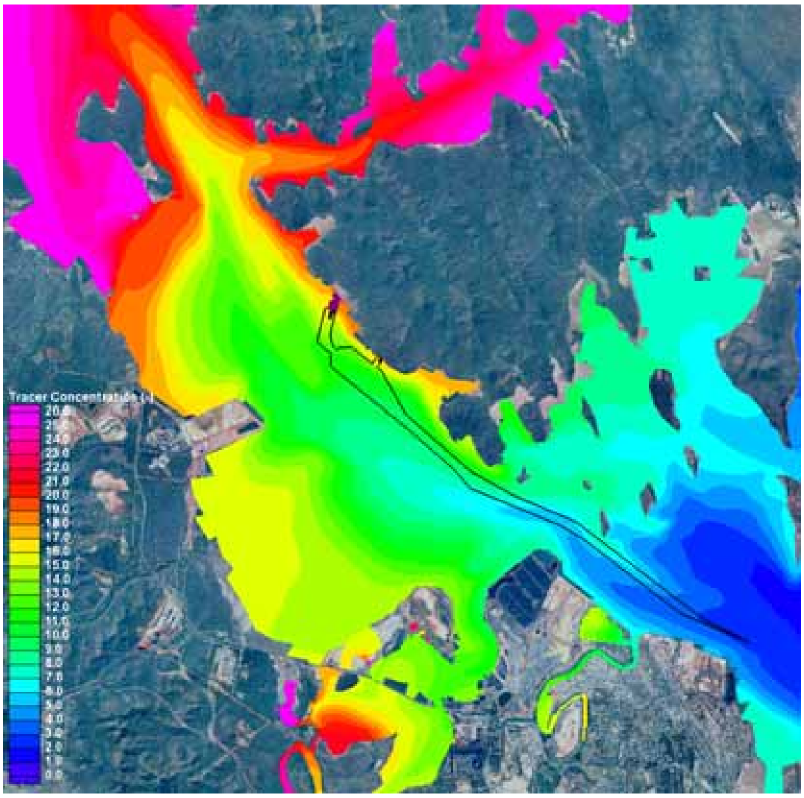

Figure Q-1 Scenario 2b tracer concentration

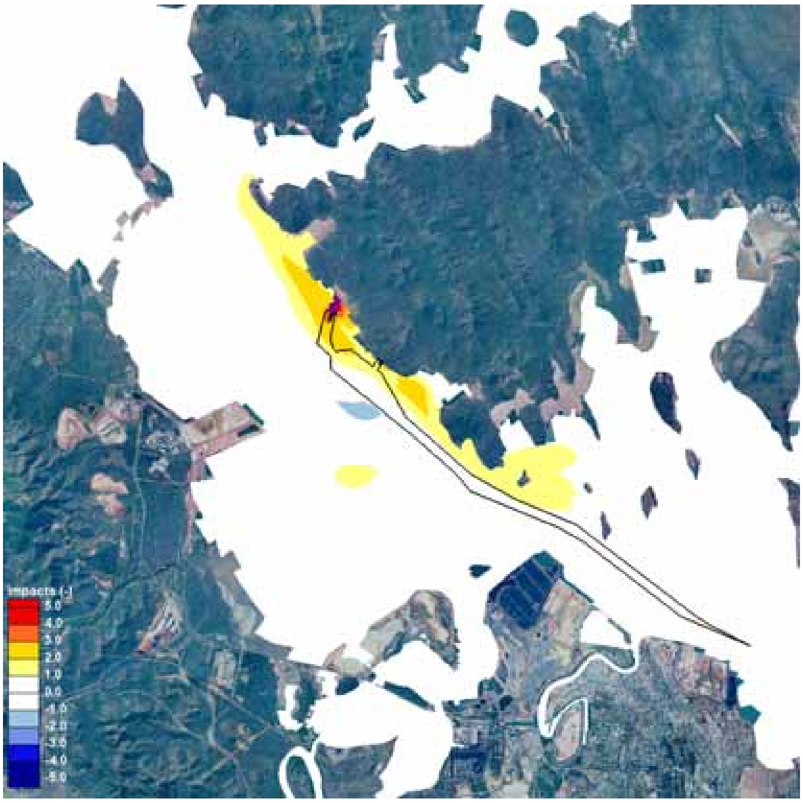

Figure Q-2 Scenario 2b tracer concentration differences

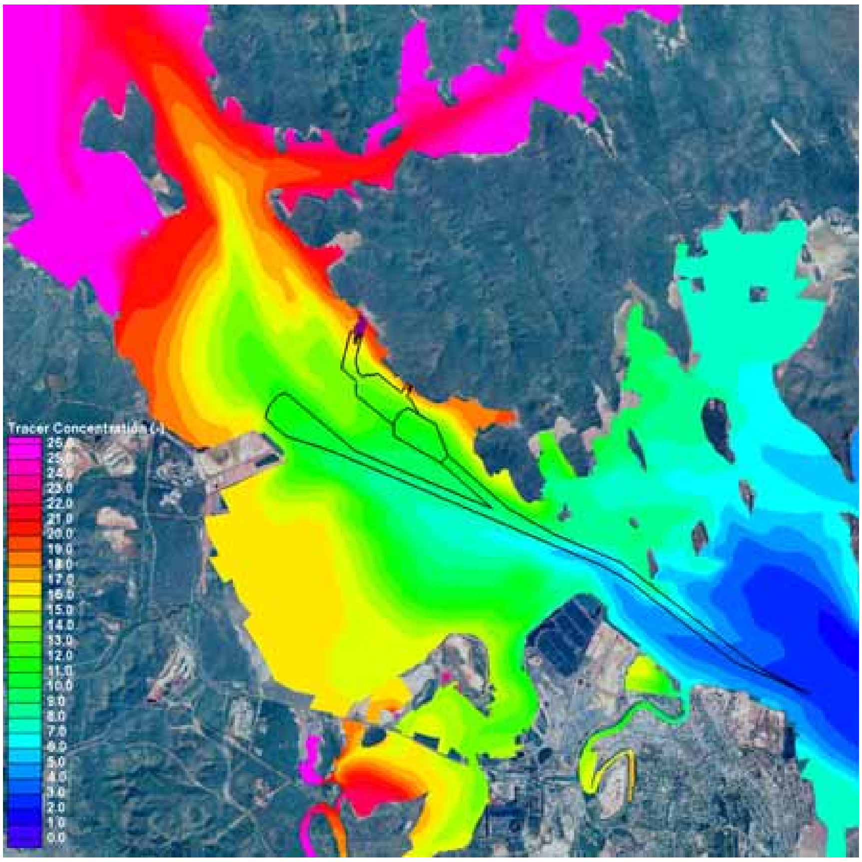

Figure Q-3 Scenario 3 tracer concentration

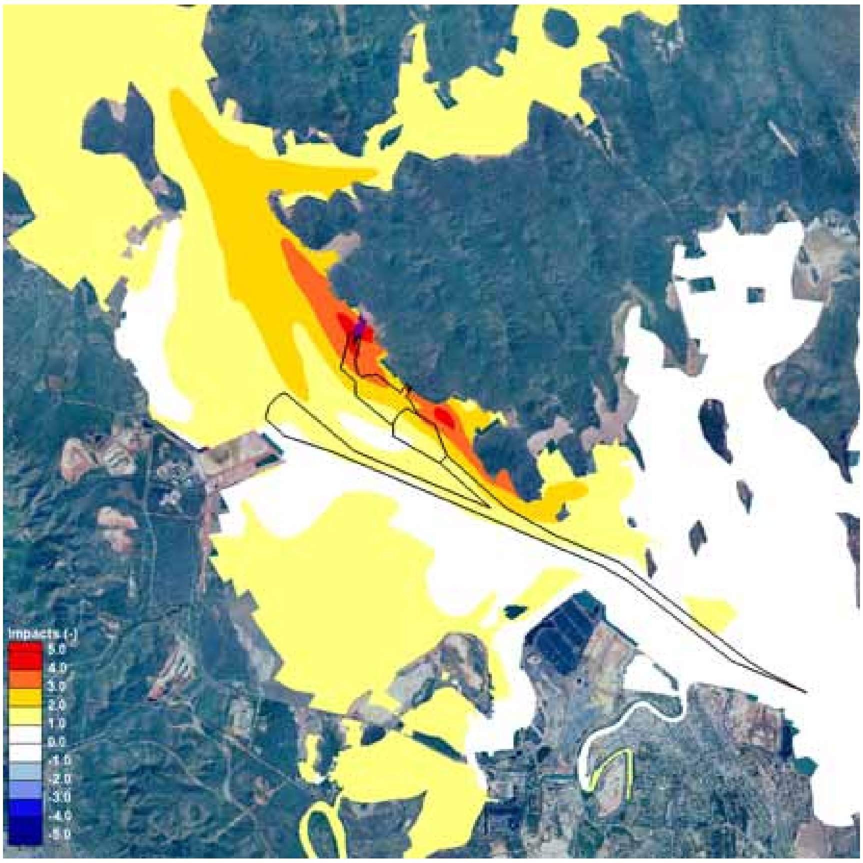

Figure Q-4 Scenario 3 tracer concentration differences

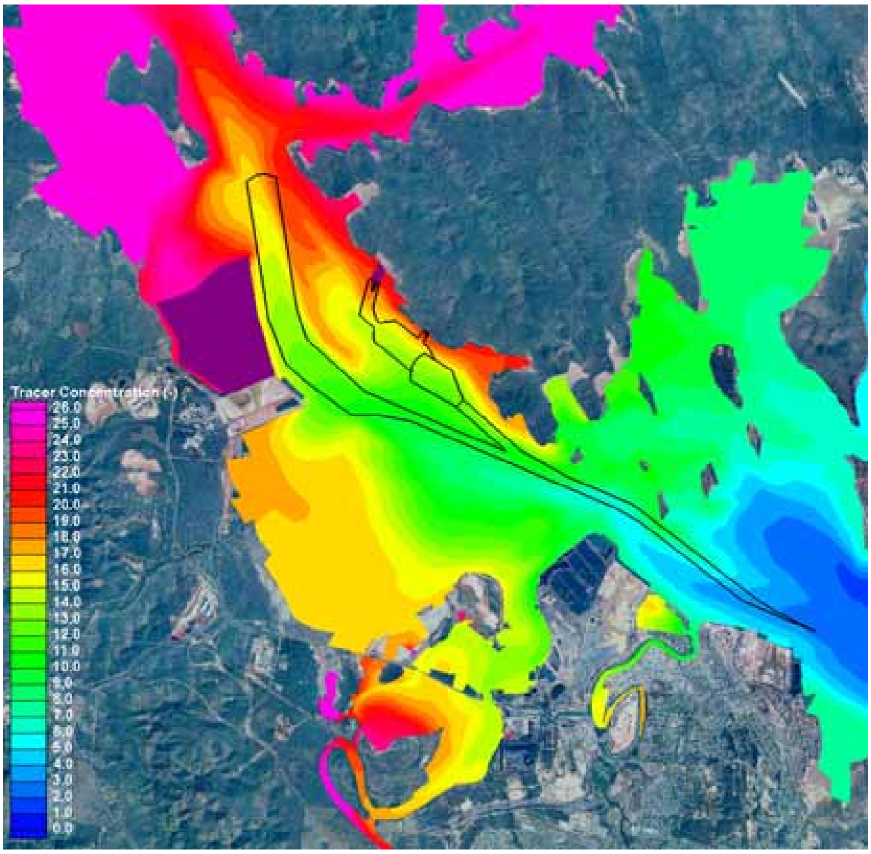

Figure Q-5 Scenario 4 tracer concentration

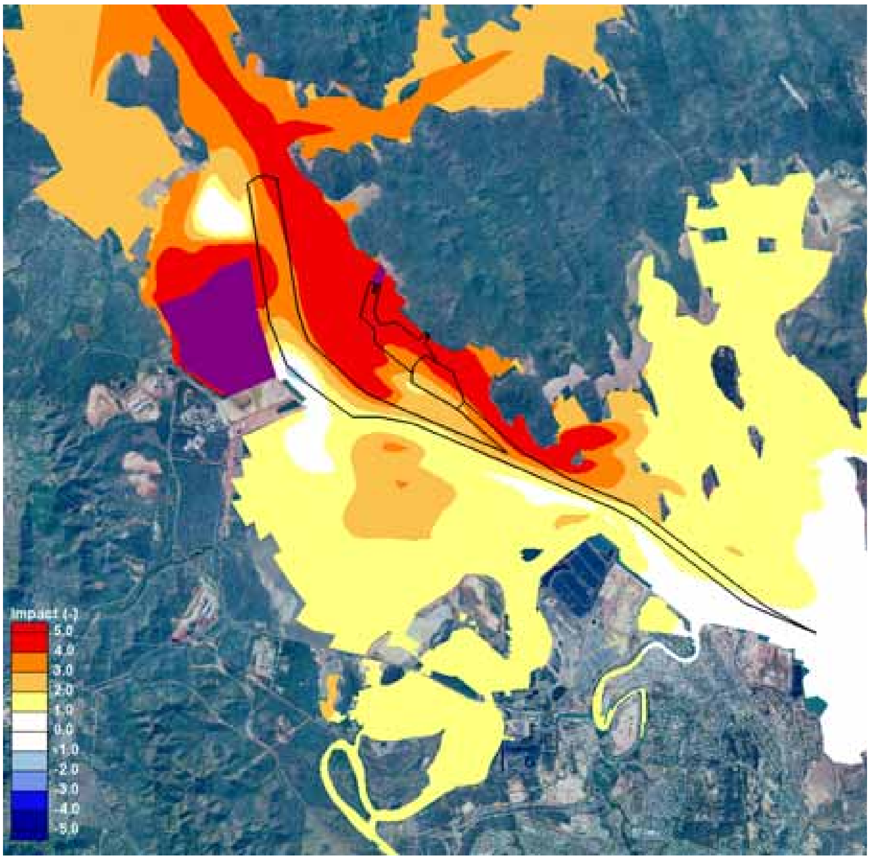

Figure Q-6 Scenario 4 tracer concentration differences

APPENDIX R: E-FOLDING TIME CONTOURS – PIPELINE CROSSING OPTION 3

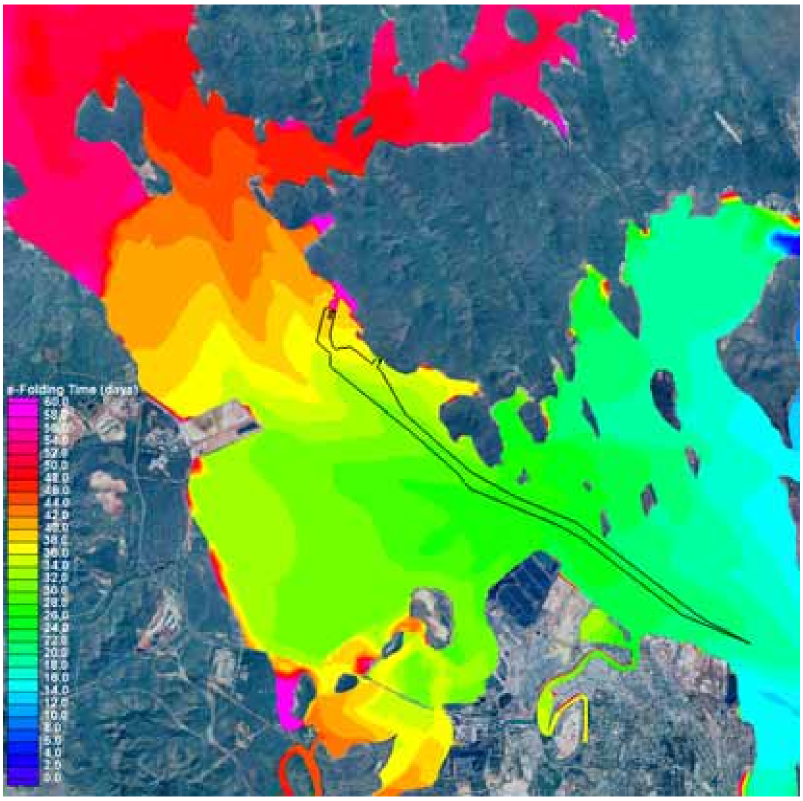

Figure R-1 Scenario 2b e-folding time

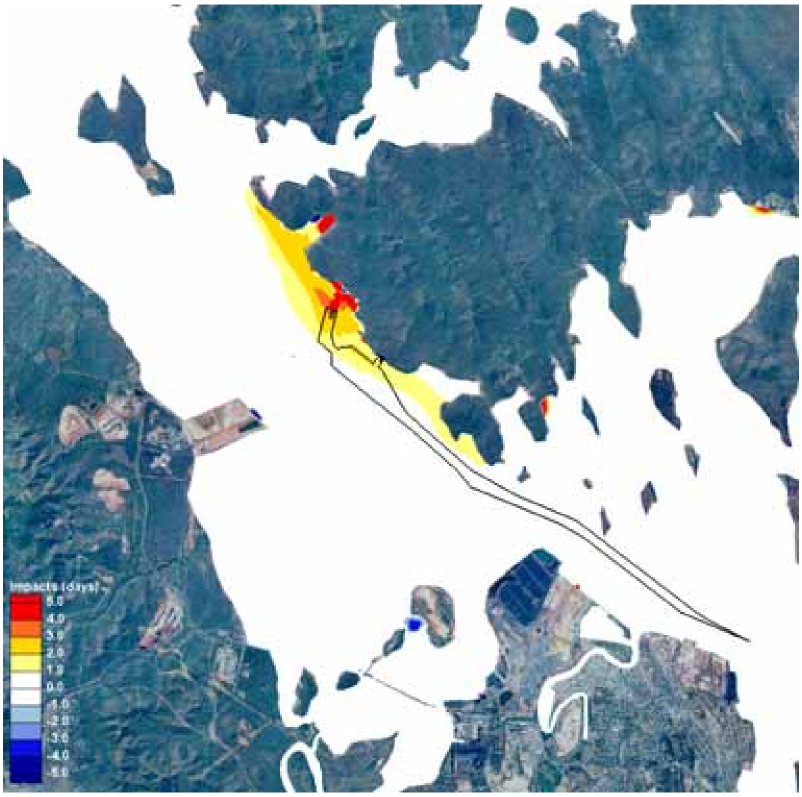

Figure R-2 Scenario 2b e-folding time differences

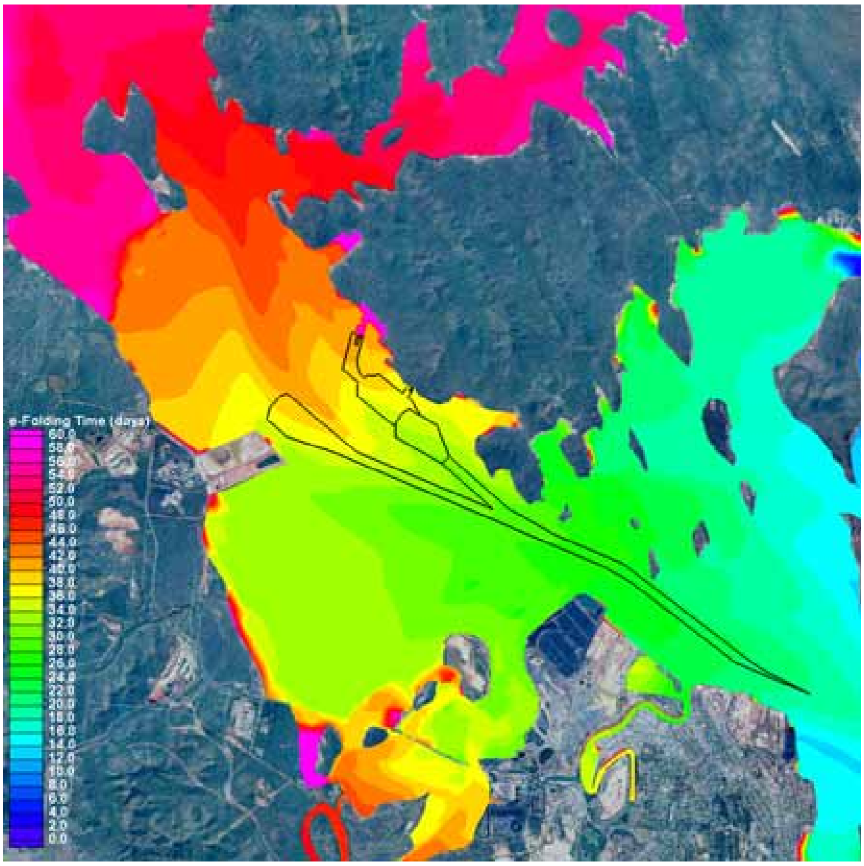

Figure R-3 Scenario 3 e-folding time

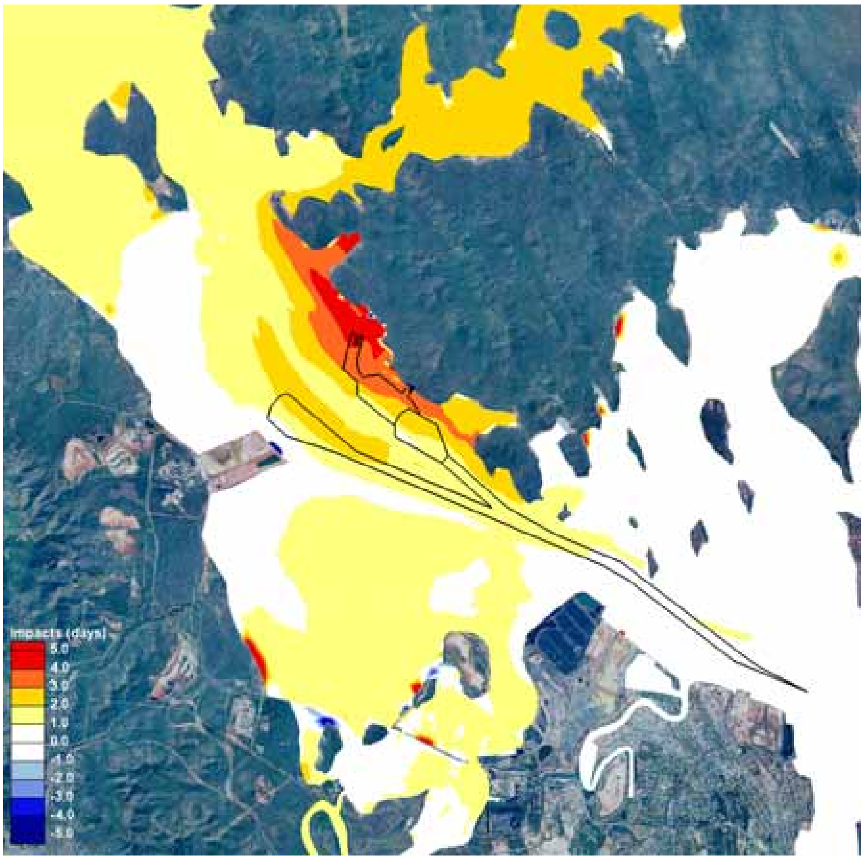

Figure R-4 Scenario 3 e-folding time differences

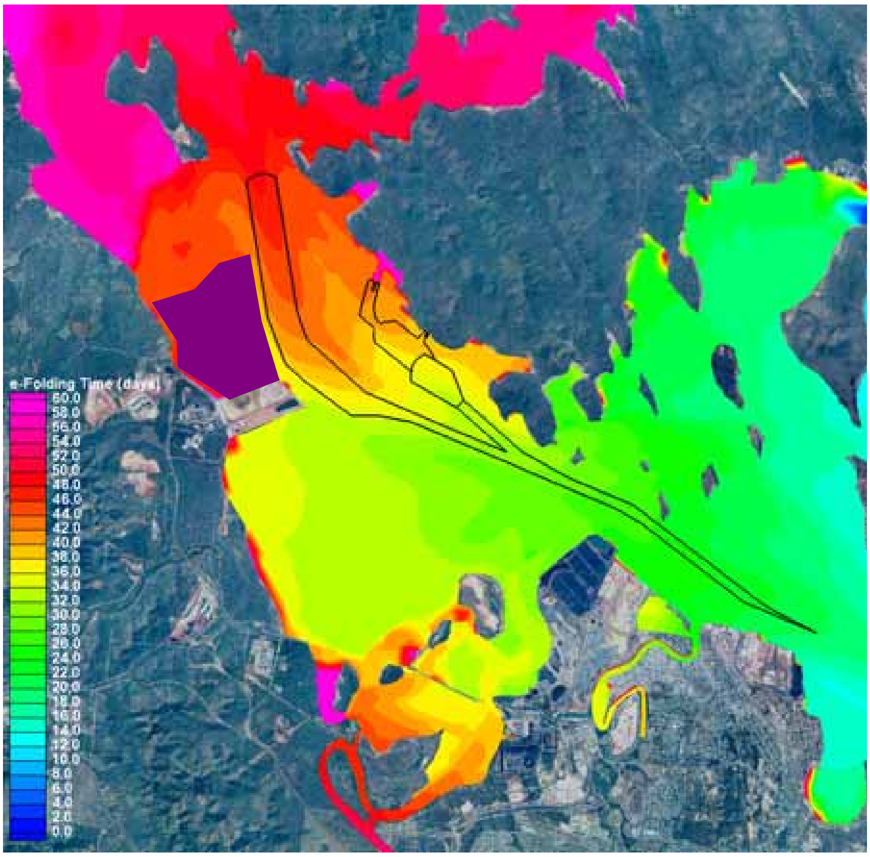

Figure R-5 Scenario 4 e-folding time

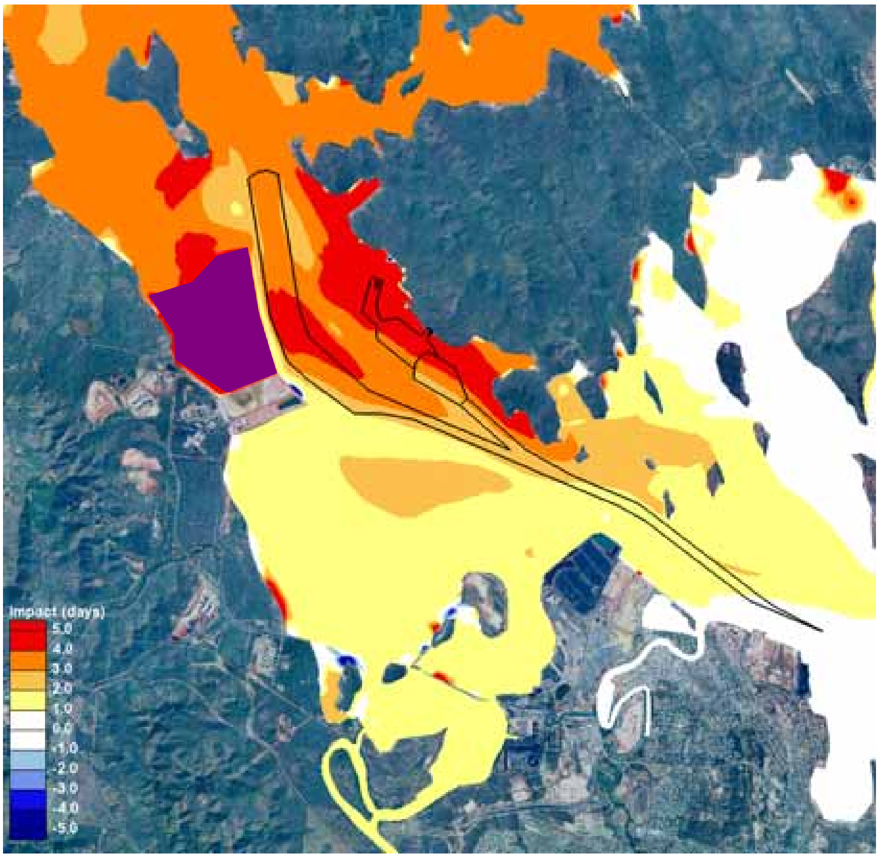

Figure R-6 Scenario 4 e-folding time differences

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