Parramatta River Masterplan

Water Quality Modelling

July 2018

Prepared for Sydney Water and Parramatta River Catchment Group by: Jacobs on behalf of the ENSure JV.

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Executive summary

The Parramatta River is a heavily urbanised freshwater and estuarine river in Sydney, Australia. The River has a long history of contamination, primarily related to urban and industrial activities, which have taken place in the River's catchment throughout the last two centuries. It is one of the most modified waterways in Australia due to a highly urbanised catchment and high population growth.

In 2014, an alliance of councils, government agencies and community groups, the Parramatta River Catchment Group (PRCG), established the mission to make the River swimmable by 2025. To inform this planning, an integrated catchment-river modelling framework was developed to predict expected enterococci levels at 16 proposed and existing swimming sites along the River under a range of policy and intervention scenarios. The modelling framework is a significant contribution to the evidence-base that underpins the Masterplan, and provides an assessment of 'swimmability' with respect to recreational water quality objectives. This contributes to the overall evidence-based options from which preferred pathways to swimming site activation will be determined that also considers ecosystem health, urban form and waterway access, and community values and amenities.

Incorporating an integrated modelling approach in the development of the Masterplan will help guide microbial water quality evaluation and target setting in order to meet regulatory recreational water quality objectives following a risk assessment approach as outlined in Dela-Cruz and Wearne, 2017. Enterococci were chosen as the modelled indicator as this correlates to current primary recreation risk assessment frameworks and is the current preferred indicator in recreational water quality guidelines. The integrated modelling framework involved sewer modelling, catchment modelling and hydrodynamic receiving waters water quality modelling. This report documents the data sources, the model construction and calibration, and scenario modelling of 'Business as Usual' (BAU) and intervention scenarios.

In order to establish mitigation strategies for enterococci two 'book end' scenarios were assessed; 1) 'Business as Usual' (BAU) - population growth and land use change forecasts at 2025, and 2) reduction of all wet-weather overflows to zero discharge to establish the relative impact between point and diffuse sources of enterococci contamination. Mitigation scenarios explored:

- A combination of medium and high level stormwater interventions such as rainwater tanks and raingardens,
- Restriction of domestic animal waste from waterways, and
- Sewer overflow discharge targets.

The integrated modelling demonstrated:

- There is a significant microbial pollution in the existing case, which presents a challenge to achieving swimmability by 2025.
- By 2025 enterococci loads will increase across the majority of the catchment under current management practices (or BAU).
- The major sources of enterococci loads are from diffuse sources such as pet waste deposition in residential areas, an increase in imperviousness in new growth areas, as well as localised wet weather overflow inputs. However, the modelling would benefit from further investigations into characterisation of stormwater sources through field data collection activities, as well as

collection of local data on pet and bird numbers across the catchment to improve model uncertainties.

- Wet weather overflow volumes increase around 3% on average, and up to 48% in some sub catchments with increasing population density and flows to the wastewater system
- In some areas where industrial or commercial land is converted to high density housing imperviousness decreases resulting in significant decreases in localised enterococci loads.
- Diffuse sources of enterococci estimated by the model contribute substantially more load to the river (average catchment contribution of 70%) than wet weather overflow sources.
- The modelled catchment intervention options (both medium and high) arrest the trajectory of BAU enterococci loads entering the river, and in many cases improve on baseline conditions.
- A high level of catchment intervention (an intensive level of stormwater intervention and strong community outreach/education programs) coupled with targeted overflows (the combined scenario) performs the best for reducing enterococci concentrations in the river. This results in a reduction to the number of non-swimmable days across the majority of sites, although only an additional week of swimmable conditions is achieved.
    - Targeting overflows further upstream of some sites may improve swimmable conditions by an additional 2 weeks in a year.
- The modelled intervention options did not improve 95th percentile concentrations for the sites upstream of Brays bay (with the exception of Lake Parramatta). Significant additional effort within the catchment would be required to further improve water quality for swimming at these sites. More extensive water quality monitoring followed by revised modelling at a local scale would be required.
- The RMA modelling demonstrates that implementing a high level of catchment intervention would improve 95th percentile concentrations above NHMRC Category B guidelines at the Brays Bay swim site.

The current modelling explores a number of options for mitigating poor water quality, but there are other options that could be explored within the risk assessment framework, such as establishment of urban riparian buffers, disinfection or addressing sewer leakages (not simulated explicitly in the current model).

Note that the modelling outcomes will inform a benefit/cost analysis that is to be undertaken separately, which will allow prioritisation of swim sites for activation under the Masterplan.

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Acronyms

Acronym	Defenition
BAU	Business as Usual
CFU	Colonym Forming Units
DWC	Dry Weather Concnetration
EIA	Effective Impervious Areas
EMC	Event Mean Concentrations
ERSs	Emergency Relief Structures
FU	Functional Unit
LEP	Local Environmental Plan
LGA	Local Government Area
LOAEL	Lowest observed-adverse-effect level.
LZN	Land Zoning
MAF	Mean annual flow
NHMRC	National Health and Medical Research Council
NOAEL	No observed-adverse-effect level
NSE	Nash-Sutcliff Efficiency
OEH	NSW Office of Environment and Heritage
PRCG	Parramatta River Catchment Group
RMA	Resource Management Associates Software
SURM	Simple Urban Runoff Model
WHO	World Health Organisation
WWOF	Wet weather overflows

1 Introduction

The Parramatta River is a heavily urbanised river in Sydney, Australia (Figure 1.1). The River extends from Blacktown Creek in the west to the confluence of the Lane Cove River in the east. It is the largest river entering Port Jackson (Sydney Harbour). The river is tidal to the Charles Street Weir in Parramatta, some 30 km upstream from Sydney Heads, and freshwater in its upper reaches.

The Parramatta River is 19 km in length, yet has around 220 km of waterways within its catchment, including a number of significant tributaries (Parramatta River Catchment Group, 2016). These include Subiaco Creek, Tarban Creek, Duck River, Duck Creek, Haslams Creek, Iron Cove Creek, Hawthorne Canal and Powells Creek. The total area of the catchment is 257 km^2.

The estuary covers 12 km^2 and is in a constant tidal flux with additional movements of freshwater from the River's tributaries changing the chemical composition of the water on a daily basis. Tidal flushing for complete water exchange takes on average 17 days (Roper et al., 2011).

The Parramatta River has a long history of contamination, primarily related to urban and industrial activities, which have taken place in the River's catchment throughout the last two centuries. It is one of the most modified waterways in Australia due to a highly urbanised catchment and high population growth (Birch et al., 2015c).

The *Strategic Analysis of Water Quality in the Parramatta River literature review* report (Khan and Byrnes, 2016) presents a literature review of microbial (and chemical) contaminants within the river, the major sources and recommendations on suitable frameworks for risk assessment and monitoring strategies. This report identifies urban stormwater as a significant conveyor of microbial loads, originating from municipal sewage. These loads are transferred from sewers to stormwater systems by leakage or wet-weather overflows designed into the sewage system as Emergency Relief Structures (ERSs). In addition, increased rainfall, runoff from increased impervious areas and stormwater overflow due to urbanisation results in pathogen wash off from surfaces, and leads to more events carrying peak concentrations of waterborne pathogens in surface water. Population growth and urban intensification within the Parramatta River catchment over the next decade will exacerbate these source loads. The Strategic Analysis report, along with stakeholder engagement, has informed the conceptualisation of the modelling framework.

In 2014 the Parramatta River Catchment Group (PRCG), an alliance of state and local government agencies and the community, established the mission to make the River swimmable by 2025. Known as the 'Our Living River' initiative, the group embarked on the development of a Parramatta River Masterplan to detail the direction and planning required to progress to this target. To inform this planning, an integrated catchment-river modelling project was used to predict expected enterococci levels at 16 proposed and existing swimming sites along the river under a range of policy and intervention scenarios. Incorporating an integrated modelling approach in the development of the Masterplan will help guide microbial water quality evaluation and target setting in order to meet regulatory objectives associated with recreational water quality.

Enterococci were chosen as the modelled indicator as this correlates to current primary recreation risk assessment frameworks, and is the current preferred indicator in recreational water quality guidelines.

The overarching modelling framework to support the development of the Masterplan aims to explore the following:

- The major sources of pathogens within the catchment and the risk of non-compliance with regulatory water quality objectives.
- What is the current trajectory of the water quality considering significant infill development growth underway and planned?
- In which areas could open water (free) swimming be achievable in the Parramatta River by 2025? Where not achievable, what needs to be done to gain water quality objectives?

- The quantity and quality improvements gained in the catchment by the implementation of infrastructure, water sensitive urban design and policy solutions to mitigate high risk pathogen contamination sites.

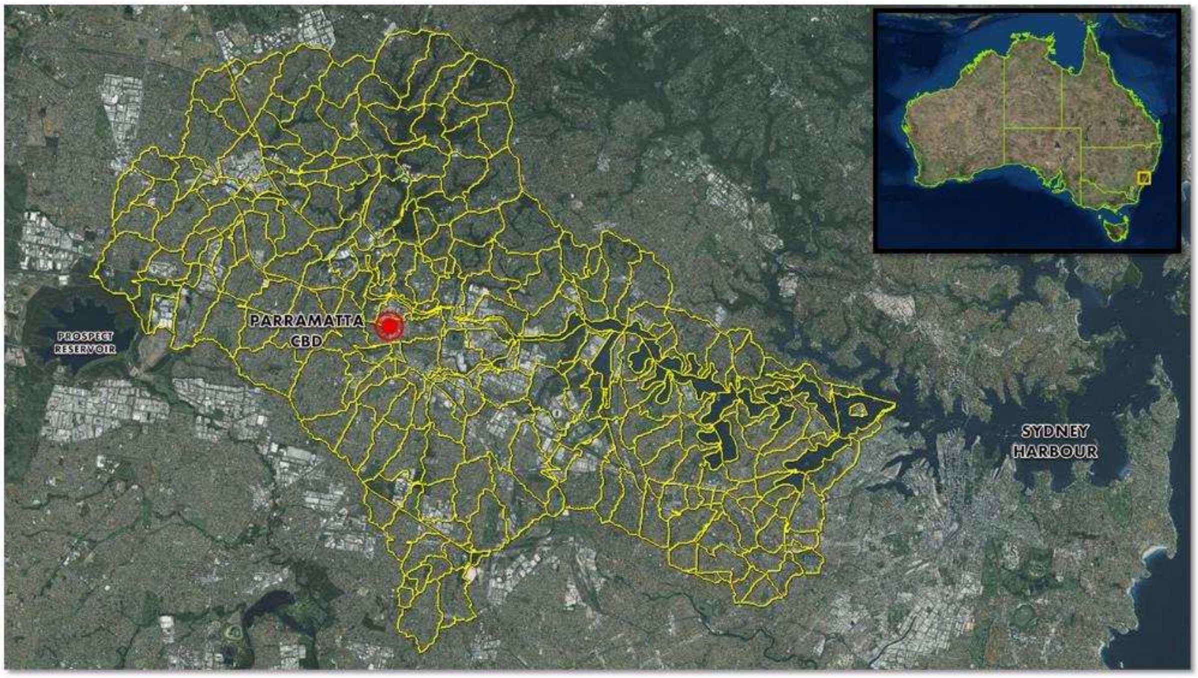


Figure 1.1: Location of the Parramatta River Catchment. Yellow subcatchments illustrate the model extent.

1.1 Purpose of this report

Sydney Water engaged Jacobs, in collaboration with Sydney Water RMA Hydrodynamic modellers, to develop an integrated catchment water quality modelling framework to assess different sources of enterococci (diffuse, stormwater and wastewater overflows) to the River. The integrated modelling framework was used in an effects-based assessment of existing and potential swimming zones under various population growth and pollutant intervention scenarios. This is considered to be Sydney Water's major contribution to the Our Living River Initiative.

This report documents the development of the integrated modelling framework, including:

- Data used to build the modelling framework,
- Model framework construction and calibration,
- Integration between the catchment and hydrodynamic River models, and
- Scenario modelling of BAU and intervention scenarios.

1.2 Integrated Parramatta River Model overview

In order to identify sites suitable for swimming in the Parramatta River, the current microbial concentrations of key indicator species that can affect human health needs to be understood at potential swimming sites that do not have sufficient monitoring data. To do this, a modelling approach is required that will calculate microbial water quality at a sufficient scale.

Water quality objectives for enterococci need to be defined in the model so that recreational suitability at a site can be determined. With a defined target, a range of management and policy scenarios can be modelled to determine if a site is suitable for swimming with respect to bacterial quality.

The Integrated Parramatta River model or modelling framework developed for this project is comprised of three separate but linked models (Figure 1.2). These are:

- Wet weather (sewer) overflows model that provides point-source discharges into the catchment model. This was completed in MOUSE model developed by Sydney Water.
- A catchment model that calculates sub-daily runoff and enterococci loads from a variety of urban landuses and source pathways for input into the hydrodynamic model. This was developed in eWater SOURCE.
- A hydrodynamic model of the Parramatta River and estuary, developed in the Resource Management Associates (RMA) software. This model simulated the hydrodynamics and enterococci fate and transport in the Parramatta River.

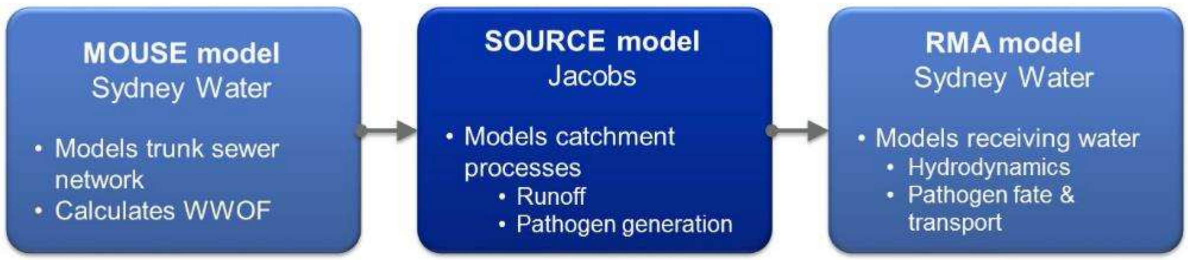


Figure 1.2: The Parramatta River Masterplan water quality modelling framework

The MOUSE model covers Sydney Water trunk sewer network within the Parramatta River catchment, and provided point-source inputs to the SOURCE model as discharge time-series that adds flow and concentrations to the SOURCE node-link network. The catchment modelling extent includes the Parramatta River subcatchments and a node-link representation of the river itself plus the smaller tributaries that feed the Parramatta River. The RMA model extent is defined by the explicit (geographical) boundaries of the Parramatta River, and provides two dimensional depth-averaged (varying horizontally and averaged vertically) simulations of the physical properties and biological interactions within the water column and length of the Parramatta River. Figure 1.3 illustrates the MOUSE wet weather overflow locations, SOURCE model subcatchment delineation, the RMA model mesh extents and the location of the 16 swim sites of interest.

The SOURCE model interfaces with the RMA model by aligning model nodes with those currently set up in the RMA model of the Parramatta River. Generally, catchment scale modelling occurs at a daily time-step. However, sub-daily (2-hourly) time-step has proven crucial in providing a finer temporal resolution to model short–term fluctuations in pathogen densities (Oliver et al., 2016).

The SOURCE catchments model provides a sub-catchment level view of Enterococci fate and transport from point and diffuse sources generated from the catchments. It also provides a view of how these sources impact on Enterococci concentrations and loads at the key swimming sites under investigation. Outputs from the SOURCE model are inputs into the RMA receiving water model of the Parramatta River, which provided a detailed assessment of changes in Enterococci concentrations at the key swimming sites.

1.2.1 Modelling Challenges

Cho et al., (2016) outline a range of knowledge gaps, and subsequent modelling challenges and limitations that impact on the feasibility of catchment-scale modelling of microbial water quality. Some key points to note from this literature review that are relevant to the Masterplan catchment modelling include:

- In-stream processes are lumped together in catchment models, and as a result a few parameters are often used to simulate much of the complexity of in-stream processing. For example, die-off rates are affected both by radiation and temperature, and yet a simple decay function is adopted to determine an aggregated die-off rate. The outcome of process lumping or aggregation is a high degree of sensitivity in modelled outputs attributed to lumped in-stream parameters.
- SOURCE is a conservative model and does not model transformations, such as partitioning microbial cells in runoff into those that are freely suspended and those that are bound with

sediments, which is known to be a key contributor of in-stream microbial concentrations through resuspension processes.

- Parameterisation of pathogen model from literature studies often involves adopting parameter values that have been derived through laboratory or in-situ field experiments. Upscaling from individual fields, land use practices and management systems to obtain a single homogeneous soil, land use, and management parameters across hydrological response units introduces unavoidable uncertainty. However, this aggregation helps to deliver manageable and interpretable modelling results across large areas of interest.

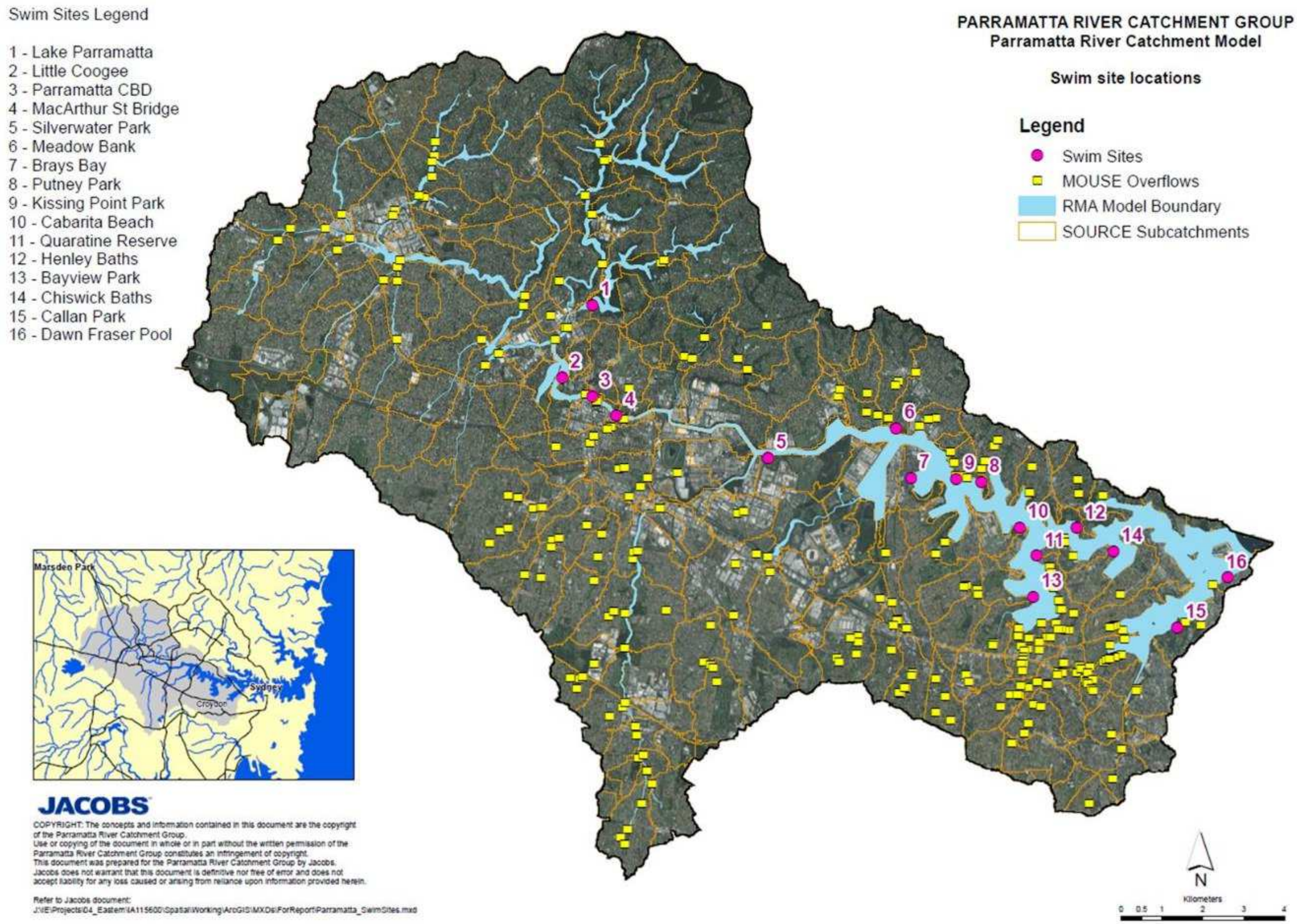


Figure 1.3: Location of the 16 swim sites of interest in relation to the subcatchment boundaries and RMA model mesh extent of the Parramatta River.

2 Current knowledge and data to support modelling framework

The *Strategic Analysis of Water Quality in the Parramatta River literature review* (Khan and Byrnes, 2016) has been completed as part of the development of the Parramatta River Masterplan. The review of current scientific literature was undertaken with the following key aims:

- To identify current knowledge regarding water quality in the Parramatta River with direct relevance to potential increased primary contact recreational activities such as swimming.
- To consider potential future approaches to monitoring recreational water quality in the Parramatta River to assess the public health safety for potential increased primary contact recreational uses.

The Parramatta River Strategic Analysis Literature Review focuses on Enterococci, Bacteroides, Faecal bacteriophages, and viruses for assessing risks to direct contact recreation activities. These species are quite specific (other than Enterococci) and there is insufficient science and data available to undertake catchment-scale modelling of these species at this time.

Although Enterococci and Escherichia coli (E.coli) are not strictly pathogenic, they do indicate the presence of faecal contamination, and are commonly referred to as faecal indicator organisms (Ashbolt et al., 2001; Noble et al., 2003). Enterococci is the indicator under the National Health and Medical Research Council (NHMRC) (2008) *Guidelines for Managing Risks in Recreational Waters* (as adopted by NSW Office of Environment and Heritage (OEH) beachwatch program) for assessing risks to primary contact recreation, and therefore chosen as the key modelled indicator for swimmability. In addition, there is a more substantive body of literature and data for Enterococci (and E.coli) from which to draw on. The catchment and river models can be expanded to include other pathogen species when suitable data is available for model parameterisation and for calibration.

It is worth noting that other water quality attributes, such as suspended sediments (turbidity), presence of algal blooms or litter also affects a site's 'swimmability'. A healthy environment is one where water quality supports a rich and varied community of organisms and protects public health. The water quality of a watercourse influences the way in which communities use the water for activities such as swimming (Khan and Byrnes, 2016). Therefore, the effects-based assessment of a sites 'swimmability' ultimately will need to take into account a range of water quality and ecosystem health indicators within an overarching risk assessment framework, as documented in Dela-Cruz and Wearne (2017).

2.1 Pathogen sources

Microbial contamination of water sources is influenced by surrounding land use, with sources of contamination being both point and nonpoint (diffuse) within a catchment.

The Parramatta River Strategic Analysis literature review along with a recently published literature review on modelling the fate and transport of faecal indicator organisms (Cho et al., 2016) has informed the key sources of contamination and the key pathogen transport pathways that are required in the modelling. Table 2-1 outlines the key pathogen sources that were considered and subsequently included in the catchment model.

Table 2-1: Microbial sources affecting swimmability in the Parramatta River and the model framework required to assess intervention options.

Pathogen Source	Will it be modelled in the framework? How or why not?	
Sewer overflows (point-source)	✓	Yes. Wet-weather overflows from ERSs during storm events lead to peak concentrations of waterborne pathogens in surface waters. This will be modelled by the MOUSE model as inputs to the SOURCE Catchment model
Stormwater (Diffuse source)	✓	Yes. Urban stormwater conveys pathogens washed from surfaces where pathogens from animals have been deposited. This will be modelled in the SOURCE Catchment model as event mean and dry weather concentration (EMCDWC) generation models It should be noted that pathogens that originate from leaks from municipal sewage and are transferred from sewers to stormwater systems by leakage were considered, but are represented implicitly in the model as a lumped diffuse stormwater source, given the dominance of animal sources and direct inputs from ERSs.
Water fowl (Diffuse Source)	✓	Yes. Runoff contaminated with pathogens from direct defecation by waterfowl in waterways. Water fowl are the dominant source of in-stream pathogen generation. This will be modelled in the SOURCE Catchment model as event mean and dry weather concentration (EMCDWC) generation models
Sediment resuspension	✗	No. Recreational users may be exposed to contaminants that are resuspended from the bottom sediment to the water column by a variety of processes. These include natural processes such as wind, waves or tidal movements, or anthropogenic processes including the effect of watercraft. There is little data on the presence and survival of Enterococci in the Sydney region, so the resuspension process is not explicitly modelled.
Stratified stormwater plumes	✗	No. Following a large storm, large volumes of stormwater flow can cause significant stratification. Such circumstances could lead to significant exposure to pathogens by swimmers. Stratification is an issue in the Upper Parramatta, however modelling this process requires a three dimensional model (a depth-average RMA model was used). While stratification is observed through salinity monitoring of the water column, the effect on velocities was small enough that the extra computational time required for a 3D model would be out of proportion to the effect on the results
Human vs non-human enterococci source	✗	No. It is recognised that there is a species barrier for pathogen interactions with humans (e.g. human sources of pathogens have a much higher risk than non-human sources) but the exact relationship between risk of human illness and pathogen source is not yet clear.

2.2 Assessment criteria

Australian National Health and Medical Research Council (NHMRC) guidelines for recreational water quality monitoring refer to World Health Organisation (WHO) recommendations for the use of enterococci as a faecal indicator in marine waters (NHMRC 2008; WHO 2003). This is because faecal coliforms may grow in the environment providing a misleading assessment, whereas enterococci survive longer in marine waters and therefore pose more of a risk to recreational users.

NHMRC guidelines provide a number of categories for determining microbial water quality using 95th percentile (see technical memo in Appendix 1:). The applied microbial water quality objectives categories are “A” (≤40 cfu/100mL), “B” (41-200 cfu/100mL), “C” (201-500 cfu/100mL) and “D” (>500 cfu/100 mL). The RMA model outputs of enterococci concentrations will be tested against the objectives in Table 2-2.

Table 2-2: Compliance criteria for determining microbial water-quality categories, following the NHMRC (2008) *Guidelines for Managing Risks in Recreational Water* (Page 72). NOAEL = No observed-adverse-effect level; LOAEL = Lowest observed-adverse-effect level.

Category[a]	95th percentile value for intestinal enterococci/ 100 mL (rounded values)	Basis of derivation	Estimation of probability
A	≤40	This value is below the NOAEL in most epidemiological studies.	GI illness risk: < 1% AFRI risk: < 0.3% The upper 95th percentile value of 40/100 mL relates to an average probability of less than one case of gastroenteritis in every 100 exposures. The AFRI burden would be negligible.
B	41–200	The 200/100 mL value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or LOAEL for GI illness and AFRI.	GI illness risk: 1–5% AFRI risk: 0.3–1.9% The upper 95th percentile value of 200/100 mL relates to an average probability of one case of gastroenteritis in 20 exposures. The AFRI illness rate would be 19 per 1000 exposures or approximately 1 in 50 exposures.
C	201–500	This represents a substantial elevation in the probability of all adverse health outcomes for which dose–response data are available.	GI illness risk: 5–10% AFRI risk: 1.9–3.9% This range of 95th percentile values represents a probability of 1 in 20 to 1 in 10 risk of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI in the range of 19–39 per 1000 exposures or a range of approximately 1 in 50 to 1 in 25 exposures.
D	> 501	Above this level there may be a significant risk of high levels of illness transmission.	GI illness risk: > 10% AFRI risk: > 3.9% There is a greater than 10% chance of illness per single exposure. The AFRI illness rate at the guideline value of 500 enterococci per 100 mL would be 39 per 1000 exposures or approximately 1 in 25 exposures.

3 Catchment Model

3.1 Overview of SOURCE model

The eWater SOURCE platform is a semi-distributed catchment modelling framework designed for exploring a range of water management problems (Welsh et al., 2012). It conceptualises a range of catchment processes using subcatchments which are composed of Functional Units (FU) that represent areas of similar hydrology and water quality generation, typically characterised through landuse or soils. Daily rainfall-runoff modelling, calibrated using spatially-distributed historical climate data enables the representation of spatial and temporal variability in runoff and water quality generation from different land uses across the catchment. Flows and pollutants are routed through a node-link network representation of the river, where point-sources, water extractions and river operational rules augment the flow in the river network (Figure 3.1).

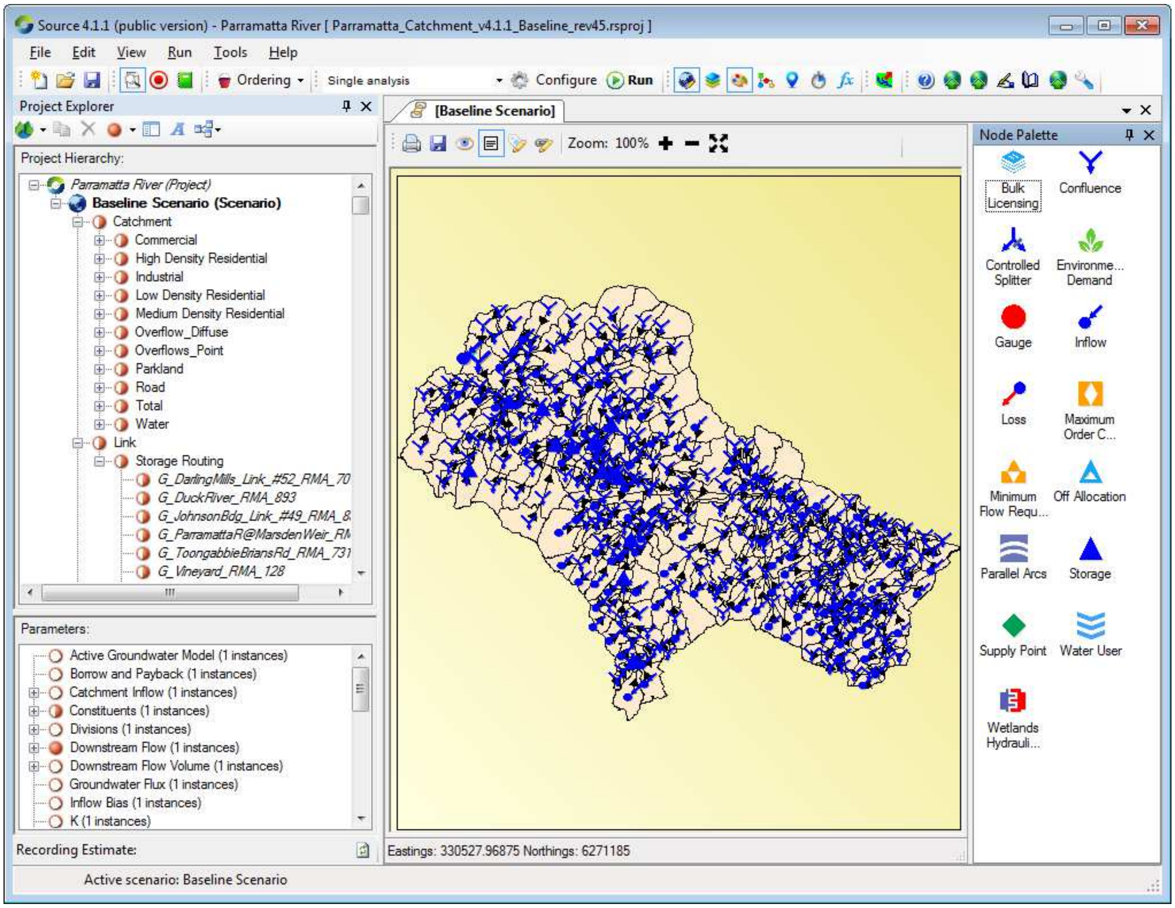


Figure 3.1: User Interface of SOURCE software. Blue nodes = river confluences; Black arrows denote direction of flow and constituent transport

3.2 Hydrological model development

The development process of the SOURCE model of the Parramatta River catchment is illustrated in Figure 3.2. Spatial data for subcatchment boundaries, node-link network, and landuse data are directly imported to the SOURCE model to generate the underlying model structure from which climate and point-source discharge timeseries can be imported, component models for rainfall-runoff and constituent generation are assigned, and in-stream processing models are applied. The SOURCE model was configured for a 2-hourly timestep, with a full simulation period spanning 1/01/1982 – 01/07/2015. This time period was chosen to cover the scenario modelling period (1 Jan 1984 to 31 Dec 1994) and enable calibration of the flows and enterococci concentrations over the available data collection periods.

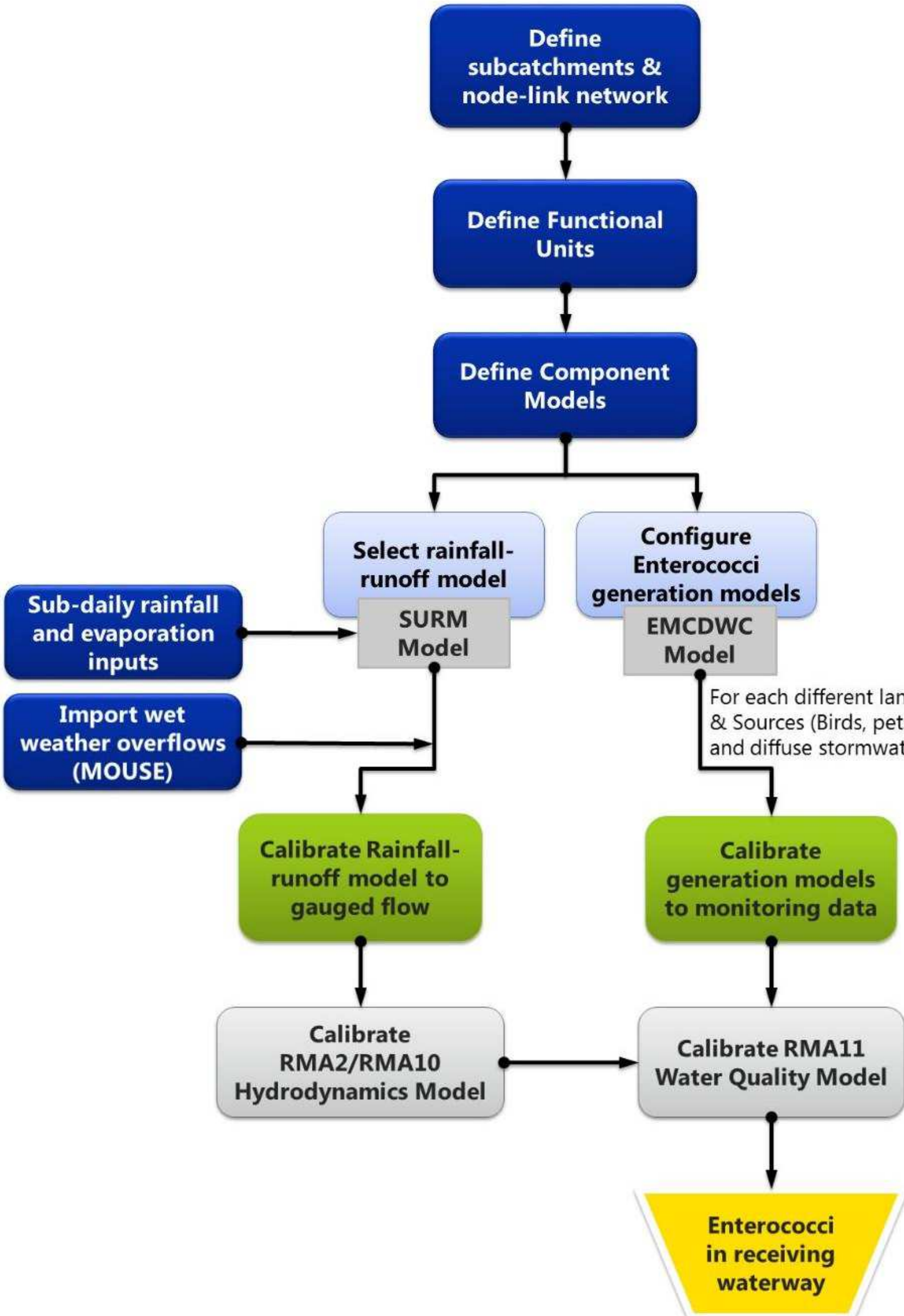


Figure 3.2: The Parramatta River Catchment SOURCE model development process, and linkages. SURM = Simple Urban Runoff Model

3.2.1 Subcatchment boundaries and node-link network

Substantial effort by Stewart (2013) has been invested in developing the original subcatchment delineation for the Sydney Harbour SOURCE model. These subcatchments were developed from a number of existing subcatchment delineations and overlayed with Local Government Area boundaries. Subcatchments were amalgamated to align with gauging locations and water quality sampling points.

The Parramatta River subcatchments have been extracted from this model and preserved in the current model where possible. The RMA model mesh extent has been included as discrete subcatchments, and some subcatchments have been further split to facilitate reporting on individual swimming sites and for RMA data exchange linkages (Figure 3.3).

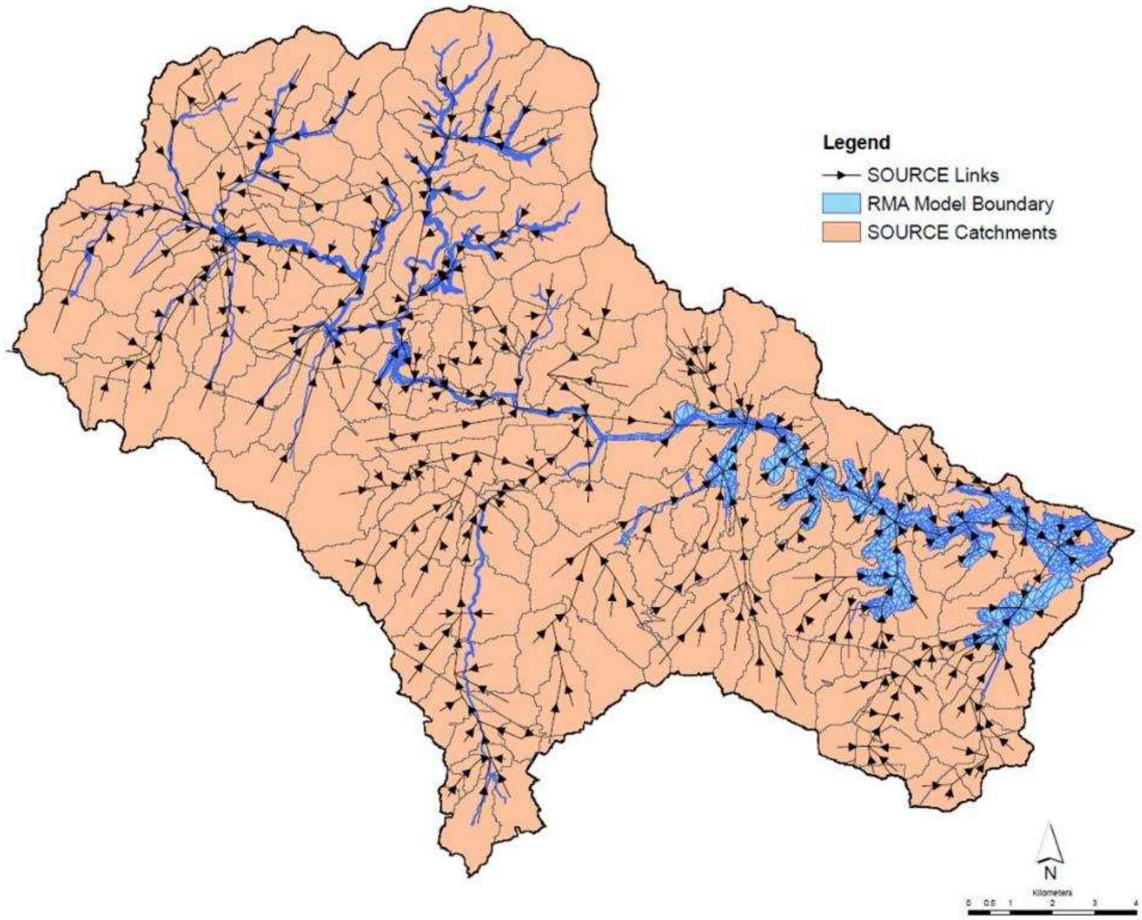


Figure 3.3: The Parramatta River SOURCE Catchments Model subcatchment delineation and node-link network.

3.2.2 Functional Units

The 2015 Local Environmental Plan (LEP) – Land Use Zoning (LZN) spatial data, sourced from NSW Spatial Data Catalogue, was used to categorise subcatchment into Functional Units (FUs). The land use for SOURCE is required to cover the entire extent of the subcatchments; therefore, gaps in the 2015 land use layer were infilled with land use data from the 2013 SOURCE model and crosschecked with aerial imagery and landuse data from Blacktown and Parramatta City Councils. Refinement of land use within the Sydney Olympic Park area was undertaken based on detailed land parcel spatial information provided by Sydney Olympic Park Authority.

Land use categories were selected based on the different areas of hydrological response and Enterococci sources, and requirements for scenarios. Baseline land use categories represented in the model are illustrated in Figure 3.4

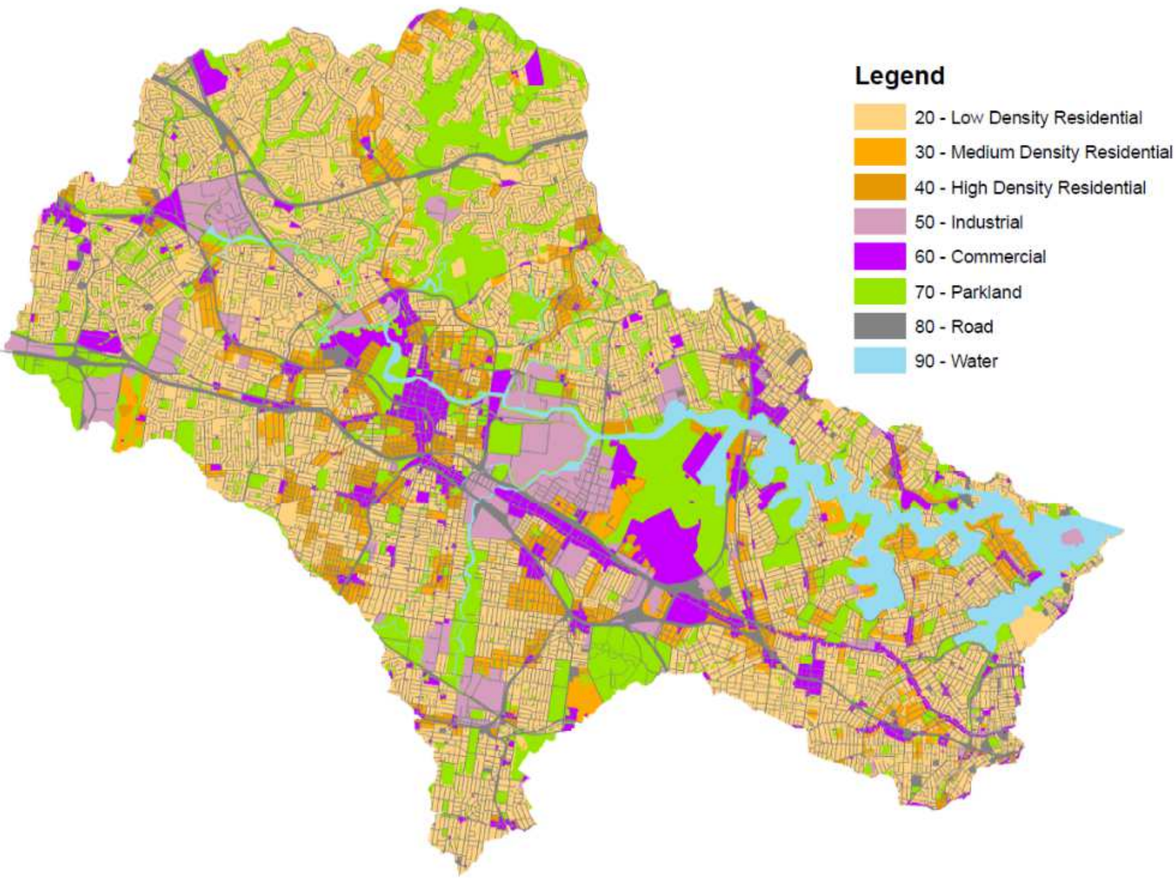


Figure 3.4: The Parramatta River land use representation for Baseline SOURCE model

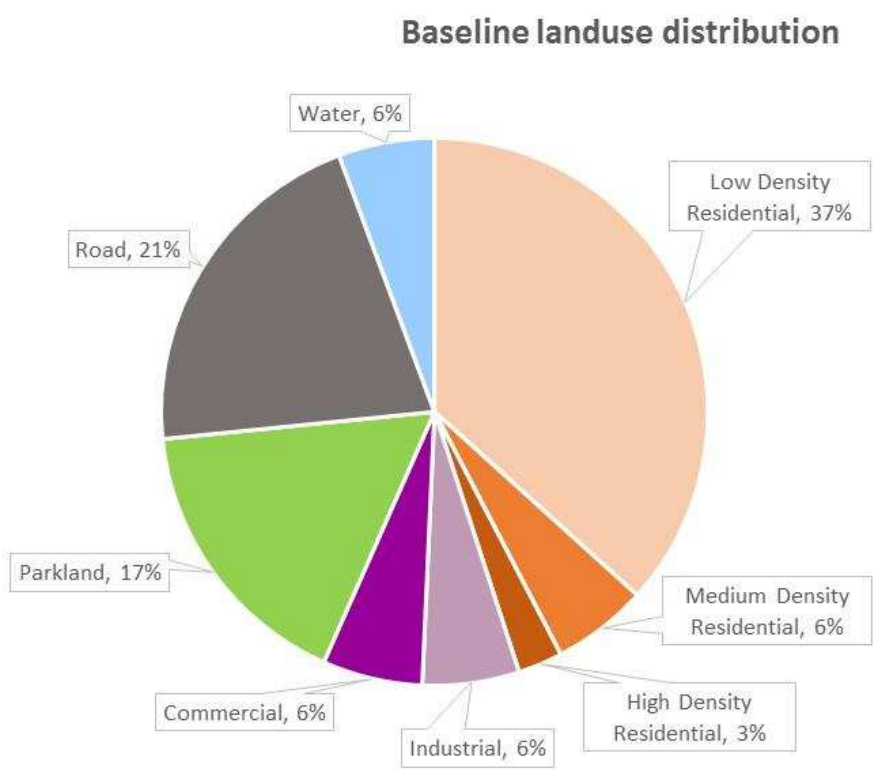


Figure 3.5: Baseline land use distribution as a percent of total catchment area

3.2.3 Climate

Rainfall data was obtained from Sydney Water for 15 sites (Figure 3.6). Data was at an hourly time-step and aggregated to a 2-hourly time-step to be in line with the model simulation time-step. The majority of rainfall records spanned 1992 to present.

In order to derive rainfall timeseries that spanned the full gauged flow record (starting from 1980), Homebush and Potts rainfall station data were selected as the most representative long-term records and used to infill the remaining timeseries for periods between 1984 and 1992. Infilling of other station data was completed based on nearby comparison stations using histograms and the Wilcoxon rank sum t-test statistics.

Rainfall timeseries were assigned to model subcatchments based on Theissen polygons derived from station coordinates (Figure 3.6).

Monthly mean potential evapotranspiration values were obtained from the Climate Atlas of Australia. A repeating monthly series of gridded evapotranspiration data was used disaggregated into a 2-hourly time step.

Figure 3.6: Assignment of rainfall station data to each subcatchment. MAR = Mean annual rainfall (mm).

3.2.4 Gauged flow data

Streamflow data is required to calibrate the rainfall-runoff model; therefore, this data contains the most relevant information for the catchments. Five streamflow datasets from gauging stations were obtained from Sydney Water and NSW Realtime Water data website (Table 3-1).

Two flow gauge sites were assessed as suitable for the purposes of the project (Figure 3.7). The other sites did not sufficiently cover the required period of record (1983–1994) (Table 3-1). The two sites identified as suitable were:

1. 13005 - Toongabbie Creek At Briens Road
2. 9270 – Parramatta River at Marsden Weir

Table 3-1: Parramatta River Catchment available flow gauge data quality summary

Flow gauge site	Start date	End date	Missing data
13005 - Toongabbie Creek at Briens Road	24/09/1979	5/11/2013	3% of record
9270 - Parramatta River at Marsden Weir	06/02/1979	08/04/2013	15% of record between 23/03/2000 – 21/02/2005
213219 - Toongabbie Creek at Johnstons Bridge	30/06/1992	7/08/2013	Majority of record missing (94%)
2VYC01 – Vineyard Creek at Kissing Point Road	10/09/2013	19/09/2014	Nil, but short record overall
213209 – Duck River at Mackay Road South Granville	3/06/1992	29/01/2012	Record missing up between 7/08/2003 – 10/03/2011

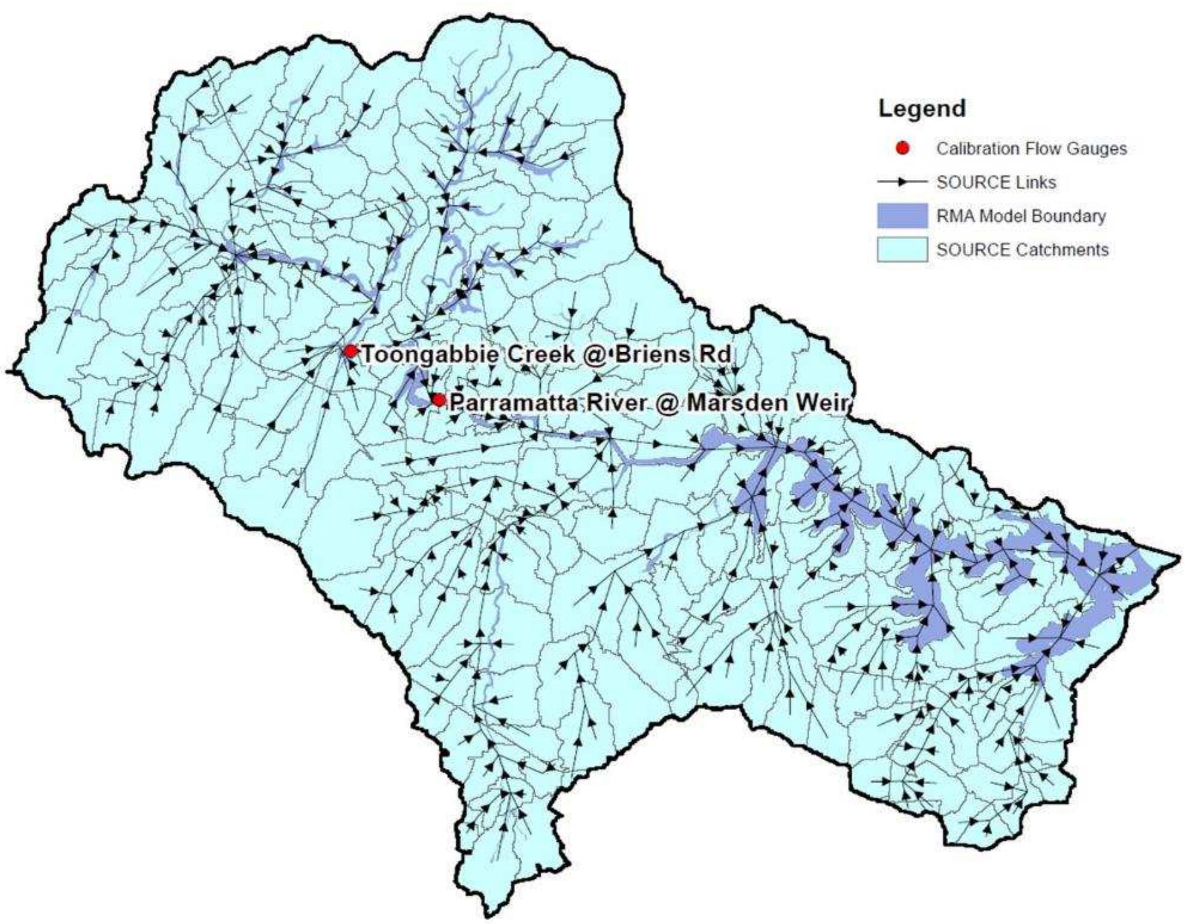


Figure 3.7: Flow gauge sites (red dots) used in SOURCE model calibration.

3.2.5 Rainfall-runoff model

Due to the Parramatta River catchment being highly urbanised, the Simple Urban Runoff Model (SURM) (Chiew et al., 1997) was used in the current Parramatta SOURCE model. SURM is a simplified version of the SIMHYD model developed for urban hydrological application and specifies separate pervious and impervious stores. Table 3-2 lists the model parameter definitions and typical parameter ranges.

Table 3-2: SURM Model Parameter definition and typical ranges

Parameter	Description	Units	Min	Max
bfac	Base flow coefficient		0	1
Coeff	Infiltration coefficient		0	400
dseep	Deep seepage		0	1
Frac. field capacity	The field capacity, expressed as a fraction of the maximum soil moisture capacity		0	1
Fimp	Impervious fraction		0	1
initgw	Initial groundwater level	mm	0	500
Initial moisture	Initial soil moisture content, as a fraction of the maximum store capacity		0	1
Rfac	Recharge coefficient		0	1
smax	Soil moisture store capacity (mm)	mm	1	500
sq	Infiltration shape		0	10
thres	Impervious threshold	mm	0	5

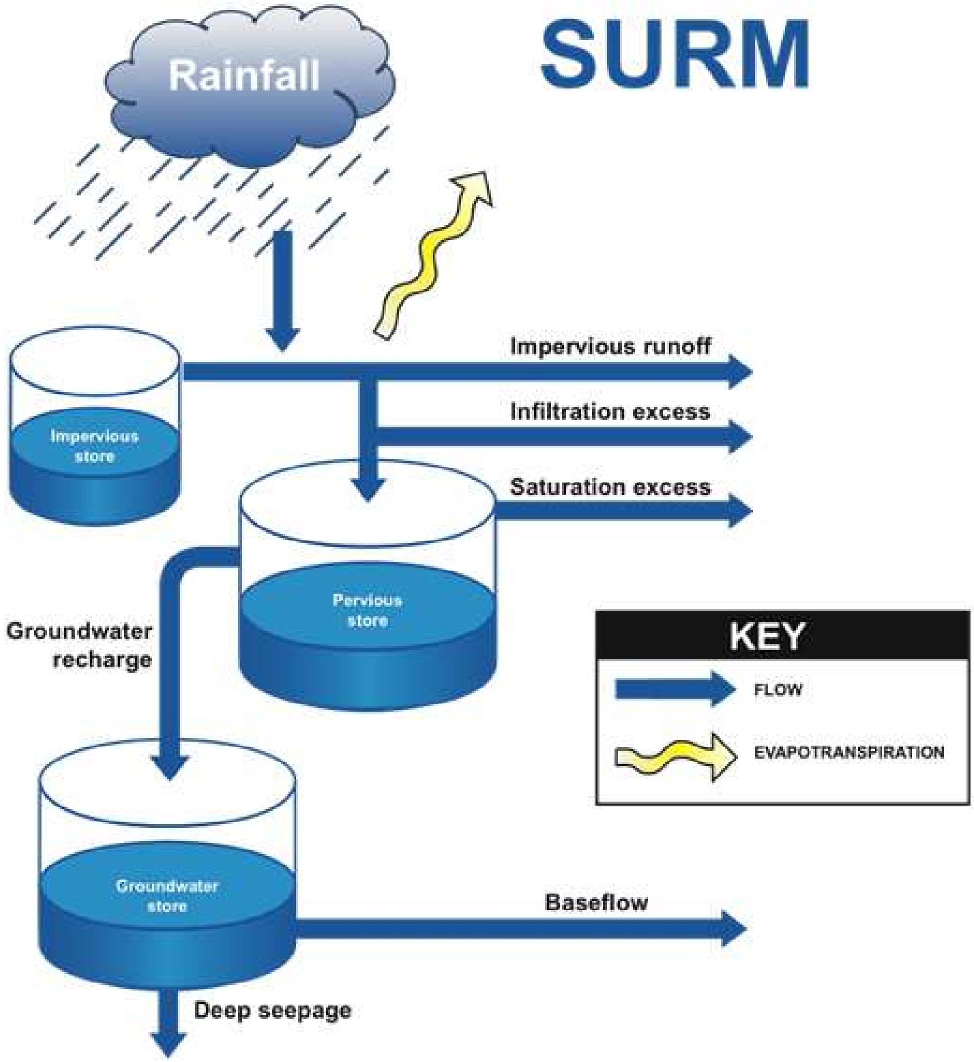


Figure 3.8: Conceptual structure of SURM (eWater, 2017)

The impervious fraction parameters used as input into SURM were calculated based on the Directly Connected Impervious Areas (or Effective Impervious Areas (EIA)) method. This method generally provides a realistic measure of the total impervious area throughout the catchment that generates runoff which reaches the catchment outlet as it excludes impervious areas that have no direct connection to the drainage network. This method helps in avoiding an overestimation of urban runoff volumes and peak flows.

AR&R (2014) provides EIA factors for various land use types which were used in order to quantify the portion of effective impervious areas in standard land use types including residential, commercial, industrial, green space and roads. In order to determine the fraction impervious parameters for input into the SURM model, the fraction impervious for each land use type obtained from Sydney Water data was multiplied by the AR&R (2014) EIA factors, resulting in a fraction impervious for only the directly connected impervious areas (Table 3-3).

Table 3-3: Fraction Impervious SURM parameter applied in SOURCE model

Functional Unit	Fraction Impervious
Low Density Residential	36%
Medium Density Residential	41%
High Density Residential	47%
Commercial	78%
Industrial	81%
Parkland	0%
Road	75%

3.2.6 Point-source inputs

MOUSE modelling undertaken by Sydney Water was used to inform waste water overflows (WWOF) in the model. As there are 271 sewer point-sources within the catchment, some grouping of individual overflow points is warranted. WWOF point sources were grouped per subcatchment and included in the model as inflow nodes that intersect the node-link network.

MOUSE model WWOF discharges were available for 1984 – 1995 and for 2012 to Jul-2015, to accommodate the RMA calibration period. A monthly pattern of overflow discharge was derived from the daily modelled overflow to 'infill' the remaining period to aid in water quality calibration.

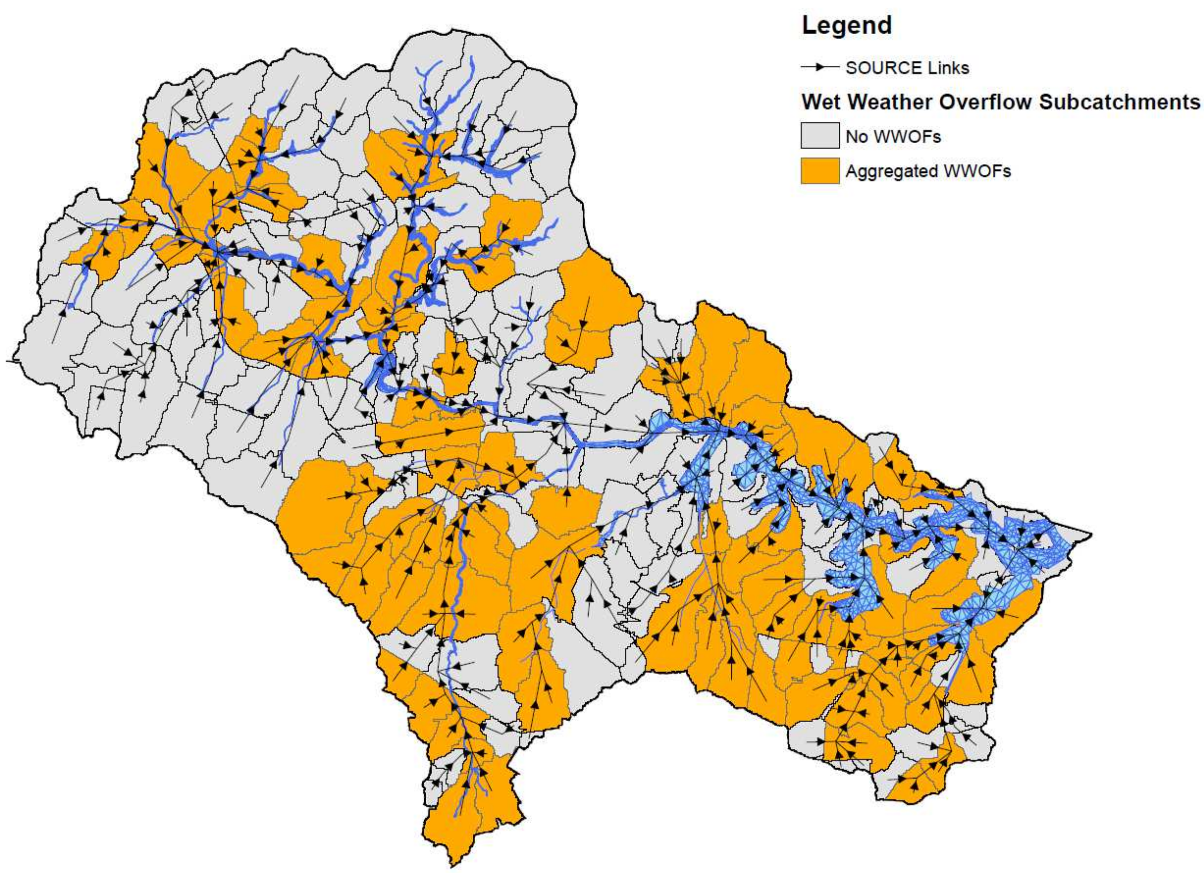


Figure 3.9: Subcatchments with wet weather overflow (WWOF) point-source inputs. Individual WWOFs have been aggregated for each subcatchments as a single timeseries input

3.2.7 Storages

Twelve storages were included in the model as per the 2013 SOURCE Sydney Harbour model:

- Lake Parramatta, approximately 370 ML;
- Lower Parramatta River below Toongabbie Creek (3 storages to Charles Street Weir), approximately 20, 100, and 36 ML;
- 3 storages along Toongabbie Creek, including the gauging weir;
- Upper Greystanes creek, approximately 58 ML;
- Impoundments behind weirs on the lower Duck River; and
- 1 storage on the upper Duck River.

Storage data and configuration from the 2013 SOURCE model were used unaltered.

3.2.8 Flow Calibration

Calibration/validation data

Toongabbie at Briens Road flow gauge were the best quality data with the longest period of record (1979 to 2013), and this was the main flow calibration site. Calibration was constrained by the length of record of the overflow inputs which were only available for Jan 1983 to Dec 1994, and for Jan 2013 to Dec 2014 (to coincide with RMA model calibration period). Therefore, calibration of the Toongabbie gauge was for the same period, with a two-year warm-up period (1 January 1982 – 31 December 1983).

Site validation of the calibrated SURM parameters was undertaken using the flow data at Parramatta River at Marsden Weir site.

Evaluation metrics

A combined Nash-Sutcliff Efficiency (NSE) daily and log flow duration curve objective function was used in the automated calibration in order to achieve a good fit between baseflows and peak flows.

Simulated catchment flows at the two gauge locations were assessed against observed flow data using:

- Summary statistics
  - The NSE statistic (Equation 1) (as a measure of goodness-of-fit, where 0 is poor and 1 is a perfect fit to observed data)

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2} \right]$$

Equation 1

  Where Y_i^{obs} = ith flow observation; Y_i^{sim} = ith simulated flow; Y^{mean} = mean of observed data; n = total number of observations

  - Percent bias (% difference between modelled and gauged mean daily flow; positive % bias indicates overestimation and negative % bias indicates underestimation compared to observed)
  - The mean annual flow (MAF)
- Timeseries plots and flow duration curves of daily flow.

A joint calibration between SOURCE and RMA models was conducted to achieve a harmonised catchment hydrology-river hydrodynamics calibration.

Calibration/validation results

Moriasi et al., (2007) suggests that daily or monthly streamflow model simulations are deemed satisfactory if the NSE statistic is between 0.5 and 0.65, and percent bias is ± 25%. Calibration is deemed good if the NSE is greater than 0.65 and percent bias is ± 15%.

It is important to note that a lumped rainfall-runoff model operating on a sub-daily timestep will typically result in a poor NSE statistic compared to a daily or monthly model. Therefore, emphasis was placed on calibration to minimising percent bias, obtaining similar mean annual flow and 95th percentile flow statistics, and graphical comparisons.

Generally, at a daily time-step the catchment model was able to reproduce the high to medium flow behaviour reasonably well, and comparisons between NSE and % bias at the Toongabbie flow gauge demonstrates that the simulation results fall within the 'good' calibration criteria suggested by Moriasi et al., (2007). At a sub-daily timestep the calibration meets the 'satisfactory' criteria (Table 3-4).

For Marsden Weir validation site, modelled flow achieved a good fit between mean and 90th percentile flows, and a satisfactory % bias statistic, but the daily timeseries plot indicates the model is underrepresenting the higher flow events which results in a 'satisfactory' rank for the NSE statistic (Table 3-4). Nevertheless, RMA modelled river flows calibrate well at this site.

The flow duration curves demonstrate that the low flows at each of the comparison gauge sites are underestimated by the model. This may also explain the underestimated MAF at the Marsden Weir site, where MAF at Toongabbie is slightly overestimated by the model. In terms of pathogen generation and transport, high to medium flow events are the main drivers, and in this regard the model is performing reasonably well.

Table 3-5 gives the calibrated SURM parameters used in the Parramatta River catchment model.

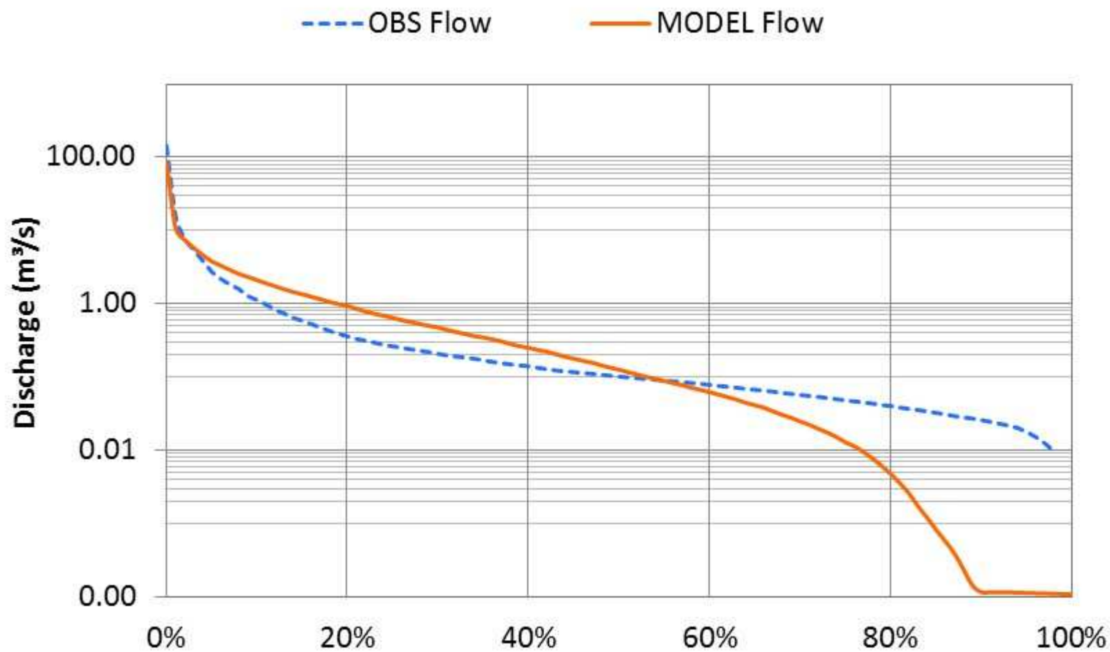
Table 3-4: SOURCE catchment model calibration statistics.

	Toongabbie Creek at Brien's Rd			Parramatta River at Marsden Weir		
	Sub daily	Daily	Monthly	Sub daily	Daily	Monthly
NSE	0.54	0.65	0.76	0.57	0.58	0.71
% Bias	5.8%	4.4%	7.1%	-9%	-22.1%	4.8%
Observed Mean Annual Flow (m^3/s)	0.82			1.9		
Modelled Mean Annual Flow (m^3/s)	0.87			1.5		
Observed flow 90th percentile (daily flow m^3/s)	1.12			3.1		
Modelled 90th percentile (daily flow m^3/s)	2.11			3.5		

Table 3-5: Calibrated SURM parameters. Parameter definitions given in Table 3-2.

Functional Unit	Smax*	Frac. field capacity	rfac	bfac	coeff	dseep	fimp	thres	sq	Initial moistur	initgw
Low Density Residential	450	0.001	0.01	0.2	400	0	0.36	2	0.05	0.3	10
Medium Density Residential	450	0.001	0.01	0.2	400	0	0.41	2	0.05	0.3	10
High Density Residential	450	0.001	0.01	0.2	400	0	0.47	2	0.05	0.3	10
Industrial	450	0.001	0.01	0.2	400	0	0.81	2	0.05	0.3	10
Commercial	450	0.001	0.01	0.2	400	0	0.78	2	0.05	0.3	10
Parkland	450	0.001	0.01	0.2	400	0	0	2	0.05	0.3	10
Road	450	0.001	0.01	0.2	400	0	0.75	2	0.05	0.3	10
Water	0	0	0	0	0	0	0	0	0	0	0

*Smax= 250 for Duck River subcatchments



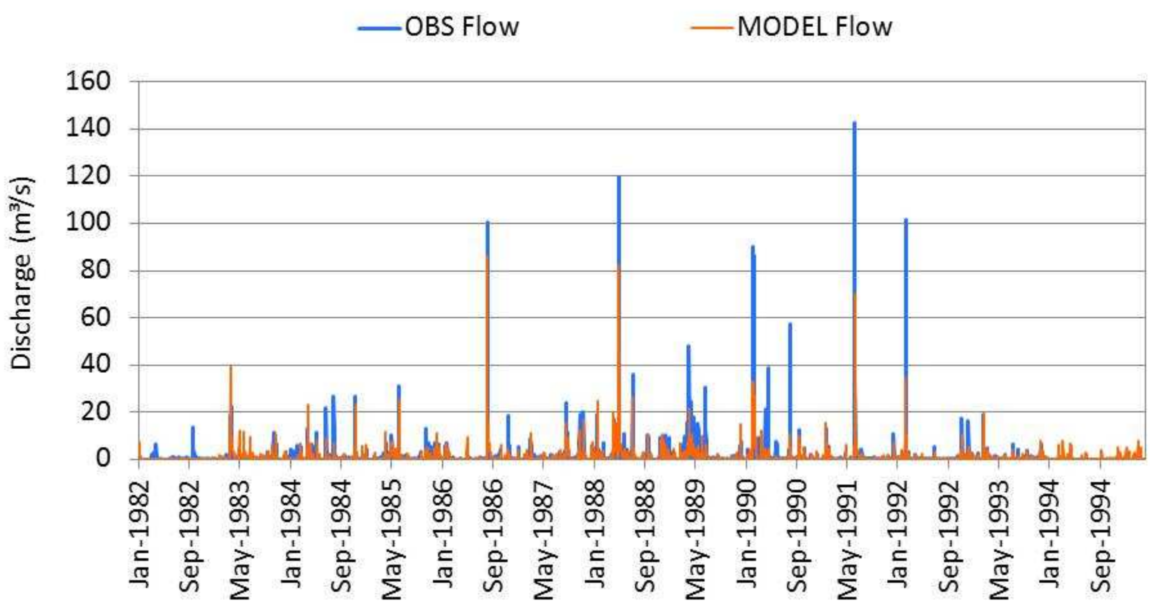
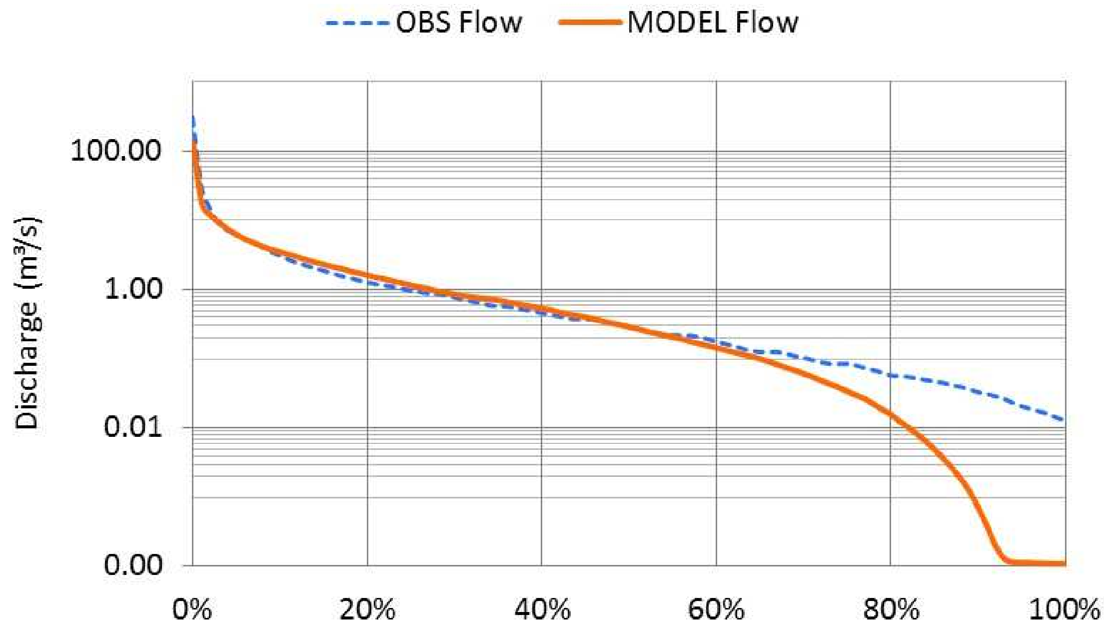


Figure 3.10: Toongabbie at Briens Road gauge calibration comparisons between modelled and observed daily flows



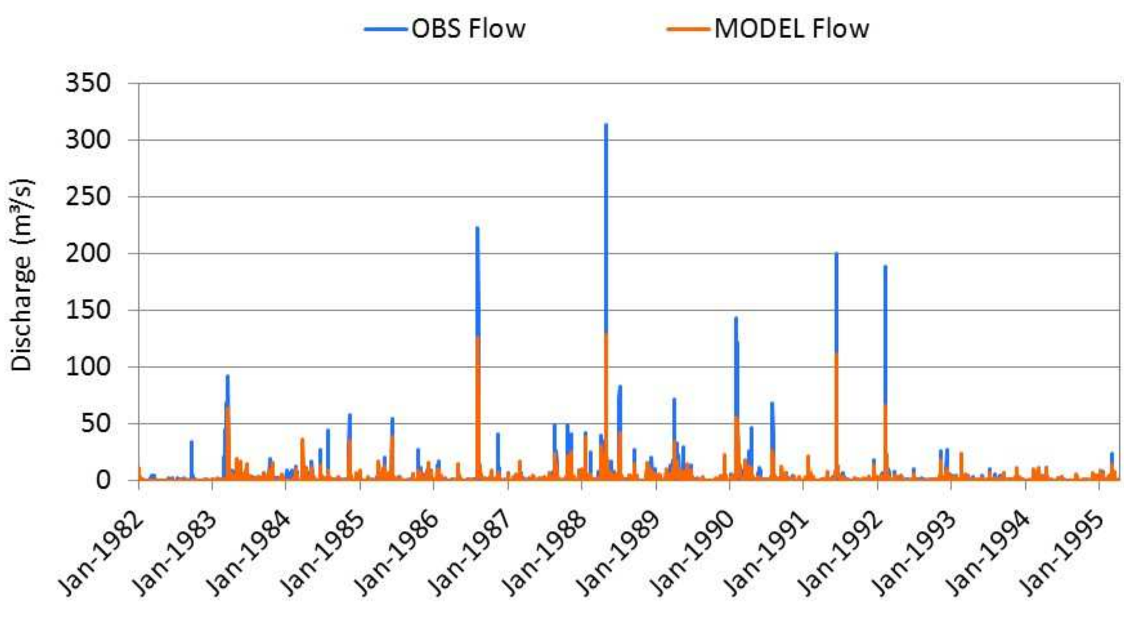


Figure 3.11: Parramatta River at Marsden Weir gauge validation comparisons between modelled and observed daily flows

3.3 Enterococci generation model development

3.3.1 Enterococci sources and generation rates

Enterococci sources considered in the model include:

- Deposition from domestic and feral animals (dogs and cats)
- Deposition from birds
- Stormwater contamination from commercial and industrial areas
- Runoff from roads
- Wet weather overflows (WWOF)

An extensive literature review was conducted to derive Enterococci source inputs to the catchments model, and obtain Enterococci concentration ranges for different land uses to guide calibration (summarised in Table 3-6). Local data and studies conducted in New South Wales urban catchments were used where available, particularly studies in urbanised catchments. Where no local or regional data was available, international literature was used. Where no Enterococci data was available, information on E.coli was adopted. A bibliography of literature reviewed is presented in Appendix 1:.

The Enterococci fate and transport process incorporated in the model includes deposition, build-up in the soil, wash-off and die-off (inactivation) (Figure 3.12). The representation of these processes in the model has been derived based on the pathogen catchment budget (PCB) model developed by Ferguson et al., (2007). The PCB model was developed for Australian catchments, therefore model parameterisation are locally derived from field studies (Cox et al., 2005).

The PCB model quantifies the key processes affecting the generation and transport of microorganisms from humans and animals using land use and flow data, and catchment specific information including point sources such as sewage treatment plants and on-site systems. The model generates event and dry weather loads, and has been applied in the Wingecarribee catchment in New South Wales and used to rank those sub-catchments that would contribute the highest pathogen loads in dry weather, and in intermediate and large wet weather events. The pathogen process algorithms in the PCB model are simple and commensurate with available data. The PCB model algorithms for deposition, wash-off and inactivation in the soil were used to derive constituent generation input concentrations in SOURCE for different land uses.

Table 3-6: Enterococci concentration ranges for different land uses and sources

Enterococci ranges (CFU/100mL)	Mins	Max	Reference
General livestock/pasture	1,200	4,350	Long and Plummer (2004); Duncan (1999) – for faecal coliforms
	24,000	120,000	Stein et al., (2008)
Dog faeces	100,000	1,000,000,000	Gilmore et al., (2014)
Bird Faeces	1,000	10,000,000	Gilmore et al., (2014)
General urban stormwater	100	1,100,000	Davies and Bavor (2000)
	84	33,800	Kapiti Coast District Council (NZ) Ecoli event sampling data 2006 – 2015 (Jacobs, 2017)
Residential	700	2,600	Long and Plummer (2004)
	27,000	55,000	Stein et al., (2008); Duncan (1999)
Commercial	15,000	77,000	Stein et al., (2008)
Industrial	1,500	21,000	Stein et al., (2008); Duncan (1999)
Transportation (roads)	4,500	18,000	Stein et al., (2008); Duncan (1999)
Open space	5,400	21,000	Stein et al., (2008)

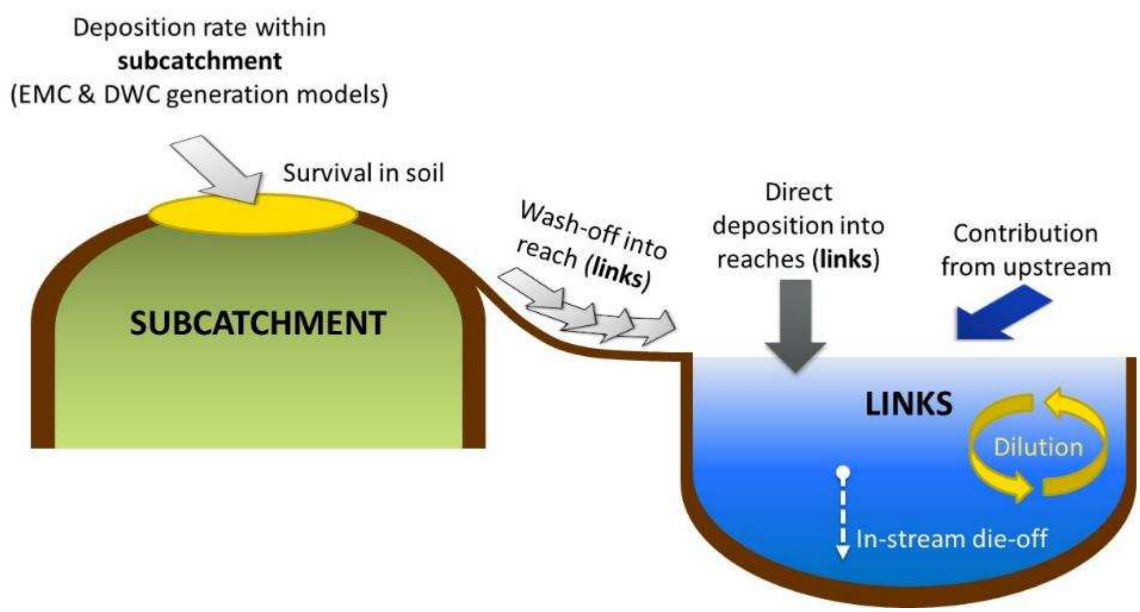


Figure 3.12. Conceptual diagram of Enterococci fate and transport processes within the SOURCE catchment model

The generation inputs required by the SOURCE model are Event Mean Concentrations (EMC) and Dry Weather Concentrations (DWC) for each land use. EMCs are multiplied by the quickflow generated from the rainfall-runoff model to calculate the event load. DWCs are multiplied by the baseflow to generate the dry weather load. The EMC and DWC parameters are applied at a functional unit (i.e. land use) scale and summed at each subcatchment outlet to provide the generated Enterococci loads, which are then inputs to each link in the model where dilution and in-stream decay occurs (Figure 3.12). In-stream die-off is represented as half-life decay functions.

Based on Ferguson et al., (2007) with some modification, the DWC and EMC generation rates were calculated for each subcatchment as per Equation 2 and Equation 3 respectively:

$$DWC_{1,l} = \sum_{s=1}^{a} A_{s,l} d_s P_s X_s D_s \delta_s \qquad \text{Equation 2}$$

$$EMC_{1,l} = \sum_{s=1}^{a} M_s A_{s,l} P_s \delta_s \qquad \text{Equation 3}$$

Where

$DWC_{1,l}$ = Dry weather Enterococci input to stream from animal species *s* for subcatchment *l* (CFU/d)

$EMC_{1,l}$ = Wet weather Enterococci input to stream from animal species *s* for subcatchment *l* (CFU/d)

$A_{s,l}$ = Number of animals (s) in subcatchment (l) (per km^2)

d_s = amount of manure produced (kg/d/animal)

X_s = access to streams for animal species *s*

D_s = probability of species *s* defecating directly into a stream

P_s = Enterococci concentration in faecal material of animal species *s* (CFU/kg)

M_s = Fraction of faeces for animal species *s* on land that would be transported to stream in a large rainfall event

δ_s = proportion of initial Enterococci population surviving in soil (per day)

The EMC equation assumes that the modelled quickflow associated with the EMC generation rate acts as the 'wash-off' trigger, rather than effective rainfall as in Ferguson et al., (2007), to avoid the need to develop a custom generation model.

The information utilised to parameterise the EMC and DWC generation models are given in Table 3-7.

Animal deposition rate assumptions

The number of domesticated cats and dogs were assumed to be 400 per km^2. This value was adopted from Ferguson et al., (2007) as data provided from councils on pet ownership were sparse, but were consistent with general NSW pet ownership numbers per population in each Local Government Area (ACAC, 2010).

It was difficult to obtain reasonable estimates of bird numbers from different land uses based on published bird surveys in the catchment. Therefore, the number of organisms entering the stream from bird sources was derived for residential, parkland and commercial and industrial areas based on percentage abundance documented in ASCE (2014): 52% Parklands; 27% residential; 21% commercial/industrial.

The amount of manure produced by cats and dogs was adopted from Ferguson et al., (2007), and the concentration in faecal material from Cox et al., (2005), based on faecal coliform concentrations. Manure deposition rate for birds sourced from ASCE (2014) based on ducks and gulls.

EMC and DWC derived for domestic pets applied uniformly to residential FUs, and for feral cats/dogs applied to parkland FUs. EMC and DWC derived for birds were applied to Parkland, residential, commercial and industrial FUs.

Table 3-7: Deposition rate parameters (from Ferguson et al., 2007)

Deposition Parameter	Dogs	Cats	Birds
A_s = Number of animals in subcatchment (per km^2)	Domestic – 400 Feral – 0.25	Domestic – 400 Feral - 1	Parkland – 200 Residential – 100 Commercial & industrial - 85
d_s = Amount of manure produced (kg/d)	0.5	0.2	0.11
P_s = Concentration of microorganism in faecal material (CFU/kg)	31,000,000	31,000,000	8,100
D_s = Probability of animal defecating directly into a stream	0.001	0.001	0.01
X_s = Access to streams **M_s = Likely fraction of material mobilized to the stream during a rainfall event**	Domestic – 0.2 Feral - 1 0.05	Domestic – 0.2 Feral - 1 0.02	1 0.03
δ_s = survival in soil (per day)	0.05	0.05	

In-stream die-off

In-stream die-off was represented by decay models within each link. The decay model is a half-life function, and the half-life was determined through calibration to observed in-stream data and RMA calibration results (refer to Section 3.3.3).

Initial deposition rates

Table 3-8 gives the initial EMC and DWC values calculated using the methods described for each Enterococci animal source. Commercial, industrial and road stormwater runoff parameters are adopted from Stein et al., (2008). Generally, the mean and upper parameter ranges agree well with literature concentrations. Deriving the EMC and DWC parameters based on FU area (i.e. to ascertain the number of animals per subcatchment contributing to deposition) gives a wide range in Enterococci concentrations.

Table 3-8: Initial range in Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) parameters for Enterococci concentrations (CFU/100mL). EMC and DWC parameters differ across subcatchments for animal sources. Mean is presented in parentheses.

Source	Land use	EMC (CFU/100mL)	DWC (CFU/100mL)
Domestic animals (dogs and cats)	**Residential**	1,700 – 17,546,000 (1,400,000)	16 – 165,800 (13,400)
	Parkland	16,000 – 2,269,000 (287,700)	430 – 61,000 (7,770)
Birds	**Residential**	50 – 3,500 (280)	1 - 340 (28)
	Parkland	10 – 219,000 (27,757)	1 – 22,000 (2,773)
	Commercial	20 – 77,000 (3,535)	2 – 7,700 (353)
	Industrial	5 – 77,000 (18,400)	1 – 28,000 (1,838)
Commercial & industrial* stormwater	**Commercial**	77,000	770
	Industrial	21,000	210
Roads*	**Roads**	8,900	2,000

*Parameters adopted from Stein et al., 2008

Figure 3.13 illustrates the different Enterococci source loads across the catchment. These maps have been derived based on the mean daily modelled flow (ML/d) for each subcatchment multiplied by the Enterococci event mean concentration that was used in the model. These maps are not direct model outputs, rather they give an indication of the magnitude and distribution of subcatchment loads of surviving organisms after deposition and inactivation in the soil has occurred (therefore, the organisms that are available for transport in runoff).

The source load maps, viewed with modelled results, can be used to identify which sources may be contributing to 'hot spots' of Enterococci contamination that could be mitigated through catchment interventions, implementation of water sensitive urban design or infrastructure works on sewer overflows.

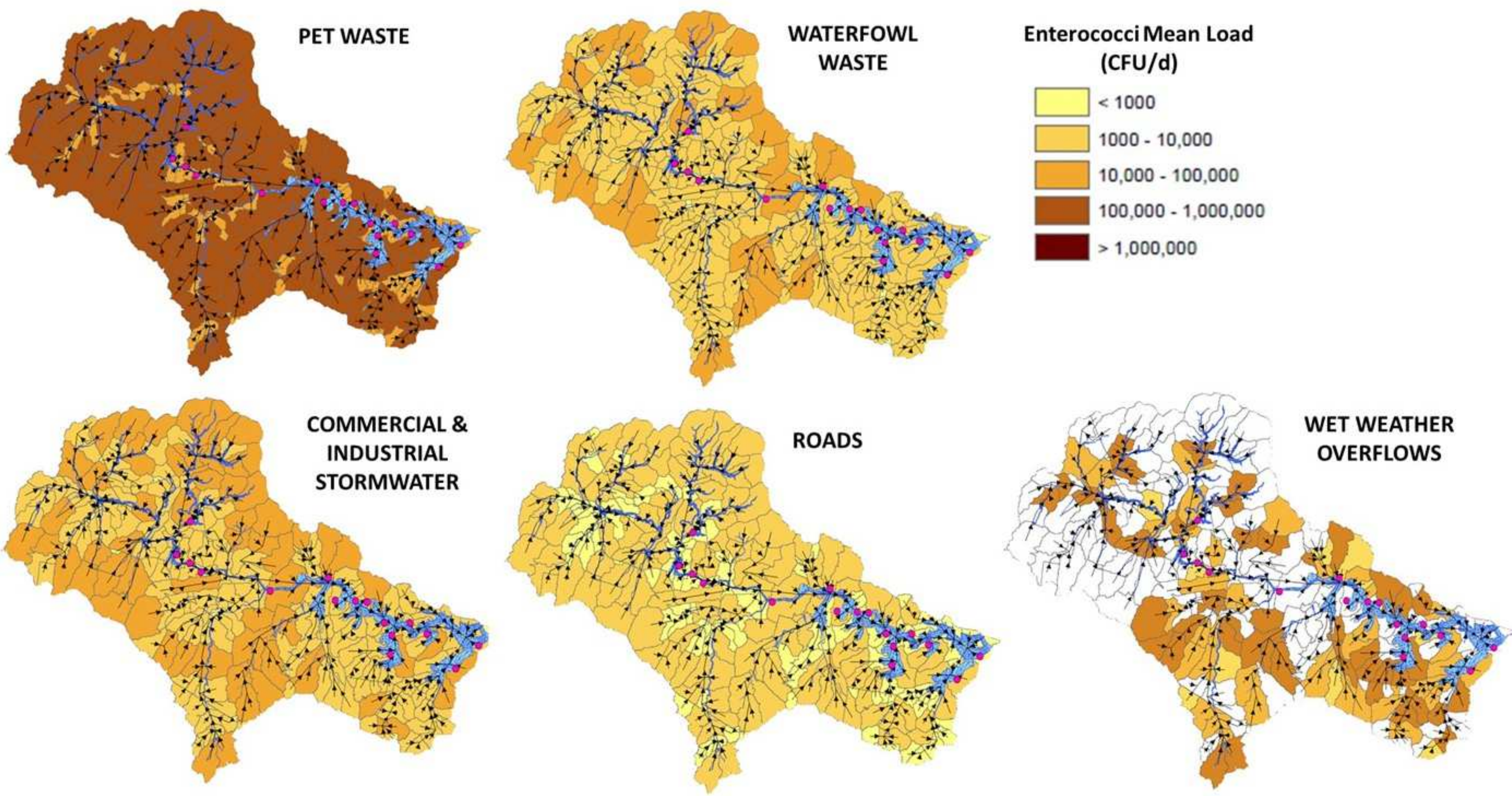


Figure 3.13: Enterococci loads from different sources represented in the catchment model. Note: these are unattenuated loads not influenced by die-off which occurs within the model links

3.3.2 Point-source inputs

Whilst land use (and runoff) are a source of bacterial contamination so too are sewer overflows from ERSs. Concentrations of enterococci in sewer overflows have been informed by the NHRMC (2008) Guidelines for managing risks in recreational waters and provided in Table 3-9. The Upper Parramatta River model (Sydney Water 2014), which is considered well calibrated, applied an EMC for sewer of 1,000,000 CFU/100mL which is in line with the NHRMC guidelines and will be adopted for this project (refer to Appendix 1:).

Table 3-9: Typical Enterococci and E coli numbers in sewage (NHRMC 2008)

Pathogens/indicator organisms	Disease or role	Numbers/100 mL
Bacteria		
Campylobacter spp	Gastroenteritis	10^4–10^5
Clostridium perfringens spores	Indicator	10^4–10^5
Escherichia coli	Indicator (except specific strains)	10^6–10^7
Intestinal enterococci	Indicator	10^5–10^6
Salmonella spp	Gastroenteritis	0.2–8000
Shigella spp	Bacillary dysentery	0.1–1000
Viruses		
Somatic coliphages (viruses to *E. coli*)	Indicator	10^5–10^7
F-RNA coliphages (viruses to *E. coli*)	Indicator	10^4–10^6
Polioviruses	Indicator (vaccine strains) Poliomyelitis	$180 – 5 \times 10^5$
Rotaviruses	Diarrhoea, vomiting	$400 – 8.5 \times 10^4$
Adenoviruses	Respiratory disease, gastroenteritis	not enumerated[a]
Noroviruses[b]	Diarrhoea, vomiting	not enumerated[a]
Hepatitis A	Hepatitis A	not enumerated[a]
Parasitic protozoa[c]		
Cryptosporidium spp oocysts	Diarrhoea	0.1–39
Entamoeba histolytica	Amoebic dysentery	Non-detect–0.4
Giardia lamblia cysts	Diarrhoea	$10–2 \times 10^4$

a Many important pathogens in sewage have yet to be adequately enumerated, such as adenoviruses, noroviruses and hepatitis A virus

b Noroviruses were formerly known as Norwalk viruses

c Parasite numbers vary greatly due to differing levels of endemic disease in different regions

Sources: Höller (1988), Long and Ashbolt (1994), Yates and Gerba (1998), Bonadonna et al (2002), Contreras-Coll et al (2002)

3.3.3 Enterococci Calibration

Calibration/validation data

Routine (weekly and monthly) monitoring data (representative of dry weather conditions) and autosampler (wet weather) event data for 12 sites (Figure 3.14) were sourced from various state agencies (Table 3-10), collated into a database by the PRCG as part of the *Strategic Analysis of Water Quality in the Parramatta River* report (Khan and Byrnes, 2016). The majority of data were of good quality and covered a sufficient calibration period of at least 5 years. The autosampler data provided sub-daily samples of 5 – 7 events.

It is noted that there is no event monitoring in the catchment or along the Parramatta River downstream of the confluence with Vineyard Creek, which will bias the model performance to dry weather concentrations in the Lower Parramatta.

Parramatta City Council also provided more recent Lake Parramatta monitoring data collected in Dec 2014 – Mar 2017 (Hackney, *pers. com.).* The Lake Parramatta data did not coincide with the Source model simulation period, but was useful as an indication of the range in concentrations that should be expected for the Lake for at least the last 2-3 years of the calibration period. Table 3-10 summarises the available water quality sites used in calibration.

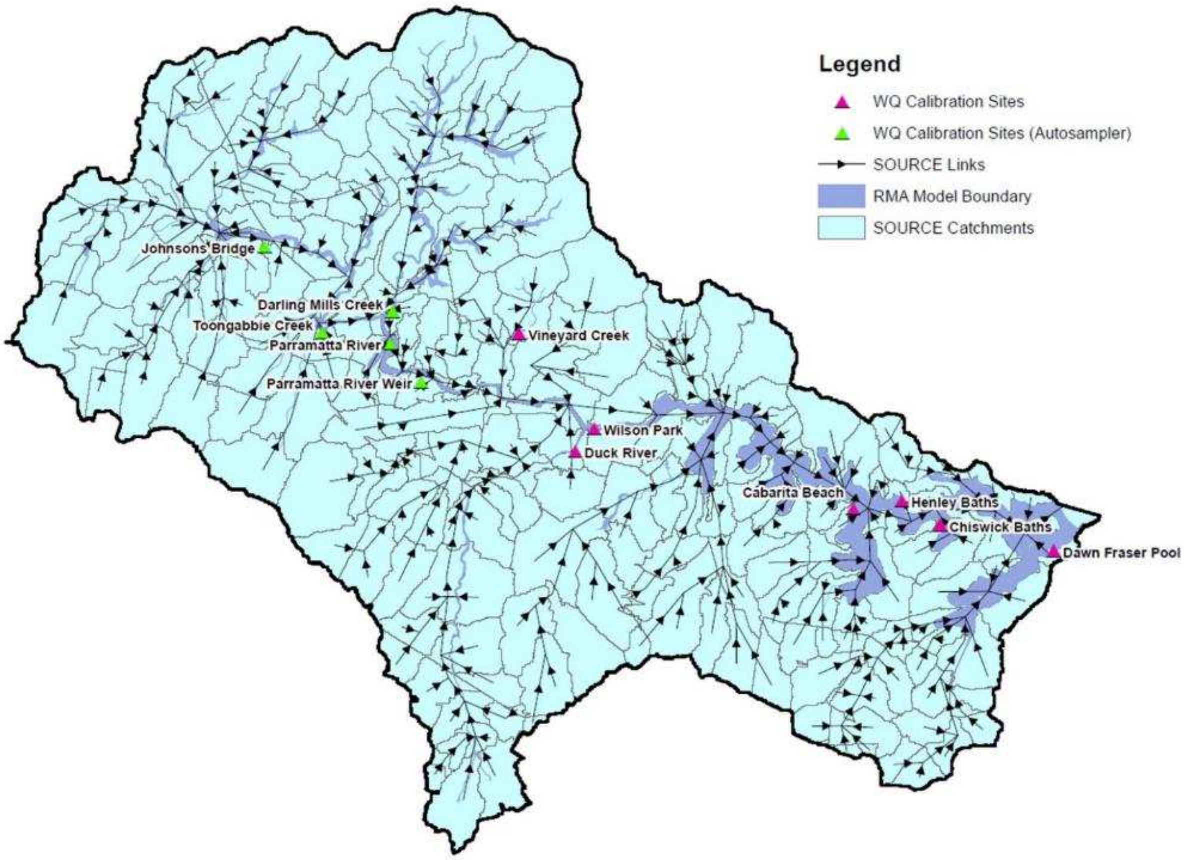


Figure 3.14: Water quality calibration sites. Pink triangles are routine monthly monitoring sites; green triangles are autosamper event monitoring sites.

Table 3-10: Summary of Enterococci sampling locations, period of record and sampling method.

Water Quality Site	Record period	Number of samples	Sampling method	Data Source
PJPR - Parramatta weir near footbridge	May 1996 – Apr 2008	36 events	Autosampler	Sydney Water or Parramatta City Council
UPR01 - Darling Mills Creek	Jan 2013 – Jun 2013	7 events	Autosampler	Sydney Water
UPR02 - Johnsons Bridge	Jan 2013 – Jun 2013	5 events	Autosampler	Sydney Water
UPR03 - Toongabbie Creek	Jan 2013 – Jun 2013	6 events	Autosampler	Sydney Water
UPR04 - Parramatta River	Jan 2013 – Jun 2013	6 events	Autosampler	Sydney Water
Vineyard Creek	Nov 2013 – Aug 2014	3 events	Autosampler	Sydney Water
Cabarita Beach	Oct 1996 – Jan 2016	1243 samples	Routine monitoring (weekly)	OEH Beachwatch
Chiswick Baths	Mar 1999 – Jan 2016	1088 samples	Routine monitoring (weekly)	OEH Beachwatch
Dawn Fraser Pool	Oct 1994 – Jan 2016	1434 samples	Routine monitoring (weekly)	OEH Beachwatch
Duck River	Jul 2003 – Jun 2008	76 samples	Routine monitoring (monthly)	Sydney Water
Henley Baths	Oct 1996 – Mar 2010	901 samples	Routine monitoring (weekly)	OEH Beachwatch
Wilson Park	Jul 2003 – Jun 2008	75 samples	Routine monitoring (monthly)	Sydney Water and Auburn Council

Evaluation metrics

Simulated Enterococci concentrations for each calibration site were assessed against observed monitoring data using:

- Percent bias (% difference between modelled and observed concentrations)
- Box-whisker plots (illustrating the median, 25th and 75th percentiles – the box; 1.5×IQR (interquartile range) above or below the 25th and 75th percentiles – the whiskers)
- Timeseries plots where autosampler data were available

Joint calibration between the SOURCE and RMA models was conducted to achieve a good fit between in-stream concentrations at key sites located within the estuary. Priority was given to achieve the best fit possible with the RMA model rather than the Source model due to limited catchment data, and therefore, some sites in the SOURCE did not calibrate well whereas in the RMA model the calibration was improved.

The resulting calibrated parameters are given in Table 3-11 for the generation (EMCDWC) rates and Table 3-12 for the Decay half-life parameters. Generally, the calibrated EMC and DWC parameters are in line with literature ranges, although concentrations from Bird sources are somewhat low in residential land uses. Given the 'lumped' conceptualisation of SOURCE, decay rates are representative of a generalised attenuation function that represents a combined inactivation and die-off rate. Therefore, half-life parameters were adjusted based on subcatchment regions corresponding to the four different RMA models in order to achieve a good fit between observed and modelled data as well as good calibration of the RMA model.

Table 3-11: Range in calibrated Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) parameters for Enterococci concentrations (CFU/100mL). Mean is presented in parentheses.

Source	Land use	EMC	DWC
Domestic animals (dogs and cats)	Residential	50 – 832,000 (58,000)	1 – 4,800 (180)
	Parkland	4 – 57,000 (6,621)	1 – 15,000 (1,237)
Birds	Residential	1 – 500 (30)	1 – 30 (12)
	Parkland	2 – 36,500 (4,746)	1 – 22,000 (2,000)
	Commercial	4 – 13,000 (590)	2 – 7,700 (219)
	Industrial	1 – 46,000 (3,084)	1 – 21,000 (1,033)
Commercial & industrial* stormwater	Commercial	3,300 – 92,000 (9,830)	4 – 77 (36)
	Industrial	900 – 25,000 (3,241)	1 – 21 (12)
Roads	Roads	2,543 – 18,000 (6,440)	125 – 2,000 (930)

Table 3-12: Calibrated decay function half-life parameters

Subcatchment Regions	Decay Half-Life (hr)
Lower Parramatta	0.5
Vineyard Creek	5
Duck River	1.9
Upper Parramatta	20

Calibration results

Simulation of microbial concentrations with a semi-distributed catchment model is challenging, and the expectation was to achieve mean concentrations within a reasonable order of magnitude to the observed data, and similar trends in timing of peak concentrations. Therefore, a percent bias of around 90% is deemed acceptable (comparatively, Moriasi et al., 2007 suggest a percent bias of 70% for nutrients is satisfactory for a monthly timestep model).

Generally, sites in the upper Parramatta and Vineyard Creek yielded a reasonable calibration in terms of the timing of event concentrations (Figure 3.15), and in some cases achieved a good fit to mean concentrations, with the best result for the Parramatta Weir site with a percent bias of 24% (Table 3-13).

Comparison of sub-daily observed and modelled data for Parramatta River autosampler sites achieved a very good calibration in terms of timing and in some cases magnitude of event concentrations (Figure 3.15), despite a somewhat high percent bias indicating overestimation of mean concentrations.

The Lower Parramatta and Duck River calibration resulted in a reasonable fit to the distribution of the observed data, with the model performing well for all sites, with the exception of Chiswick Baths site. The large differences between median and mean concentrations are caused by the skewed distribution typical of microbial concentration datasets. Generally, the model underpredicts mean and median concentration at most sites, but overestimates mean and median concentrations for Chiswick Baths site.

Table 3-13: Comparison between observed in-stream data and modelled SOURCE outputs for mean concentrations and the percent bias between mean concentrations.

Monitoring Site	Mean Concertation (CFU/100mL)		% Bias between means
	OBS	**MODEL**	
Parramatta weir near footbridge	1,800	2,100	24%
Darling Mills Creek*	3,700	8,000	-119%
Johnsons Bridge*	11,000	5,000	54%
Toongabbie Creek*	11,000	3,400	69%
Parramatta River (Marsden weir)*	7,500	1,100	85%
Vineyard Creek	12,000	5,800	-71%
Cabarita Beach	110	51	-54%
Chiswick Baths	87	790	812%
Dawn Fraser Pool	110	49	-57%
Duck River	1,500	585	-60%
Henley Baths	174	60	-65%
Wilson Park	1,200	201	-84%

*Auto sampler sites with short data period (Jan 2013 to June 2013)

The largest source of uncertainty in the catchment model is from the assumptions around the number of pets and birds per km^2, which could be better estimated by detailed data analysis of LGA pet ownership and feral animal control statistics, parkland bird survey data or by conducting surveys of pet ownership for each LGA. Given the lack of locally-source Enterococci deposition rates or EMCs from a particular landuse to parameterise the catchment model, the configuration and calibration of the model has relied heavily on existing studies that document ranges in Enterococci concentrations from different land uses. The relative proportion of simulated Enterococci concentrations from the dominant landuses within the SOURCE model is consistent with these literature ranges in Table 3-6.

In addition, the SOURCE model does not include any tidal flushing so there will be a discrepancy between the SOURCE output and observations that cannot be improved through calibration. However, this discrepancy is not reflected in the calibrated output of the RMA model, which does include tidal flushing and is able to achieve reasonable calibrations for sites within the estuary (See Section 4).

Therefore, the results from the SOURCE model should be viewed as indicative concentrations and loads of Enterococci from each subcatchment. Nevertheless, the SOURCE model is useful in assessing the relative (% change) impact of intervention scenarios from baseline conditions.

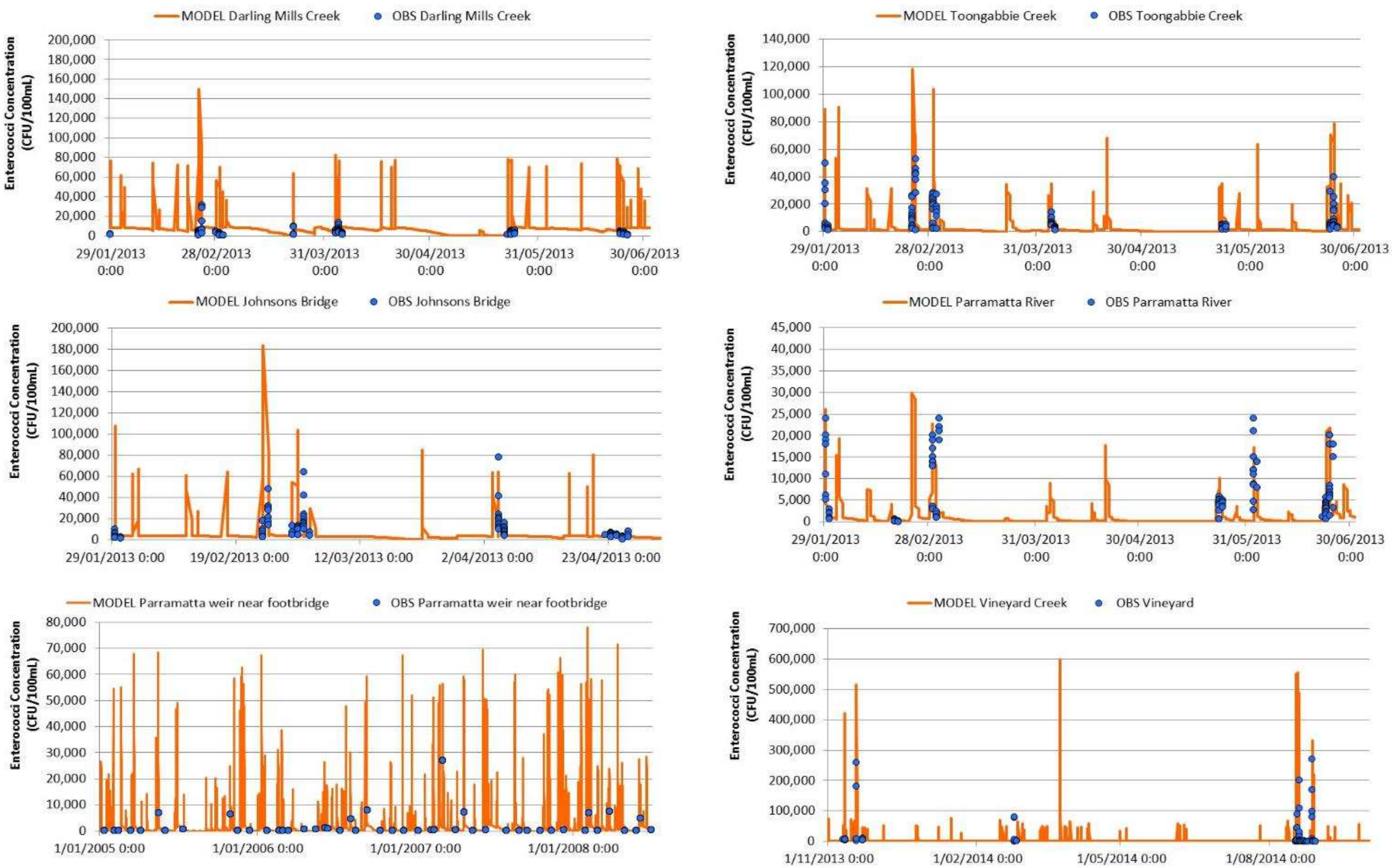


Figure 3.15: Comparisons of SOURCE sub-daily modelled and observed Enterococci concentrations for sites with event autosampling

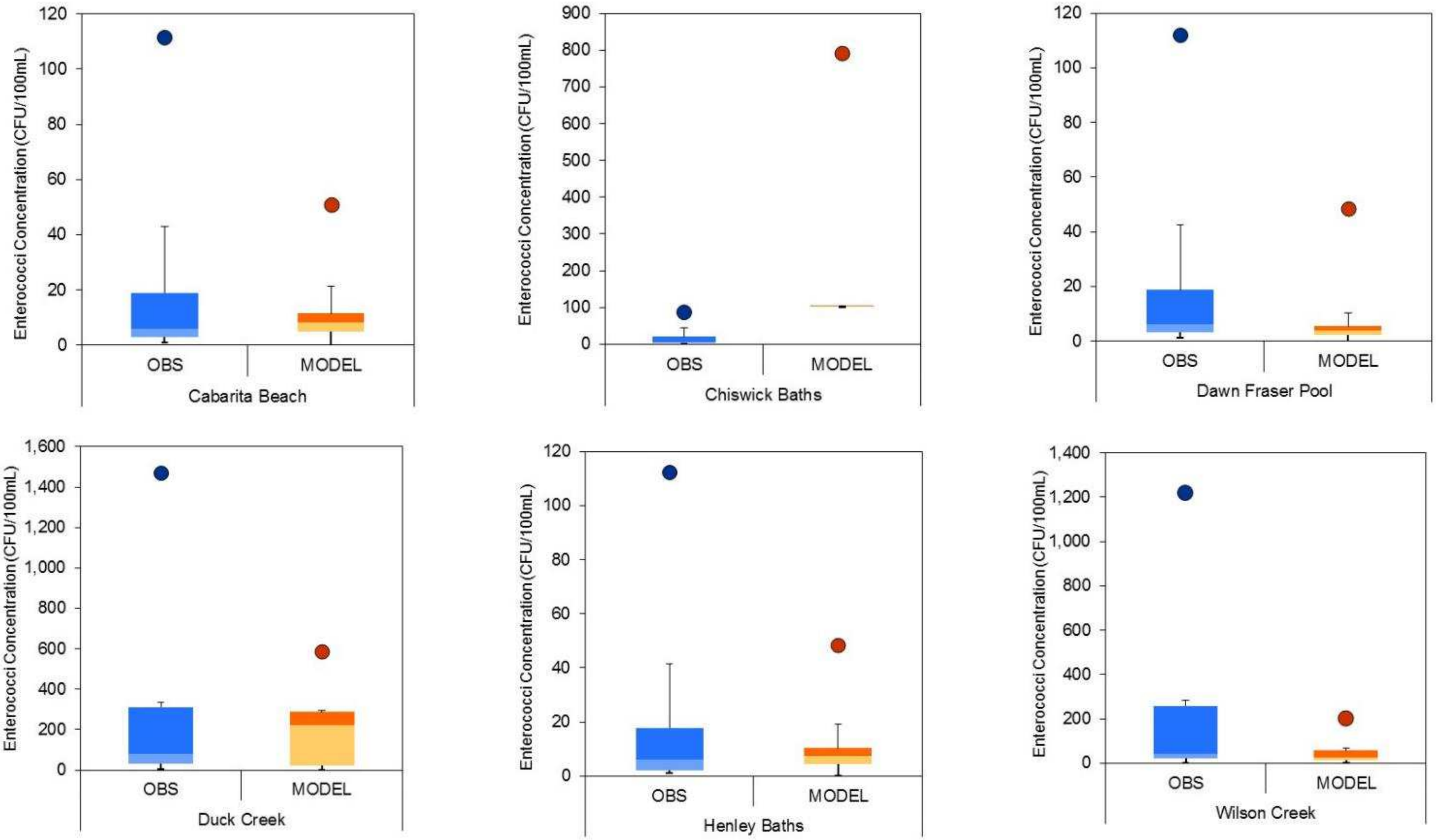


Figure 3.16: Comparison of observed and SOURCE modelled box-whisker plots for sites with routine sampling. Modelled outputs are for the same period as the routine monitoring data record. The box represents the 25th percentile, median and 75th percentiles, the whiskers represent the 1.5×IQR (interquartile range) above or below the 25th and 75th percentiles. Values outside the whiskers are considered outliers. Mean concentration is given as a single point.

4 River Model

4.1 Overview of RMA models

The RMA model suite is a collection of models for simulating hydrodynamics and water quality in water bodies (King, 1993,2006). The models can be operated in one, two or three dimensions using a finite element formulation. Being a finite element model, the mesh can examine a high resolution representation of river features while maintaining computational efficiency in areas where high resolution is not required. Wetting and drying options in the model allow floodplains to be incorporated into the simulations. The model mesh comprises both triangular and quadrilateral elements, enabling an accurate representation of water bodies.

The RMA-2 model (RMA-2, 1997; Version 6.3c, King, 1997) is a two dimensional (depth-averaged) hydrodynamic model. The RMA-10 hydrodynamic model (RMA-10, 2016: Version 8.7s King, 1993.) includes salinity coupling and also has three-dimensional capability. In both models, wetting and drying options allow floodplains and marshes to incorporated into the simulations. The RMA-11 model (RMA-11, 1997. Version 3.2C) is water quality model which simulates water quality processes based on the results from an RMA hydrodynamic model. In this project, the processes modelled were the advection, dispersion and decay of Enterococci.

For this project, all models were used in depth averaged mode, meaning that velocities and concentrations were modelled as a single value at each point, representing the average velocity/concentration in the water column at that point. Spatial resolution is also limited by the size of the mesh (elements are up to several hundred metres long) and by the resolution of the SOURCE catchment model which provides inputs. Results in an area of the river should be considered indicative of the average water quality throughout the area, without taking into account localised effects of particular discharges.

4.2 Hydrodynamic models

Four separate model meshes were used to model the Parramatta River. The two most significant tributaries, the Upper Parramatta River and Upper Duck River, as well as Vineyard Creek, a catchment with disproportionate sewer overflow input, were modelled in RMA-2 from the tidal limit upstream. This allows the model mesh to be extended upstream, covering a significant range of bed elevation, and for these upstream river models to include weirs and other flow control structures. The Parramatta River estuary was modelled as a depth-averaged RMA-10 model with salinity coupling.

The meshes for the upstream models (Upper Parramatta River and Upper Duck River) were originally developed for Sydney Water's Wet Weather Overflow Abatement Sydney Harbour water quality models (Sydney Water, 2014). The estuary mesh was adapted from the Sydney Harbour estuary model, cut off at Woolwich/Birchgrove. The hydrodynamic parameters and friction coefficients used were the same as those originally used in the Sydney Harbour modelling, shown in Table 4-1 and Figure 4.1.

Table 4-1 Hydrodynamic parameters

Model	Turbulence coefficient	Diffusion (m^2/s)
Upstream models	0.5	0.08 (in direction of flow) 0.5 (lateral)
Estuary	0.2-0.3	1

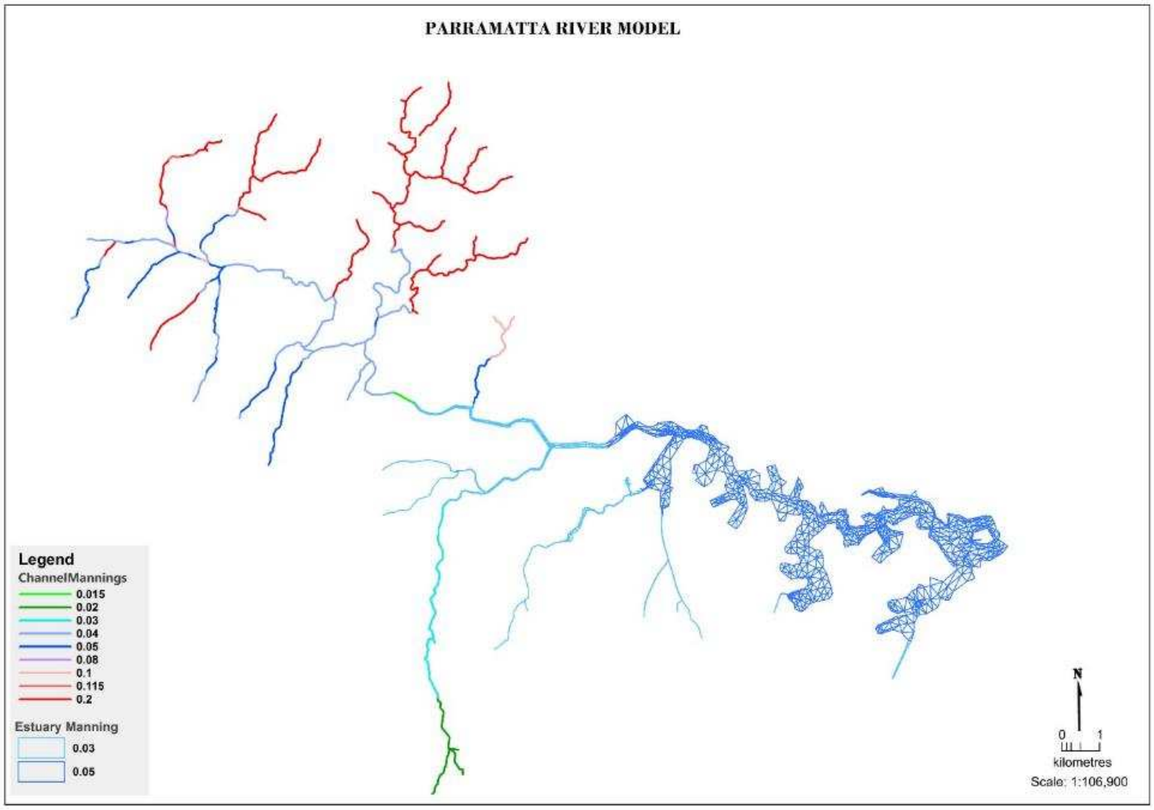


Figure 4.1 Map of Manning's *n* friction coefficients used in hydrodynamic models

The boundary conditions for the hydrodynamic models are:

- Catchment flows for each SOURCE model catchment, added to the hydrodynamic models as element inflows. For the estuary model, the flows at the downstream boundary of the freshwater models are additional element inflows.
- In the freshwater models, baseflow is applied as a constant flow across the upstream boundaries. For Upper Parramatta River and Vineyard Creek, this baseflow is initially artificially high to achieve model stability in the steeper parts of the system, and corrected after the hydrodynamic model is run.
- The tidal water level at the downstream boundary, taken from runs of the Sydney Harbour estuary model, which itself has a tidal boundary condition given by water level observations at Camp Cove.

A validation run of the RMA models was conducted for the period 2013-2014, covering the events where sampling was conducted for the purpose of calibrating the Sydney Harbour model.

Modelled flows were compared with flows calculated from observed water levels and rating curves at three locations in the Upper Parramatta catchment for periods of different length starting with the first half of 2013. Modelled and observed flows were compared in the estuary at two transect locations during dry weather in December 2013 and at five locations after wet weather in August 2014.

The freshwater location results were compared on the basis of the 15-minute model timestep. Generally, this will produce worse NSE and percent bias statistics than daily or monthly flows. Despite this, the NSE results for the short periods involved were good at Cumberland Hospital and Marsden Weir, and satisfactory at Johnstons Bridge. All three sites showed a low % bias, partly explained by a tendency for modelled flows to be slightly high in the tails of events.

Table 4-2: RMA river model calibration statistics.

	Johnstons Bridge	Cumberland Hospital	Marsden Weir
NSE	0.56	0.81	0.80
% bias	-64	-32	-37

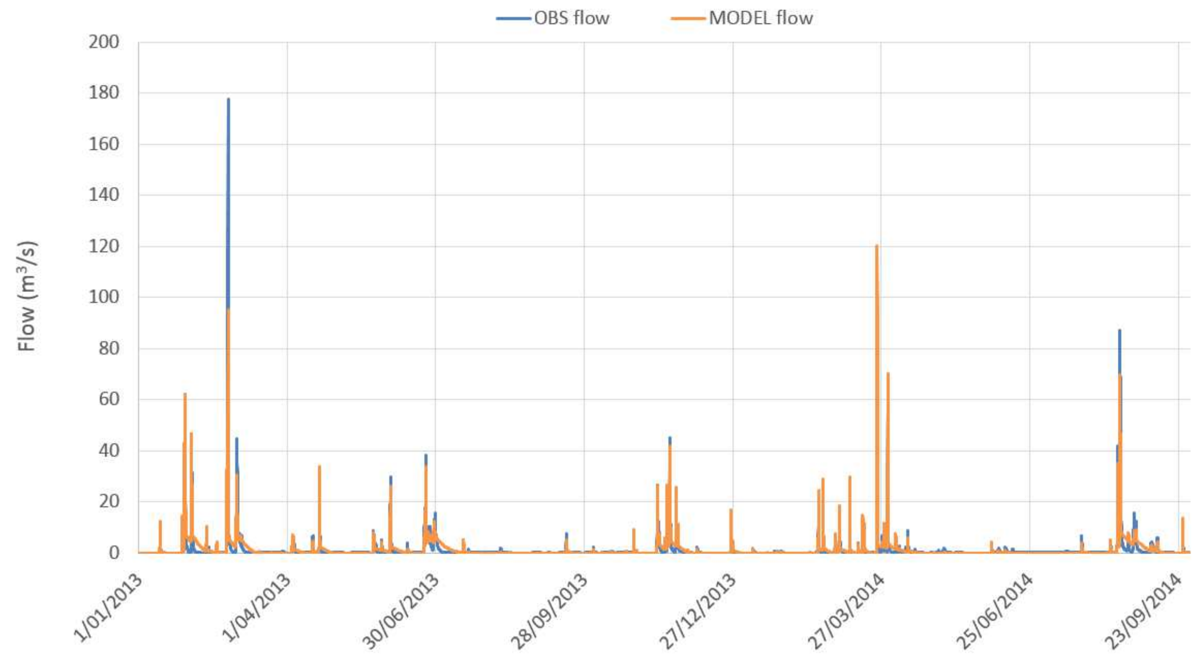


Figure 4.2: Parramatta River at Cumberland Hospital comparison between modelled and observed flows

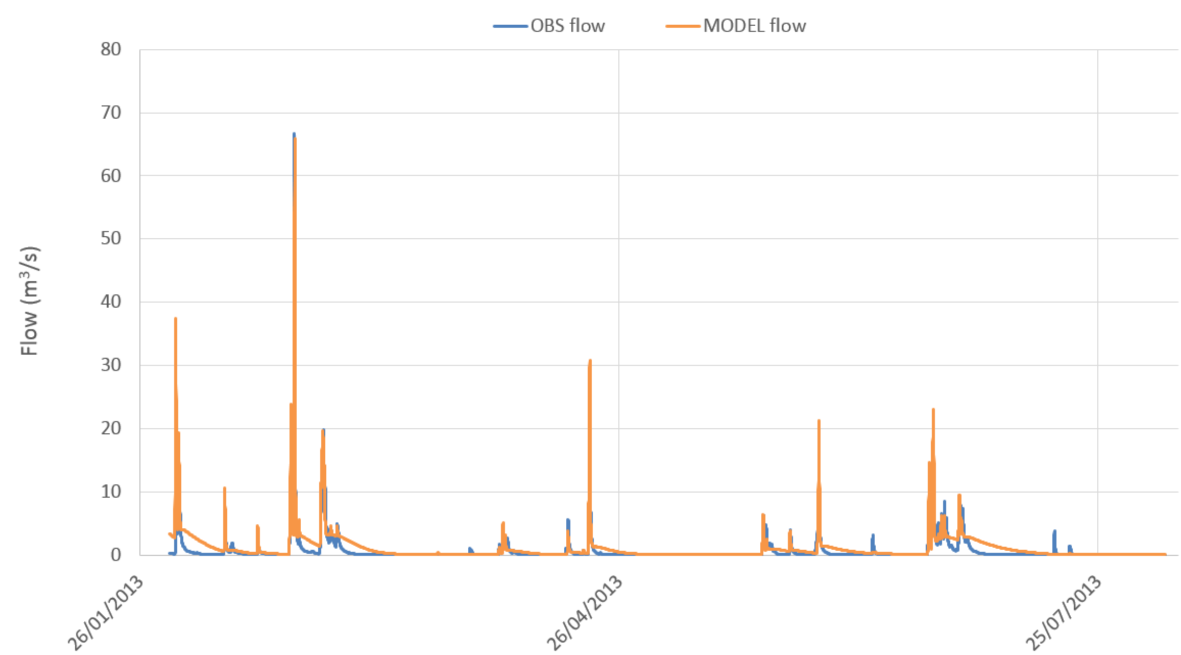


Figure 4.3: Toongabbie Creek at Johnstons Bridge comparison between modelled and observed flows

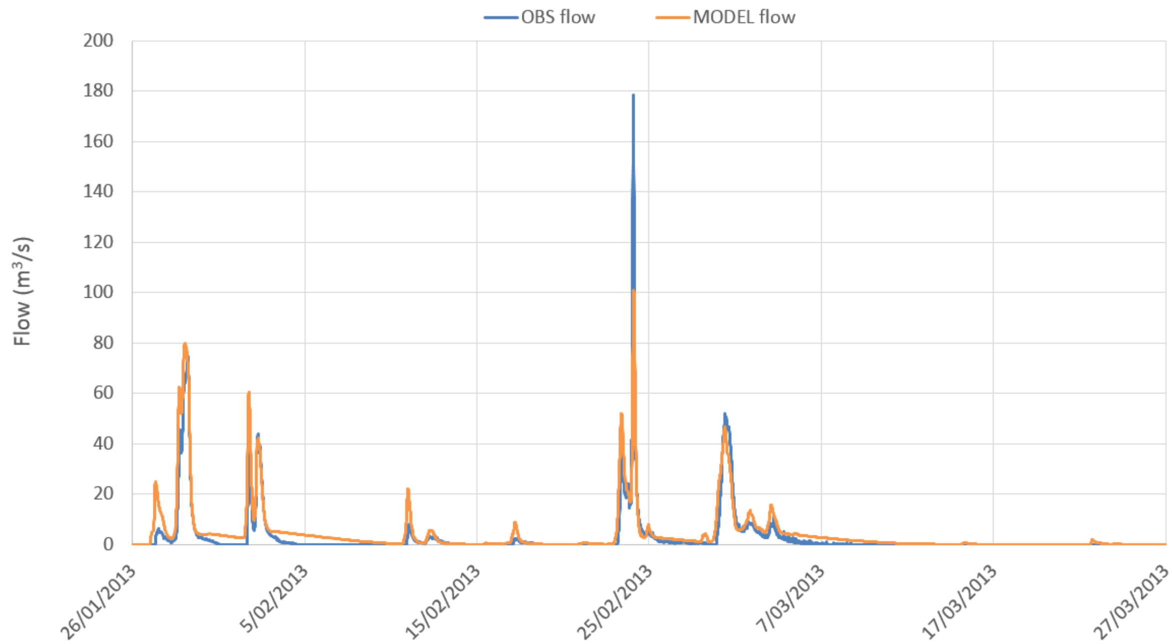


Figure 4.4: Parramatta River at Marsden Weir gauge comparison between modelled and observed flows

For the estuary sites, the observations comprised of four or five data points over a tidal cycle for each of the events. Comparison with the model results show generally a good fit, with a slight tendency for the model to underpredict the magnitude of tidal flows at the downstream end of the river.

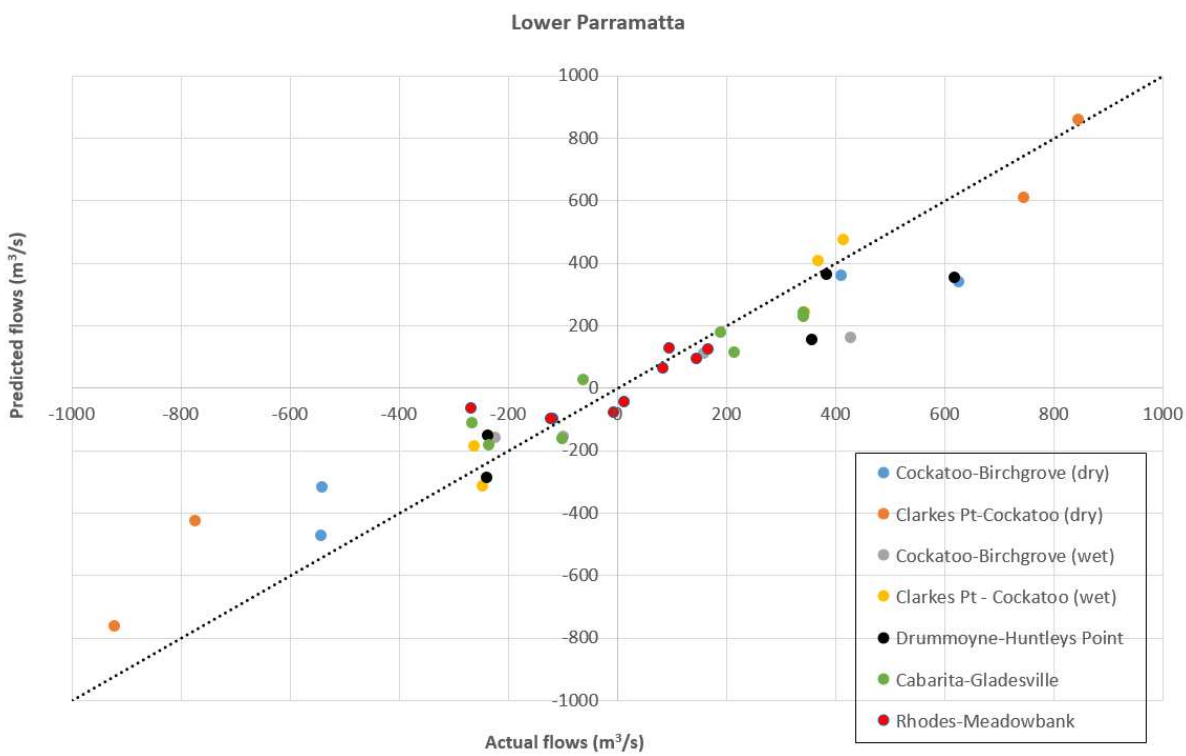


Figure 4.5: Comparison of observe and modelled flows in the Parramatta River estuary over one dry and one wet weather event

4.3 Enterococci models

Enterococci concentrations are modelled in RMA-11 using the results of the hydrodynamic models. The concentrations of the element inflows are determined by the catchment model. At the downstream boundary, tidal inflows have a concentration equal to 60% of the mean concentration of the outflows during the previous phase of the tide. The processes modelled are advection-dispersion and decay of Enterococci. The parameter for the decay equation is a T90 of 40 hours, that is, a half-life of 12 hours. The decay parameter, calibrated to observations, therefore accounts for die-off, settling and resuspension in a single decay rate.

Model results were compared with a range of observations. In the Upper Parramatta River catchment, council data was available for Parramatta CBD locations in 2013, and Lake Parramatta in December 2014. During January-July 2013, enterococci observations were collected at four locations, using autosamplers triggered by water level sensors (Sydney Water data). Each autosampler collected multiple samples over each of at least six wet weather events. The events sampled included events where nearby wastewater overflows were known to discharge, and others where the impact of overflows was less direct. An autosampler was used in the same way at one location in Vineyard Creek, capturing six events between November 2013 and August 2014.

Samples were collected from six locations in the estuary during a wet weather event on 20 August 2014 and then daily from 22-25 August, in order to validate the modelling of the tidal processes dispersing the constituents after a wet weather event. Where relevant, samples were taken at several depths in the water column. The time series plots below compare all samples with the depth-averaged model results.

Calibration of the decay parameter was undertaken to fit the slope of modelled results after events with the observations as best possible across the sites. The tidal sites were most important in this process, as in the upstream models the Enterococci from each event is quickly washed downstream and the effect of the decay parameter is less visible.

In the final results, some discrepancies can be seen. In particular, the model is expectedly less reliable close to the downstream boundary at Cockatoo Island, and the downstream Lake Parramatta sites (LP1 and LP2) are more reliable than the upstream ones, where the dilution effects are underestimated. Overall, the model appears to be reproducing the relevant processes correctly, making the combination of the Source model and RMA models appropriate for comparison of different scenarios.

Recommendations from the *Strategic Analysis of Water Quality in the Parramatta River* (PCC, 2016) with respect to a targetted monitoring programs at key sites, will provide useful data to further refine the models and their performance.

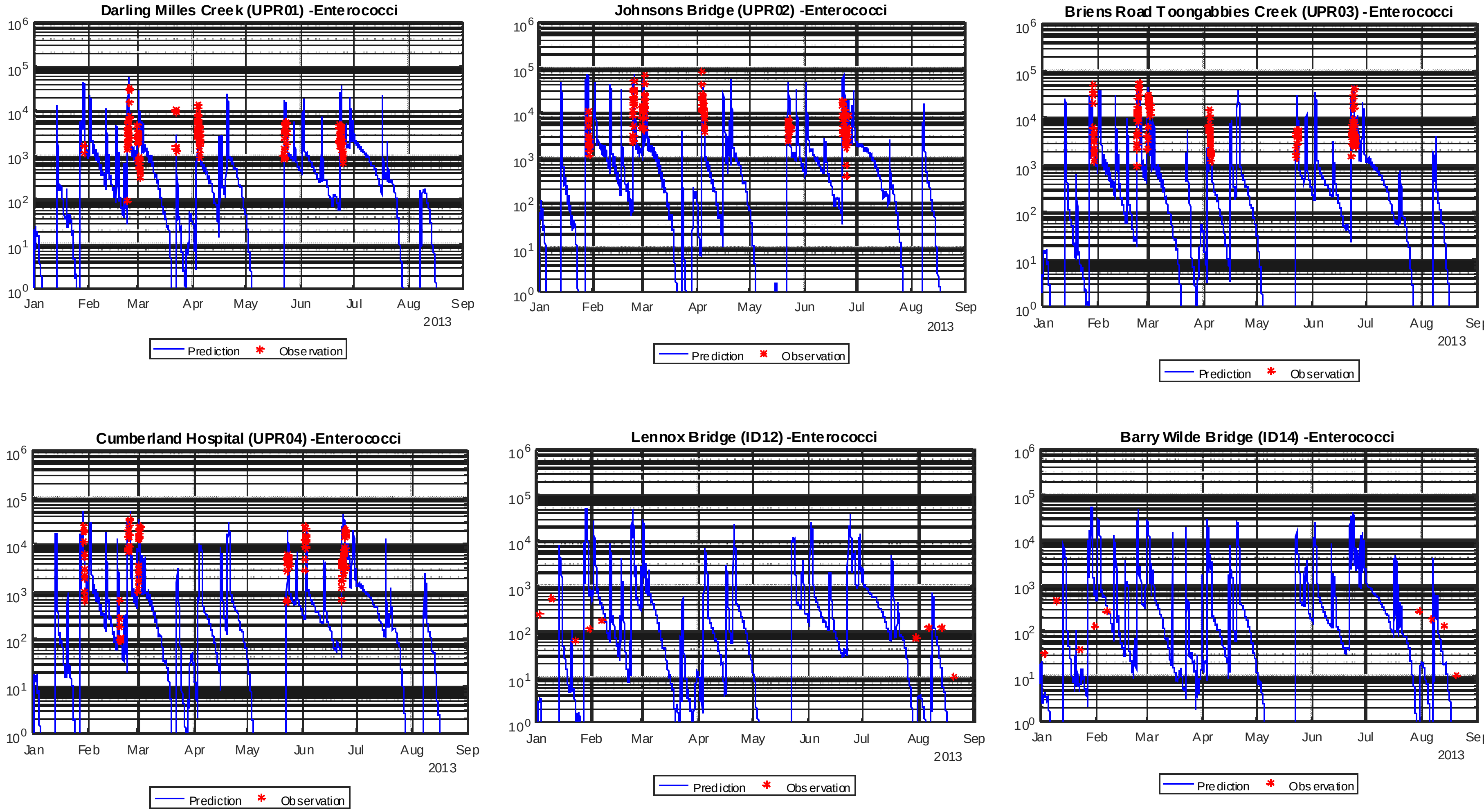


Figure 4.6 Comparison between observed and modelled Enterococci concentrations at Upper Parramatta River sites in 2013. Y-axis is concentration (CFU/100mL)

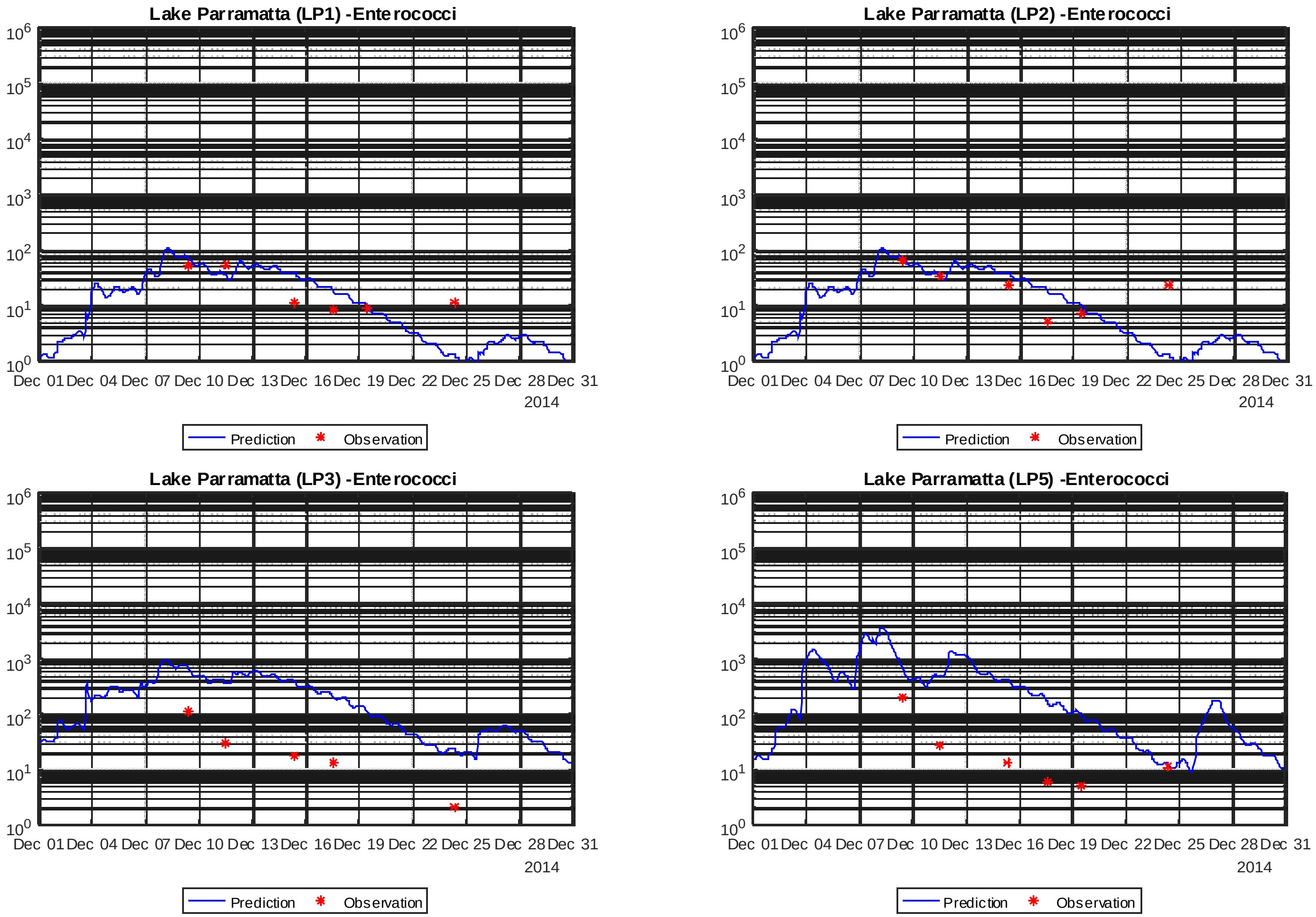


Figure 4.7 Comparison between observed and modelled Enterococci concentrations at Lake Parramatta, December 2014. Y-axis is concentration (CFU/100mL).

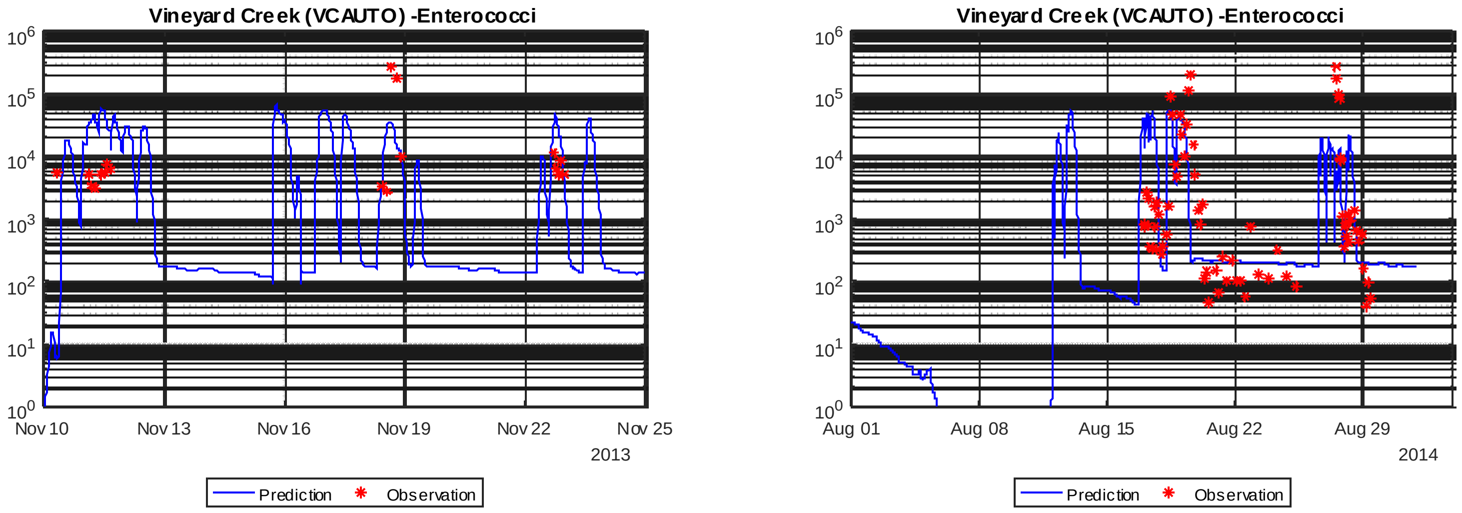


Figure 4.8 Comparison between observed and modelled Enterococci concentrations at Vineyard Creek. Y-axis is concentration (CFU/100mL).

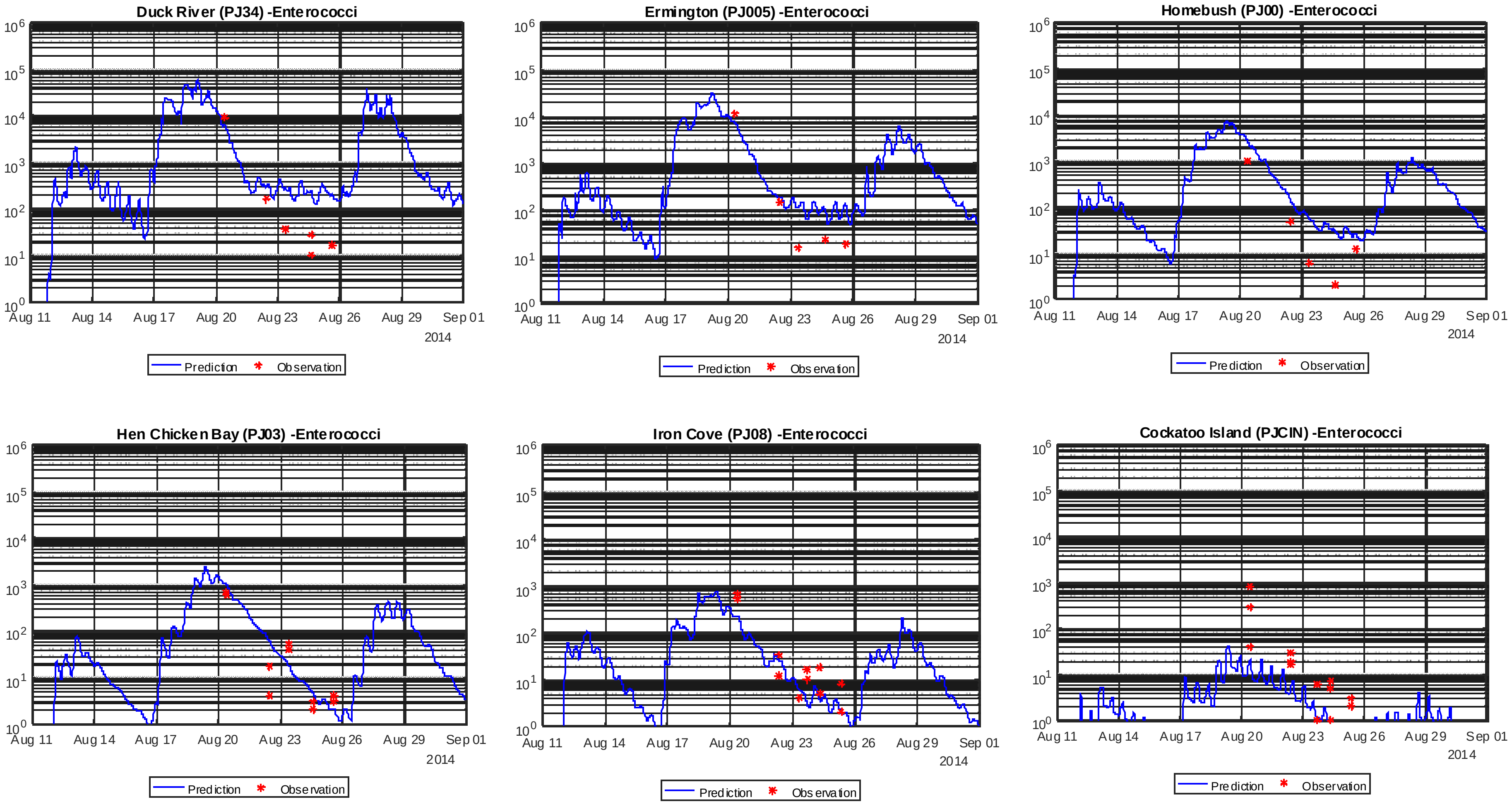


Figure 4.9 Comparison between observed and modelled Enterococci concentrations at Parramatta River estuary sites, August 2014. Y-axis is concentration (CFU/100mL).

5 Scenario Conceptualisation

Without interventions, wastewater and stormwater will increase with population growth, causing further stress to the water quality of the Parramatta River. Capturing the impacts of population growth in 2025 was a key driver in scenario conceptualisation. Population growth and land use change was represented in the SOURCE Catchment model. Population growth was represented through land use change (and the consequent densification of population) and in wet weather overflow (WWOF) discharge. Each scenario was configured within the SOURCE model, and outputs were used as inputs to the RMA scenario models.

Through a series of stakeholder workshops, seven scenarios were conceptualised from a long list of options (see Technical memo 2 – Scenario Workshop in Appendix 2). The scenarios modelled were:

- The baseline (current conditions),
- Business As Usual (BAU) and no WWOFs book-end scenarios to encapsulate the Enterococci pollution context in 2025, and
- Four intervention scenarios to mitigate stormwater and wastewater impacts.

A summary of scenarios is illustrated in the scenario matrix (Figure 5.1), with detailed descriptions given in the following sections.

5.1 Scenario metrics

Scenario results reported from each of the RMA model outputs are compared to the calibrated baseline model for the full 10 year scenario modelling period (1984–1994), and used to assess each site according to the NHMRC 2008 guidelines. The NHMRC 2008 guidelines are used to categorise the microbial risk associated with recreational water quality based on measurements of the 95th percentile intestinal enterococci densities. The applied microbial water quality objectives categories are given in Table 5-1.

The scenario simulation period was from 1 Jan 1984 to 31 Dec 1994, with a 2 year warm-up period (1 Jan 1983 – 31 Dec 1984). This simulation period was chosen as a 10-year period representative of long term historical rainfall (1913-1995).

Table 5-1: Microbial water quality objectives (NHMRC 2008 guidelines)

NHMRC 2008 category	Enterococci Concentration (CFU/100mL)	Estimation of human health risk (source: NSW Beachwatch program)
A*	≤40	No illness seen in most epidemiological studies
B**	41-200	Upper threshold is above the threshold of illness transmission reported in most studies
C	201-500	Represents a substantial elevation in the probability of adverse health outcomes
D	>500	Above this level there may be a significant risk of high levels of illness transmission

*Beachwatch compliance - Location has generally excellent microbial water quality and very few potential sources of faecal pollution. Water is considered suitable for swimming for almost all of the time

**Beachwatch compliance - Location has generally good microbial water quality and water is considered suitable for swimming for most of the time. Swimming should be avoided during heavy rain, and for up to one day at ocean beaches and three days at estuarine sites following heavy rain.

Scenario reporting metrics for the modelling period included:

- For each swimming site, the 95th percentile enterococci concentration, and the corresponding NHMRC 2008 category (reported from RMA model outputs).
- For each swimming site, the number of swimmable days where the 95th percentile enterococci concentration is less than Category B objective of 200 cfu/100 mL (reported from RMA model outputs).
- For each subcatchment, the mean load of enterococci across subcatchments to indicate 'hotspots' (reported from SOURCE model outputs).

	1	Book-end Scenarios		Mitigation scenarios			
		2	3	4	5	6	7
	Baseline	**BAU 2025**	**No WWOF**	**Medium Level of Catchment Intervention**	**High Level of Catchment Intervention**	**Targeted WWOF**	**Combined Interventions**
Population growth	current land use	2025 projected change in residential density		2025 projected change in residential density			
catchment rainfall-runoff	Historical flows	Increased impervious areas > increased runoff		**Flow reduction from rainwater tanks and rain gardens** - MEDIUM water reuse to existing areas - HIGH water reuse to new growth areas	**Flow reduction from rainwater tanks and rain gardens** - HIGH water reuse to existing areas - HIGH water reuse to new growth areas	As per scenario 2	**Flow reduction from rainwater tanks and rain gardens** - HIGH water reuse to existing areas - HIGH water reuse to new growth areas
Enterococci concentrations (diffuse)	Historical concentrations	Increased diffuse loads		- MEDIUM level pet waste removal (15%) - 90% reduction in Enterococci from rain gardens	- HIGH level pet waste removal (30%) - 90% reduction in Enterococci from rain gardens	As per scenario 2	- HIGH level pet waste removal (30%) - 90% reduction in Enterococci from rain gardens
Wet-weather Overflows (WWOF)	Historical point-source discharge	MOUSE model 2020 WWOF discharges	Remove WWOFs	As per scenario 2	As per scenario 2	**Discharge from high volume overflow reduced to 0**	**Discharge from high volume overflow reduced to 0**

Figure 5.1: Scenario modelling matrix

5.2 Business as Usual scenarios

Two 'Business as Usual' (BAU) scenarios provided a 'book end' of water quality conditions in the catchments impacting proposed swimming sites before implementation of management interventions. The two BAU scenarios included:

1. BAU 2025 – 2025 projected land use and WWOF discharge factored for population growth under historical climate.

2. No WWOFs - 2025 projected land use factored for population growth under historical climate, but with no WWOF discharge.

Essentially, the BAU 2025 scenario will give an indication of worst case. Although the no WWOFs scenario is unrealistic it will give an indication of the relative contributions of diffuse versus point-sources to increased Enterococci pollution.

The BAU 2025 scenarios were assessed against the calibrated baseline model, which represents current (2017) land use and Wet Weather Overflows (WWOF) discharged under historical climate.

5.2.1 2025 Land Use

Population growth is represented as a change in land use area that reflects the estimated increase in residential dwelling projections for 2025. This has been considered for both new precinct redevelopments and for residential infill allotments (e.g. subdivisions). The estimates are broad scale for each precinct and for each LGA, given that population projections are under regular revision.

Growth projection data was obtained from Sydney Water for new precincts (Figure 5.2) and for residential infill for each Local Government Area (LGA) as residential dwelling numbers. The data was available for 2020 and 2031 projections; therefore, 2025 projections were determined as the difference between the medium projections for 2020 and 2031 and the percent change determined from 2015 existing dwelling numbers (Table 5-2). The percent change in dwellings was used to scale residential landuse areas.

Changes to baseline land use are driven by expansion of residential land use types, whereby low density areas grow into medium density areas (i.e., medium density areas increased in size at the expense of low density areas), and medium density areas grow into high density areas. For precincts that were largely industrial and commercial, it was assumed these areas changed into high density residential.

Parkland, roads and water landuse areas remained unchanged, although roads associated with new precinct areas were noted as 'Precinct roads' in order to apply specific intervention options for scenarios (discussed in Section 5.3.1). Changes to areas were applied to new precinct areas first, and then the remaining areas were changed as per the LGA growth percentage.

Figure 5.3 illustrates the overall percent change in land use areas across the catchment to represent a 2025 landuse input to the model.

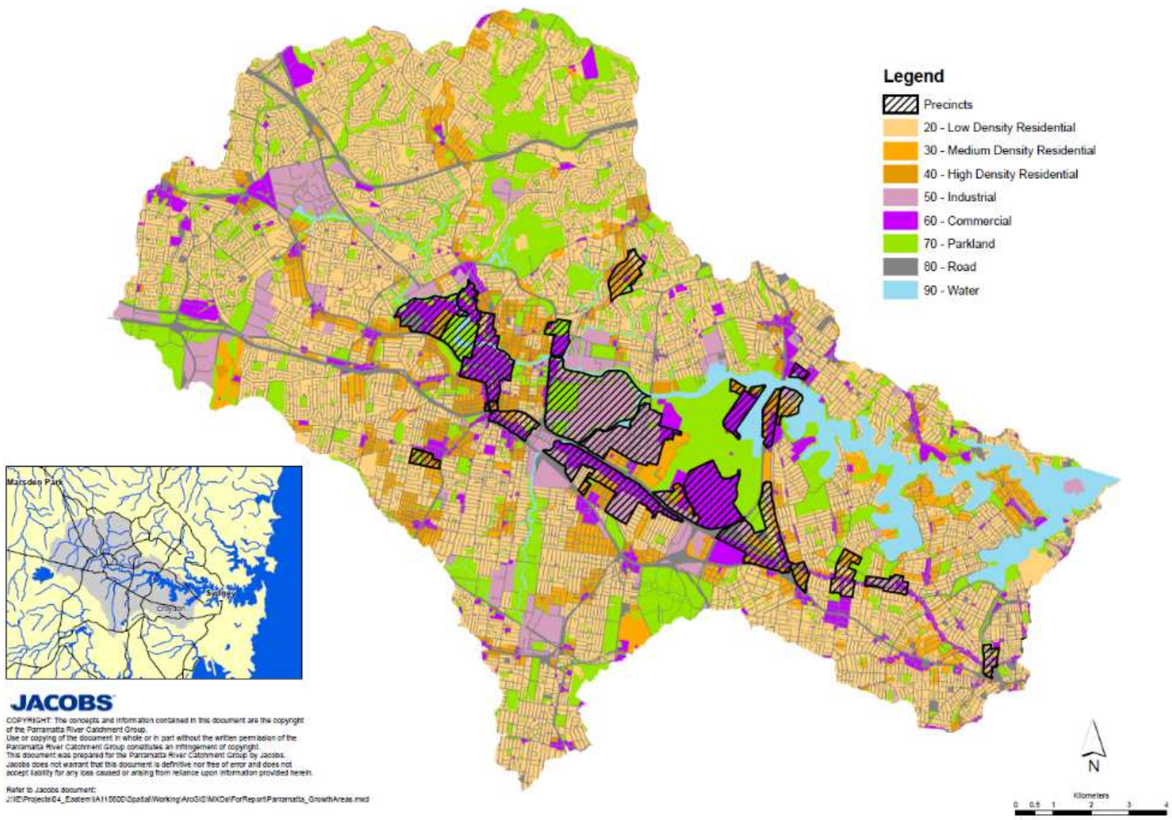


Figure 5.2: Location of new growth area precincts (black hash area) overlaying baseline (current) landuse.

Table 5-2: Precinct and infill percent growth in residential dwellings by 2025 (data provided by Sydney Water).

Precinct	% change
Greater Parramatta to Olympic Peninsula	
Westmead Health	35%
Parramatta North	100%
Parramatta CBD	64%
Camellia	100%
Sydney Olympic Park	92%
Wentworth Point PP	100%
Wentworth Point Fairmead Carter Street	53% 100%
Rhodes	21%
Parramatta Road Urban Transformation	
Granville	89%
Auburn	64%
Homebush	75%
Burwood	64%
Kings Bay Taveners Hill	84% 72%
Other precincts	

Precinct	% change
Rhodes East PP	80%
Holroyd	43%
Telopea	90%
Shepherds Bay	74%
Infill growth Blacktown LGA (West Central District)	 30%
Burwood LGA (Central District)	41%
Canada Bay LGA (Central District)	29%
Canterbury-Bankstown LGA (West Central District)	48%
Cumberland LGA (West Central District)	41%
Hunters Hill LGA (North District)	67%
Inner West LGA (Central District)	25%
Parramatta LGA (West Central District) Ryde LGA (North District)	38% 56%
Strathfield LGA (Central District)	48%
The Hills LGA (West Central District)	33%

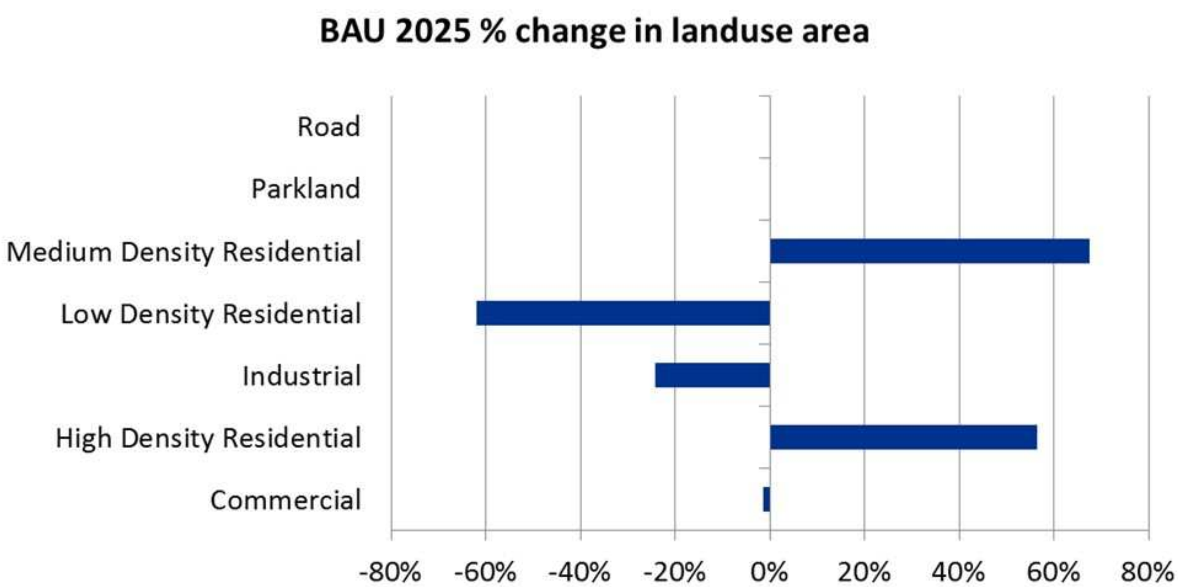


Figure 5.3: Change in land use types for Business as Usual 2025 land use representation.

The resulting change in landuse for BAU 2025 was reflected in the change in impervious fraction (Figure 5.4), which was around a 5% increase in imperviousness across the catchment. This results in increased runoff and a subsequent increase in Enterococci loads. Conversely for some precinct areas, conversion of industrial and commercial landuse to high density residential, will result in a decrease in imperviousness (up to 30%) and therefore a decrease in Enterococci loads.

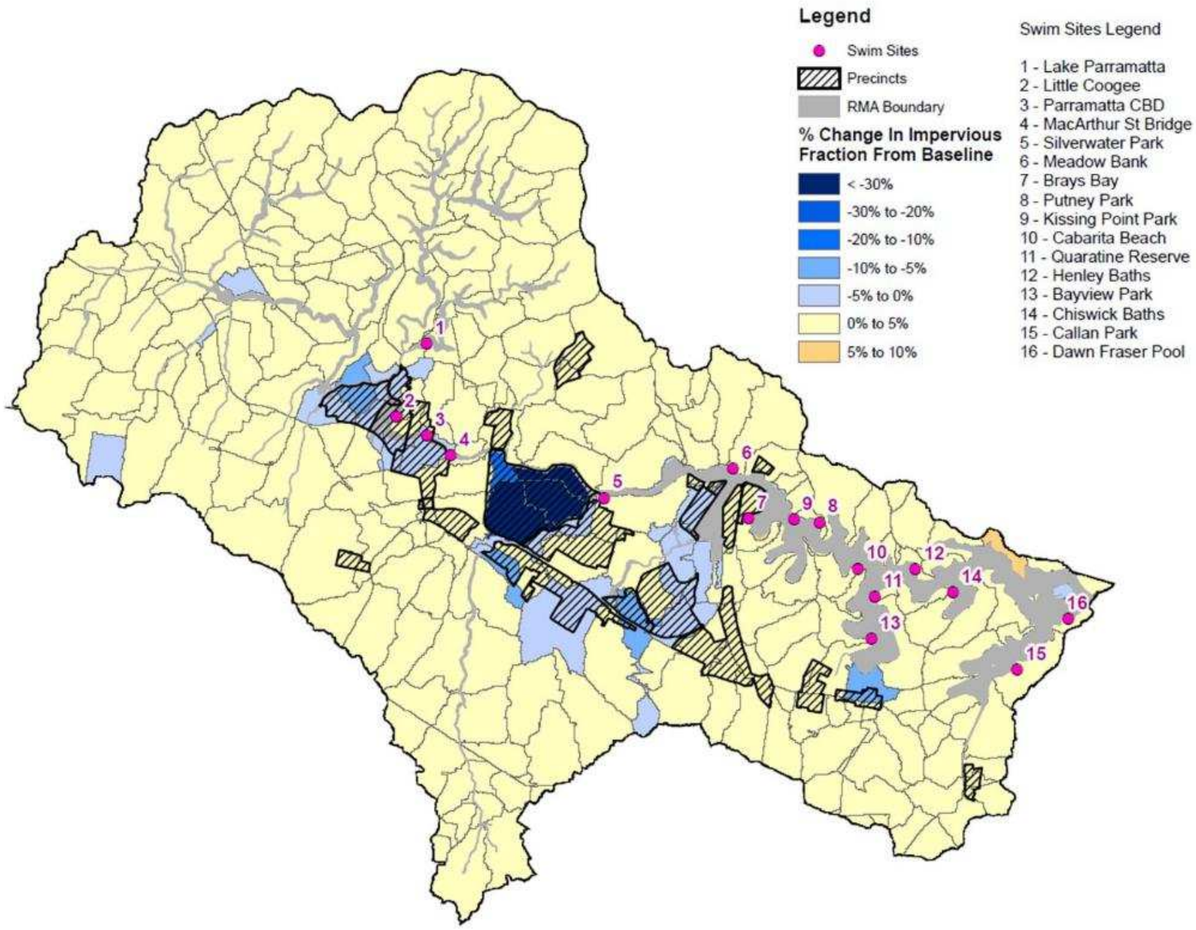


Figure 5.4: Percent change in impervious area across catchment

5.2.2 2025 wet weather overflows

MOUSE model outputs for BAU 2020 scenario were provided from Sydney Water. Although the MOUSE modelling was for 2020 future time horizon, this was assumed to be suitable to represent 2025 projected demands and discharge volumes.

On average subcatchment WWOF volumes increase around 3% in 2025, with some subcatchments exhibiting an increase in WWOF discharge volumes of up to 48%.

5.3 Intervention scenarios

Catchment intervention scenarios were considered as medium and high intervention scenarios, where different levels or 'strictness' in stormwater harvesting controls and pet waste policies were tested. For new growth areas, a high level of intervention was adopted in both scenarios, and medium to high level of intervention was adopted to existing areas considered as retrofit.

5.3.1 Stormwater harvesting (MUSIC modelling)

Stormwater interventions are focused on removing the Enterococci loads to the River via harvesting and bio-retention technology. In particular, there was a focus on rainwater harvesting via rainwater tanks on residential, commercial and industrial properties. Rainwater capture reduces the amount of stormwater that flows to the waterway and therefore the amount of pollutants delivered. Further, raingardens (pocket bio-retention systems) on roads in new growth areas were also included as options within the scenarios. This assumes that there is a direct linear relationship between flows and Enterococci loads.

MUSIC modelling was undertaken to determine an overall percent reduction in runoff that would then be upscaled to the catchment model as a % reduction factor on the rainfall runoff model. The MUSIC model represents a 1-hectare scale urban area 'case study' (Figure 5.5).

The following 2025 case studies were modelled in MUSIC:

- S01: Residential Low Density, Rainwater Tank for medium and high Scenarios
- S02: Residential Medium Density, Rainwater Tank for medium and high Scenarios
- S03: Residential High Density, Rainwater Tank for medium and high Scenarios
- S04: Roads, Bioretention for medium and high Scenarios
- S05: Commercial, Rainwater Tank for medium and high Scenarios
- S06: Industrial, Rainwater Tank for medium and high Scenarios

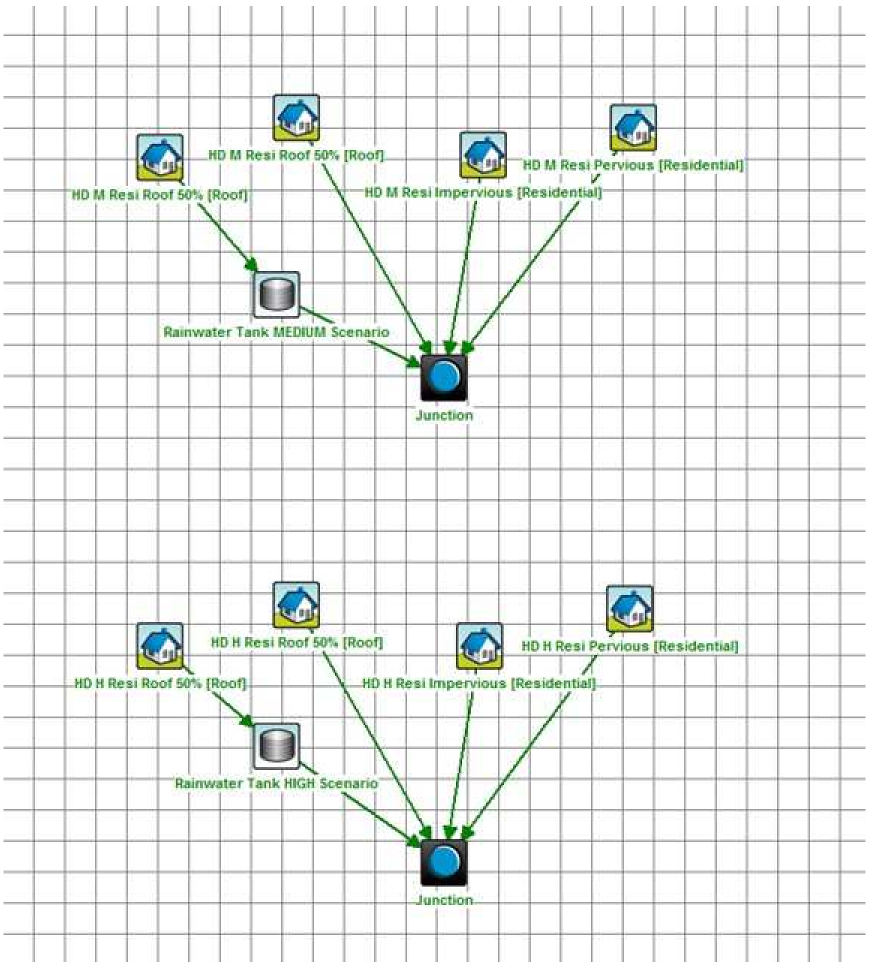


Figure 5.5: MUSIC Model case study (example for medium and high intervention scenarios)

The parameters and assumptions adopted for each case study are given in Appendix 4:. Data was obtained from Sydney Water and NSW MUSIC modelling guidelines (Witt et al., 2015). Where NSW data was unavailable, Melbourne Residential Water Use Studies parameters (Athuraliya, 2013) were used.

The key differences between medium and high stormwater harvesting options are:

Medium intervention –

- assumes re-use for toilet flushing and garden watering;
- 50% of house roofs connected to tanks;
- 50 % shops/industry buildings have tanks

High intervention –

- assumes re-use for toilet flushing, garden watering, and washing machine
- 90% of house roofs connected to tanks;
- 90% of shops/industry buildings have tanks

Results of the MUSIC modelling and the adopted percent reduction in flows are given in Table 5-3, Table 5-4, and Table 5-5. Rainwater tank flow reductions were applied to the quick- and baseflow components of the rainfall-runoff model (SURM), and raingardens flow reductions were applied to the quickflow component of SURM. Raingardens were only applied to the proportional area of roads within growth area precincts.

Table 5-3 Residential landuses percent reduction in flows from rainwater tank harvesting derived from MUSIC modelling

RAINWATER TANKS	Medium Intervention Scenario			High Intervention Scenario		
	Low Density Residential	Medium Density Residential	High Density Residential	Low Density Residential	Medium Density Residential	High Density Residential
Tank Size	6kL tank	3kL tank	1kL tank	6kL tank	3kL tank	1kL tank
Total Flow no tank (ML/yr)	10.5	10.7	10.9	10.5	10.7	10.9
Total Flow with tank (ML/yr)	9.29	9.21	8.56	8.79	8.54	7.54
% Reduction applied to SURM	**11.5%**	**13.9%**	**21.5%**	**16.3%**	**20.2%**	**30.8%**

Table 5-4: Roads landuse percent reduction in flows from raingardens (applied to new precinct areas only) derived from MUSIC modelling

RAINGARDENS (BIORETENTION)	Roads	
	Medium (2% of catchment harvested)	High (3% of catchment harvested)
Total Flow no bioretention (ML/yr)	9.71	9.71
Total Flow with bioretention (ML/yr)	9.21	8.75
% Reduction applied to SURM	**5.1%**	**9.9%**

Table 5-5: Commercial and Industrial landuse percent reduction in flows from rainwater tank harvesting derived from MUSIC modelling

RAINWATER TANKS	Commercial		Industrial	
	Medium	High	Medium	High
Tank Size	2kL tank	2kL tank	4k tank	4k tank
Total Flow no tank (ML/yr)	8.28	8.28	10.5	10.3
Total Flow with tank (ML/yr)	7.93	7.75	10.3	9.98
% Reduction applied to SURM	**4.2%**	**6.4%**	**1.9%**	**3.1%**

5.3.2 Pet waste control

There is little published information in Australia (and generally internationally) on the effectiveness of pet waste removal programs that translates into a quantifiable load reduction that could be used to inform the modelling.

A single Australian study (Gough, 2013), conducted by Pure Profile for pet healthcare company Milbemax, surveyed 1000 dog owners on their behaviour in relation to waste removal. The survey found on average:

- 58% of owners dispose of their dog's waste
- 9% never dispose of their dog's waste
- 33% of owners wait up to a week to dispose of their dog's waste in their own backyards (in NSW)

The original report from Pure Profile was not able to be obtained, so these numbers were verified based on surveys conducted by the Centre for Watershed Protection of Chesapeake Bay (USA) on residents' behaviours and attitudes regarding pet waste disposal (CWP, 1999). The CWP (1999) report provided similar survey results for Maryland and Washington studies in the USA. These studies reported, on average 60% of community generally dispose of pet waste, and 26% of community never pick up after their pets.

These studies supported the statistics produced by the Pure Profile report, although the percent of community who never dispose of pet waste was higher. For the scenario modelling the following was adopted:

- 60% of community generally dispose of pet waste.
- 10% of community never pick up after their pets.

The scenario then considers the remaining 30% of pet owners that can be influenced by community programs and policy incentives. For high level of catchment interventions, the scenario assumed the full 30% of pet owners can be influenced and will pick up after their pets (optimal outcome). For the medium level of catchment intervention scenario, it was assumed 15% of pet owners will dispose of waste. It is noted that for effective microbial reductions it is important that pet owners not only remove waste when walking their dogs in parkland or around residential areas, but also remove waste in their own backyards. For this reason, the modelling has assumed reduction on both cat and dog sources collectively.

These factors have then been interpreted in the model as a reduction in the number of dogs and cats contributing to the deposition rate, which equates to a 11% reduction in the EMC and DWCs for medium intervention scenario and 18% reduction in EMC and DWCs for the high intervention scenario.

5.3.3 Target wet weather overflows

Comparisons of the BAU and No WWOFs scenarios illustrated the key 'hot spots' within the catchment that are largely driven by the influence of sewer overflows. This resulted in ten subcatchment being identified. Individual overflows within these ten subcatchments were assessed for those that produced the largest discharge volumes, and consequently contribute the highest loads to the river (Table 5-6). The timeseries inputs for the selected overflows were set to zero discharge in the Target WWOF scenario. This resulted in ten subcatchments within the model with reduced WWOF discharges (Figure 5.6).

Table 5-6: Wet weather overflows assessed for Target WWOF scenario

SOURCE Subcatchment	Number of WWOFs in subcatchment	WWOF with largest discharges (MOUSE Model codes)	Daily mean flow rate (ML/d)	Maximum Volume (ML/d)	% of Total of all WWOF volume per subcatchment
SC #119	4	W481797Q	3.38	5.54	78.0%
SC #155	2	W260332Q	4.46	8.2	40.8%
		W260344Q	6.87	11.28	59.2%
SC #165	2	W247941Q	4.34	7.62	83.7%
SC #168	1	W247943Q	10.62	21.16	100.0%
SC #172	1	W247942Q	24.21	42.27	100.0%
SC #192	4	W47014Q	4.38	9.7	49.7%
		W50141Q	3.79	9.44	44.2%
SC #203	1	W47015Q	4.79	11.04	100.0%
SC #277	4	W384599Q	17.63	27.36	44.8%
		P384682Q	27.24	41.45	42.5%
SC #48	1	P384668Q	0.5	0.54	100.0%
SC #63	3	W384559Q	7.72	17.21	31.0%
		W384584Q	28.27	56.48	32.0%
		P479681Q	1.17	1.36	37.0%

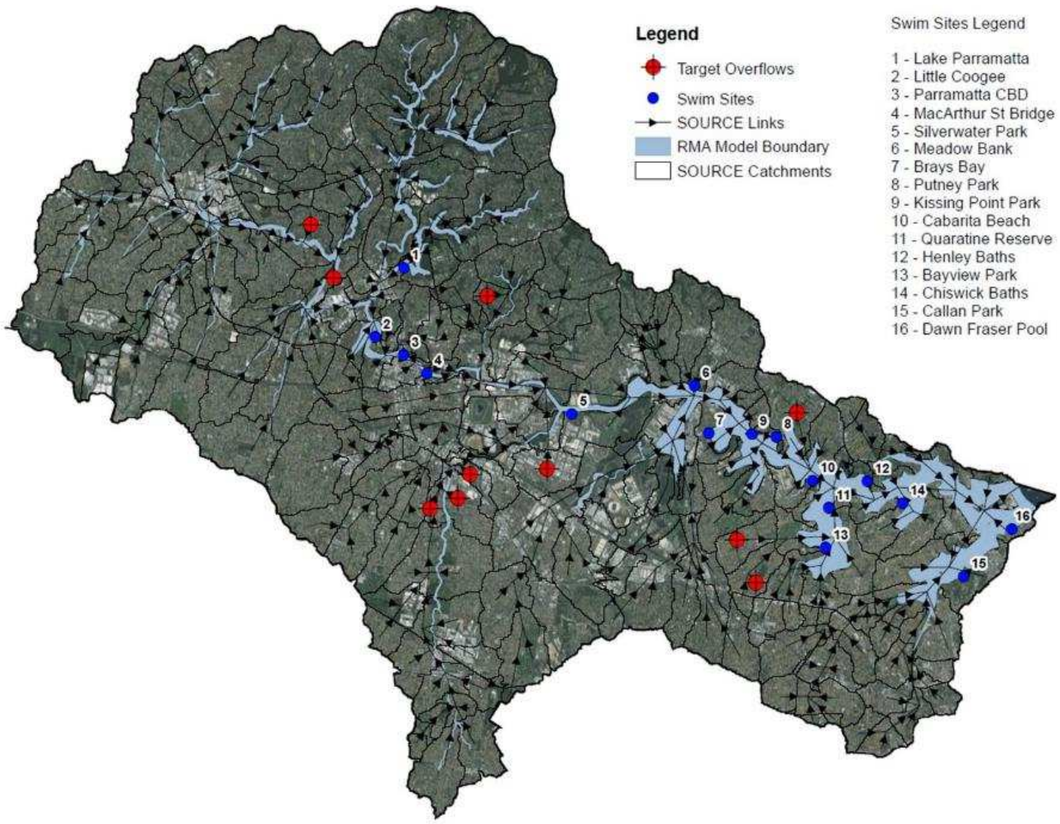


Figure 5.6: Target wet weather overflows (WWOF) subcatchment locations.

5.3.4 Combined intervention scenario

The high catchment intervention options and target WWOF are combined into a single scenario as a measure of the 'optimal' load reduction measures.

6 Scenario modelling results

6.1 Changes in Enterococci loads across the catchment

The scenario modelling results at the catchment-scale are reported as the mean Enterococci loads for each link in the SOURCE catchment model. The modelled load within the links represent the cumulative subcatchment runoff and Enterococci concentration, attenuated by instream die-off processes. Therefore, as Enterococci are generated within the upper subcatchments, dilution and decay occurs within the links reducing the load towards the river main stem. These attenuated loads therefore differ by an order of magnitude compared to the source loads presented in Figure 3.13.

The SOURCE model gives an indication of the degree of risk of Enterococci contamination from different sources. Figure 6.2 shows the mean Enterococci load for the Baseline (current conditions) scenario. Hot spots of high loads are illustrated by orange and red coloured subcatchments. The modelling demonstrates the cumulative impacts of these high loads at the confluence of several tributaries in the Upper Parramatta at Marsden Weir. The effect of attenuation on loads can be seen in subcatchments closer to the main river. The background Enterococci loads estimated by the model from diffuse sources are significant and outweighs the influence of wet weather overflow sources. The modelling found that diffuse sources account for 71% of overall catchment enterococci loads, compared to 29% of loads from wet weather overflows.

Figure 6.1 illustrates the distribution of subcatchments based on the proportion of diffuse and wet weather overflow contribution to total catchment enterococci loads. For the majority of subcatchments (187), diffuse loads are the highest contributors to total catchment loads (greater than 60% contribution), noting that many of these subcatchments (132) are not influenced by wet-weather overflows. However, for the remaining subcatchments it is clear that both diffuse and point-sources are factors influencing the total enterococci loads in the River and need to be conjunctively managed.

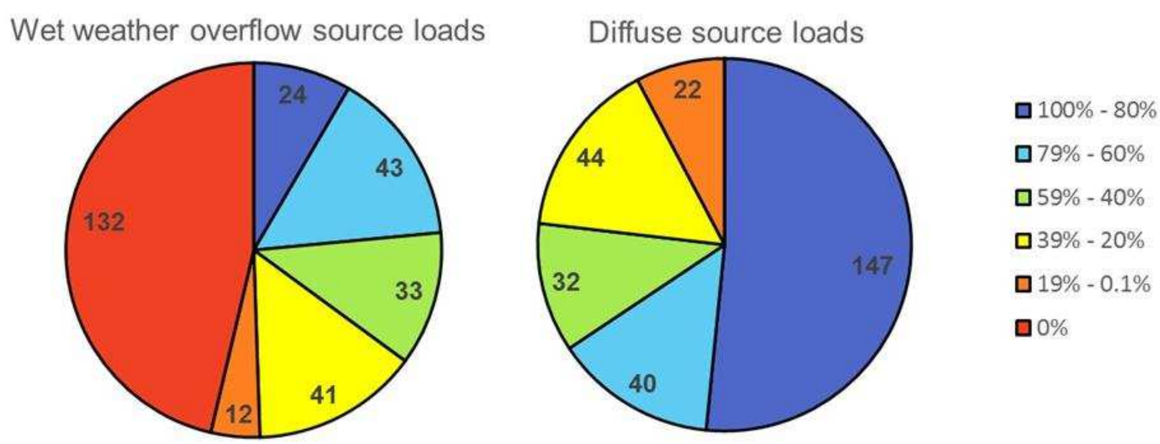


Figure 6.1: The distribution of subcatchments as a percent of diffuse sources and wet weather overflow Enterococci loads. Values inside each segment of the pie chart is the number of subcatchments that fall within the percentage ranges.

Comparing the percent change in Enterococci load between BAU 2025 and Baseline conditions (Figure 6.3) shows in the majority of the subcatchments Enterococci loads will increase by around 10 - 25%, mostly due to the expansion of high density residential areas and an increase in imperviousness (Figure 5.4). In some subcatchments there is a substantial decrease in loads as commercial and/or industrial areas have been converted to high density residential resulting in a decrease in imperviousness (Figure 5.4).

Removal of all WWOF from the catchment (Figure 6.4) illustrates the percent reductions in loads that could be achieved in comparison to the BAU 2025 loads. Regions in dark green show a reduction in loads of between 50 to 90%, and these were chosen as the focus of the Target WWOF scenario as it was thought they were the largest contributors to high loads.

Catchment intervention scenarios comprising of reduction in Enterococci loads due to stormwater harvesting (rainwater tanks) and pet waste control resulted in a 5 to 25% reduction of loads for the medium level of intervention scenario (Figure 6.5). In the high level of catchment intervention scenario, a reduction of up to 50% load reduction was estimated (Figure 6.6).

The target overflows scenario results in a substantial change in loads of greater than 50% from BAU 2025 conditions (Figure 6.7), albeit with a lesser reduction for the upper Parramatta sites with 6% change in loads. This indicated that the upper Parramatta diffuse sources are the dominant contributor to Enterococci loads.

Combining high catchment interventions and target overflows gives an overall increase in the reduction of Enterococci loads from BAU 2025 across the catchment (Figure 6.8), where future loads are reduced back to current levels, and in many parts of the catchments further improved on baseline loads.

A summary of the key SOURCE catchment modelling results for each intervention scenarios for each LGA is provided in Appendix 5:.

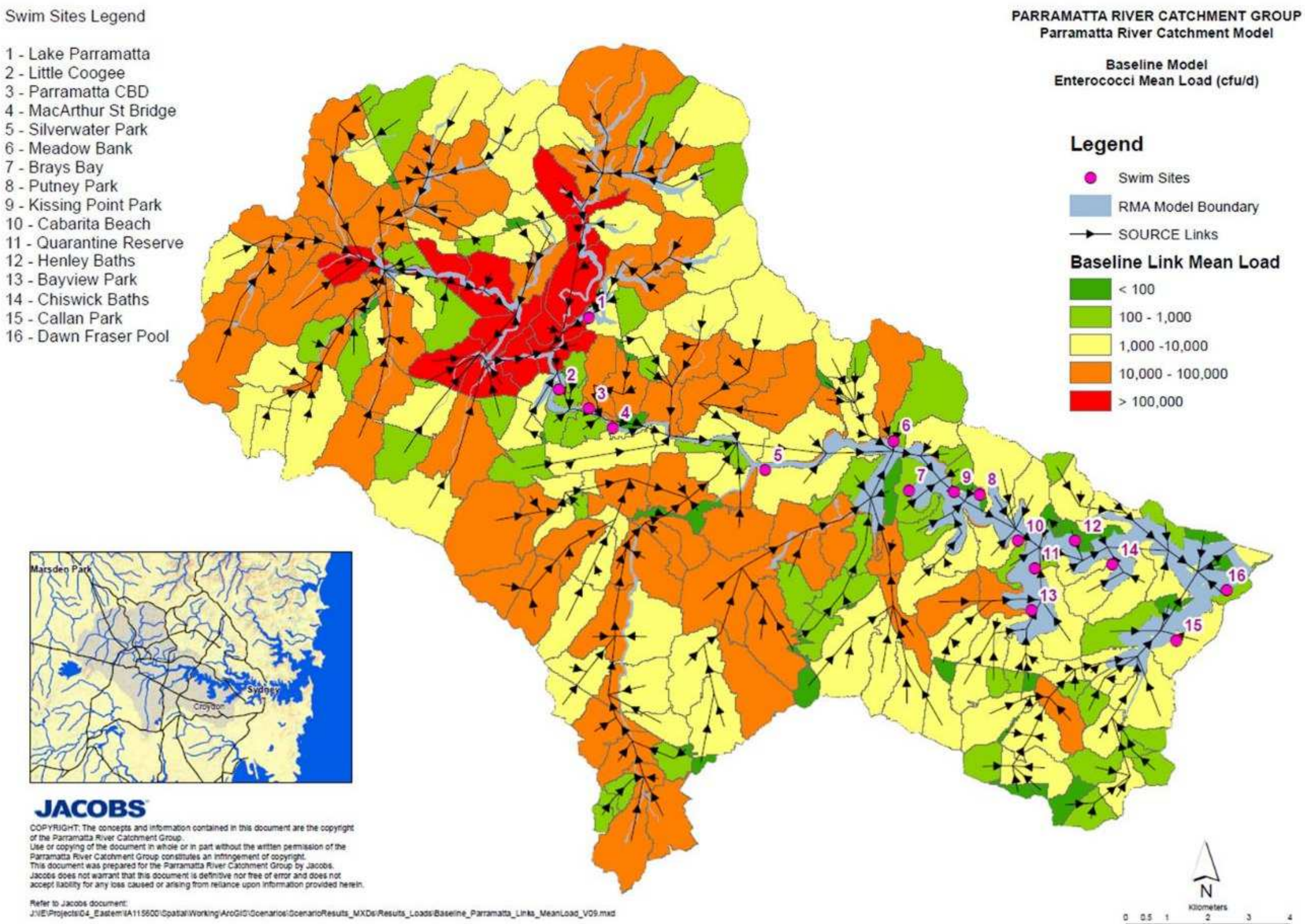


Figure 6.2 : Baseline mean Enterococci load (CFU/d)

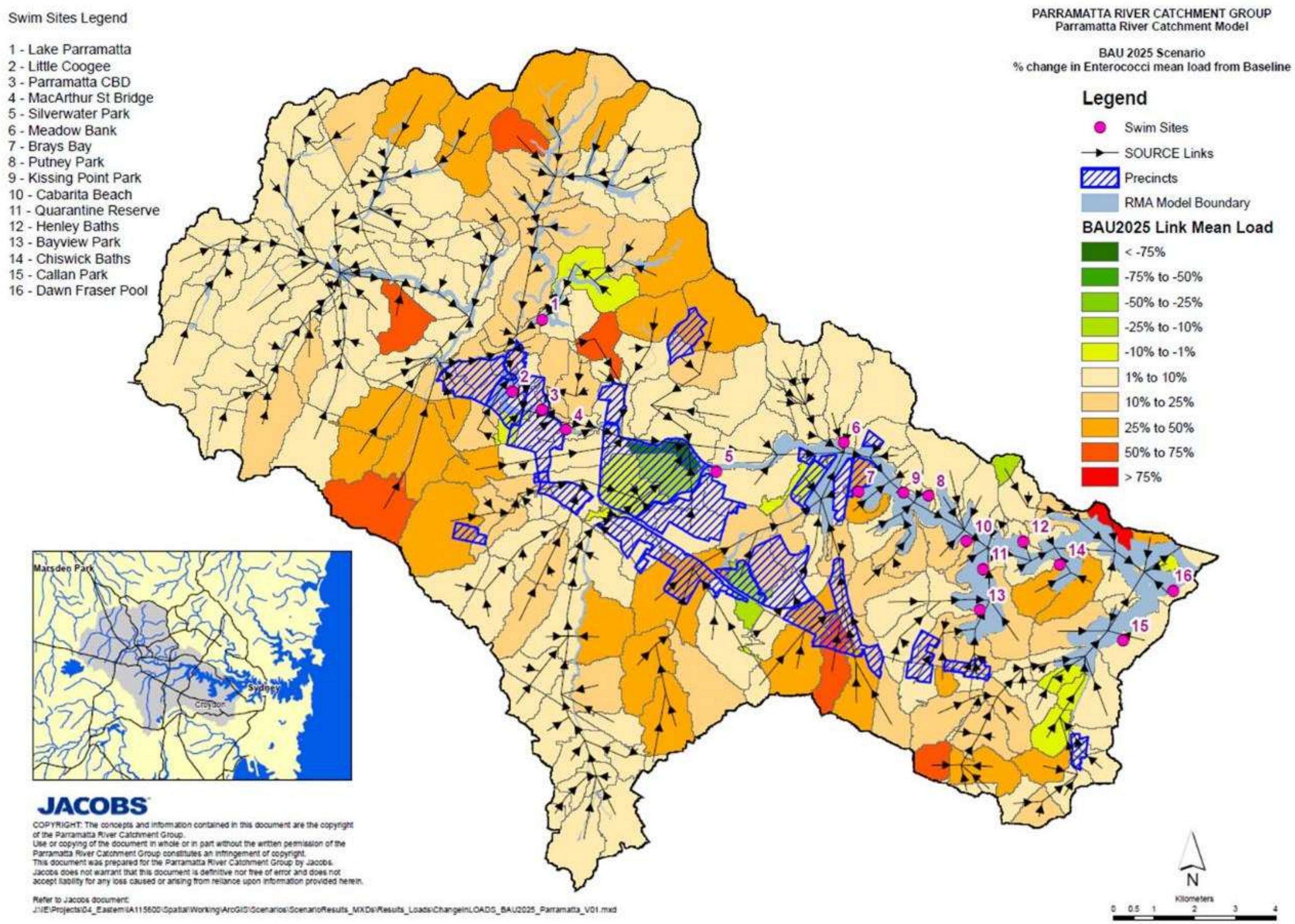


Figure 6.3: Business as Usual 2025 scenario – Percent difference in Enterococci load (CFU/d) from Baseline loads. Negative percent indicates a reduction in loads from baseline.

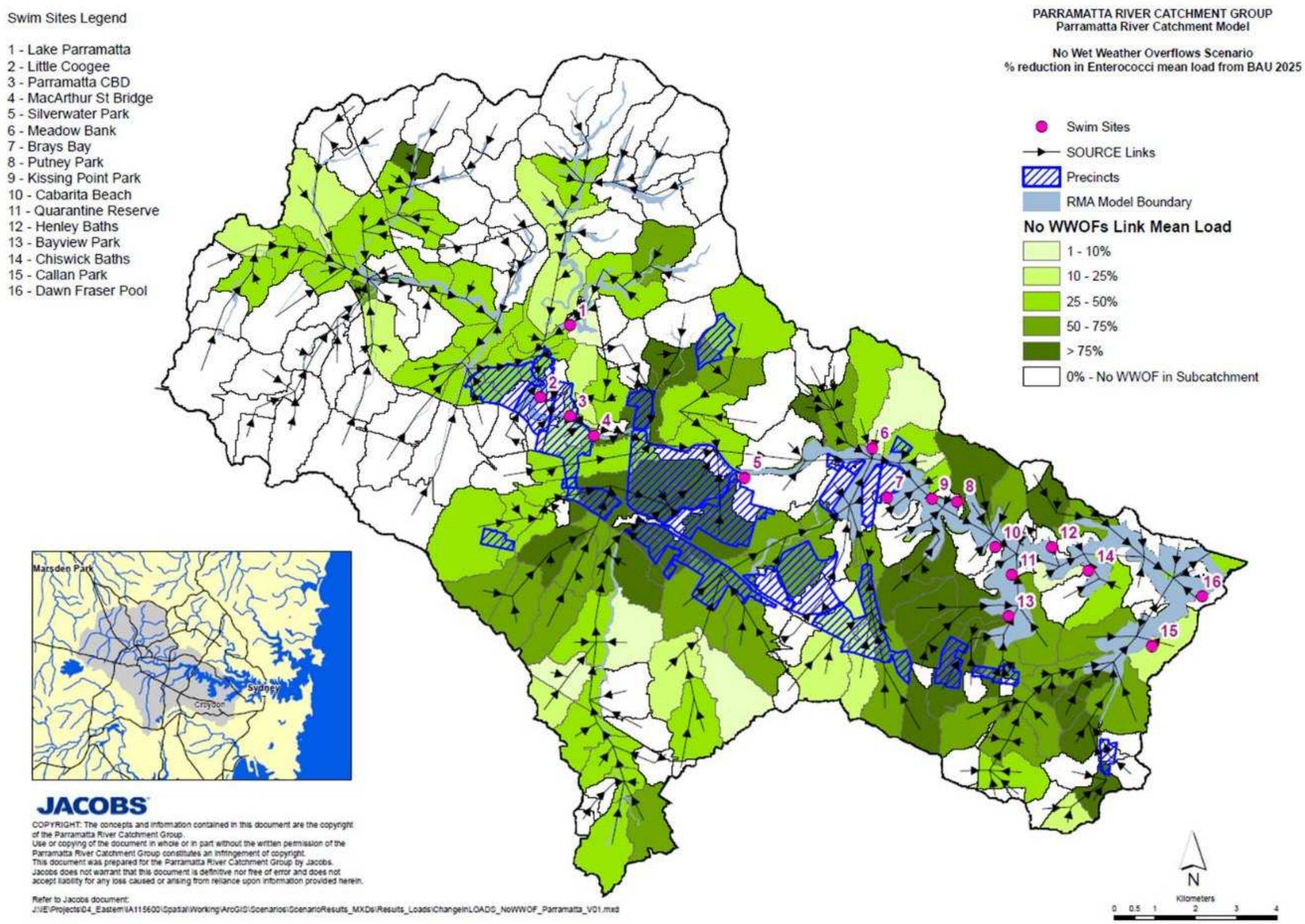


Figure 6.4: No Wet Weather Overflows (WWOF) scenario – Percent difference in Enterococci load (CFU/d) from BAU 2025 loads.

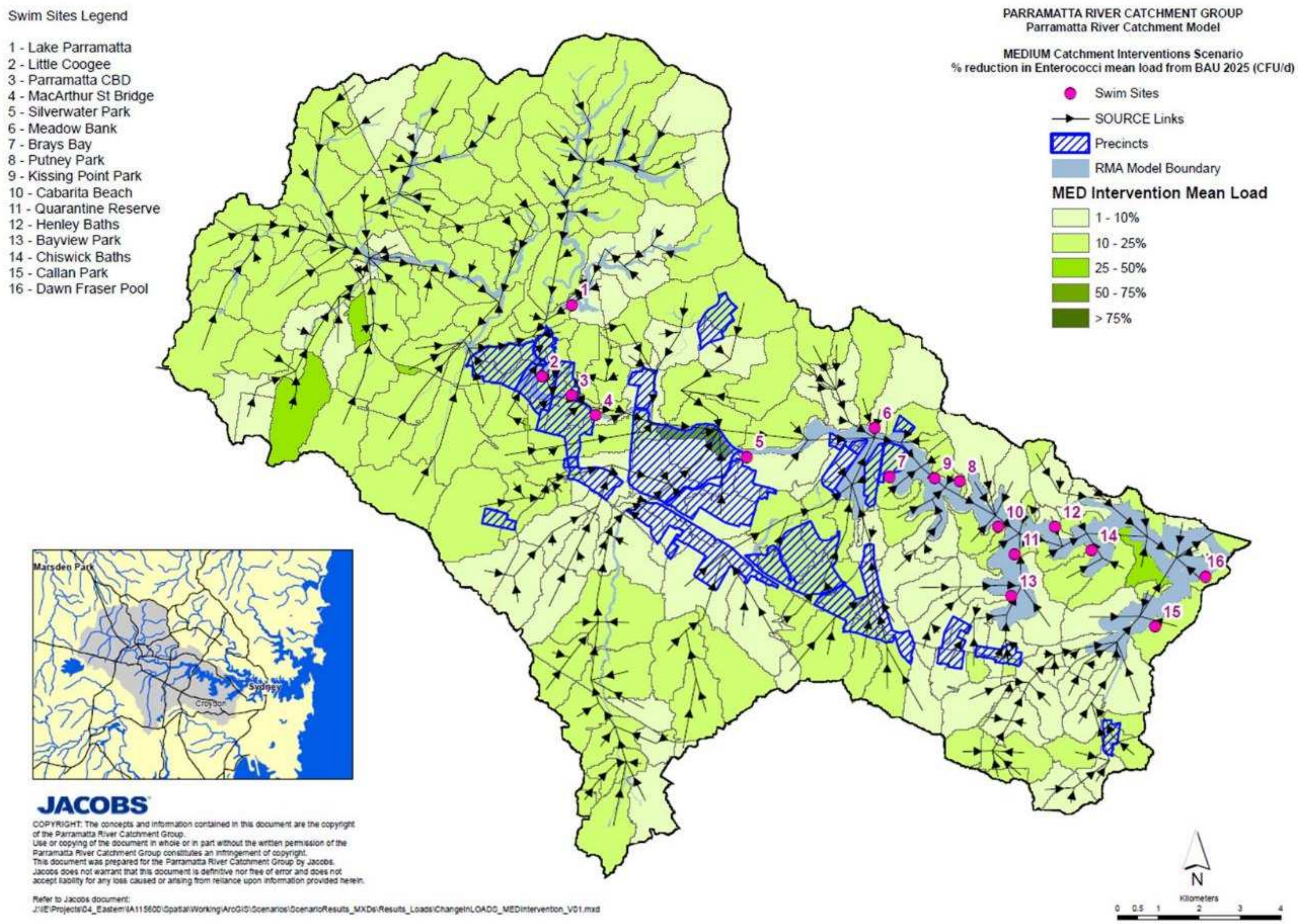


Figure 6.5 : Medium level of catchment intervention scenario – Percent change in Enterococci load (CFU/d) from BAU 2025 loads

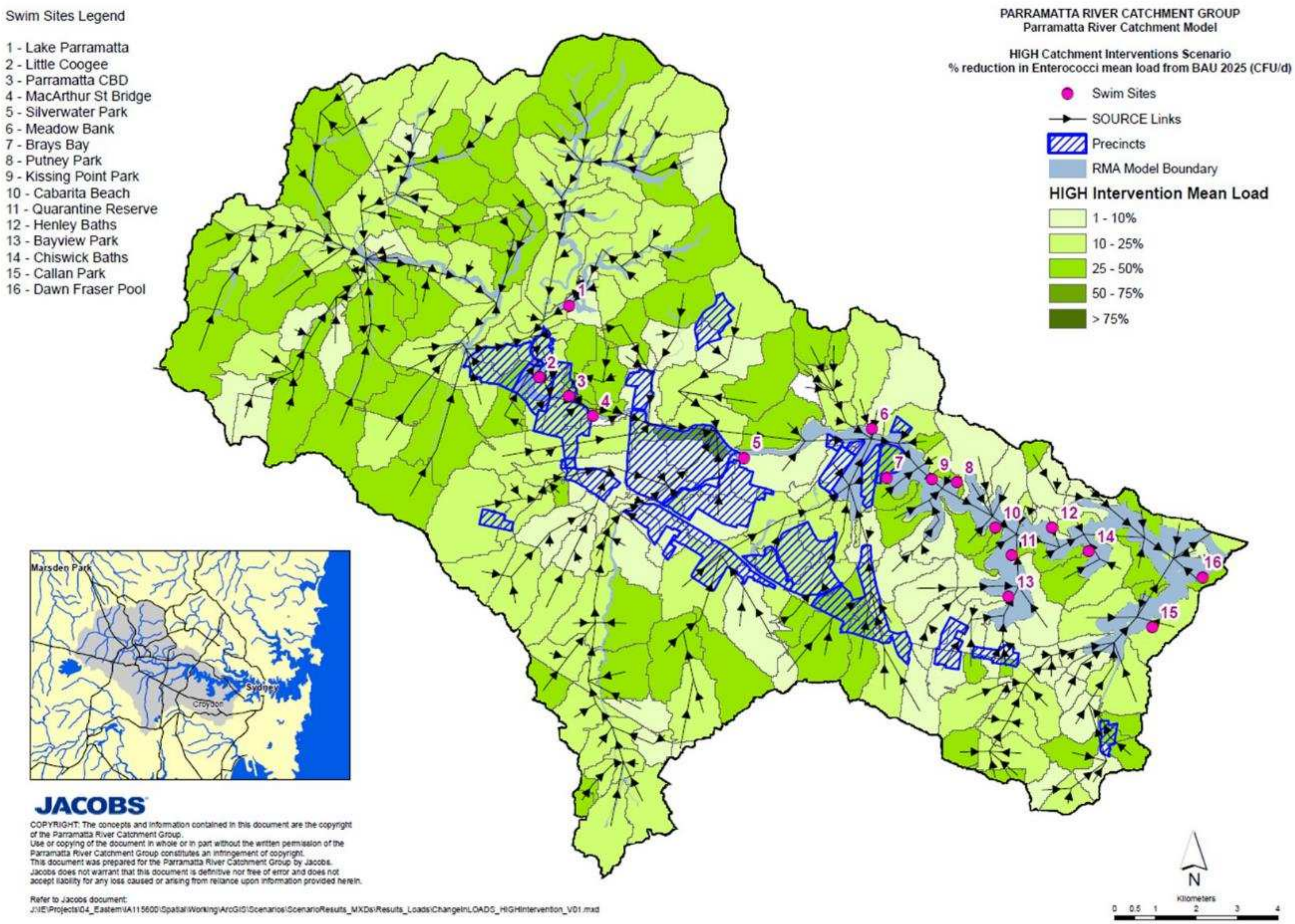


Figure 6.6 : High level of catchment intervention scenario – Percent change in Enterococci load (CFU/d) from BAU 2025 loads

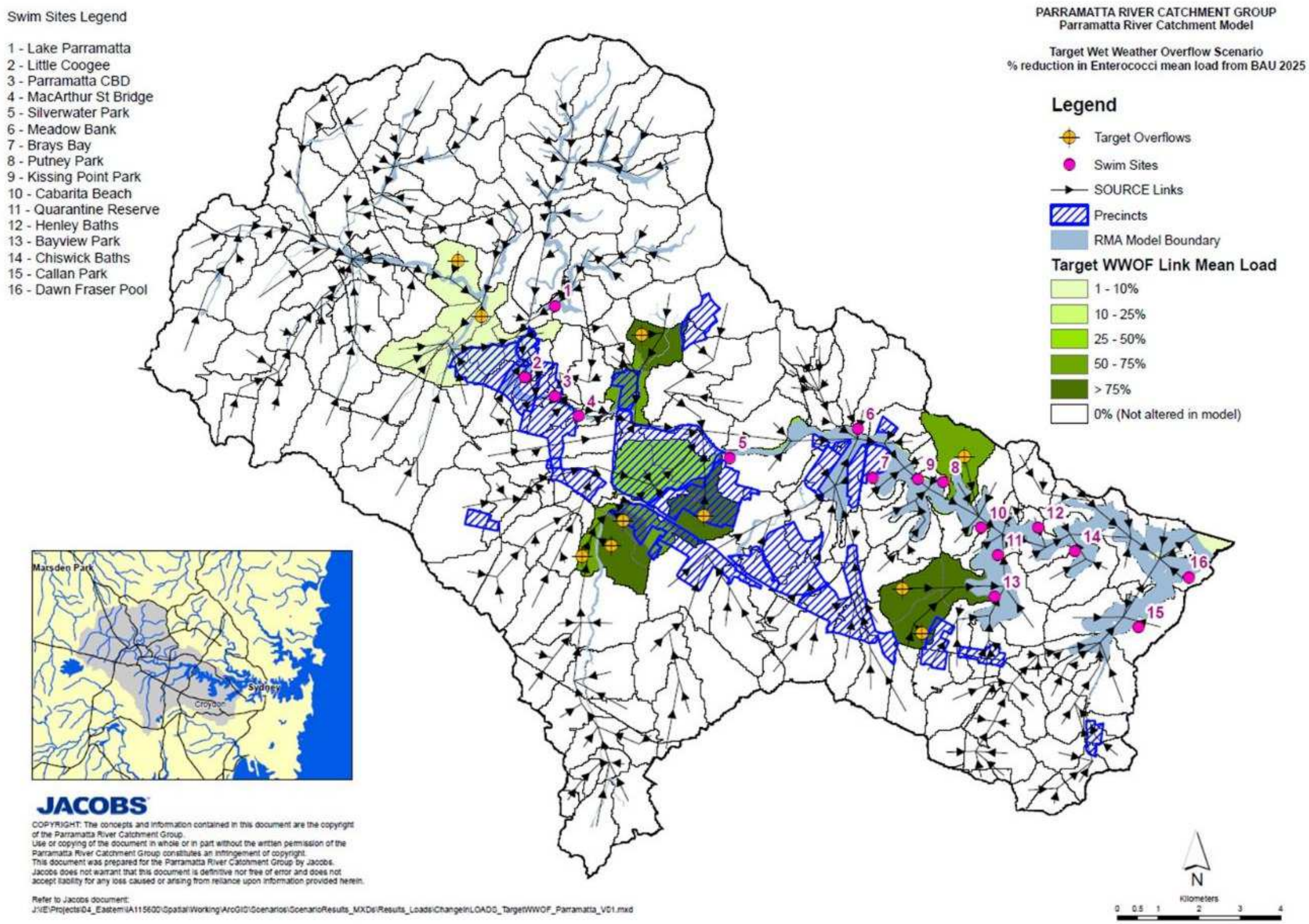


Figure 6.7 : Target WWOF scenario – Percent change in Enterococci load (CFU/d) from BAU 2025 loads

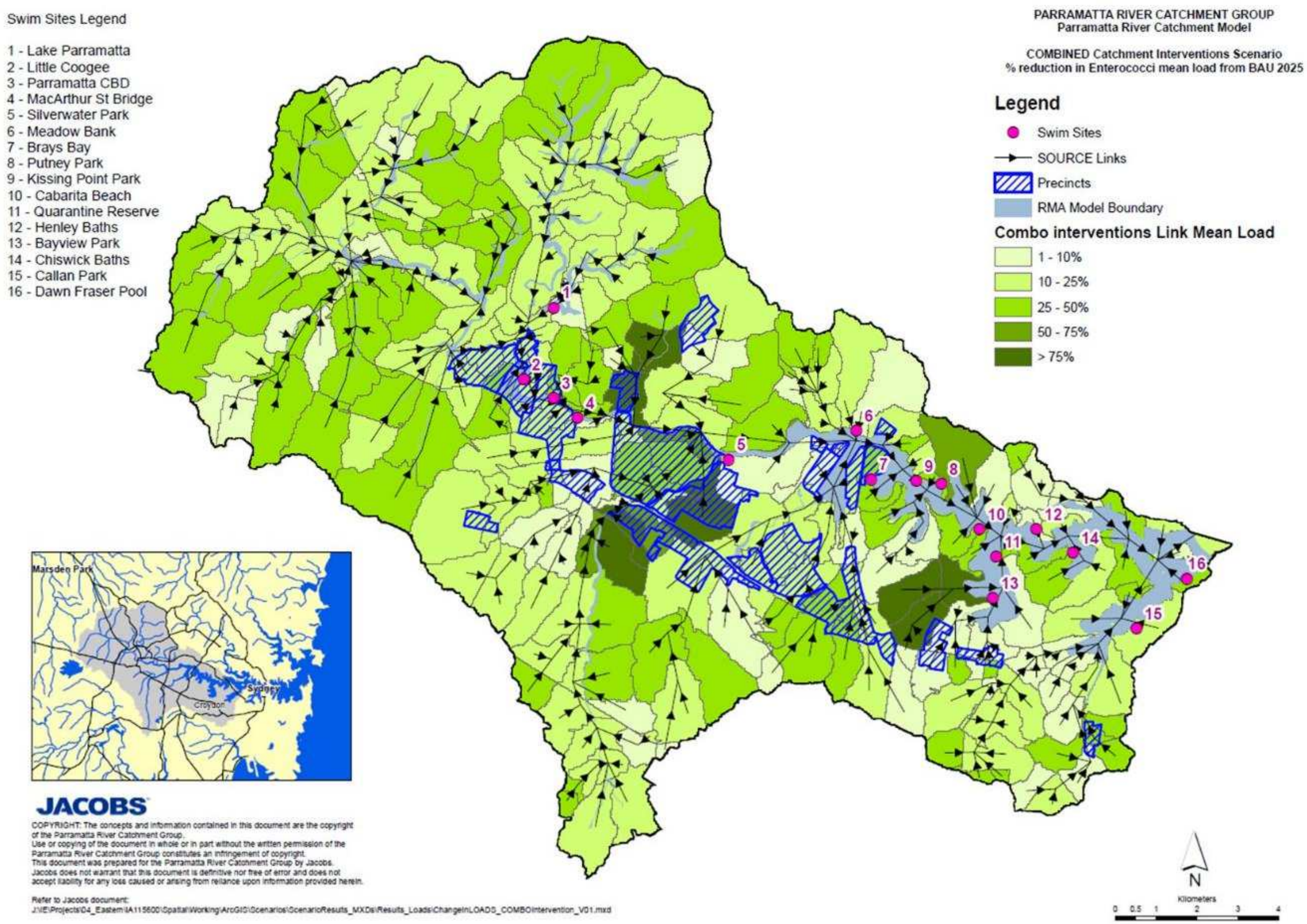


Figure 6.8 : Combined high level of catchment intervention + Target WWOF scenario – Percent change in Enterococci load (CFU/d) from BAU 2025 load

6.2 Swimmability assessment for each swim sites

6.2.1 Variation in Enterococci concentrations

The results from the RMA models provide an estimate of how enterococci concentrations vary near each site over time. There are slight differences in the distribution at different times of the year, in particular, elevated median concentrations in Autumn months (see Figure 6.9). However, the variation over time is most strongly related to rainfall.

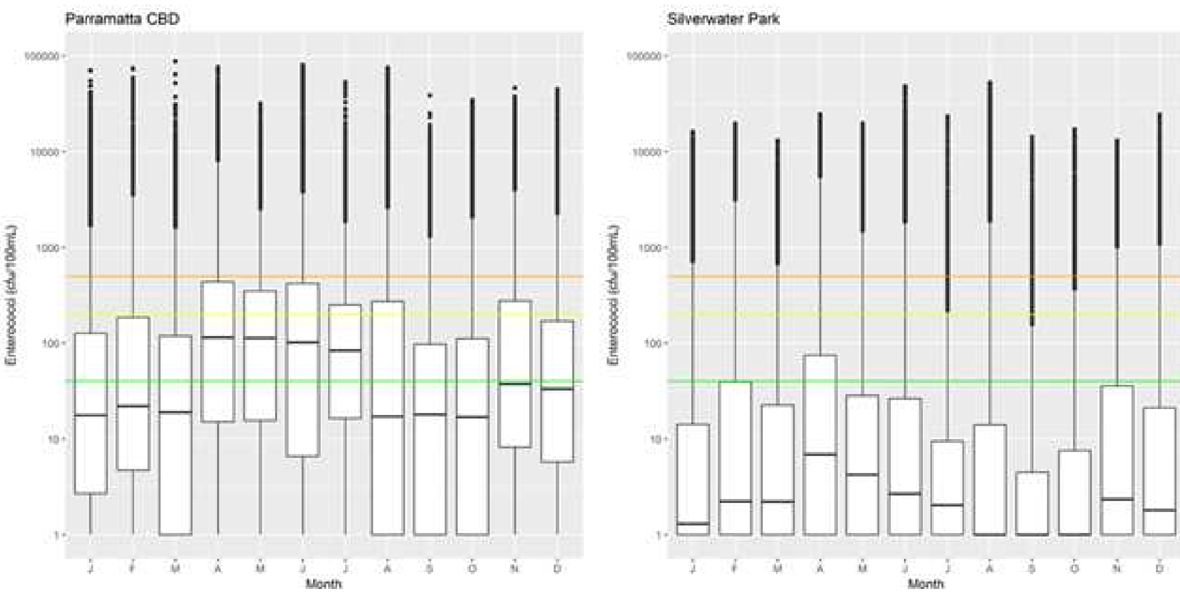


Figure 6.9: Monthly enterococci concentration boxplots for BAU scenario at Parramatta CBD and Silverwater Park. Coloured lines correspond to NHMRC categories (Green = 40 – 200 CFU/100mL; Yellow = 200 – 500 CFU/100mL; orange = 500 – 1000 CFU/100mL).

The impact of rain can be seen in the following boxplots (Figure 6.10 to Figure 6.12). For each site, the BAU scenario modelled results are grouped based on the previous day's recorded rainfall (taken from North Parramatta rainfall station). The middle 50% of results for each level of rainfall fall within the range indicated by the box, while the whisker at the top extends to the 95th percentile (consistent with NSW Beachwatch *State of the Beaches* reporting).

The 95th percentile concentration is a summary of the distribution which takes greater account of the top-end variability in concentrations than other measures such as the mean. It is a value that enterococci concentrations are below for a majority of the time, and are only higher for 5% of the time (1 in 20). Other ways of looking at the distribution include calculating the time above thresholds, or equivalently, the number of swimmable days.

The change in enterococci concentrations when rainfall is greater than 5mm is noticeable for all sites, except for Lake Parramatta where the response in concentrations to rainfall is less variable. During large rainfall events greater than 10mm, 95th percentile concentrations exceed the NHMRC category B water quality objective, with the exception of Dawn Fraser Pool. These results illustrate the importance of the amount of rainfall as a trigger for elevated 95th percentile concentrations.

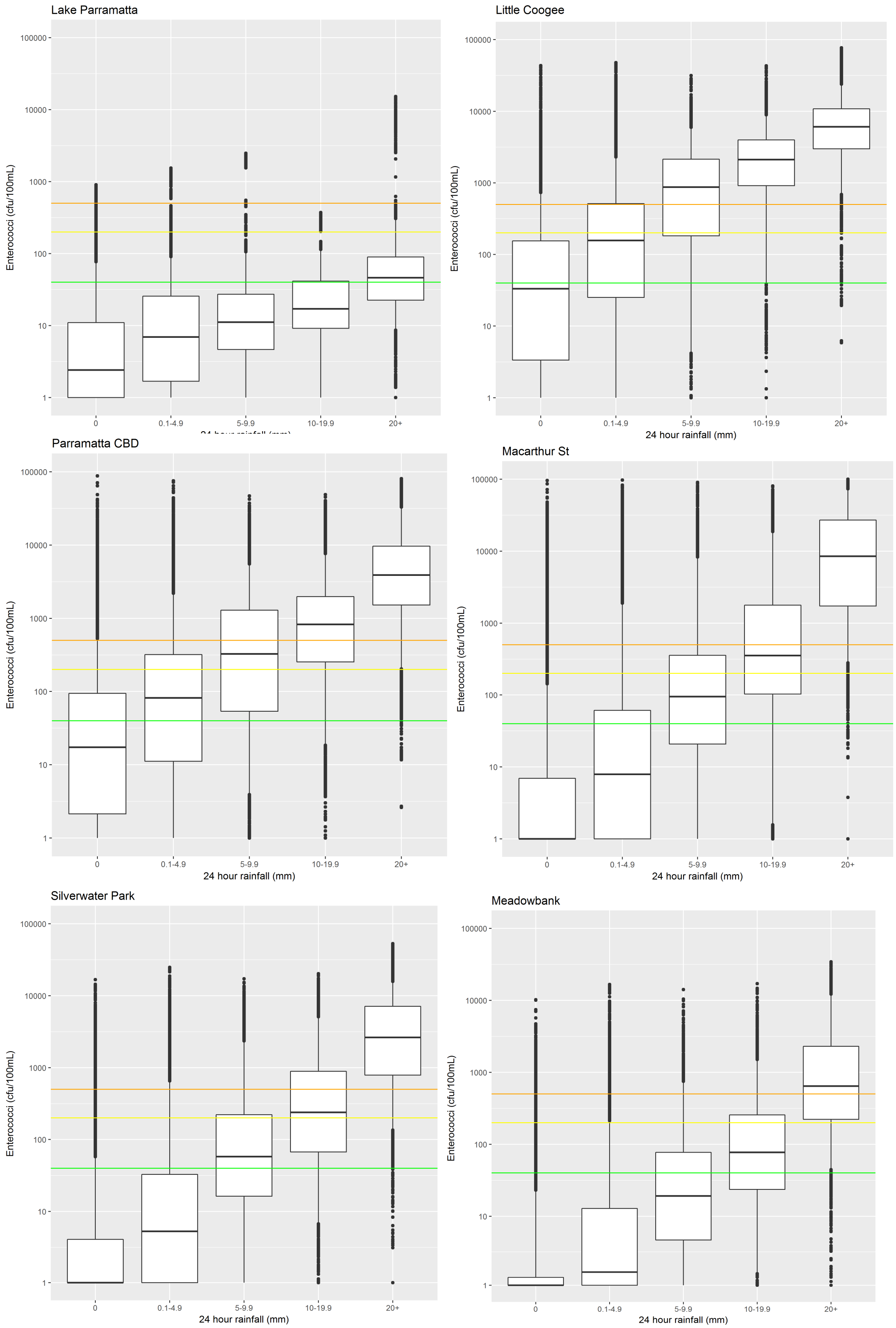


Figure 6.10: Enterococci concentration by preceding rainfall for BAU scenario at sites 1-6. Coloured lines correspond to NHMRC categories (Green = 40 – 200 CFU/100mL; Yellow = 200 – 500 CFU/100mL; orange = 500 – 1000 CFU/100mL).

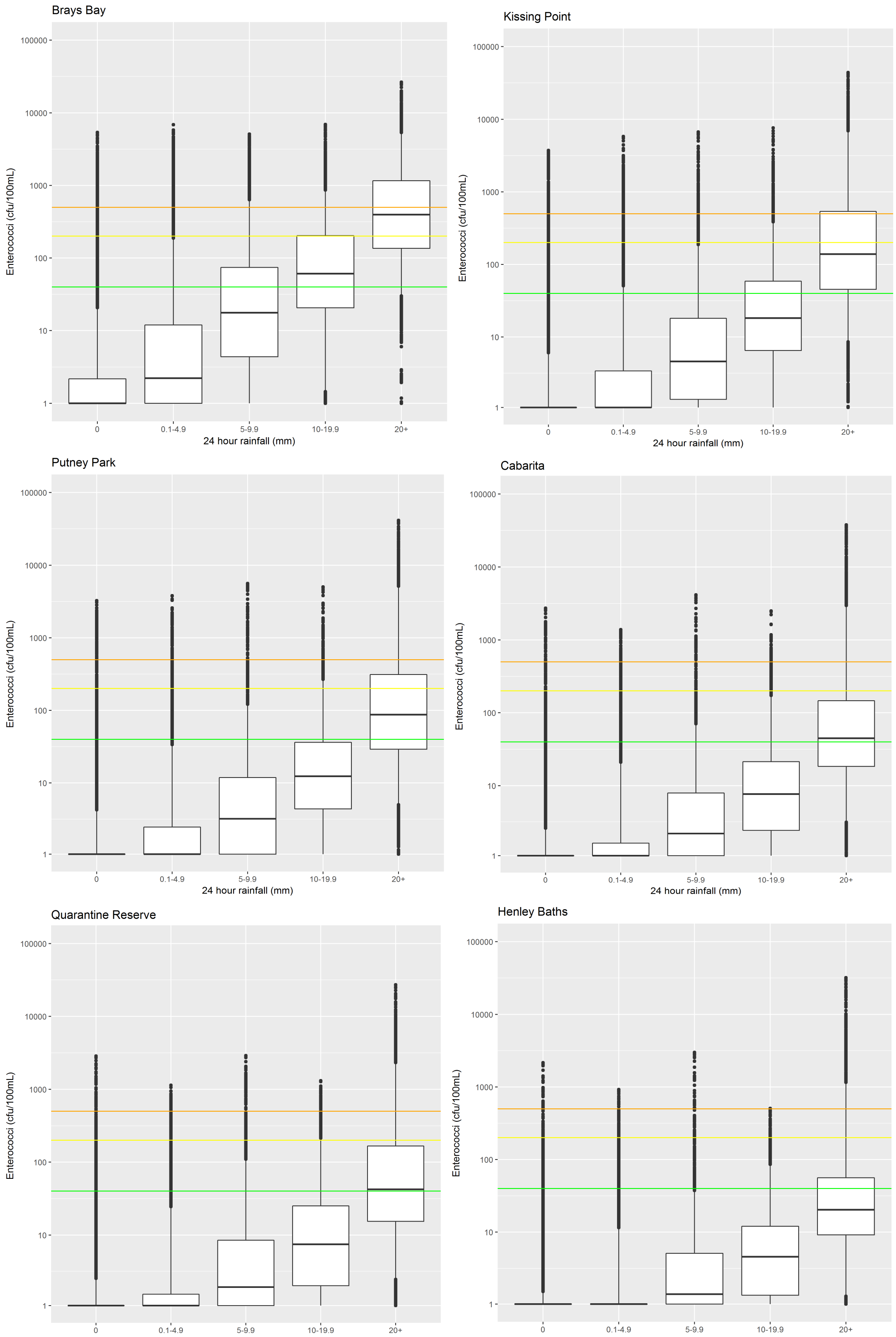


Figure 6.11: Enterococci concentration by preceding rainfall for BAU scenario at sites 7-12. Coloured lines correspond to NHMRC categories (Green = 40 – 200 CFU/100mL; Yellow = 200 – 500 CFU/100mL; orange = 500 – 1000 CFU/100mL).

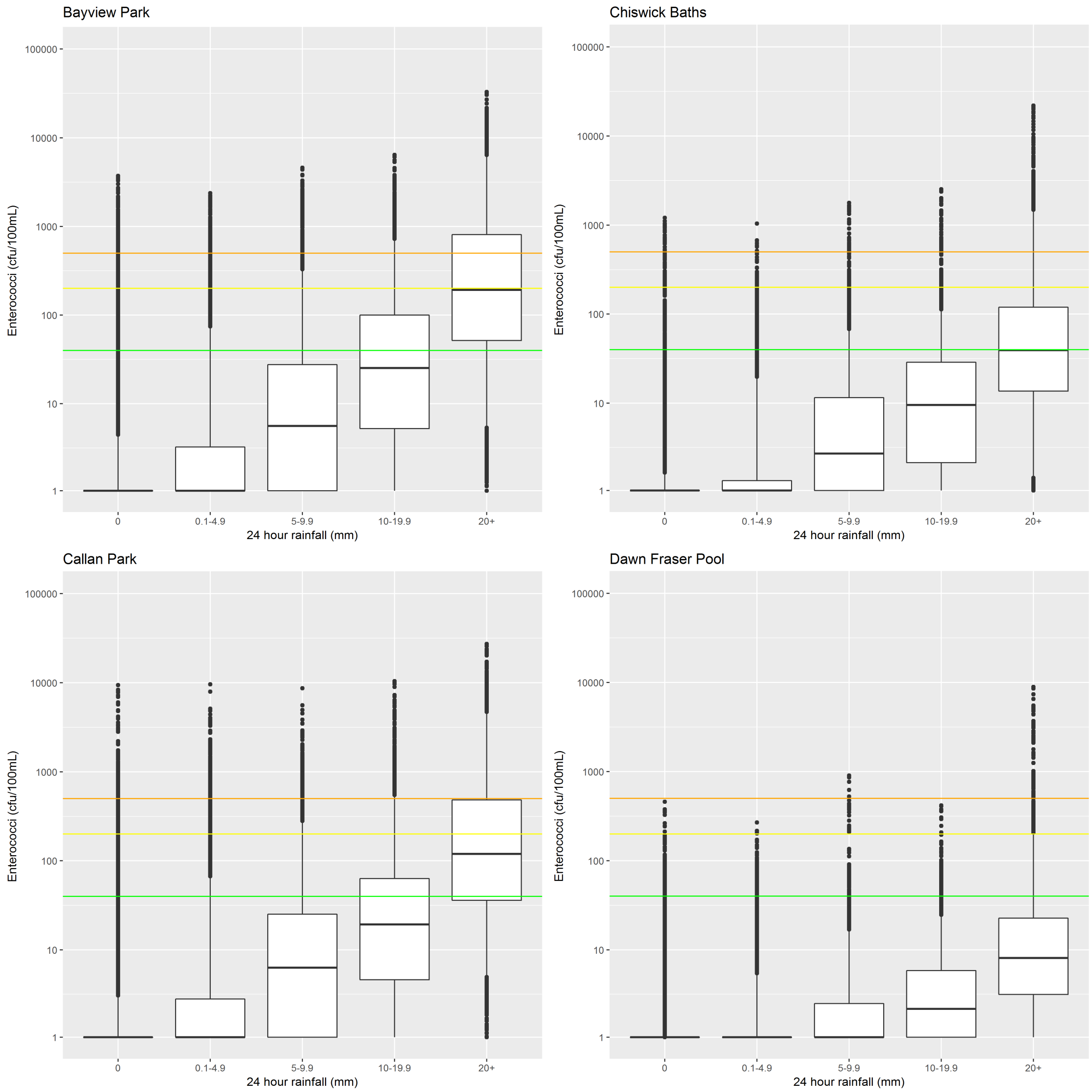


Figure 6.12: Enterococci concentration by preceding rainfall for BAU scenario at sites 13-16. Coloured lines correspond to NHMRC categories (Green = 40 – 200 CFU/100mL; Yellow = 200 – 500 CFU/100mL; orange = 500 – 1000 CFU/100mL).

6.2.2 Assessment of RMA modelling results against NHMRC Guidelines

The scenario results from the RMA model gives a more detailed estimate of enterococci concentrations than the catchment model as well as the number of days swimmable at a given swim site. The 95th percentile is used by the NHMRC guidelines to relate observed concentrations with levels of risk of illness and so to provide a categorisation of microbial water quality at a particular site. For model results that do not account for localised effects, categorisation by 95th percentile gives a general indication of which parts of the river would fall in each NHMRC category under each scenario.

Table 6-1 presents the 95th percentile concentrations for each scenario for each swim site. For all sites there is an increase in the 95th percentile concentration under BAU 2025 conditions, but there is no change in NHMRC guideline category compared to baseline.

Generally, enterococci concentrations are very high in the upper Parramatta reaches where swim sites are located in freshwaters impounded by the weir, and progressively reduces from the

MacArthur Street site towards the river outlet near Cockatoo Island, due to the tidal flushing in the estuary. The difference is significant when looking at dry weather concentrations after three days of flushing in the estuary (Table 6-2). Lake Parramatta has substantially lower concentrations than other Upper Parramatta sites, and is consistent with findings from the Strategic Analysis report (Khan and Byrnes, 2016).

Removing WWOFs improves water quality conditions for MacArthur Street, Silverwater Park, Bayview Park and Putney Park sites, decreasing the 95th percentile concentrations into a lower NHMRC category. The same result can be achieved at Silverwater Park site by targeting high discharging overflows, and this is reflected in the combined intervention scenario result. With respect to Bayview Park and Putney Park, turning off all overflows results in the 95th percentile concentrations reducing further below 40 CFU/100mL. However, the target overflow scenario does not result in the same outcome. There may be additional overflows further upstream that are still contributing to high enterococci concentrations at these sites that warrant further investigation.

Intervention scenarios show noticeable improvement in the 95th percentile concentrations for the Brays Bay site, with swimmable conditions potentially achieved at concentrations less than 200 CFU/100mL. For the remainder of sites there is no change in NHMRC guideline category across scenarios.

Table 6-1: Assessment of 95th percentile concentration against microbial water quality objectives (NHMRC 2008 guidelines) calculated from the 10-year scenario period RMA model outputs. Intv. Abbreviation refers to catchment intervention.

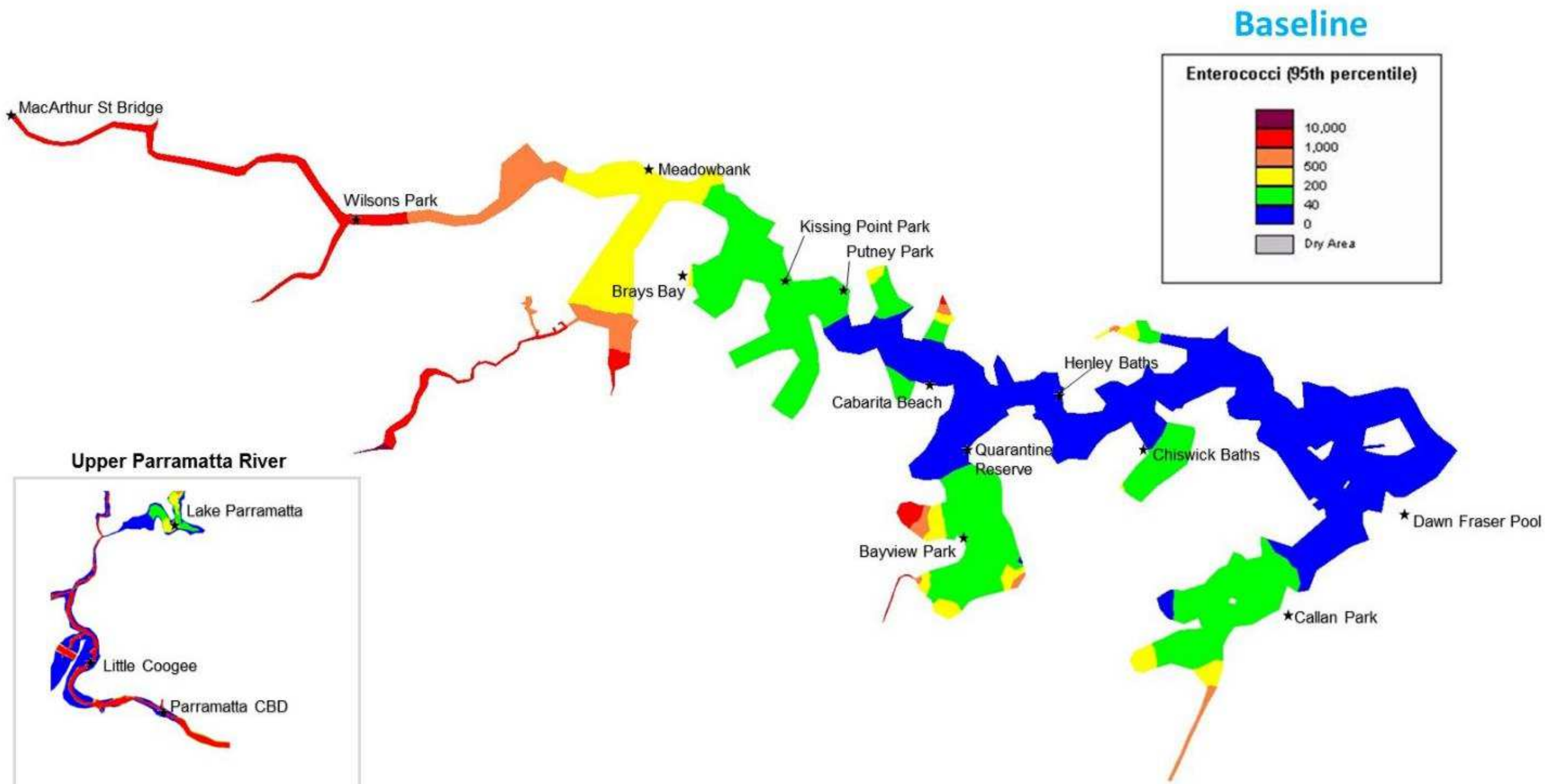
NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category	Blue	Green	Yellow	Orange	Red

Swim Site	95th percentile concentration (dry weather) (CFU/100mL)						
	Baseline	BAU 2025	No WWOF	Target WWOF	Medium Intv.	High Intv.	Combo Intv.
Lake Parramatta	94	96	96	96	90	87	87
Little Coogee	3307	3856	3850	3858	3114	2857	2857
Parramatta CBD	2475	2817	2605	2819	2250	2064	2064
MacArthur St	2617	3426	792	3421	2856	2819	2827
Silverwater Park	1115	1261	524	823	1096	1063	626
Meadowbank	357	405	254	354	320	299	254
Brays Bay	217	272	210	262	207	197	184
Kissing Point	73	83	52	74	64	60	52
Putney Park	45	51	33	45	40	37	31
Cabarita	26	31	19	25	24	22	17
Quarantine Reserve	26	32	13	19	27	26	14
Henley Baths	14	16	10	13	12	11	9
Bayview Park	87	112	36	71	98	95	56
Chiswick Baths	24	30	25	29	22	20	20
Callan Park	88	96	71	97	78	71	72
Dawn Fraser Pool	6	7	6	7	5	5	5

From the RMA modelling, 95th percentile concentration maps covering the river extent are shown in Figure 6.13 to Figure 6.19 for baseline and each scenario. Colours correspond to the NHMRC recreational water quality objectives.

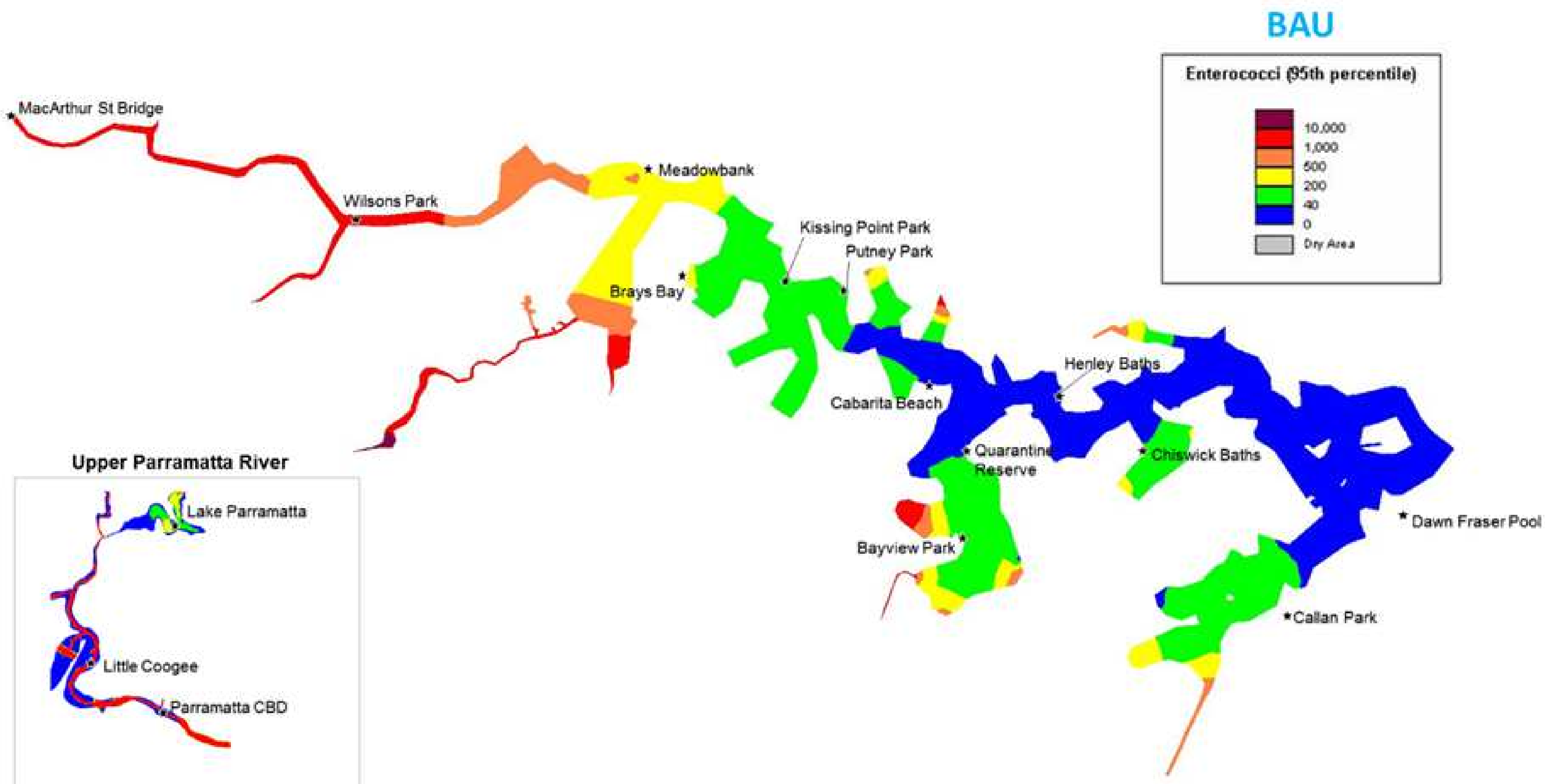
The above results in Table 6-1 are a single concentration value (95th percentile calculated from the 10-year scenario period) taken from the nearest RMA model mesh cell to each swim site location. Conversely, these maps show the progressive change in 95th percentile concentrations from upstream to downstream. Tidal flushing and dilution results in low concentrations suitable for swimming conditions for sites closer to the main channel, whereas those sites within larger bays less influenced by flushing, such as Bayview Park and Callan Park sites, exhibit higher concentrations.

Comparisons of BAU (Figure 6.14), no WWOFs (Figure 6.15) and high catchment intervention (Figure 6.18) scenario maps illustrate the extent of the NHMRC 95th percentile concentration categories that could be gained by addressing either diffuse or point-sources of enterococci. Addressing diffuse sources of enterococci extends the NHMRC Category B (Green) upstream close to the Meadowbank site and into the larger bays, also reducing the extent of Category C and D 95th percentile concentrations. Conversely, addressing WWOF enterococci sources reduces 95th percentile concentrations in the upper reaches between MacArthur street bridge and Meadowbank sites, and in the deeper bays near Bayview Park site where WWOFs have a greater influence.



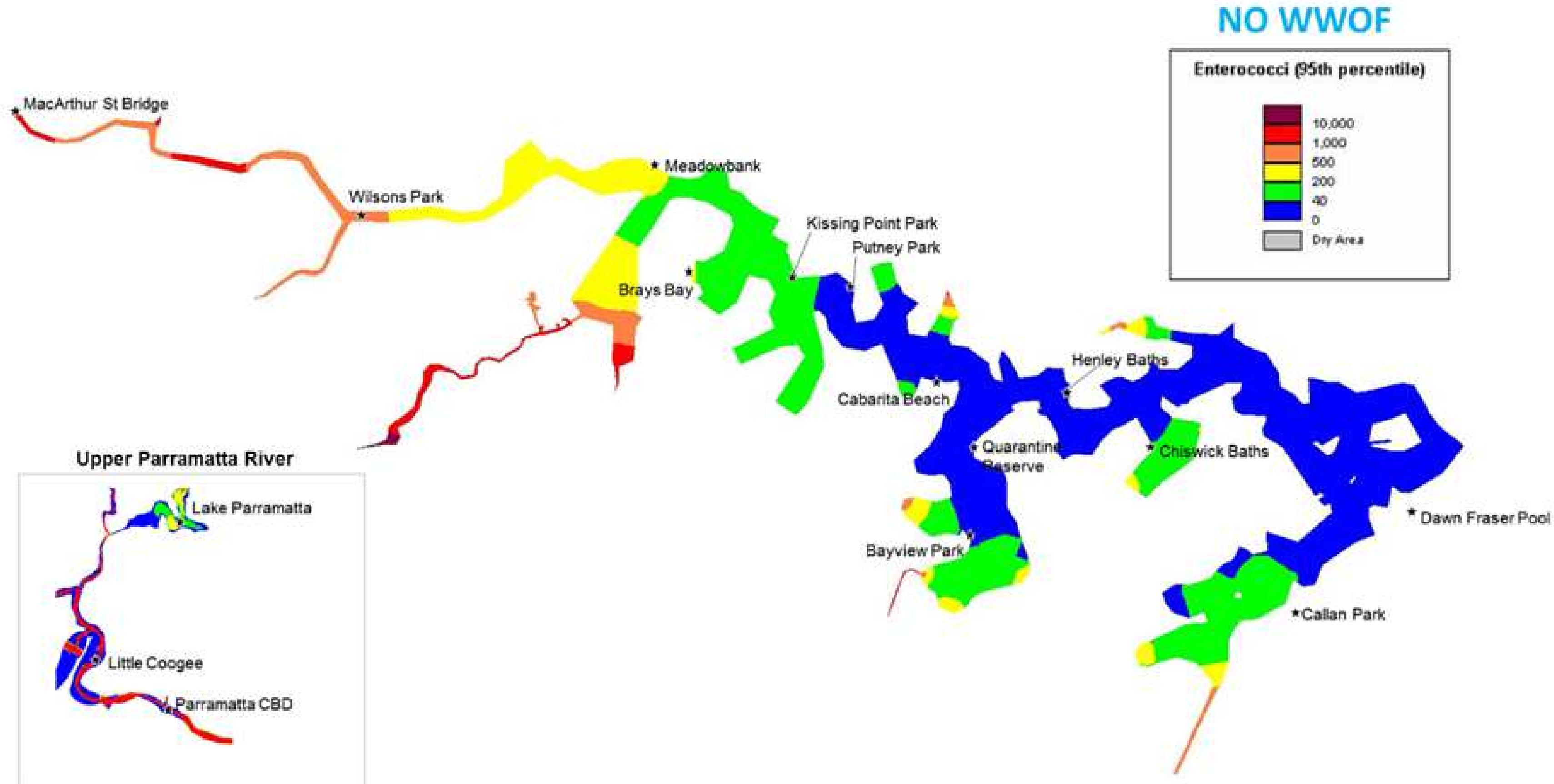
NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.13: Baseline scenario 95th percentile Enterococci concentrations for the RMA model river extent



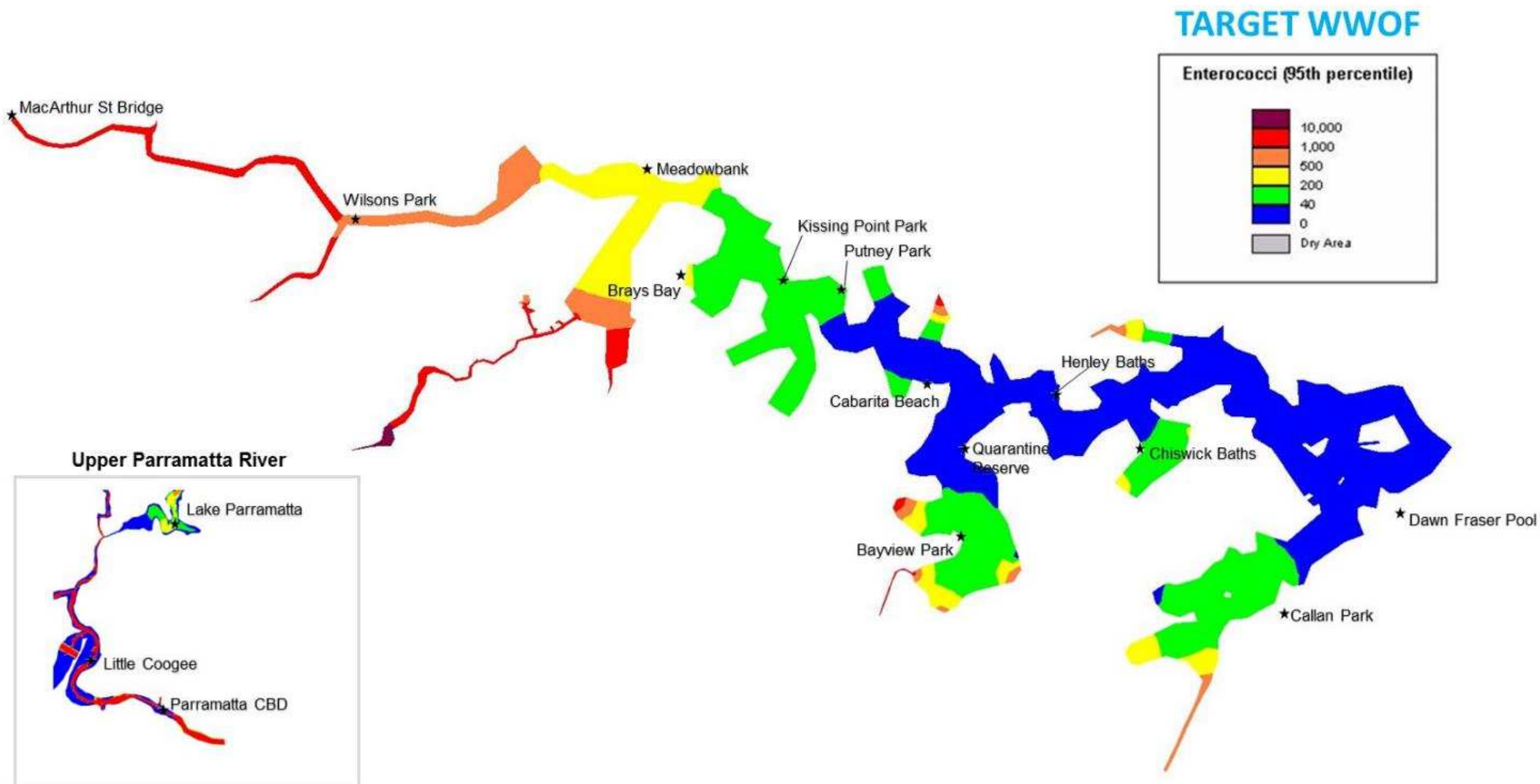
NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.14: Business as usual (BAU) 2025 scenario 95th percentile Enterococci concentrations for the RMA model river extent



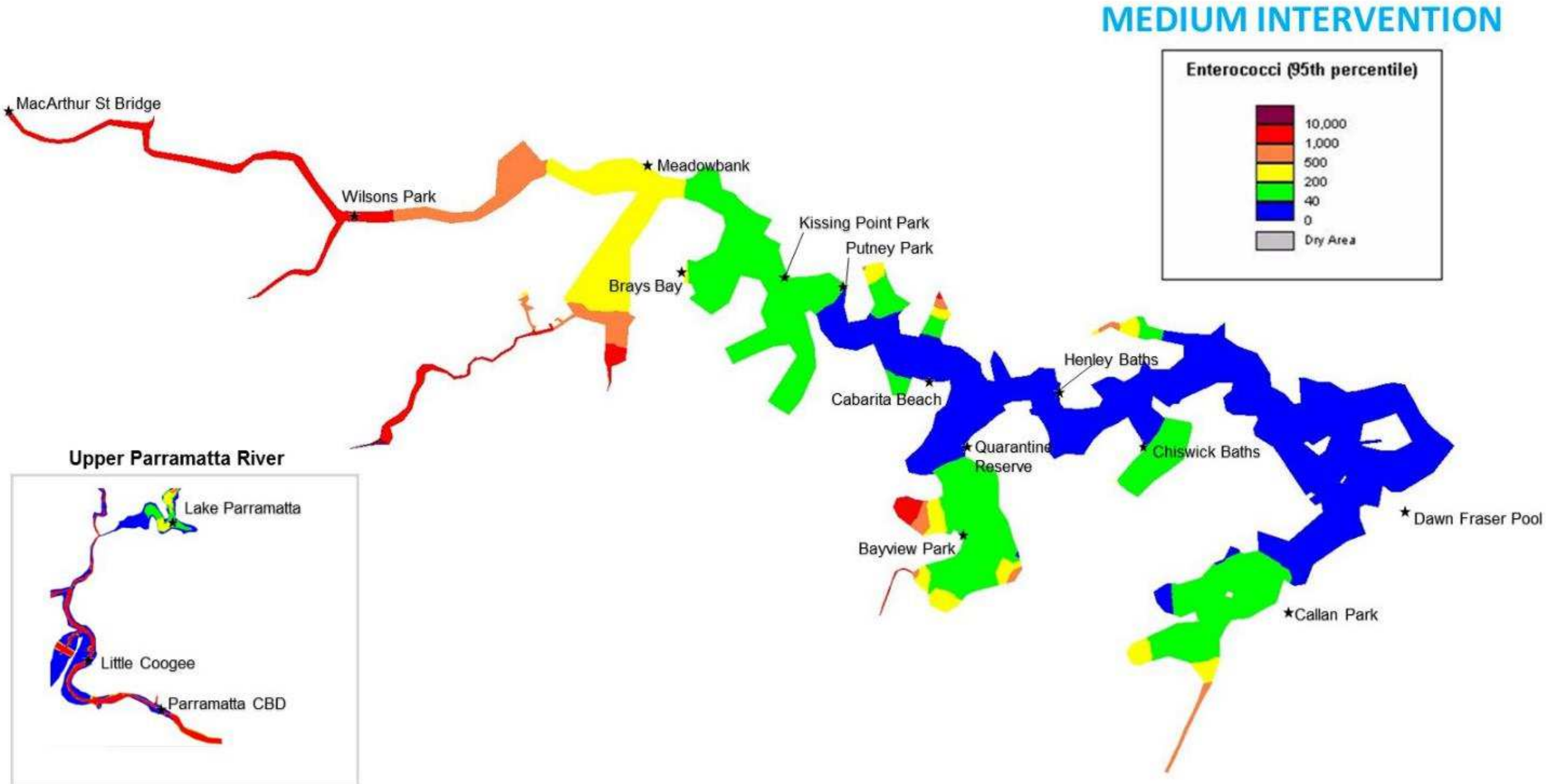
NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.15: BAU 2025 + No wet weather overflows (WWOF) scenario 95th percentile Enterococci concentrations for the RMA model river extent



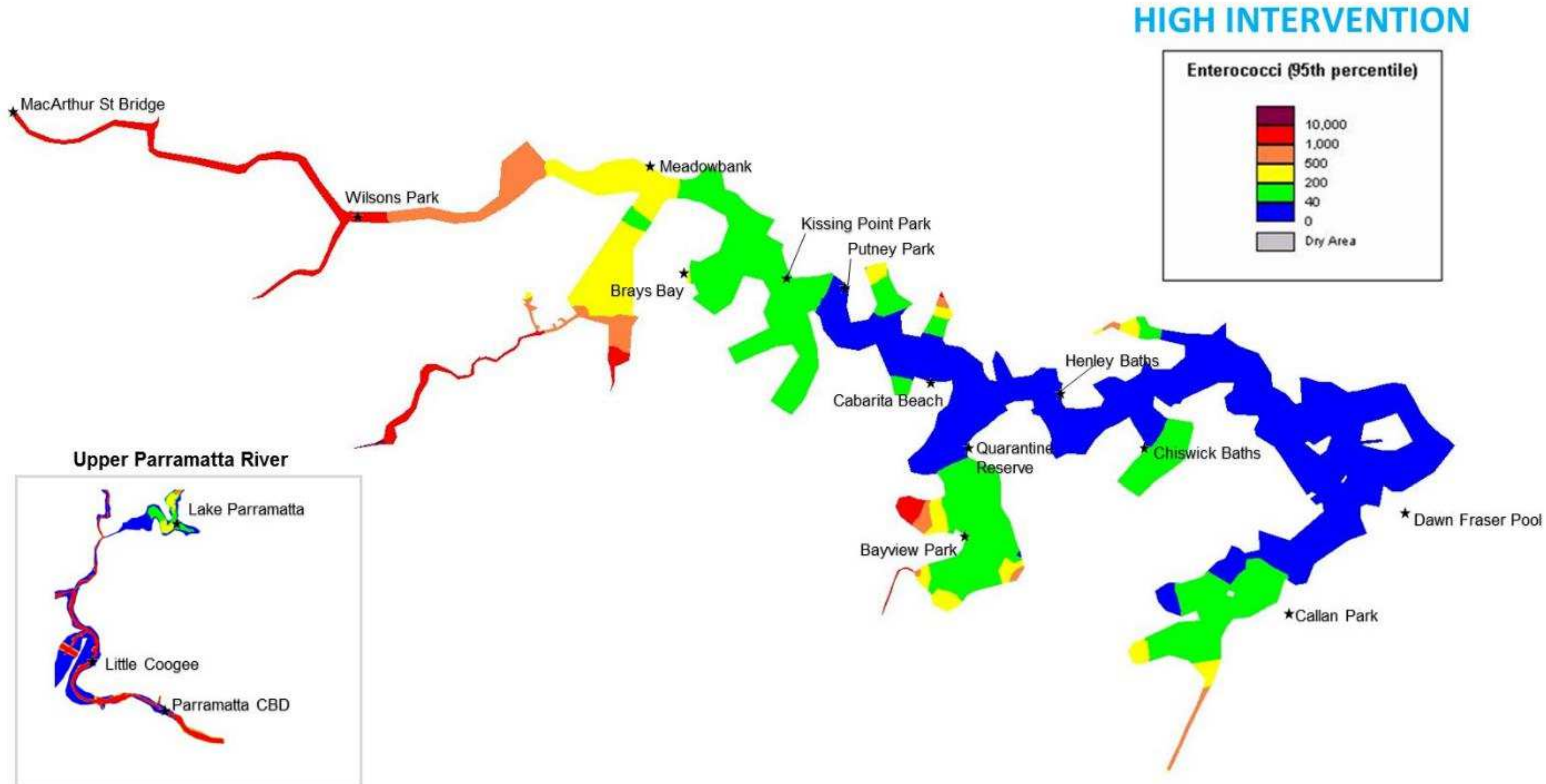
NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.16: Target wet weather overflows (WWOF) scenario 95th percentile Enterococci concentrations for the RMA model river extent



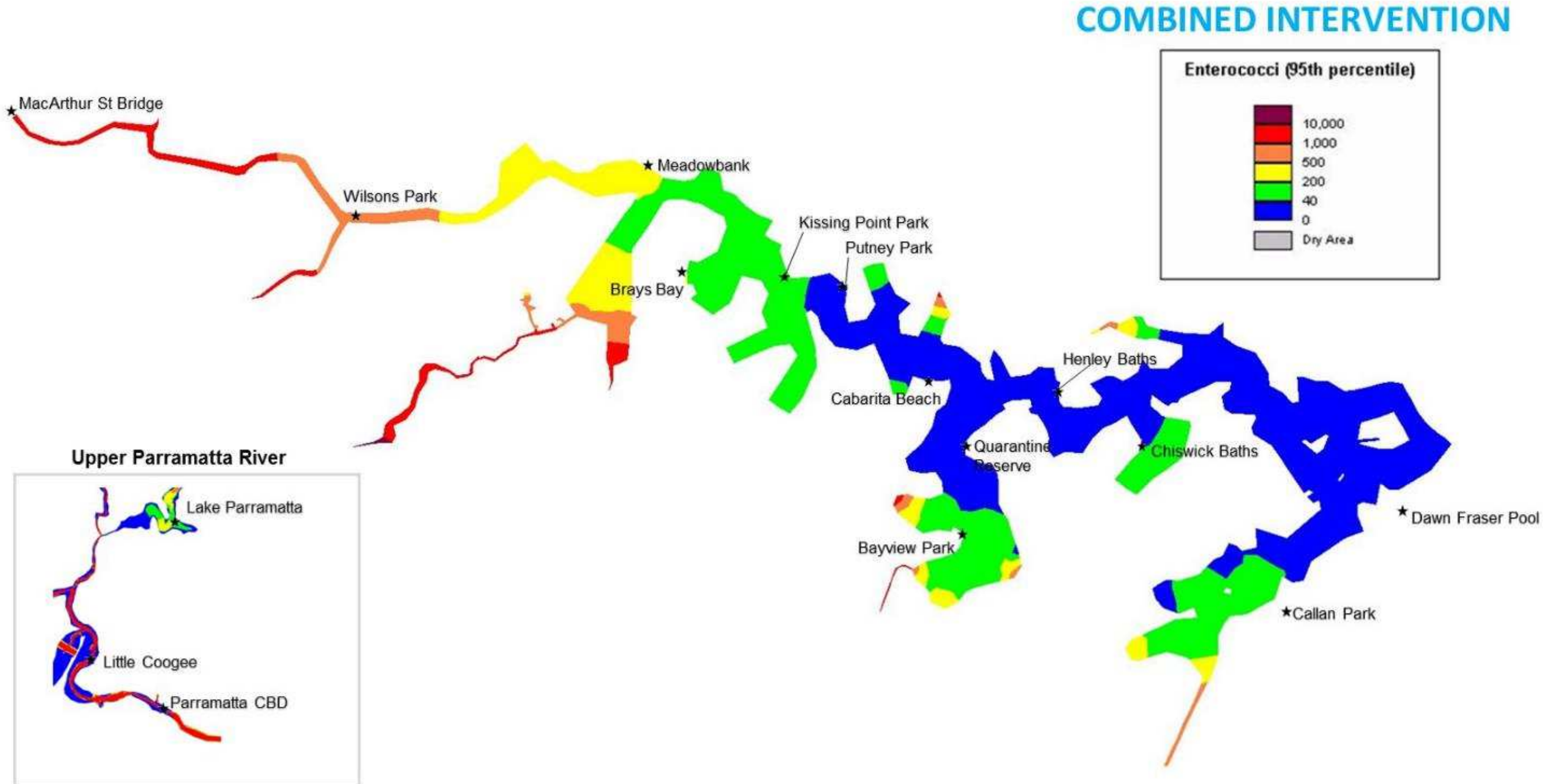
NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.17: Medium catchment intervention scenario 95th percentile Enterococci concentrations for the RMA model river extent



NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.18: High catchment intervention scenario 95th percentile Enterococci concentrations for the RMA model river extent



NHMRC guideline category (CFU/100mL)	< 40 (A: Very Low)	41 – 200 (B: Low)	201 – 500 (C: Moderate)	501 – 1000 (D: High)	>1000 (Extreme)
Colour category					

Figure 6.19: Combined catchment intervention scenario 95th percentile Enterococci concentrations for the RMA model river extent

6.2.3 Swimmability response after rainfall

An increase in microbial loads is typically strongly related to rain, as rainfall tends to flush pollutants from wastewater and stormwater systems into waterbodies (PCC, 2016). As a result, Beachwatch advice is often set as 'do not swim' at a site for 3 days after rainfall.

Results from the RMA model were used to calculate the 95th percentile dry weather concentrations from 3 to 7 days preceding rainfall to determine if the 95th percentile concentrations are further reduced following prolonged periods of dry weather. In this case dry weather is defined as 3 (up to 7) consecutive days where rainfall is less than 1mm following the method of Khan and Byrnes (2016). Rainfall recorded at the North Parramatta weather station greater than 1mm was considered as a 'rain day'.

Table 6-2 shows the results for the poorest water quality swim sites. For sites downstream of MacArthur street bridge (and Lake Parramatta), dry weather 95th percentile concentrations all comply with Category A NHMRC guideline regardless of 3 or 7 days following rainfall, and are not further discussed.

Dry weather concentrations remain poor for Little Coogee and Parramatta CBD sites, with minimal impact of intervention scenarios on reducing concentrations below Category B NHMRC guidelines. However, 5 days after rainfall the 95th percentile dry weather concentrations at the Parramatta CBD site decreases sufficiently to be within NHMRC Category B under both high and combined catchment intervention scenarios.

Three days after rainfall, the dry weather concentrations for the MacArthur street bridge site are within NHMRC category A guideline under all scenarios, demonstrating the effectiveness of tidal flushing in diluting concentrations to acceptable levels.

Table 6-2: The 95th percentile dry weather concentrations for poor water quality sites from 3 to 7 days preceding rainfall less than 1mm.

	Little Coogee						
Days after rainfall	**Baseline**	**BAU 2025**	**No WWOF**	**Target WWOF**	**Medium Intv.**	**High Intv.**	**Combo Intv.**
3	524	540	540	540	512	496	496
4	455	471	471	471	442	427	427
5	369	380	380	380	354	341	341
6	296	305	305	305	285	274	274
7	237	245	245	245	226	217	217
	Parramatta CBD						
3	319	326	325	326	305	296	296
4	284	293	289	293	273	263	263
5	215	222	220	222	203	195	195
6	181	187	186	187	174	168	168
7	156	162	161	162	146	140	140
	MacArthur Street Bridge						
3	36	38	36	38	30	29	29
4	26	26	26	26	21	20	20
5	20	20	20	20	16	15	15
6	15	15	15	15	12	11	11
7	13	13	13	13	10	9	10
Sites further downstream and Lake Parramatta all comply with NHMRC Category A guideline							

However, given intervention scenarios are largely targeted at reducing inflows (and consequently load) transporting Enterococci to the river, the impact of intervention scenarios is observed more strongly on the 95th percentile concentrations that include both dry and wet weather conditions. Table 6.3 shows the 95th percentile concentrations (inclusive of both wet and dry weather concentrations) for each scenario calculated based on the previous day's recorded rainfall (taken from North Parramatta rainfall station).

Intervention scenarios begin to show noticeable improvement in the 95th percentile concentrations for sites downstream of Meadowbank, either arresting the trajectory of increased loads under BAU 2025 conditions, or improving on baseline concentrations as is observed for Putney Park, Quarantine Reserve and Bayview Park swim sites. These site 95th percentile concentrations fall below the NHMRC category B objective that indicates low risk conditions.

Table 6.3: All weather 95th percentile enterococci concentrations for each scenario calculated based on the previous day's recorded rainfall.

24 hour rainfall (mm)	*Baseline*	BAU 2025	No WWOF	Target WWOF	Medium Intv.	High Intv.	Combo Intv.
	Lake Parramatta						
0	77	77	77	77	73	71	71
0-5	90	91	91	91	86	83	83
5-10	105	106	106	106	100	97	97
10-20	114	114	114	114	109	106	106
>20	294	306	306	306	280	269	269
	Little Coogee						
0	711	735	735	735	691	668	668
0-5	2060	2310	2310	2310	1940	1780	1780
5-10	5150	5970	5970	5970	4820	4400	4400
10-20	7910	8920	8900	8920	7060	6410	6410
>20	21300	23900	23900	23900	19200	17400	17400
	Parramatta CBD						
0	505	532	532	532	477	454	454
0-5	1990	2200	2170	2200	1830	1690	1690
5-10	4830	5520	5050	5520	4260	3870	3870
10-20	6660	7630	7500	7640	5950	5490	5490
>20	30100	33000	28000	33000	27100	24900	24900
	MacArthur Street Bridge						
0	129	144	108	143	113	110	109
0-5	1581	1900	559	1900	1520	1520	1520
5-10	5820	8400	1660	8400	7530	7510	7560
10-20	16300	18700	2980	18600	17500	17200	17200
>20	84400	86200	18500	86200	83800	84000	84000
	Silverwater Park						
0	60	58	43	52	49	46	41
0-5	619	654	300	489	659	520	371
5-10	1920	2350	759	1370	2080	2020	1150
10-20	4880	5090	1720	3200	4780	4730	2720
>20	14400	15800	6500	13500	15400	15400	12600

24 hour rainfall (mm)	Baseline	BAU 2025	No WWOF	Target WWOF	Medium Intv.	High Intv.	Combo Intv.
				Meadowbank			
0	23	24	19	22	20	19	17
0-5	214	237	145	207	188	175	149
5-10	748	863	525	749	702	657	528
10-20	1510	1555	826	1340	1310	1264	980
>20	12200	13900	5480	12400	12700	12500	11200
				Brays Bay			
0	20	21	19	20	18	17	17
0-5	150	189	137	171	143	135	122
5-10	474	638	498	618	462	433	431
10-20	678	864	774	883	649	605	610
>20	4300	5360	3910	5320	4390	4230	4050
				Kissing Point			
0	6	6	5	6	5	5	4
0-5	45	51	32	46	40	37	32
5-10	170	188	114	160	148	141	114
10-20	364	389	199	357	318	306	261
>20	6160	6920	2610	6320	5870	5710	5220
				Putney Park			
0	4	4	3	4	3	3	3
0-5	30	34	20	28	27	25	20
5-10	111	121	66	99	95	92	71
10-20	254	269	118	234	230	223	174
>20	4560	5150	2000	4860	4420	4230	3820
				Cabarita			
0	2	3	2	2	2	2	2
0-5	19	21	13	17	17	16	12
5-10	64	71	34	51	59	56	38
10-20	166	173	53	121	155	149	96
>20	2590	2960	909	2520	2372	2330	1920
				Quarantine Reserve			
0	2	2	1	2	2	2	1
0-5	21	25	10	14	21	21	11
5-10	95	110	25	48	100	100	37
10-20	204	213	40	96	201	198	78
>20	2020	2320	447	1210	2050	2000	898
				Henley baths			
0	1	2	1	1	1	1	<1
0-5	10	13	7	9	9	9	7
5-10	34	38	19	28	32	30	21
10-20	79	76	30	66	72	70	50
>20	1080	1160	354	939	900	857	647

24 hour rainfall (mm)	Baseline	BAU 2025	No WWOF	Target WWOF	Medium Intv.	High Intv.	Combo Intv.
				Bayview Park			
0	3	4	2	3	4	4	3
0-5	57	75	25	46	64	64	36
5-10	264	359	70	190	317	314	159
10-20	619	727	116	417	675	671	373
>20	4650	6390	813	4230	5960	5890	3860
				Chiswick Baths			
0	1	2	1	1	1	1	1
0-5	16	20	17	19	15	14	13
5-10	52	68	52	66	52	47	45
10-20	89	114	101	113	90	81	79
>20	1080	1480	526	1400	1260	1220	1190
				Callan Park			
0	3	3	2	3	3	2	2
0-5	60	67	47	67	55	51	51
5-10	240	279	171	277	230	215	215
10-20	517	547	403	547	441	414	414
>20	3610	4680	1810	4650	3990	3860	3860
				Dawn Fraser			
0	<1	<1	<1	<1	<1	<1	<1
0-5	5	5	5	5	4	4	4
5-10	16	17	17	17	13	12	12
10-20	23	25	25	25	20	18	18
>20	192	203	198	198	161	148	146

6.2.4 Increase in swimmable days

As an assessment of swimmability, the objective of the modelling is to test intervention scenarios that maximise the number of swimmable days per year as measured by the 95th percentile concentration less than 200 CFU/100mL, and indicate where the greatest benefit could be realised. Table 6-4 gives the number of swimmable days for each scenario for each site. Cells highlighted in red indicate a reduction of the number of swimmable days, and cells highlighted green indicate an increase in the number of swimmable days compared to baseline.

Overall the modelling shows that BAU 2025 conditions either have no impact or slightly decrease the number of swimmable days, but the combined intervention scenario performs the best at increasing the number of swimmable days across the majority of sites, improving on Baseline conditions by up to an additional 9 swimmable days.

The modelling indicates that turning off all overflows impacting the Bayview Park swim site could result in an additional 12 days of swimmability in a year. The targeted overflow scenario does contribute to an improvement in swimmable days at this site, albeit by only an additional 2 days a year. However, there are additional overflows in adjacent subcatchments upstream that are contributing to the higher concentrations observed in the targeted overflow scenario. The feasibility of turning off all overflows impacting Bayview Park is unrealistic but further localised modelling of key overflows may assist in prioritising future infrastructure solutions.

Table 6-4: Comparison of the number of swimmable days for each swim site for each scenario, as measured by the 95th percentile concentration less than 200 CFU/100mL. Cells highlighted in red indicate a reduction of the number of swimmable days, and cells highlighted green indicate an increase in the number of swimmable days compared to baseline. Cells not coloured indicate no change from baseline.

SITE	Baseline	BAU 2025	BAU 2025 + no WWOF	Medium intervention	High intervention	Target WWOF	Combined intervention
Lake Parramatta	357	357	357	357	358	358	358
Little Coogee	216	214	214	214	218	219	219
Parramatta CBD	241	238	238	238	244	246	246
MacArthur St Bdg	302	299	307	300	306	307	307
Silverwater Park	310	311	318	314	315	316	319
Meadowbank	323	321	326	324	325	327	329
Brays Bay	329	326	328	326	330	331	332
Kissing Point	349	348	352	348	350	350	351
Putney Park	354	353	358	353	355	355	355
Cabarita	358	358	362	359	359	359	360
Quarantine Reserve	356	356	363	360	356	356	361
Henley Bath	361	361	363	362	361	362	362
Bayview Park	348	347	360	351	347	348	352
Chiswick Baths	361	359	361	359	361	361	361
Callan Park	337	336	339	336	339	340	340
Dawn Fraser Pool	363	363	364	363	363	363	363

7 Conclusions and Recommendations

An integrated catchment-river modelling framework has been adopted for supporting the Parramatta River Masterplan. This will contribute to an evidence-based strategy that aims to improve the swimmablity of the river by 2025. The modelling framework is comprised of an eWater SOURCE model of the Parramatta River catchments that generates sub-daily Enterococci loads from a variety of urban landuses and source pathways. Wet weather overflows (MOUSE modelling by Sydney Water) provides point-source discharges in the catchment model. Catchment runoff volumes and Enterococci concentrations generated by the SOURCE model are provided as inputs to the RMA modelling suite that simulates the hydrodynamics and Enterococci fate and transport in the Parramatta River. This is the first time combined wastewater and stormwater systems have been modelled in such an integrated way for waterway management in Australia.

The modelling framework has been used to calculate the expected Enterococci 95th percentile concentrations near 16 proposed swimming sites along the river under a range of policy and intervention scenarios that target stormwater harvesting, pet waste control and infrastructure improvements to wet weather overflows. 'Swimmability' in this case is assessed against the NHMRC recreational water quality objectives that relate enterococci 95th percentile concentrations to human health risks. However, it should be noted that 5% of the time (1 in 20) the Enterococci concentration may indicate non-swimmable conditions.

This modelling framework shows that downstream of the MacArthur Street Bridge site, the number of swimmable days can be improved through catchment interventions, despite little change in NHMRC categories of 95th percentile concentrations between intervention scenarios.

The results for sites upstream (excluding Lake Parramatta) indicated that more intensive interventions would be required to reduce the 95th percentile concentrations to a lower risk NHMRC category. This highlights the extent of the existing microbial pollution within the catchment.

The overarching modelling framework provides answers for the following key modelling questions:

What are the major sources of pathogens within the catchment and the risk of non-compliance with regulatory water quality objectives?

The major sources of Enterococci represented in the catchment model include animal faecal deposition (cats, dogs and waterbirds), stormwater runoff from commercial and industrial areas, roads, and direct discharge into the river from wet weather overflows (ERSs). Animal sources and wet weather overflows are dominant contributors to the catchment Enterococci load.

Overall, diffuse sources of enterococci estimated by the model contribute substantially more load to the river (average catchment contribution of 70%) than wet weather overflow sources. For subcatchments that are influenced by both point- and diffuse sources, conjunctive management will be necessary to effectively reduce enterococci loads to the river.

The modelling indicates that the following sites potentially have high risk 95th percentile concentrations above NHMRC guidelines (Category B) for swimmability under any scenario intervention:

- Little Coogee
- Parramatta CBD
- MacArthur street bridge
- Silverwater Park
- Meadowbank

However, 95th percentile concentrations for Parramatta CBD site decreases sufficiently to be within NHMRC Category B under both high and combined catchment intervention scenarios 5 days after rainfall. MacArthur Street Bridge and sites downstream have the potential for 95th percentile concentrations to comply with NHMRC Category A guidelines during dry periods of at least 3 days after rainfall.

The modelling illustrates that rainfall is a significant factor in the variability of 95th percentile concentrations at all sites, and that intervention scenarios can assist in reducing 95th percentiles concentrations in moderate (between 5 – 10 mm rainfall) wet weather conditions.

The modelling demonstrates that diffuse sources and large areas of imperviousness are the main contributors to current high Enterococci loads, and 95th percentile concentrations that result in high human health risk under the NHMRC guidelines. Furthermore, the modelling would benefit from further investigations and field data collection campaigns that better characterise stormwater for human and animal sources.

What is the current trajectory of the water quality considering significant infill development growth underway and planned?

The existing case results demonstrate that there is significant microbial pollution within the River, particularly in the Upper Parramatta catchments. Under BAU 2025 conditions, precinct and infill residential development increases from low density to high density housing, increasing the total subcatchment imperviousness and Enterococci loads on average by 15% across the catchment, exacerbating the existing conditions. In some areas where industrial or commercial land is converted to high density housing, imperviousness decreases resulting in significant decreases in localised Enterococci loads.

All LGAs will experience an increase in loads under BAU 2025 scenario.

The results of the modelling framework demonstrate that policies directed to reducing imperviousness such as permeable paving or increasing infiltration, such as on-site raingardens, would be of benefit to mitigating Enterococci loads.

In which areas could open water (free) swimming be achievable in the Parramatta River by 2025? Where not achievable, what needs to be done to gain water quality objectives?

Downstream of the Kissing Point swim site enterococci concentrations significantly decrease by the tidal flushing of the river and sites have the potential for low risk concentrations in line with Category B NHMRC guidelines (Less than 200 CFU/100mL).

Swim sites in the Upper Parramatta catchments have high risk 95th percentile concentrations above category B NHMRC guidelines, with the exception of Lake Parramatta. The intervention scenarios explored with the modelling do have an impact on reducing enterococci concentrations for these swim sites, but significant additional effort within the catchment would be required to further improve water quality for swimming.

The RMA modelling demonstrates that implementing high level of catchment interventions would potentially improve 95th percentile concentrations to comply with NHMRC Category B guidelines at the Brays Bay swim site.

Overall the modelling shows that the combined intervention scenario performs the best at reducing the number of non-swimmable days across the majority of sites, although only an additional week per year of swimmable conditions are achieved. Addressing overflows further upstream of Bayview Park may further improve swimmable conditions by an additional 2 weeks in a year.

The current modelling explores a number of options for mitigating poor water quality, but there are other options that could be explored within the risk assessment framework, such as establishment of urban riparian buffers, disinfection or addressing sewer leakages (not simulated explicitly in the current model).

In addition, enterococci is only one metric used to assess swimmability. Other factors such as presence of other pathogenic microbial contaminants or accessibility to a site will also contribute to the assessment of a sites suitability for swimming.

What are the quantity and quality improvements gained in the catchment by the implementation of infrastructure, water sensitive urban design and policy solutions to mitigate high risk pathogen contamination sites?

Overall, the catchment intervention options (both medium and high) arrest the trajectory of BAU increased microbial loads entering the river, and in many cases improve on baseline conditions. However, for most areas of the catchment targeting both high level of catchment intervention (high level of stormwater harvesting, biofiltration systems along roads and strong community outreach/education programs) and overflow abatements will be necessary to improved concentrations in the river for the majority of sites.

The intent of this modelling was to give an indication of the potential enterococci levels in broad regions of the river. Where the modelling indicates scenario impacts are small, it is recommended that field studies be conducted to verify the modelling outcomes. Field studies that distinguish between enterococci from animal and leaky sewer sources, in-situ measurements of die-off rates within different regions of the river, and local information on pet and feral dog/cat numbers within the catchment would provide valuable datasets to further refine the modelling. Furthermore, more detailed modelling at specific sites would take into account the effects of stormwater stratification in proximity to nearby ERS outlets, and the effects of sediment resuspension by swimmers, and may improve the 95th percentile concentration estimates to align with localised monitoring data.

Note that the modelling outcomes will inform a benefit/cost analysis that is to be undertaken separately, which will allow prioritisation of swim sites for activation under the Masterplan.

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Appendices

Memorandum

Appendix 1: Technical Memo 1 – Water Quality Targets

30 May 2016

To PRCG Technical Committee			
Copy to			
From Kate Byrnes		Tel	9928 2538
Subject	**Parramatta River Water Quality Modelling** Technical Memorandum 1 – Water Quality Targets	Job no.	IA115600

Purpose of this Technical Memo – Water Quality Targets

The Parramatta River Catchment Group (PRCG) has a vision for making the Parramatta River swimmable by 2025, otherwise known as the 'Our Living River' initiative. The initiative is to provide the planning and implementation of the Parramatta River Masterplan. The Parramatta River Masterplan will identify an evidence based strategy to achieve the PRCG objective of making the river swimmable by 2025.

The Parramatta River Masterplan is supported by the Water Quality Modelling Project, which has the objective of identifying expected microbial levels at 12 nominated swimming sites in the Parramatta River catchment under a range of policy and intervention scenarios. Incorporating a modelling approach in the Masterplan development will help guide microbial water quality evaluation and target setting in order to meet regulatory objectives associated with swimmability.

In order to identify sites suitable for swimming in the Parramatta River, the current microbial concentrations of key indicator species that can affect human health needs to be understood at potential swimming sites. To do this, a water quality model is being developed that will model microbial water quality. A requirement for the model is to provide event mean concentrations (EMCs) and dry weather concentrations (DWCs) for enterococci and E.coli for input into the model and to provide water quality targets to be achieved at swimming sites. The purpose of this technical memo is to provide the approach for deriving these values and to seek endorsement from the technical committee.

Methodology

A number of literature sources were reviewed to identify a range of EMCs and DWCs that could potentially be adopted for the Parramatta River Water Quality Model. Literature sources included:

- Stewart, J (2013) Development of the Sydney Harbour Catchment Model. Report prepared for the Hawkesbury-Nepean Catchment Management Authority.
- Sydney Water (2014) Wet weather Overflow Abatement Project - *Upper Parramatta River Model Calibration Report*
- Sydney Water (2016) Wet weather Overflow Abatement Project – *Lane Cove River (pers comm).*
- Hawkesbury Nepean and South Creek Water Quality modelling project.
- Fletcher et al., (2004) Stormwater Flow and Quality and the effectiveness of non-proprietary stormwater treatment measures 0 a review and gap analysis. Technical Report – Report 04/8. Cooperative Research Centre for Water Quality and Treatment.
- Haydon, S. (2008) Development and Testing of a Coupled Pathogen- Hydrologic Catchment Model. Research Report No 54. Cooperative Research Centre for Water Quality and Treatment.
- Sydney Water Autosampler date for the Upper Parramatta River.

The EMCs and DWCs for a range of landuse types were extracted for enterococci, E. coli and faecal coliforms. Whilst only enterococci and E.coli will be modelled, faecal coliforms concentrations were reviewed as EMCs and DWCs are more widely documented and current water quality data in the Parramatta River infers that there is almost a 1 to 1 ratio between E.coli and faecal coliforms.

From the literature a range of values for different landuses during dry and wet weather have been derived. These are provided in the tables below.

Table 8-1. EMC and DWC for Enterococci (cfu/100mL)

Source	Stewart 2013		Sydney Water 2014 (Upper Parramatta River)		Sydney Water 2016 (Lane Cove River)	
Land use	**EMC**	**DWC**	**EMC**	**DWC**	**EMC**	**DWC**
Bushland	120	20	2,000	100		
Commercial	1,000	260	10,000	2,000		
Industrial	1,000	260	10,000	2,000		
Parkland	120	260	2,000	100		
Railway	1,000	260	10,000	2,000		
Residential	4,000	260	10,000	2,000	20,000	4,000
Roadway	1,000	70	10,000	2,000		
Rural	120	20	2,000	100	4,000	200

The event mean concentrations for enterococci were variable between the literature sources. The concentrations recommended in Stewart 2013 were used in the Sydney Harbour Catchment model which reviewed existing literature for EMCs and DWCs and adjusted accordingly following collation of recorded water quality data. The Enterococci numbers provided by Sydney Water are those that have been used recently for the modelling of the Upper Parramatta and Lane Cove River. Both these models were calibrated against water quality data collected using auto-samplers during events at key locations in the catchments.

Table 2. EMC and DWC for E.coli (cfu/100mL)

Source	Stewart (2013)		Haydon (2008) minimums		Haydon (2008) maximums		Autosampler data
Land use	EMC	DWC	EMC	DWC	EMC	DWC	
Bushland	120	20	51	1	2,000	260	
Commercial	1,000	260					
Industrial	1,000	260					
Parkland	120	260					
Railway	1,000	260					
Residential	4,000	260	270	86	130,000	13,000	26,634
Roadway	1,000	70					
Rural	120	20					

Table 3. EMC and DWC for Faecal coliforms (cfu/100mL)

Source	Stewart (2013)		Hawkesbury-Nepean River Model		Fletcher et al., (2004) Minimums		Fletcher et al., (2004) Typical value		Fletcher et al., (2004) Maximums	
Land use	EMC	DWC	EMC	DWC	EMC	DWC	EMC	DWC	EMC	DWC
Bushland	600	100	600	600	20	3	600	100	20,000	3,000
Commercial	10,000	300	4,000	4,000	300	40	4,000	350	50,000	3,000
Industrial	10,000	300	4,000	4,000	300	40	4,000	350	50,000	3,000
Parkland	600	100			300	40	4,000	350	50,000	3,000
Railway	10,000	100								
Residential	10,000	300	20,000	20,000	2,000	200	20,000	2,500	200,000	30,000
Roadway	10,000	300			1,700	1,700	7,000	7,000	30,000	30,000
Rural	600	100	20,000	20,000	20	3	600	100	20,000	3,000

Tables 2 and 3 provide the EMCs and DWCs from a range of literature sources for E.coli and faecal coliforms. As mentioned previously, Stewart (2013) values are those that were used in the Sydney Harbour Model. Haydon (2008) provided a range of pathogen concentrations for baseflow and event samples across three different catchments. The catchments included a fully forested catchment with no human development (considered as bushland), an open multi use catchment and a small urbanised catchment with high pathogen load (considered as residential). The nominated minimum and maximum values for E.coli have been provided in Table 2. Table 2 and 3 also displays the average E.coli and faecal coliform concentrations collected via auto-samplers in the Parramatta River. Values for faecal coliforms were also obtained from the Hawkesbury-Nepean and South Creek Water Quality model that was developed for Sydney Water. Fletcher et al., (2004) reviewed a range international and local literature and provided typical concentrations for faecal coliforms including a minimum, maximum and 'typical' value for wet and dry weather from a range of landuses.

Whilst landuse (and runoff) are a source of bacterial contamination so too are sewer overflows. Concentrations of enterococci and E.coli in sewer overflows have been adopted from the NHRMC (2008) Guidelines for manaing risks in recreational waters and provided in Table 4.

Table 4. Typical Enterococci and Ecoli numbers in sewage (NHRMC 2008)

Pathogens/indicator organisms	Disease or role	Numbers/100 mL
Bacteria		
Campylobacter spp	Gastroenteritis	10^4–10^5
Clostridium perfringens spores	Indicator	10^4–10^5
Escherichia coli	Indicator (except specific strains)	10^6–10^7
Intestinal enterococci	Indicator	10^5–10^6
Salmonella spp	Gastroenteritis	0.2–8000
Shigella spp	Bacillary dysentery	0.1–1000
Viruses		
Somatic coliphages (viruses to *E. coli*)	Indicator	10^5–10^7
F-RNA coliphages (viruses to *E. coli*)	Indicator	10^4–10^6
Polioviruses	Indicator (vaccine strains) Poliomyelitis	$180 - 5 \times 10^5$
Rotaviruses	Diarrhoea, vomiting	$400 - 8.5 \times 10^4$
Adenoviruses	Respiratory disease, gastroenteritis	not enumerated[a]
Noroviruses[b]	Diarrhoea, vomiting	not enumerated[a]
Hepatitis A	Hepatitis A	not enumerated[a]
Parasitic protozoa[c]		
Cryptosporidium spp oocysts	Diarrhoea	0.1–39
Entamoeba histolytica	Amoebic dysentery	Non-detect–0.4
Giardia lamblia cysts	Diarrhoea	$10–2 \times 10^4$

a Many important pathogens in sewage have yet to be adequately enumerated, such as adenoviruses, noroviruses and hepatitis A virus
b Noroviruses were formerly known as Norwalk viruses
c Parasite numbers vary greatly due to differing levels of endemic disease in different regions

Sources: Höller (1988), Long and Ashbolt (1994), Yates and Gerba (1998), Bonadonna et al (2002), Contreras-Coll et al (2002)

Water quality targets for enterococci and E.coli need to be defined in the model so that recreational suitability at a site can be determined. With a defined target, a range of management and policy scenarios can be modelled to determine if a site is suitable for swimming with respect to bacterial quality. Proposed water quality targets have been recommended following the review the following guidelines and literature sources:

- NHMRC (2008) *Guidelines for Managing Risks in Recreational Waters*
- PCC (2016) *How should recreational water quality in the Parramatta River be assessed? A review of current literature*.
- ANZECC (1992) *Australian Water Quality Guidelines for Fresh and Marine Waters*

The NHMRC (2008) guidelines provide recommended ranges for enterococci as per Table 5.

Table 5. Recommended categories for determining microbial water quality (NHMRC 2008)

Category[a]	95[th] percentile value for intestinal enterococci/ 100 mL (rounded values)	Basis of derivation	Estimation of probability
A	≤40	This value is below the NOAEL in most epidemiological studies.	GI illness risk: < 1% AFRI risk: < 0.3% The upper 95th percentile value of 40/100 mL relates to an average probability of less than one case of gastroenteritis in every 100 exposures. The AFRI burden would be negligible.
B	41–200	The 200/100 mL value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or LOAEL for GI illness and AFRI.	GI illness risk: 1–5% AFRI risk: 0.3–1.9% The upper 95[th] percentile value of 200/100 mL relates to an average probability of one case of gastroenteritis in 20 exposures. The AFRI illness rate would be 19 per 1000 exposures or approximately 1 in 50 exposures.
C	201–500	This represents a substantial elevation in the probability of all adverse health outcomes for which dose–response data are available.	GI illness risk: 5–10% AFRI risk: 1.9–3.9% This range of 95[th] percentile values represents a probability of 1 in 20 to 1 in 10 risk of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI in the range of 19–39 per 1000 exposures or a range of approximately 1 in 50 to 1 in 25 exposures.
D	> 501	Above this level there may be a significant risk of high levels of illness transmission.	GI illness risk: > 10% AFRI risk: > 3.9% There is a greater than 10% chance of illness per single exposure. The AFRI illness rate at the guideline value of 500 enterococci per 100 mL would be 39 per 1000 exposures or approximately 1 in 25 exposures.

The US Environment Protection Agency recommends recreational water quality criteria which were referred to in the recently completed literature review (PCC 2016). The recommended values provided in the review are detailed below.

Analogous to the use of *E. coli* for fresh water quality criteria, the US EPA provides two recommendations for enterococci limits in marine and fresh waters, relating to estimated illness rates of 36/1000 (Recommendation 1) and 32/1000 (Recommendation 2) (US EPA 2012). Recommendation 1 is based on exceeding enterococci densities with a geometric mean of 35 cfu/100 mL or statistical threshold value of 130 cfu/100 mL. Recommendation 2 is based on exceeding enterococci densities with a geometric mean of 30 cfu/100 mL or statistical threshold value of 110 cfu/100 mL.

The ANZECC (1992) guidelines which recommended values for faecal coliforms for assessing suitability for recreation have been referred to for nominating E.coli targets. This information is displayed below.

- *150 faecal coliform organisms/100 mL (minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less than 600 organisms/100 mL);*

Recommended EMCs, DWCs and water quality targets.

Following the review of the abovementioned literature, the EMCs and DWCs for enterococci and E.coli recommended for use in the Parramatta River Water Quality Model are provided in Table 6. Endorsement of these concentrations is required by the technical committee.

The enterococci values recommended for use are those derived from the Upper Parramatta River Model (Sydney Water 2014) (Table 6). The reasoning for use of these values over those recommended by Stewart (2013) are that the enterococci values in Stewart (2013) are very different to measured data, and the Upper Parramatta River is considered a well calibrated model.

The E.coli EMC for urban landuse is derived from measured data (average of autosampler data from 4 sites used to calibrate the Upper Parramatta River Model) (Table 6). The E.Coli non-urban EMC was calculated as 20% of the urban EMC (based on the ratio applied between urban and non-urban EMCs in the Upper Parramatta River Model). The E.coli DWC for urban landuse is derived from the residential 'typical' value recommended in Fletcher (2004). The non-urban landuse E.Coli DWC has been calculated as 5% of the Urban DWC (based on the same urban and non-urban ratio applied in the Upper Parramatta River Model). The proposed EMCs for E.coli are annotated into Figure 1 which provides summary of faecal coliforms EMCs for different landuses (Fletcher et al., 2004).

Table 6. Recommended EMCs and DWCs for use in the Parramatta River Water Quality Modelling

	Enterococci (cfu/100mL)		E coli (cfu/100mL)	
Land use	**EMC**	**DWC**	**EMC**	**DWC**
Urban	10000	2000	26634	2500
Non-Urban	2000	100	5326	125
Sewer	1,000,000	0	10,000,000	0

The Upper Parramatta River model applied an EMC for sewer of 1,000,000cfu/100mL which will be adopted for this project. This EMC the upper limit of the range recommended by NHRMC (2008) (refer table 4). Therefore the upper limit of the range for E.coli being 10,000,000cfu/100ml is also proposed to be adopted.

These nominated values can be modified within the model if required.

The proposed water quality targets to be adopted in the model are those recommended by NHRMC (2008) for enterococci (<40cfu/100ml) and ANZECC (1992) for E.coli (<150 cfu/100mL).

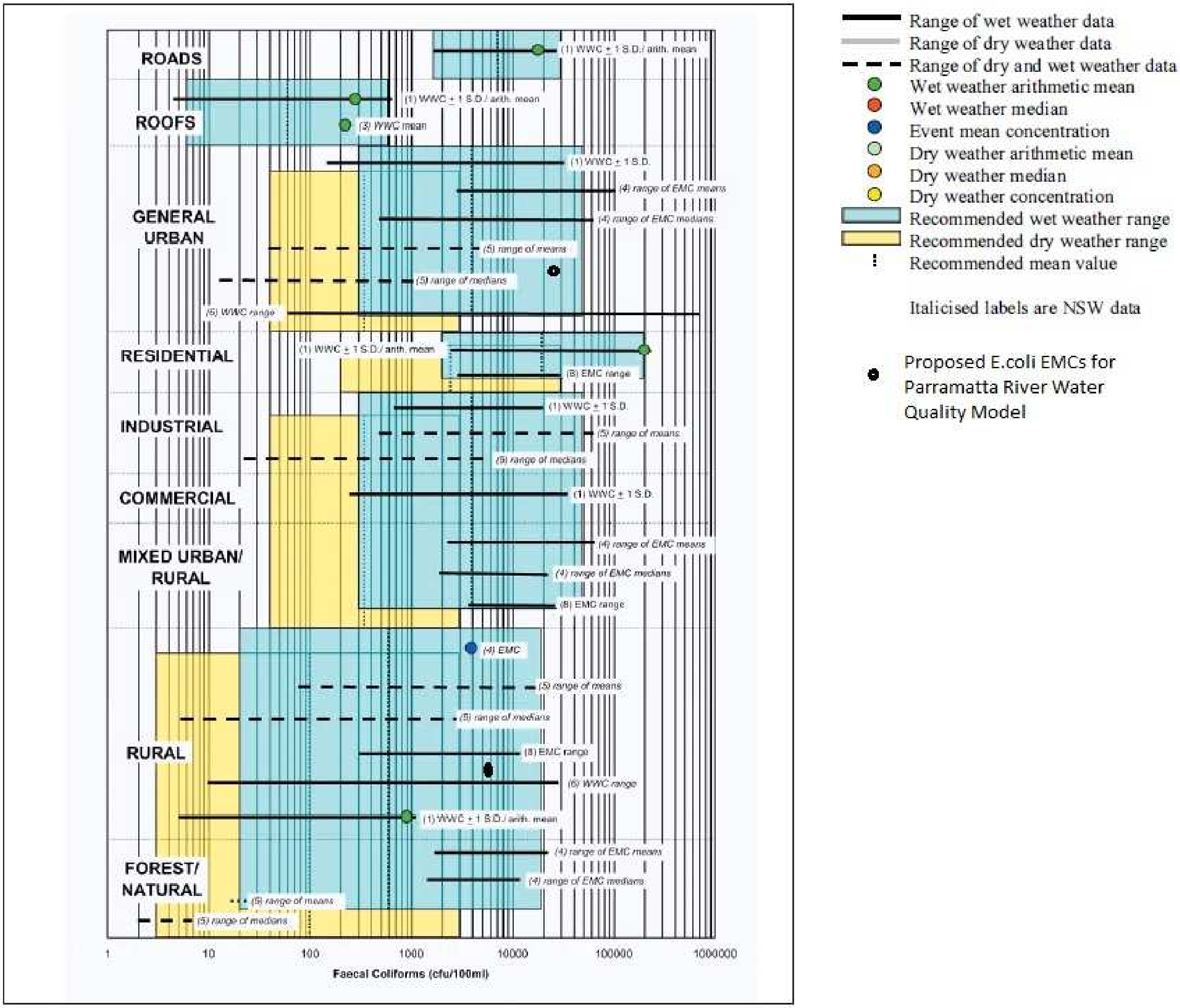

Figure 2.9 Summary of Faecal Coliforms (cfu) with Respect to Land-use (refer to legend in Figure 2.5). Shaded boxes represent recommended range; recommended mean represented by vertical dashed line. (reference source in brackets)

Figure 1. Proposed E.coli EMCs annotated onto faecal coliform concentrations (source Fletcher et al., 2004).

Memorandum

Appendix 2: Technical Memo 2 – Scenario Workshop

02 August 2016

To PRCG Technical Committee			
Copy to			
From Phil Pedruco		Tel	8668 3469
Subject	**Parramatta River Water Quality Modelling** Technical Memorandum 2 – Scenario Workshop	Job no.	IA115600

Background

The Parramatta River Water Quality modelling project aims to develop an evidence base to investigate the swimmability of the Parramatta River both now in the future. This will be achieved by the development of an integrated modelling framework as illustrated in Figure 8.1. This model together with data collected by Sydney Water and other government agencies will be used to calculate Enterococci levels now and also in the future under a range of scenarios.

The scenarios to be investigated in the model were developed in conjunction with the Parramatta River Catchment Group and a number of stakeholders. This memo outlines the development of these scenarios.

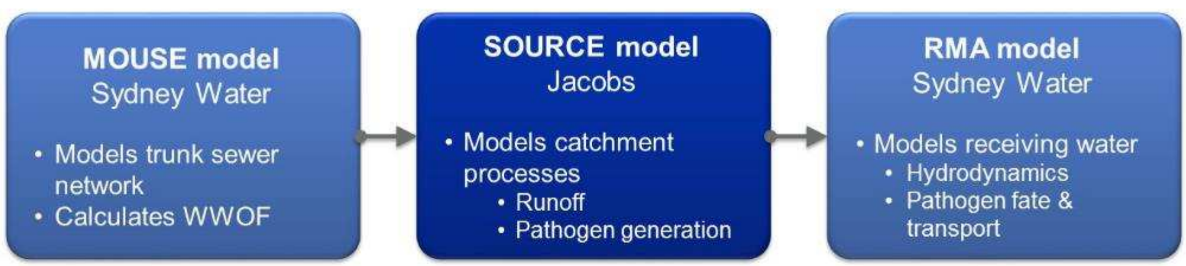

Figure 8.1: Integrated modelling framework

Aims

The aim of this memo is to document the outcomes of the Water Quality Modelling Workshop 2- Scenario Development Parramatta River Masterplan. The purpose of this workshop was to develop a number of options to reduce pathogen concentrations in the Parramatta River with the aim of opening swimming sites. Specifically, this memo will outline:

- A set of criteria to assess proposed options against
- A long list of possible options to improve the water quality of Parramatta River
- A list of options to be modelled in the integrated modelling framework

- A set of three Scenarios that are (potentially) a combination of different options

Criteria

Attendees at the workshop were asked to develop a set of criteria to assess options against. Those options that performed well against the criteria were then developed into scenarios; that is, criteria were used to reduce a long list of options into short list. These short listed options were then developed into scenarios to be modelled.

All criteria listed by workshop participants were collated and similar criteria were grouped together. These criteria were then categorised into:

- Core Criteria,
- Secondary Criteria; and
- Site Specific.

Core Criteria are those that are essential to achieve for the desire outcomes (lower pathogen levels). Secondary Criteria are those that would enhance the outcomes of the project. Site Specific Criteria are those that need to be applied on a site by site basis. A number of suggested criteria involve the timing and phasing of potential works. While these criteria are important in terms of delivering options they are not as important during the optioneering stage.

The resulting criteria are listed under the appropriate heading below and one of the criteria lists developed at the workshop is shown in Figure 8.2.

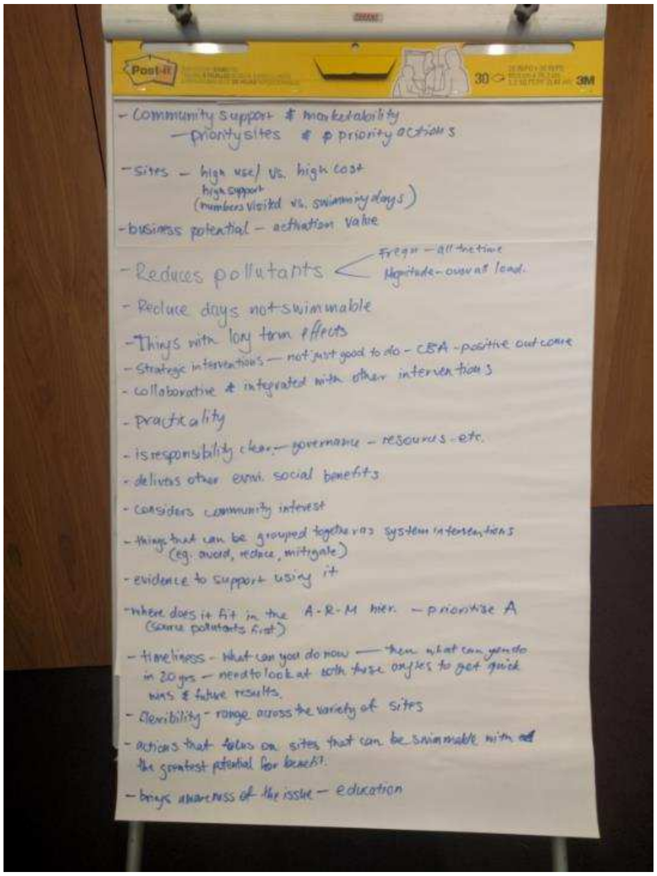

Figure 8.2: Criteria list developed by workshop attendees

Core criteria

1. Reduces pollutant loads
    1.1. Reduces pollutants – in terms of both frequency and magnitude
    1.2. Increases swimmable days
2. Is practical
    2.1. Is the option feasible?
    2.2. Flexibility – the option can be applied across a range across a variety of sites
    2.3. Actions that are focused on site that can be made swimmable first
    2.4. Has long term benefits
    2.5. Account for new and existing issues
3. Is economic
    3.1. CBA positive outcome
    3.2. Is the option affordable
    3.3. Evidence to support using it

Secondary criteria

1. Has co-benefits
    1.1. Collaborative and integrative with other interventions
    1.2. Delivers other environmental and social benefits
    1.3. Considers community interests
    1.4. Brings awareness of the issue (educate)
2. Timing - Timeliness
    2.1. What can be done now
    2.2. What can / needs to be done in the future
    2.3. What timescale?

Site specific

1. Sites – high use versus high cost
    1.1. High support
    1.2. Number of visits versus swimming days
2. Business potential – attraction value
3. Community support and marketability – priority sites and actions

Long List of Options

No.	Intervention	Scale	Type	Approach	Type of develop ment	Reduces pollutant loads	Feasible	Flexible	Long Term Benefits	Cost	Has co-benefits	Timing	Further Consideration for Modelling
1	Ban wet wipes (and similar)	Source	Avoid	Awareness	Existing	Minor	Yes	Yes	Yes	$	Yes	Short	Yes
2	Pet waste - manage at home and well as when walking	Source	Reduce	Awareness	Existing	Moderate	Yes	Yes	Yes	$	Yes	Short	Yes
3	Pet waste - park infrastructure	Source	Reduce	Engineering	Existing	Moderate	Yes	No	Yes	$	Yes	Short	Yes
4	Pet waste - Off-lesh parks proximity to watercourses	Source	Mitigate	Planning	Existing	Moderate	Yes	No	Yes	$	No	Short	Yes
5	Fix illegal connections	Source	Avoid	Engineering	Existing	Minor	Yes	Yes	Yes	$$	No	Medium	No
6	Leakage from private connections	Local	Avoid	Engineering	Existing	Major	Yes	Yes	Yes	$$$	No	Medium	Yes
7	Reline all of the waste water pipes	Regional	Avoid	Engineering	Existing	Major	No	Yes	Yes	$$$	Yes	Long	Yes
8	Higher standard of wastewater network	Local	Avoid	Engineering	New	Major	Yes	Yes	Yes	$$	Yes	Long	No
9	Leachate from landfill	Source	Reduce	Engineering	Existing	Minor	No	No	Yes	$$	No	Long	No
10	Upgrade sewer network WWOF	Regional	Reduce	Engineering	Existing	Moderate	Yes	No	Yes	$$$	No	Medium	Yes
11	Restore riparian vegetation	Local	Mitigate	Planning	Existing	Moderate	Yes	Yes	Yes	$$	Yes	Long	Yes
12	Concrete channel restoration – naturalisation	Local	Reduce	Engineering	Existing	Moderate	Yes	Yes	Yes	$$	Yes	Medium	Yes
13	WSUD - site level	Source	Reduce	Planning	New	Moderate	Yes	Yes	Yes	$$	Yes	Long	Yes

No.	Intervention	Scale	Type	Approach	Type of develop ment	Reduces pollutant loads	Feasible	Flexible	Long Term Benefits	Cost	Has co-benefits	Timing	Further Consideration for Modelling
14	WSUD - regional wetlands	Local	Reduce	Engineering	Existing	Moderate	Yes	Yes	Yes	$	Yes	Medium	Yes
15	WSUD - streetscape	Local	Reduce	Engineering	Existing	Moderate	Yes	Yes	Yes	$$	Yes	Long	Yes
16	Risk management signage at swim sites	Local	Avoid	Planning	Existing	None	Yes	No	Yes	$	No	Short	No
17	Contaminated sediments				Existing	Moderate	No	Yes	Yes	$$	Yes	Medium	No
18	Implement Riverwatch monitoring program	Regional	Mitigate	Planning		None	Yes	Yes	Yes	$$	No	Short	No
19	Reduce number of sites					None	Yes	Yes	No	$	No	Short	No
20	Planning - District plans	Regional	Mitigate	Planning	New	Major	Yes	Yes	Yes	$	Yes	Long	No
21	Developer contributions to Regional Water Quality interventions	Regional	Mitigate	Planning	New	Moderate	Yes	Yes	Yes	$	Yes	Long	No
22	Using District Plan framework of Blue/Green grid to treat water in wetlands / street scape systems etc.	Regional	Mitigate	Planning	New	Moderate	Yes	Yes	Yes	$$$	Yes	Long	No
23	Metropolitan Greenspace program to fund Blue/Green infrastructure	Regional	Mitigate	Planning	New	Moderate	Yes	Yes	Yes	$	Yes	Long	No
24	Ensure planning investments across	Regional	Mitigate	Planning	New	Moderate	Yes	Yes	Yes	$$	Yes	Long	No

No.	Intervention	Scale	Type	Approach	Type of develop ment	Reduces pollutant loads	Feasible	Flexible	Long Term Benefits	Cost	Has co-benefits	Timing	Further Consideration for Modelling
	the catchment have consistent water principles												
25	New development precincts have net zero water discharge due to recycling (harvesting/disposal) requirements in regional planning	Regional	Mitigate	Planning	New	Moderate	Yes	Yes	Yes	$$	Yes	Long	No
26	Management of illegal discharges from developments - construction phase	Regional	Mitigate	Planning	New	Minor	Yes	Yes	No	$	Yes	Long	No

Appendix 3: Microbial Sources Bibliography

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Appendix 4: MUSIC parameters and assumptions

Recommended Climatic data according to NSW MUSIC Modelling guidelines:

Central and Eastern Sydney: Sydney Meteorological Office: 5/1/1962 – 31/12/1966

Approximate Mean Annual Rainfall Volume: 1300mm

Used: SYDNEY AIRPORT AMO 6min Rainfall. Assessed 10 year ranges and selected one where the mean annual rainfall is +/- 10% of the approximate mean annual rainfall for Sydney Meteorological Office, as recommended by the NSW MUSIC Modelling Guidelines.

- 1969 – 1979 Mean Annual Rainfall Volume: 1261mm

Sydney Monthly Areal potential evapotranspiration (PET) from MUSIC

MUSIC Assumptions (based on NSW MUSIC Modelling Guidelines):

- Total area per land type = 1 hectare
- Soil Storage Capacity: 170mm
- Initial Storage (% of capacity): 30%
- Field Capacity: 70mm

Land Type	% Impervious (BASIX)	Land/ Node Type	% breakdown (BASIX)	Zoning/ Surface Type MEDIUM SCENARIO	Final Area MEDIUM	Zoning/ Surface Type HIGH SCENARIO	Final Area HIGH	Treatment Type
Residential Low Density	62% (0.62 ha)	Roof	45% (0.279 ha)	Roof, 100% Impervious	0.140ha	Roof, 100% Impervious	0.251ha	Rainwater Tank
				50% of roof connected to tank – 0.140ha		90% of roof connected to tank – 0.251ha		
				50% of roof not connected – 0.140ha	0.140ha	10% of roof not connected – 0.028 ha	0.028 ha	None
		Impervious	55% (0.341 ha)	100% Impervious 50% EIA – 0.171 ha	0.170 ha	100% Impervious 50% EIA – 0.171 ha	0.170 ha	None
				50% not connected – 0.171 ha – as 100% pervious	-	50% not connected – 0.171 ha – as 100% pervious	-	None

Land Type	% Impervious (BASIX)	Land/ Node Type	% breakdown (BASIX)	Zoning/ Surface Type MEDIUM SCENARIO	Final Area MEDIUM	Zoning/ Surface Type HIGH SCENARIO	Final Area HIGH	Treatment Type
	38% (0.38ha)	Pervious	100% (0.380 ha)	Residential, 100% Pervious 0.380 + 0.171 = 0.551	0.550 ha	Residential, 100% Pervious 0.380 + 0.171 = 0.551	0.550 ha	None
Residential Medium Density	73% (0.73 ha)	Roof	60% (0.438 ha)	Roof, 100% Impervious 50% of roof connected to tank – so 0.219 ha	0.219 ha	Roof, 100% Impervious 90% of roof connected to tank – 0.394ha	0.394ha	Rainwater Tank
				50% of roof not connected – 0.219ha	0.219ha	10% of roof not connected – 0.044 ha	0.044 ha	None
		Impervious	40% (0.292 ha)	100% Impervious 50% EIA – 0.146 ha	0.146 ha	100% Impervious 50% EIA – 0.146 ha	0.146 ha	None
				50% not connected – 0.146 ha – as 100% pervious	-	50% not connected – 0.146 ha – as 100% pervious	-	None
	27% (0.27ha)	Pervious	100% (0.270 ha)	Residential, 100% Pervious 0.270 + 0.146 = 0.416	0.416 ha	Residential, 100% Pervious 0.270 + 0.146 = 0.416	0.416 ha	None
Residential High Density	80% (0.80 ha)	Roof	70% (0.560 ha)	Roof, 100% Impervious 50% of roof connected to tank – 0.280ha	0.280ha	Roof, 100% Impervious 90% of roof connected to tank – 0.504 ha	0.504 ha	Rainwater Tank
				50% of roof not connected – 0.280ha	0.280ha	10% of roof not connected – 0.056 ha	0.056 ha	
		Impervious	30% (0.240 ha)	100% Impervious 50% EIA – 0.120 ha	0.120 ha	100% Impervious 50% EIA – 0.120 ha	0.120 ha	None
				50% not connected – 0.120 ha – as 100% pervious	-	50% not connected – 0.120 ha – as 100% pervious	-	

Land Type	% Impervious (BASIX)	Land/ Node Type	% breakdown (BASIX)	Zoning/ Surface Type MEDIUM SCENARIO	Final Area MEDIUM	Zoning/ Surface Type HIGH SCENARIO	Final Area HIGH	Treatment Type
	15% (0.20ha)	Pervious	100% (0.200 ha)	Residential, 100% Pervious 0.200 + 0.120 = 0.320	0.320 ha	Residential, 100% Pervious 0.200 + 0.120 = 0.320	0.320 ha	None
Roads	75% (0.75ha)	Combined	75% IMP	Road, 75% Impervious				Bioretention
Commercial	95% (0.95ha)	Roof	50% (0.475 ha)	Roof, 100% Impervious 50% of roof connected to tank – 0.238 ha	0.238 ha	Roof, 100% Impervious 90% of roof connected to tank – 0.428 ha	0.428 ha	Rainwater Tank
				50% of roof not connected – 0.238 ha	0.238 ha	10% of roof not connected – 0.048ha	0.048ha	
		Impervious	50% (0.475 ha)	Commercial, 100% Impervious 80% EIA – 0.190 ha	0.190 ha	Commercial, 100% Impervious 80% EIA – 0.190 ha	0.190 ha	None
				20% not connected – 0.095 ha – as 100% pervious	-	20% not connected – 0.095 ha – as 100% pervious	-	
		Pervious	100% (0.050 ha)	Commercial, 100% Pervious 0.050 + 0.095 = 0.145 ha	0.145 ha	Commercial, 100% Pervious 0.050 + 0.095 =	0.145 ha	None
Industrial	90% (0.90ha)	Roof	60% (0.540 ha)	Roof, 100% Impervious 50% of roof connected to tank – 0.270 ha	0.270 ha	Roof, 100% Impervious 90% of roof connected to tank – 0.488 ha	0.468 ha	Rainwater Tank
				50% of roof not connected – 0.270 ha	0.270 ha	10% of roof not connected – 0.054ha	0.054ha	
		Impervious	40% (0.360 ha)	Commercial, 100% Impervious 90% EIA – 0.324 ha	0.324 ha	Commercial, 100% Impervious 90% EIA – 0.324 ha	0.324 ha	None

Land Type	% Impervious (BASIX)	Land/ Node Type	% breakdown (BASIX)	Zoning/ Surface Type MEDIUM SCENARIO	Final Area MEDIUM	Zoning/ Surface Type HIGH SCENARIO	Final Area HIGH	Treatment Type
				20% not connected – 0.095 ha – as 100% pervious	-	20% not connected – 0.095 ha – as 100% pervious	-	
		Pervious	100% (0.100 ha)	Commercial, 100% Pervious 0.100 + 0.036 = 0.136	0.136 ha	Commercial, 100% Pervious 0.100 + 0.036 = 0.136	0.136 ha	None

Water Demand Modelled – Residential

- Medium Intervention Scenario – assumes re-use for toilet flushing and garden watering
- High Intervention Scenario – assumes re-use for toilet flushing, garden watering and washing machine use

Toilet flushing water use *(source: Melbourne Residential Water Use Studies):*

- 3.3 flushes/pp/day
- Average toilet flush volume – 5.8 l/flush

Outdoor use *(source: Sydney Water Water Use model):*

- Average volume used for irrigation per day: 334 l/d = 122 kL/yr
- Average use of 651 l/week on garden = 34 kL/yr if water saving measures are implemented
- Average use of 1116 l/week on garden = 58 kL/yr if no water saving measures are implemented
- Summer water use: watering 2 times a week for 61 minutes/day using 6.3 l/min = 39.312 kL/yr = 0.108 kL/day

Laundry *(source: Sydney Water Water Use model):*

- Average of 4.6 loads per week
- Average of 85 l/load used = 391 l/week = 20332 l/year = 20.33 kL/year = 0.0559 kL/d

	Low Density Development	Medium Density Development	High Density Development
Description and assumptions	House on >500 m² sized lot	Townhouses on 200-300 m² lots	Apartment building. 4 storeys; each apartment 100 m. Building takes up 1/3rd of total lot
Number of houses/apartments	20	40	130
No. of people/household (based on ABS population data)	3.0	2.8	2.5
Number of Tanks	20	40	130
Demand Per All Tanks (kL/d) Medium	0.282 Total of 5.64 kL/d/20 tanks	0.162 Total of 6.48 kL/d/40 tanks	0.156 Total of 20.28 kL/d/130 tanks
Demand Per All Tanks (kL/d) High	0.382 Total of 7.64 kL/d/20 tanks	0.241 Total of 9.64 kL/d/40 tanks	0.214 Total of 27.82 kL/d/130 tanks
Size of tank	6kL	3 kL	1 kL

Final Water Use:

Total Household Demand – kL/d (kL/yr)	Low Density Development	Medium Density Development	High Density Development
Toilet Flushing	0.057 (20.8)	0.054 (19.7)	0.048 (17.5)
Outdoor Use	0.23 (82.1)	0.11 (39.4)	0.11 (39.4)
Laundry	0.10 (36.9)	0.08 (28.8)	0.06 (21.2)
TOTAL MEDIUM	**0.28 (102.9)**	**0.16 (59.1)**	**0.16 (56.9)**
TOTAL HIGH	**0.38 (139.4)**	**0.24 (88.0)**	**0.21 (78.9)**

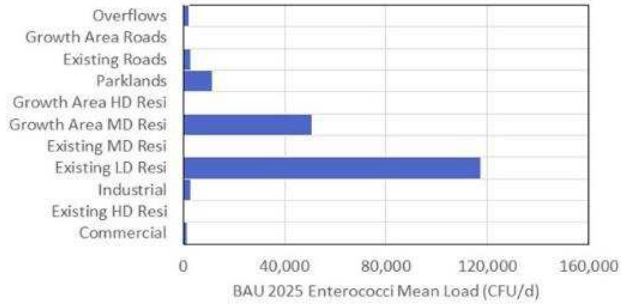
Water Demand Modelled – Commercial & Industrial

- Medium Intervention Scenario – assumes re-use for toilet flushing only. 50% of shops/industry buildings have tanks.
- High Intervention Scenario – assumes re-use for toilet flushing only. 75% of shops/industry buildings have tanks.
- Toilet flushing - 3.3 flushes/per person/day; 5.8 litres/flush

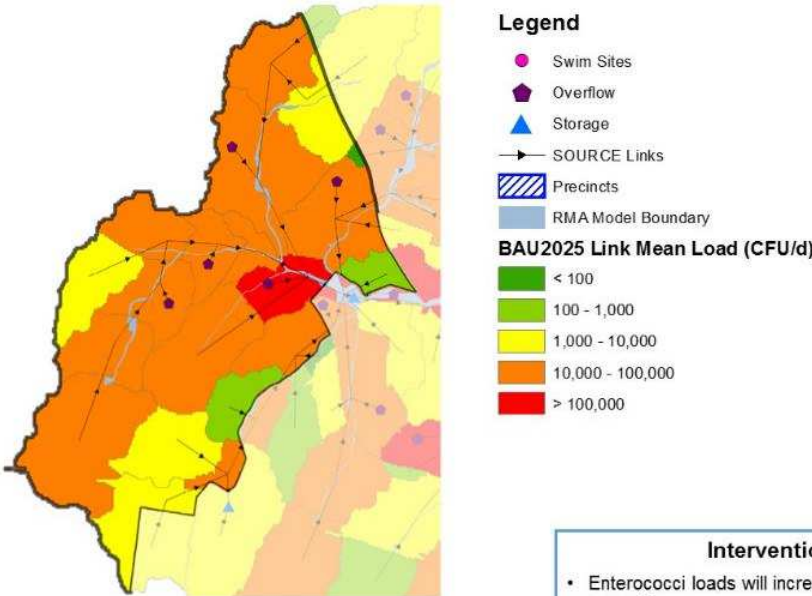
	Commercial – MEDIUM	Commercial – HIGH
Description and assumptions	Assume 50% of 1ha is shops and 50% is carpark	Assume 50% of 1ha is shops and 50% is carpark
Number of shops	Assume each shop 100 m^2 -> so 50 shops	Assume each shop 100 m^2 -> so 50 shops
No of people/shop	2 people	2 people
Size of tank	2 kL	2 kL
Number of Tanks	25 (50% of shops have a tank)	38 (75% of shops have a tank)
Demand Per All Tanks (kL/d)	0.0383 kL/d * 25 tanks - Total of 0.958 kL/d/25 tanks	0.0383 kL/d * 38 tanks - Total of 1.455 kL/d/38 tanks
	Industrial – MEDIUM	**Industrial – HIGH**
Description	Assume 60% of 1ha is industry and 40% is carpark	Assume 60% of 1ha is industry and 40% is carpark
Number of industry shops	Assume each shop 500 m^2 -> so 6,000 m^2/500 = 12 shops	Assume each shop 500 m^2 -> so 6,000 m^2/500 = 12 shops
No of people/shop	5 people	5 people
Size of tank	4 kL	4 kL
Number of Tanks	6 (50% of shops have a tank)	9 (75% of shops have a tank)
Demand Per All Tanks (kL/d)	0.0957 kL/d * 6 tanks -Total of 0.574 kL/d/6 tanks	0.0957 kL/d * 9 tanks - Total of 0.861 kL/d/9 tanks

Appendix 5: LGA Summaries

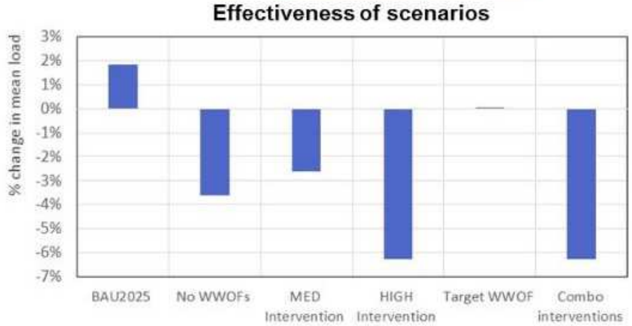
BLACKTOWN LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
  - From pet waste in residential areas
  - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
  - This provides an estimate of the cumulative loads within the river network



Effectiveness of scenarios



Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

- Enterococci loads will increase slightly under BAU 2025 scenario
- Catchment intervention scenarios will arrest future loads, and improve on current loads

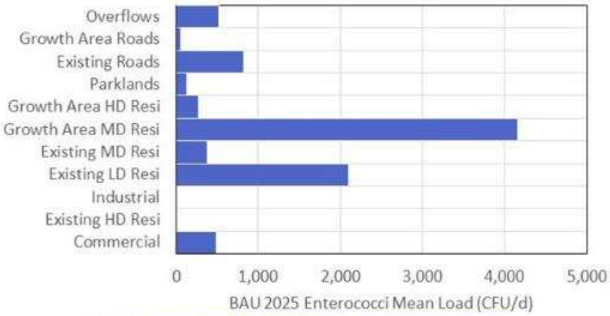
Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

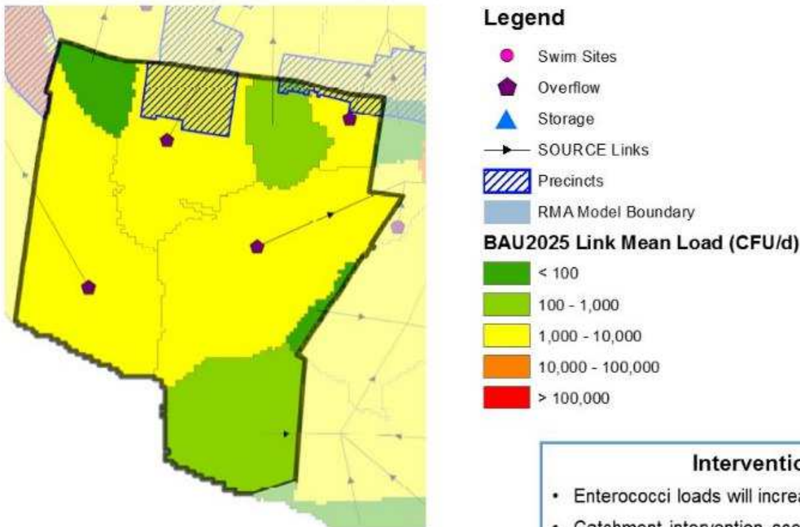
Target WWOF
- Highest discharging overflows remediated (No target WWOFs selected in this LGA)

Combined Intervention
- High intervention scenario + target WWOF

BURWOOD LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
    - From pet waste in residential areas
    - Growth areas
    - Established roads
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
    - This provides an estimate of the cumulative loads within the river network



Intervention Options

- Enterococci loads will increase under BAU 2025 scenario
- Catchment intervention scenarios will slightly reduce future loads,
- Addressing overflow discharge will reverse trajectory of current loads

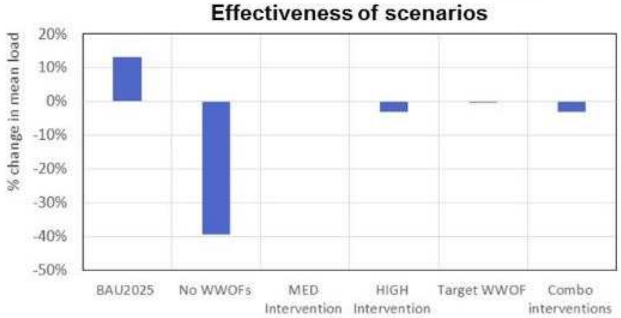
Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

Target WWOF
- Highest discharging overflows remediated (No target WWOFs selected in this LGA)

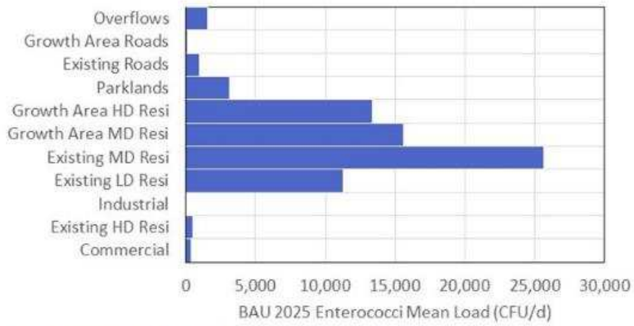
Combined Intervention
- High intervention scenario + target WWOF

Effectiveness of scenarios

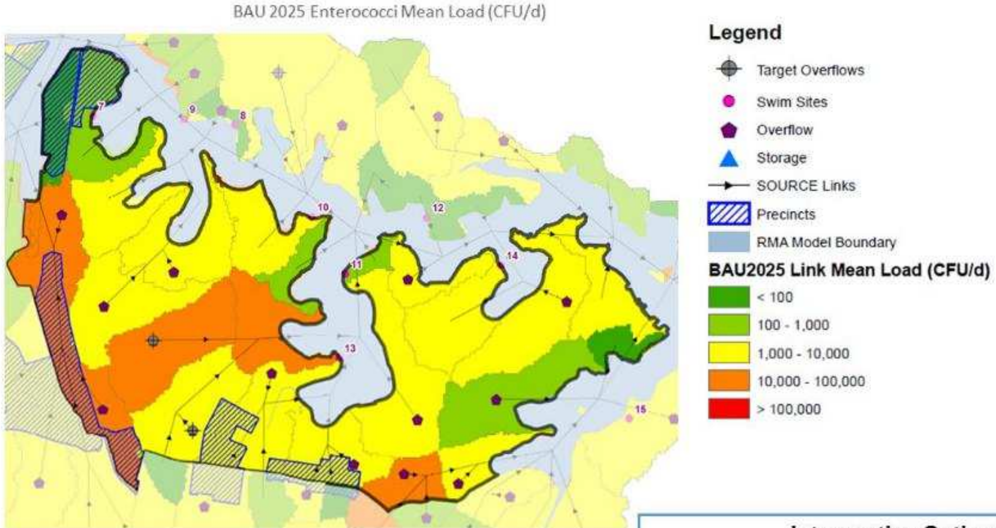


Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

CANADA BAY LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
  - From pet waste in residential areas
  - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
  - This provides an estimate of the cumulative loads within the river network



Intervention Options

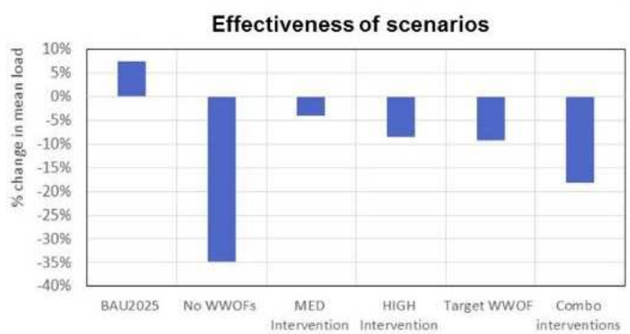
- Enterococci loads will increase slightly under BAU 2025 scenario
- Catchment intervention scenarios will reduce future loads, and improve on baseline conditions

Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

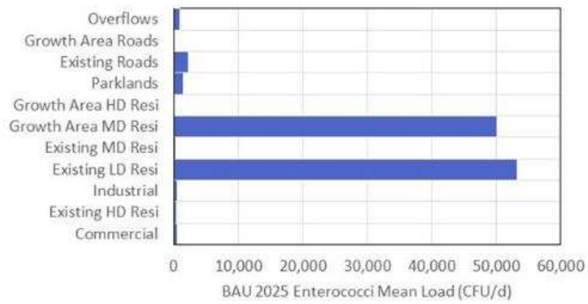
Target WWOF
- Highest discharging overflows remediated

Combined Intervention
- High intervention scenario + target WWOF

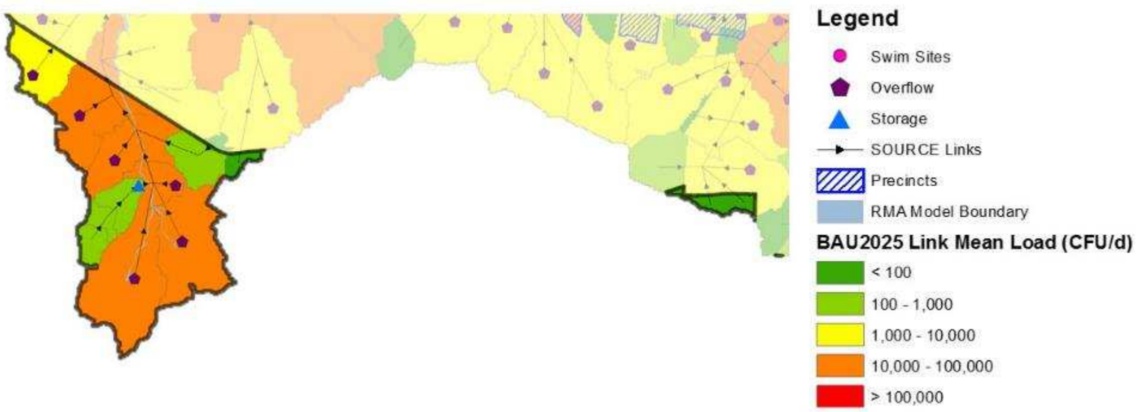


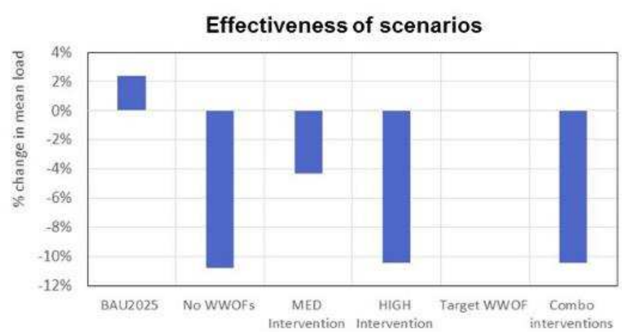
Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

CANTERBURY-BANKSTOWN LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
    - From pet waste in residential areas
    - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
    - This provides an estimate of the cumulative loads within the river network





Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

- Enterococci loads will increase slightly under BAU 2025 scenario
- Catchment intervention scenarios will reduce future loads, and substantially improve on baseline conditions

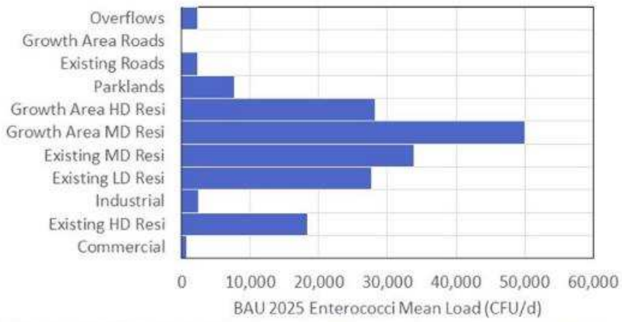
Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

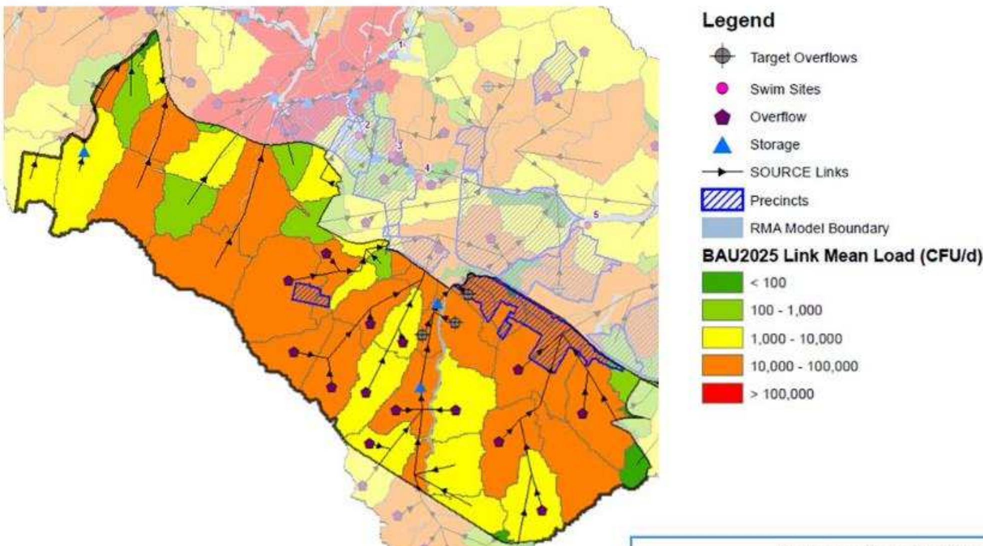
Target WWOF
- Highest discharging overflows remediated

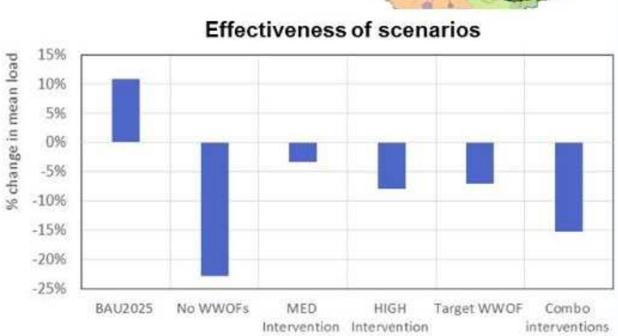
Combined Intervention
- High intervention scenario + target WWOF

CUMBERLAND LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
  - From pet waste in residential areas
  - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
  - This provides an estimate of the cumulative loads within the river network





Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

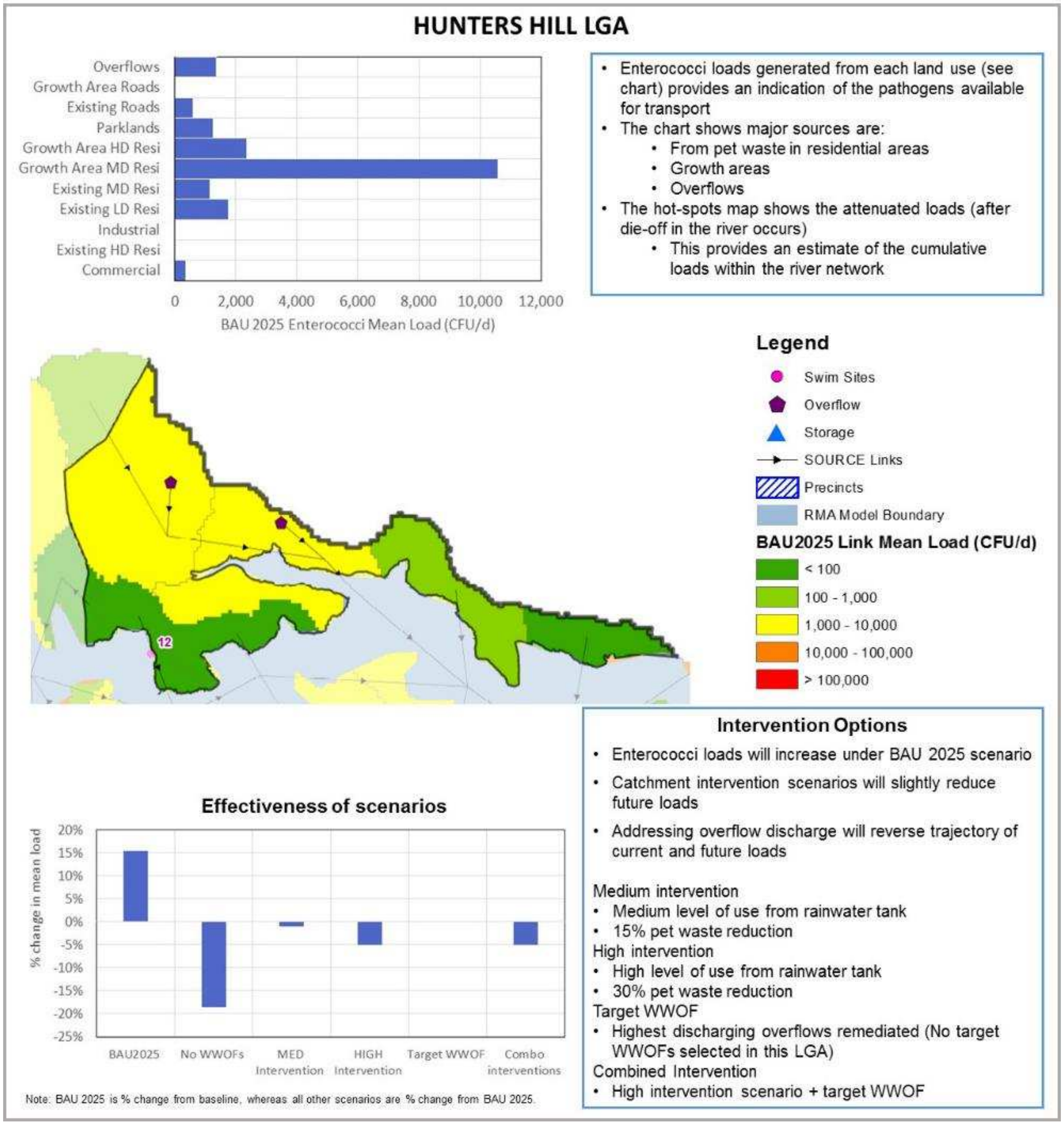
- Enterococci loads will increase under BAU 2025 scenario
- Catchment intervention scenarios will reduce future loads, and substantially improve on baseline conditions

Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

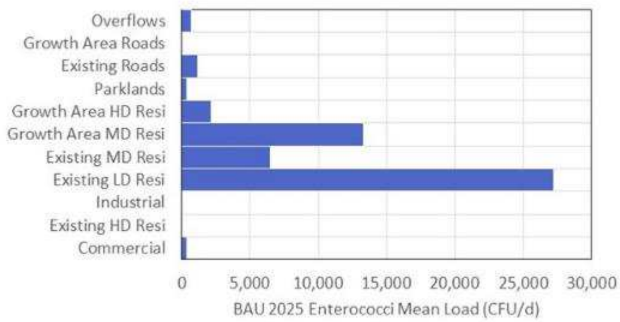
High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

Target WWOF
- Highest discharging overflows remediated

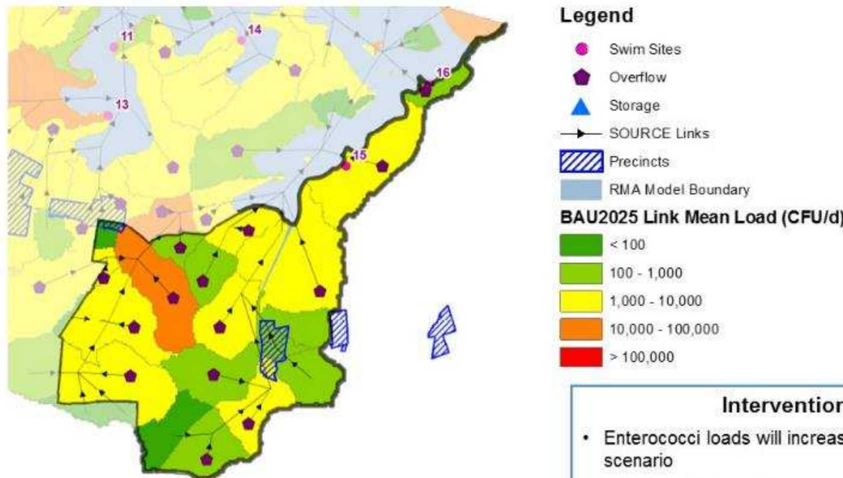
Combined Intervention
- High intervention scenario + target WWOF


HUNTERS HILL LGA
Overflows
Growth Area Roads
Existing Roads
Parklands
Growth Area HD Resi
Growth Area MD Resi
Existing MD Resi
Existing LD Resi
Industrial
Existing HD Resi
Commercial
0 2,000 4,000 6,000 8,000 10,000 12,000
BAU 2025 Enterococci Mean Load (CFU/d)
• Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
• The chart shows major sources are:
• From pet waste in residential areas
• Growth areas
• Overflows
• The hot-spots map shows the attenuated loads (after die-off in the river occurs)
• This provides an estimate of the cumulative loads within the river network
Legend
Swim Sites
Overflow
Storage
SOURCE Links
Precincts
RMA Model Boundary
BAU2025 Link Mean Load (CFU/d)
< 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
> 100,000
12
Intervention Options
• Enterococci loads will increase under BAU 2025 scenario
• Catchment intervention scenarios will slightly reduce future loads
• Addressing overflow discharge will reverse trajectory of current and future loads
Medium intervention
• Medium level of use from rainwater tank
• 15% pet waste reduction
High intervention
• High level of use from rainwater tank
• 30% pet waste reduction
Target WWOF
• Highest discharging overflows remediated (No target WWOFs selected in this LGA)
Combined Intervention
• High intervention scenario + target WWOF
Effectiveness of scenarios
% change in mean load
20% 15% 10% 5% 0% -5% -10% -15% -20% -25%
BAU2025
No WWOFs
MED Intervention
HIGH Intervention
Target WWOF
Combo interventions
Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

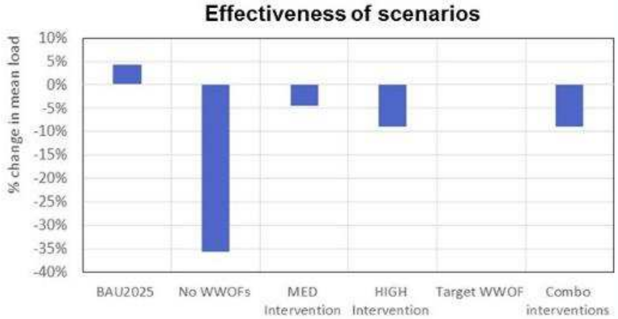
INNER WEST LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
    - From pet waste in residential areas
    - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
    - This provides an estimate of the cumulative loads within the river network



Effectiveness of scenarios



Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

- Enterococci loads will increase slightly under BAU 2025 scenario
- Catchment intervention scenarios will reduce future loads, and improve on baseline conditions
- Addressing overflow discharge will substantially reduce loads

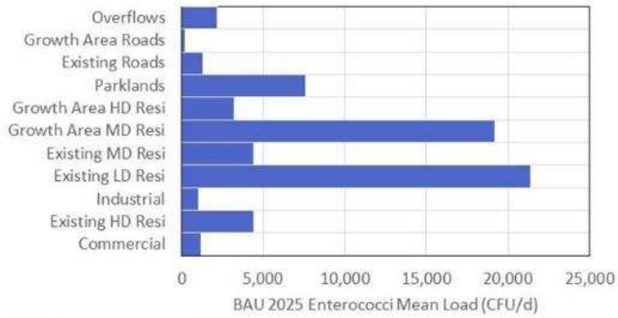
Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

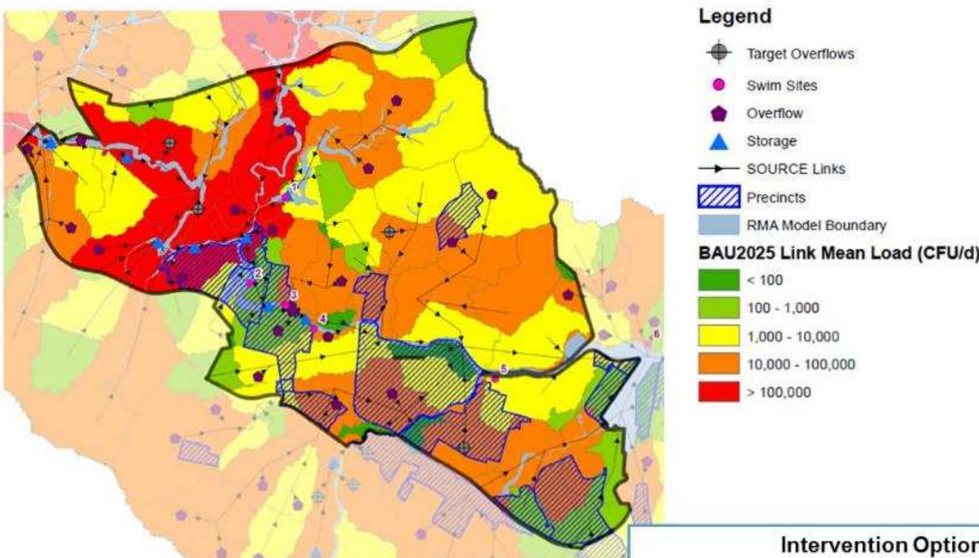
Target WWOF
- Highest discharging overflows remediated (No target WWOFs selected in this LGA)

Combined Intervention
- High intervention scenario + target WWOF

PARRAMATTA CITY LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
    - From pet waste in residential areas
    - Growth areas
    - Parklands
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
    - This provides an estimate of the cumulative loads within the river network



Intervention Options

- Enterococci loads will increase under BAU 2025 scenario
- Catchment intervention scenarios will arrest future loads,
- Combined high level intervention and target overflows produces the highest gain in water quality improvements

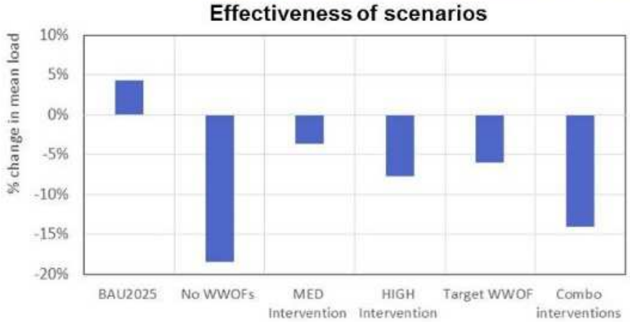
Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

Target WWOF
- Highest discharging overflows remediated

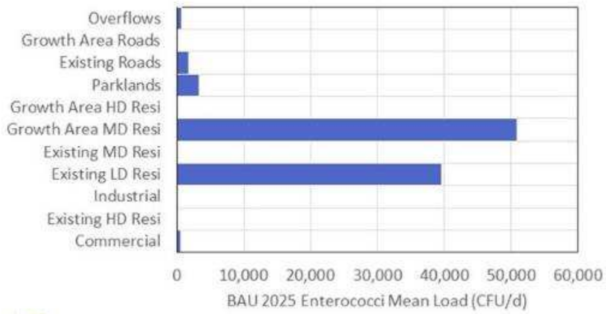
Combined Intervention
- High intervention scenario + target WWOF

Effectiveness of scenarios

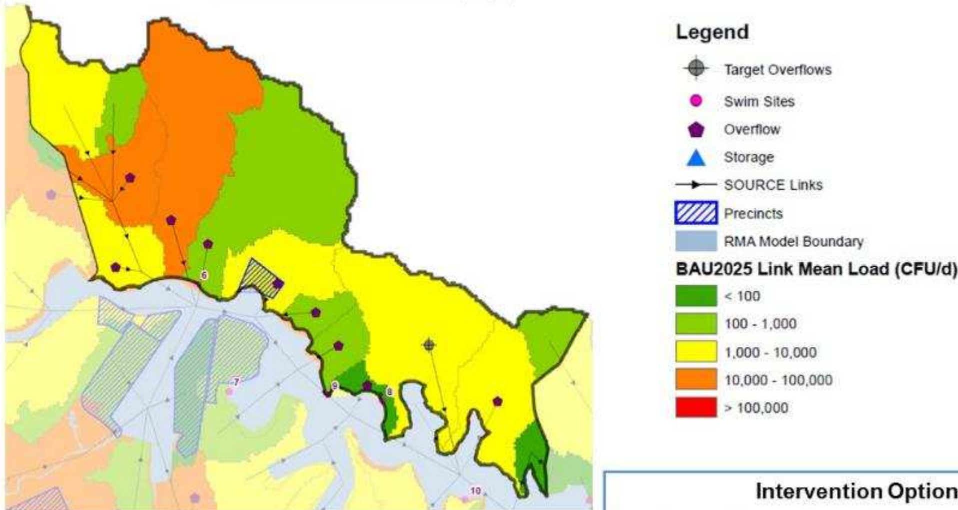


Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

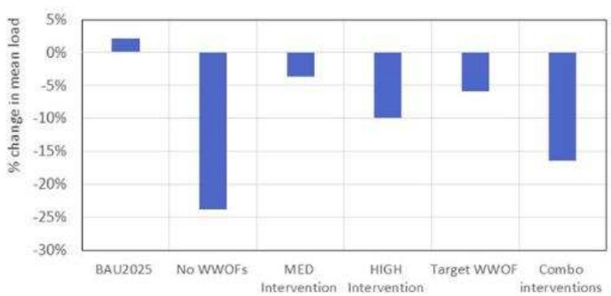
RYDE LGA



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
    - From pet waste in residential areas
    - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
    - This provides an estimate of the cumulative loads within the river network



Effectiveness of scenarios



Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

- Enterococci loads will increase slightly under BAU 2025 scenario
- Catchment intervention scenarios will reduce future loads, and improve on baseline conditions

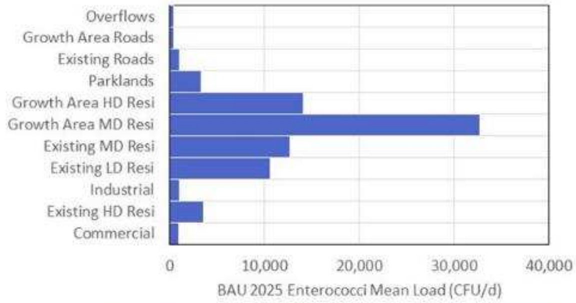
Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

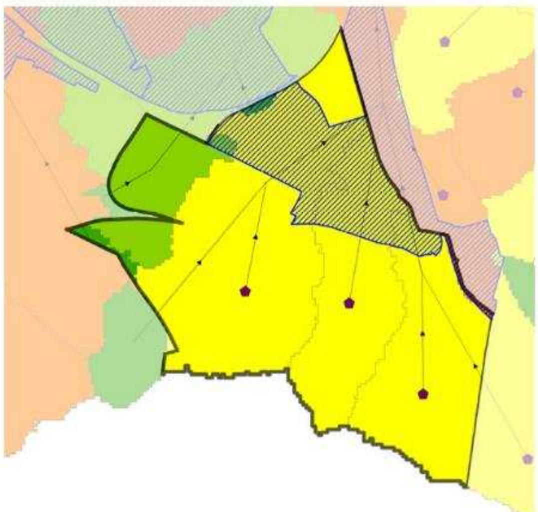
Target WWOF
- Highest discharging overflows remediated

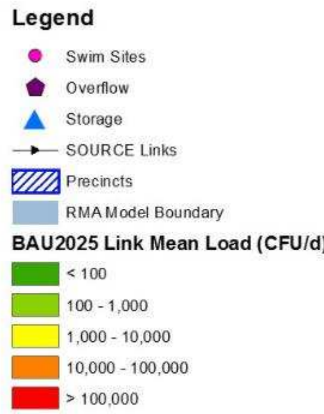
Combined Intervention
- High intervention scenario + target WWOF

STRATHFIELD LGA

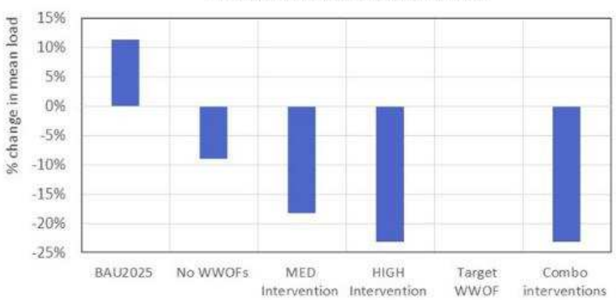


- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
    - From pet waste in residential areas
    - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
    - This provides an estimate of the cumulative loads within the river network





Effectiveness of scenarios



Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

- Enterococci loads will increase under BAU 2025 scenario
- Catchment intervention scenarios will reduce future loads, and improve on baseline conditions

Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

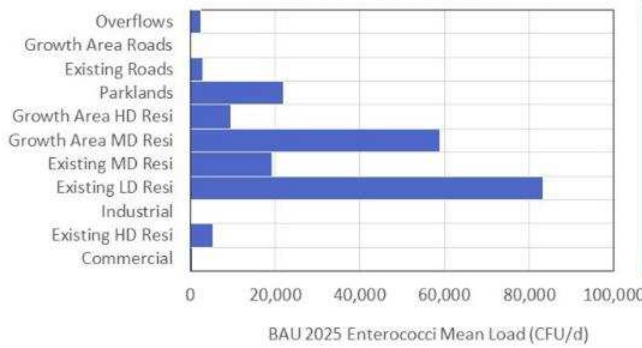
High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

Target WWOF
- Highest discharging overflows remediated (No target WWOFs selected in this LGA)

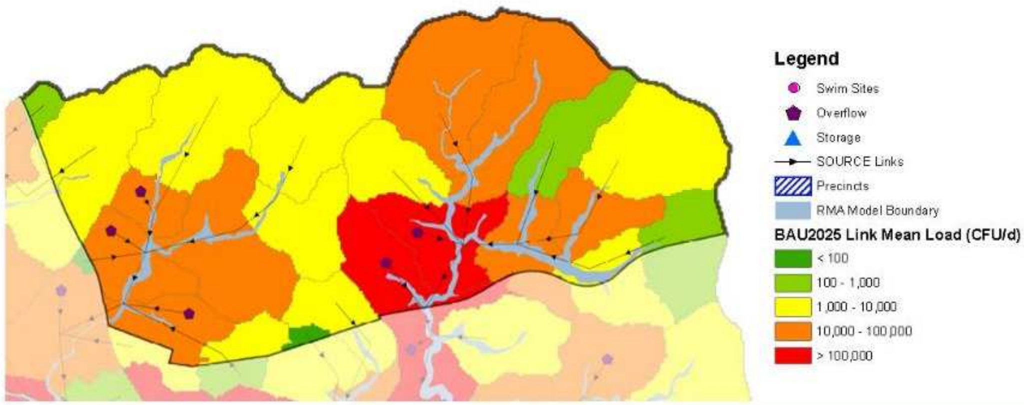
Combined Intervention
- High intervention scenario + target WWOF

THE HILLS SHIRE LGA

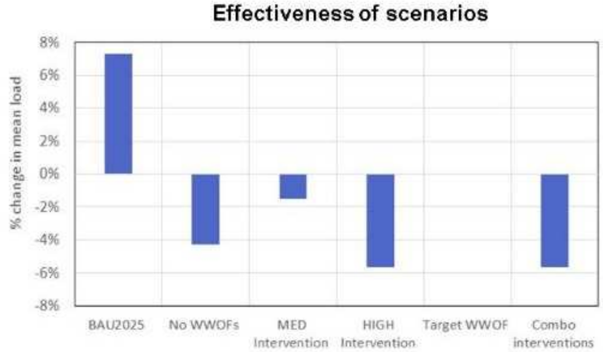
Sources of Enterococci Loads



- Enterococci loads generated from each land use (see chart) provides an indication of the pathogens available for transport
- The chart shows major sources are:
  - From pet waste in residential areas
  - Growth areas
- The hot-spots map shows the attenuated loads (after die-off in the river occurs)
  - This provides an estimate of the cumulative loads within the river network



Effectiveness of scenarios



Note: BAU 2025 is % change from baseline, whereas all other scenarios are % change from BAU 2025.

Intervention Options

- Enterococci loads will increase under BAU 2025 scenario
- Catchment intervention scenarios will arrest future loads, but will not reverse trajectory of current loads

Medium intervention
- Medium level of use from rainwater tank
- 15% pet waste reduction

High intervention
- High level of use from rainwater tank
- 30% pet waste reduction

Target WWOF
- Highest discharging overflows remediated (No target WWOFs selected in this LGA)

Combined Intervention
- High intervention scenario + target WWOF

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