Merimbula Effluent Reuse

30 September 2010

Pilot Water Quality Model Final Report

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Prepared for

Bega Valley Shire Council

30 September 2010

60102089

Quality Information

Document Pilot Water Quality Model Final Report

Ref 60102089

Date 30 September 2010

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Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
1	2nd Sept 2010	Draft Report	Matthew Renshaw / Project Manager	
2	30th Sept 2010	Final Report (incorporating client comment)	Matthew Renshaw / Project Manager	

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1.0 Introduction

The Merimbula Sewerage System Options Investigation for Beneficial Use and Disposal of Effluent involves a comprehensive study of the current and future beneficial use and disposal options for treated effluent from the Merimbula Sewage Treatment Plant (STP) on behalf of the Bega Valley Shire Council (BVSC).

The intent of the broader study is to provide Council with a better understanding of the options available for the beneficial reuse of effluent from the STP and to develop a program of works to implement the design and construction of the most appropriate option.

This report presents the results of a pilot hydrodynamic and water quality model developed to provide an indication of the effects of proposed ocean outfall locations.

2.0 Background

2.1 Current Disposal System

Effluent from the Merimbula STP currently is managed in three ways:

1) Reused as irrigation water for the Pambula Merimbula Golf Course
2) Discharged to the ocean via an exposed pipeline in the middle of Merimbula Main Beach.
3) Disposed of to two exfiltration ponds that are located in the dunes of Merimbula Main Beach

In the future, another method for effluent use is planned with treated effluent to be used for the Pambula River Flats irrigation scheme, which is currently in the final stages of construction.

The annual effluent usage from Merimbula STP is shown below for the financial year of 2008-09.

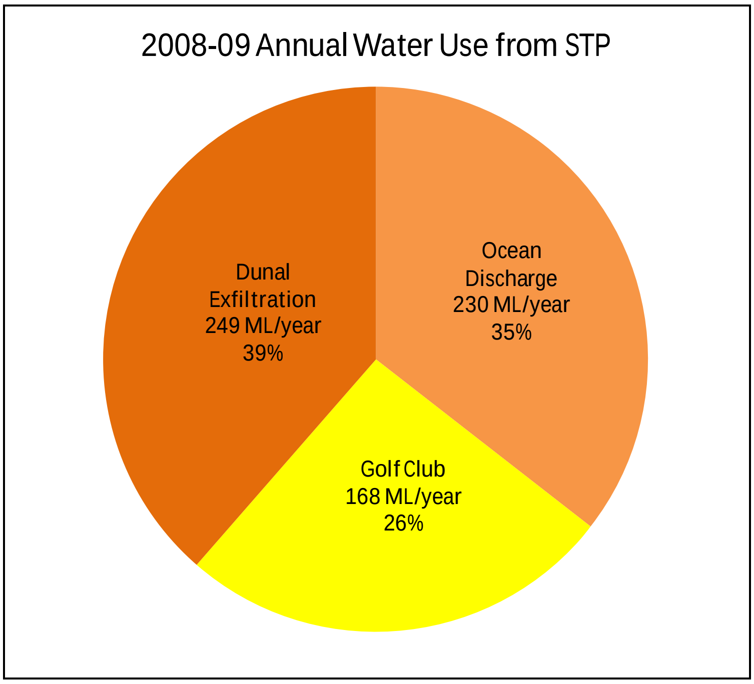

Figure 1 2008-09 Annual Beneficial Use and Disposal of Effluent from STP

2.2 Ocean Discharge

The ocean outfall currently consists of a pipeline connected to the treated effluent pumping station at the STP terminating in the dunes at the centre of Merimbula's Main Beach. Treated effluent is discharged from this pipe onto the beach and flows across the beach to the ocean. The pipeline originally extended into the wave zone but was damaged in a large storm event in the 1970's and was not repaired.

The discharge to the ocean outfall pipeline is undertaken at night to minimise the risk of public exposure. Typically, maximum flows to the ocean occur during the winter months. The occurrence of algae in summer periods on local beaches and a perception of a possible link to the ocean discharge of treated effluent have attracted significant media and community attention. The BVSC has committed to discontinuing the existing shore based discharge of treated effluent to the ocean.

At the time of study, the discharge licence (EPL1741) for the Merimbula STP allowed a maximum of 3,000 kL/day of effluent to be released to the ocean. This was changed from 3,000 kL/day to 4,000 kL/d via licence variation number 1102762. This change came in to effect on the 29th June 2009.

Data provided by BVSC indicated that between 2005 and 2009 this limit was exceeded a total of 29 times with the maximum flow realised in a single day being 11,764 kL.

Table 1 Ocean discharge licence exceedance

Year	Number of Times Daily Limit Exceeded	Daily Maximum (kL/d)
2009-2010[1]	5	15,130
2008-2009	1	3,959
2007-2008	7	4,514
2006-2007	8	8,500
2005-2006	13	11,764

[1] **Based on a daily discharge limit increased to 4,000 kL**

3.0 Water Quality

3.1 Water Quality of Effluent

The following table provides a summary of the quality of the effluent discharged across the data sampling period from January 2008 to April 2010. The table shows that the ocean outfall's effluent discharge has exceeded licence limits

Table 2 Summary of Effluent Quality from the Merimbula STP for Period January 2008 to April 2010 (Source: BVSC)

Parameter	Units	No.	50%ile	90%ile	Max	EIS Maximum & Licence Limits
pH		124	7.9	8.3	9	8.7
Biological Oxygen Demand (BOD)	mg/L	124	3	7	31	17
Suspended Solids (TSS)	mg/L	124	5	13	56	30
Ammonia & Ammonium	mg/L	124	0.4	3.9	18	0.83
Oxidised Nitrogen	mg/L	120	1.7	8.6	14.0	
Total Nitrogen	mg/L	124	5.1	13	22	17
Total Phosphorus	mg/L	120	9.7	13	18	13
Oil & Grease	mg/L	124	<2.0	<2.0	<3.0	2
Ortho Phosphorus	mg/L	38	8.6	12.3	13	-
Chlorine Residual	mg/L	33	0.1	0.2	0.4	-
Faecal Coliforms	cfu/100mL	121	100	1420	6,300,000	200
Dissolved Oxygen (DO)	mg/L	36	9.1	15.1	24	-
Chlorophyll "a"	mg/L	22	5.4	95.9	120	-
Electrical Conductivity (EC)	µs/cm	61	740	800	1500	-

3.2 Water Quality Objectives & Mixing Zone

Water quality for discharge into the ocean or Merimbula Bay is guided by the ANZECC Guidelines. This study has adopted the default marine environment water quality trigger values based on the 95%ile protection values obtained from Section 8.2 of the ANZECC Guidelines. The 95th %ile should ensure protection of 95% of the species in that environment.

The WQO's relate to the ambient water quality and not specifically to the effluent discharged to the site. Determination of the quality of effluent appropriate for discharge to Merimbula Bay or the ocean depends on mixing factors, and also on the sensitivity of the aquatic ecology in the local environment.

The existing ocean outfall water quality requirements are shown for comparative purposes only and are not intended for benchmarking use. Again, there may also be chemical contaminants not outlined below that may be toxic to the aquatic flora and fauna within the area.

Table 3 Comparison of the current STP effluent quality with the Water Quality Objectives for Marine environments in NSW and Existing Ocean Outfalls (ANZECC Guidelines)

Parameter	Effluent (50th %ile)	Water Quality Objective[1]	Units
Total Nitrogen	5.1	0.12[1]	mg/L
NO_x (NO_2+NO_3)	1.7 [2]	0.025[1]	mg/L
Ammonia & Ammonium	0.4	0.015[1]	mg/L
Total Phosphorous	9.7	0.025[1]	mg/L
Ortho Phosphorus	8.6	0.01[1]	mg/L
Chlorophyll-a	5.4	0.001[1]	mg/L
DO	9.1mg/L	90 - 110%[1]	-
pH	7.9	8.0 - 8.4[1]	-
TSS	5	0.5[2]	mg/L
Faecal coliforms	100	<150[2]	/100 mL
BOD	3	-	mg/L
Chlorine	0.1	-	mg/L

[1] Based ANZECC Guidelines Volume 1 Table 3.3.2; [2] Volume 2 Table 8.2.2.1

[2] AECOM has been advised by BVSC that the main component of the measured NO_x is NO_3 and as such it is assumed that the NO_2 concentration in the effluent can be taken as zero.

Further, as stated within PRP6 licence variation for the Merimbula STP, DECCW defines "the mixing zone as the volume within which initial mixing occurs". AECOM conducted a literature review of a number of environmental assessments for ocean outfalls to determine what would be reasonably considered as a best-practice "mixing zone" target for the Merimbula STP outfall. Typical sizes of mixing zones (or zones of initial dilution), defined in the Environmental Impact Statements for the following projects, are:

- Gunns Pulp Mill (TAS): 500 m x 275 m
- Adelaide Desalination Plant (SA): 400 m radius
- Sydney Desalination Plant (NSW): 75 m radius

It is further noted that the USEPA maximum recommended mixing zone is 26 acres (approximately 300 m x 300 m).

On this basis, AECOM suggested a mixing zone radius of less than 100 m as a reasonable 'best practice' target, while appreciating that the local hydrodynamics would likely influence the volume not to be perfectly circular or spherical. Therefore a dilution zone of an equivalent area (approximately 31,420 m^2) in model space was used as input to the model.

This allowed direction for the hydrodynamic modelling to restrict the mixing zone to approximately a 100 m radius, considered to be the area beyond which the WQO's are not to be exceeded.

4.0 Marine Climate

4.1 Tidal Planes

The tidal regime of Merimbula is meso-tidal semi-diurnal with a diurnal inequality; the tidal range lies between 2 and 4 metres, there are two high tides and two low tides each day and there is a once-daily inequality in the tidal range.

The higher spring tides occur near and around the time of new or full moon and rise highest and fall lowest from the mean sea level. The average spring tidal range is 1.6m and the maximum range reaches 2.1m. Neap tides occur near the time of the first and third quarters of the moon and have an average range of around 0.4m.

Tidal planes for Eden (37° 04'S, 149° 54'E), which approximate closely those at Merimbula, are noted on Marine Chart AUS 806 and reproduced in Table 4. Chart Datum is approximately the level of Lowest Astronomical Tide (LAT).

The Australian Height Datum (AHD), the standard topographic levelling datum used in Australia, is an approximation of mean sea level based on historical tide gauge data from around Australia. The relation of AUS 806 Chart Datum to AHD is also shown in Table 4.

Table 4 Tidal Plane Levels for Eden

Australian Height Datum (m, AHD)	Tidal Planes	Chart Datum (m, CD) *Marine Chart AUS 806*
1.1	Highest Astronomical Tide (HAT)	2.1
0.8	Mean High Water Springs (MHWS)	1.8
0.2	Mean High Water Neaps (MHWN)	1.2
0.0	Mean Sea Level (MSL)	1.0
-0.2	Mean Low Water Neaps (MLWN)	0.8
-0.8	Mean Low Water Springs (MLWS)	0.2
-1.0	Lowest Astronomical Tide (LAT)	0.00

4.2 Currents

Offshore currents have been measured along the NSW coastline and can be attributed to a number of phenomena including the East Australian Current, coastally trapped waves and local climatic conditions. There is no data available for offshore of Merimbula. Nevertheless, for preliminary pilot modelling, the ocean current characteristics may be taken from those offshore of Sydney. Work undertaken for the Bondi and Malabar ocean outfall projects included extensive current sampling. A monitoring site, the Ocean Reference Station (ORS), was set up offshore of Sydney to measure currents both surface and deepwater currents.

Monitoring indicated that currents travel in a general shore parallel direction (Figure 2).

Table 5 Prevalence of Offshore Ocean Currents

Current	Surface water	Deep water
Southerly	60%	45%
Northerly	15%	30%

Table 5 shows that for surface waters, southerly currents were measured 60% of the time and northerly currents around 15% of the time. Deepwater results differ in that there is decreased current action from the south with northerly currents measured 30% of the time. Southerly currents were measured only around 45% of the time, about 15% less than near the surface.

Over the monitoring period, current speeds up to 0.9 m/s were measured. Currents were generally larger near to the surface. At the 1% exceedance probability, currents greater than 0.7m/s were measured at a depth of 17m and 0.4m/s at a depth of 52.5m. At the 50% exceedance probability, currents greater than 0.2m/s were measured at a depth of 17m and 0.1m/s at a depth of 52.5m (Figure 3).

Similar conditions to those measured in Sydney could be expected at Merimbula. The width of the Continental Shelf at Sydney is around 33 km and at Merimbula is around 32 km. As the width of the Inner Continental Shelf does not vary greatly along the NSW coast, ranging from around 15 km to 45 km, and the scales of the processes generating the ocean currents is relatively large (some hundreds of kilometres), the current climate at Merimbula, offshore of the headlands and beyond the embayment, is expected to be similar to that at Sydney. The headlands modify the ocean current nearshore and cause circulations within the embayment. This has been modelled and the results of this are presented in Section 5.

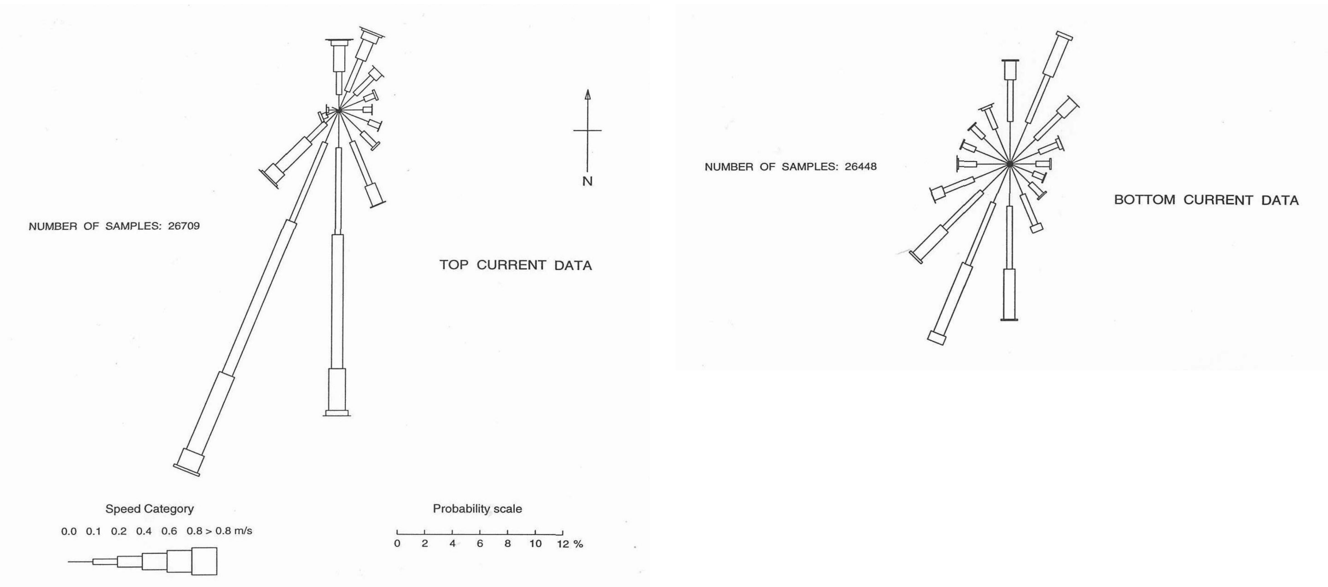

Figure 2 Current roses measured off Sydney at the Ocean Reference Station (21/07/1989 to 31/08/1991, AWACS 1992)

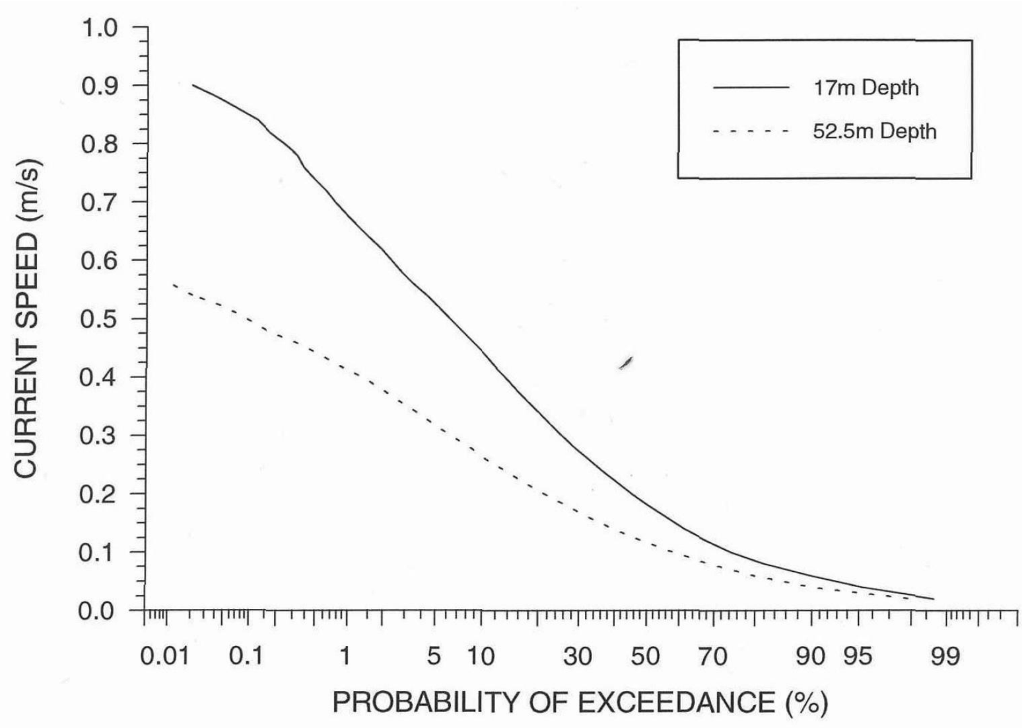

Figure 3 **Current speed exceedance probability, Sydney Ocean Reference Station (21/07/1989 to 31/08/1991, AWACS 1992)**

5.0 Model Configuration

5.1 Model Descriptions

5.1.1 Hydrodynamic Model (RMA-2)

The program RMA-2 was used to model the hydrodynamics at the site. The program comprises a two-dimensional depth averaged finite element hydrodynamic numerical method. RMA-2 is a general-purpose model designed for far-field problems in which vertical accelerations are negligible and velocity vectors generally point in the same direction over the entire depth of the water column at any instant of time. The model requires a vertically homogeneous fluid with a free surface. It computes water surface elevations and horizontal velocity components for subcritical, free-surface two-dimensional flow fields.

RMA-2 computes a finite element solution of the Reynolds and Navier-Stokes equations for turbulent flows, solving the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions. Friction is calculated using the Manning or Chezy equations, eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady (dynamic) problems can be analysed.

5.1.2 Pre and Post Processing (SMS)

The Surface Water Modelling System (SMS) was used to construct a 2D finite element mesh for the Merimbula region. The triangular finite element mesh, developed in the SMS package, allows for an accurate schematisation of the model domain over areas where there are steep gradients in the boundary conditions and was used for this exercise.

All post processing of the hydrodynamic and water quality results was undertaken within the SMS package.

5.1.3 Water Quality Model (RMA-11)

Water quality modelling was undertaken using the RMA-11 modelling software. RMA-11 is a finite element water quality model for simulation of three-dimensional estuaries, bays, lakes and rivers. It is also capable of simulating one and two dimensional approximations to systems either separately or in combined form. The model is designed to accept input of velocities and depths, either from an ASCII data file or from binary results files produced by the two-dimensional hydrodynamic model, RMA-2, or the three-dimensional stratified flow model, RMA-10.

Results in the form of velocities and depth from the hydrodynamic models are used in the solution of the advection diffusion constituent transport equations. Additional terms for each constituent represent source or sinks and growth or decay. The model operates independently of the time steps in the hydrodynamic model as input velocities and depths are interpolated automatically.

Constituents that may be represented in the model include:

- Temperature with a full atmospheric heat budget at the water surface
- BOD/DO
- The nitrogen cycle (including organic nitrogen, ammonia, nitrite and nitrates)
- The phosphorous cycle (including organic phosphorous and phosphates)
- Algae growth and decay
- Cohesive suspended sediment
- Non-cohesive suspended sediment such as sand
- Arbitrary conservative or non-conservative constituents that may be linked to each other
- Coliforms with related decay
- Salinity

Each individual constituent is linked appropriately to derive growth and decay based on current concentrations. Additional terms represent benthic and sediment sources and sinks.

5.2 Model Domain

Survey data provided by DECCW, and Australian marine chart AUS806 were used in SMS to develop a digital bathometric model of the area (Figure 4). Once this data was referenced, digitised, and consolidated, a triangular finite element mesh was generated (Figure 5). The mesh was refined within both the Merimbula and Pambula estuaries and their respective entrances to ensure accurate modelling of the tidal exchange (Figure 6). Further, the mesh was refined at the proposed discharge locations as presented in section 5.6.

The model domain extends from Turingal Point in the north, south to Lennards Head and a distance of around 15km offshore. Tidal conditions were assigned to the open ocean, eastern boundary, while flow conditions were assigned to the northern and southern boundaries (Figure 5).

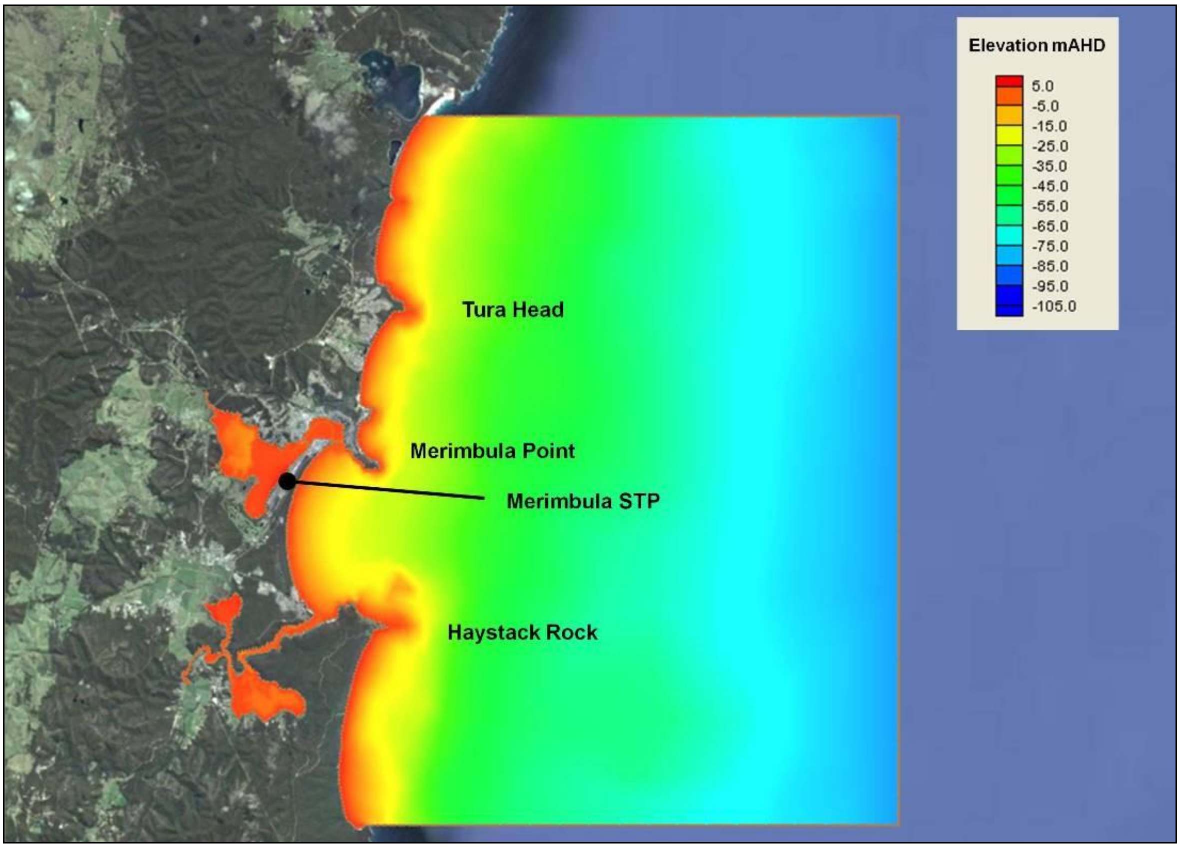

Figure 4 Digitised bathymetry

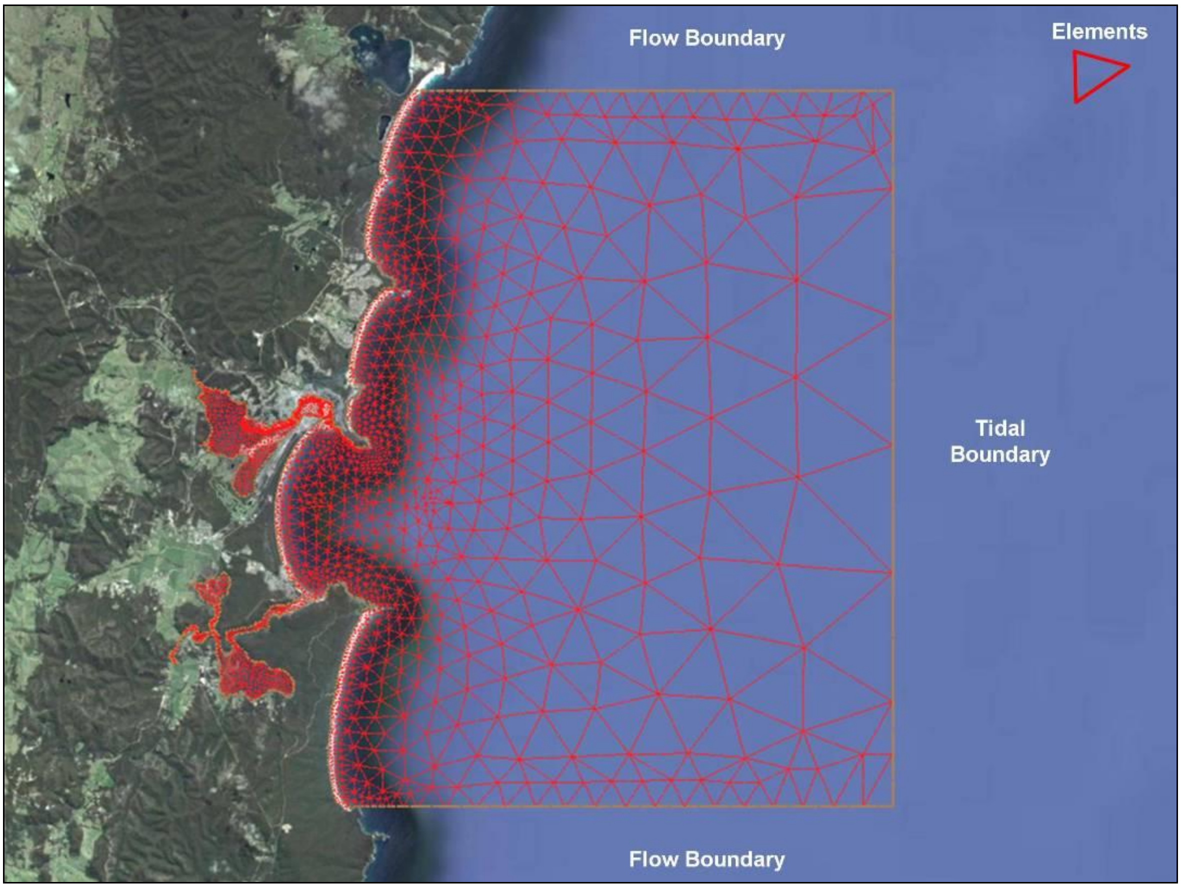

Figure 5 Finite element mesh and boundary conditions

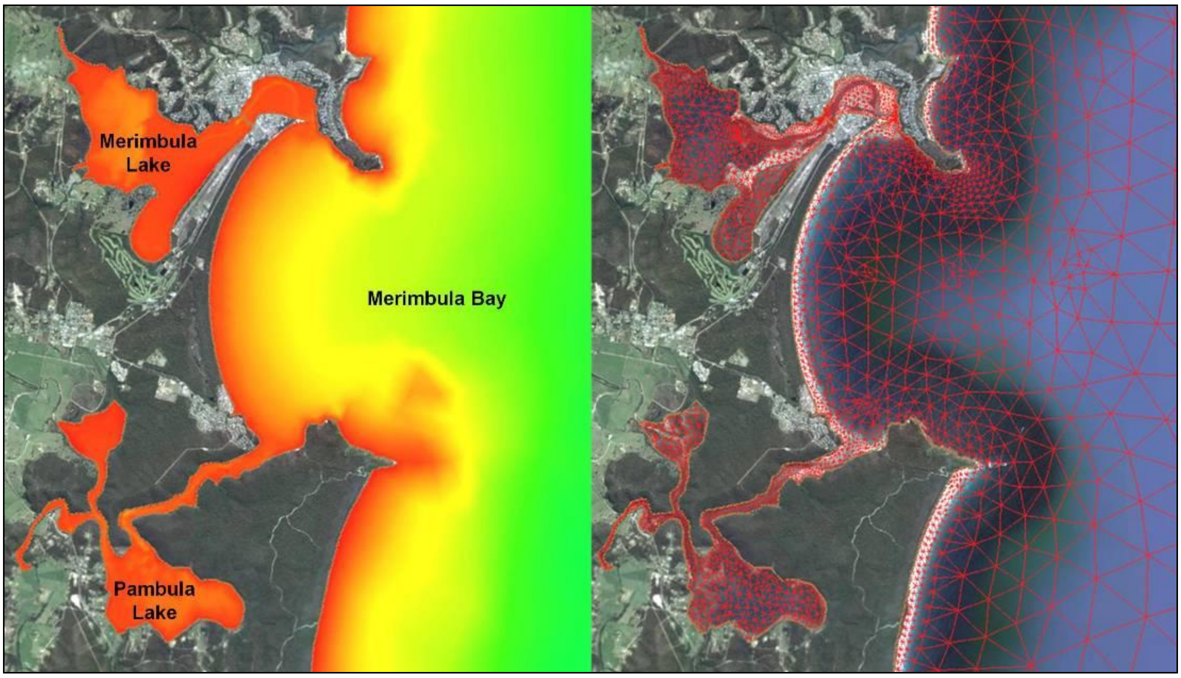

Figure 6 Digitised bathymetry and finite element mesh of Merimbula Bay and estuaries

5.3 Hydrodynamic Input Data

5.3.1 Tides

The WXTide program was used to generate tidal data. Using the software an hourly predicted tidal data set was generated for Eden, the closest station for the site. Fourteen days of this data set were used comprising typical spring and neap tidal cycles (Figure 7).

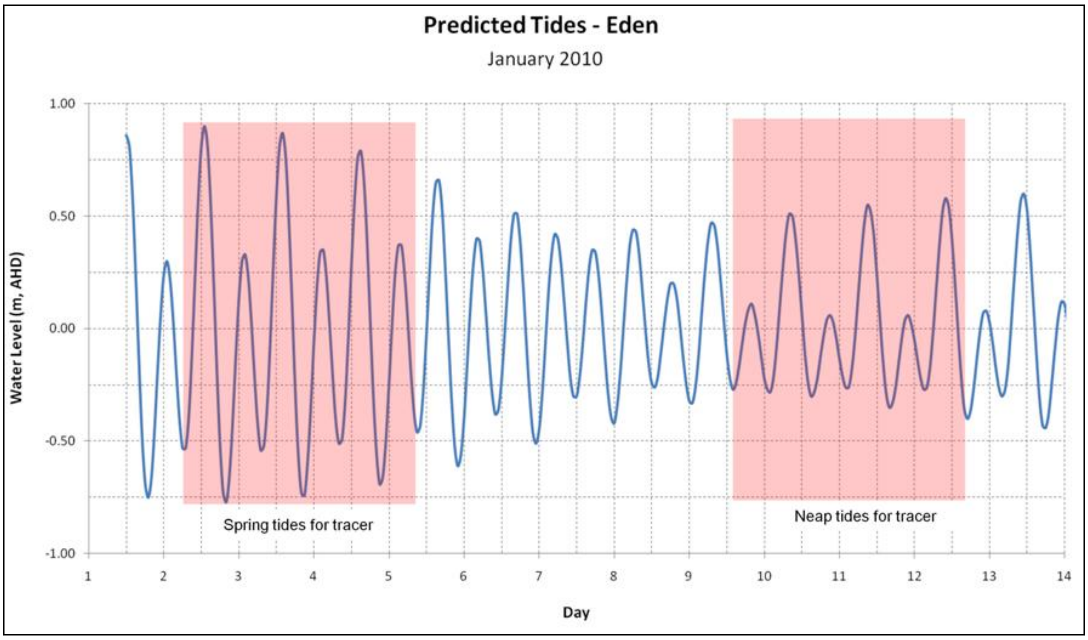

Figure 7 **Predicted tides for Eden showing spring and neap periods (WXTide)**

5.3.2 Currents

Flow conditions were input on both the northern and southern boundaries to represent the shore parallel offshore ocean currents prevalent at the site by considering the shore normal cross-sectional areas at these locations. A current velocity of 0.15m/s was used, representing approximately the 50% exceedance probability.

5.4 Hydrodynamic Scenarios

To account for the varying current and tidal conditions around Merimbula, three hydrodynamic scenarios were run in RMA-2. These are shown below in Table 6:

Table 6 **Hydrodynamic Scenarios Modelled**

Scenario	Tidal cycles	0.15 m/s Current
1	A month long run of typical spring and neap	-
2	A month long run of typical spring and neap	Northerly[1]
3	A month long run of typical spring and neap	Southerly[2]

[1] current travelling south to north

[2] current travelling north to south

5.5 Water Quality Input Data

5.5.1 Effluent Flow

At the time of study, the EPA licence for the Merimbula STP allowed a maximum of 3,000 kL/day of effluent to be released to the ocean. This value was converted to 35 L/s and used in the water quality model representing a continuous discharge.

Although flows of this magnitude are generally not released continuously, the adoption of this upper limit allows for conservative results to be obtained.

5.5.2 Constituents

BVSC measures a number of water quality parameters at the STP. The constituents modelled were total suspended sediment (TSS), total nitrogen, total phosphorous and faecal coliforms.

Total suspended solids (TSS) is the measure of the mass of fine inorganic particles suspended in water. Excessive suspended particulate matter can reduce light penetration and result in reduced primary production, possible deleterious effects on phytoplankton, macrophytes and seagrasses, or smother benthic organisms and their habitats (ANZECC Guidelines, 2000).

High concentrations of nutrients such as nitrogen and phosphorus can result in excessive growth of aquatic plants and algae. The ANZECC guidelines (2000) identify the following issues related to the excessive growth of aquatic plants and algae:

- Toxic effects, particularly due to cyanobacteria in fresh and brackish waters, and dinoflagellates in marine waters;
- Reduction in dissolved oxygen concentrations when the plants die and are decomposed;
- Reduction in recreational amenity (phytoplankton blooms and macrophytes in wetlands and lakes, seagrasses in estuaries and coastal lagoons);
- Blocking of waterways and standing waterbodies by macrophytes;
- Change in biodiversity

The presence of faecal coliforms in aquatic environments may indicate contamination with the faecal material of humans or other animals and provides a warning of possible contamination with pathogens.

A summary of the typical measured values of these constituents is provided in Table 2.

TSS

For the modelling, the 90^{th} percentile value of 13mg/L was adopted for input into the model. The ANZECC Guidelines specify an ambient concentration of 0.5mg/L for TSS. As TSS is inorganic, it is the most conservative of the constituents modelled.

Total Nitrogen

Total nitrogen is the combination of all species where nitrogen is present. For water quality applications this generally included nitrite, nitrate, organic nitrogen and ammonia as follows;

$$\text{Total Nitrogen} = NO_2^- + NO_3^- + NH_3 + \text{Org-N}$$

AECOM has been advised by BVSC that the main component of the measured NO_x (see Table 2) is NO_3^- and as such it is assumed that the NO_2^- concentration in the effluent can be taken as zero.

The Merimbula STP ammonia data is total ammonia-nitrogen. This consists of unionized ammonia (NH_3) + ionized ammonium ion (NH_4^+) = Total (NH_3/NH_4-N). As such, BVSC has advised that the ammonium concentrations in Table 2 can be taken as ammonia and used as input in the model.

Organic nitrogen was calculated as Org-N = TN – NO_3^- – NH_3. In all cases the 90th percentile values were used as follows;

- NO_3^- = 8.6mg/L
- NH_3 = 3.9mg/L
- Org-N = TN – NO_3^- – NH_3 = 13 – 8.6 – 3.9 = 0.5mg/L

The model results were combined to give Total Nitrogen.

Total Phosphorus

For water quality applications total phosphorus is typically a combination of phosphate and organic phosphorous;

Total Phosphorus = PO_4^{3-} + Org-P

BVSC measures ortho-phosphorous and total phosphorous at the Merimbula STP. Ortho-phosphorus is equivalent to phosphate in this case. Organic phosphorus was calculated as Org-P = TP - PO_4^{3-}.

Taking the 90th percentile values from Table 2 the following input concentrations were used.

- Ortho-phosphorous = PO_4^{3-} = 12.3mg/L
- Org-P = TP – PO_4^{3-} = 13 – 12.3 = 0.7mg/L

The model results were combined to give Total Phosphorous.

Faecal Coliforms

BVSC currently measures faecal coliform concentration and the 90th percentile value of 1420 cfu/100mL was used as input into the model.

5.5.3 Concentrations for Input

RMA-11 requires a mass per unit time constituent concentration input. This was calculated by multiplying the concentration, in mg/L, by the flow, in L/s (35L/s in this case). Table 7 summarises the input concentrations.

Table 7 Constituent concentrations for model input

Constituent	Effluent Concentration mg/L	Mass for Input g/s
TSS	13.0	0.455
NO_3^-	8.6	0.301
NH_3	3.9	0.137
Org-N	0.5	0.018
PO_4^{3-}	12.3	0.431
Org-P	0.7	0.025

For faecal coliforms, the inflow mass is converted by multiplying by flow so that mass inflow is in cfu/100mL x m^3/s. RMA-11 does not account these odd units, however, all output results are presented as cfu/100mL. Using this methodology, the input concentrations for faecal coliforms is 1420cfu/100mL*0.035m^3/s which is 49.7 cfu/100mL x m^3/s.

5.5.4 Initial Dilution

In RMA-11, the constituent is added to the model by distributing the input mass over the entire volume of the receiving element. To ensure that this initial distribution was representative of typical initial dilution rates, the volume of the input elements was set to achieve a dilution of 20.

Similar sized plants, such as Boambee at Sawtell, Penguin Head at Culburra, The Ladders at Batemans Bay and Plantation Point at Jervis Bay have initial dilution rates ranging from 10 to 30 (Ingleton & Large 2004).

5.6 Water Quality Scenarios

To ascertain the optimum location for the effluent outfall a standardised approach to the water quality modelling was developed. BVSC has indicated that an outfall in line with the existing would be preferred and as such three locations were considered, offshore of the beach, -20m at a distance of 1350m, -30m at 2975m and -40m at 5225m AHD (Figure 8). It was considered not to be practical to discharge in depths less than 20m because the diffusers may be affected adversely by littoral processes.

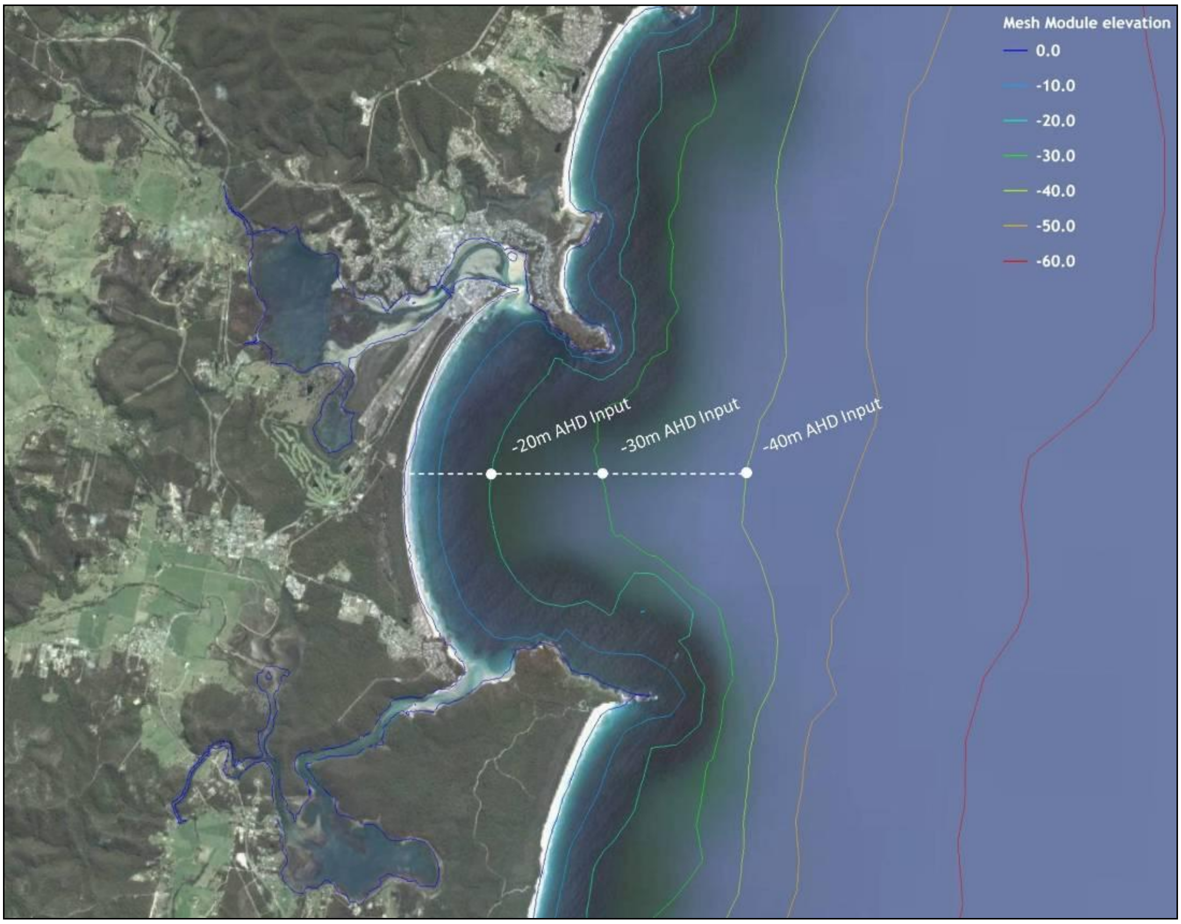

Figure 8 Water Quality model input locations

A total of 15 water quality scenarios were modelled. TSS, being the most conservative constituent, was modelled at the three locations for all three hydrodynamic scenarios. Further modelling was undertaken for the most economically viable option (-20m AHD) and the preferred option (-40m AHD).

Total nitrogen, total phosphorus and faecal coliform were modelled for these options with the worst case hydrodynamic scenario.

In summary, the 15 water quality scenarios modelled were as per Table 8.

Table 8 Water Quality Scenarios Modelled

Water Quality Scenario	Hydrodynamic Scenario	Constituent	Depth (AHD)
1	1	TSS	- 20
2	1	TSS	- 30
3	1	TSS	- 40
4	2	TSS	- 20
5	2	TSS	- 30
6	2	TSS	- 40
7	3	TSS	- 20
8	3	TSS	- 30
9	3	TSS	- 40
10[1]	1	TN (including: Organic Nitrogen, Ammonia and Nitrate)	- 20
11[1]	1	TP (including: Organic Phosphorus and Phosphate)	- 20
12[1]	1	Faecal Coliform	- 20
13[1]	1	TN (including: Organic Nitrogen, Ammonia and Nitrate)	- 40
14[1]	1	TP (including: Organic Phosphorus and Phosphate)	- 40
15[1]	1	Faecal Coliform	- 40

[1] Hydrodynamic Scenario 1 is considered to be worst case scenario with minimal hydrodynamic influence

It is noted that all water quality scenarios were run for a month of hydrodynamics with a continuous discharge release of effluent.

5.7 Assumptions and Caveats

The model developed for this project is considered as a 'pilot' model as no site specific hydrodynamic, stratification, initial dilution or ambient water quality data were available with which to calibrate or validate the model against. Wherever possible, conservative assumptions were made.

The following assumptions and caveats apply to the modelling results and any conclusions drawn;

1) Tidal data used was extracted from the WXTide application (although not considered to be contentious).
2) Currents were assumed to be the same as those measured at the Sydney Ocean Reference Station.
3) The maximum allowable discharge flow was used as input in the water quality component of the model and ran for a full month. Realistically, this value is achieved only a few days each year.
4) The 90^{th} percentile water quality concentrations were used for the modelled constituents making the results highly conservative.
5) An initial dilution of 20 was assumed based on the work of Ingleton & Large (2004).

6.0 Model Results and Discussion

6.1 Hydrodynamic Results

The model was run for the three scenarios in RMA and hydrodynamic results loaded into SMS. The largest currents calculated were in the Merimbula estuary, particularly at the entrance and in the vicinity of the Market St causeway. In these locations currents reached velocities of 1.6 m/s - 1.7 m/s during spring tides.

In both Scenarios 2 and 3, where offshore currents were included, the headlands, particularly Haycock Point at the southern end of Merimbula Bay caused currents to separate resulting in the formation of eddies in the lee of the protrusions. Typical hydrodynamic results for Scenario's 1, 2 and 3 are shown in Figure 9, Figure 10 and Figure 11 respectively.

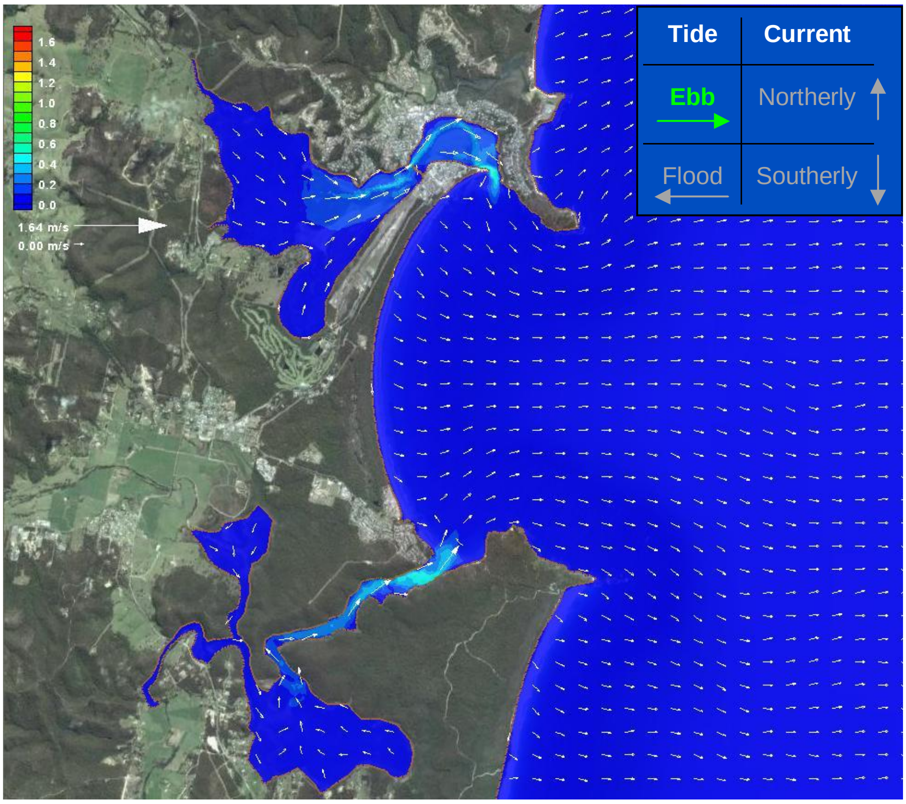

Figure 9 Illustration of typical hydrodynamic results, Scenario 1 for ebb (running out) tides

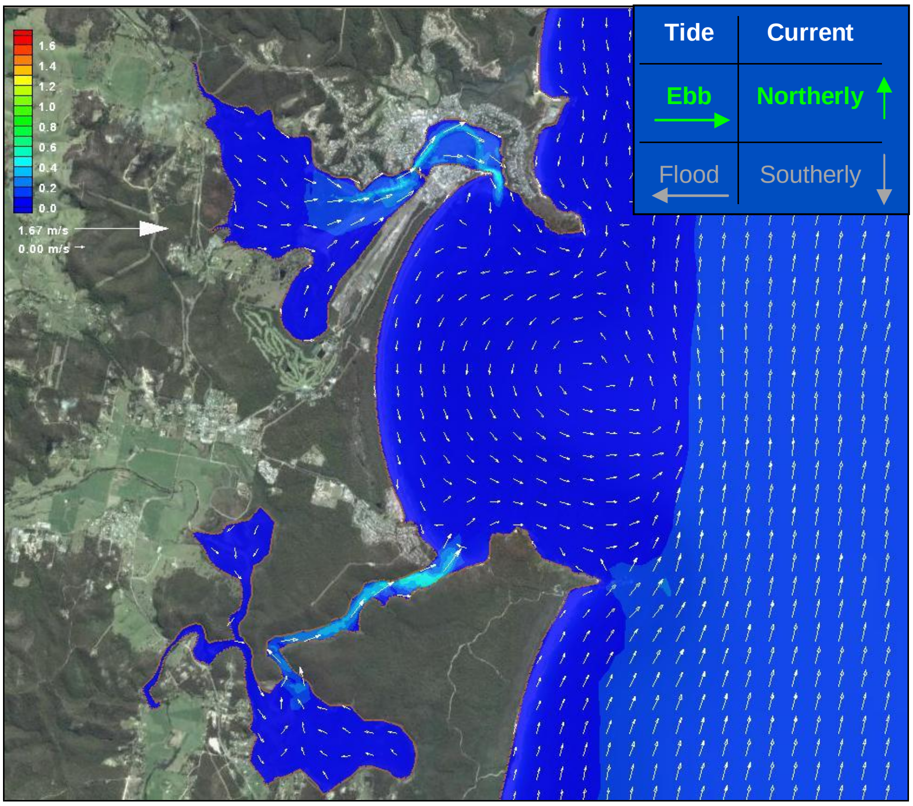

Figure 10 **Illustration of typical hydrodynamic results, Scenario 2 for ebb (running out) tides, a large eddy can be seen within Merimbula Bay**

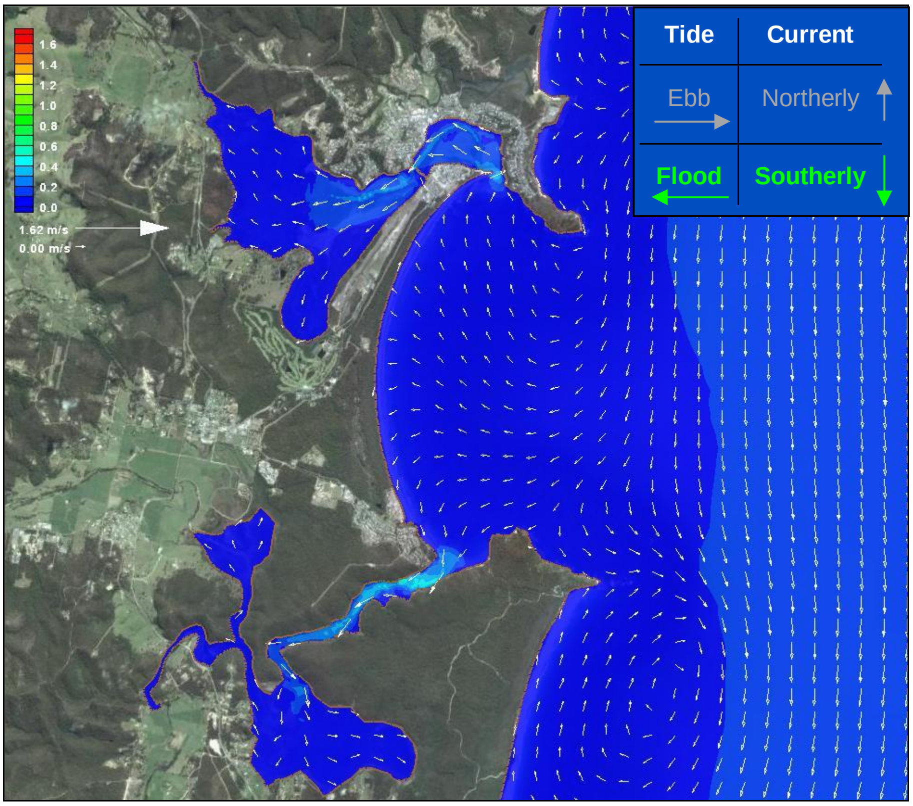

Figure 11 **Illustration of typical hydrodynamic results, Scenario 3 for flood (running in) tides, a large eddy can be seen within Merimbula Bay and south of Haycock Point**

6.2 Water Quality Modelling Results

6.2.1 Water Quality Scenarios 1-3 – Tidal Hydrodynamics with TSS

Figure 12, Figure 13 and Figure 14 present the modelling results for total suspended solids for the tidal hydrodynamic scenario. The highest TSS concentration modelled was 0.13 mg/L for the -20m discharge scenario.

The -20m discharge scenario resulted in an accumulation of TSS within Merimbula Bay and in the Pambula Estuary. The -30m discharge scenario resulted in a similar accumulation of TSS within Merimbula Bay although in this case TSS accumulated in the Merimbula Estuary. The -40m deepwater discharge resulted in an accumulation of TSS offshore of Merimbula Bay, however, only trace amounts (<0.001mg/L) of the constituent were present within the two estuaries.

At no time during the modelling was the water quality objective of 0.50 mg/L for TSS exceeded.

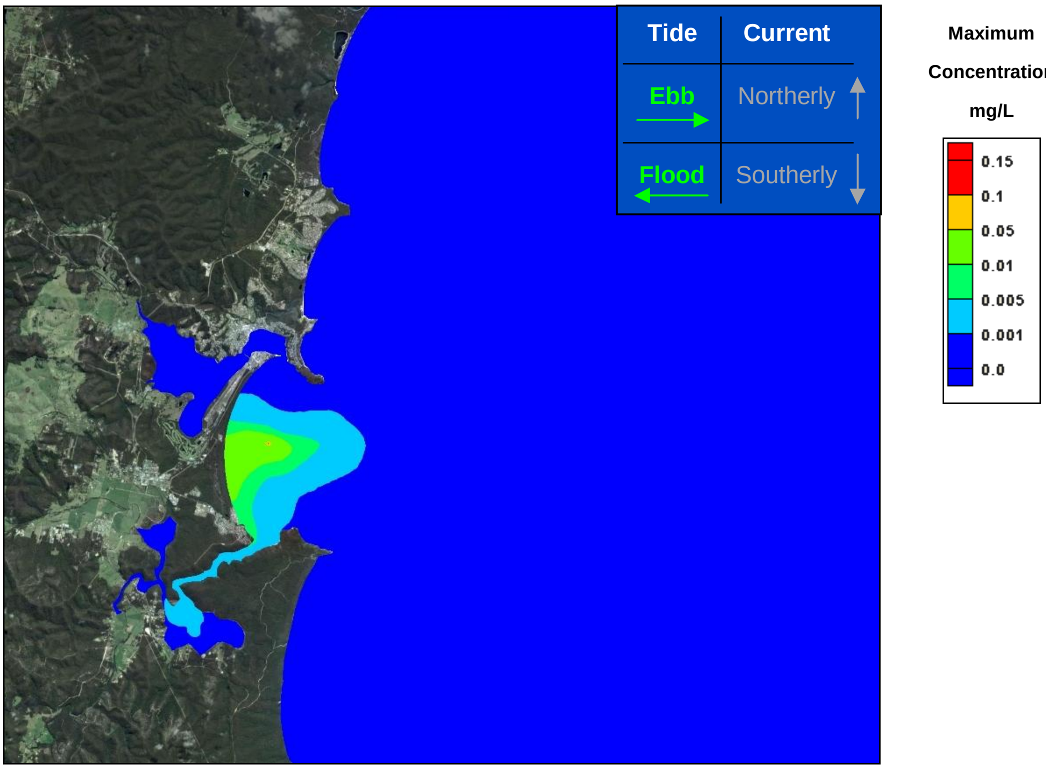

Figure 12 Results of WQ Scenario 1. Tidal with TSS input at -20m AHD

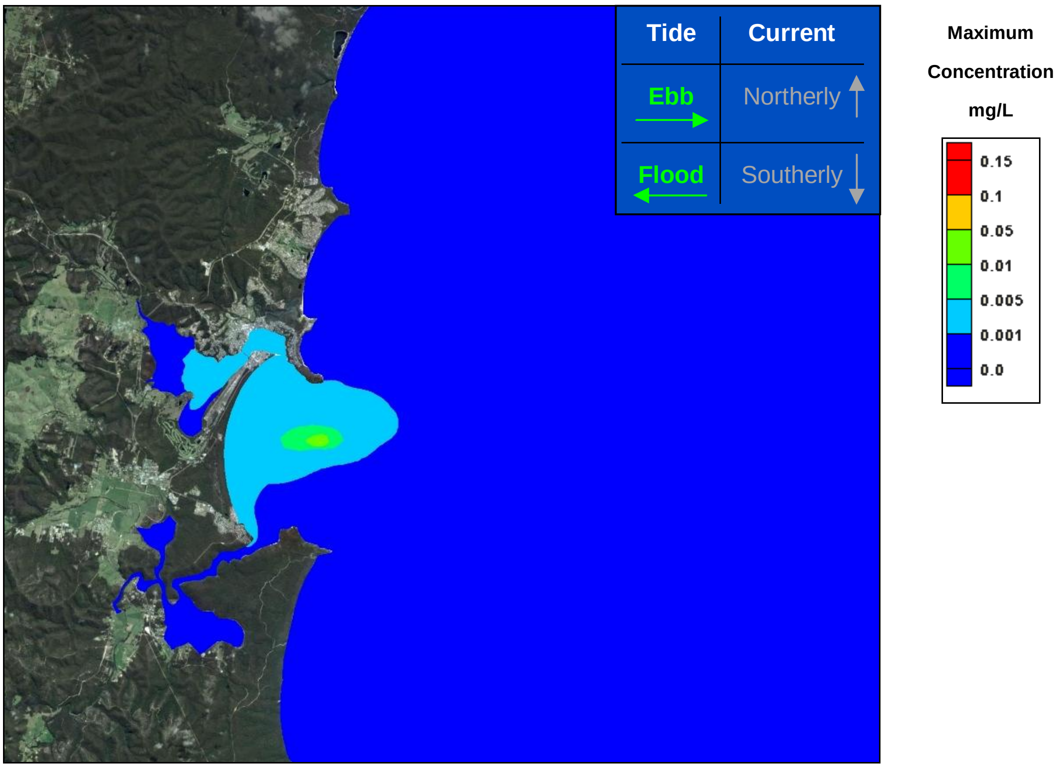

Figure 13 Results of WQ Scenario 2. Tidal with TSS input at -30m AHD

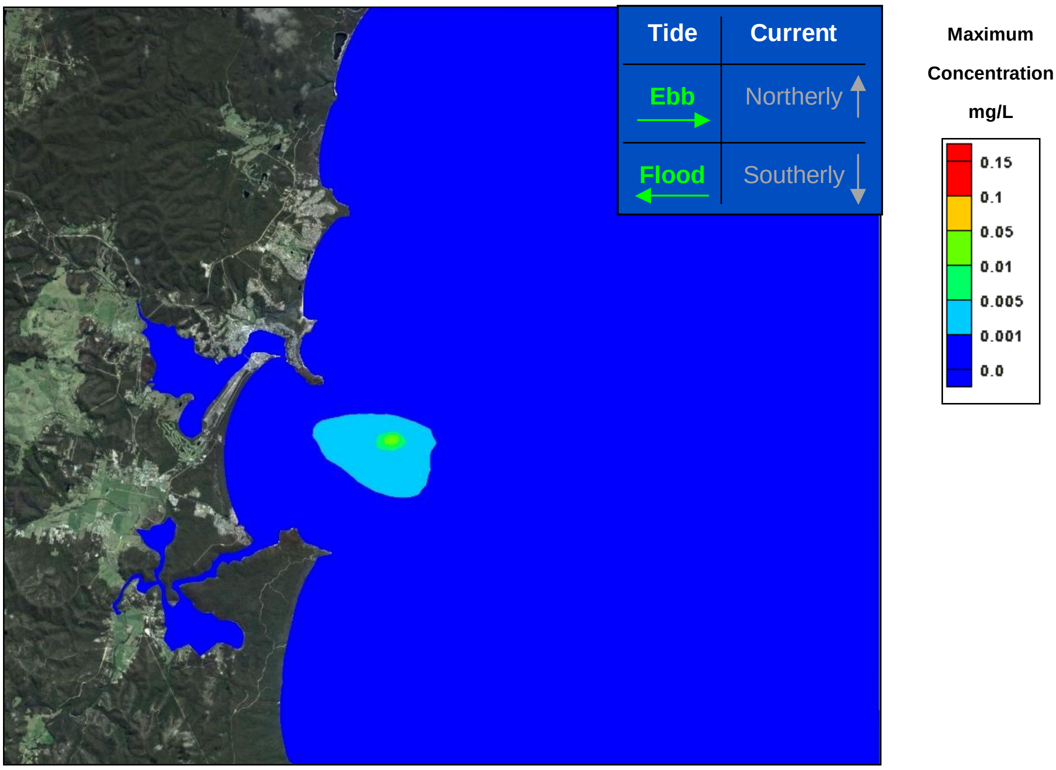

Figure 14 Results of WQ Scenario 3. Tidal with TSS input at -40m AHD

6.2.2 Water Quality Scenarios 4-6 – Tidal and Northerly Current Hydrodynamics with TSS

Figure 15, Figure 16 and Figure 17 present the modelling results for total suspended solids for the tidal and north current hydrodynamic scenario. The highest TSS concentration modelled was 0.079 mg/L for the -30m discharge scenario.

The -20m discharge scenario resulted in a movement of TSS south towards Haystack Rock due to the anti-clockwise eddy present in the bay under the modelled hydrodynamic conditions. The -30m discharge scenario resulted in an accumulation of TSS within Merimbula Bay, attributable to the discharge being located in the centre of the eddy. The -40m deepwater discharge resulted show efficient clearance with a small area TSS accumulation.

At no time during the modelling was the water quality objective of 0.50 mg/L for TSS exceeded.

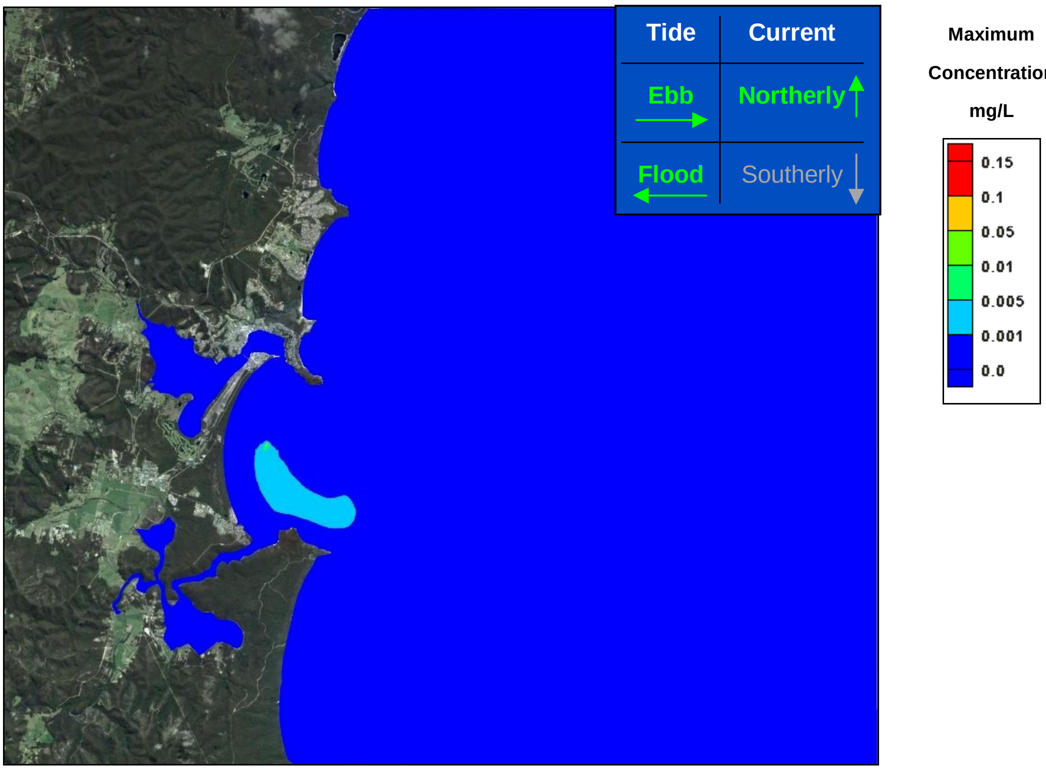

Figure 15 Results of WQ Scenario 4. Tidal + Northerly Current with TSS input at -20m AHD

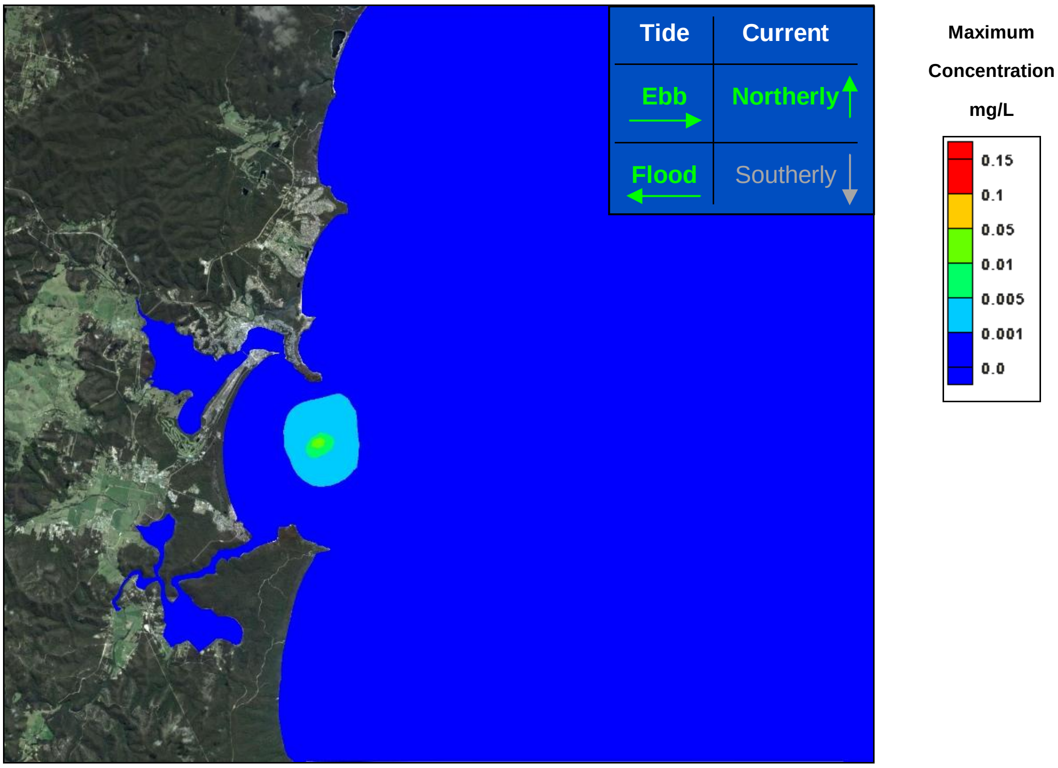

Figure 16 **Results of WQ Scenario 5. Tidal + Northerly Current with TSS input at -30m AHD**

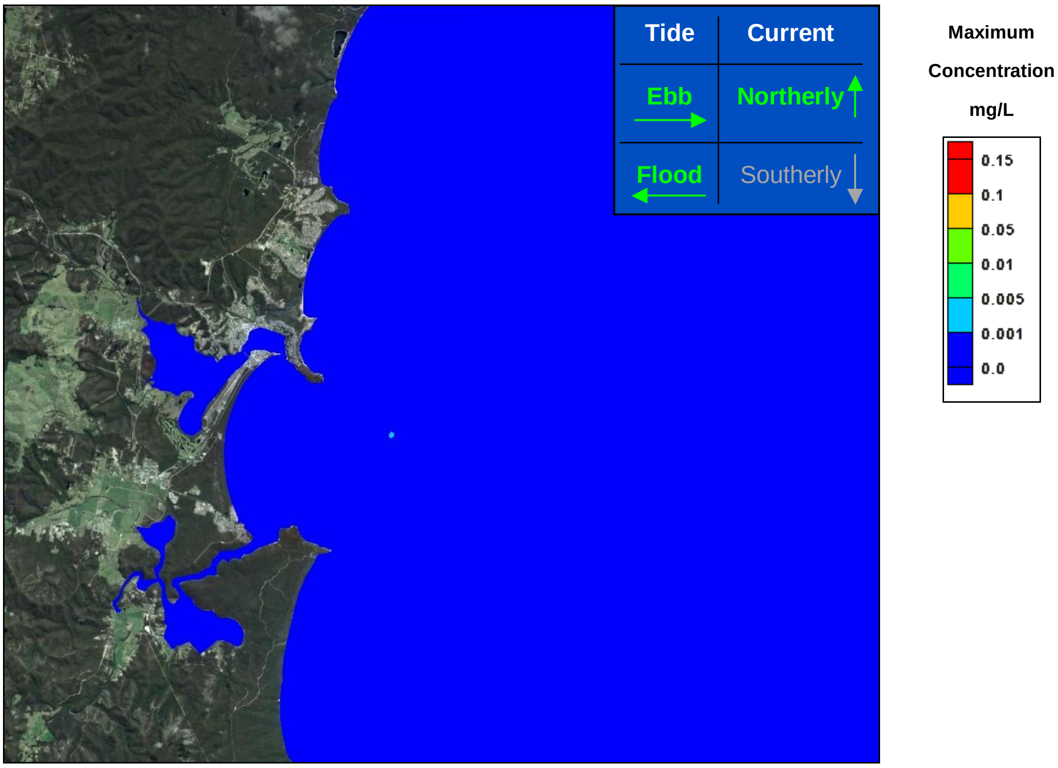

Figure 17 **Results of WQ Scenario 6. Tidal + Northerly Current with TSS input at -40m AHD**

6.2.3 Water Quality Scenarios 7-9 – Tidal and Southerly Current Hydrodynamics with TSS

Figure 18, Figure 19 and Figure 20 present the modelling results for total suspended solids for the tidal and south current hydrodynamic scenario. The highest TSS concentration modelled was 0.082 mg/L for the -20m discharge scenario.

The -20m discharge scenario resulted in an accumulation of TSS around the northern end of Merimbula Bay due to the clockwise eddy present in the bay under the modelled hydrodynamic conditions. The -30m discharge scenario resulted in a similar accumulation of TSS within Merimbula Bay. TSS up to 0.005mg/L was modelled within the Merimbula Estuary for both the -20m and -30m discharge scenarios. The -40m deepwater discharge resulted show efficient clearance with a small area of TSS accumulation.

At no time during the modelling was the water quality objective of 0.50 mg/L for TSS exceeded.

Figure 18 Results of WQ Scenario 7. Tidal + Southerly Current with TSS input at -20m AHD

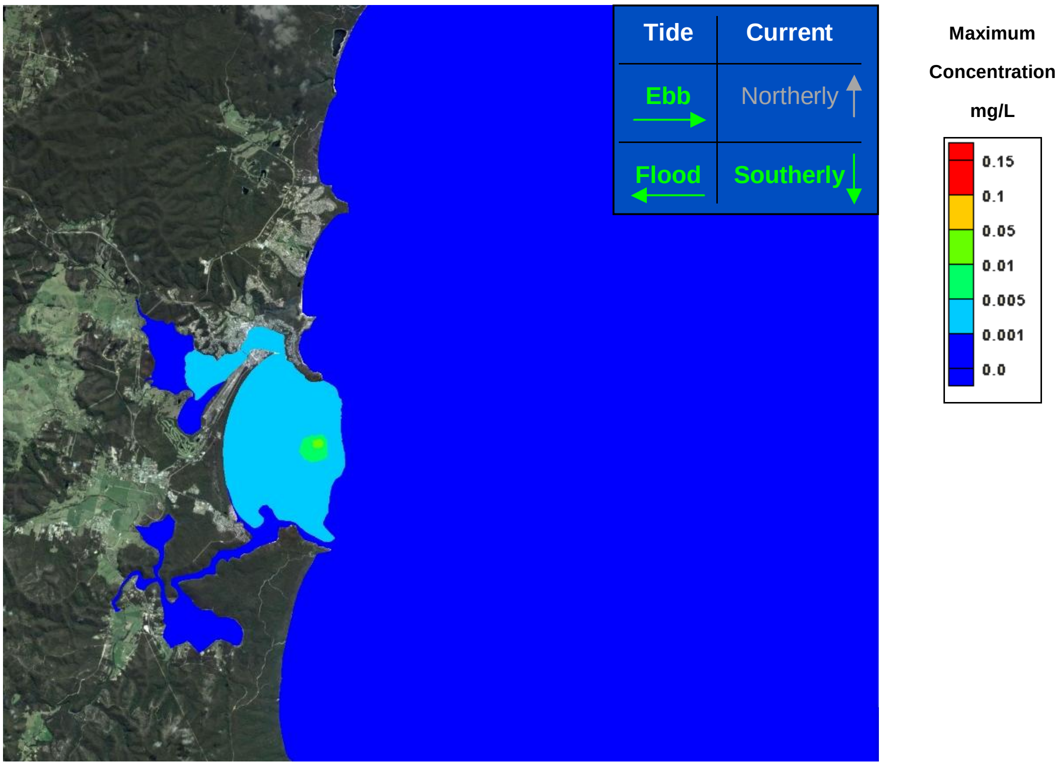

Figure 19 Results of WQ Scenario 8. Tidal + Southerly Current with TSS input at -30m AHD

Figure 20 Results of WQ Scenario 9. Tidal + Southerly Current with TSS input at -40m AHD

6.2.4 Discussion of TSS Results

Total suspended solids are the most conservative of the constituent modelled. Based on the results, the -40m AHD discharge was selected as the preferred location from a water quality perspective. Considering the water quality objective was not exceeded for any of the discharge locations, the most economically viable option (i.e. -20m AHD) was also selected for further modelling. The remaining three constituents; total nitrogen, total phosphorus and faecal coliforms were modelled for these locations.

6.2.5 Water Quality Scenario 10 - Nitrogen Results at -20m AHD

The maximum concentration results for the three nitrogen species modelled are presented in Figure 21, Figure 22 and Figure 23. Total nitrogen is presented in Figure 24.

The results for organic nitrogen indicate very little accumulation at the discharge with a maximum concentration of 0.005 mg/L modelled.

The ammonium and nitrate results indicate accumulation at the discharge with maximum concentrations of 0.037 mg/L and 0.087 mg/L modelled respectively. These values exceed the water quality objectives for ammonium, which is 0.02mg/L and oxidised nitrogen, which is 0.025 mg/L. The implications of these concentration levels is discussed in greater detail in Section 6.2.11 Exceedance of Water Quality Objectives.

The total nitrogen results marginally exceeded the water quality objective of 0.12 mg/L with a maximum concentration of nitrogen of 0.129 mg/L modelled when all species were combined.

Figure 21 Results of WQ Scenario 10. Tidal with Org-N input at -20m AHD

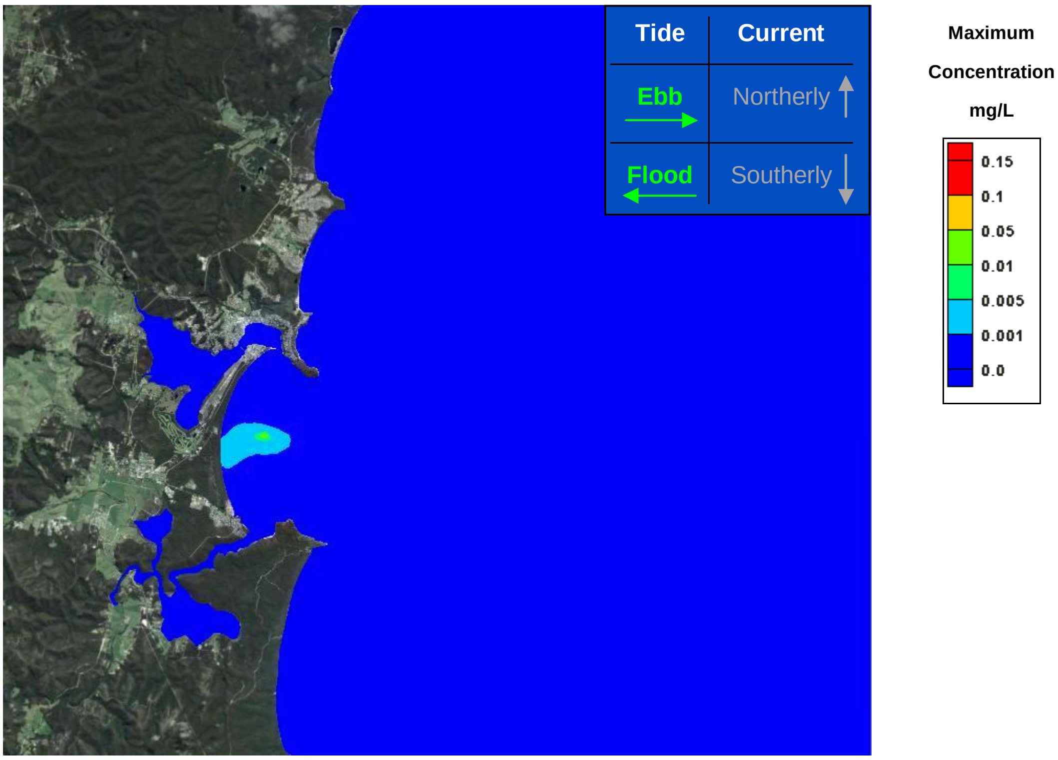

Figure 22 **Results of WQ Scenario 10.** **Tidal with NH_3 input at -20m AHD**

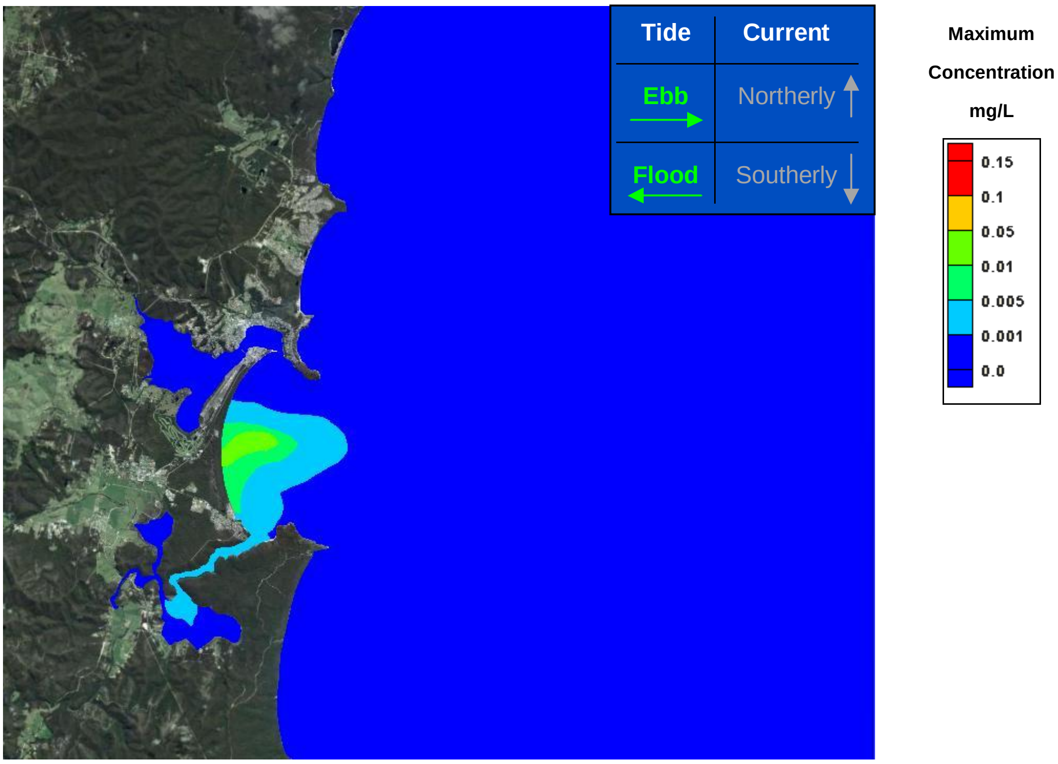

Figure 23 **Results of WQ Scenario 10.** **Tidal with NO_3^- input at -20m AHD**

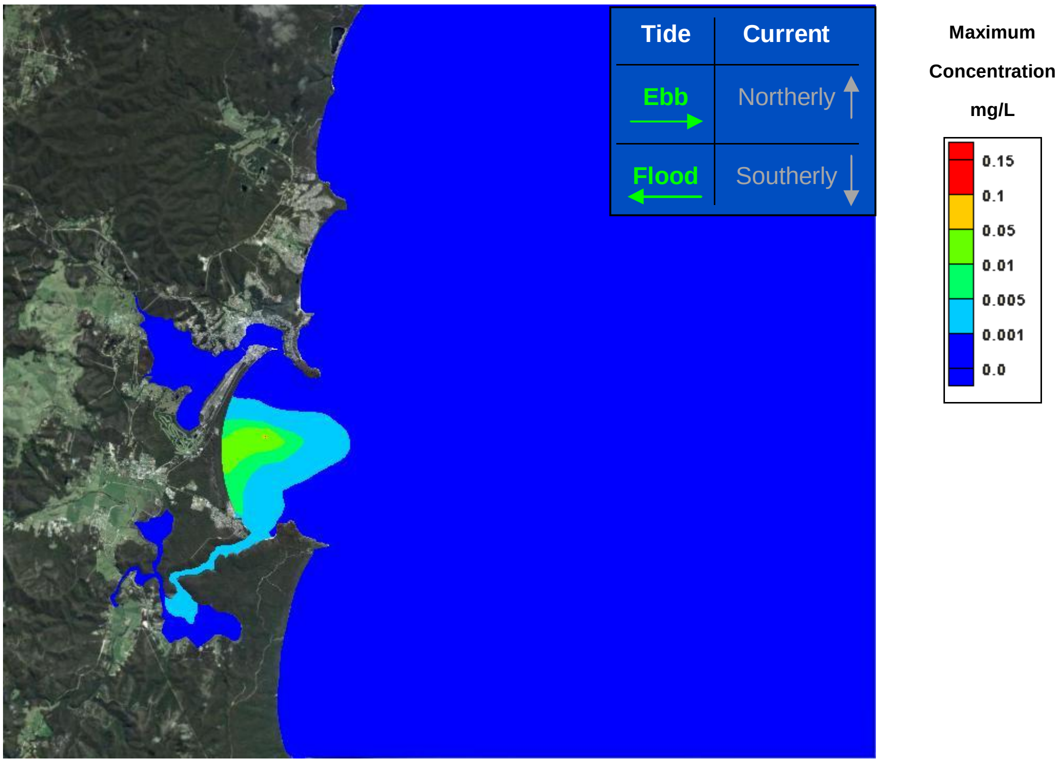

Figure 24 Results of WQ Scenario 10. Tidal with Total Nitrogen at -20m AHD

6.2.6 Water Quality Scenario 11 - Phosphorus Results at –20m AHD

The maximum concentration results for the two phosphorus species modelled are presented in Figure 25 and Figure 26. Total phosphorous is presented in Figure 27.

The results for organic phosphorus indicate very little accumulation at the discharge with a maximum concentration of 0.0065 mg/L modelled.

The phosphate results indicated accumulation at the discharge with a maximum concentration of 0.126 mg/L modelled. This value exceeds the water quality objective for othophosphate which is 0.01 mg/L and is discussed in greater detail in Section 6.2.11 Exceedance of Water Quality Objectives.

Due to the high concentrations of phosphate modelled at the discharge, the total phosphorous results also exceed the water quality objective with a maximum concentration of 0.133 mg/L calculated when the two species are combined. The implications of this are discussed in greater detail in Section 6.2.11 Exceedance of Water Quality Objectives.

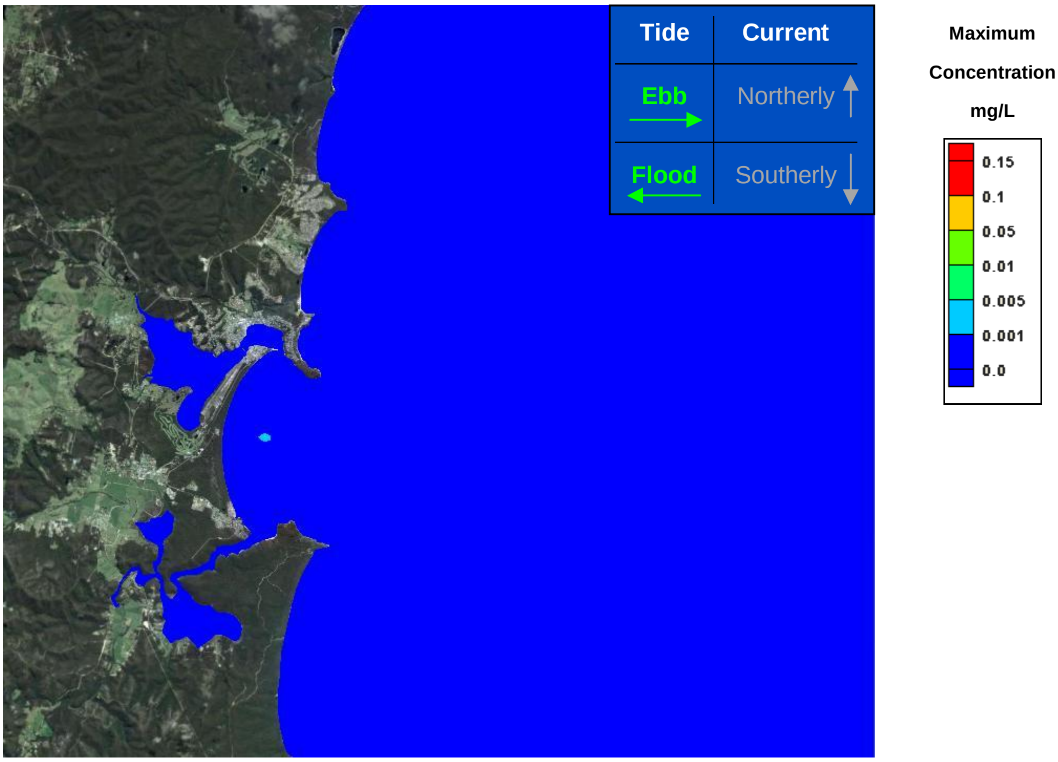

Figure 25 Results of WQ Scenario 11. Tidal with Org-P at -20m AHD

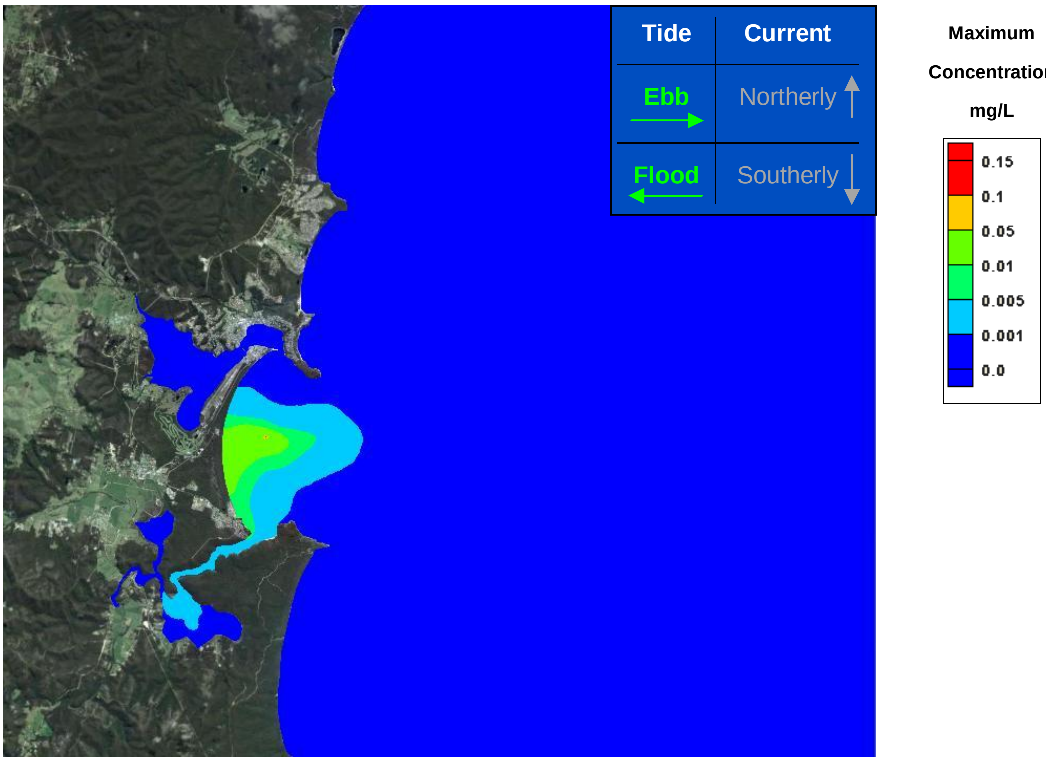

Figure 26 **Results of WQ Scenario 11. Tidal with PO_4^{3-} at -20m AHD**

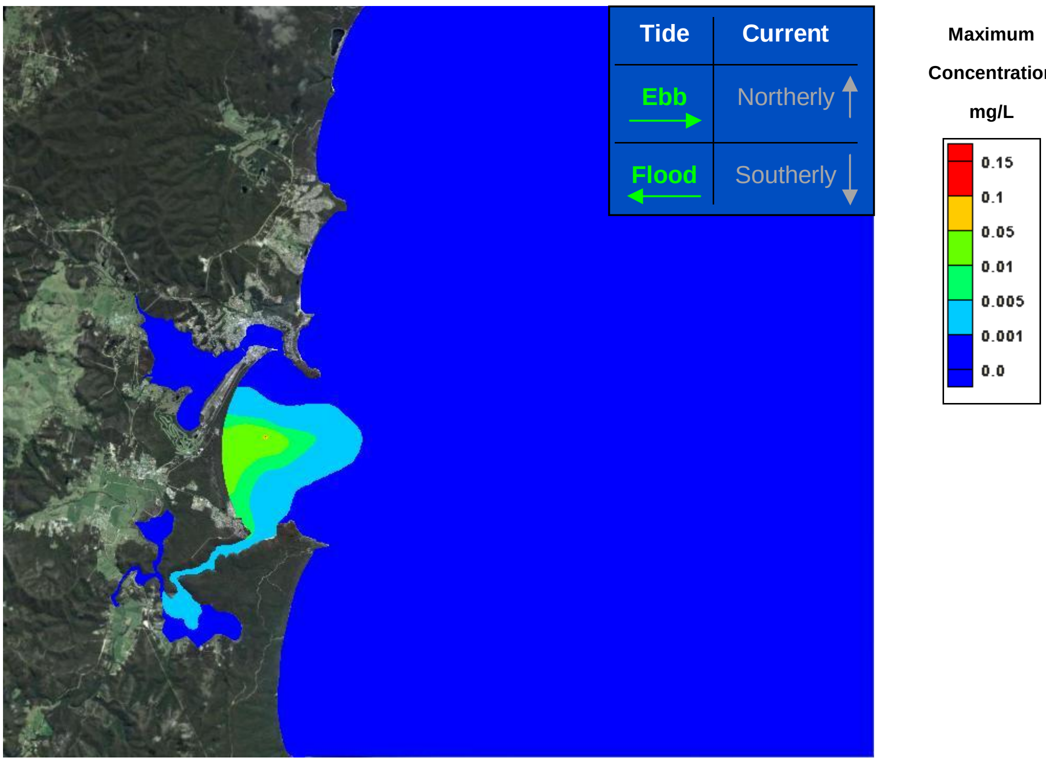

Figure 27 **Results of WQ Scenario 11. Tidal with Total Phosphorous at -20m AHD**

6.2.7 Water Quality Scenario 12 - Faecal Coliform Results at -20m AHD

The maximum faecal coliform concentrations are presented in Figure 28. The results indicated an accumulation of material at the discharge which quickly disperses. The maximum concentration modelled was 849 cfu/100mL which exceeds the water quality objective for faecal coliform of 150 cfu/100mL. The implications of this exceedance are discussed in detail in Section 6.2.11 Exceedance of Water Quality Objectives.

Figure 28 Results of WQ Scenario 12. Tidal with Faecal Coliform input at -20m AHD

6.2.8 Water Quality Scenario 13 - Nitrogen Results at -40m AHD

The maximum concentration results for the three nitrogen species modelled are presented in Figure 29, Figure 30 and Figure 31. Total nitrogen is presented in Figure 32.

The results for organic nitrogen indicate very little accumulation at the discharge with a maximum concentration of 0.002 mg/L modelled. Similarly ammonium results indicate a very little accumulation with a maximum concentration of 0.019 mg/L modelled.

The nitrate results indicate some accumulation at the discharge with a maximum concentration of 0.044 mg/L modelled. This value exceeds the water quality objective for oxidised nitrogen, which is 0.025mg/L and is discussed in greater detail in Section 6.2.11 Exceedance of Water Quality Objectives.

The total nitrogen results were positive with a maximum concentration of nitrogen of 0.065 mg/L modelled when all species were combined. At no time during the model run was the water quality objective for total nitrogen of 0.12 mg/L exceeded.

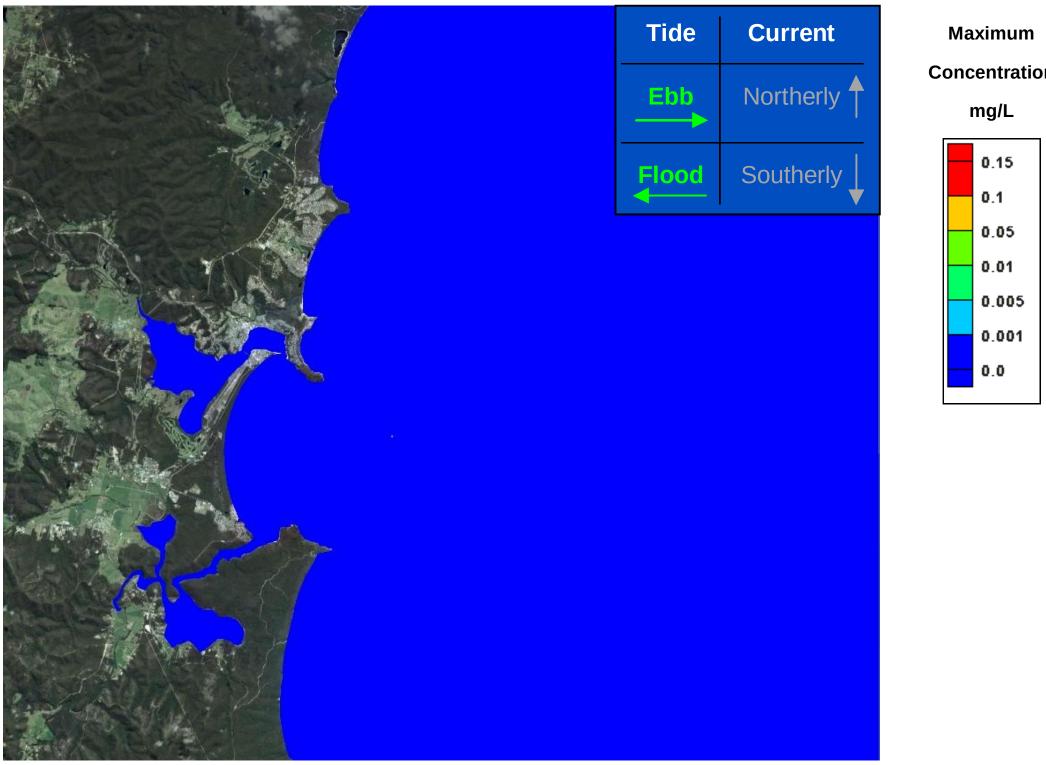

Figure 29 Results of WQ Scenario 13. Tidal with Org-N input at -40m AHD

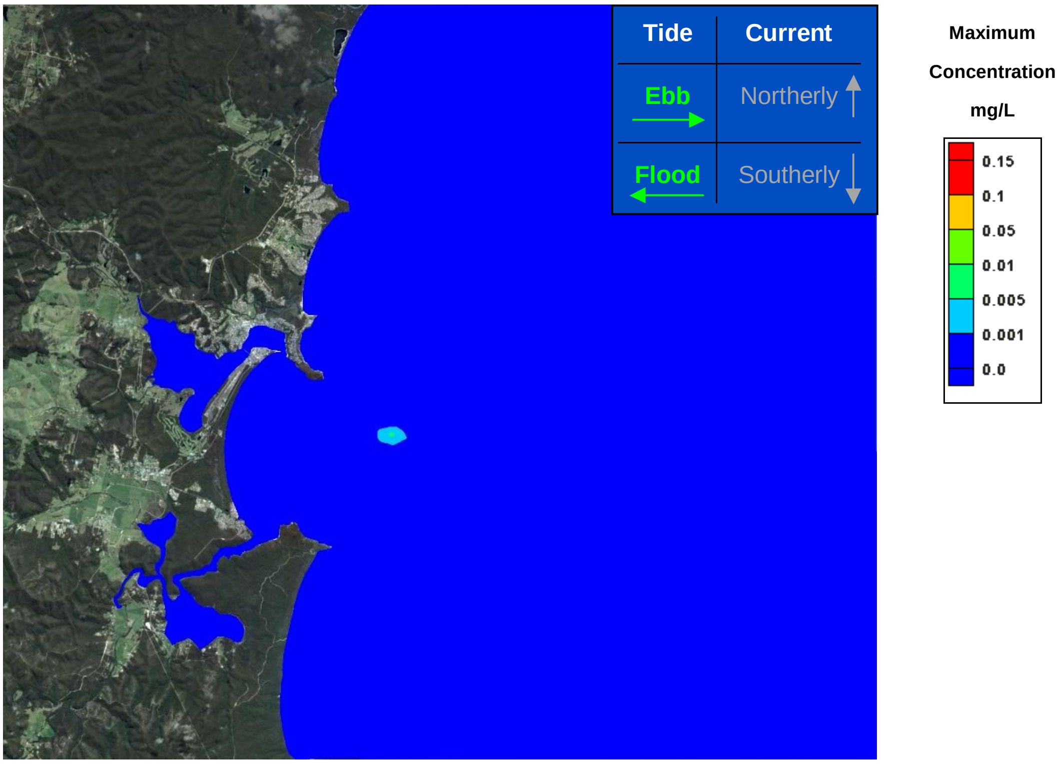

Figure 30 Results of WQ Scenario 13. Tidal with NH_3 input at -40m AHD

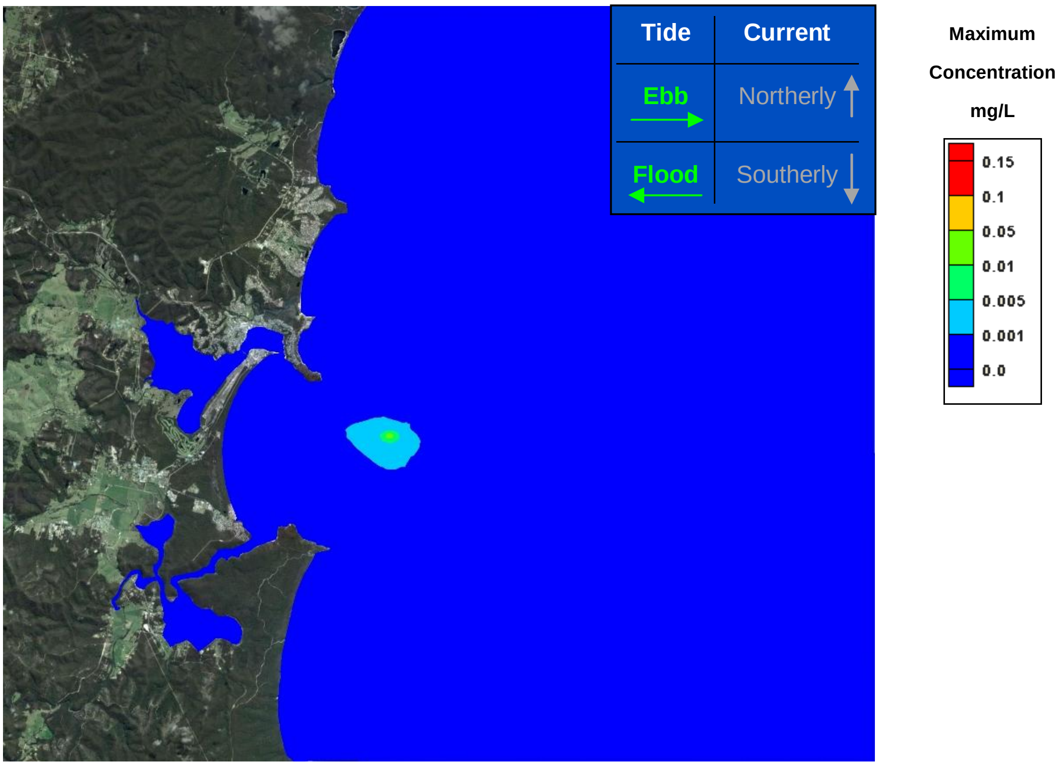

Figure 31 Results of WQ Scenario 13. Tidal with NO_3^- input at -40m AHD

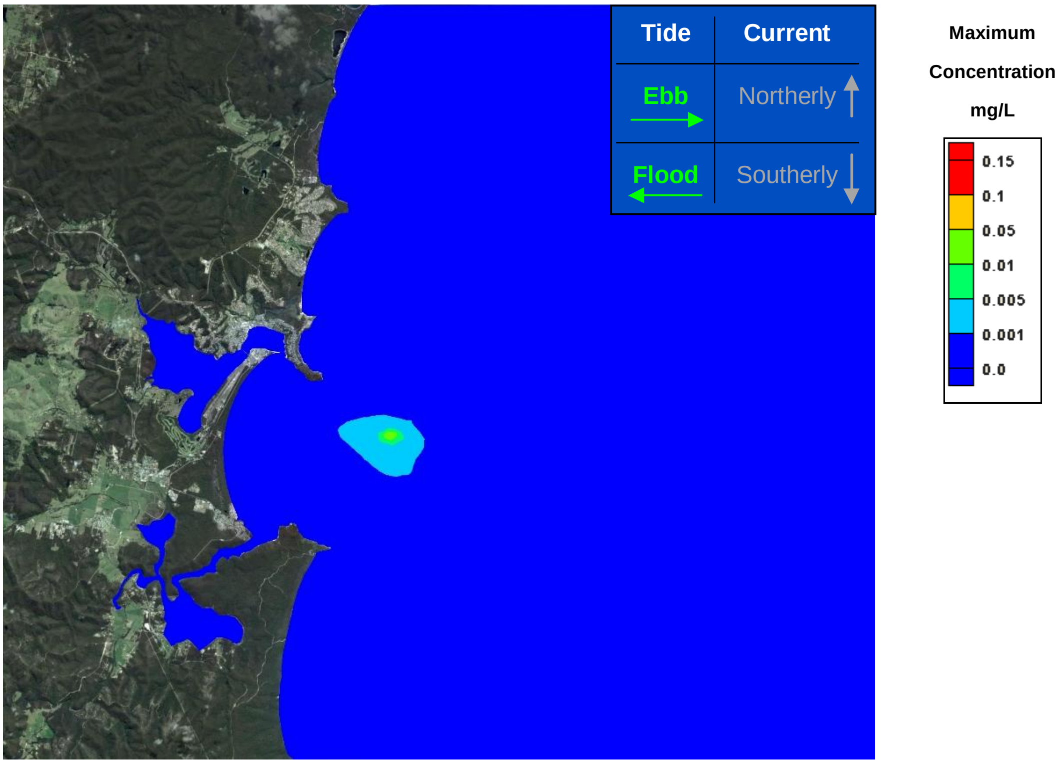

Figure 32 Results of WQ Scenario 13. Tidal with Total Nitrogen at -40m AHD

6.2.9 Water Quality Scenario 14 - Phosphorus Results at –40m AHD

The maximum concentration results for the two phosphorus species modelled are presented in Figure 33 and Figure 34. Total phosphorous is presented in Figure 35.

The results for organic phosphorus indicate very little accumulation at the discharge with a maximum concentration of 0.0034 mg/L modelled.

The phosphate results indicated some accumulation at the discharge with a maximum concentration of 0.062 mg/L modelled. This value exceeds the water quality objective for othophosphate which is 0.01 mg/L and is discussed in greater detail in Section 6.2.11 Exceedance of Water Quality Objectives.

Due to the high concentrations of phosphate modelled at the discharge, the total phosphorous results also exceed the water quality objective with a maximum concentration of 0.066 mg/L calculated when the two species are combined. The implications of this are discussed in greater detail in Section 6.2.11 Exceedance of Water Quality Objectives.

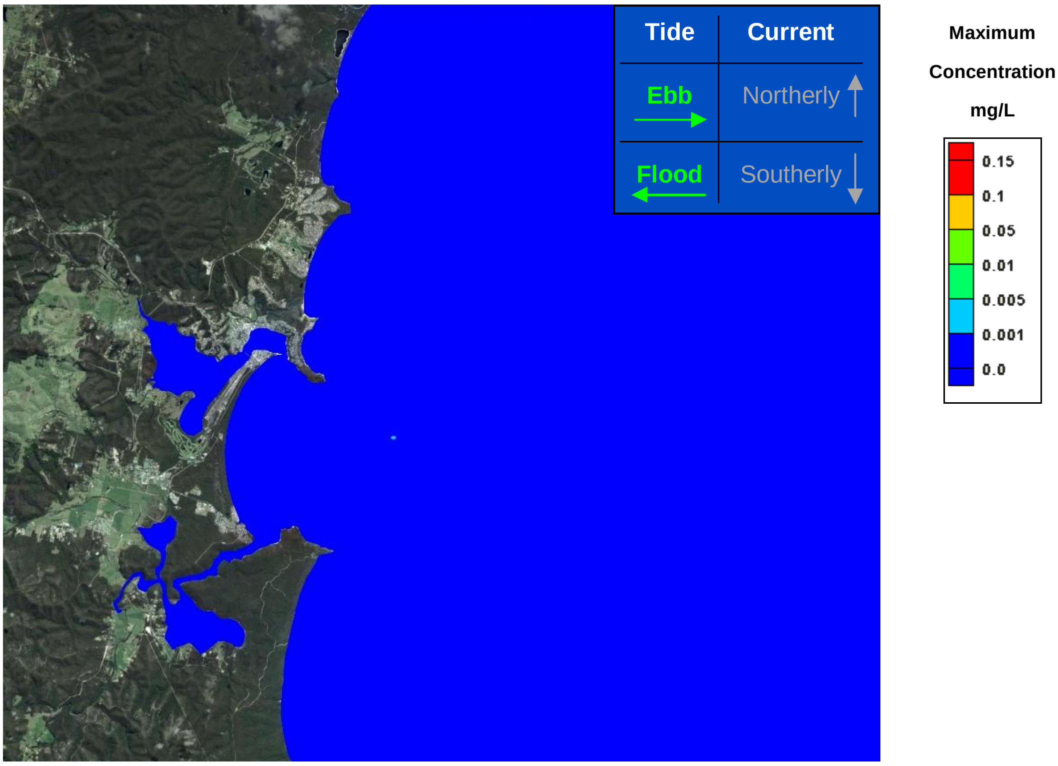

Figure 33 Results of WQ Scenario 14. Tidal with Org-P at -40m AHD

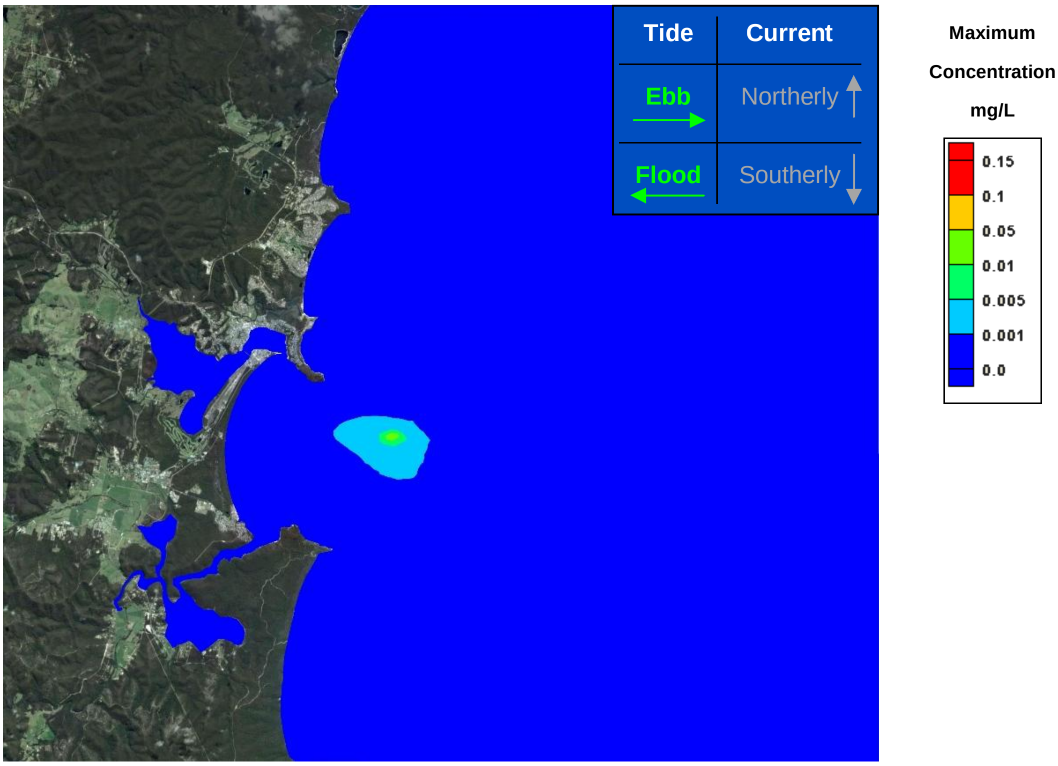

Figure 34 Results of WQ Scenario 14. Tidal with PO_4^{3-} at -40m AHD

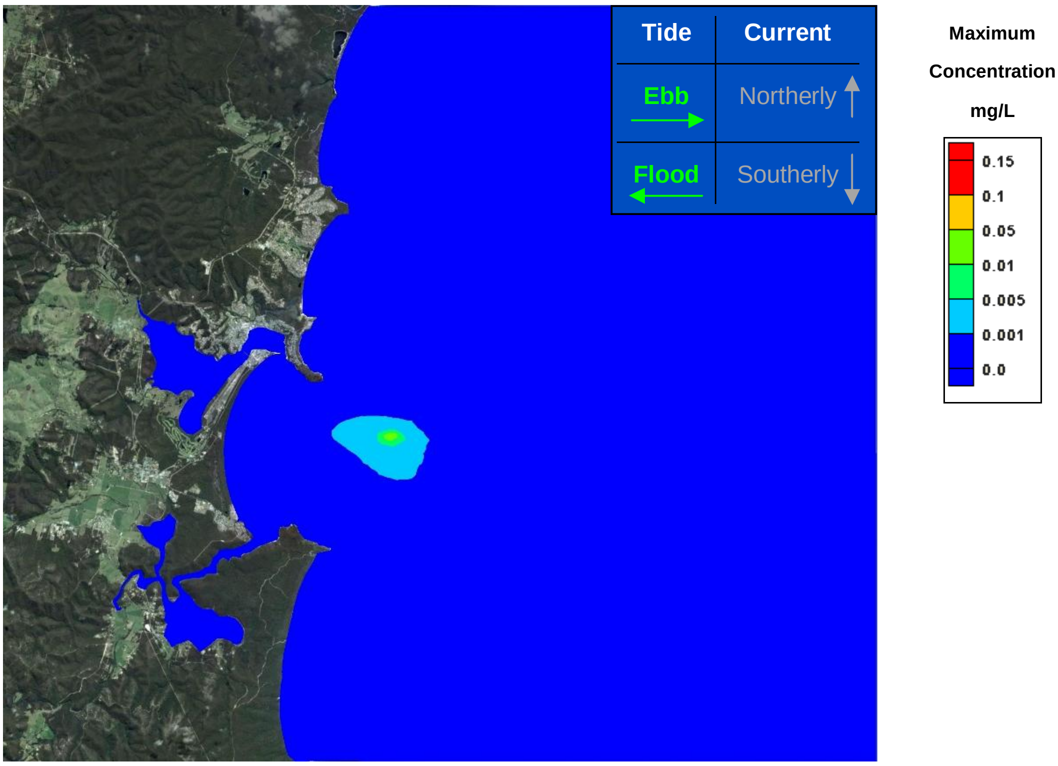

Figure 35 Results of WQ Scenario 14. Tidal with Total Phosphorous at -40m AHD

6.2.10 Water Quality Scenario 15 - Faecal Coliform Results at -40m AHD

The maximum faecal coliform concentrations are presented in Figure 36. The results indicated an accumulation of material at the discharge which quickly disperses. The maximum concentration modelled was 274 cfu/100mL which exceeds the water quality objective for faecal coliform of 150 cfu/100mL. The implications of this exceedance are discussed in detail in Section 6.2.11 Exceedance of Water Quality Objectives.

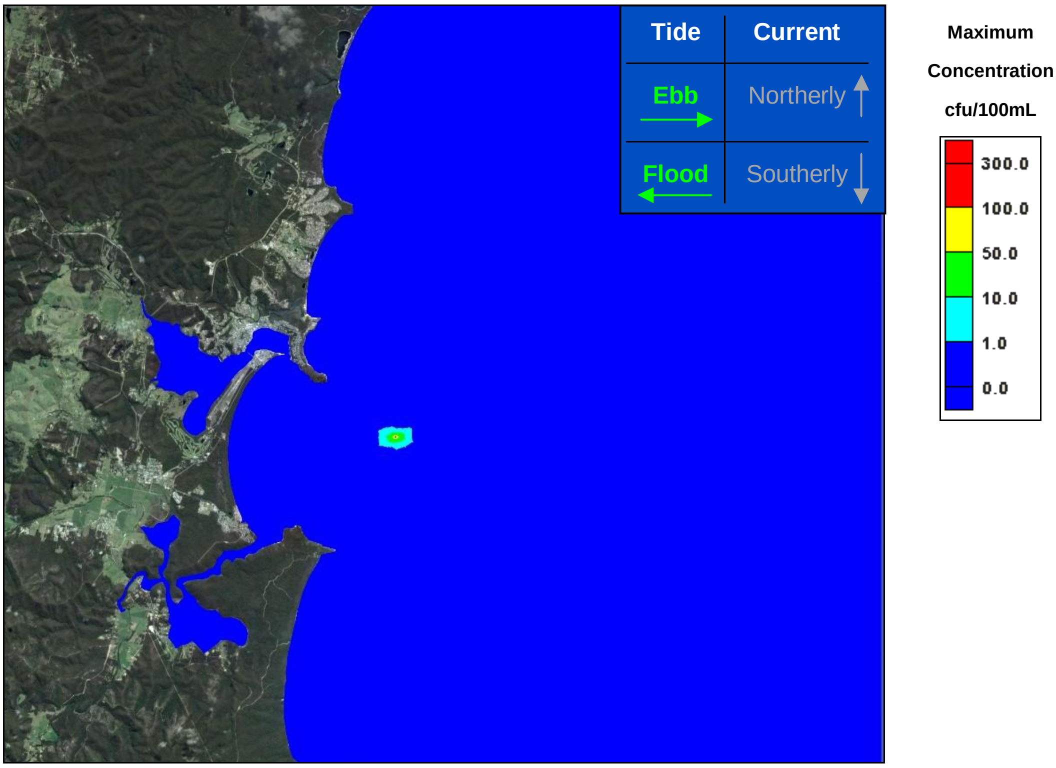

Figure 36 Results of WQ Scenario 15. Tidal with Faecal Coliform input at -40m AHD

6.2.11 Exceedance of Water Quality Objectives

The modelling, under the conservative worst case hydrodynamic scenario of tidal influence only, has indicated that for a number of constituents, the water quality objectives outlined in the ANZECC guidelines were exceeded at both a 20 m and 40 m discharge depth. For the 20 m depth, species were ammonium, nitrate, total nitrogen, phosphate, total phosphorus and faecal coliform. The areas of exceedance for these species can be seen in Figure 37, Figure 38, Figure 39, Figure 40, Figure 42 and Figure 43 respectively. For the 40 m depth, species were nitrate, phosphate, total phosphorus and faecal coliform with the areas of exceedance shown in Figure 44, Figure 45, Figure 46 and Figure 47 respectively. The figures show the area exceeding half the objective (green) and the area where the objective is exceeded (red). The areas are summarised in Table 9 and Table 10.

Table 9 Areas of constituents modelled where values exceed ANZECC water quality objectives at a -20m AHD discharge depth

Constituent	Effluent Discharge 90th %ile concentration	Water Quality Objective	Maximum Concentration recorded (over modelling time / space domain)	Area 50% of WQO Exceeded (m^2)	Area 100% of WQO Exceeded (m^2)	Equivalent Radius (m)
Ammonium	3.9 mg/L	0.020 mg/L	0.037 mg/L	29,650	2,200	27
Nitrate	8.6 mg/L	0.025 mg/L	0.087 mg/L	366,800	40,300	113
Total Nitrogen	13.0 mg/L	0.12 mg/L	0.129 mg/L	5,000	80	5
Phosphate	12.3 mg/L	0.010 mg/L	0.126 mg/L	7,839,200	2,059,100	810
Total Phosphorous	13.0 mg/L	0.025 mg/L	0.133 mg/L	1,639,900	145,100	215
Faecal Coliforms	1,420 cfu/100mL	150 cfu/100mL	849 cfu/100mL	49,700	18,850	77

Table 10 Areas of constituents modelled where values exceed ANZECC water quality objectives at a -40m AHD discharge depth

Constituent	Effluent Discharge 90th%ile concentration	Water Quality Objective	Maximum Concentration recorded (over modelling time / space domain)	Area 50% of WQO Exceeded (m^2)	Area 100% of WQO Exceeded (m^2)	Equivalent Radius (m)
Nitrate	8.6 mg/L	0.025 mg/L	0.044 mg/L	23,400	1,200	20
Phosphate	12.3 mg/L	0.010 mg/L	0.062 mg/L	331,500	81,700	160
Total Phosphorous	13.0 mg/L	0.025 mg/L	0.066 mg/L	51,700	7,200	48
Faecal Coliforms	1,420 cfu/100mL	150 cfu/100mL	274 cfu/100mL	7,400	800	16

An additional model was run with a reduced phosphate input at the -20 m AHD outfall location to determine what level of additional treatment will be required to achieve an acceptable level of water quality objective exceedance, within the defined mixing zone radii (i.e. <100 m). This is seen in Figure 41 and is summarised in Table 11. A 90th percentile level of 2.5 mg/L was adopted (reduced from 12.3 mg/L) which resulted in achieving the 100% water quality exceedance level within an area with equivalent radius of 82 m.

Table 11 Area of phosphate modelled where values exceed ANZECC water quality objectives at a -20m AHD discharge depth with reduced phosphate input.

Constituent	Effluent Discharge 90th%ile concentration	Water Quality Objective	Maximum Concentration recorded (over modelling time / space domain)	Area 50% of WQO Exceeded (m^2)	Area 100% of WQO Exceeded (m^2)	Equivalent Radius (m)
Phosphate	2.5 mg/L	0.010 mg/L	0.026 mg/L	215,600	20,800	82

The water quality objectives relate to the ambient water quality in the region and not, specifically, to the area adjacent to the effluent discharge location. It is likely that initial dilution rates exceeding the assumed (x 20) could be achieved during the detailed design of the effluent diffusers.

Furthermore, the modelling was undertaken using the maximum daily flow and the 90th percentile constituent concentrations and run for an entire month with no offshore currents. In reality, it is unlikely that these conditions would occur. Indeed the data issued by the BVSC indicated that continuous flows exceeding 2,000 kL/day have not occurred over the past five years. Based on the Sydney current data, it is likely that offshore currents would, in effect, be at least some of the time over an entire month which would aid in dispersion. These factors should be kept in mind when considering the following figures.

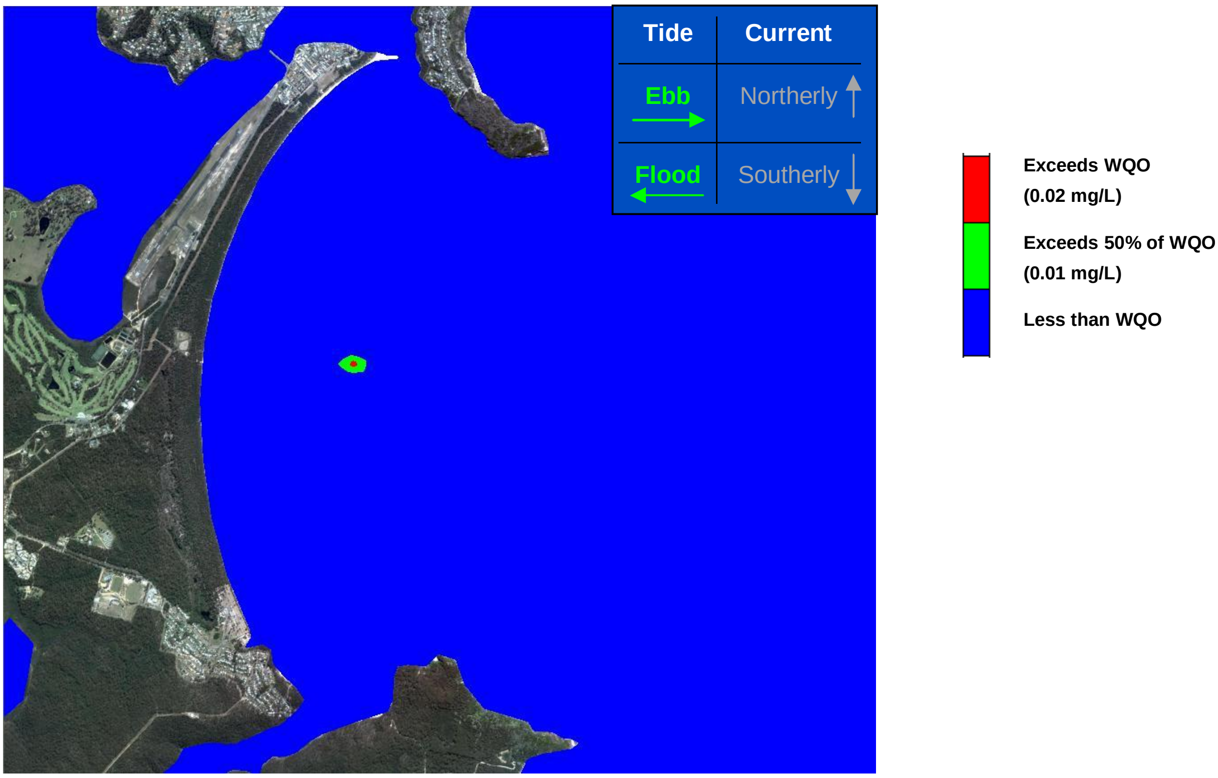

Figure 37 **Exceedance of NH_3 water quality objective (0.02mg/L) from 90%ile discharge (3.9 mg/L) at -20m AHD**

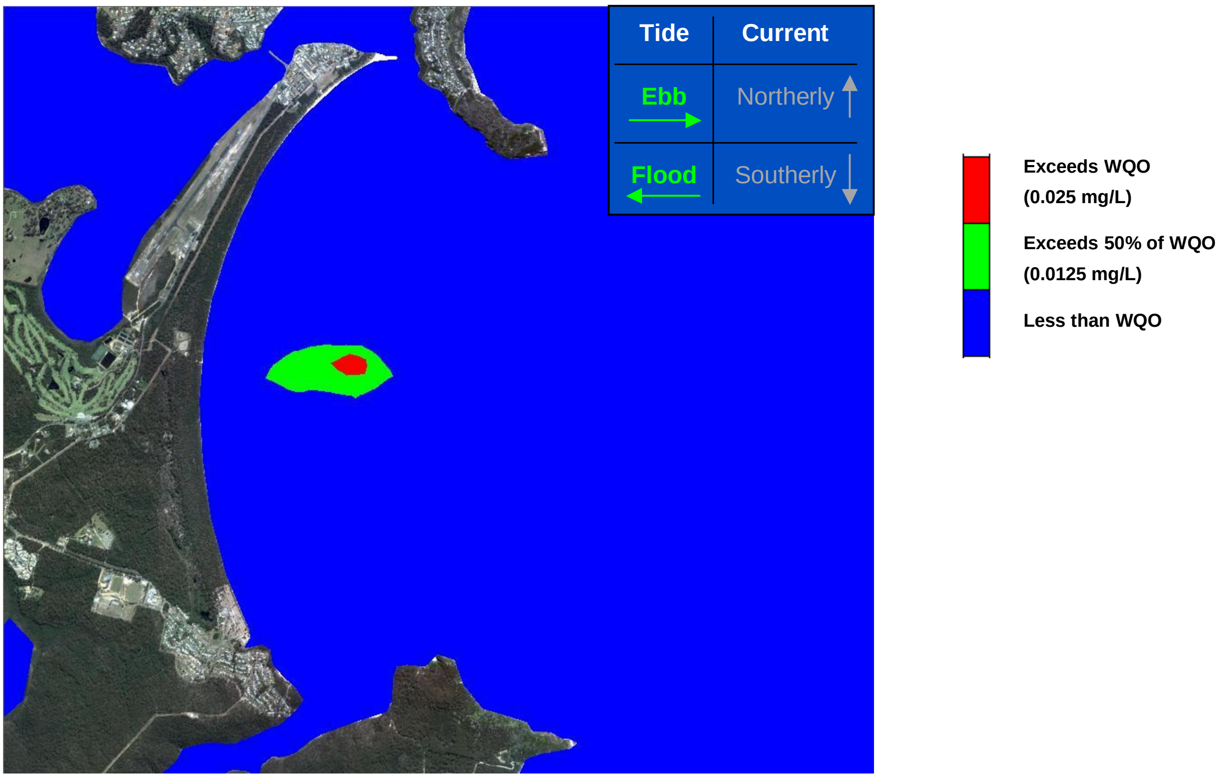

Figure 38 **Exceedance of NO_x water quality objective (0.025mg/L) from 90%ile discharge (8.6 mg/L) at -20m AHD**

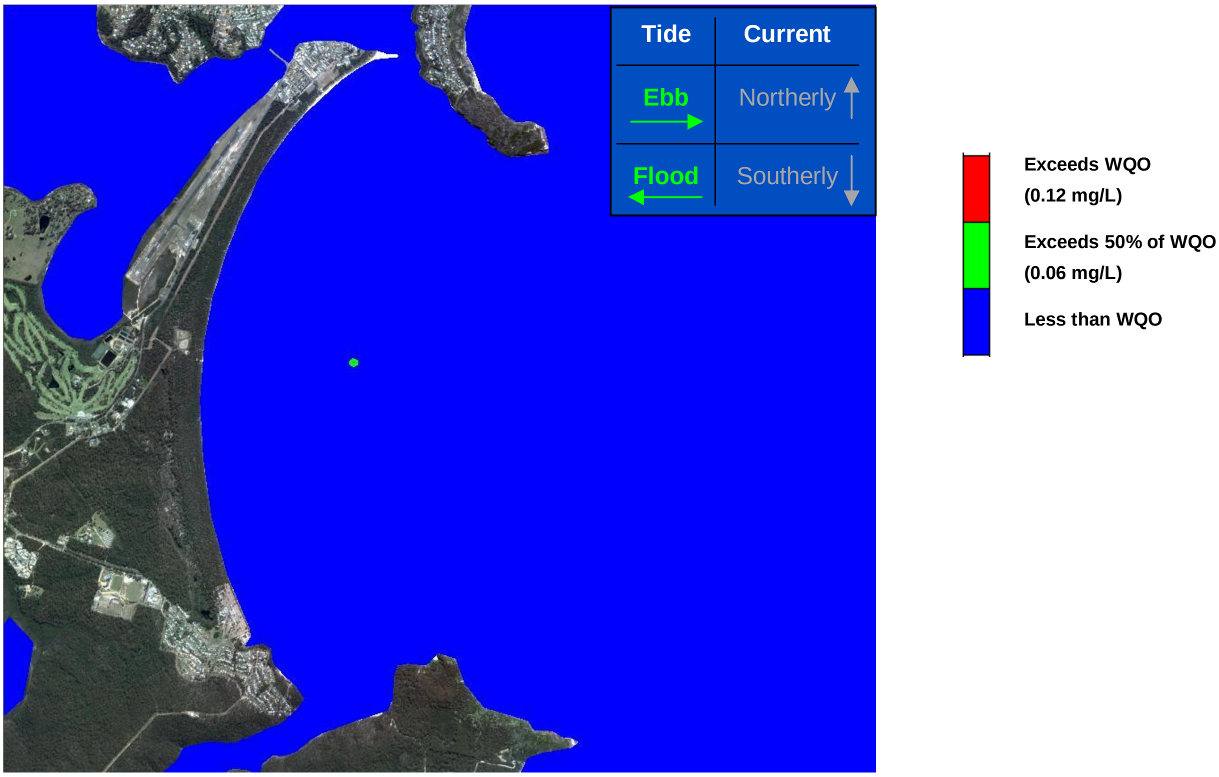

Figure 39 **Exceedance of Total Nitrogen water quality objective (0.12mg/L) from 90%ile discharge (13.0 mg/L) at -20m AHD**

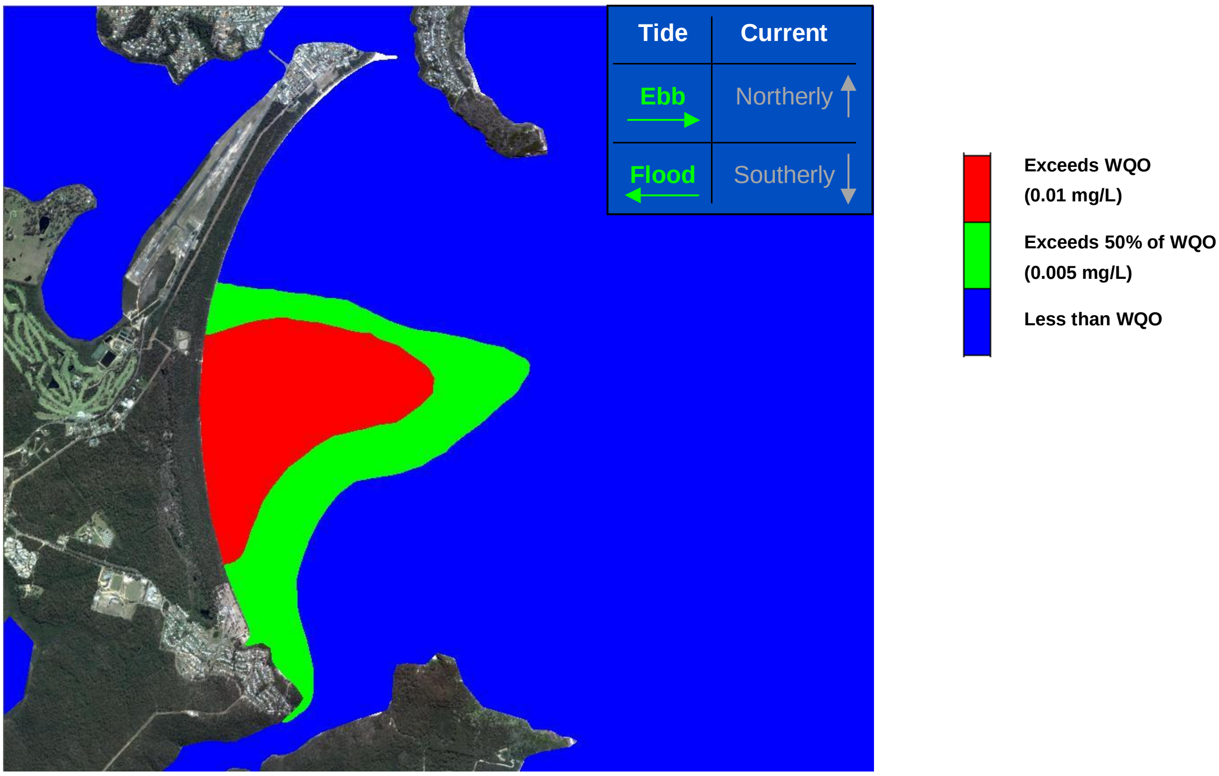

Figure 40 **Exceedance of PO_4^{3-} water quality objective (0.01mg/L) from 90%ile discharge (12.3 mg/L) at -20m AHD**

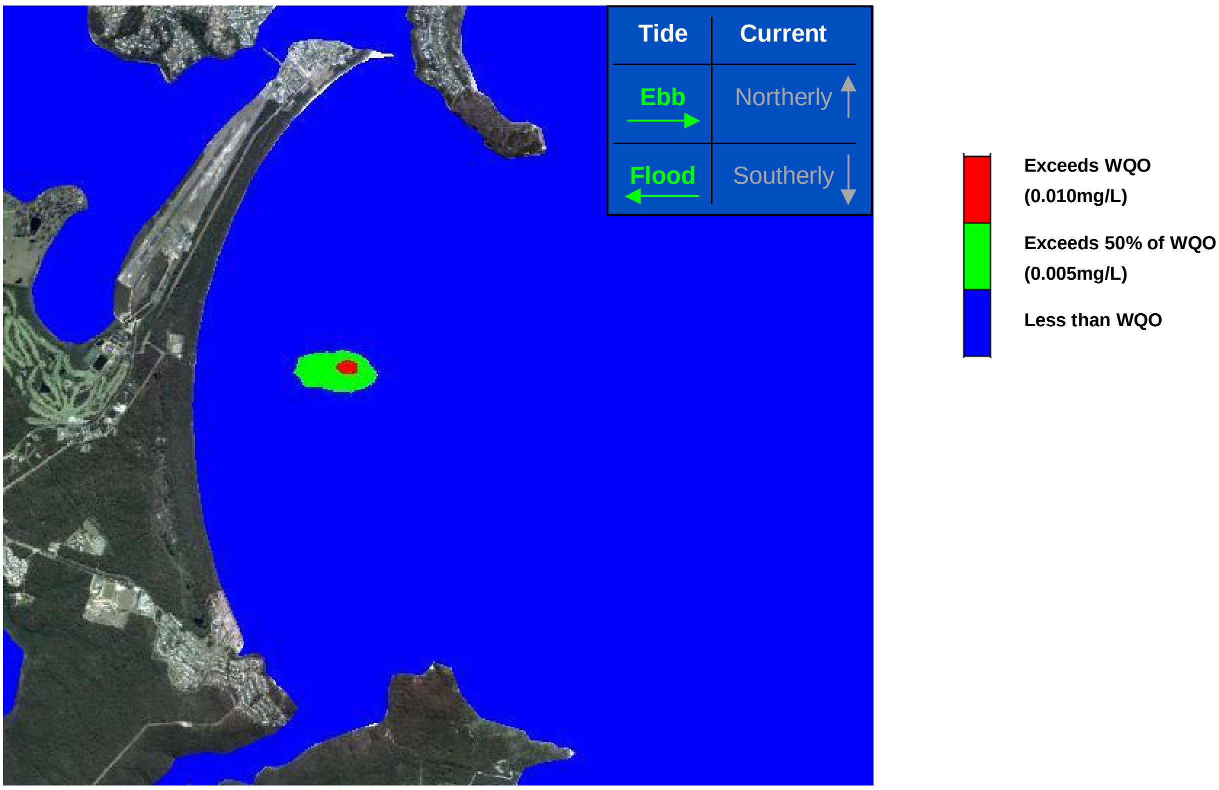

Figure 41 **Exceedance of PO_4^{3-} water quality objective (0.01mg/L) from reduced discharge (2.5 mg/L) at -20m AHD**

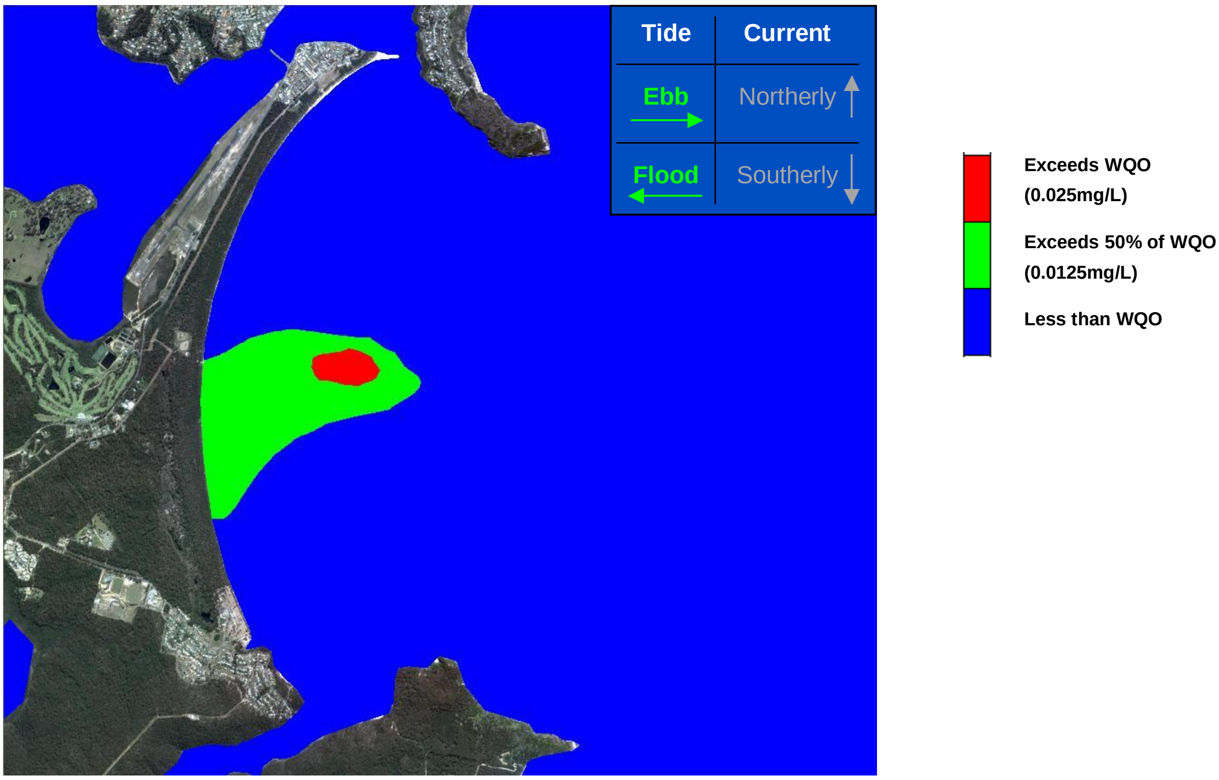

Figure 42 **Exceedance of Total Phosphorus water quality objective (0.025mg/L) from 90%ile discharge (13.0 mg/L) at -20m AHD**

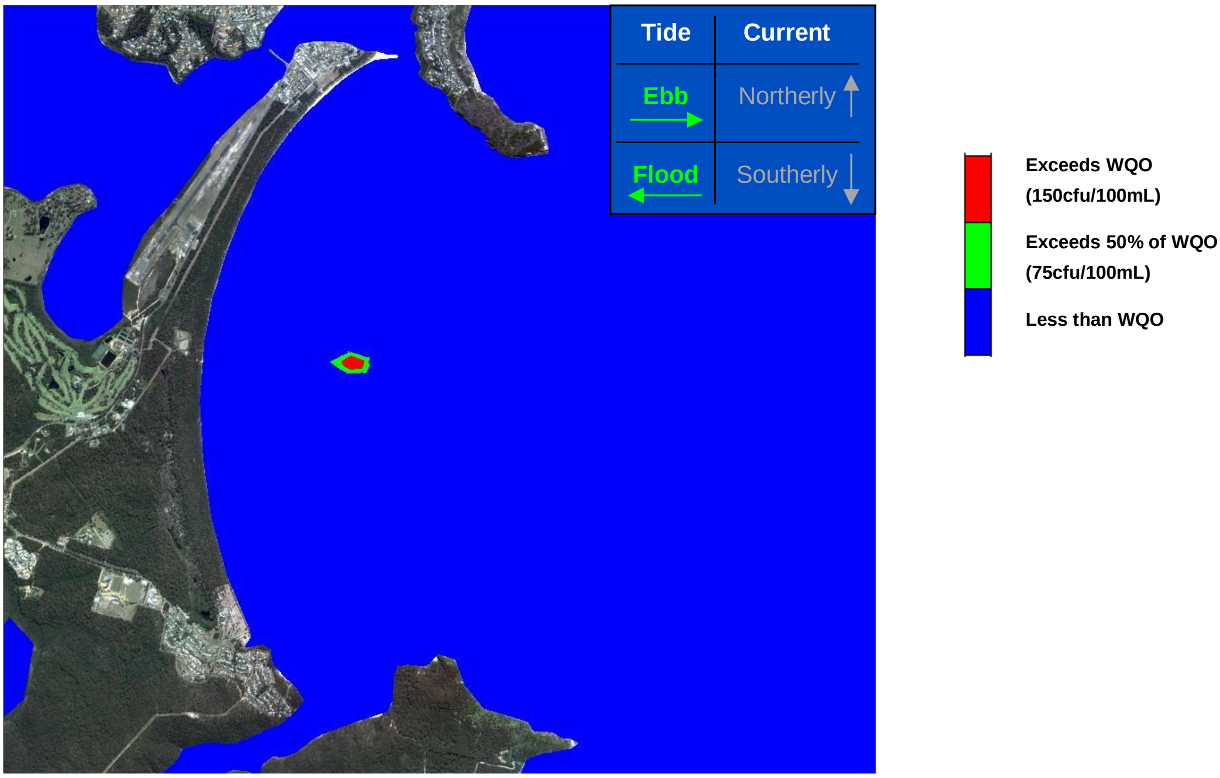

Figure 43 Exceedance of faecal coliform water quality objective (150cfu/100mL) from 90%ile discharge (1,420 cfu/100mL) at -20m AHD

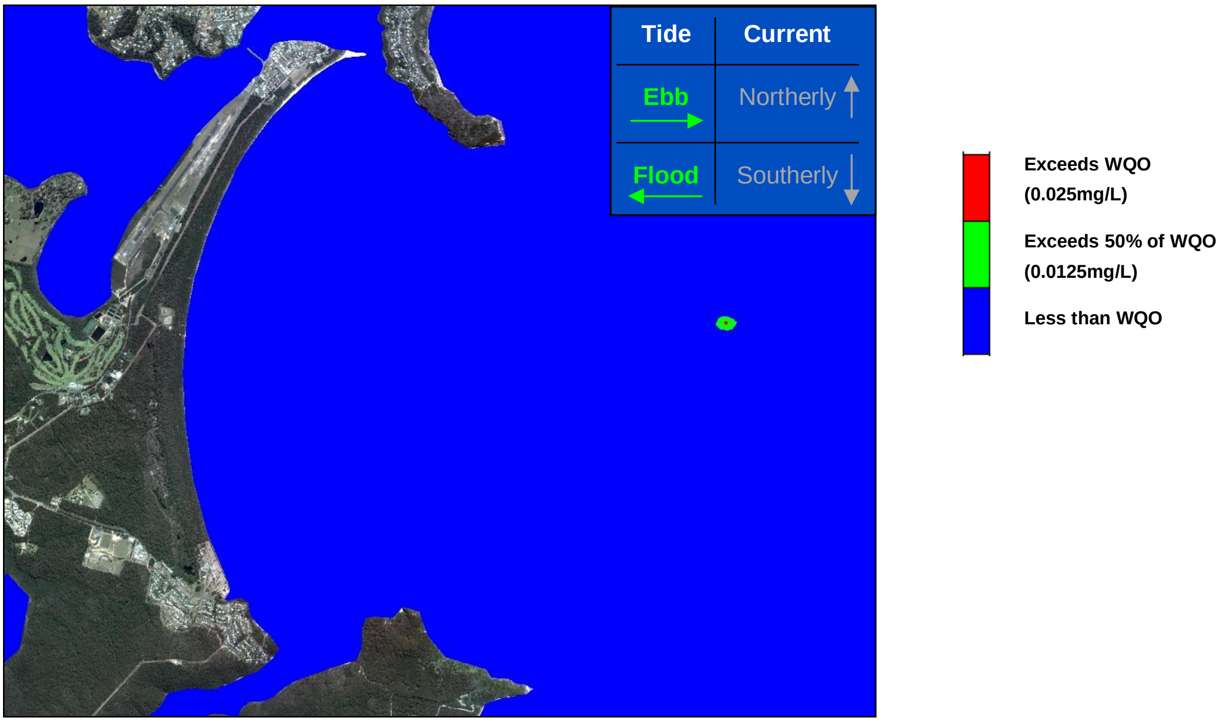

Figure 44 Exceedance of NO_3^- water quality objective (0.025mg/L) from 90%ile discharge (8.6 mg/L) at -40m AHD

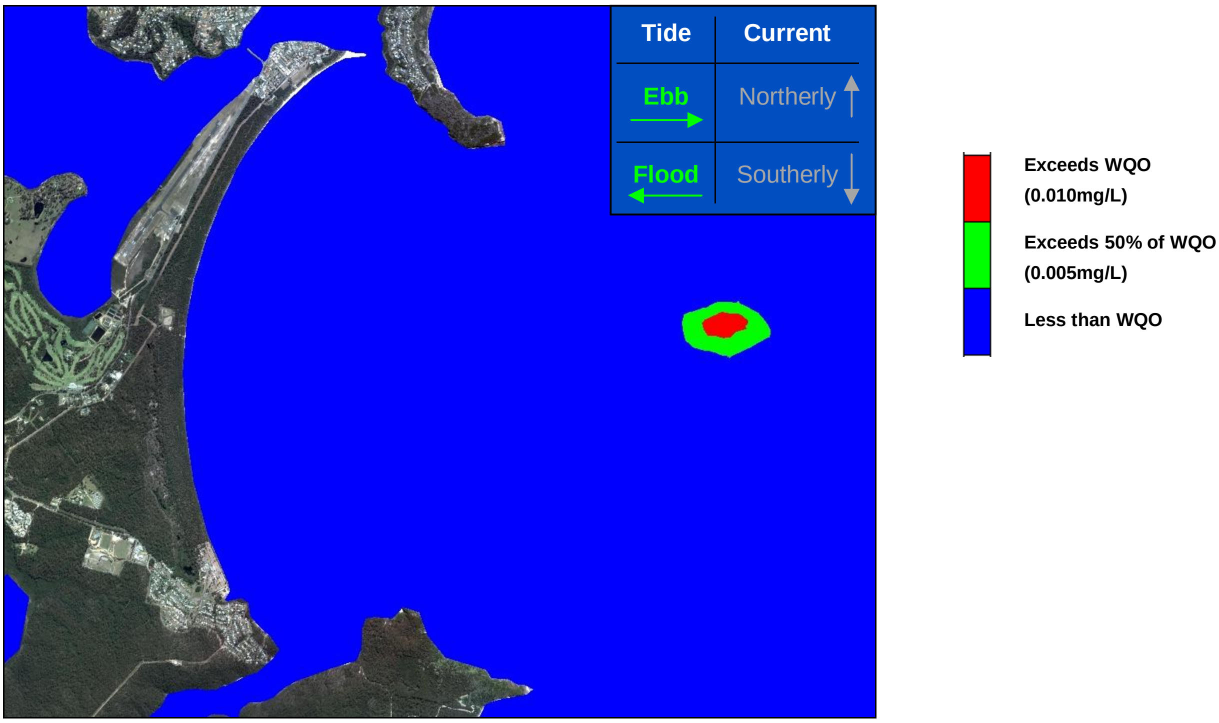

Figure 45 Exceedance of PO_4^{3-} water quality objective (0.01mg/L) from 90%ile discharge (12.3 mg/L) at -40m AHD

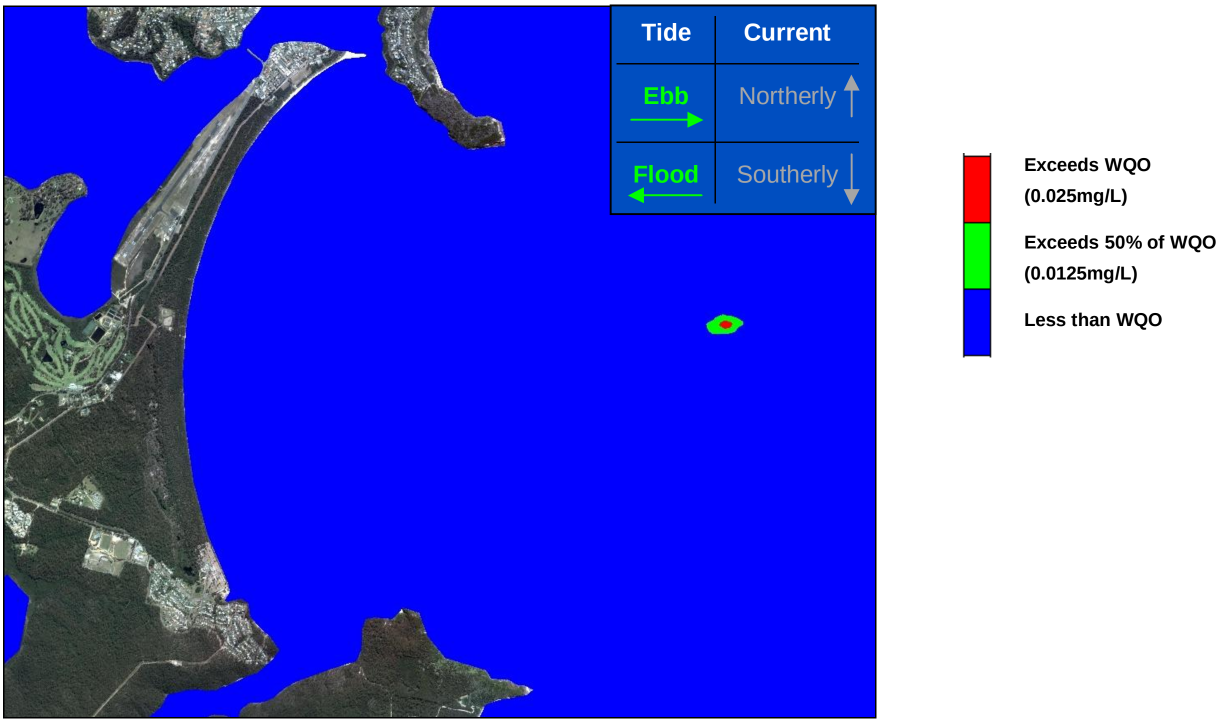

Figure 46 Exceedance of Total Phosphorus water quality objective (0.025mg/L) from 90%ile discharge (13.0 mg/L) at -40m AHD

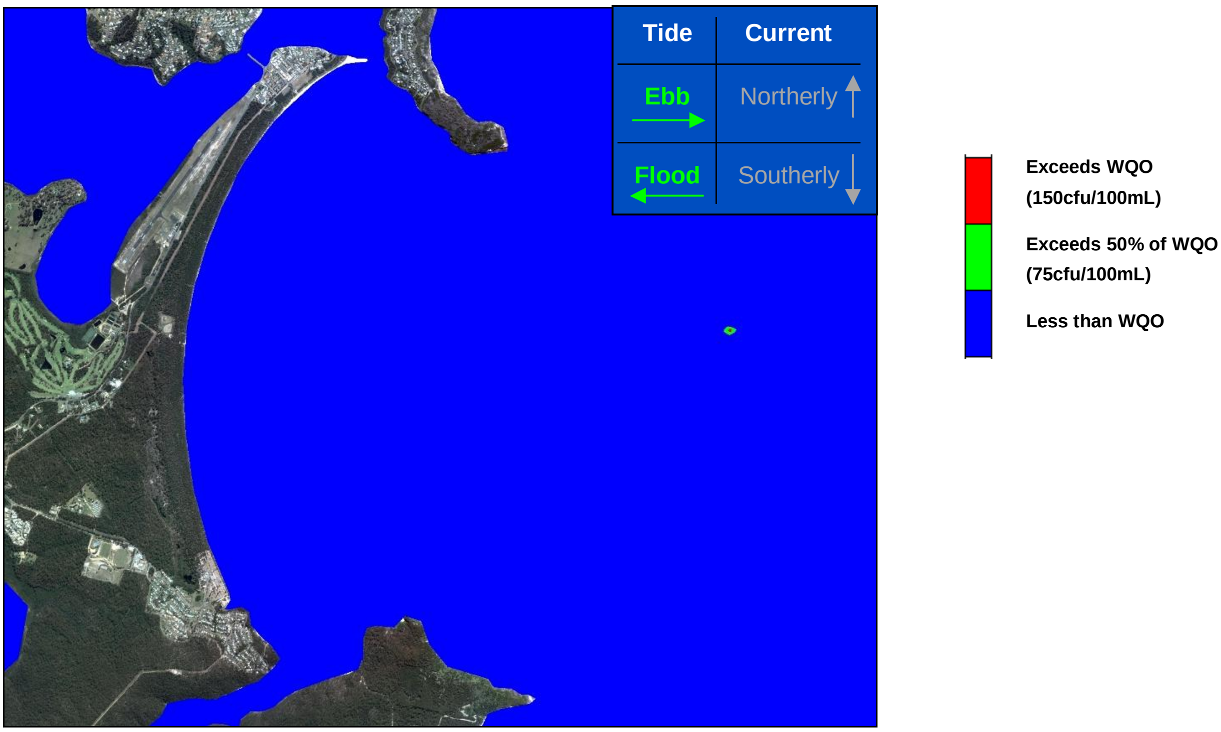

Figure 47 Exceedance of faecal coliform water quality objective (150cfu/100mL) from 90%ile discharge (1,420 cfu/100mL) at -40m AHD

6.3 Discussion

The far field modelling undertaken has provided useful information to aid the decision making process for the progression of the project. In general, the results indicate that an ocean outfall located at a depth of -40m would be feasible from a water quality perspective with the current treatment system.

At no stage during the modelling was the water quality objective for TSS exceeded including the three scenarios with the discharge located at -20m. The best results for TSS were achieved with the -40m discharge with the scenarios where a current was included having very little accumulation of material at the discharge.

The other constituents all had species where the water quality objectives were exceeded at both the -20m and -40m discharge depths. At a discharge depth of -20m, water quality objectives were exceeded by a significant margin for some species. Of particular concern were phosphate levels which reached over 12 times the water quality objective at its maximum, with levels above the water quality objective recorded up to the shore on a large area of Merimbula Bay. An additional model was run for scenario 11, to determine what level of additional treatment to effluent would be required to produce more acceptable results. Reducing phosphate input at the outfall location from 12.3 mg/L to 2.5 mg/L resulted in a significantly smaller area of water quality objective exceedance. Maximum faecal coliform levels were also found to exceed the water quality objective significantly. However, levels above the water quality objective were localised near the discharge area. It can be seen that constituents discharged at a depth of -20m in Merimbula Bay have a tendency to accumulate at higher levels across a larger area when compared with the -40m discharge depth scenarios. Low concentrations of constituents were found to accumulate along the shore of Merimbula Bay and within the estuaries with minimal offshore dispersal. The only exception to this was shown in Scenario 4, with a North current providing movement of total suspended solids out of the bay.

Results from TSS scenarios with a -30m discharge depth were found to be similar to the results for the -20m discharge depth. The constituent remained in Merimbula Bay with low concentrations found along the shore of the bay and within the estuaries. It is expected that further modelling at this depth would yield similar results shown for the -20m depth.

At a discharge depth of -40m, water quality objectives were exceeded for some species. However, these were all located in a relatively small area in the vicinity of the discharge and there was no accumulation of material within Merimbula Bay or the adjacent estuaries. Moreover, the ANZECC guidelines apply to the ambient water quality and some initial exceedance may be allowable in the initial dilution zone. A discharge depth of -40m is, therefore, the preferred option for an ocean outfall.

As no near field dilution modelling has been undertaken, an initial dilution rate of 20 was assumed based on the literature. During the detailed design of the diffusers for the final option it is likely that the dilution rates far exceeding that assumed could be achieved. This would improve the water quality contours for the project.

Finally, a number of conservative assumptions were made in the development of the pilot water quality model including; the daily flow volume, the constituent concentrations and the absence of offshore currents. It is unlikely that, in reality, all of these conditions would occur concurrently, a point that should be remembered when considering the results.

Further, in addition to those constituents considered above, there is potentially other chemical constituents which have not been outlined that may need to be considered as part of a full ecological assessment to determine their required mixing and/or treatment to enable a safe and sustainable ocean discharge.

7.0 Conclusion

The Merimbula pilot water quality model has been developed to investigate the water quality impacts and a range of possible offshore discharge locations. A number of key constituents were modelled at designated depths and for varying hydrodynamic conditions. The results indicated that, for the most part, the specified water quality objectives can be achieved with no alteration to the existing STP process.

For some species, results were obtained where the water quality objectives were exceeded. However, it is likely that further modelling and, ultimately, the detailed design of the preferred option would overcome these issues.

Indeed, with a conservative approach taken to develop the pilot model, results indicated that shallower depths for an outfall may be viable also, which could be investigated with fully developed, calibrated and validated near field and far field models.

8.0 References

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