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# Hunter Estuary Wetlands Ramsar Contaminant Transport Modelling

WRL TR 2018/31 Revision 1 | September 2019

By B M Miller, P F Rahman and W C Glamore

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## Project details

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|---|---|
| **Report title** | Hunter Estuary Wetlands Ramsar Contaminant Transport Modelling |
| **Authors(s)** | B M Miller, P F Rahman and W C Glamore |
| **Report no.** | 2018/31 |
| **Report status** | Revision 1 Final |
| **Date of issue** | September 2019 |
| **WRL project no.** | 2018059 |
| **Project manager** | B M Miller |
| **Client** | Department of Environment and Energy |
| **Client address** | |
| **Client contact** | |
| **Client reference** | |

## Document status

| Version | Reviewed by | Approved by | Date issued |
|---|---|---|---|
| Preliminary draft | W C Glamore | | 28 September 2018 |
| Final draft | W C Glamore | G P Smith | 15 October 2018 |
| Final | W C Glamore | G P Smith | 25 October 2018 |
| Revision 1 Final | B M Miller | G P Smith | 23 September 2019 |

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# 1 Introduction

The Department of the Environment and Energy aims to understand the potential for chemical contaminants from diffuse and point sources in the Lower Hunter River on the Kooragang component of the Hunter Estuary Wetlands Ramsar site. In this study, the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney has:

- Completed a review of historical pollutant sources;
- Refined an existing hydrodynamic and water quality model to resolve dispersion from all potential lower estuary pollutant sources;
- Numerically simulated twelve months of dry weather (baseflow) conditions to predict the fate and transport of contaminants from various potential pollutant sources;
- Analysed and interpreted these numerical modelling scenarios for the existence of potential impacts upon the Kooragang component of the Hunter Estuary Wetlands Ramsar site; and
- Provided recommendations regarding how these initial simulations can be applied and/or confirmed onsite.

Figure 1 presents the Lower Hunter River Estuary and the location of the Kooragang component of the Hunter Estuary Wetlands Ramsar site. The Kooragang Nature Reserve, which is now part of Hunter Wetlands National Park, was listed under the international Ramsar convention in 1984. The Hunter Estuary Wetlands Ramsar site is particularly important because it (i) supports nationally and internationally listed threatened species, (ii) supports species of waterbirds and migratory birds listed under international agreements and (iii) supports more than 1% of the population of waterbird species of the eastern curlew and the red-necked avocet.

In 2017 the NSW Office of Environment and Heritage (NSW OEH) published a summary of the historical pollution in the Lower Hunter River (Swanson *et al.*, 2017a). The majority of information on pollutant sources used in this study comes from that report. Swanson *et al.,* (2017a) noted that Newcastle has a long history as an industrial city and regulation of industrial waste was non-existent for most of the last century. While the majority of this activity has now ceased, and significant remediation works have been undertaken, there remains contamination in the sediments and groundwater within several known areas. The majority of these pollutant sources are downstream of the Kooragang component of the Hunter Estuary Wetlands Ramsar site.

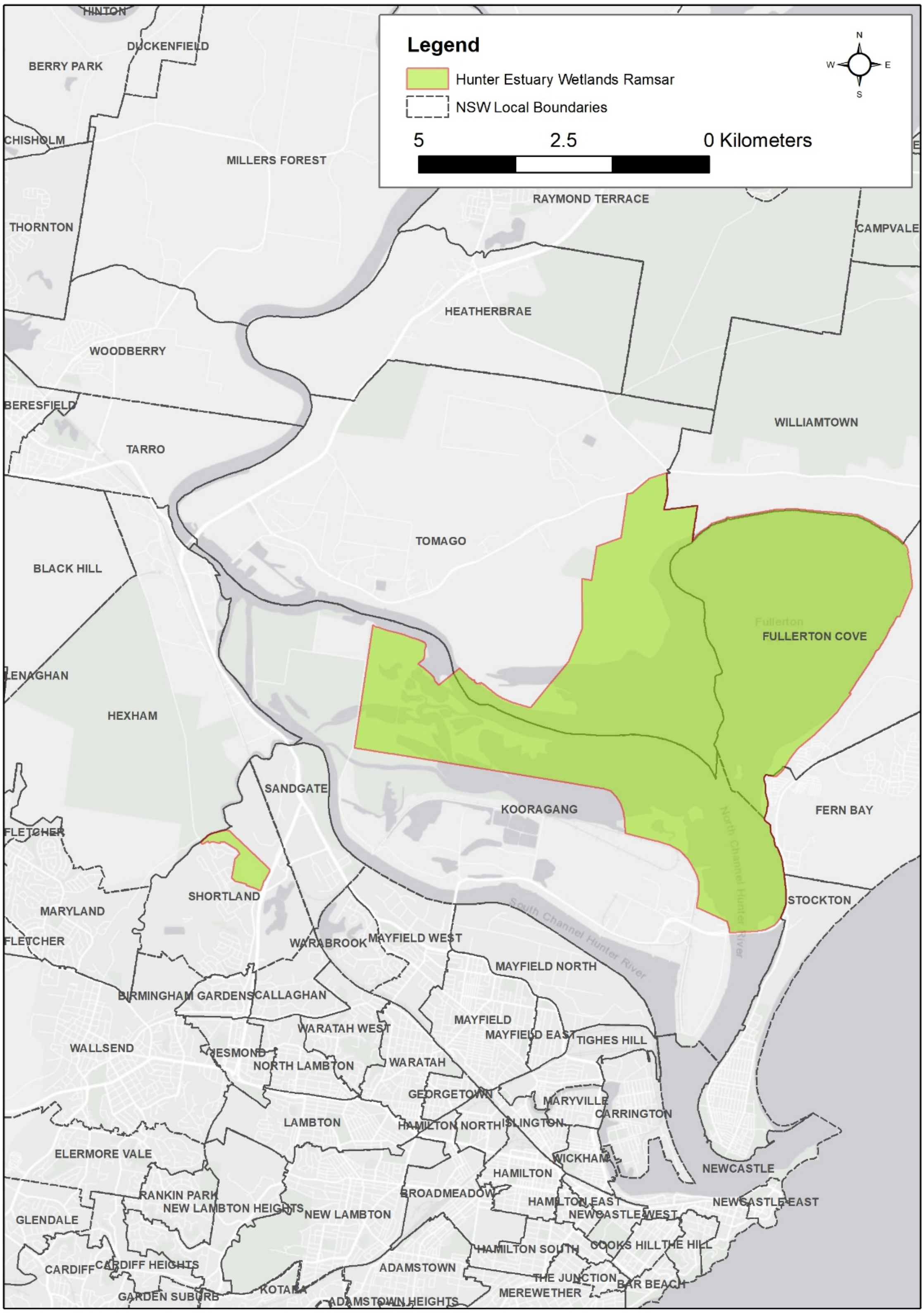


**Figure 1 - Kooragang component of the Hunter Estuary Wetlands Ramsar site**

Glamore *et al.,* (2017) produced an existing hydrodynamic and water quality model suitable for predicting the fate and transport of soluble contaminants in the tidally dominated Lower Hunter River. For the current study, this model was further refined to provide a tool for assessing potential transport pathways from the pollutant sources into the Kooragang component of the Hunter Estuary Wetlands Ramsar site. Within the available scope for this study, pollutant transport during extended dry weather scenarios was simulated to assess whether transport pathways into the Kooragang component of the Hunter Estuary Wetlands Ramsar site may exist. A dry weather approach was adopted because during wet weather conditions run-off from the upland catchment ensures that contaminants are moved in a downstream direction away from the Kooragang component of the Hunter Estuary Wetlands Ramsar site. As such, during these wetter conditions it is less likely that transport upstream to the wetlands would occur and, hence, the dry weather scenario is expected to present the worst case scenario.

The primary hypothesis of this study was that soluble contaminants could be transported towards the Kooragang component of the Hunter Estuary Wetlands Ramsar site during dry periods. As such, conservative decisions were made to test the hypothesis. Limitations of this approach include:

- The model is depth averaged. As the majority of the Lower Hunter (other than the dredged area at Port of Newcastle) is typically unstratified, this is likely to be a reasonable assumption;
- The constituents were modelled as conservative tracers that did not react nor decay. As such, predicted concentrations are expected to be conservative (or overestimate the extent of potential pollution). Heavy metals would likely precipitate and settle/assimilate into bed material where they would be expected to remain unless they were disturbed (i.e. scoured) or removed. Organics and other chemical compounds are wide ranging and, while some may decay (e.g. Nitrogen), the fate of others, such as PFAS, is unknown[1]. These issues, as well as the lack of historical records of pollutant sources, suggest that the use of conservative tracers is appropriate;
- There was no wind based mixing within Fullerton Cove. Fullerton Cove being a large open shallow waterbody would be expected to have substantial or significant wind based mixing. Such mixing would reduce local concentrations within Fullerton Cove and spread contaminants within the entire cove. While the study was focused on the transport of

[1] PFASs can have hydrophobic (non-polar) and hydrophilic (polar) components. The more hydrophilic the compound, the more rapidly it will dissolve in water and travel as a dissolved constituent. Hydrophobic materials which do not dissolve in water will be carried through the water column as an undissolved compound.

pollutants to Fullerton Cove, versus the distribution within, this was deemed a reasonable assumption. It is recommended that future modelling include wind mixing; and

- Constituents were modelled as dissolved, non-particulate behaviour. The modelling did not include the processes of contaminants becoming bound to, and moving with, the transported bed sediments. As such, the modelling represents the transport of the soluble component, which is expected to be transported faster through the system than by sediment transport.
- The overland inundation of the Hexham and Tomago wetlands was not included in the model. These tidal volumes are relatively small compared to the tidal volumes in the main river. Inclusion of these areas would potentially increase transport into the Kooragang component of the Hunter Estuary Wetlands Ramsar site.
- Dispersion was used as a constant arbitrary, relatively low value. This was based on experience but has not been verified by field experiments.

Analysis of the model results has shown that transport pathways exist that could carry contaminants from historical pollutant sources into the Kooragang component of the Hunter Estuary Wetlands Ramsar site. The flushing or removal of accumulated contaminants during rainfall runoff conditions has not been considered, though this may result in the reduction of contaminants in the area. This removal mechanism is particularly relevant to historic pollutant sources that may have been transported to the area in the past. Based on these assumptions, the results presented in this report should be interpreted as approximate, but conservative.

Since the results of the modelling simulations suggest a potential transport pathway exists, recommendations to further confirm/contest these preliminary findings as provided in Section 6 should be pursued. These recommendations include fieldwork and laboratory analysis of water and sediments from the Kooragang component of the Hunter Estuary Wetlands Ramsar site. Contingent on the results of the field campaign, simulations could be re-run to further validate the model and the modelling be extended to assess potential ecological impacts.

# 2 Contaminant sources in the Lower Hunter Estuary

## 2.1 Pollutant locations

NSW OEH (Swanson, Potts and Scanes, 2017a) list the following sites as historical sources of pollution in the Lower Hunter River:

- Industry – past and present, including:
  - The previous BHP Steelworks and Mayfield North
  - Port of Newcastle dredging and coal exports
  - Forgacs Shipyard
  - Aluminium production at Tomago, Kurri Kurri and Cessnock
  - Fertiliser and chemical production at Walsh Point
  - Various industries including textiles, electrical appliances, fertilisers, compressed gases, asphaltic products, pharmaceutical products, industrial chemicals and minerals;
- Wastewater pollution from sewage treatment plants and direct discharge;
- Changes in land use and agriculture;
- Urbanisation;
- Leachate from contaminated landfill;
- Contaminated sites in the vicinity of the Hunter River or tributaries (with orders in place):
  - AGL Gasworks
  - BHP Kooragang Island Emplacement Facility
  - BHP Mayfield Closure Site
  - BHP Mayfield supply area
  - Kopper Coast Tar Products at Mayfield
  - OneSteel Mayfield
  - Orica – Kooragang Island
  - Shell Depot Hamilton
  - Steel River Industrial Estate.

Figure 2 maps key locations of historical pollutants in the Lower Hunter system. The majority of the sites are in the vicinity of the South Arm of the Hunter River in Newcastle's industrial suburbs nearby the port. The notable exception being the Tomago Aluminium site on the North Arm. It should be noted that PFASs were not reported as a contaminant of concern at the aforementioned historically contaminated sites. More recently per- and poly-fluoryl alkyl substances (PFASs)

contamination has been detected at the RAAF Williamtown airbase. Recent studies (AECOM 2017) have shown that these chemicals have been transported into the Kooragang component of the Hunter Estuary Wetlands Ramsar site via a surface water drain into Fullerton Cove. It is also possible that groundwater contaminated with PFASs has also leached into Fullerton Cove. Measured concentrations of PFASs reported in water quality and sediment samples (AECOM 2018 *Pending Publication)* are included in Appendix B.

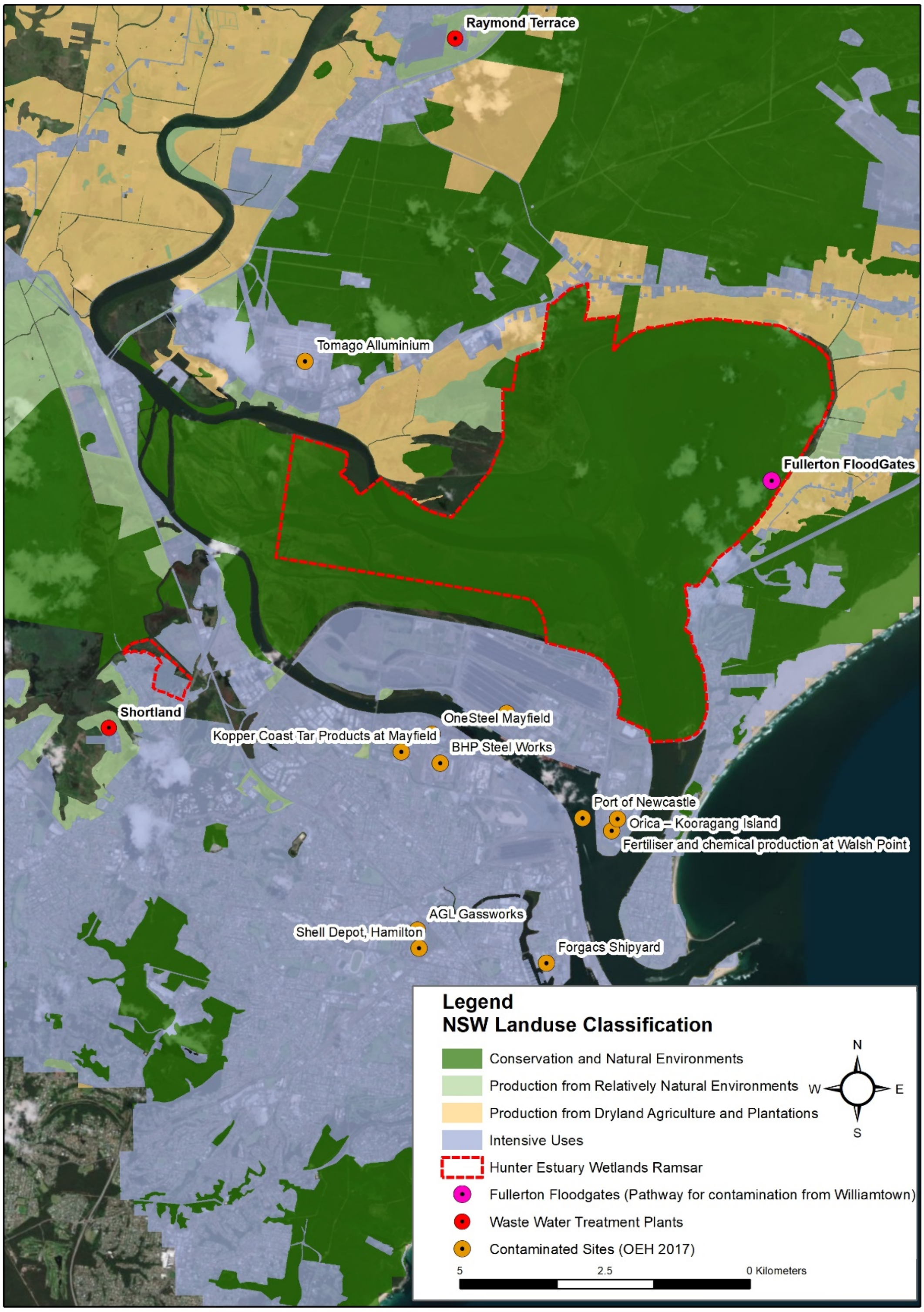


**Figure 2 - Locations of historical pollutants in the Lower Hunter**

## 2.2 Contaminants of concern and measured concentrations

A wide range of contaminants of concern exist in the Hunter River estuary. For this study the Department of the Environment and Energy was particularly interested in contaminants that would persist over long periods and potentially have been transported into or within the Hunter Estuary Wetlands Ramsar site since listing in 1984. Example contaminants include heavy metals, nutrients, pesticides and organic pollutants (including PFASs, particularly PFOS, PFOA, and PFHxS). NSW OEH (Swanson, Potts and Scanes, 2017a) provided a review of the impacts to the lower estuary from the legacies of heavy industries around Carrington, Mayfield and Kooragang Island and suggests that many of these compounds are transported to the estuarine system through overland flows and/or mobilisation through groundwater. A summary of this review is provided in Appendix A.

A survey of contaminants in sediments from the Hunter River estuary in the early 1990s found sediments highly enriched in metals and other contaminates in undredged areas of Thorsby Creek, the South Arm and Newcastle Harbour. Metal concentrations in surficial sediments were consistently three (3) times greater than background levels NSW OEH (Swanson, Potts and Scanes, 2017a). It should be noted that PFASs were not reported as a contaminant of concern at the historical sources reported by Swanson at al. (2017a).

Section 3.2 of the NSW OEH Report “Lower Hunter River Health Monitoring Program – Literature and Data Review” (Swanson, Potts and Scanes, 2017a) provides a comprehensive (though not exhaustive) list of historical concentrations within the Lower Hunter River. Based on the varied (and incomplete) sources of data that exist across spatial and temporal timescales, it is difficult to draw conclusions on the historic discharge rates or pollutant sources discharged into the estuary. This review alongside other known water quality and sediment data are summarised in Appendix B.

# 3 Numerical modelling methodology

## 3.1 Hunter River estuary hydrodynamic and water quality model

Numerical modelling was undertaken using the RMA modelling suite (King, 2015). The RMA models have been used widely throughout Australia and internationally for the prediction of hydrodynamics, water quality and sediment transport in rivers, estuaries, reservoirs and oceans. The RMA hydrodynamic solution uses a finite element mesh that is an irregular connection of nodes and elements. Finite elements are suitable for modelling complex estuaries, rivers and coastal shorelines as the elements can vary in size and shape to represent the water body geometry. Water velocities and water depths are predicted at every node within the finite element mesh of the model.

The Hunter River Estuary RMA hydrodynamic model was developed using one dimensional elements upstream of Hexham Bridge and two dimensional elements downstream of Hexham Bridge. The model domain covered the entire tidal region of the Hunter, Paterson and Williams Rivers as shown in Figure 3. The hydrodynamic model was previously verified against extensive field data which included water levels, currents and discharges throughout the Hunter River. This included current metering of the lower Hunter River estuary in the vicinity of the Hunter Estuary Wetlands Ramsar site pertinent for this study. A full description of the calibration of the Hunter River hydrodynamic model can be found in Glamore *et al.*, (2017) (WRL Technical Report 2017/20 "Hunter River Estuary Water Quality Model - Hydrodynamic Calibration and Validation"). The model has been extensively peer reviewed including a commissioned review by experts at CSIRO (Robson and Cuddy, 2017).

The full water quality model of the Hunter River estuary was not used in this investigation. As stated above, contaminants were modelled as arbitrary, conservative constituents that underwent advection and diffusion but did not react with other constituents nor decay.


**Figure 3 - Numerical modelling domain**

## 3.2 Refinement of model resolution

The finite element mesh was refined in the lower Hunter River estuary throughout the North and South Arms, Fullerton Cove, Kooragang Island and the Kooragang component of the Hunter Estuary Wetlands Ramsar site. The majority of the intertidal areas on the northern side of the Hunter River were included in the model as elements that are able to run dry during low tides. On Kooragang Island, the main tidal channels were included. The overland inundation of the Hexham and the Tomago wetlands was not included in the model as the volumes within these systems are relatively small compared to tidal volumes in the main estuary. The inclusion of these areas would increase the model complexity and run-times and was not considered crucial for understanding transport mechanisms in the estuary. The updated finite element mesh has two-dimensional elements between 10 m and 50 m resolution, as shown in Figure 4.

## 3.3 Hydrodynamic scenario

The RMA-2 hydrodynamic model was simulated for an initial period followed by a repeating 28 day spring-neap cycle to simulate twelve months of regular ocean tides and ongoing, constant river base-flow. The model was run with a 15 minute timestep and the velocities and depths were solved at every node throughout the model domain. Model parameters were adopted from the calibration/verification of the main Hunter River estuary model (Glamore, *et al.,* 2017).

Local rainfall and high river discharge events were not simulated since contaminants from sources in the lower Hunter River would be transported seaward in these events and have limited potential to impact the Kooragang component of the Hunter Estuary Wetlands Ramsar site (non-conservative). The results from the hydrodynamic model were used as the basis for the water quality simulations.

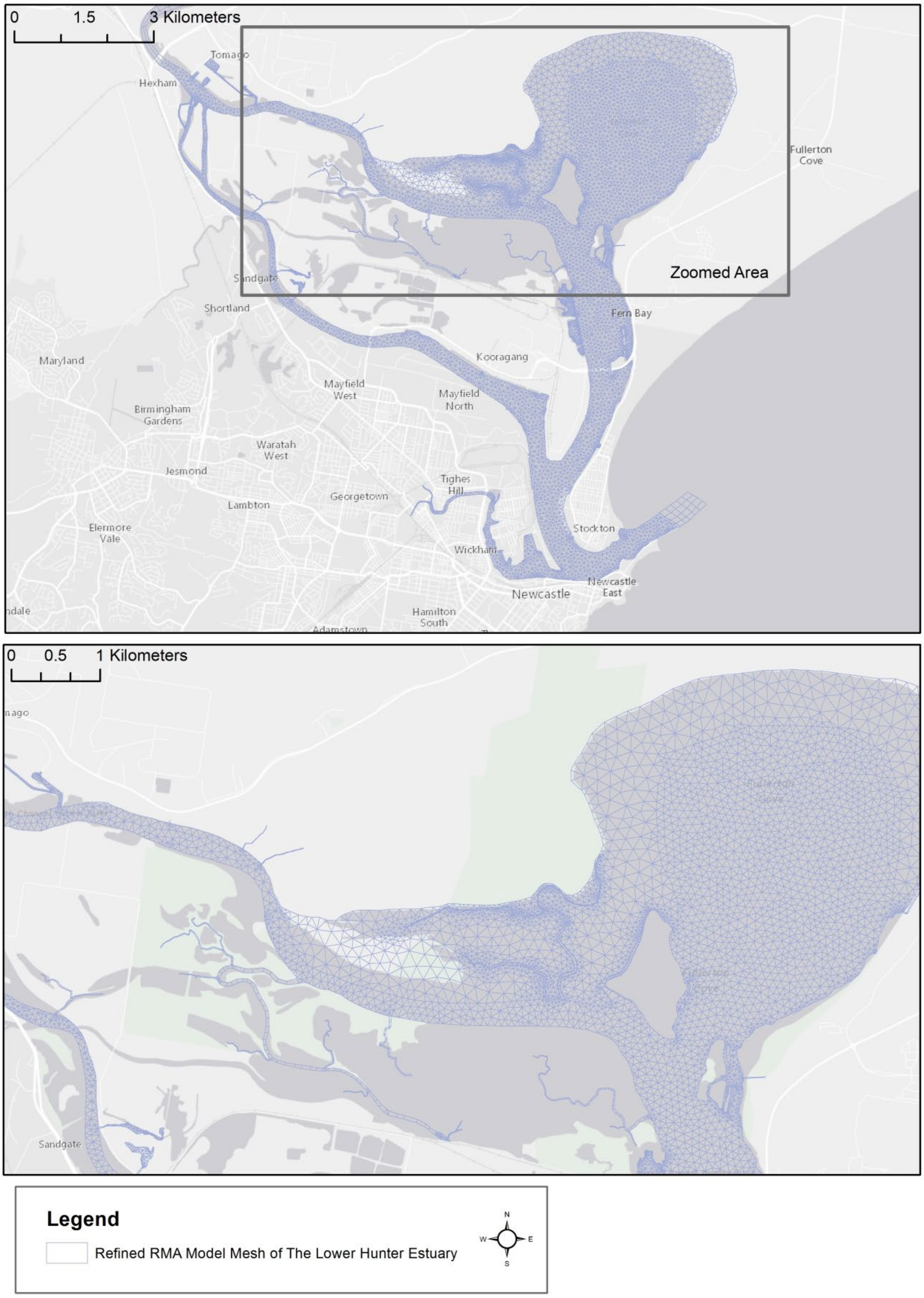


**Figure 4 - Refined hydrodynamic mesh**

## 3.4 Water quality scenarios

The RMA-11 water quality model simulated the transport of arbitrary conservative constituents throughout the model domain. Twenty-four (24) source locations were selected as representative of potential pollutant locations throughout the Lower Hunter as shown in Figure 5. Four constituents were simulated per model run, so the number convention is “run number” – “ constituent number”. Each release point was modelled as a different numbered constituent allowing for the identification of both the source and the fate throughout the model domain.

With greater model resolution, the dispersion parameter was set arbitrarily to 1.0 $m^2/s$. Dispersion coefficients are best determined through field measurements, however estimates can be made by using the work of Elder (1959), Fischer *et al.,* (1979) and Bowie *et al.,* (1985) as a function of depth averaged velocity, water depth and bottom friction. For the lower Hunter, this was calculated as approximately $1.0m^2/s$, which in WRL’s experience is typical for large rivers and estuaries. The implications of using a higher dispersion coefficient would be lower peak concentrations with a greater dispersion of pollutants throughout the estuarine system.

This parameter has not been verified through fieldwork and there is a potential that dispersion is either lower or higher in the Hunter River depending on winds, tidal velocities and river discharges.

The initial concentration of each constituent was set to zero throughout the entire model domain. Each constituent was released into the model at an arbitrary rate of 100 units per second for the simulated 12 month period so as to represent an ongoing source. By the end of the simulation, the constituent concentrations both nearby the source point and throughout the rest of the domain had reached a quasi-equilibrium, allowing for calculation of the ratio of source concentration to destination concentration to be analysed.

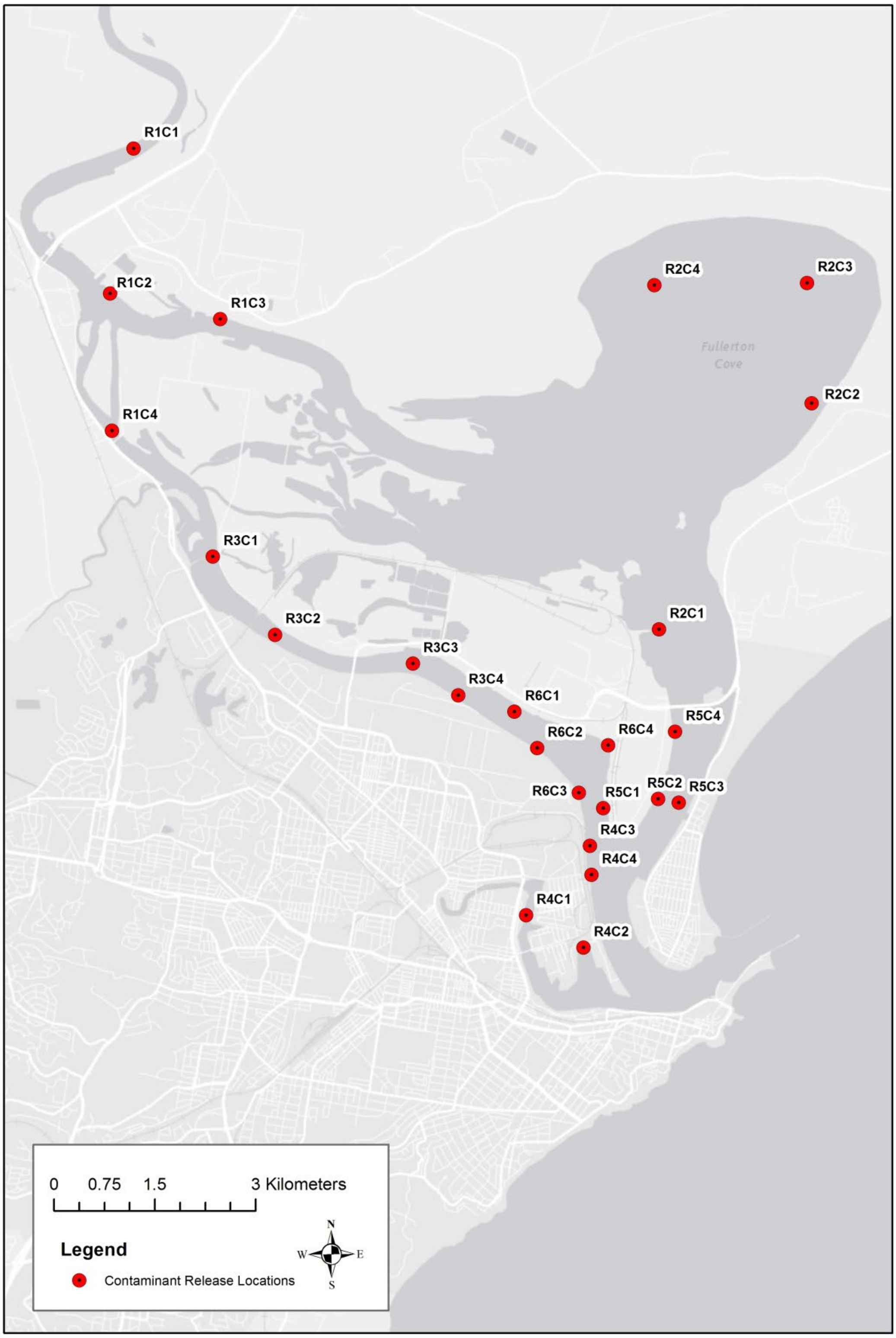


**Figure 5 - Modelled constituent release locations**

# 4 Predicted transport, fate and impacts

## 4.1 Result overview

This section discusses the general transport pathways observed in the model simulations. Throughout this section, ratios of source to fate concentrations have been presented to highlight which sources are likely to have the strongest presence within the Kooragang component of the Hunter Estuary Wetlands Ramsar site.

As the modelling conditions were synthetic (e.g. the spring-neap cycle is repeating and base-flow ongoing), over time the concentrations throughout the estuary asymptote towards concentrations based on flushing, transport and the distance between the source and the destination. Figure 6 presents an example timeseries of the tidally averaged concentrations at a release location (as shown in Figure 7) and a destination in the middle of Fullerton Cove. The variation in concentration is an artefact of the spring-neap tide cycle, however it can be observed that the final ratio between the source and destination is approximately 50%.

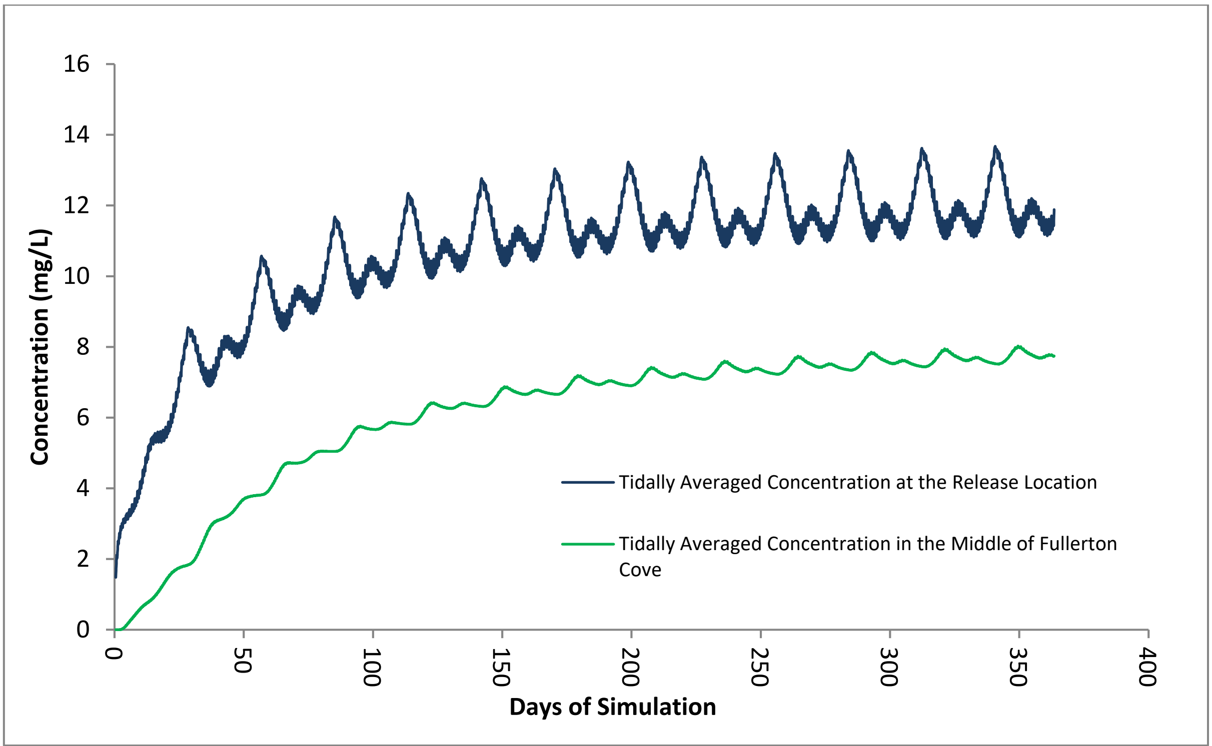


**Figure 6 - Timeseries of tidally averaged concentrations for a discharge in the South Arm and a destination in Fullerton Cove**

Figure 7 presents contours of an arbitrary constituent's concentration (as marked as a red dot) at mid-tide after a 12 month simulation. The constituent has been released at a constant, arbitrary rate of 100 units per second. Transport varies in direction with each tidal cycle but the net transport from the release location in the South Arm is upstream in the South Arm and then downstream in the North Arm. The contour plot allows for interpretation of the relative impacts from the site.

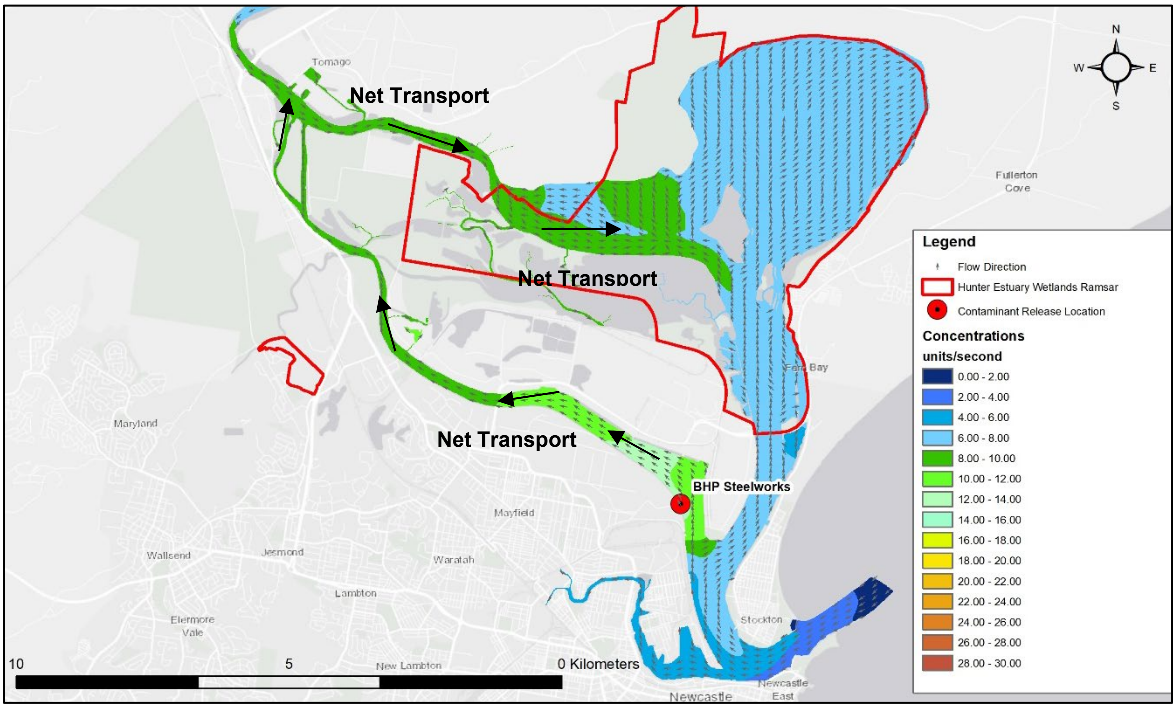


**Figure 7 – Example of relative concentrations and transport pathways of an arbitrary constituent within the Lower Hunter Estuary after a 12 month simulation**

## 4.2 Concentration contours

Twenty four locations were selected as sources of contaminant discharge as shown in Figure 5. Following review of the results, five (5) sites were selected to highlight the fate of contaminants from each source point. Inspection of the results show similar trends for nearby sites, so a subset of three (3) discharge locations and four (4) fate sites has been presented in this report, as shown in Figure 8. The full analysis result set has been provided electronically.

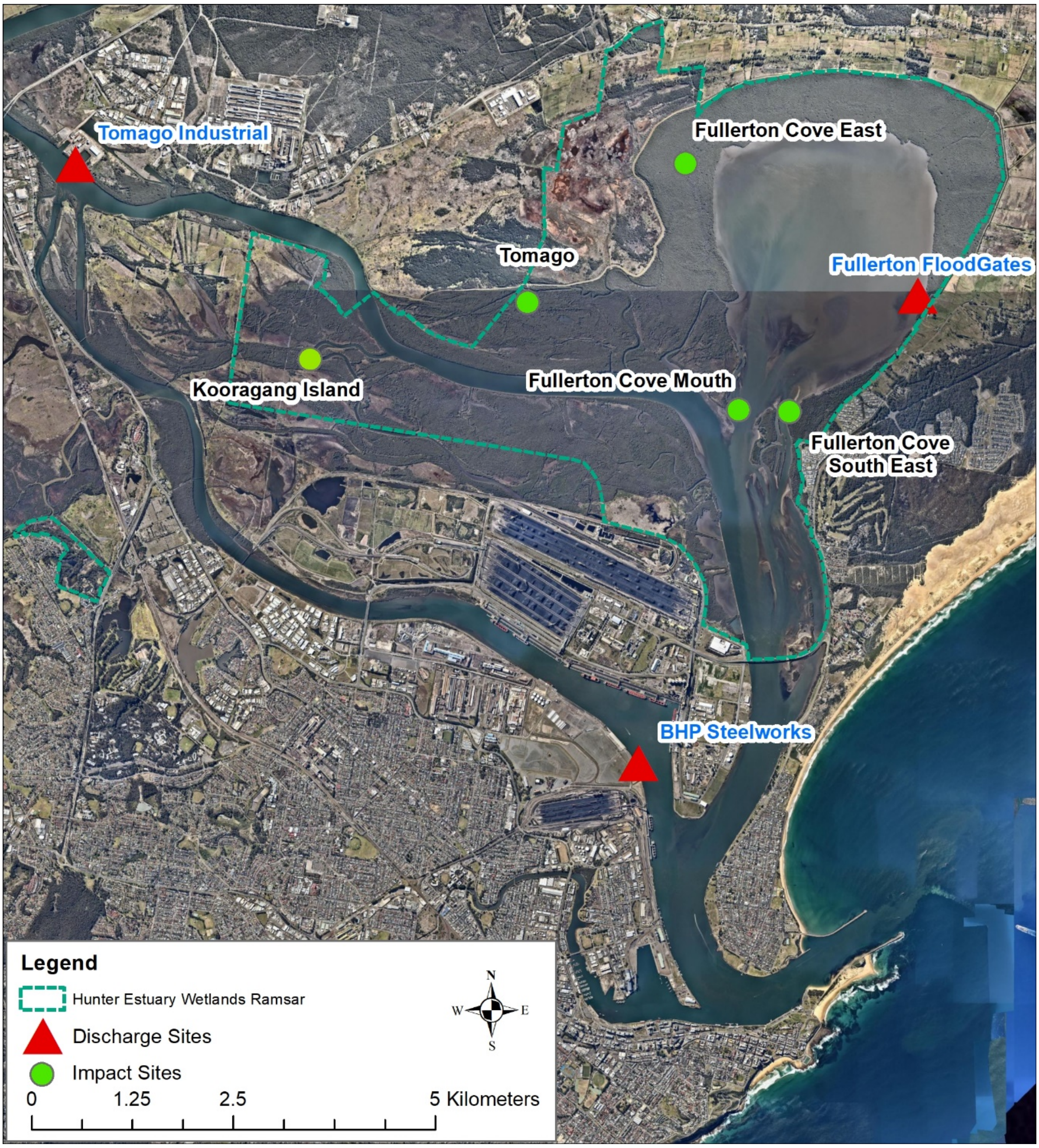


**Figure 8 - Selected discharge and fate locations**

When a constituent is released into a tidal estuary at a given rate, the resulting concentration in the immediate (near-field) receiving waters will be dependent upon the amount of tidal exchange (flushing) in that area. The dispersion and net transport result in further dilution with distance away from the source. As such, releasing at 100 units/second at each of the three (3) discharge locations shown in Figure 8 results in differing concentrations near the source.

Figure 9, Figure 10 and Figure 11 present the end of simulation mid-tide concentrations for discharges from each of the three sites (without discharges at the other sites). These contour plots provide an insight into the relative concentrations throughout the estuary (including near each discharge point) should the rate of source contamination be the same at each site. From these results it is apparent that the BHP Steelworks discharge location has the lowest concentration at the release locations, while the Fullerton Cove floodgates discharge location has the greatest concentration at the release location (e.g. the least amount of contaminant dispersion). This suggests that flushing from the Fullerton Cove floodgates location is the lowest of the three sites presented and any discharges from that location would be more persistent (e.g. highest concentrations near the discharge locations).

All three contour plots in Figures 9, 10 and 11 have been presented on the same scale to enable a comparison of concentrations within the Kooragang component of the Hunter Estuary Wetlands Ramsar site. Based on the scenarios presented, if all contaminant sources were to discharge equal amounts, the Tomago Industrial Area would have the widest spatial impact on the Kooragang component of the Hunter Estuary Wetlands Ramsar site, followed by the BHP Steelworks site and then the Fullerton Cove floodgates site. In contrast the Fullerton Cove floodgates site would be responsible for the highest concentration. Importantly, these simulations do not take into consideration wind driven mixing, which is a known transport mechanism across Fullerton Cove.

When interpreting these contour plots, it is important to recognise that they represent the *potential* for transport into Kooragang component of the Hunter Estuary Wetlands Ramsar site and not actual transport into the site. As discussed in Section 2.2, there is limited knowledge of the historical, ongoing and present discharges of contaminant concentrations from each of these locations. The results, however, highlight that sites from three distinct locations throughout the lower Hunter River each have the potential to impact upon Kooragang component of the Hunter Estuary Wetlands Ramsar site.

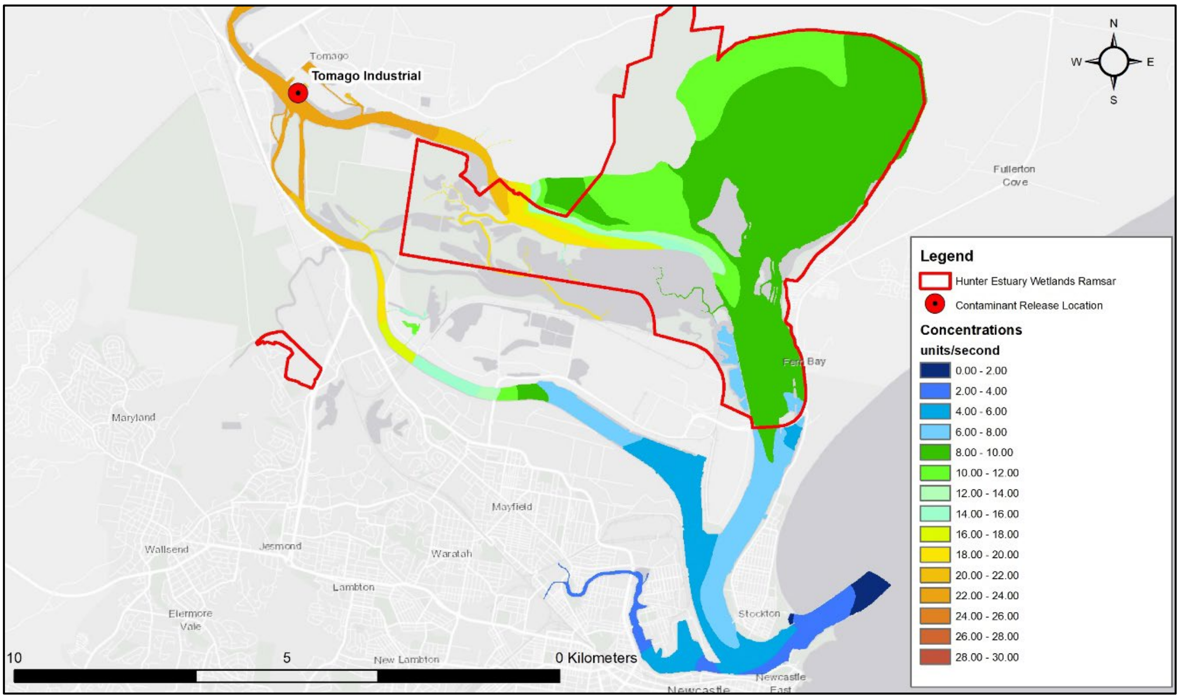


**Figure 9 - End of simulation mid-tide contours of constituent concentration released at the Tomago Industrial point (red dot)**

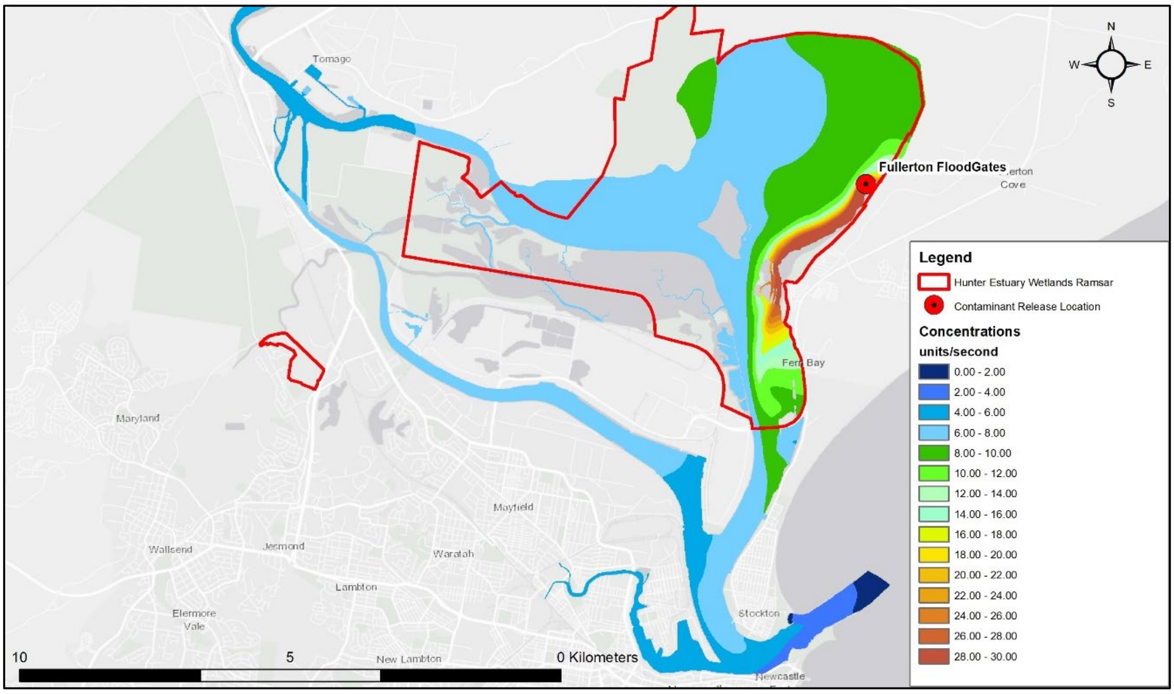


**Figure 10 - End of simulation mid tide contours of constituent concentration released at the Fullerton Cove Floodgates site (red dot)**

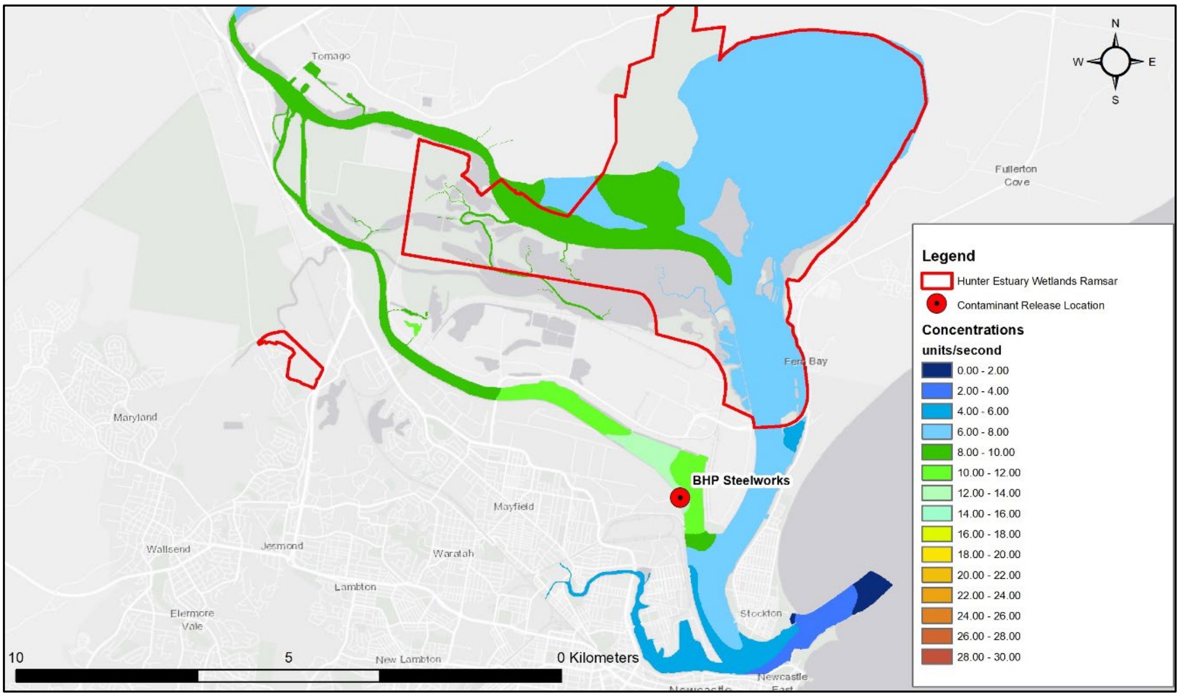


**Figure 11 - End of simulation mid tide contours of constituent concentration released at the BHP Steelworks site (red dot)**

## 4.3 Fate concentrations relative to sources

As stated above, the potential historical and present discharges of contaminants are unknown. However, it is possible to undertake field monitoring near each location to measure actual concentrations in the water column and bed sediments.

The model results have been analysed to provide concentrations at each of the *fate* sites as a percentage of the concentrations near each source site in Table 1. Note that Figure 8 provides the locations referred to in Table 1.

**Table 1 - Concentrations at the fate sites as a percentage of concentrations at the discharge sites**

| Source Site | Fate Site | Relative Concentration |
|---|---|---|
| Tomago Industrial Area | Fullerton Cove East | 46% |
| | Fullerton Mouth | 36% |
| | Fullerton Cove South East | 41% |
| | Tomago | 51% |
| | Kooragang | 91% |
| Fullerton Cove Floodgates | Fullerton Cove East | 28% |
| | Fullerton Cove Mouth | 26% |
| | Fullerton Cove South East | 54% |
| | Tomago | 25% |
| | Kooragang | 22% |
| Previous BHP Steelworks | Fullerton Cove East | 69% |
| | Fullerton Cove Mouth | 78% |
| | Fullerton Cove South East | 67% |
| | Tomago | 71% |
| | Kooragang | 82% |

The results in Table 1 indicate that during extended dry weather periods, the concentrations found within various locations of the Kooragang component of the Hunter Estuary Wetlands Ramsar site would be greater than 20% and up to 90% of the concentrations measured near the contaminant sources.

The relative concentrations at the five (5) selected fate sites from discharges from the Fullerton Cove Floodgates vary between 22-54%. Whilst this may appear that the Fullerton Cove Floodgates have lesser impact than the other source sites at certain locations within Fullerton Cove (i.e. at Fullerton Cove East and Fullerton Cove Mouth), these low relative concentrations are due to:

- A much more higher concentration near the source due to the lesser tidal exchange at the sites (hence reducing the percentages); and
- The less dispersive plume from the Fullerton Cove Floodgates tracking along the eastern bank (as shown in Figure 10).

The modelling scenario has not considered winds or high dispersion throughout Fullerton Cove which may have the influence of spreading the plume with a lower concentration over a greater area. Additional fieldwork would be required to determine the dispersion in Fullerton Cove under a wide range of environmental conditions. These results must be considered within the constraints of the model and the scenarios considered. In particular:

- Constituents were modelled assuming dissolved, non-particulate behaviour. The modelling did not include the flocculation, aggregation or settling of contaminants. As such, the modelling represents the transport of the soluble component only, which is expected to be faster than sediment transport.
- The modelled constituents did not decay or transform.
- There was no wind based mixing within Fullerton Cove.
- The simulated impacts would only occur during extended periods of dry weather with no rainfall-runoff flushing of the estuary.
- The results do not consider the potential for flushing or removal of contaminants from the Kooragang component of the Hunter Estuary Wetlands Ramsar site during rainfall runoff conditions.
- The results did not simulate the potential binding of contaminants to sediments within the wetlands (which in turn become an ultimate storage location of such contaminants) or the burying of contaminants via natural sedimentation processes.

Based on the above assumptions, the contaminant transport results presented in this report should be viewed as the 'potential' transport mechanisms under worst case scenarios. It is worth noting that the concentrations of contaminants measured in the Lower Hunter River (discussed in Section 2.2) have been historically many times greater than ANZECC (2000) guidelines. As such, even if these ratios presented in Table 1 are highly conservative, the potential exists for impact within the

Kooragang component of the Hunter Estuary Wetlands Ramsar site to also be above the ANZECC guidelines. Further recommendations are provided below.

# 5 Shear and Resuspension of Bottom Sediments

The bed shear stress is an indication of the potential for resuspension and transport of sediment materials on the estuary bed. The bed shear stress ($\tau_b$) is a measure of the frictional forces from a fluid acting on bed and in the case of the Lower Hunter Estuary, is predominantly caused by the incoming and outgoing tides. Bed shear as a function of bed roughness (Manning's n), water depth and velocity can be described by:

$$\tau_b = \frac{gn^2\rho u^2}{R_h^{\frac{1}{3}}}$$

Where

g = gravity

n = manning N friction

$\rho$ = density of fluid (water = 1000)

u = depth averaged velocity

$R_h$ = hydraulic radius = (area / wetted perimeter)

The peak bed shear occurring during the peak flood tide and the peak ebb tide are presented in Figure 12 and Figure 13.

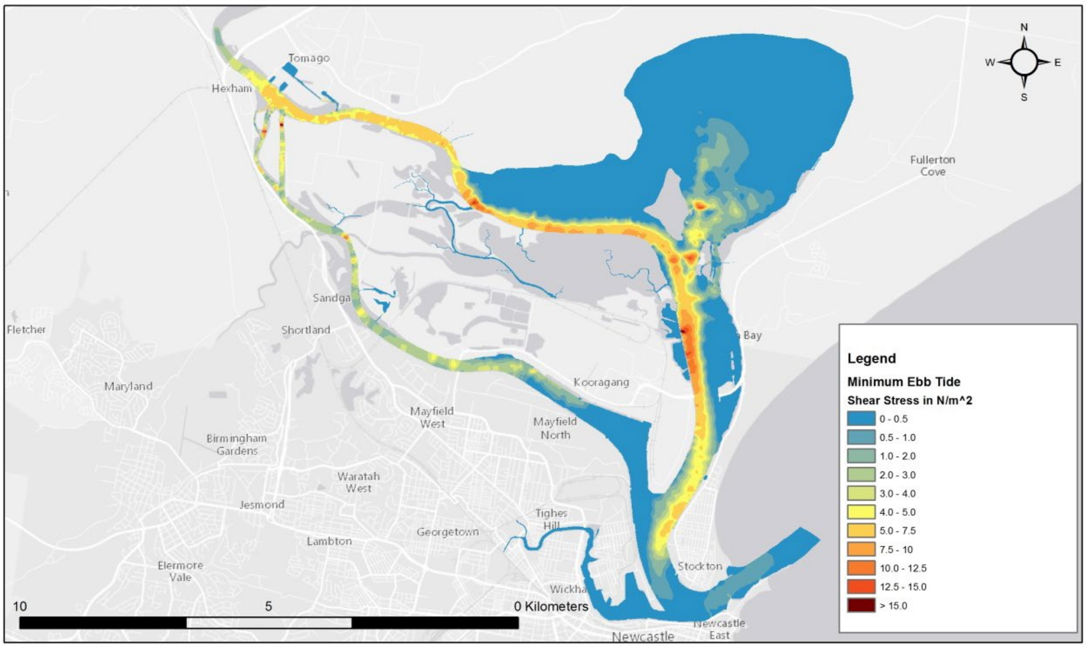


**Figure - 12 Bed shear stress during peak ebb tide**

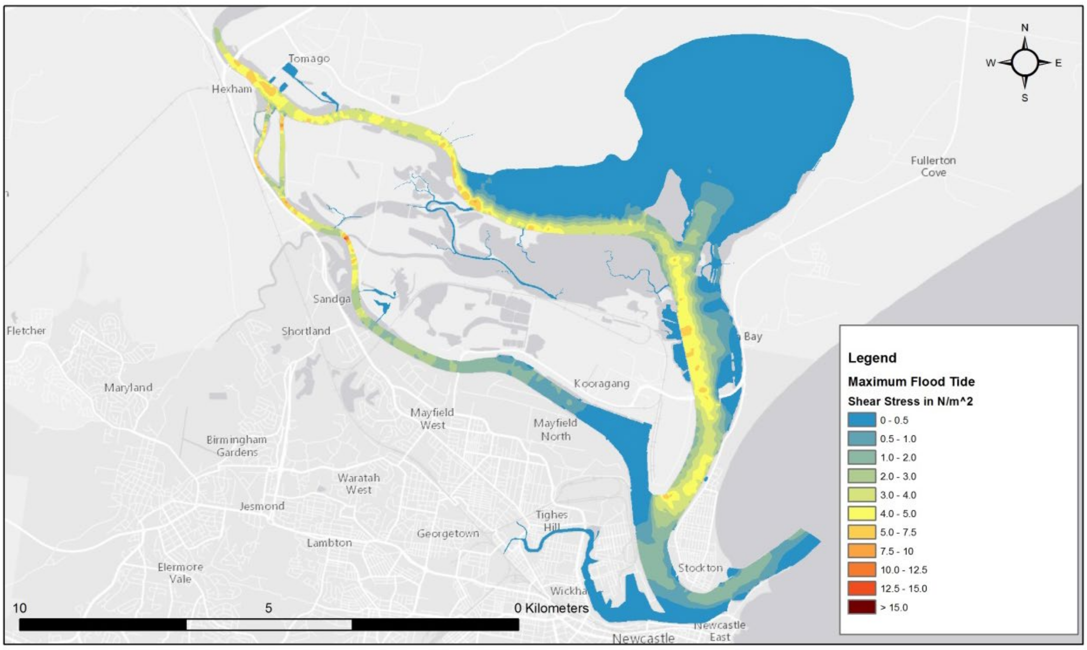


**Figure 13 - Bed shear stress during peak flood tide**

Some typical values of sediment mobility due to bed shear stress are presented in Table 2 When the bed shear stress is greater than the critical bed shear stress for a particular particle size, resuspension and transport of those particles may occur.

**Table 2 - Critical shear stress by particle-size classification**

| Particle Classification Name | Ranges of Particle Diameters (mm) | Critical Bed Shear Stress $\tau_b$ (N/m$^2$) |
|---|---|---|
| Coarse Cobble | 128 - 256 | 112 - 223 |
| Fine Cobble | 64 - 128 | 54 - 112 |
| Very Coarse Gravel | 32 - 64 | 26 - 54 |
| Coarse Gravel | 16 - 32 | 12 - 26 |
| Medium Gravel | 8 - 16 | 5.7 - 12 |
| Fine Gravel | 4 - 8 | 2.7 - 5.7 |
| Very Fine Gravel | 2 - 4 | 1.3 - 2.7 |
| Very Coarse Sand | 1 - 2 | 0.47 - 1.3 |
| Coarse Sand | 0.5 - 1 | 0.27 - 0.47 |
| Medium Sand | 0.25 - 0.5 | 0.194 - 0.27 |
| Fine Sand | 0.125 - 0.25 | 0.145 - 0.194 |
| Very Fine Sand | 0.0625 - 0.125 | 0.110 - 0.145 |
| Coarse Silt | 0.0310 – 0.0625 | 0.0826 - 0.110 |
| Medium Silt | 0.0156 - 0.0310 | 0.0630 - 0.0826 |
| Fine Silt | 0.0078 - 0.0156 | 0.0378 - 0.0630 |

Source: Table 7 of USGS, 2008.

Based on the hydrodynamic model results, bed shear stresses in the main channel are typically less than 5.0 N/m$^2$. Using Table 2, this indicates that sediments smaller than medium gravels may be mobilised under dry weather flow conditions. Bed shear stresses at Fullerton Cove and dredged channel areas near the Port of Newcastle are relatively low (bed shear stress < 0.5 N/m$^2$) which indicates that only sediments smaller than course sands would be mobilised from tidal currents in those areas. Whilst larger sediments may be scoured during flood events sediments mobilised during floods will generally be transported out to sea.

Although the peak bed shear is greater on the ebb tide than the flood tide, this does not necessarily represent transport seawards of all sediments. In particular, the fine grained material will be transported by both the flood and the ebb tides.

# 6 Conclusions

This investigation has provided a rapid assessment of the potential for soluble chemical contaminants from diffuse and point sources in the Lower Hunter River to impact upon the Kooragang component of the Hunter Estuary Wetlands Ramsar site.

This investigation has made use of a calibrated, peer reviewed, numerical model of the Hunter River estuary to consider contaminant transport from potential pollution sites. Results indicate that soluble contaminants can be transported throughout the Kooragang component of the Hunter Estuary Wetlands Ramsar site, even from sites downstream, during prolonged dry times due to tidal asymmetry and flood tide dominance.

The extent and concentration of these contaminants is difficult to determine based on available information but the highest concentrations are likely to be found nearest the Fullerton Cove floodgate discharge location.

As a first pass assessment, the model has not considered a range of contaminant transport or mixing regimes. Of most importance to Fullerton Cove is the absence of wind mixing in the model. Further, the results are expected to be conservative as previously released contaminants may have been transported from the estuary during flood periods, buried by deposition, chemically transformed or be limited in transport mechanisms by flocculation, aggregation or settling.

Major improvements to water quality and remediation of contaminated sites did not start in earnest in the Hunter estuary region until 2000. Therefore, for roughly half of time since the listing of the Hunter Estuary Wetlands as a Ramsar site in 1984, there were highly elevated contaminants (particularly in the South Arm) within the estuarine system. The modelling simulations in this preliminary study suggest these contaminants had the potential to migrate and remain within the Kooragang component of the Hunter Estuary Wetlands Ramsar site. However, the fate and ecological impact of these pollutants is unknown.

Since the modelling scenarios have predicted receiving concentrations of upwards of 20% of the source concentration, the results of this investigation warrant further investigations. As a minimum these should include fieldwork and laboratory analysis of water and sediments within the Kooragang component of the Hunter Estuary Wetlands Ramsar site . This could be supported by detailed analyses of contaminant discharges and associated chemical processes that may encourage or inhibit transport. If found, the ecological impact of these contaminants should be assessed. If warranted, further modelling could be undertaken to simulate settling, chemical transformation or other bed related transport processes.

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# APPENDIX A

**Table A.1 Contamination to Hunter Estuary from previous industries NSW OEH (Swanson, Potts and Scanes, 2017a)[2]**

| Location | Constituent | Time Period / Date | Recorded Levels /Comments | Reference | Additional Comments |
|---|---|---|---|---|---|
| **BHP Steel Works** Closure and Supply Area | TPH (C6-C36 range including Benzene, Ethyl Benzene, Toluene and Xylene:BTEX) | 1998-2001 | Significantly contaminated land and elevated levels detected. | Woodward-Clyde 1999 ANZECC 1998 Simpson *et al.*,\ 2001 a, b,c RCA 1998 | Heavy metal concentrations often exceeded ANZECC trigger values while levels of Benzo(a)pyrene and total PAH were up to 9000 times higher than ANZECC guideline trigger values for the protection of aquatic ecosystems. |
| | PAH | | 3.4-1.2 ug/L | | |
| | Manganese | | 0.08-1.4mg/L | | |
| | Zinc | | <0/01 – 0.02 mg/L | | |
| | Arsenic | | <0.02-0.22 mg/L | | |
| | Benzo(a)pyrene | | <0.2 – 0.9 ug/L | | |
| **BHP Steel Works** (Following Remediation) Closure and Supply Area | Volatile Hydrocarbons BTEX) TPH PAH TSS | 2005 – 2009 | Overall River quality results (as per grab samples collected daily from three monitoring stations at least two hours after dredging had commenced) indicated that results were below standard detection limits for PAH and other contaminants and when contaminants were detected above the limit of reading they did not exceed the ANZECC guidelines | URS 2009 | |

[2] Note that PFASs are not reported as a contaminant of concern at these historical sites.

| Location | Constituent | Time Period / Date | Recorded Levels /Comments | Reference | Additional Comments |
|---|---|---|---|---|---|
| **OneSteel Manufacturing Pty Ltd, Mayfield**<br><br>(Continued under a new business out of BHP group – located adjacent to the former steelworks site in Mayfield Industrial Park) | Benzene | September 2013 – September 2014 | Increased from 145 to 165 mg/L in estuarine aquifer and decreased from 20 to 20 mg/L in fill aquifer. | Environ Australia 2015 | Part of this site is classified as a Benzene Impacted Area.<br><br>Benzene was generally below the guideline criteria in monitoring wells. |
| | TPH (C6 – C10 fraction) | | Increased from 194 to 417 mg/L in estuarine aquifer and decreased from 149 to 30 mg/L in fill aquifer. | | |
| | PAH (predominantly Naphthalene) | | Decreased from 49 to 18 mg/L. | | PAHs were generally below the guideline criteria in monitoring wells. Benzene and TPH were not detected in any seep samples coming from the fill embankment, however seep 4 Contained PAH at levels that exceeded guideline criteria by up to 5-30 times. |
| | Manganese | | 0.23-5.0mg/L | | Exceeded the ANZECC interim guideline criteria of 0.08 mg/L |
| **Koopers Coal Tar Products** | PAH (in particular Naphthalene) and Benzo(a)pyrene | | Capital works required the construction of a barrier wall to isolate hydrocarbon contaminants from groundwater. | | |
| **Steel River Industrial Estate, Mayfield** | Groundwater at the site is | | | | There exists a 20 m easement between |

| Location | Constituent | Time Period / Date | Recorded Levels /Comments | Reference | Additional Comments |
|---|---|---|---|---|---|
| (Originally formed a part of the BHP Newcastle steelworks operation but was sold to Steel River Pty Ltd in 2001). | contaminated by TPH (including Benzene and Toluene) PAH, Metals (including Arsenic), Phenols, Cyanide and Ammonium. | | | | the Steel River site and the South Arm of the Hunter River (Foreshore buffer zone FBZ). This is the primary target for remediation. |
| **AGL Gasworks Hamilton** | TPH, Benzene, PAH, Arsenic and Lead. | | Groundwater at the site is depredated by these contaminants and has the potential to migrate to Styx Creek and the Hunter River. | | |
| **Shell Depot Hamilton** | Petroleum, TPH including Benzene and Lead. | To 2014 | | | Groundwater at this site is contaminated by petroleum contaminants |
| **Orica Australia Pty Ltd, Kooragang Island** | Ammonium Nitrate | 1969 to 1994 | Recent monitoring results show that concentrations of Ammonium and Oxidised Nitrogen (i.e. nitrate, nitrite) in groundwater wells typically exceeded trigger values by often 3 orders of magnitude, with nitrate concentrations reaching 5,000 mg/L and 10,000 mg/L in shallow and deeper groundwater. | Golder Associates 2015 URS 2006c, URS 2012a, URS2014a | OEH water quality monitoring of 2014 suggest that Ammonium and Nitrate from contaminated groundwater are migrating offsite via seeps discharging to the North Arm of the Hunter River. |
| | Arsenic | | Groundwater is contaminated with Arsenic at concentrations significantly | | Arsenic has migrated off site in groundwater and has contaminated other landholdings. |

| Location | Constituent | Time Period / Date | Recorded Levels /Comments | Reference | Additional Comments |
|---|---|---|---|---|---|
| | | | exceeding the ANZECC guidelines. Low reliability marine trigger values for the protection of aquatic ecosystems.<br><br>Long term (~10 years) of data collected reveals partitioning of Arsenic into different groundwater layers. | | Orica is required to do bi-annual monitoring of dissolved arsenic concentrations in groundwater wells. |

# APPENDIX B

**Table B.1 Lower Hunter water and sediment quality assessments (not exhaustive)**

| Location | Constituent | Time Period / Date | Recorded Levels /Comments | Reference | Additional Comments |
|---|---|---|---|---|---|
| **South Arm adjacent to the steelworks site and in the Middle of Fullerton Cove** | Iron | 1977-1978 | 2808 ug/L (South Arm) 195 ug/L (Fullerton Cove) | Hodda and Nicholas 1986 | The State Pollution Control Commission (SPCC) collected water quality data in the heavily industrialised catchments of South Arm.<br><br>Zinc levels were over 10 times the ANZECC guidelines screening level for 80% protection of marine species.<br><br>Concentrations of Ammonium and Phosphate were 30 and 60 times higher than the NSW trigger values for riverine estuaries (saline reaches).<br><br>Concentrations of Phosphate were 20 times higher than the NSW trigger values. |
| | Zinc | | 595 ug/L (South Arm) 18 ug/L (Fullerton Cove) | | |
| | Lead | | 21 ug/L (South Arm) 0 ug/L (Fullerton Cove) | | |
| | Ammonium | | 256 ug/L (South Arm) 0 ug/L (Fullerton Cove) | | |
| | Orthophosphate | | 176 ug/L (South Arm) 49 ug/L (Fullerton Cove) | | |
| **South Arm adjacent to the steelworks site and the North Arm near the entrance of Fullerton cove** | Iron | 1982 | 3600 ug/L (North Arm) | Hodda and Nicholas 1986 | Metals were not detected in the North Arm near Fullerton Cove and there were moderate levels of Phosphate (10 ug/L) implying this mid-section of the North Arm is at least impacted by industry. |
| | Zinc | | 76 ug/L (North Arm) | | |
| | Lead | | 24 ug/L (North Arm) | | |
| | Ammonium | | 462 ug/L (North Arm) | | |
| | Orthophosphate | | 26 ug/L (North Arm) 10 ug/L (Fullerton Cove) | | |
| | Nitrates | 1998 | Extremely high levels at most locations 280-320 ug/L) at most locations. | | Concentrations of Nitrate in the river were at least 50 times higher than NSW trigger values for Nitrate in saline reaches of riverine estuaries. |
| **Hunter Estuary (Collected by EPA)** | Metals | 1990 | Data was difficult to interpret as low detection limits for analysis at the time were well above the ANZECC guidelines. | ERM Mitchell McCotter 1996 | Only concentrations of Lead and Zinc in the estuary were above detection limits with very high levels |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | of Zinc (up to 930 ug/) detected in the North Arm and very high levels of Lead reported in the South Arm nearby the steelworks. |
| **Orica effluent pipe** | Zinc | 2014 - 2015 | 270 kg | ERM Mitchell McCotter 1996 | |
| | | 2009 - 2010 | 920 kg | | |
| **Hunter River (collected by Hunter Water Corporation 1993 – 2000 and by EPA 1975 – 2000)** | 25 Water Quality Variables<br>DIN<br>NOx<br>Ammonium<br>Total Phosphorous (TP)<br>Chlorophyll-a | 1975-2000 | Dissolved Inorganic Nitrogen levels in the Estuary were high with a distributed source of DIN along the lower reaches of the river.<br>NOx had increased slightly in the North Arm and South Arm from 1975 – 2000.<br>Ammonium Concentrations were stable.<br>Weak source of TP was located around 40 kms upstream (between Raymond Terrace and Morpeth) with TP decreasing downstream (likely due to particulate Phosphorous).<br>Time averaged trends of Chlorophyll-a concentrations indicate that they are high upstream of the estuary with concentrations decreasing downstream towards the mouth. | Sanderson and Redden 2001 | Data was collected at irregular spatial and temporal scales with majority of the data collected between 1997 and 2000 and databased by Sanderson and Redden 2001. The authors also present a variety of spatio-temporal contexts for various<br>Nutrients and Chlorophyll-a concentrations in the estuary well exceeded the ANZECC guidelines.<br>Spatio-temporal properties of all Chlorophyll-a data collected between 1975 and 2000 indicate the highest concentrations occurred in the lower estuary in the 1980s and in the mid to upper estuary in 1990s. As majority of the data from the mid to late 1990s was collected in the lower estuary so no spatial trends are available and consistent temporal trends are not apparent. |
| **Throsby Creek (collected by Hunter Water)** | Biological Oxygen Demand (BOD) | Limited Stormwater Sampling (~20 samples) collected during 1995-1998. | 5-6 mg/L | NCC 2004 | |
| | Dissolved Oxygen (DO) | | 3.62-6.96 mg/L | | |
| | Suspended Solids (SS) | | 4-6303 (col/100ml) | | |
| | Total Organic Carbon (TC) | | 0.01-0.34 mg-N/L | | |
| | Total Phosphorous | | 0.016-0.12 Mg-P/L | | |

| | | | | | |
|---|---|---|---|---|---|
| | (TP) | | | | |
| **Lower Hunter Estuary** | Nutrients Physical water quality parameters Biological DNA and abundance. | 2010-2017 | See report. | Glamore *et al.*, 2018 | A range of spatial and temporal data collected between 2010-2017 mainly upstream of Hexham Bridge. |
| **Lower Reaches of the Hunter Estuary across 14 sites collected by NSW Office of Environment and Heritage** | Nutrients | 2015 | Very High Concentrations of Ammonia, Nitrate and Phosphates were measured near stormwater drains. | NSW OEH (Swanson, Potts and Scanes, 2017b) | Primary sources of dissolved nutrients to the lower estuary are chemical and fertiliser industries. |
| | Metals (Major Trace Elements) | | In some areas, concentrations of dissolved Zinc and Manganese exceeded ANZECC guidelines for 80% or 90% protection of marine species.<br><br>High concentrations of dissolved Copper were widespread in the lower estuary, approaching and occasionally exceeding ANZECC guidelines for 80% or 90% protection of marine species. | | Leaching of dissolved Copper from anti-fouling coatings on ship hulls contribute a constant source of copper, as does fabrication, handling and distribution of metal concentrates.<br><br>Arsenic is a common by-product of heavy industry and moderate concentrations were measured at multiple sites. |
| | Chemical Compounds | | Sites in upper Throsby Creek, near to and upstream of Hannell Street Bridge, were the only sites where any organic pollutants were detected in water samples. PAH were detected in Throsby Creek at very low concentrations. | | |
| | Sediments | | | | Contaminated sediments and contaminated landfill are likely to contribute dissolved metals to estuary waters. |
| **Fullerton Cove** | Soil, Biota, Sediment and Surface Water Samples | 2018 | <u>Surface Water:</u><br>PFOS - 0.02 mg/L<br>PFHxS – 0.02 mg/L<br><br><u>Sediment Samples:</u><br>PFOS:<br>0.0002-0.0293 mg/kg<br>PFOA:<br>0.0005-0.0012 mg/kg<br>PFHxS:<br>0.0003-0.0025 mg/kg<br>PFHxA :<br>0.0002 mg/kg<br>PFHpA : | AECOM 2018 (*pending publication*) | Based on the unpublished raw data reviewed from AECOM. PFPS was detected in all 6 samples collected by the EPA in 2016. |

| | | | | | |
|---|---|---|---|---|---|
| | | | 0.0003 mg/kg<br>PFDS :<br>0.0001 mg/kg | | |
| **Broad scale survey of sediment contamination in the Lower Estuary** | Metals | Early 1990s | Diverse mix of metals were detected including; Chromium, Copper, Lead and Zinc) with high concentrations of Cadmium. | Batley and Brocknank 1992; Ingleton 1994 | The process of enrichment was found to be rapid (at the time) as metal concentrations increased rapidly in unpolluted sediments that were introduced into the dredged areas. |
| **Analysis of maintenance dredge soil** | Metals | Newcastle Harbour in 1970s and South Arm in the 1980s | High concentrations of metals detected. Concentrations of Zinc in surficial sediments from Throsby Creek often exceeded screening levels. Deeper samples revealed extremely high levels of zinc (2000-5000mg/kg) and manganese (4500-10,500 mg/kg). | MSB 1976,1989 | |
| **Sediment analysis in the South Arm for extension of shipping channel.**<br><br>**(CSIRO engaged by Newcastle Port Corporation).** | Metals, PAH, acid volatile Sulphides, Radionuclides, Tributyltin, Organochlorine pesticides, toxicity. | 2000 | The lowest total PAH concentration to cause any toxicity was 75mg/kg while the lowest TPH concentration to cause toxicity was 450mg/kg. | Simpson et al 2001a,b | Sediments closer to the BHP site, concentrations of PAH were considerably higher and whole sediments were considerably more toxic.<br><br>Approximately half of the sediments adjacent to the BHP site had total PAH concentrations up to 3 times the guideline screening level for disposal at sea, and individual PAH concentrations (e.g., Naphthalene) were up to ten times the ANCESS Interim Ocean Disposal Guideline (1998) maximum level.<br><br>The study concluded that PAHs were the only possible toxicants in those sediments exhibiting a toxic effect in bioassays. |
| **Sediment analysis in Throsby Creek** | Heavy Metals and Metalloids | 1996-1997 | Copper – 110 mg/kg<br>Lead – 330 mg/kg<br>Zinc – 730 mg/kg<br>Mercury - 0.3 mg/kg<br>Cadmium – 1.3 mg/kg | NCC 2004 | Concentrations of Lead and Zinc exceeded interim sediment quality guideline criteria. |

| | | | | | |
|---|---|---|---|---|---|
| | | | Nickel – 45 mg/kg<br>Arsenic - 6.9 mg/kg | | |
| **Newcastle Port Corporation Port Wide Strategy – Maintenance Dredging Assessment** | Chemical Compounds, Toxicity Metals and metalloids. | 2013 | Since 1990 mean concentration of many of the COPCS have been gradually decreasing and very clearly for Cd, Hg, Pb and Zn.<br><br>The mean concentration of nickel has been reasonably constant for the past 10 years (30-40mg/kg range).<br><br>Concentration of total petroleum Hydrocarbons (TPHs) have been detectable, particularly where PAHs have been elevated, but generally below 550 mg/kg. | Simpson et al 2014 | The concentrations of historical COPCs continue to decline or remain constant.<br><br>Toxicity tests indicate low risk of adverse effects to benthic organisms.<br><br>Sediments are assessed as suitable for offshore disposal. |