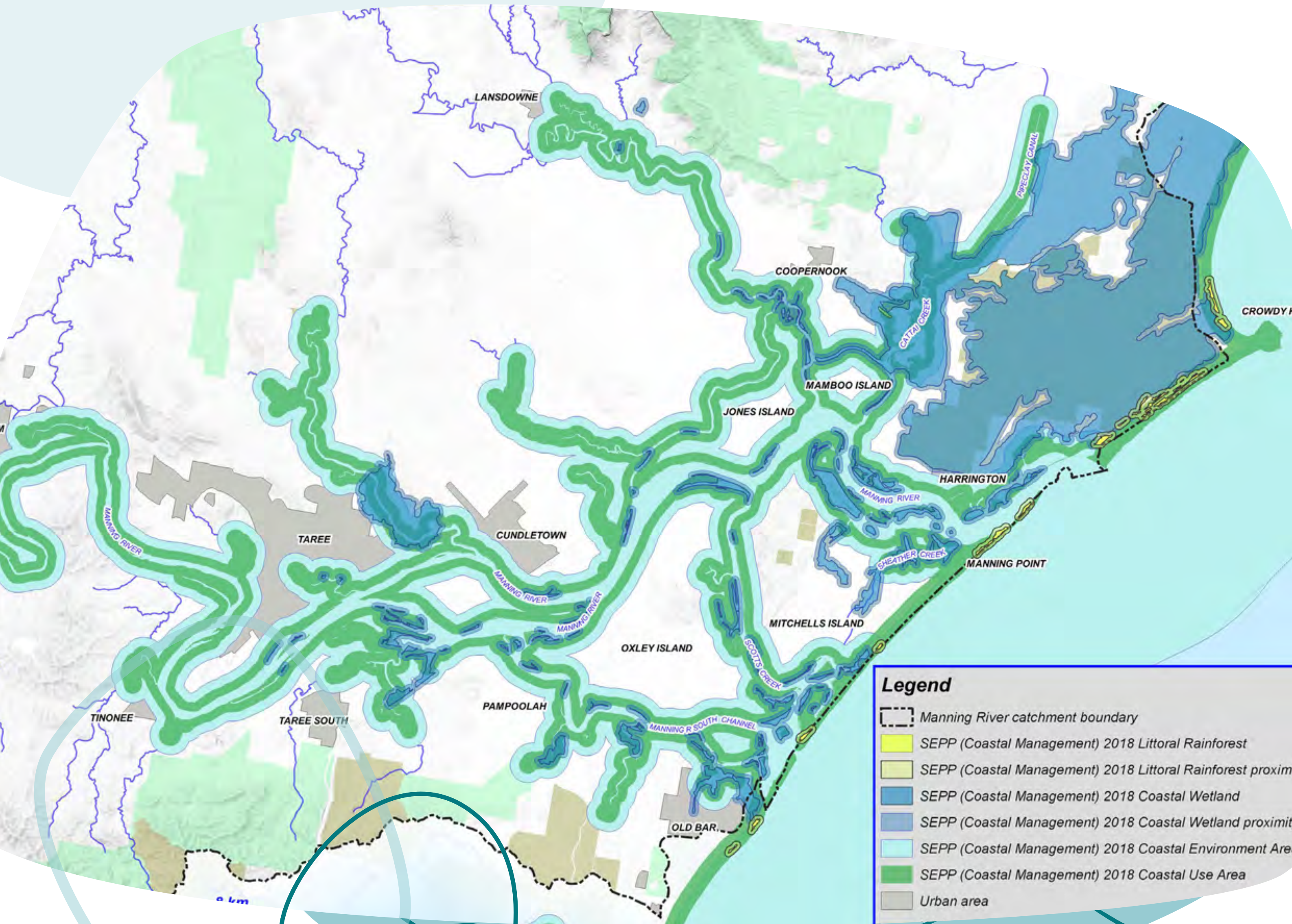

MIDCOAST council

MANNING RIVER ESTUARY & CATCHMENT

SPATIAL RISK ASSESSMENT 2020

Annexure G

Cover photo: Cattle near Gloucester NSW. Rebecca Swanson/DPIE

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Executive Summary

Outcomes of Risk Assessments

The Scoping Study in Stage 1 of preparing the Coastal Management Program for the Manning Estuary identified detailed risk assessments of catchment pressures as a priority study for Stage 2. Science Division of Environment Energy and Science (EES, Department of Planning, Industry and Environment) have developed Estuary Health Risk Maps for NSW estuaries (Dela-Cruz et al. 2019). The maps are based on a risk assessment to identify subcatchments that pose the highest risk to water quality in the estuary, and subsequently where land use intensification is best avoided, and more stringent management controls are needed. The risk maps facilitate identification of strategic priorities for managing nutrient and sediment runoff in the catchment.

MidCoast Council (MCC) engaged EES to produce an updated and more specific Estuary Health Risk Map for the Manning River estuary and to assess risk of additional pressures in the catchment that may impact on ecological and community values of the river and estuary. The impact of stock on water quality and riparian zones, pathogens from animal and human waste, hill-slope and streambank/bed erosion, and acid run-off from acid sulphate soils are additional pressures in the Manning catchment that impact on the values of the river and estuary. Specifically, the following risks were assessed in this report:

- The risk of impact of total nitrogen, total phosphorous and total suspended solids exports from land use on the water quality in the estuary
- The risk of impact of pathogens from stock on water quality required for the community values of drinking water, aquaculture (oyster farming) and secondary recreation were assessed
- The risk of hillslope erosion and streambank erosion to riparian vegetation, an ecological asset, were assessed.

The report also includes results from two standalone risk assessments of additional pressures on estuary health done by other investigators:

- On-site sewage management system risk assessment (DWC 2018b)
- Acidic run-off from acid sulphate soils risk assessment (Glamore et al. 2016)

The risk assessments are spatial prioritisation tools which identify areas in the catchment where investment of resources for on-ground actions would achieve the best benefits for managing estuary health. Relative spatial trends were used to prioritise higher risk subcatchments. Further field assessments / investigations need to occur in the high risk subcatchments to quantify the threat to the estuary, and to determine appropriate on-ground works that will mitigate the threat to estuary health.

High risk subcatchments

Subcatchments which were found to pose the greatest risk to the particular asset being assessed have been identified (Table 1). A subset of subcatchments pose a high risk to estuary health from multiple threats arising from these subcatchments. Targeted on-ground works in these subcatchments will have the best chance of improving the health of the Manning estuary by mitigating threats using a multi-pronged approach. The highest risk of impacts from nutrient and sediment inputs, acidic runoff from acid sulphate soils, and pathogen inputs from stock on ecological and community values of the Manning estuary comes from the Lansdowne River catchment (subcatchments 88, 223).

Other catchments which pose a high risk to ecological and community values of the Manning River estuary include Cedar Party Creek (subcatchment 95, nutrient risk to water quality and pathogen risk to secondary recreation), Cattai Creek (subcatchment 93, acidic runoff impacts), Dingo Creek (subcatchment 86, pathogen risk to drinking water quality) and Barrington River (subcatchment 117, pathogen risk to drinking water quality and secondary recreation). Manning River (subcatchment 105, 110), Upper Manning River (subcatchments 92 and 96), Myall Creek (subcatchment 76) and Barnard River (subcatchment 82) pose the highest risk of hillslope and streambank/bed erosion impacting on riparian vegetation and ultimately water quality in streams and estuary.

Table 1 A summary of subcatchments deemed to pose the highest risk to ecological and community values in Risk Assessments

Risk Assessment	High risk subcatchments
Estuary Health Risk	Lansdowne River (88, 223), Cedar Party Creek (95)
Pathogen Risk - Stock intensity *Community value*	
Drinking water quality	Dingo Creek (86), Manning River (99, 105), Barrington River (117), Gloucester River (98, 122)
Aquaculture	Oxley Island (203), Mamboo Island (204), Jones Island (205), Lansdowne River (88,223) Cattai Creek (93)
Secondary Recreation	Barrington River (117), Cedar Party Creek (95) and subcatchments listed above for Aquaculture
Pathogen Risk - On-site sewage management	Unsewered areas - catchment wide – were rated High Hazard Class for porous soil types, close to sensitive receptors/assets. Hazard level pertains to potential impacts IF on-site sewage systems fail or are inadequate, not fit-for-purpose
Erosion Risk	Manning River (105,110), Upper Manning River (92, 96), Myall Creek (76), Barnard River (82)
Acidic runoff	Lansdowne River (88, 223), Cattai Creek (93)

Catchment-wide issues

Cattle farms are widespread throughout the catchment and cattle frequently have access to waterways. Cattle access to waterways degrades water quality and impacts on the riparian zone. Nutrients from cattle urinating and defecating directly into the stream, and loose sediments from trampled streambanks, are an additional source of nutrients and sediments to waterways associated with agricultural land use. Cattle access degrades the riparian zone through weakening of bank structure, trampling of regrowth and grazing established vegetation. Cattle directly accessing waterways also increases the pathogen risk arising from stock. Excluding access, in part or wholly, to waterways is only part of the solution, however farmers would need to provide alternate shade and water for their cattle, preferably in an area away from the stream.

Erosion of hillslopes and streambanks is a widespread pressure in the catchment leading to loss of structure in the riparian zone and loss of vegetation, leading to further erosion. There are extensive areas of hillslopes and pastures with limited ground and vegetation cover across the catchment. Active erosion and gully erosion were also noted. Coupled with poor riparian vegetation these areas pose a risk to estuary health as large amounts of sediment are likely to be mobilised from the catchment when wetter conditions return.

Ground-truthing spatial layers

Existing local data and additional field data collected in Rapid Site Assessments during a catchment wide ground-truthing program were used to validate the spatial layers used in risk assessments. Four categories were assessed:

- Land Use (and agricultural pressure)
- Geomorphic Condition (freshwater catchment only)
- Instream Condition and
- Riparian Condition

Each site was assigned a total score for all site attributes within these categories which were summed for an Overall Condition score. A separate report has been completed on the Rapid Site Assessments (Swanson 2019).

Ground-truthing of spatial layers used in risk assessments using subcatchment averages had mixed results. In most cases, there was poor alignment of subcatchment averaged data from the Rapid Site Assessments with Likelihood Scores in the spatial layers to be ground-truthed. One explanation for the discrepancy is that site condition was often highly variable within subcatchments, for example, the site in the worst condition and in the best condition were both in Avon River subcatchment 123. As a baseline catchment-wide assessment the aim was to survey as many subcatchments as possible in the short time frame and limited resources available, rather than intensively survey a smaller number of subcatchments as this could be done at later stage. Over 200 sites were assessed across the catchment which is 8400 km^2 with sites in 44 EES subcatchments (based on 3rd order streams). The outcome was that only a small number of sites (typically 4-6), were assessed in each subcatchment which, given the variability in condition within each subcatchment, was not enough for ground-truthing purposes. A critical lesson from this part of the project is that effective risk assessments will require a larger investment to ensure that sufficient sites are assessed with each sub-catchment.

Existing local data were used to supplement the field data collected in Rapid Site Assessments, as part of the validation of the spatial layers used in risk assessments. Both quantitative and qualitative data were used to ground-truth the spatial layers, with varying success. Catchment model outputs used in the updated Estuary Health Risk Map were validated at a coarse level with independent water quality data (MidCoast and data collected in the Rapid Site Assessments. Observations across the catchment were used to validate stocking intensity layer and hillslope erosion layer. Attributes of geomorphic condition from Rapid Site Assessments were used to validate the Fragility (streambank/bed erosion) layer for the freshwater catchment (River Styles assessment only applies to freshwater streams). The pathogen risk assessments are based on stocking rates and known locations of assets rather than on-site measurements of pathogens. Limited in-stream bacterial data were available to ground-truth the layers and high risk subcatchments identified in the risk assessments should be the focus of future monitoring of faecal bacteria. It is the responsibility of the particular industry groups to undertake in-depth investigations into the risk of pathogens to their industry. Human pathogens are of most concern to the oyster industry therefore poor on-site sewage management should be investigated as a priority.

Several confounding factors affected the data collected in Rapid Site Assessments and can partly explain some of the inconclusive outcomes of the ground-truthing exercise. The MidCoast of NSW is in severe drought which has led to many farmers de-stocking cattle.

The extended dry period resulted in low flow or no flow in many streams assessed. Good water clarity was recorded in most perennial streams/rivers and in many cases did not reflect surrounding land-use because of a lack of recent overland flow to transport pollutants (nutrients, sediment) in surface runoff.

This study had a short timeframe so it prioritised sites on Crown Land to reduce the complexity of logistics in planning the ground-truthing exercise. However, this biased results because the protection afforded to Crown land meant that it was not uncommon for the riparian vegetation at the Crown Land site (for example) to be in far better condition than riparian vegetation on adjoining private land. These pockets of Crown Land are often an 'oasis' in amongst the agricultural landscape of the Manning Valley and floodplain and future sampling needs to account for this.

Despite the shortcomings of the ground-truthing program, a valuable dataset was obtained from across the entire Manning River catchment and estuary which provide a snapshot of condition and land use activities in the catchment. Field data collected can be interrogated by Council at the whole river catchment, EES subcatchment and site scale.

Further monitoring is required to confirm whether environmental values are, or are not, being met in high risk subcatchments.

Spatial risk model

The spatial layers used in the risk assessments can be integrated using spatial multi-variate analyses, to create a single spatial risk model for the Manning River estuary. There are arguments for and against combining risk for different values into a single risk layer. This process does provide a single risk outcome but can also hide much of the nuance and value of individual risk layers – and may lead to many areas with "average" risk. Council can choose to integrate the spatial layers to produce a spatial risk model for the Manning River estuary, or the individual risk assessments can be used to guide future investigations in the catchment.

Background

The Manning River Estuary covers an area of approximately 32 km^2 and has an extensive and varied catchment over 8,400km^2. The majority of the catchment is in the MidCoast Council Local Government Area (LGA) but also crosses over other LGAs (Upper Hunter Shire, Walcha Council, Tamworth Regional Council and Port Macquarie-Hastings Council). The catchment of the Manning River and estuary is comprised of 16 major river/creek catchments (Nowendoc River, Myall Creek, Barnard River, Upper Manning River, Lower Manning River, Barrington River, Gloucester River, Avon River, Waukivory River, Bowman River, Burrell Creek, Dingo Creek, Cedar Party Creek, Dawson River, Lansdowne River and Cattai Creek). The Manning River is a single channel west of Taree, with the tidal limit located in the vicinity of Abbotts Falls, a gravel bar approximately 54km from the entrance. The lower reaches of the Cattai Creek, Lansdowne and Dawson Rivers are estuarine in nature.

The estuary has two natural ocean entrances, one at Harrington and the other 12km to the south, at the Farquhar Inlet at Old Bar. The Manning River Estuary is a mature barrier estuary, with a wave dominated delta (Roper *et al.* 2011). The estuary has a relatively long flushing time of 31.6 days, compared with a State-wide median estuary flushing time of 9 days (Roper *et al.* 2011). Due to the long residence time of fresh water, the estuary is sensitive to the accumulation of catchment inputs such as sediments, nutrients, pathogens and acidic runoff. These freshwater inputs can severely degrade the ecological health of the estuary and its tributaries and can impact on the community values, both social and economic, of the river and estuary. Water quality monitoring programs in the estuary have shown the estuary experiences both high turbidity and algal levels in response to catchment runoff (MidCoast Council Waterway and Catchment Reports).

Science Division of Environment, Energy and Science (EES, formerly Office of Environment and Heritage - OEH) has developed Estuary Health Risk Maps for NSW estuaries (Dela-Cruz et al. 2019) as a spatial risk assessment tool to help identify strategic priorities for managing nutrient and sediment runoff from catchments. The overall objective is for estuary health to be protected, maintained or improved, for the greatest environmental and socioeconomic benefit under both current and future scenarios. The risk assessment requires estuary catchments to be divided into smaller drainage units (subcatchments) based on 3rd order streams using Strahler stream order, which are referred to as EES subcatchments in this report.

In collaboration MCC, a first-pass Estuary Health Risk Map for the Manning River Estuary was produced for the *Scoping Study - Manning River Estuary Coastal Management Program* (MCC 2018) as Stage 1 of preparing Coastal Management Programs (CMP). The risk map was developed by applying the first two steps of the *Risk-based Framework for Considering Waterway Health in Strategic Planning Decisions* (Dela-Cruz et al. 2017). Risk of impact on water quality in the Manning River Estuary from total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP) was modelled and spatially mapped at a subcatchment scale. More detailed investigations on the causes of the risks are done in Stage 2 of developing the CMP which is the purpose of this study.

The preliminary Estuary Health Risk Map showed nutrients and sediment runoff from subcatchments with primarily agricultural land use pose the highest risk to the health of the Manning Estuary. High risk areas included the catchments of Dingo Creek, Lansdowne River, Cedar Party Creek and in the west, Upper Barrington and Gloucester Rivers. A range of additional pressures impact on the health of the Manning Estuary including stocking intensity, hill-slope and streambank/streambed erosion and acidic runoff from acid sulphate soils (Glamore et al. 2016). Pathogens from stock and human waste pose risks to ecological and community values for the river and estuary.

For Stage 2 detailed risk assessments, MCC engaged EES to:

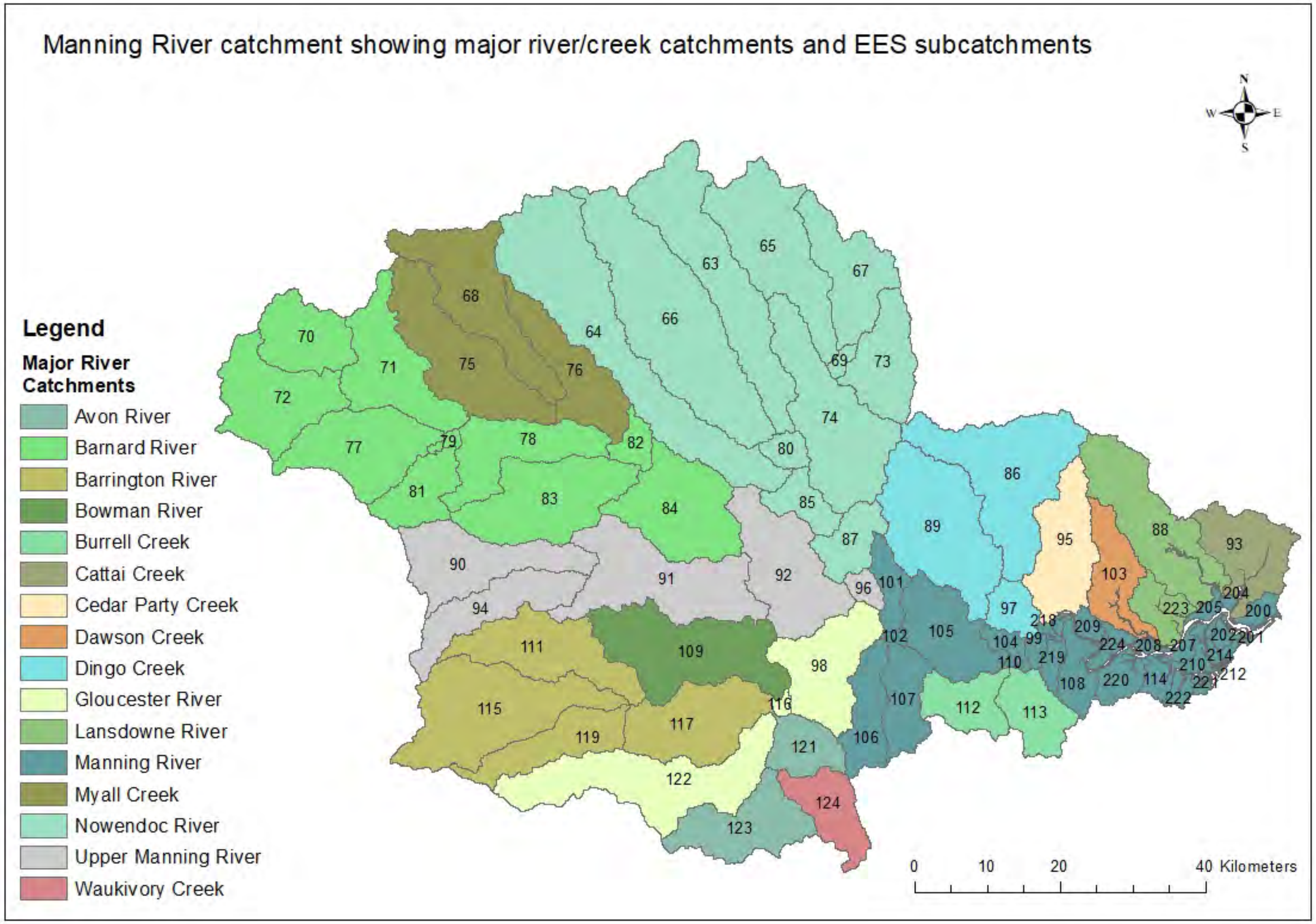
1) Produce an updated Estuary Health Risk Map using latest available land use (NSW Land Use 2017) as a risk assessment to identify subcatchments that pose the highest risk to water quality in the estuary
2) Assess risk of pressures (erosion, pathogens, acid sulphate soils) in the catchment not included in Stage 1 that may impact on ecological and community values of the river and estuary. The risk assessments allow identification of subcatchments that pose the highest risk to the ecological or community value being assessed. This required development and incorporation of:
    a. Spatial layers of additional local pressures that may impact on estuary health and community values. Pressures include stock intensity, hill-slope and streambank/streambed erosion, and acid sulphate soils
    b. Spatial layers for ecological and community values (riparian vegetation, environmental assets, drinking water catchment, aquaculture, secondary recreation)
    c. Risk assessments for pollutants/pathogens from on-site sewage management (Decentralised Water Consulting 2018b) and acid sulphate soils (Glamore et al. 2016) in preparation for possible integration to produce a spatial risk model for the Manning River estuary
3) Ground-truth spatial layers from the risk assessments with field data and observations from a catchment-wide survey program.

    The ground-truthing program centred on Rapid Site Assessments of land use, riparian, geomorphic and in-stream condition to:
    a. Assess land use, noting the level of fertilisation and irrigation in adjacent land, to validate catchment model inputs to the Estuary Health Risk Map
    b. Assess water quality in streams to compare to modelled catchment loads
    c. Assess stock impact on the riparian zone and streambanks
    d. Assess riparian condition to validate the riparian vegetation layer
    e. Assess geomorphic condition to validate streambed/streambank erosion layer.

    Observational data was collected from the catchment while travelling between sites to:
    f. Note degree of fertilisation and irrigation of pastures
    g. Note stocking rates to validate stock intensity layer
    h. Note hillslope erosion to validate hillslope erosion layer
    i. Note the presence, location of environmental assets to validate assets layer, in addition to desktop review of environmental assets.

Outcomes of the risk assessments can be used by Council as a spatial prioritisation tool to identify subcatchments that pose highest risk to ecological and community values. This information will inform future investigations at finer/local scales, and the development of appropriate on-ground works in high-risk subcatchments to mitigate the type/cause of localised risks (e.g. nutrient runoff from intensive agriculture, potential pathogens from stock intensity / stock access to waterways, hillslope erosion etc).

The spatial layers used in the risk assessments may be integrated at a later stage using spatial multi-variate analyses (e.g. MCAS) to produce a spatial risk model of the catchment of the Manning Estuary. After reviewing this report, Council can decide whether to integrate the spatial layers and which spatial layers (if not all) to include in the spatial risk model.



Map 1 The Manning River catchment showing major river/creek catchments (coloured) and constituent EES subcatchments based on 3rd order streams (numbered)

Risk assessments

Pressures on estuary health in the Manning catchment include stocking intensity, hill-slope and streambank/streambed erosion and acid sulphate soils. These pressures result in stressors such as nutrients and sediment runoff from agricultural (and other) land use, pathogen loads and pH reductions. Five separate risk assessments on the potential impact of these threats on ecological assets and community values are presented in this report. Two additional risk assessments done by other consultants/researchers are also included in this report, regarding on-site sewage management (DWC 2018a, b) and impacts from acid sulphate soils (Glamore et al. 2016). Estuary Health Risk Maps are an assessment of impact of nutrients and sediments from Land Use on water quality in the estuary.

Likelihood and consequence

All risk assessments were based on likelihood and consequence criteria. Scores for likelihood and consequence criteria were based on quantiles unless otherwise noted. Likelihood scores represent the intensity of the pressure (from land use/stock. intensity/erosion) from each subcatchment, with a score of 1 indicating the lowest likelihood i.e. chance of impact and a score of 4 the highest likelihood of impact on estuary health (or community values). Consequence scores represent the extent of impact on estuary health (or community values), with a score of 1 indicating lowest impact and a score of 4 indicating the highest impact. Risk is a product of the likelihood and consequence scores (likelihood x consequence = risk), with a maximum risk score of 16 indicating the greatest risk and a minimum risk score of 1 indicating the lowest risk.

he method for calculating risk scores follows the procedure outlined in the NSW Treasury Risk Management Toolkit (NSW Government 2017). The overall risk score serves to relatively rank each subcatchment from highest risk to low risk to assist decision makers to prioritise investigations and on-ground works. See NSW Estuary Health Risk Dataset for more information (Dela-Cruz et al. 2019).

Updated Estuary Health Risk Map

Estuary Health Risk Maps are a risk assessment of potential impact of nutrients and sediments from land use on water quality in the estuary.

Catchment model

Update Land Use

The catchment model for the Estuary Health Risk Map for the Manning Estuary produced for the Stage 1 Scoping Study used outdated land use from NSW Land Use 2007 (MCC 2018, Dela-Cruz et al. 2019). This introduces uncertainty (error) in all 3 spatial datasets (‘Nutrient/sediment Loading’, Nutrient/sediment Load Flow, Health Risk’) where land use has changed significantly. Land use in the Manning River catchment was updated using NSW Land Use 2017 spatial layer produced by NSW Government.

Updated Event Mean Concentrations

The Estuary Health Risk Map for the Manning Estuary produced for the Stage 1 Scoping Study (MCC 2018) applied ‘Grazing’ Event Mean Concentrations (EMCs) to all land-use classified as Grazing Modified Pastures (Australian Land Use and Classification - ALUM tertiary code 3.2.0). The ‘Grazing’ EMCs used were from the literature and were primarily derived from grazing of native vegetation or modified pastures that are not heavily fertilised. The majority of the agricultural catchment of the Manning River estuary is classified as Grazing Modified Pastures (GMP) however, pastures are fertilised to varying degrees, depending on production goals of the farm. ‘Grazing’ EMCs were reviewed and revised for the updated Estuary Health Risk Map to reflect the 3 types of GMP that occur in the Manning Catchment. EMCs for Grazing Native Vegetation (ALUM 2.1.0) and Grazing Irrigated Modified Pastures (ALUM 4.2.0) were also updated. Appendix 1 provides background information, literature sources and justification of the approach used in the revision of EMCs. The revised EMCs used in the catchment model are shown in Table A1-4 and Table A1-5.

Catchment model outputs

Surface flow (SF, ML/y), TN, TP and TSS loads (kg/y) and generation rates for SF (ML/ha/y) TN, TP and TSS (kg/ha/y) from each subcatchment in the Manning River catchment are shown in Maps in Appendix 2 (Maps A2 – 1-8) and Table A2-1. See Appendix 2 for discussion of the results. Loads are total flow or amount of pollutants in surface runoff exported from the subcatchment per year (ML/y, kg/y). Generation rates are flows or pollutants loads per hectare of subcatchment area (kg/ha/y) which reflects the intensity of pollutants exported from the subcatchment to receiving waters. It was decided by Council and EES that generation rates should be used in the updated Estuary Health Risk Map.

Catchment model validation

The validity of using revised catchment model inputs (i.e., EMCs) was assessed by testing modelled outputs against existing (observed) water quality data collected in the freshwater catchment by MidCoast Water Services (MCW) from 2001 - 2019. Testing the model outputs against observed water quality data from the catchment provided a coarse validation of the catchment model. See Appendix 2 for further information on validation of the catchment model.

Estuary (Hydrodynamic) Model

Estuary risk mapping used a 1D-branched hydrodynamic model to produce two metrics: base exceedance and extent of potential impact. See Appendix 2 for a full description of the 1D-branched model used for estuaries classified as barrier rivers (Dela-Cruz et al. 2019).

TN (or TP, TSS) loads arising from small rainfall events (i.e. 1-year ARI) were used as inputs to the hydrodynamic model on the assumption that the catchment runoff from these small, but frequent events will be retained within the estuary and hence pose the greatest risk of impacts on estuary health.

Base exceedance was determined for each subcatchment, by increasing the total TN (or TP, TSS) loads for one subcatchment by 20% and re-running the model. The increase in TN concentrations within the estuary relative to the base or ambient TN concentrations (i.e. base exceedance) provide a relative measure of the magnitude of impact of that one subcatchment. The extent of potential impact determines if the exported pollutants remain localised near the input point or are transported to other parts of the estuary. Further explanation of the hydrodynamic model outputs is provided in Appendix 2.

The hydrodynamic model was run separately for TN, TP and TSS at the request of Council. Maps of base exceedance and extent of potential impact are shown in Appendix 2 (Maps A2 – 10-15). These maps show which subcatchment loads have the most impact on water quality in the estuary and whether the impact is localised or spreads throughout the estuary.

Updated Estuary Health Risk Map

The generation rates for surface flow (SF – ML/ha/y) and TN, TP and TSS (kg/ha/y, Maps A2-2, -4, -6, -8) from each subcatchment were used as likelihood criteria in the water quality risk assessment. The hydrodynamic model outputs of base exceedance and extent of potential impact were multiplied to get a single volumetric index which was used as the consequence criterion in the risk assessment. Scores for the likelihood or consequence criteria were based on quantiles. Specifically, the modelled data were categorised into quantiles and attributed with a score of 1 if they were ≤ 25th percentile, a score 2 if they were >25th and ≤ 50th percentile, a score of 3 if they were > 50th and ≤ 75th percentile or a score of 4 if they were > 75th percentile.

In addition to the catchment runoff, the proximity of a subcatchment to the estuary was also considered to pose an additional likelihood of risk of impact on estuary health. Consequently, subcatchments that drain directly to the estuary were also attributed with a Likelihood Score of 4 to denote a high likelihood of risk of impacts on the ecosystem health of the estuary due to proximity. All other subcatchments were attributed with a very low Likelihood Score of 1.

Likelihood Scores for SF, TN, TP, TSS generation rates (kg/ha/y) and the proximity score for each subcatchment were averaged to get the Likelihood Score for the subcatchment, which was multiplied by the Consequence Score for that subcatchment to get Risk level. That is, the Risk that each subcatchment poses to estuary health which are rated as Very High (16), High (12), Moderate (8, 9) or Low Risk (1-6).

The updated Estuary Health Risk Map using the above criteria is shown in Map 2.

Note that the updated Estuary Health Risk Map was also produced without including proximity in the Likelihood Score and is shown and discussed in Appendix 2 (Map A2 - 16). The first pass Estuary Health Risk Map from 2018 is also shown in Map A2-17 for comparison.

Lansdowne River and Cedar Party Creek - Very High Risk subcatchments

The highest possible risk score of 16 (Very High Risk) was assigned to 3 subcatchments (88 and 223-Lansdowne River, 95-Cedar Party Creek with surface runoff from land use in these subcatchments having the greatest relative impact on water quality in the estuary.

Lansdowne River

Subcatchment 88 is on the northern side of the estuary and includes the rural townships of Coopernook, Lansdowne and Upper Lansdowne. Lansdowne River drains to the estuary on the eastern side of Mambo Island and via Ghinni Ghinni Creek.

Updated land use for subcatchment 88 is shown in Map 3 with approximately one-third of the subcatchment being classified as Grazing Modified Pasture (3.2.0). One-quarter of these modified pastures were assigned as high fertilisation (Map 4, Type 3 - Grazing Modified Pastures, see Appendix 1) thus approximately 9% of the subcatchment is heavily fertilised grazing modified pastures (Map 4). Very little land has been classed as irrigated land although farmers irrigate dairy pastures and other intensive areas such as turf farms with dam water (Pers. Comm. *Vernon*, Banksia Turf Farm, 30.8.19). Google Earth image shows intensive farming including dairy pastures, Banksia Turf Farm and a large free-range poultry farm (Photograph 1). Approximately one-third of subcatchment 88 is forested (Strict Nature Reserves 1.1.1 – 6%; and Residual Native Cover 1.3.3 – 27%).

Subcatchment 88 had some of the highest pollutant loads (TN, TP, TSS – kg/y) and generation rates per hectare (surface flow ML/ha/y, TN kg/ha/y) in the catchment model (Maps A2-1 – A2-8, Table A2-1).

- TN load = 56,300 kg/y, TN generation rate = 2.8 kg/ha/y
- TP load 13,700 kg/y, TP generation rate = 0.7 kg/ha/y
- TSS load = 2000 tonnes/y, TSS generation rate = 136 kg/ha/y
- Surface Flow (SF) = 4.5 x 10^4 ML/y, SF generation rate 2.3 ML/ha/y

Subcatchment 223 lies to the south-west of subcatchment 88 and is situated on the estuary adjacent to Jones Island. Ghinni Ghinni Creek connects the estuary to Lansdowne River. Subcatchment 223 includes the rural townships of Cundletown and Kundle Kundle (Photograph 2). Land use for subcatchment 223 is shown in Map 5. Approximately half of the subcatchment is Grazing Modified Pastures (3.2.0) and one-third of these pastures were deemed to have high level of fertiliser use (Map 5, blue highlight, 18% of total subcatchment). Grazing Native Vegetation comprises 9% of the subcatchment (2.1.0) and only 12% is forest (1.3.3. Residual Native Cover, Map 5).

Subcatchment 223 had relatively high pollutant loads and generation rates per hectare in the catchment model (Maps A2-1 – A2-8).

- TN load = 17,900 kg/y, TN generation rate = 3.6 kg/ha/y
- TP load 5,500 kg/y, TP generation rate = 1.1 kg/ha/y
- TSS load = 912 tonnes/y, TSS generation rate = 183 kg/ha/y
- Surface Flow (SF) = 8.5 x 10^3 ML/y, SF generation rate 1.7 ML/ha/y

Cedar Party Creek

Subcatchment 95 is farther upstream with a direct connection to the estuary, east of Wingham. Subcatchment 95 includes rural townships Wingham, Cedar Party, Strathcedar and Killabakh. Land use is shown in Map 6 with one-third of subcatchment designated as Grazing Modified Pasture (GMP 3.2.0) and only 3% of GMP use a high level of fertiliser. One-third of land use is Grazing Native Vegetation (2.1.0) and only 15 % of the subcatchment is forest (1.3.3. Residual Native Cover). A variety of intensive land use occurs in the subcatchment including poultry farms, an abattoir and a sawmill (Map 6, Photograph 3). The abattoir in Wingham has high stocking densities and use effluent to fertilise their pastures. Some community members have linked ta decline in water quality to land application of effluent at the abattoir.

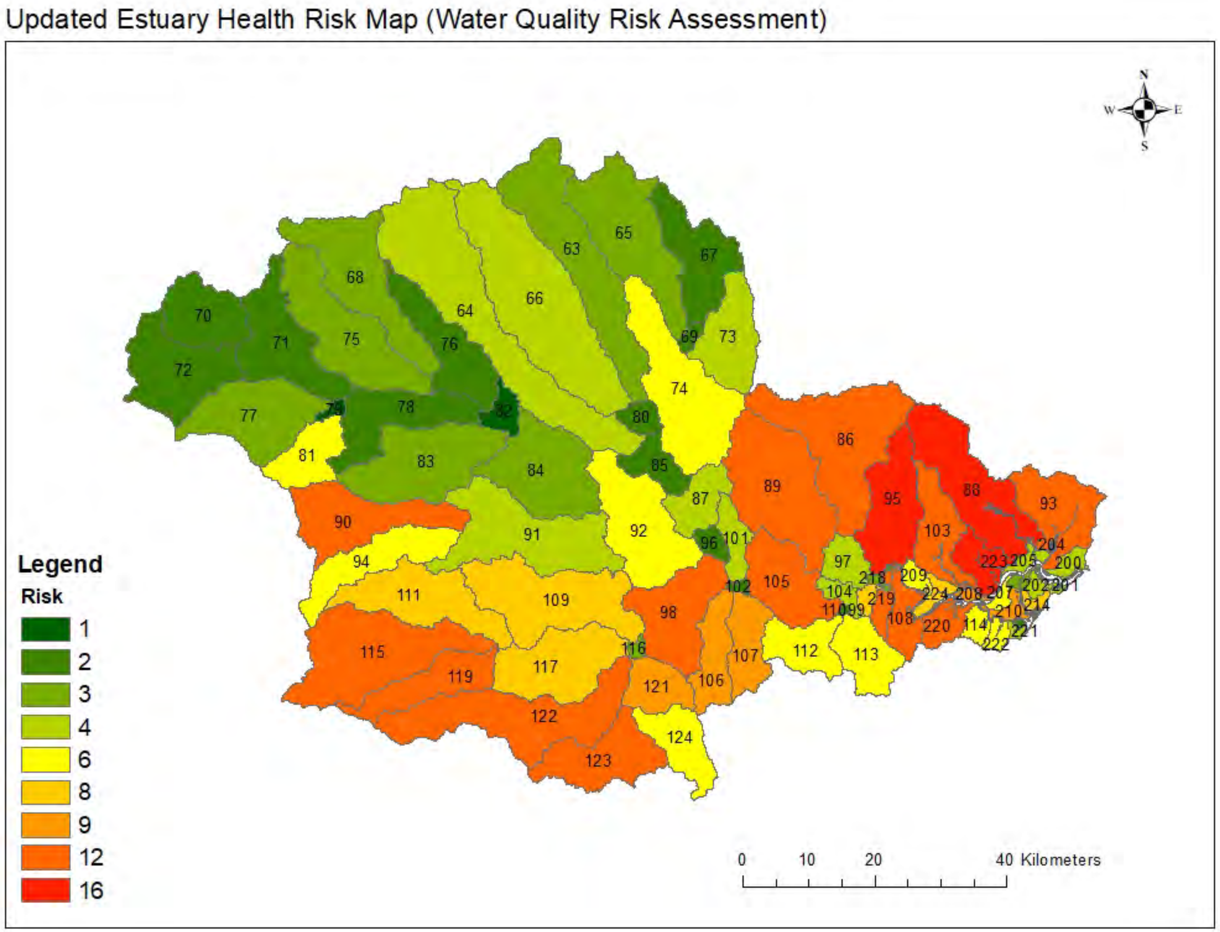
Subcatchment 95 had relatively high pollutant loads and generation rates per hectare in the catchment model (Maps A2-1 – A2-8, Table A2-1).

- TN load = 45,000 kg/y, TN generation rate = 3.2 kg/ha/y
- TP load 6,000 kg/y, TP generation rate = 0.42 kg/ha/y
- TSS load = 2,150 tonnes/y, TSS generation rate = 150 kg/ha/y
- Surface Flow (SF) = 3.4 x 10^4 ML/y, SF generation rate 2.4 ML/ha/y

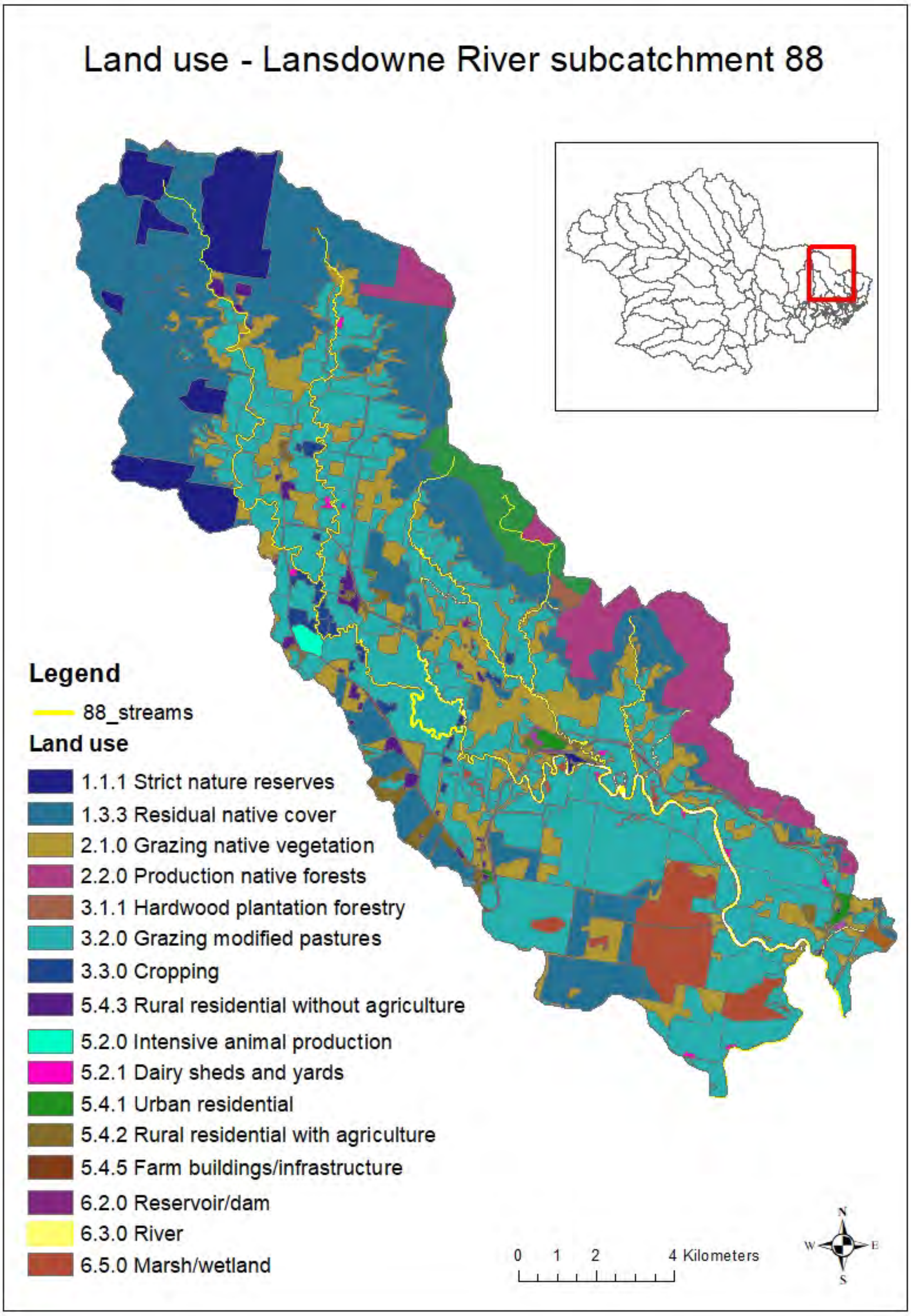
Ground-truthing

Catchment model outputs (i.e. TN and TP pollutant loads) for the freshwater subcatchments were validated by comparison with water quality data collected at monitoring sites in the catchment by MidCoast Water from 2001 - 2019. Maximum observed concentrations of TN and TP at monitoring sites was in line with modelled loads, with higher maxima recorded at sites receiving the highest loads (Graphs A2-1, A2-2).

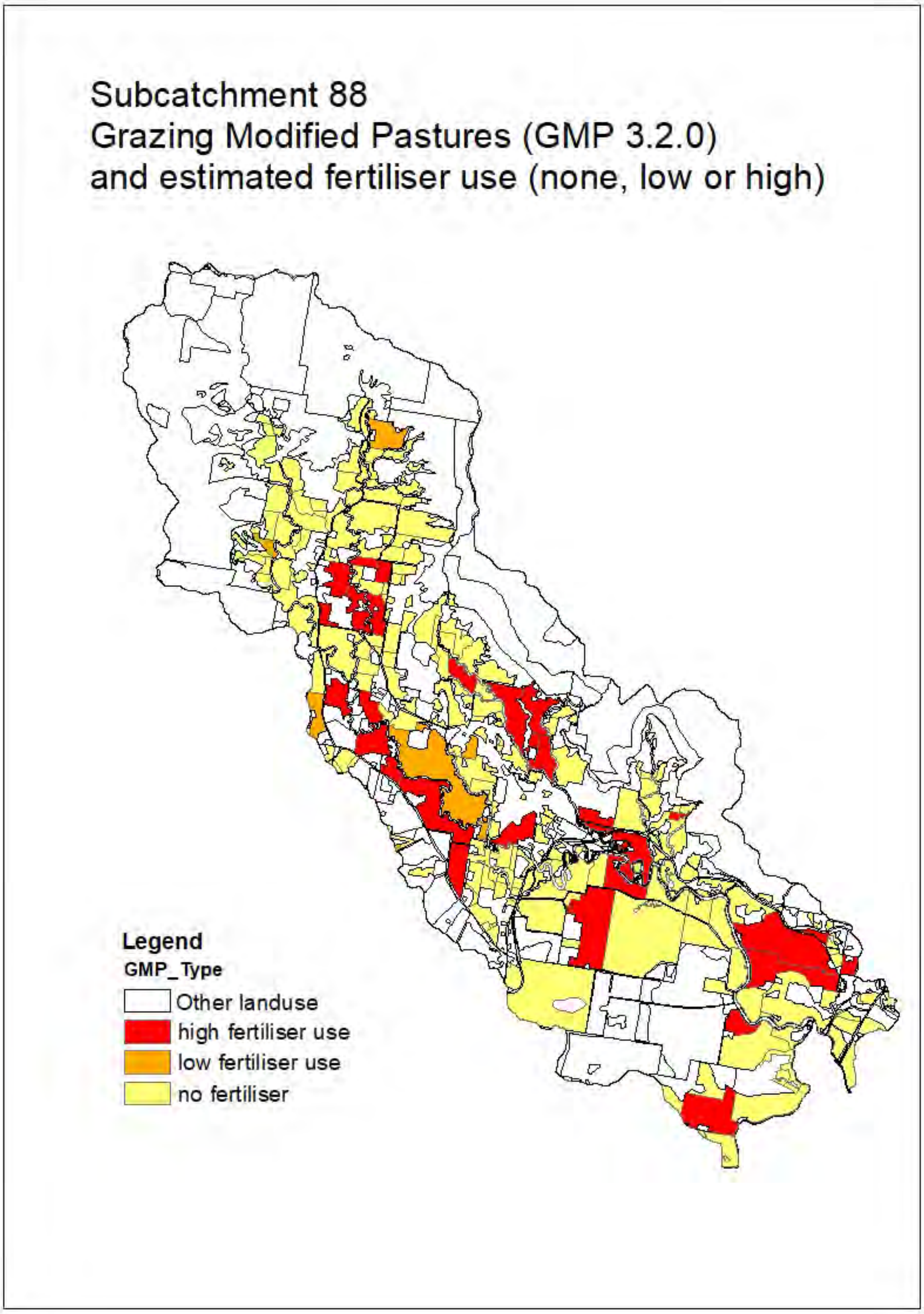
Water quality data collected in Rapid Site Assessments and Instream Condition scores, showed weak correlations with pollutant loads (TN, TP, TSS) at estuarine sites, but not for freshwater sites. Data collected during the ground-truthing program was highly variable within each subcatchment and was affected by extended drought conditions which partly explains why only a weak link was observed between water quality and modelled loads (i.e. land use). See Appendix 2 for further details on ground-truthing of the updated Estuary Health Risk Map.



Map 2 **Updated Estuary Health Risk Map showing overall risk that subcatchments pose to estuary health. All generation rates and proximity are used as likelihood criteria and hydrodynamic model outputs were used as consequence criteria.**

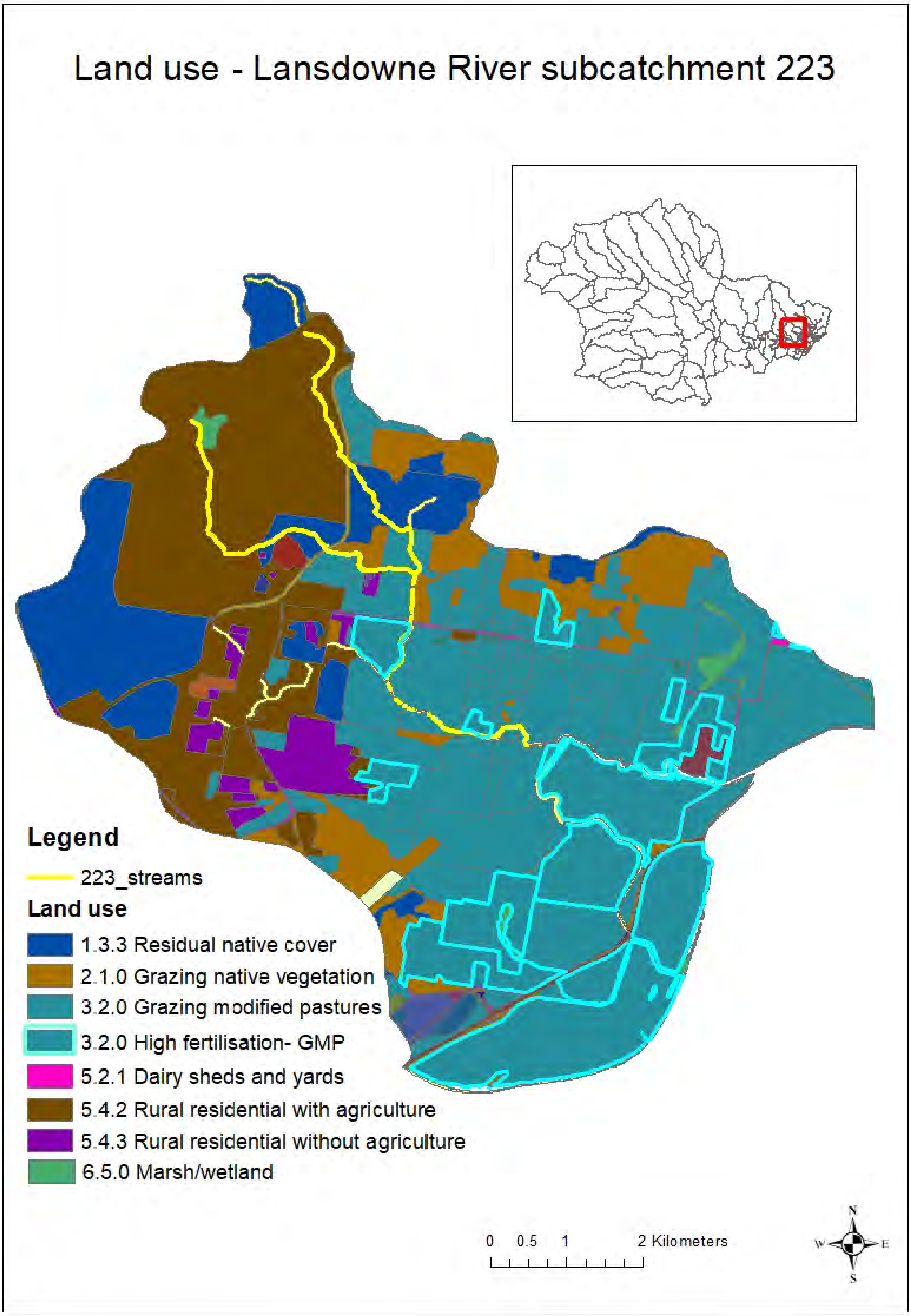


Map 3 **Land use in subcatchment 88 - Lansdowne River. Some minor land use categories have been omitted from legend. Aqua blue areas are grazing modified pastures. The fluorescent blue polygon is the large poultry farm shown in Photograph 1.**

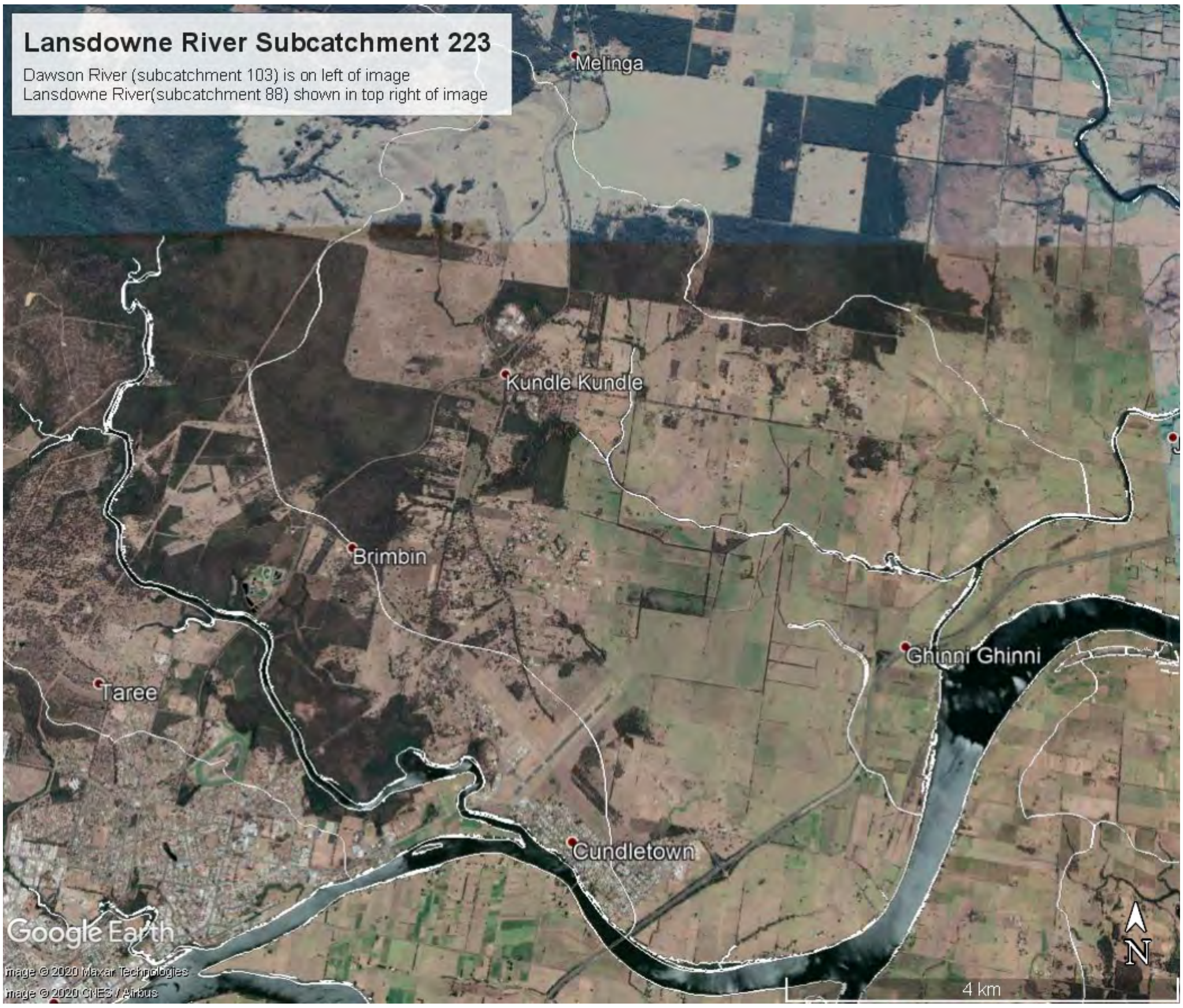


Map 4 **Three types of Grazing Modified Pastures (GMP) in subcatchment 88 - Lansdowne River. Fertiliser use was estimated from Nearmap and Google Earth imagery**

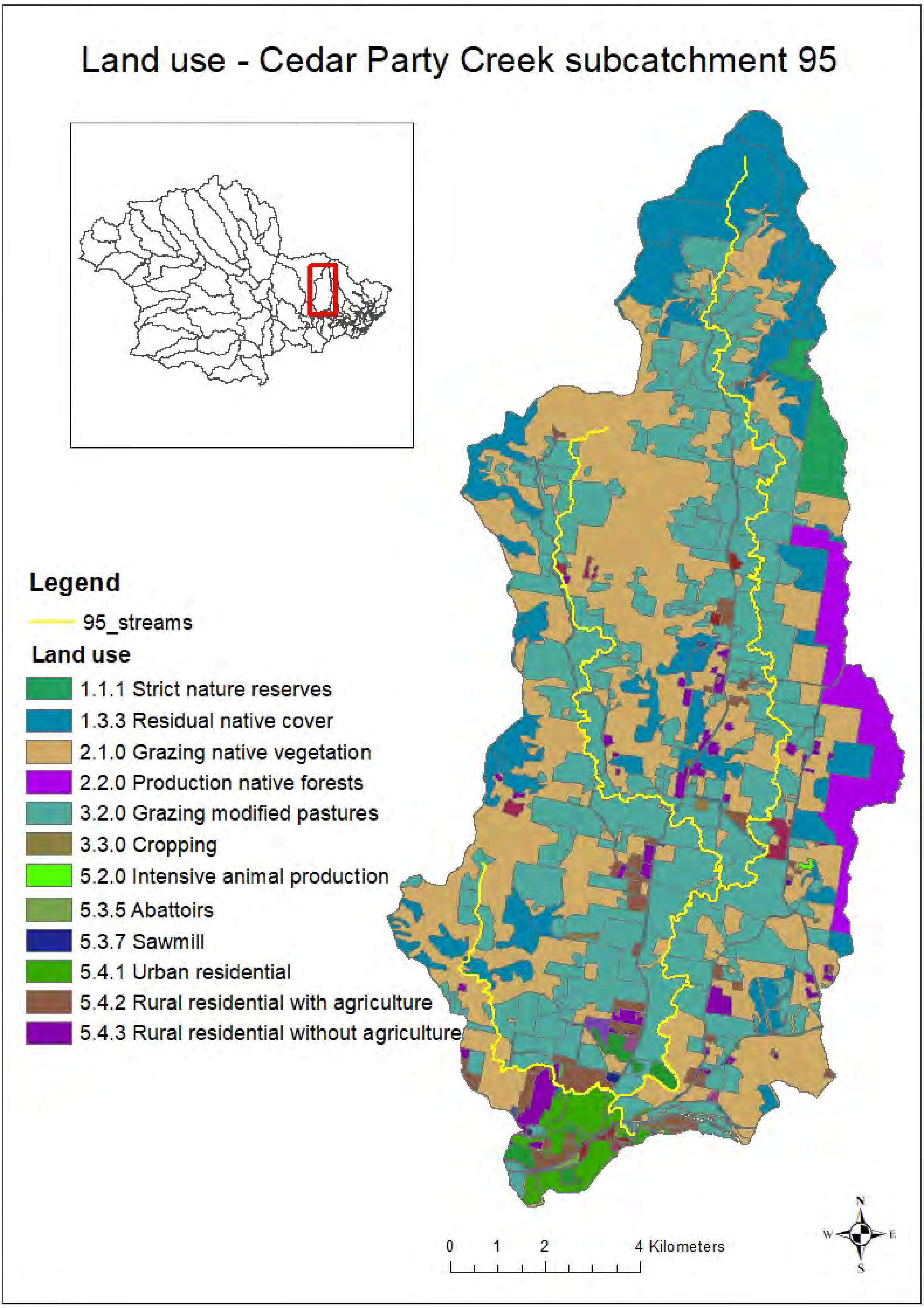
Photograph 1 **Google Earth image of Upper Lansdowne showing high fertilisation pastures, Banksia Turf Farm and a large poultry farm (white sheds) adjacent to Lansdowne River (Google Earth). A Rapid Site Assessment (88-10) of the river adjacent to turf farm showed scum layer on surface of large isolated pools suggestive of algal blooms (Swanson 2019)**



Map 5 **Land use in subcatchment 223-Lansdowne River. Minor land use categories have been omitted from Legend. Aqua blue areas are grazing modified pastures (GMP) – highlighted areas are pastures with high level of fertilisation.**



Photograph 2 **Lansdowne River subcatchment 223 (Ghinni Ghinni Creek) showing towns of Kundle Kundle and Cundletown, and the dominant land use - grazing modified pastures. The image reveals the impact of the extended drought on the catchment on December 3, 2019 (Google Earth)**



Map 6 **Land use in subcatchment 95 – Cedar Party Creek. Some minor land use categories have been omitted from the legend. Aqua blue areas are Grazing Modified Pastures surrounded by Grazing Native Vegetation (light brown)**

Photograph 3 The township of Wingham, located at the southern end of Cedar Party Creek - subcatchment 95. Sawmill and abattoir are marked on map. The image from December 3, 2019 reveals the impact of the extended drought on the catchment (Google Earth)

Pathogen risk assessments (from stock)

Cattle farms are widespread throughout the catchment and cattle frequently have access to streams. Stock graze on riparian vegetation and seek shade along the creek lines, trampling soft banks and drinking from streams. Stock waste is a potential source of pathogens to waterways, from direct access of stock and from manure on streambanks and in adjacent pastures. A stock intensity layer was developed to represent the risk (likelihood) of pathogens entering the waterways from stocking density in the catchment.

Pathogens from stock pose a risk to community use and values of the Manning River and estuary. The entire freshwater catchment of the Manning River serves as drinking water catchment that supplies town water for other parts of the LGA including Forster, as well as the major towns of Gloucester and Taree. The community also use the river and estuary for secondary recreation (boating, kayaking). Pathogens from stock also pose a risk to assets such as oyster farms in the estuary. Pathogens from stock thus pose a human health risk with regard to drinking water, oyster farming and secondary recreation. 'Consequence' layers were created for drinking water catchment, oyster farms and secondary recreation for risk assessments.

Stock data (beef cattle, dairy cattle, horses, sheep)

Annual Stock Returns data for 2009 – 2018 were supplied by Hunter LLS with the following caveats:

- data only covers the Hunter LLS region
- only properties over 20 hectares are required to submit annual stock returns
- only mature stock are required to be included in returns, and data provided is dependent on the honesty of landholders
- data is provided per holding (i.e., property)

Only beef cattle, dairy cattle, horse and sheep were included in the following analyses as 'Stock', that is, deer, alpaca etc were not included in Stock analyses. Poultry data is also included in this report but were processed separate to other 'Stock'.

Stock and Poultry data from 2009 – 2018 were included in the report as these data cover drought and non-drought years and therefore provide a good approximation of average stocking rates across the catchment.

Spatial layers and method used to develop the stock intensity layer (used as Likelihood criteria in the risk assessments) are presented in Appendix 3.

Stock intensity layer (Likelihood criterion)

The Stock Intensity Likelihood Scores spatial layer shown in Map 7 was derived from averaging Likelihood Scores from two layers – the total stock number per catchment and stock density in subcatchment (Map A3-9):

- Total stock per subcatchment layer (A3-1) and a
- Stocking density layer (A3-9) based on
    - stocking density per hectare of holding (A3-3 – A3-5) and the number of properties with stocking density (>0.5 stock per hectare) located on 5th order streams (A3-6)
    - total poultry per subcatchment (Map A3-7) and poultry per holding (Map A3-8)

Subcatchments with the highest Likelihood Scores for pathogens arising from stock were Dingo Creek (86), Cedar Party (95), Lansdowne River (88), Gloucester River (122) and Avon River (123). These subcatchments all have high numbers of stock and poultry, and many properties of moderate –high stocking density on permanent streams (5th order and above, River Styles).

Drinking Water Catchment layer (Consequence criterion)

The freshwater catchment of the Manning River supplies drinking water for the communities in major towns and villages in the LGA, including Gloucester, Taree and Forster. Barrington River is the sole source of water supply for the Gloucester offtake, and in the current drought is the major water source for Bootawa Dam offtake (comment made at meeting 30.8.19), used for Forster and Taree town water supplies. In non-drought conditions the water supply for Bootawa Dam, all major rivers in the catchment contribute to flows in the Manning River, and thus Bootawa Dam offtake, in roughly the following proportions; Barnard River (~25%), Barrington (~20%), Nowendoc (30%), Little Manning (10%) and Dingo Creek (15%), based on average flow data for 2013 provided by MCW.

Drinking Water is a community use/value of the river and the subcatchments contributing to water supply were used to develop a consequence layer for the risk assessment. Consequence Scores of 4,3 or 2 were allocated to each subcatchment in the Drinking Water catchment based on their proximity to the offtake locations and their relative contribution to flows to water supply offtakes. Estuarine (non-drinking water supply) subcatchments were assigned a score of 1. The locations of Drinking Water offtakes at Gloucester (MCW5) and Bootawa (MCW1) and consequence scores allocated to each subcatchment are shown in Map 8.

Risk assessment - pathogen risk to drinking water quality

Likelihood (Stock Intensity) Scores and Consequence (drinking water catchment) Scores were multiplied to assess risk that pathogens from stock pose to drinking water quality, shown in Map 9.

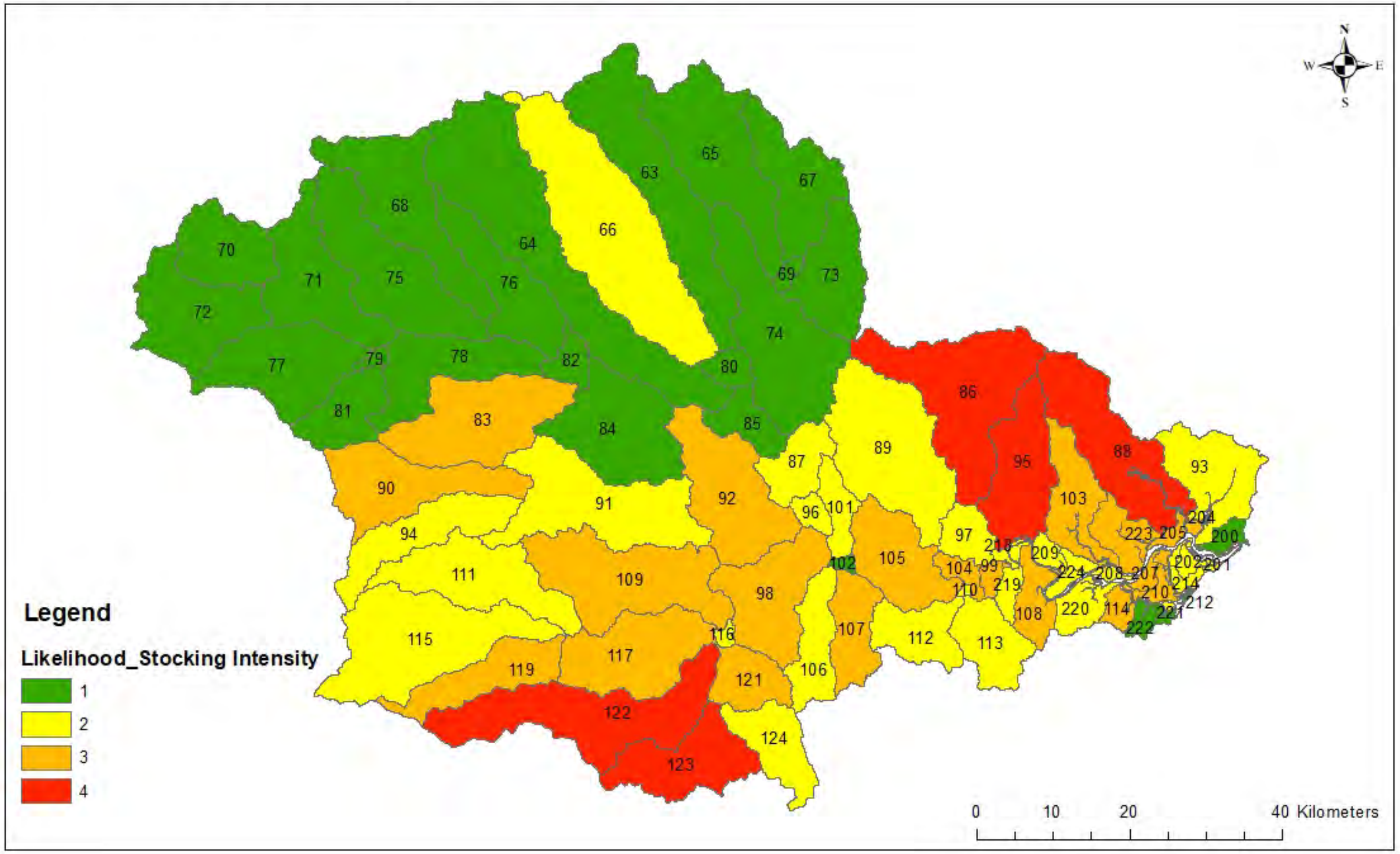
High risk subcatchments

Dingo Creek (subcatchment 86) was found to pose a Very High Risk to drinking water quality (Risk level = 16, Map 9) and 7 subcatchments posed a High Risk to drinking water quality (Risk level = 12, Map 9). Dingo Creek on average supplies up to 15% of flows to Manning River, just upstream of the offtake for Bootawa Dam. Dingo Creek subcatchment 86 had a Likelihood Score for stock intensity of 4. A score of '3' for stock density/total stock numbers was upgraded to '4' to account for a large poultry farm - 72,500 chickens - at downstream end of subcatchment. On average, 4400 stock (2009-2018) occupy pastures in subcatchment 86.

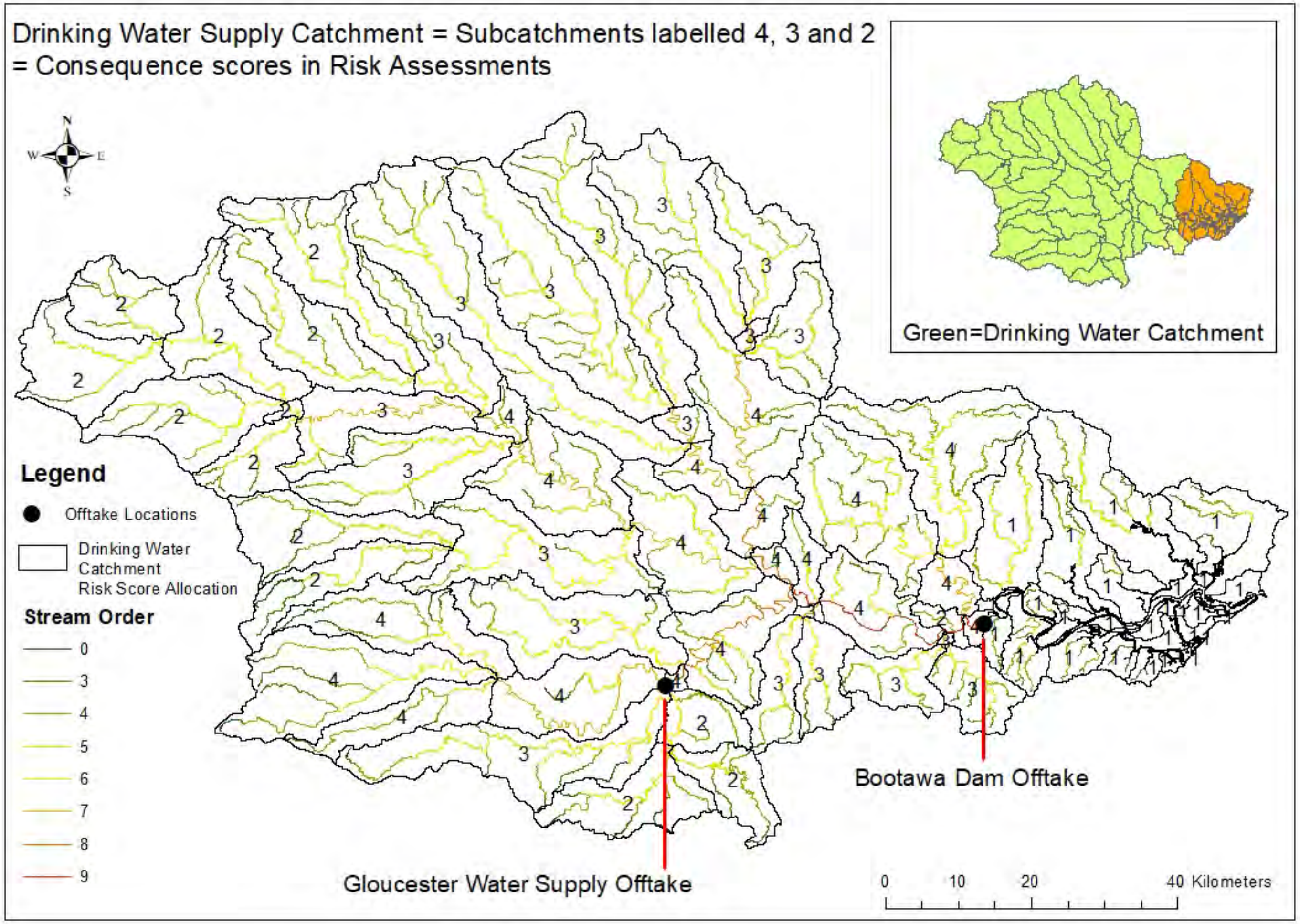
Updated land use map for subcatchment 86 is shown in Map 10. Approximately one-third of land use in the subcatchment is Grazing (3.2.0 Grazing Modified Pastures 18%, 2.1.0 Grazing Native Vegetation 15%). Only 4% of the GMP were estimated to have high use of fertiliser. Over half of the subcatchment is forest (1.3.3 Residual Native Cover 41%, 1.1.3 Nature Park 11%, 1.1.1 Strict Nature Reserves 7%).

Subcatchments with high risk rating were 99, 105, 92 (Manning River), 92 (Upper Manning River), 122, 98 (Gloucester River) and 119, 117 (Barrington River). All of these subcatchments have high stock numbers in the subcatchment and many properties of moderate-high stocking density on major waterways used for drinking water supply (Maps A3-2 – A3-6) which resulted in a Stocking Intensity Likelihood Score of 3 or 4. The subcatchments also had a Consequence Score of either 3 or 4, hence final Risk level of 12 or 16.

Stocking intensity (cattle, sheep, horse, poultry)
Likelihood score (to be used in pathogen risk asessments)

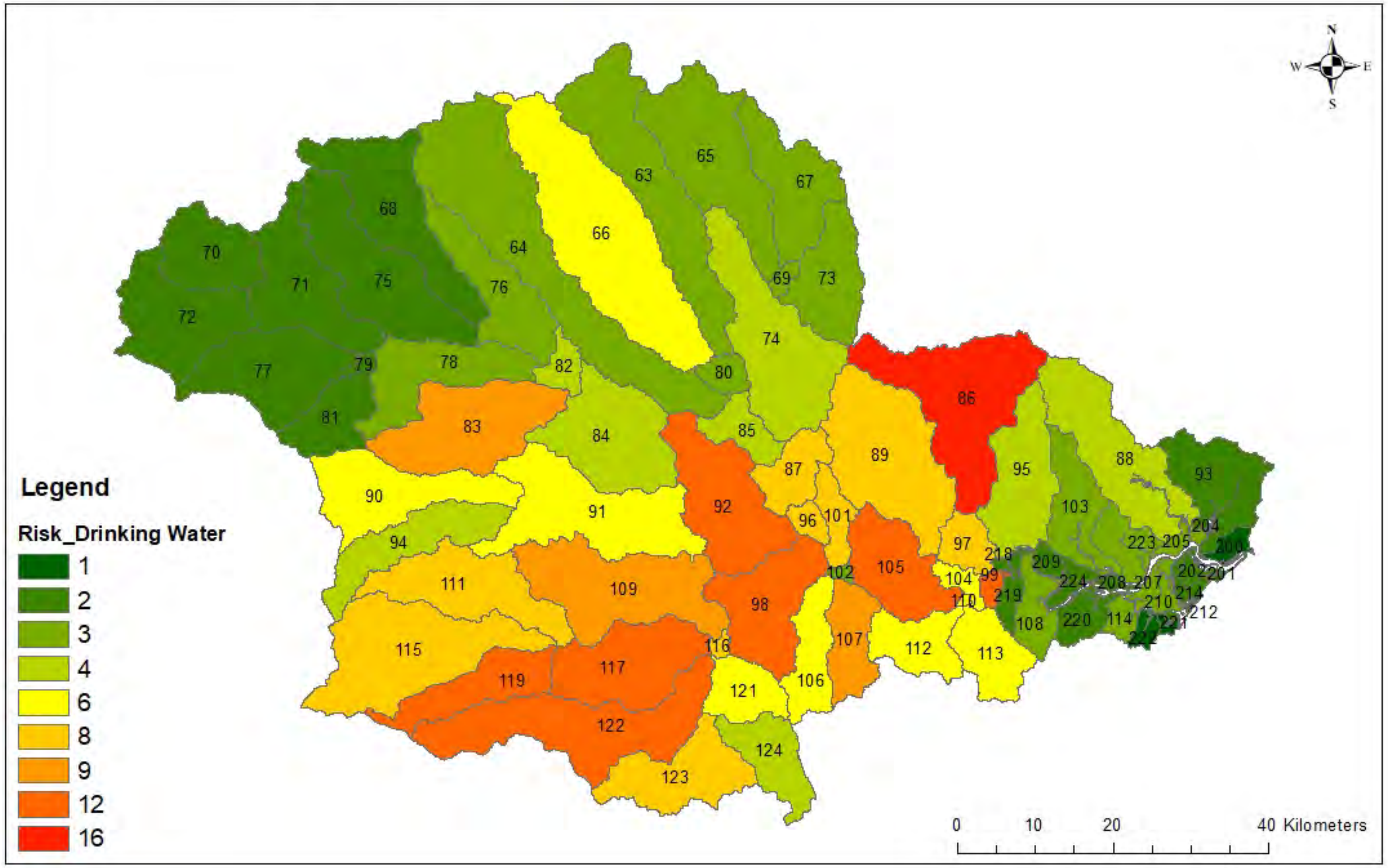


Map 7 **Stock Intensity Likelihood Scores used for pathogen risk assessments**

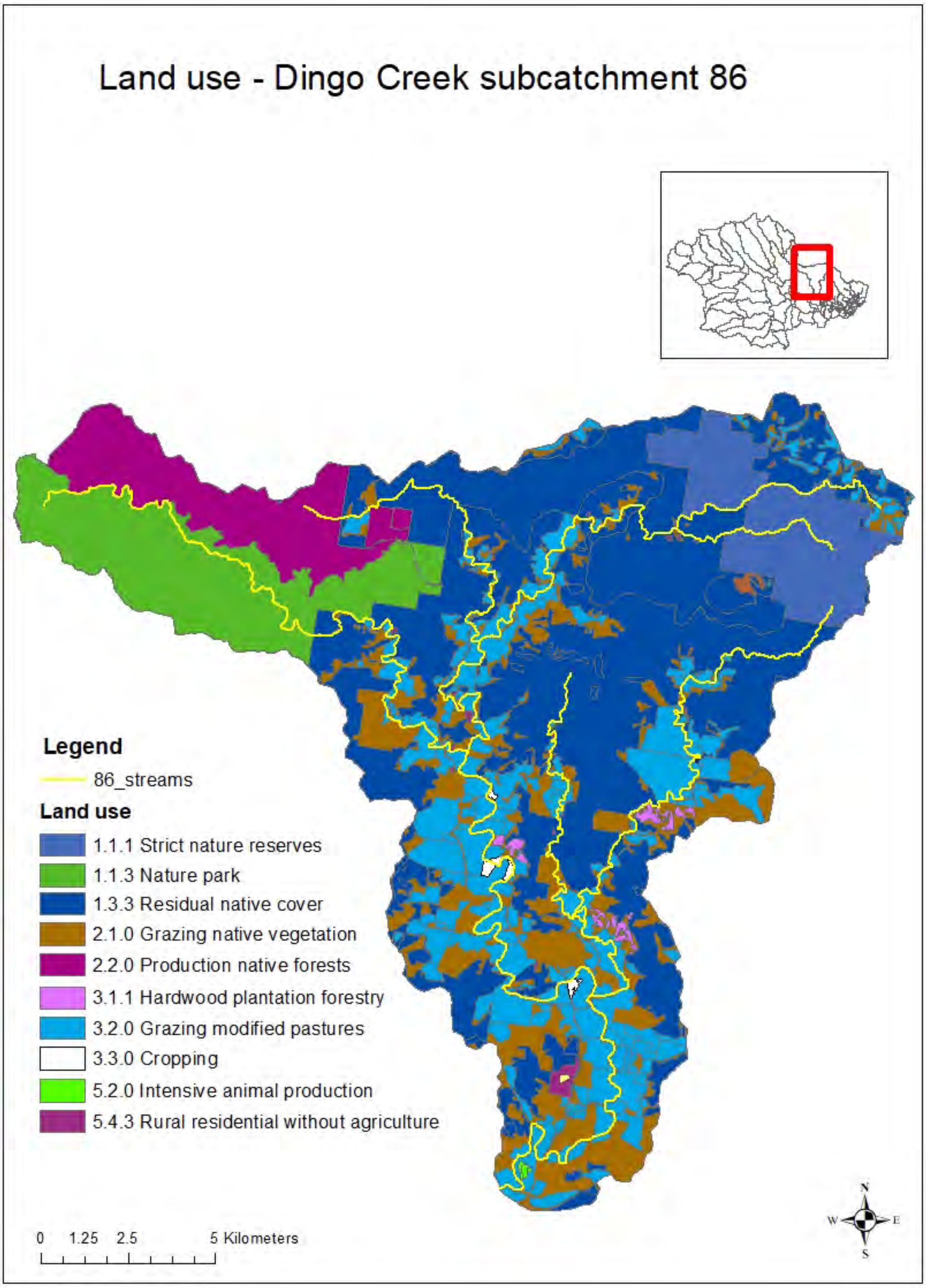


Map 8 **Drinking water supply catchment layer showing Consequence Scores allocated to each subcatchment in the drinking water supply catchment (4,3, or 2), stream order and locations of offtakes for Gloucester town water supply and Bootawa Dam (Forster and Taree water supply). Inset map shows drinking water supply catchment as green and estuarine subcatchments as orange.**

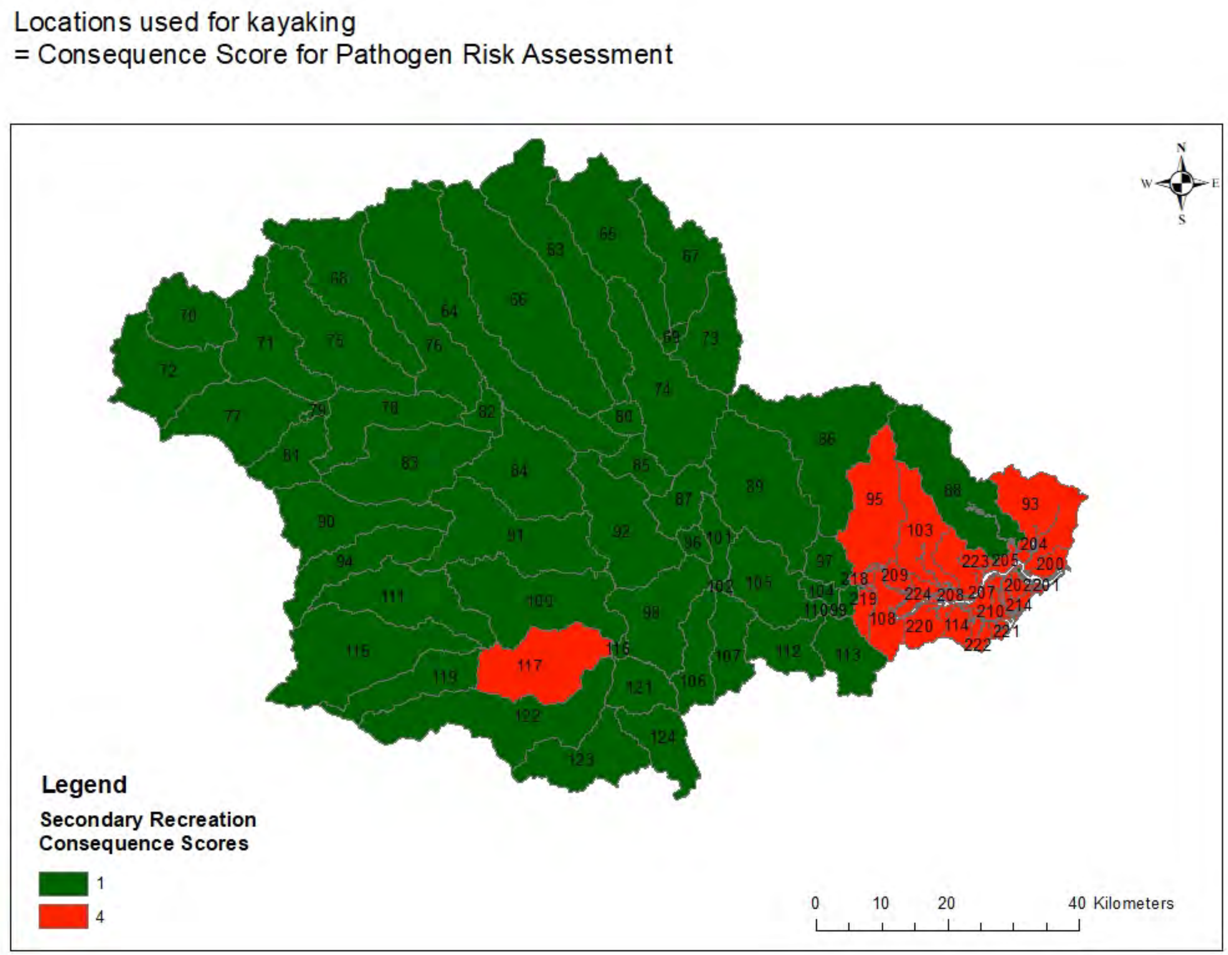
Pathogen Risk Assessment - Drinking Water
(pathogens from stocking intensity)



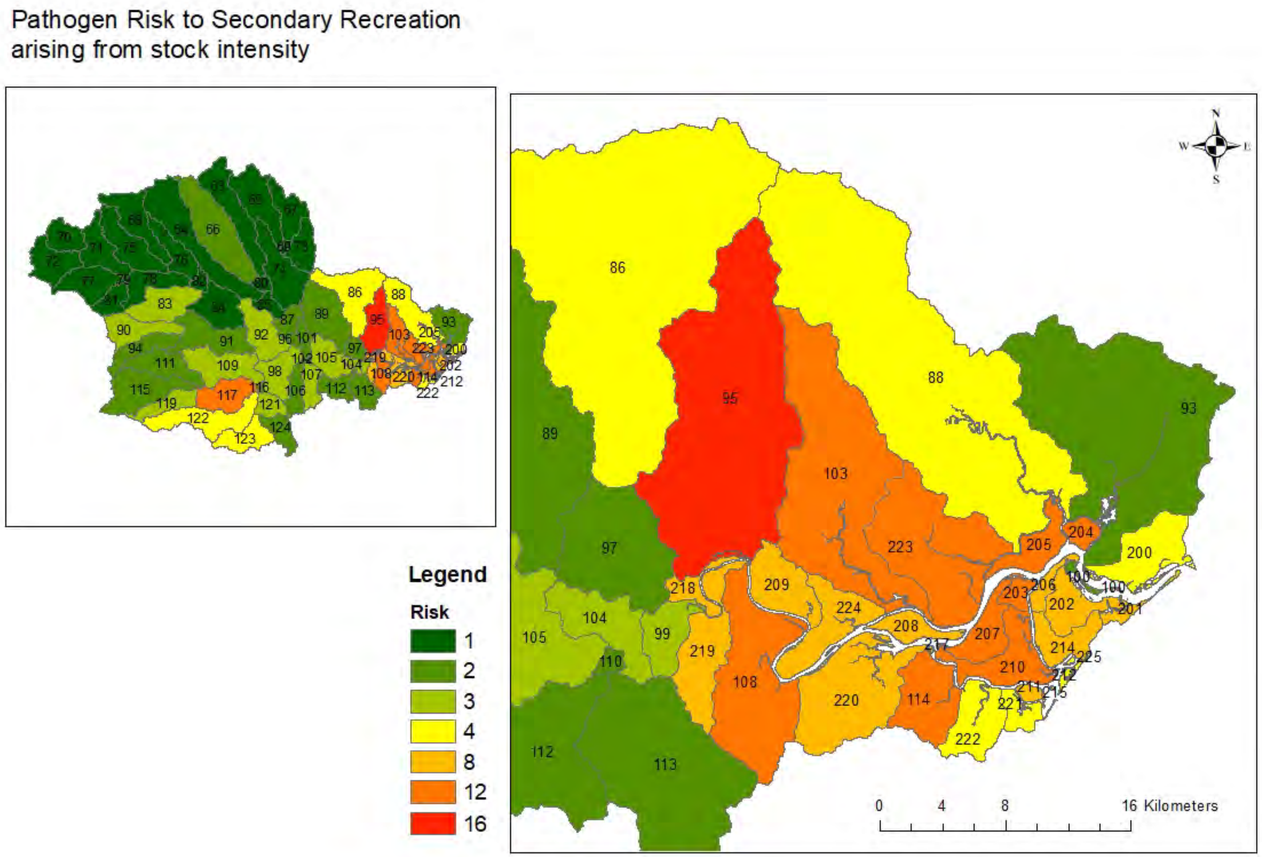
Map 9 **Risk assessment – risk of pathogens from stock intensity on drinking water quality**



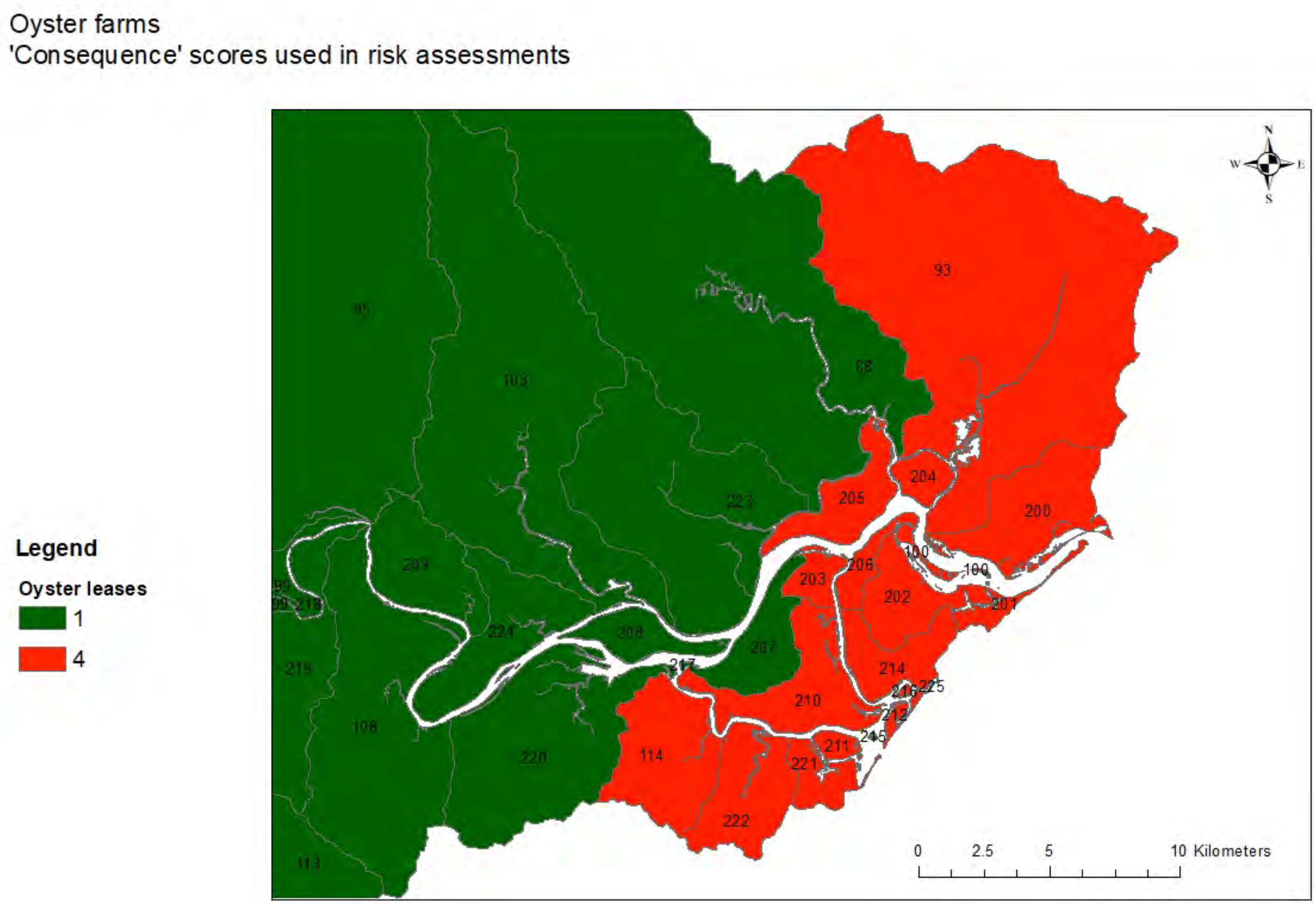
Map 10 **Updated land use for Dingo Creek subcatchment 86. Some minor land uses omitted from legend. Light blue areas are Grazing Modified Pasture. Forested areas make up a large proportion of the subcatchment (1.3.3 dark blue,1.1.1 French blue, 1.1.3 olive green and 2.2.0 magenta)**



Map 11 **Consequence Scores for secondary recreation (kayaking) used in risk assessment of potential exposure of community to pathogens arising from stock during secondary recreation (kayaking). Kayaking locations sourced from social media (Strava) and recreational guides (internet).**

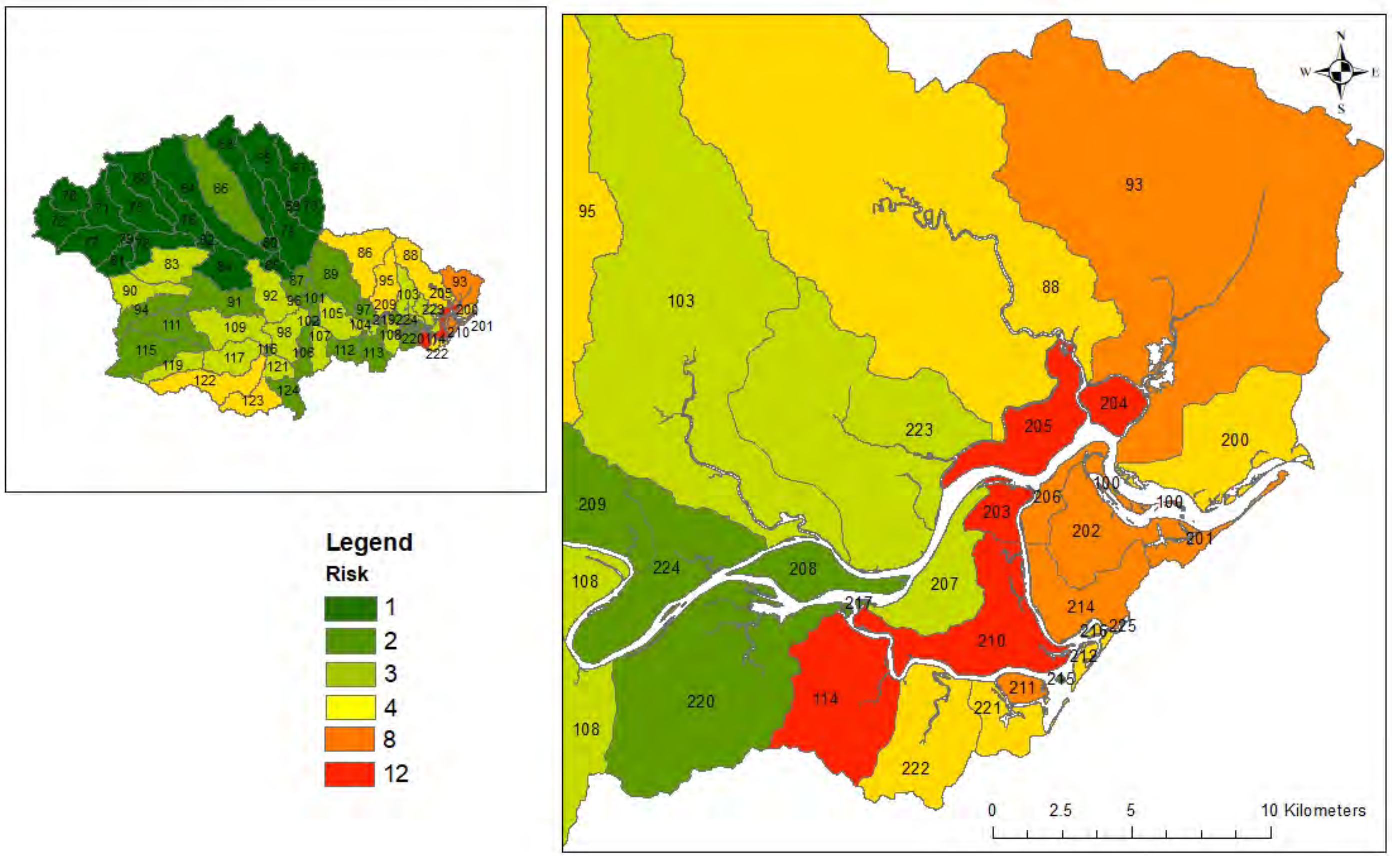


Map 12 **Risk assessment – potential exposure to pathogens from stock at known locations for secondary recreation (kayaking) in the Manning catchment.**



Map 13 Consequence Scores for aquaculture/oyster farms in the estuary, used in the assessment of risk of pathogens from stock on aquaculture

Pathogen Risk to Aquaculture (oyster farms) arising from stock



Map 14 **Risk assessment - pathogen risk to aquaculture/oyster farms posed by stock intensity in surrounding subcatchments. Risk assessment used Likelihood Scores for stock intensity (Map 7) and Consequence Scores based on locations of oyster farms (Map 13)**

Secondary Recreation Layer (consequence criterion)

Council are undertaking a review of community uses/values for the Manning River and estuary, however that data was not available to include in this report. The following risk assessments were based on qualitative information obtained from social media and recreational guides. The risk assessments should be revisited when the updated community values for Manning River estuary are available.

Information uploaded to the social media platform (social fitness network) Strava (www.strava.com) was used to identify locations used by the community for secondary recreation (kayaking, canoeing, Map A3-15). Internet guides for kayaking routes in the estuary (www.waterwaysguide.org.au) and known launch sites in the catchment were also added to the layer.

Subcatchments adjacent to locations for secondary recreation were assigned a Consequence Score of 4 while all other subcatchments were assigned a Consequence Score of 1 (Map 11)

Risk assessment – pathogen risk (from stock) to human health via secondary recreation

Likelihood Scores for stocking intensity for each subcatchment were multiplied by the consequence scores in the secondary recreation layer to get Risk Level for each subcatchment (Map 12). Secondary recreation includes activities such as kayaking, boating and fishing.

High-risk subcatchments

Cedar Party subcatchment 95 was deemed to be the subcatchment posing the highest risk of pathogen exposure from stock to community using the river for secondary recreation (Risk Level 16). Subcatchments 103, 223, 108, 114, 203-5, 207 and 210 were also deemed as High Risk (Risk Level 12) as a source of pathogens to the estuary. This risk assessment is very simple and should only be used as a rough guide for further investigation of bacterial counts in the river and estuary.

In-stream bacterial counts were only available in the estuary at locations near oyster farms (total faecal coliform) and at MCW monitoring sites in the freshwater catchment (total faecal coliform, *E. coli*). These data are presented in Appendix 3 and discussed with regard to impacts on drinking water quality and recreational use.

Barrington River subcatchment 117 received a Risk Level of 12 but probably poses the greatest risk to human health due to potential exposure to pathogens during secondary recreation, see Appendix 3 for further discussion. Very high concentrations of faecal bacteria have been recorded in subcatchment 117 (Table A3-1, A3-2) whereas counts in the estuary were relatively low in the quality control dataset (Table A3-3).

Aquaculture Assets - Oyster Farms Layer (consequence criterion)

Aquaculture is an asset of the Manning estuary of high value to the community's local economy (oyster farmers, tourism). Subcatchments adjacent to oyster farms were assigned a Consequence Score of 4 while all other subcatchments were assigned a Consequence Score of 1 (Map 13). This included all subcatchments from the mouth of the estuary and Farquhar Inlet to the South Arm of Manning River (excluding 207, Map 13)

Risk assessment – pathogen risk (from stock) to Aquaculture Assets

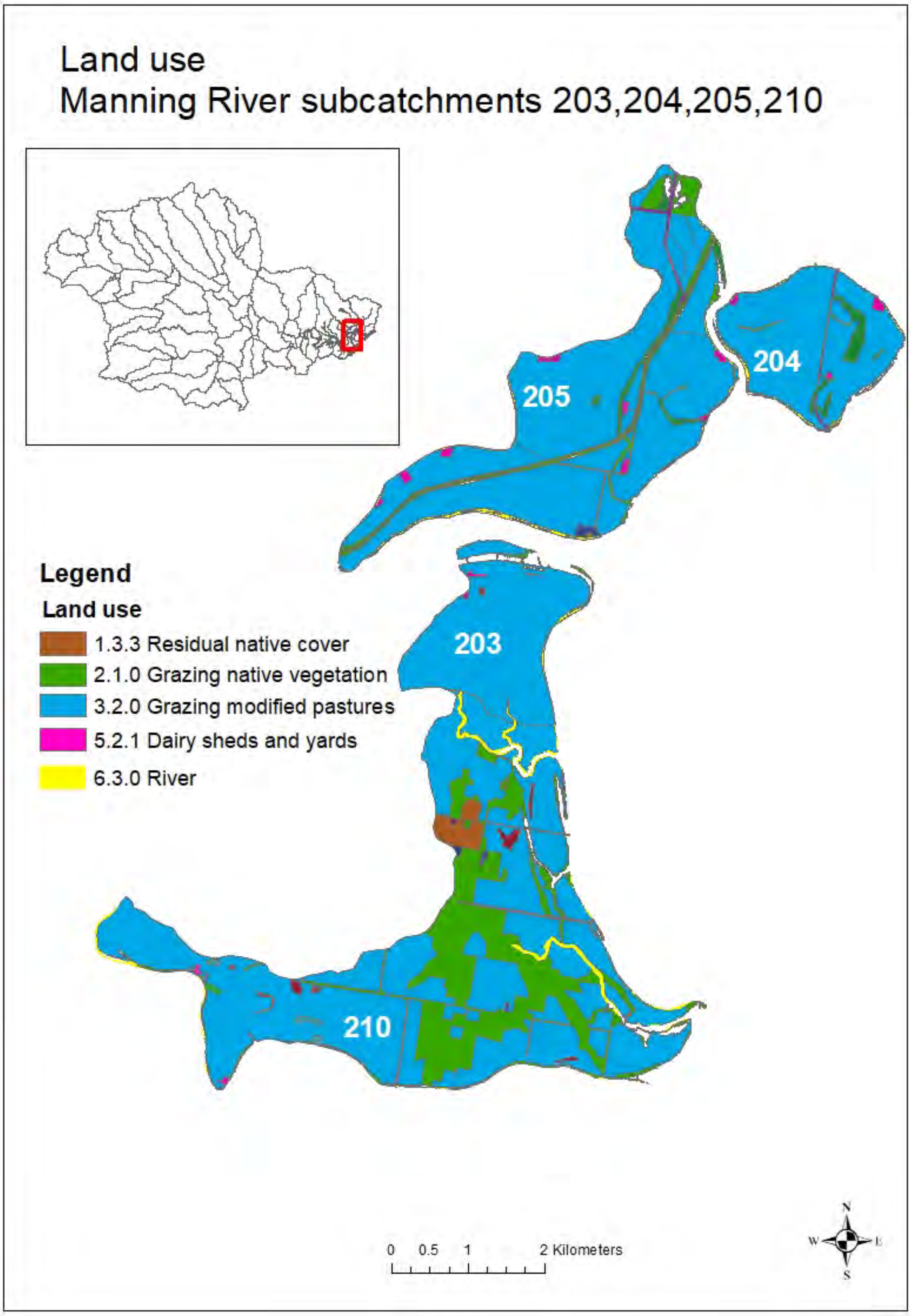
Likelihood Scores for stocking intensity for each subcatchment (Map 7) were multiplied by the Consequence Scores in the oyster farm layer (Map 13) to get Risk level for each subcatchment (Map 14).

High-risk subcatchments

Subcatchments 203, 204, 205, 210 and 114 were deemed to pose the highest risk to aquaculture assets based on stocking intensity in these subcatchments and their proximity to oyster leases. Land Use on 203, 204, 205 and 210 is primarily Grazing Modified Pasture (>90%, Map 15) and each subcatchment on average has 1400, 410, 1100 and 2600 stock per subcatchment, respectively (based on annual stock returns from 2009-2018).

Ground-truthing layers in pathogen risk assessment

Ground-truthing of stock intensity layer, and other layers used in the pathogen risk assessments is discussed in Appendix 3. Total faecal coliform data collected in the lower estuary and the freshwater catchment are also discussed in Appendix 3 (Tables A3 – 1-3).



Map 15 **Land use in Manning River subcatchments 203, 210 (Oxley Island), 204 (Mamboo Island) and 205 (Jones Island). Most minor land uses have been omitted from the legend. Grazing modified pastures are the dominant land use shown in blue.**

Pathogen Risk from On-Site Waste Management

The majority of the MidCoast LGA is unsewered. Failing systems or mismanagement of on-site waste from humans and stock present a pathogen risk to groundwater and receiving waters.

Decentralised Water Consulting (DWC) developed an On-site Sewage Management Development Assessment Framework for council to guide Council's levels of investigation, acceptable solutions (deemed to satisfy) and minimum standards for sewage management in unsewered areas (DWC 2018a). All unsewered allotments in the MidCoast area have been assigned an On-site Sewage Management Hazard Class. This Hazard Class (Low to High) determines the level of detail required for supporting information submitted with development applications and applications to install or alter sewage management systems. The mapping produced by DWC can be used to inform those subcatchments which are a source of human pathogens to aquifers, groundwater and waterways, if waste systems fail or are not fit-for purpose.

A risk assessment approach was used to determine the Hazard class for unsewered allotments in the MCC LGA, resulting in a Land Capability Hazard Class being assigned to each unsewered lot (Map 17). A 'base' hazard level was assigned to each lot which considered soil type, slope and climatic factors that influence the transport of, and attenuation of, pollutants and pathogens from land to receiving waters, for example. Annual nutrient balance and buffer calculations, standard viral die-off modelling and site-specific attenuation modelling were included in the assessment (DWC 2018b). The base hazard level was adjusted based on proximity to, and sensitivity of receiving environments. That is, the likely consequence of any failure in on-site sewage management systems was considered in the risk assessment. Table 2 shows the proximity hazards used in the risk assessments. The Land Capability Map – the outcome of the on-site sewage management risk assessment, is shown in Map 17.

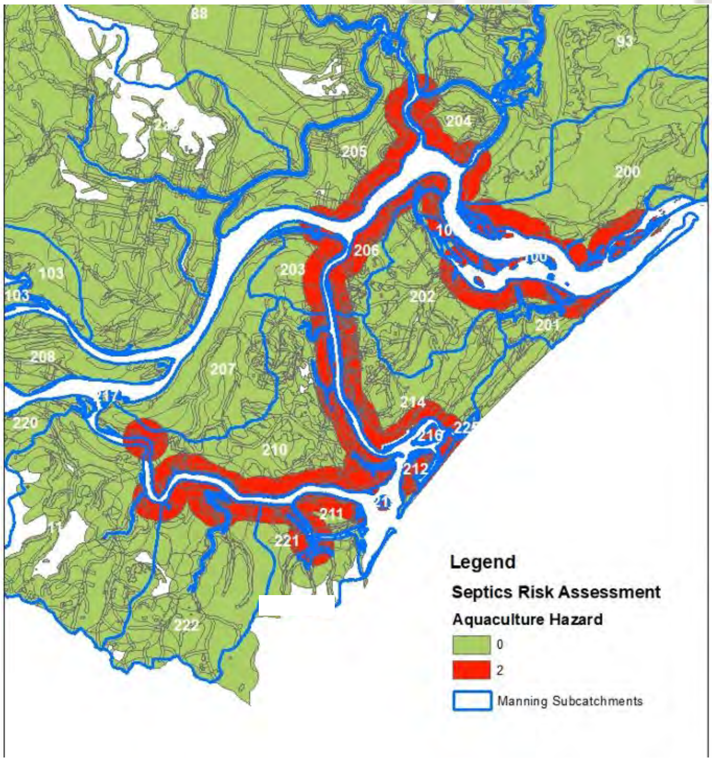
The methodology used for the risk assessment is similar to the approach used for the risk assessments in this report (i.e., risk based on likelihood and consequence). For example, aquaculture farms were treated as a sensitive receptor in the risk assessment and land adjacent to these assets were assigned 2 points to increase risk level due to proximity (Map 16, Table 2, DWC 2018b). Being located in a drinking water catchment was also considered in the risk assessment, however, points were not added for this because it covered so much of the catchment and resulted in too much land being assigned the highest hazard risk rating of 3. Instead land in the drinking water catchment had a minimum hazard risk of 2 (DWC 2018b).

The on-site sewage management risk assessment also considers nutrients from waste (DWC 2018a, b) therefore any land deemed to be high hazard class may also pose a nutrient risk to receiving waters.

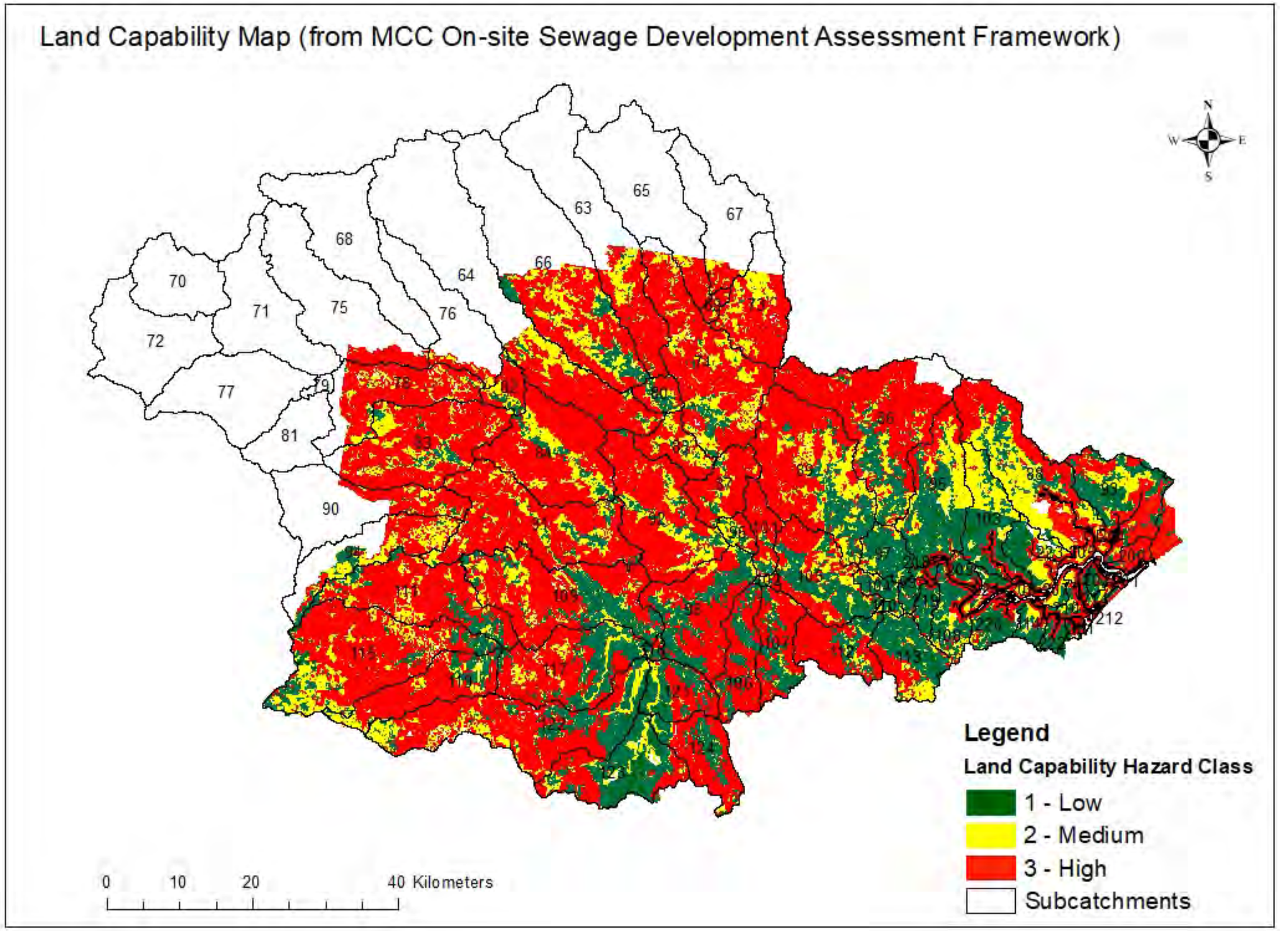
Table 2 **Proximity hazards used in the risk assessment for on-site sewage management in assigning a Land Capability hazard class (Map 15, DWC 2018b)**

Land Capability Proximity Hazards

Proximity Hazards	Proximity	Hazard Application
Minor Watercourse	40m	Raise hazard class by 1 for each proximity hazard present. Total hazard capped at 3 (High Hazard).
Farm Dam	40m	
Major Watercourse	100m	
Floodprone Land	Within	
Receiving Environments		
SEPP Coastal Zones (2018)	100m	Raise hazard class by 2 for each proximity hazard present. Total hazard capped at 3 (High Hazard).
SEPP62 Aquaculture Zones	500m	
Potable Groundwater Bores	250m	
Drinking Water Supply Catchments and Sensitive Receiving Environment Catchment (Zone 1 and 2)	Within	Increased minimum standards - outlined within MCC DAF document (Section 2.9). Minimum of Medium (2) Hazard if within these Zones.



Map 16 **On-site sewage management risk assessment - land adjacent to oyster farms was assigned an additional 2 points on top of base hazard level in the risk assessment (maximum Hazard Class 3, DWC 2018b). The Consequence layer used in pathogen risk assessments from stock assigned score of '4' to all subcatchments intercepted by the red buffer.**



Map 17 **Land Capability Map showing Hazard Class assigned to unsewered lots in the MCC LGA (catchment in other LGAs was not assessed, DWC 2018a). The risk assessment considered many factors in assigning the Hazard Class such as soil, slope, climate as well as proximity to, and sensitivity of receiving environments (DWC 2018b).**

Erosion Risk Assessment

Erosion of hillslopes and streambanks is a widespread pressure in the catchment leading to loss of structure in the riparian zone and loss of vegetation. Riparian vegetation provides critical ecosystem services including stabilising banks and reducing the amount of pollutants entering the waterway. Riparian vegetation also serves as a physical buffer, slowing down overland flow before it enters the stream. Hillslope erosion contributes large amounts of sediment to waterways in the catchment following rainfall. An intact riparian vegetation zone captures some of the sediment.

Decades of land clearing for agriculture, and extended periods of drought have left a landscape of bare steep hills with minimal groundcover. The risk of hillslope erosion and streambank/streambed erosion (pressure, likelihood criteria) to riparian vegetation (asset, consequence criterion) was assessed.

Hillslope erosion

Hillslope erosion was used as a Likelihood (pressure) criterion in the risk assessment. Mean hillslope erosion rates in the subcatchments were calculated from a spatial layer of modelled hillslope erosion (Map A4-1, Yang 2019). See Appendix 4 for calculation of Likelihood Scores for Hillslope Erosion (Map A4-2).

Streambank/streambed erosion

Fragility is an index of river condition that reflects sensitivity to change in the River Styles Framework (Brierly and Fryirs 2005). Streams with bed erosion and bank erosion are deemed as more fragile/sensitive to change. The majority of streams in the Manning catchment were rated as having moderate fragility in the River Styles assessment (Map A4-3). Fragility of streams in the subcatchment was used as a likelihood criterion (pressure) in the erosion risk assessment as a measure of streambank/streambed erosion. See Appendix 4 for calculation of Likelihood Scores for Fragility (Map A4-4).

Combined Erosion Risk Scores

Likelihood Scores for Hillslope Erosion and Fragility (Maps A4-2, A4-4) were averaged for the Combined Erosion Risk Likelihood Score shown in Map 18.

Riparian Vegetation layer (consequence criterion)

Griffith University have produced a spatial map of riparian vegetation in the Manning LGA (Pietsch 2019). Thalweg (distance from mouth/confluence upstream) were divided into 1km reaches and the areas either side of the channel were combined into a single riparian zone. A canopy height model was used to determine the 'proportion of trees in the riparian zone greater than 2m tall'.

Riparian vegetation layer is included in the risk assessment as a consequence criterion. The 'proportion of trees >2m' in the riparian zones assessed are shown in Map A4-5. This attribute of the riparian vegetation mapping was used to score each subcatchment.

Two alternative consequence layers were produced. The first method scored subcatchments with the least riparian vegetation >2m tall as Consequence level '4' because losing further riparian vegetation in these areas was considered a high risk to estuary health (following the description of Consequence Scores on page 8, Map 19). Increased sediment loads from hillslope and streambank erosion would have a negative impact on stream (or estuarine) condition. This approach is opposite to the standard Natural Resource Management philosophy to protect the assets that are in good condition as a priority. An alternative scoring of consequence was applied in the alternate risk assessments in line with NRM philosophy (i.e., higher score for areas with more riparian vegetation >2m tall). See Appendix 4 for further explanation of the calculation of Consequence Scores using the alternate method (NRM, Map A4-6).

Risk assessment – Risk of Erosion to Riparian Vegetation

Likelihood Scores for Combined Erosion Risk for each subcatchment (Map 18) were multiplied by the Consequence Score for the ecological asset Riparian Vegetation (Map 19) to get Risk level for each subcatchment. The erosion risk assessment is shown in Map 20.

High risk subcatchments

Subcatchments 105 (Manning River), 92, 96 (Upper Manning River), 76 (Myall Creek) and 82 (Barnard River) have the highest erosion rates and the least riparian vegetation >2m tall in zones assessed. These subcatchments have the High-Risk level of 16 and are priority subcatchments for riparian vegetation if Council's management approach is to restore riparian vegetation in areas lacking the important buffer between land and stream estuary.

A second risk assessment was done which used an alternative scoring of riparian vegetation Consequence based on protecting the area with good riparian vegetation in line with standard NRM prioritisation. Please see Appendix 4 for this risk assessment.

Estuary Streambank Erosion

Note that the erosion risk assessment did not include streambank erosion in the main estuary channels and estuarine creeks. This is because the River Styles assessment only applies to freshwater streams therefore Fragility ratings were only available for freshwater streams in subcatchments located in the estuary.

Bank erosion is widespread along the main estuary channels and was recorded and photographed in the ground-truthing program (Swanson 2019). Bank stabilisation has occurred in some areas with fencing to restrict cattle access. Rock revetments have been constructed in areas with severe erosion to prevent further erosion (Subcatchments 205, 207; Photograph 4).

Photograph 4 Rock revetment and fencing on Jones Island (205) to protect bank from further erosion

Ground-truthing layers used in erosion risk assessment

Hillslope erosion – pressure

Hillslope erosion, or land at high risk of erosion (for e.g. bare steep hills), was noted and photographed by field teams during the ground-truthing program. Steep hills with minimal groundcover due to clearing and extended drought conditions were very common across the catchment and active erosion and erosion gullies were noted in high risk subcatchments (e.g. 105, 74, 85)

A selection of photographs of erosion in the catchment are shown in Appendix 4.

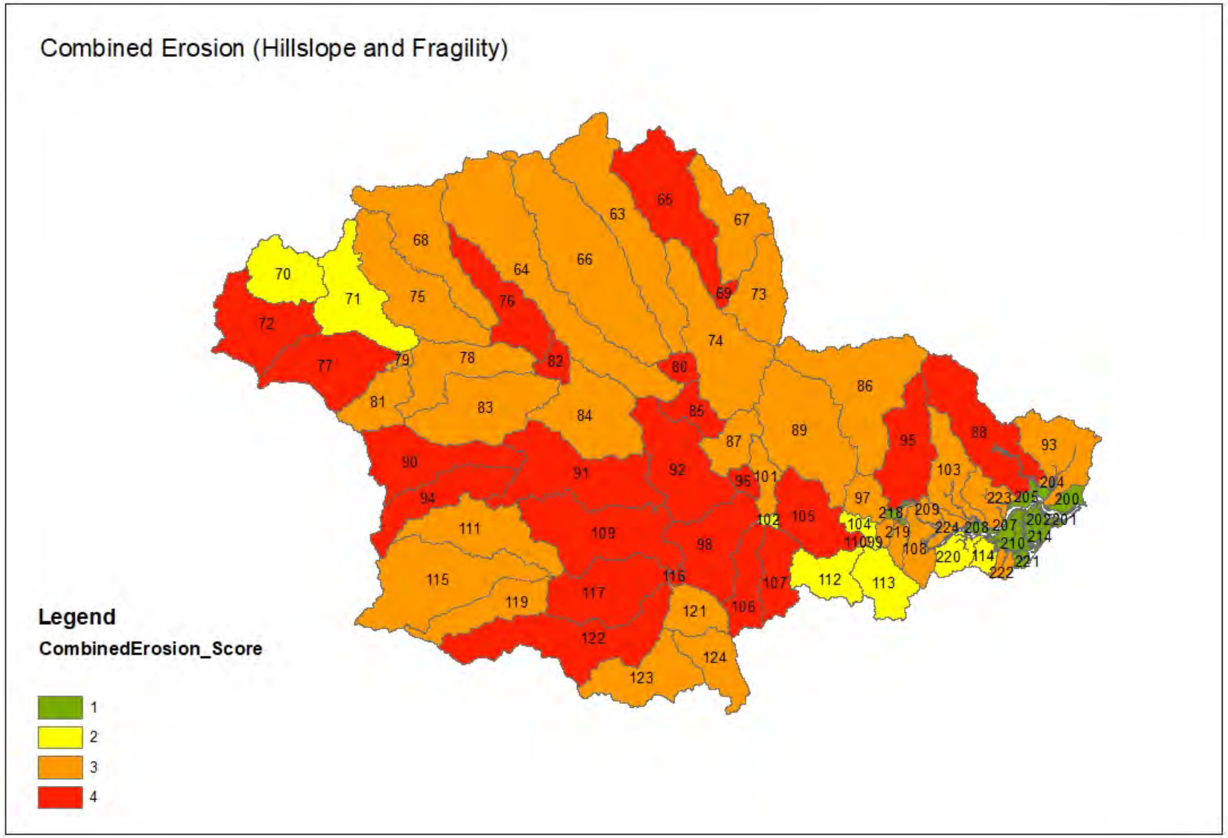
Fragility

The Rapid Site Assessment scores several geomorphic attributes for an overall Geomorphic Condition Score. There was a weak correlation of Fragility rating (1 – low, 2 – moderate, 3 – high) of the stream with the Geomorphic Condition score in the RSA (correlation = - 0.34, Graph A4-1).

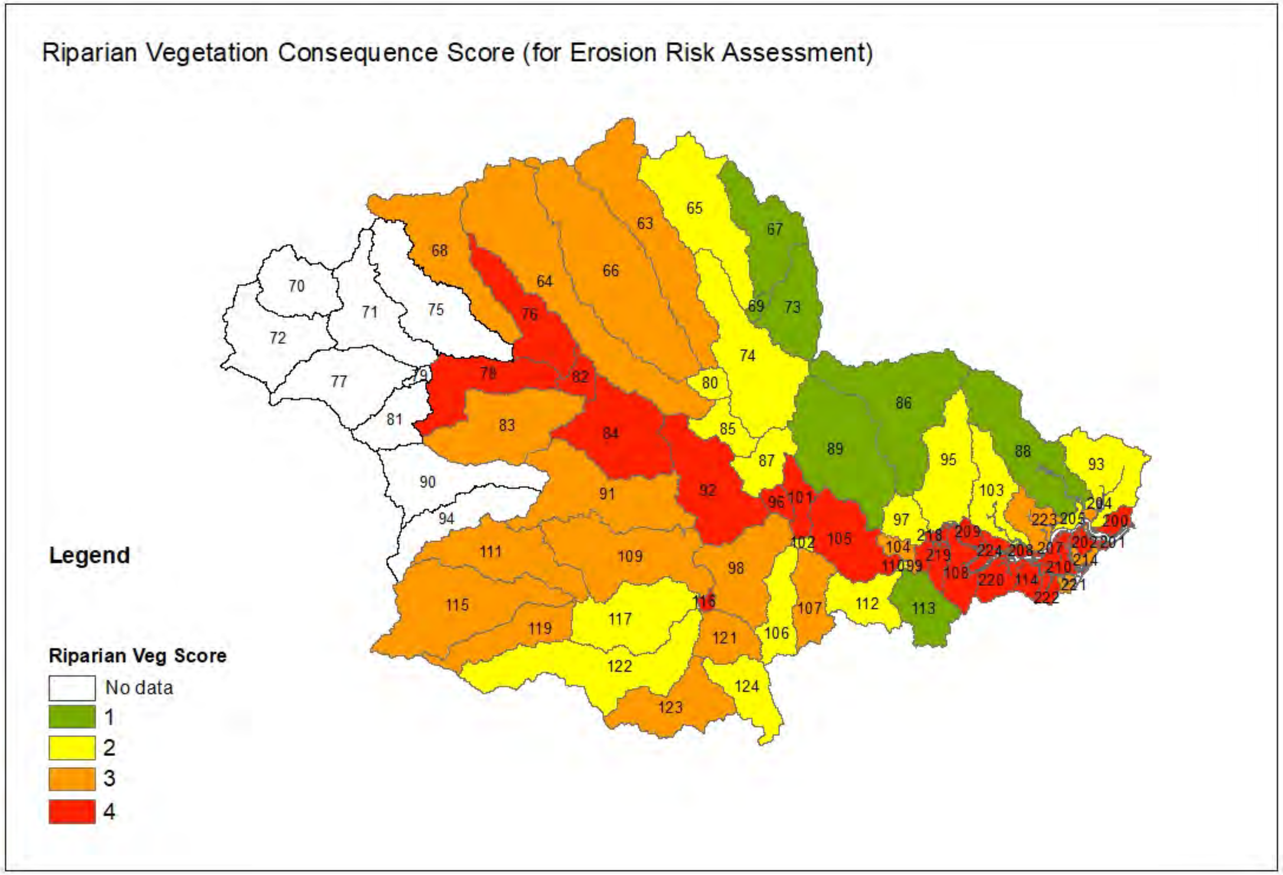
Riparian vegetation – Consequence layer

Several attributes of the riparian zone were recorded as part of the Riparian Condition component of the RSA. There were good correlations between the mapping data produced by Griffith Uni (Pietsch 2019) that was used to calculate Consequence Scores for Riparian Vegetation in the erosion risk assessment, and scores for attributes of the Riparian Zone (see Appendix 4).

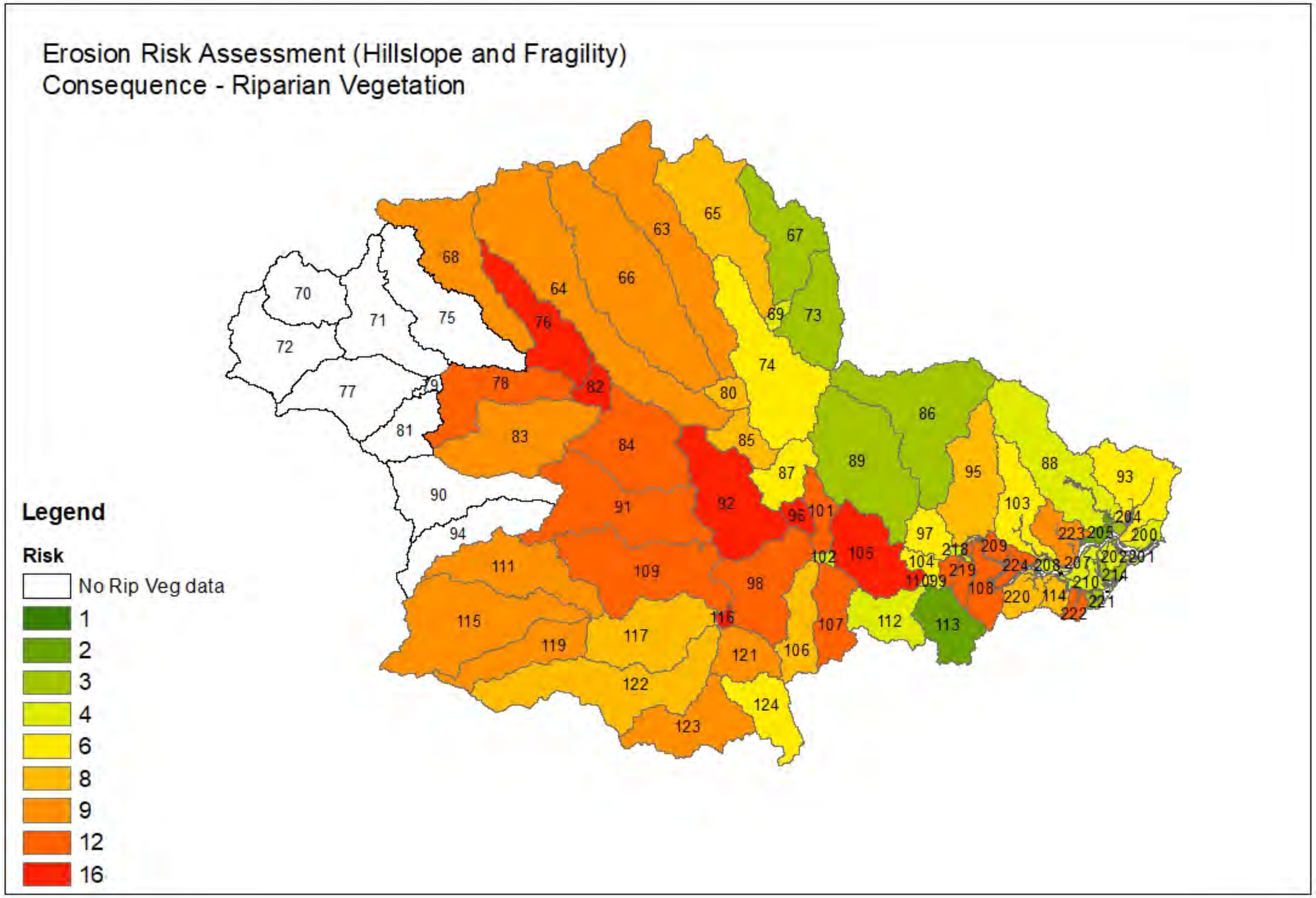
Ground-truthing of the layers used in the erosion risk assessment is discussed further in Appendix 4.



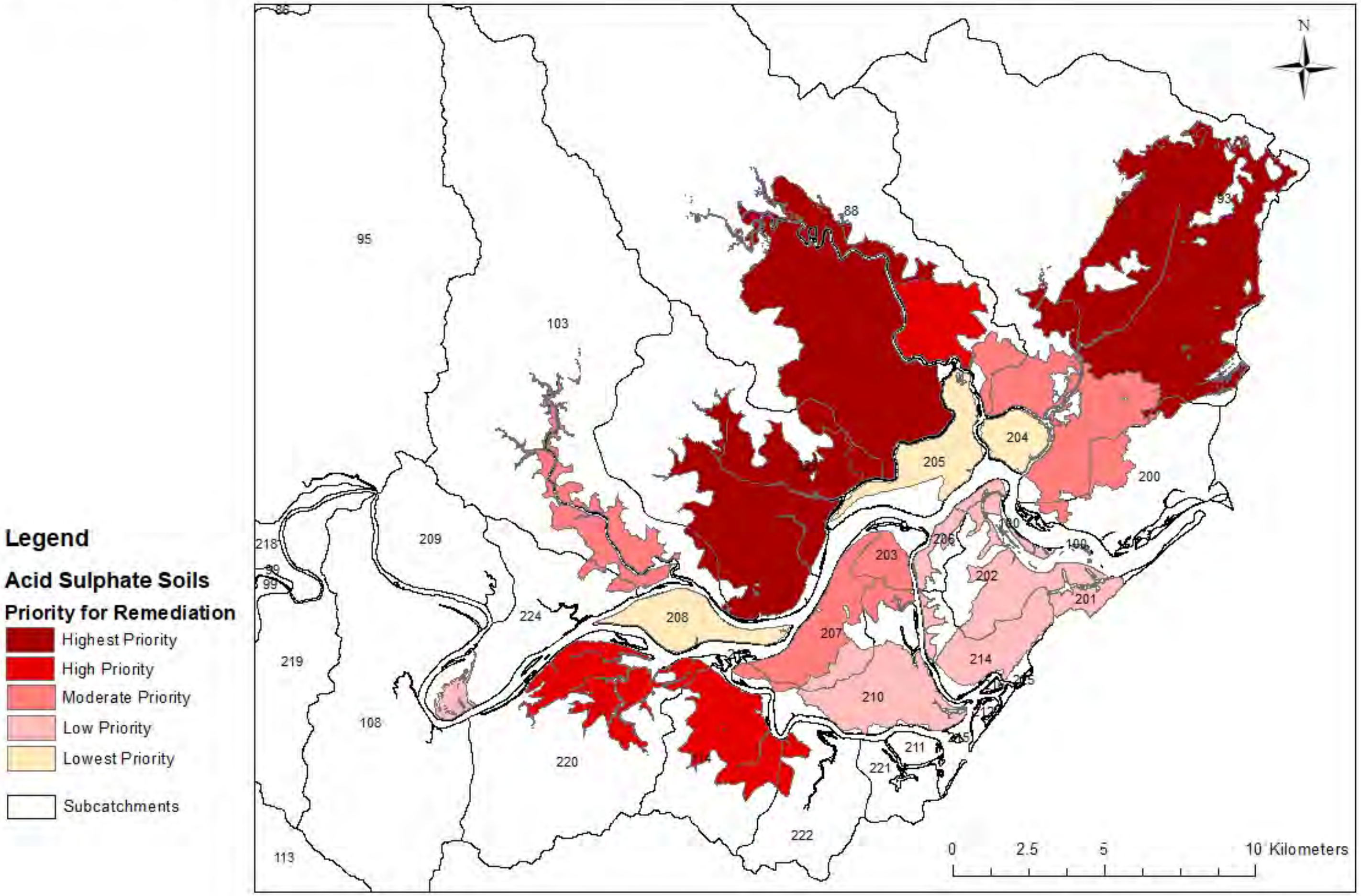
Map 18 **Likelihood Scores for Combined Erosion Risk (hillslope and fragility) used in the erosion risk assessment (Map 19). Note that Fragility ratings are only available for the freshwater catchment from the River Styles assessment.**



Map 19 **Consequence Scores for Riparian Vegetation across the catchment which scored subcatchments with the least proportion of trees>2m in the riparian zone assessed (averaged for subcatchment) as '4', and the highest proportion of trees as '1'. An alternate (opposite) method for scoring 'Consequnce' based on NRM priority to protect assets in good condition is presented in Appendix 4 (Map A4-6) which was used in Version 2 of the erosion risk assessment (Map A4-7)**

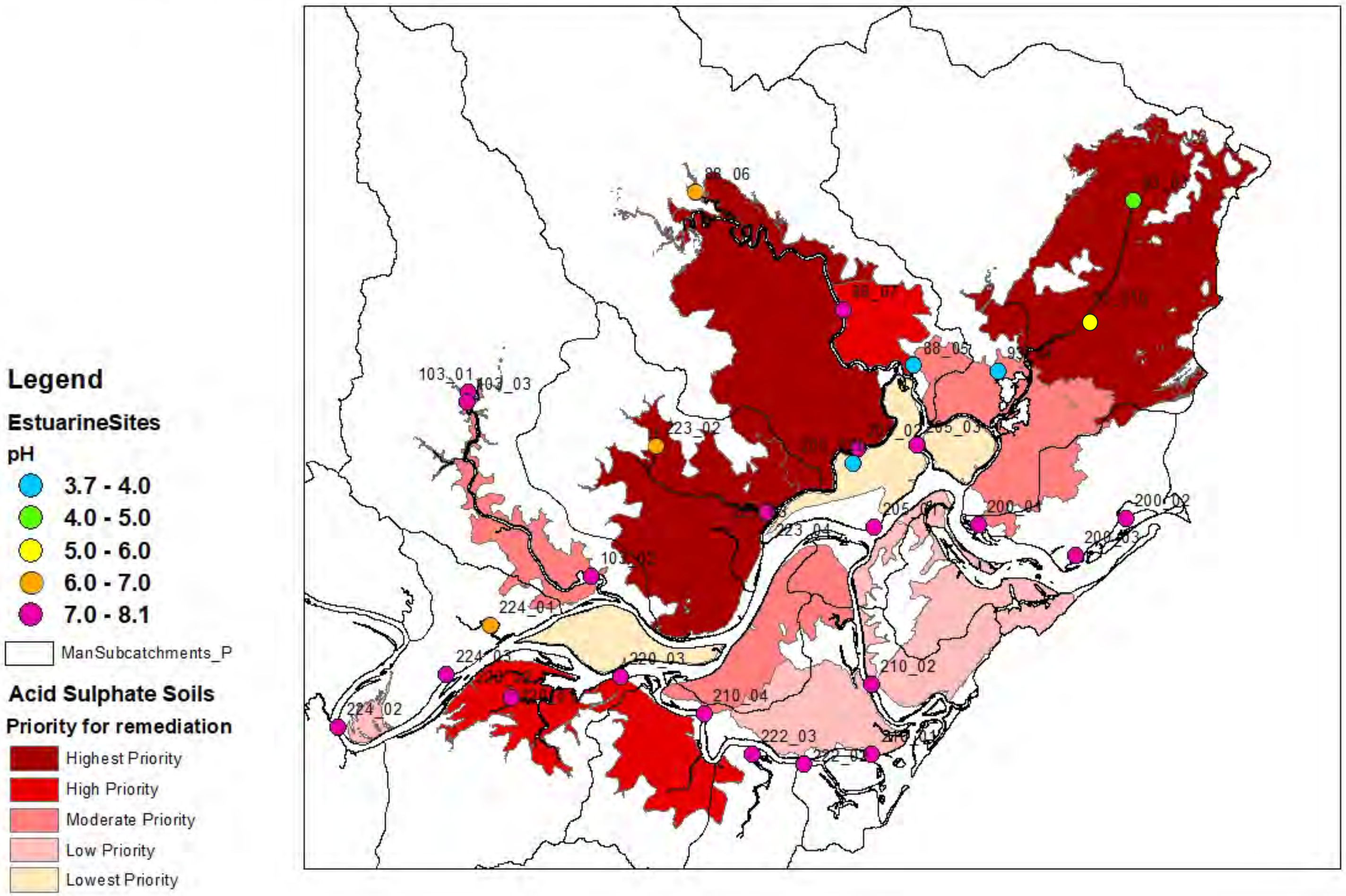


Map 20 The erosion risk assessment using combined erosion risk (hillslope and fragility) as likelihood criteria (Map 18) and riparian vegetation layer (Map 19) as consequence criteria.



Map 21 **Distribution of acid sulphate soils on the Manning floodplain showing prioritisation for remediation which based on a risk assessment (Glamore et al. 2016)**

pH recorded at Estuarine Sites and ASS distribution (Glamore et al. 2016)

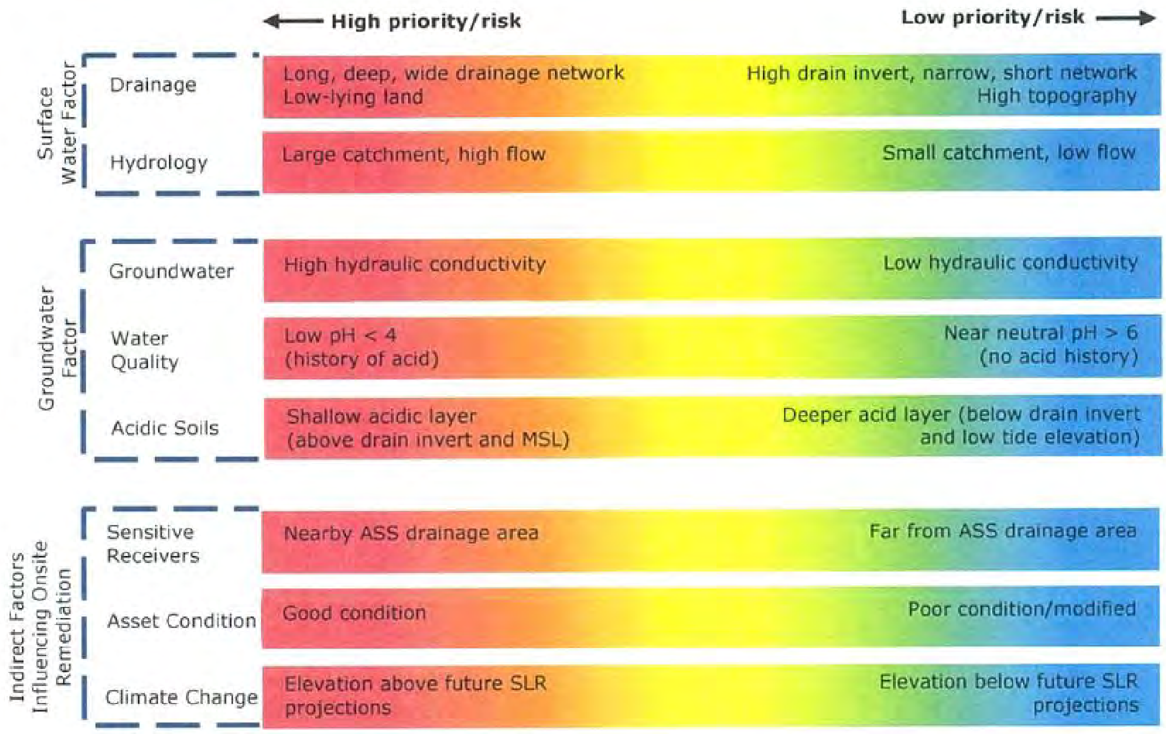


Map 22 **pH recorded at estuarine sites during the ground-truthing program. Acidic water was detected at sites downstream of highest priority areas for remediation (205-2b, 88-05, 93-04) and at sites in Cattai Creek subcatchment (93-01b, 93-03)**

Acid Sulphate Soils Risk Assessment

Acidic runoff associated with the extensive acid sulphate soils on the Manning floodplain poses a risk to estuary health, and assets such as saltmarsh, wetlands and oyster farms. A risk assessment has been done for The Lower Manning River Drainage Remediation Action Plan 2016 (Glamore et al. 2016).

The diagram below shows the factors influencing the risk of environmental impacts from ASS discharge from the Manning River Floodplain (Glamore et al. 2016). A Multi-Criteria Priority Assessment methodology was applied to rank the flood mitigation drains and larger drainage subcatchments of the Manning River floodplain. The distribution of ASS in the Manning floodplain is shown in Map 20 showing the prioritisation for remediation action that was based on risk to environmental factors (Glamore et al. 2016).



Factors Influencing the Risk of Environmental Impacts from ASS Discharge from the Manning River Floodplain (Glamore, 2016, p. iv)

High risk subcatchments

Results from *The Lower Manning River Drainage Remediation Action Plan* (Glamore *et al*. 2016) indicated that the highest priority subcatchments are primarily located on the northern side of the estuary and include Moto (Lansdowne River subcatchment 88), Ghinni Ghinni (Lansdowne River subcatchment 223) and Big Swamp (Cattai Creek subcatchment 93)(Map 21). These areas are estimated to be contributing over 80% of the total acid discharging to the estuary (Glamore et al. 2016).

Ground-truthing

Water quality data collected at some sites in Lansdowne River and Cattai Creek subcatchments showed impact from acidic runoff (Map 22). The lowest pH of 3.7 was recorded at Cattai Wetlands which was completely dry until a small rainfall event just before sampling, hence the very low pH recorded at the site (93-04, Map 22). Site 93-01B is the downstream end of Pipeclay Canal where a pH of 5.9 was recorded. The water in the canal had a turquoise hue due to the influence of aluminium released from acid sulphate soil. Roadside creek lines in Lansdowne subcatchment (88-05) and on Jones Island (205-02b) were very acidic (pH of 3.8) with a red hue to sediments indicative of iron release from ASS soils. Freshwater sites in Lansdowne River 88 and 223 had pH of 6 (site 88-11, 223-01) and water at 88-02 had a milky appearance.

The water quality data (pH) collected in the Rapid Site Assessments shows that acute changes in pH only occur in drains and tributaries in areas with acid sulphate soils but do not occur in the main channels of the river. These data align with water quality data collected by EES in the main channels of the Manning River Estuary since 2015. There are currently no identified indicators of the cumulative ecological consequences of pulses of low pH in the river which is a knowledge gap.

Discussion and Recommendations

The Manning River Estuary catchment is large and agricultural land uses dominate the landscape. Agricultural land use brings stressors which have the potential to impact on ecological and community values of the Manning River and Estuary. Widespread clearing for pastures and ongoing drought conditions have led to widespread degradation of floodplains and hillslopes in the valleys of the upper catchment. Fertilisation of pastures leads to increased nutrient runoff to waterways, particularly high concentrations of phosphate which leads to excessive algal and macrophyte growth and poor water quality.

Stock have a range of impacts including exacerbation of hillslope erosion, physical damage to riparian zone from trampling of streambanks, leading to a reduction in riparian vegetation from grazing and loss of bank structure to support vegetation. These impacts lead to increased sediment inputs to waterways from both hillslope and streambank/bed erosion. Cattle access to streams also adds nutrients and pathogens to waterways posing additional threats to water quality. The entire freshwater catchment serves as a drinking water catchment for local communities. Nutrient and sediment inputs pose a risk to the ecological values of the river and estuary while pathogens arising from stock pose a potential human health issue with regards to water quality for drinking and for secondary recreation. Similar pressures occur in the lower floodplain of the Manning Estuary. Acidic runoff associated with the extensive acid sulphate soils on the Manning floodplain poses additional risks to estuary health, and assets such as saltmarsh, wetlands and oyster farms.

This report presents separate risk assessments for each of these pressures on the Manning River and estuary. Each risk assessment is a spatial prioritisation tool which identifies the subcatchments which pose the greatest risk to the asset being assessed. It is important to emphasise that only relative spatial trends should be inferred from the estuary risk map, pathogen and erosion risk assessments. Further field assessments / investigations are recommended for those subcatchments deemed as high risk in the risk assessments, to locate specific areas where the pressure is greatest, and to determine appropriate on-ground works that will mitigate the threat to estuary health. A summary of high risk subcatchments for each pressure assessed are shown in Table 1.

High Risk subcatchments

A subset of subcatchments were rated as the highest risk to estuary health for more than one pressure occurring in these subcatchments. Targeted on-ground works in these subcatchments will have the best chance of improving the health of the Manning estuary by mitigating threats using a multi-pronged approach. Lansdowne River catchment (subcatchments 88, 223) poses the highest risk of impacts from nutrient and sediment inputs, acidic runoff from acid sulphate soils and pathogen inputs from stock (only subcatchment 223), on ecological and community values of the Manning estuary. As such, the ground works.

Other catchments which pose a high risk to ecological and community values of the Manning River estuary include:

- Cedar Party Creek (subcatchment 95, nutrient risk to water quality and pathogen risk to secondary recreation)
- Cattai Creek (subcatchment 93, acid runoff impacts)
- Dingo Creek (subcatchment 86, pathogen risk to drinking water quality)
- Barrington River (subcatchment 117, pathogen risk to drinking water quality and secondary recreation)

- Manning River (subcatchment 105, 110), Upper Manning River (subcatchments 92 and 96), Myall Creek (subcatchment 82) and Barnard River (subcatchment 82) each pose the highest risk of hillslope and streambank/bed erosion impacting on riparian vegetation and ultimately water quality in streams and estuary.

As the majority of the MidCoast (MCC) LGA is unsewered, human waste represents a risk to estuary values in many subcatchments. Failing septic systems, systems not fit-for-purpose or mismanagement of on-site human and stock waste (e.g. effluent from intensive animal production) presents a pathogen risk to groundwater and receiving waters in both the catchment and estuary. MCC commissioned Decentralised Water Consulting to do a risk assessment to determine the Hazard Class for unsewered allotments in the MCC LGA. The risk assessment produced a Land Capability Map with a Hazard Class being assigned to each unsewered lot (DWC 2018a, Map 17). This map should be used to guide Council's investigations of on-site sewage systems in high risk areas. If waste is poorly managed on land deemed to be High Hazard Class, the potential for human pathogens to enter aquifers and waterways increases.

Properties adjacent to oyster farms should be the focus for Council investigations of whether on-site sewage management systems comply with regulations. Of most concern is failing septic tanks which need to be located and removed. With current resources, MCC are presently re-active to on-site septic systems rather than pro-active (NBA Consulting 2018). Council audited high risk on-site septics in early 2000's, and complying systems were issued an "approval to operate", some of which required an annual renewal. However, no re-inspections have been carried out to ensure on-site septics continue to be operated within guidelines (NBA Consulting 2018). Discrepancies in Council records of sewered properties on Manning Point Road, and those which have on-site sewage systems, should be addressed (NBA Consulting 2018).

Human pathogens pose the greatest human health risk through consumption, or via exposure to pathogens during primary and secondary recreation. Popular sites for primary and secondary recreation should be the next priority with regards to locating and removing failing septic systems. The assessment of pathogen risk from stock to human health via secondary recreation could be improved with more local data. A water quality monitoring program for *E. coli* is recommended at recreational sites, offtake locations, aquaculture sites and at upstream locations. This sampling could also include DNA sampling to determine the source of faecal contamination (stock, human).

Ground-truthing spatial layers

The catchment model is underpinned by land use and associated Event Mean Concentrations (EMCs) that estimate pollutant concentrations in surface run-off for each land use type. The catchment model was calibrated with locally relevant EMCs for Grazing Modified Pastures (see Appendix 1), the dominant land use in the agricultural catchment. Catchment model outputs were tested with independent data collected in the freshwater catchment (MidCoast Water data). These tests provide a coarse validation of the EMCs used in the model, including the revised EMCs used for Grazing Modified Pastures. Another point to note is that the catchment model only considers nutrient and TSS export from the land (i.e. surface layer) for each land use type. It does not account for other sources of nutrients /sediments resulting from factors associated with that land use, e.g. stock waste, trampling of riparian zones, exacerbation of hillslope erosion.

Water quality data collected in the ground-truthing program showed only weak correlations with modelled loads used for the catchment model (see Appendix 2). Water quality was good in perennial streams due to lack of recent inputs from overland flow. Many streams had no flow with isolated pools ranging from puddles to large bodies of water. Water quality in isolated pools was variable and often poor. If the field program occurred during a wetter period, it is likely that water quality of streams would better reflect surrounding land use and show better alignment with predicted pollutant loads in the catchment model.

The pathogen risk assessments are based on stocking rates and known locations of assets rather than *in situ* measurements of pathogens. Limited in-stream bacterial data was available to ground-truth the layers but confidence in the assessment could be improved with more local data. A water quality monitoring program for *E. coli* is recommended at recreational sites, offtake locations, aquaculture sites and at upstream locations. This sampling could also include DNA sampling to determine the source of faecal contamination (stock, human).

The ground-truthing exercise had mixed outcomes with only partial validation of most spatial layers used in the risk assessments (Table 3). The timing of the Rapid Site Assessments (RSA) after a period of extended drought affected the field data collected in the RSA. The focus of the ground-truthing program was to cover as much of the vast catchment as possible which was achieved at the expense of number of sites assessed per subcatchment. High variability of site condition within each subcatchment contributed to the discrepancy between subcatchment average scores for attributes assessed did not always align well with subcatchment 'Likelihood' scores. Additional analyses provided some validation of the spatial layers used in risk assessments however, typically only weak correlations were found between the RSA data and data used to generate the spatial layers used in risk assessments. The intricacies of the ground-truthing analyses are discussed in the Appendices with outcomes summarised in the table below. A critical lesson from this part of the project is that effective risk assessments will require a larger investment to ensure that sufficient sites are assessed with each sub-catchment.

Spatial Risk Model

Spatial layers used in the separate risk assessments may be integrated to produce a spatial risk model for the Manning catchment which incorporates multiple pressures into a single risk map. The decision to integrate the separate layers is primarily dependent on the degree of validation (ground-truthing) of the individual layers representing the pressure to the estuary (Table 3). There are arguments for and against combining risk for different values into a single risk map. This process does provide a single risk outcome but can also hide much of the nuance and value of individual risk layers – and could lead to many areas assigned as "average" risk.

There is limited benefit from integration of spatial layers of each catchment pressure into a spatial risk model. The risk assessments address each pressure separately (= likelihood) and the consequence of that threat to ecological and/or community values of the Manning River estuary. The risk assessments are spatial prioritisation tools that identify the subcatchments posing the greatest risk to estuary health and other assets. It is recommended that Council refer to the separate risk assessments to guide future investigations and on-ground works to mitigate the pressure being assessed. For example, if Council wishes to address the source of turbidity during large storms, the erosion risk assessment identifies the high risk subcatchments contributing to the sediment load, which includes Manning River (upstream of tidal limit), Upper Manning River, Barnard River and Myall Creek.

Summary of Recommendations

- Lansdowne River subcatchments 88, 223 poses a high risk to estuary health from multiple threats (nutrient and TSS runoff, acidic run-off, pathogen risk from stock-223 only) and should be the initial focus of future investigations to locate specific areas of concern where on-ground works should occur to mitigate the threats.
- High *E. coli* counts frequently occur at the downstream end of Barrington River (subcatchment 117) at the offtake for Gloucester water supply. This stretch of river is a popular kayaking route, and the community also swim and fish at Relf's Landing. Stock are likely to be the main source of pathogens in the waterway due to the intensive farming and cropping that occurs here, however, poor on-site sewage management may also be contributing to the pathogen load. The source of *E. coli* in Barrington River (stock and/or human waste) can be characterised through DNA analyses (Seymour group, UNSW). Engagement/education of the local farmers and on-ground works to mitigate pathogen sources in this significant drinking water catchment should be a priority for Council and MidCoast Water.
- Identification of failing (or poorly maintained) septic systems in the vicinity of oyster leases should be a priority for Council and the oyster industry. Investigations should occur in unsewered areas that are also deemed as High Hazard in the Land Capability Map. Human pathogens are of most concern to the oyster industry. Currently NSW Food Authority monitor total faecal coliforms in the estuary near oyster leases as part of their Shellfish Quality Assurance program. The oyster industry should consider an in-depth investigation to identify the source of pathogens in estuary waters (stock, birds, dogs, humans) using DNA techniques. These data would help to guide on-land investigations of sources of human pathogens which are of most concern to the oyster industry.
- The assessment of risk of pathogens from stock on secondary recreation should be revisited when more bacterial data from waterways in the catchment becomes available and the community uses and values for Manning River and Estuary have been updated. The revised risk assessments should include an assessment of risk on primary recreation (swimming)
- There is limited benefit from integration of multiple risks/pressures into a spatial risk model. It is recommended that Council use the risk assessments separately, however outcomes of other risk assessments should also be considered for a wholistic approach to catchment management.

Table 3 The outcome of the ground-truthing of spatial layers used in Risk Assessments with field and observational data from the Rapid Site Assessments (validated, partial validation, not validated). Existing water quality data was also used to ground-truth some spatial layers. Note that 'RSA subcatchment average scores' are actually 'percentile rankings' of RSA subcatchment average scores (see Appendices for further information).

Spatial layer	Rapid Site Assessments (RSA)	Outcome – Validation
Catchment model inputs (generation rates for TN, TP, TSS and surface flow)	Existing water quality data (freshwater catchment) RSA subcatchment average scores for Land Use pressure RSA turbidity/chlorophyll data -freshwater sites -estuarine sites RSA Instream Site Scores (estuarine sites)	TN and TP inputs – validated TSS inputs – not validated Poor alignment of most scores but high risk subcatchments validated Not validated Validated Validated
Stock Intensity Likelihood Scores	Field observations of stock numbers in pastures RSA subcatchment average scores for Stock Impact Existing water quality (bacterial data)	Partial validation Not validated Validated (only for subcatchments which had data)
Hillslope Erosion risk Likelihood Scores	Field observations of hillslope erosion risk RSA subcatchment average scores for Streambed attributes	Validated Not validated
Fragility (River Styles) – streambank/bed erosion	RSA subcatchment average scores for Geomorphic Condition Individual site scores for Geomorphic Condition	Not validated Partial validation
Riparian Vegetation layer	RSA subcatchment average scores for Riparian Zone attributes Individual site scores for various Riparian Zone attributes	Validated Validated
Acid Sulphate Soil Risk Assessment	Water quality (pH) from RSA	Validated

Ground-truthing program

Full details on the methods adopted for the Rapid Site Assessments and an overview of the data collected are presented in another report: Manning River Estuary and Catchment RAPID SITE ASSESSMENT *A snapshot of stream condition in the Manning River Estuary and its catchment from the ground-truthing program* (Swanson 2019).

The following summary provides context for the ground-truthing analyses presented in the Appendices. Refer to the Rapid Site Assessment report for further details (Swanson 2019).

Sites assessed

- The Manning catchment is one of the largest coastal catchments in NSW comprised of 16 major river/creek catchments. Each major river catchment has been further divided into subcatchments based on 3rd order streams (EES subcatchments) for the catchment model (Map 1).

- Many Council staff were not familiar with the Manning River catchment, particularly the upper catchment, as this region only recently came under their jurisdiction following the merger of Taree City Council and Great Lakes Council in 2016.

- The decision was made to survey as many subcatchments as possible in the short time frame and limited resources available, rather than intensively survey a smaller number of subcatchments. Rapid site assessments across the whole catchment provided a holistic ‘snapshot’ of condition across the catchment

- 175 sites were assessed across all major river catchments and 31 sites were assessed in estuarine subcatchments.

- 44 EES subcatchments in total were included in the ground truthing surveys with an emphasis on subcatchments that rated as high to moderate risk to estuary health, in the first pass estuary risk map. A small number of low-risk subcatchments were however included for comparative purposes.

- At least 3 sites were assessed in each subcatchment surveyed with two exceptions (68 – 2 sites, 82 – 1 site). Typically, 4-6 sites were assessed in each subcatchment.

- The majority of sites assessed were on public land (e.g., Crown Land) to allow ease of access and planning, such as reducing the need to consult with landowners for access to/through their property which can be a time-consuming exercise.

Analysis of Rapid Site Assessment Scores

Site attributes

- Four attributes were selected that provide an assessment of ecological condition and severity of impact.
    - Land Use and agricultural pressure
    - Geomorphic condition (freshwater catchment only)
    - Instream condition
    - Riparian condition

Scoring methodology

- Within each category (Land Use, Instream Condition, Geomorphic Condition, Riparian Condition), specific site attributes were rated by a condition index score assigned to a description of the attribute representing worse (0) to best (5) condition (based on OEH 2015, 2016).
- Each site was assigned a total score for all site attributes within the categories Land-use, Geomorphic Condition (only freshwater sites), Instream Condition and Riparian Condition. These scores were combined for an Overall Condition score. Scores for each category were graded from Very Poor to Excellent. All scores for individual sites assessed in the ground-truthing program and an overview of field data collected in the catchment are presented in the Rapid Site Assessment report (Swanson 2019)
- Scores for each category representing Land Use pressure and Geomorphic, Instream, and Riparian Condition were averaged for each subcatchment. Average pressure/condition scores for each subcatchment were ranked into percentiles and compared to Likelihood Scores in the relevant spatial layers used in risk assessments of catchment pressures on ecological and community values of the Manning River estuary.
- These analyses were the initial step in ground-truthing of spatial layers used in risk assessments and are presented in this report in the ground-truthing section of the relevant Appendix. In most cases, there was poor alignment of subcatchment average condition scores with Likelihood Scores in risk assessments
- Site condition was often highly variable within freshwater subcatchments, which is one explanation for Rapid Site Assessment scores showing poor alignment with Likelihood Scores. Further analyses of data collected in the Rapid Site Assessments were undertaken in an attempt to ground-truth the spatial data used in risk assessments with mixed results. These analyses and shortcomings are discussed in more detail in the next section.

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Appendix 1 – Revision of EMCs for catchment model

Rebecca Swanson, Environmental Scientist

Reviewed by Peter Beale – Local Land Services (Hunter) and Jocelyn Dela-Cruz (EES-Placed Based Science) (September 2019)

Background

Catchment models use Event Mean Concentrations (EMCs) for pollutants (TN, TP, TSS). EMCs can be locally derived from monitoring programs which target a land use type in the area of interest, analysing pollutant concentrations in surface runoff. Derivation of local EMCs is a costly exercise so typically EMCs from the literature are used instead, for example, 'typical' EMCs for each land use type from Fletcher et al. 2004 are applied in MUSIC (Model for Urban Stormwater Improvement Conceptualisation) catchment models used by Councils and consultants.

The preliminary Estuary Health Risk Map for the Manning Estuary (MCC 2018) applied 'Grazing' EMCs to all land-use classified as Grazing Modified Pastures (GMP) using Australian Land Use and Classification (ALUM tertiary code 3.2.0). The 'Grazing' EMCs used were from the literature which were derived from grazing of native vegetation or modified pastures not heavily fertilised. Approximately 12% of the Manning catchment is classified as GMP however, pastures are fertilised to varying degrees, depending on production goals of the farm.

The EMC data in Table A1-1 were derived from an extensive literature search and analysis for CERAT - Coastal Eutrophication Risk Assessment Tool (OEH 2011) which assessed the risk of pollutants in surface runoff to the health of NSW Estuaries (Littleboy et al. 2009, Roper et al 2011). Only EMC data from NSW and Victoria were considered when formulating recommended values due to similar climatic / landscape features as NSW. Since the time of that review, the literature has been searched for publications to update the EMCs however very little new data for NSW/Victoria has become available. A recent review of the EMCs used in CERAT modelling resulted in adjustment of some EMCs, and the inclusion of additional categories of EMCs, for use in Estuary Health Risk Maps (Table A1-2).

EMC data proposed for the updated Estuary Health Risk Map have been selected from the original EMC data used in CERAT (Table A1-1), the revised set of EMCs (Table A1-2) and some adjustment made to EMCs for pastures in the Manning catchment based on local knowledge and conditions.

Pastures comprise most of the agricultural areas in the Manning River estuary catchment including irrigated and dryland pastures, heavily fertilised pastures on the flood plain and fertilised pastures on arable land adjacent to rivers in the catchment. Expert advice from LLS - Hunter (Peter Beale) and EES-Placed Based Science (Jocelyn Dela-Cruz) were considered when adjusting the EMCs for the second-pass risk model for The Manning River estuary.

Text below is taken from a description of Catchment Modelling for CERAT on OzCoasts website – with Table A1-1 showing the EMCs used in CERAT models.

A summary of concentration data for each Land Use type is provided in the tables below, and a list of publications from which concentration data were derived are provided in Data Types and Sources. Concentration data are expressed as event mean concentrations (EMC) *and dry weather concentrations (DWC). The EMC is equivalent to the mean concentration of nutrients or sediments in runoff from a rain event. The DWC is equivalent to the mean concentration of nutrients or sediments in the river or stream during dry weather or base flow conditions. A search of the literature (publications available between the period 1900's and June 2008) for local EMC and DWC data produced a total of only 25 relevant publications. The results demonstrate not only the paucity of EMC and DWC data in Australia but also the large variation in EMCs and DWCs for various Land Use types. Only total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) EMCs and DWCs were used for the modelling because these were the dominant forms of catchment export data found in the literature. To account for the limited and large variation in the EMC and DWC data, bootstrap techniques (Monte Carlo random sampling of the original data to produce a new data set, Baginska et al., 2003) were used to derive EMC and DWC median, means and confidence intervals for each Land Use type. Event mean concentrations (EMC, mg.L^{-1}) of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) determined from various land use types along the east coast of Australia used in CERAT modelling. EMCs are presented as medians, means and 95% confidence intervals (CI)*

Table A1 - 1 Event mean concentrations (EMC, mg/L) of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) determined from various land use types along the east coast of Australia used for CERAT. EMCs are presented as medians, means and 95% confidence intervals (CI) except for the land use classes with insufficient data to do bootstrap analyses.

Event mean concentrations (mg/L)									
Land Use classes	TSS			TP			TN		
	median	mean	95% CL	median	mean	95% CL	median	mean	95% CL
Crops	200			0.32			2.39		
Dry and Irrigated Horticulture	2972			1.81			31.9		
Forest	13.5	13.46	11 - 16	0.04	0.04	0.03-0.04	0.65	0.66	0.59 - 0.71
Grazing	18	18.33	12 - 25	0.21	0.21	0.16-0.27	1.58	1.58	1.39 - 1.8
Irrigated pasture	2972			4.5	4.53	3.6-4.9	10.45	10.64	5.2 - 14.6
Urban	63.25	67.29	5.25 - 129	0.38	0.37	0.25-0.47	2.05	1.9	1 - 2.32
Cleared Land (reflects DWC for unsealed roads)	900	1168.5	710 - 2625	1.10			12.17		

Table A1 - 2 Event mean concentrations (EMC, mg/L) of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) from Land Use types along the south-east coast of Australia used for NSW Estuary Health Risk Maps (Dela-Cruz et al. 2019). Additional Land Use categories have been added to the set of EMCs used in CERAT models (Table A1-1).

Land Use	Mean TSS mg/L	Mean TP mg/L	Mean TN mg/L
Cleared	900	1.1	12.17
Commercial	141.25	0.25	2
Crops	200	0.32	2.39
DryHort	2972	1.81	31.9
Forest	13.5	0.04	0.65
Forestry	33	0.58	1
Grazing	18	0.21	1.58
Industrial	141.25	0.25	2
Irrigated Horticulture	2972	1.81	31.9
Irrigated Pasture	2972	4.5	10.45
Other	0	0	0
Road	270	0.5	2.2
Rural Residential	89.13	0.22	2
Urban Residential	141.25	0.25	2

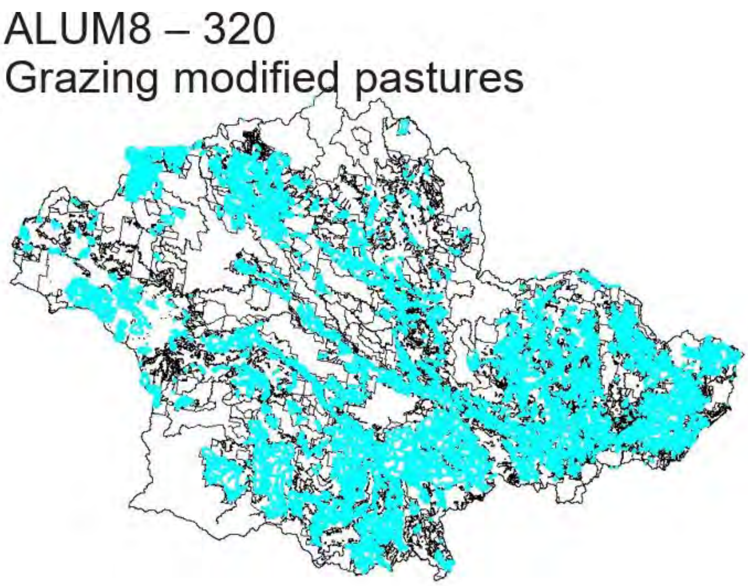


Figure A1 - 1 Grazing modified pastures (blue) in the Manning River catchment in NSW Land Use Map 2017, comprising approximately 12% of the catchment.

Revised EMCs for different types of pastures in Manning River catchment

Approximately 12% the catchment of the Manning River estuary has been classified as GMP (Figure A1 - 1) in the updated NSW Land Use Map 2017, however, pastures are fertilised to varying degrees, depending on production goals of the farm. Pastures vary from zero fertiliser use to heavily fertilised (50 -200 kg N/ha/y, 10-40 kg P/ha/y) with the higher rates typical for dairy farms and intensive beef production. Historical nutrient loading of the floodplain soils is another factor that has been considered in the proposed EMCs for grazing modified pastures in the updated Estuary Health Risk Map. Applying the 'Grazing' EMCs which reflect low intensity grazing, to all land use classified as GMP in the NSW Land Use Map 2017, is therefore not appropriate for the Manning catchment (see Figure A1-1).

The following advice from Peter Beale (Pastures Officer, LLS-Hunter) was considered in the revised EMCs for Grazing Modified Pastures in the Manning River catchment (summarised in Table A1-4) to use in the updated Estuary Health Risk Map.

Below is an email from Peter Beale – Monday 2/9/19

" the original TSS is too high for Irrigated Pastures. While they have higher fertility, they would have much lower sediment loads because ground cover is generally higher for more of the year. Also kikuyu is a mat forming grass that maintains very good ground cover with stolons and decaying leaf litter.

So I think your comments to reduce the levels [from those used in first run of second pass model] are justified.

For my purposes I would see pastures as being in three categories:

1. unfertilised... very low P and N but potential high sediment after drought... I think these cover 60 to 80% of the catchment

2. fertilised beef pastures.. maybe 5-10 kg P and S / ha per years... they produce some clover so N levels are higher.. so higher P&N but lower sediment because ground cover is more stable.. they cover 10 to 15% of catchment

3. intensively fertilised kikuyu ryegrass, lucerne chicory ryegrass in both beef and dairy farms these are the dark greens areas in June July satellite images ... my guess is 5 to 10% of the catchment..

they are quite varied in inputs from 10 to 40P/ha and 50 to 250 kg N/ha, very good ground cover

These will be potentially very high P levels on say 60% of the land due to long history of applying P and well documented high P soil tests.. this will show up in run off as it cannot be stopped

Nitrogen won't be extreme though because N is usually only applied over winter and below environmental yield potential... also N doesn't accumulate in soil like P..

Sediment low due to good ground cover, minimal or no cultivation and kikuyu Matt protecting soils

The Irrigation is in some respects not as significant as you would think.. firstly it is always supplementary ie not used all year due to high rainfall and unregulated streams that cease to pump..

This is different to many irrigated areas because the say in they Riverina it makes a huge difference in annual productivity... my modelling says Irrigation increases pastures by 30% on average ie we get wet years where it is hardly used.. and in dry years like this it becomes unavailable when you need it... that does depend on the river you're on but still true generally

I can't be definitive on loads and EMC as it's ages since I reviewed them but I think your headed in the right direction by lowering your original estimates [this statement is in reference to applying EMCs for Irrigated Pastures to all Grazing Modified Pastures in the first run of updated estuary risk map)

Land classed as Grazing Irrigated Modified Pasture (ALUM tertiary code – 4.2.0)

A very low proportion of the Manning River catchment is classified as Irrigated Land Use; Grazing Irrigated Modified Pasture (0.06%, ALUM tertiary code 4.2.0), Irrigated Cropping (0.003%, ALUM 4.3.0) in the NSW Land Use Map 2017. Land use mapping of irrigated land seems to be underestimated so other sources of imagery and mapping were interrogated. Irrigated modified pastures (grazing and cropping) in the Manning catchment were identified from NSW Land Use 2017 Map (ALUM 420), Nearmap interrogation and an Irrigated Land map provided by the Water Group (Department of Planning, Industry and Environment) which was based on NDVI thresholding, a type of imagery analysis, Map A1-1). Thus, for this study irrigated land was identified from various sources of aerial imagery rather than from irrigation/extraction licences.

The following caveat for the Irrigated Land mapping (Maps A1-1, A1-2) was provided by Ivars Reinfelds on 10/9/19 from the Natural Resources Access Regulator, former NSW Department of Industry.

The irrigated areas mapped for the Manning Estuary Tributaries Water Source appear conservative and are likely to be underestimated in the estuary but more accurate for the (i.e. could well be an underestimate by a large amount). This is because the greenness of the METWS was such that it was somewhat difficult to be confident of what was irrigated and what was not without field verification. We did quite a lot of verification through the main irrigation areas in Gloucester, Barrington, Bowman and Manning River water sources and what is depicted is an accurate representation of irrigated areas there In the Irrigated Land mapping (Pers. Comm. Ivars Reinfelds,10/9/19).

The EMC used for TSS for Irrigated Pastures (2972 mg/L, Table A1- 1,2) in the Estuary Health Risk Map in Stage 1 was based on a study done in Hawkesbury River floodplain

(Hollinger et al. 2001). There is very little EMC data for TSS from irrigated pastures in NSW and Victorian catchments. The EMC of 2972mg/L TSS is likely be an overestimation for the Manning catchment and instead it was replaced with the high range value for Agricultural EMCs for TSS (500 mg/L) from Fletcher et al. (2004, Table A1-3). Fletcher et al. 2004 reviewed stormwater quality from all types of catchments (although the main focus was on urbanised catchments) which gave preference to data from NSW studies when formulating recommended EMCs (Table A1-3 – original data from Tables 2.43-2.45 in Fletcher et al. 2004, pg 48).

Note that some irrigated pastures are grazed by dairy cattle and others are cropped for hay/silage.

Table A1 - 3 Recommended EMCs for agricultural Land Use from Fletcher et al. 2004

EMCs	TSS (mg/L) Low	TSS (mg/L) Typical	TSS (mg/L) High	TP (mg/L) Low	TP (mg/L) Typical	TP (mg/L) High	TN (mg/L) Low	TN (mg/L) Typical	TN (mg/L) High
Agricultural	40.00	140.00	500.00	0.20	0.60	2.00	1.00	3.00	9.00

Revised EMCs for Irrigated Pastures

Median values for TP, TN (Table A1-1) and high value for TSS - Agricultural from Fletcher et al. (Table A1-3)

- TSS – 500 mg/L, TP – 4.5 mg/L, TN – 10.45 mg/L

Land classed as Grazing Native Vegetation (ALUM tertiary code – 2.1.0)

Revised EMCs for Grazing Native Vegetation

Lower range values for TSS, TP, TN for Grazing (95% Confidence Interval, Table A1-1)

- TSS – 12 mg/L, TP – 0.16 mg/L, TN – 1.39 mg/L

Land classed as Grazing Modified Pasture (ALUM tertiary code – 3.2.0)

Based on advice from LLS-Hunter, land classed as GMP in the Manning River catchment was divided up into 3 subgroups and a different set of EMCs were applied to each type, reflecting the intensity of fertiliser application on those pastures and predicted TSS export based on ground cover.

Polygons assigned as GMP (ALUM 3.2.0) in the updated Manning land use map were segregated into the 3 types of pastures listed in Table A1-4 using a combination of Nearmap, Google Earth and other satellite imagery. Recent Nearmap imagery was used for lower catchment 2015-2019 however only Google Earth (2004) imagery was available for the upper catchment. LPI NSW Imagery was also used (2012) for the upper catchment. Winter timelines were interrogated where available, as intensively fertilised ryegrass pastures (Type 3) are clearly seen as bright green/dark green. Broadly speaking, Type 2 pastures were identified as the lighter green pastures. Distance from freshwater streams also helped to clarify Type 2 versus Type 3 GMP. All remaining pastures were assigned as Type 1. Approximately 70% of GMP were assigned as Type 1, 18% as Type 2 and 12% as Type 3 which agreed with projections in LLS advice.

EMCs for TSS for grazing in the literature ranged from 2 to 1000 mg/L TSS (median = 18, Table A1-1, A1-2). The median EMC of 18 mg/L TSS in the Grazing category seems too low for the modified pastures in the Manning River catchment based on personal observations during ground-truthing exercise and local knowledge. Instead, the 'typical' TSS EMC for agricultural land-use from Fletcher et al. 2004 was used for Type 1 and 2 pastures (140 mg/L TSS) to reflect local conditions. For Type 3 pastures, the median EMC for TSS (75 mg/L TSS) from the literature on dairy grazing was used (Austin and Prendergast 1996, Stevens et al. 1999, Cornish et al. 2002, Barlow et al. 2007)

Grazing Modified Pasture - Type 1 – Unfertilised pastures estimated to be 60-80% of (modified pastures in) the catchment. These pastures carry low stocking rates (<350 kg LW/ha) and are dominated by carpet grass and a mixture of native species (Kangaroo Grass, Red Grass etc) with no legume component because soil phosphorous levels are too low.

Revised EMCs for GMP-Type 1

Recommended values for TP and TN (median) for Grazing (Table A1-1 and A1-2) and typical value for TSS from Fletcher et al. 2004 (Table A1-3)

- TSS – 140 mg/L, TP – 0.21 mg/L, TN – 1.58 mg/L

Grazing Modified Pasture - Type 2 – Fertilised pastures for beef cattle estimated to be 10-15% of (modified pastures in) the catchment. These pastures are typically fertilised with single super, often intermittently, at rates of 5 to 10 kg P/ha/y. They support stocking rates of 350 to 600 kg LW/ha grazing introduced perennial tropical species such as Rhodes grass, kikuyu, setaria with very variable white clover component in the winter spring that provides 30 to 100 kg N/ha/y of fixed nitrogen (Mears et al. 1993). There is no cultivation of these soils. Some of the area is retired dairy pastures with moderate to high P levels.

Revised EMCs for GMP-Type 2

High range value for TP and TN (95% Confidence Interval) for Grazing (Table A1-1) and typical value for TSS from Fletcher et al. 2004 (Table A1-2)

- TSS – 140 mg/L, TP – 0.27 mg/L, TN – 1.8 mg/L

Grazing Modified Pasture - Type 3 – Heavily fertilised pastures and fodder crops (e.g. mostly kikuyu over sown with ryegrass for winter, also lucerne chicory pastures and a small proportion (<5%) with annual fodder crops such as maize summer ryegrass winter phase). They are predominantly located on the flatter, arable terrain and deeper alluvial soils with close proximity to watercourses. In the upper catchment (Wingham west, with a fresh water source) 30 to 40% are irrigated (Watson 2012) but are exclusively dryland on the lower floodplain where the estuary is saline. There is limited cultivation 5-10% of these pastures where annual fodder crops are grown or preparation for newly sown lucerne. Most ryegrass is established into existing kikuyu sward without cultivation.

Revised EMCs for GMP-Type 3

Low range of recommended values for TP and TN in Irrigated Pasture class (Table A1-1) to reflect high nutrient load, both current application and historical. TSS for dairy grazing (median) from the literature (Austin and Prendergast 1996, Stevens et al. 1999, Cornish et al. 2002, Barlow et al. 2007)

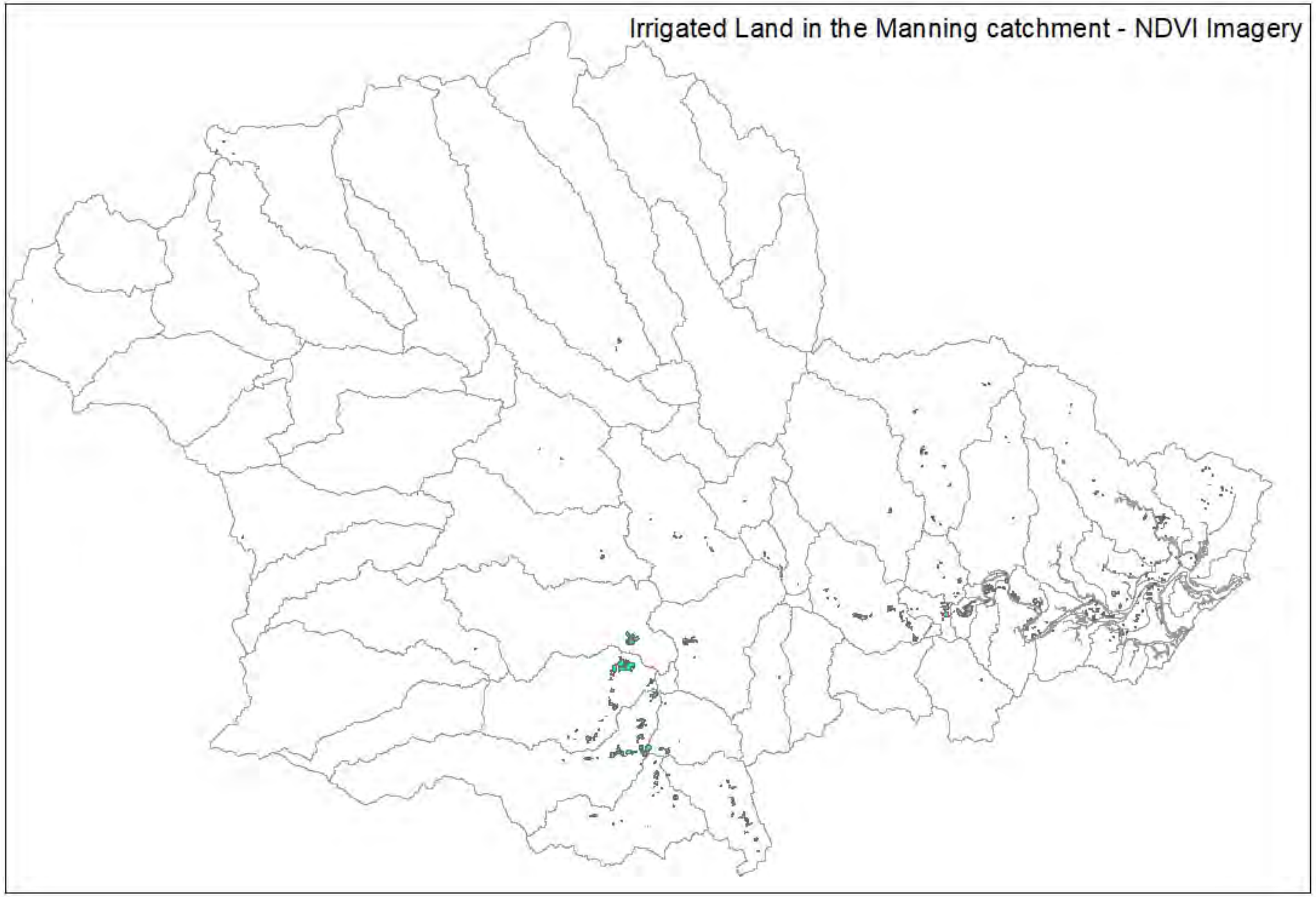
- TSS – 75 mg/L, TP – 3.6 mg/L, TN – 5.2 mg/L

Table A1 - 4 A summary of revised EMCs used for the land use classes, Grazing Native Vegetation, Grazing Modified Pastures and Irrigated Modified Pasture, in the updated Estuary Health Risk Map for Manning River Estuary

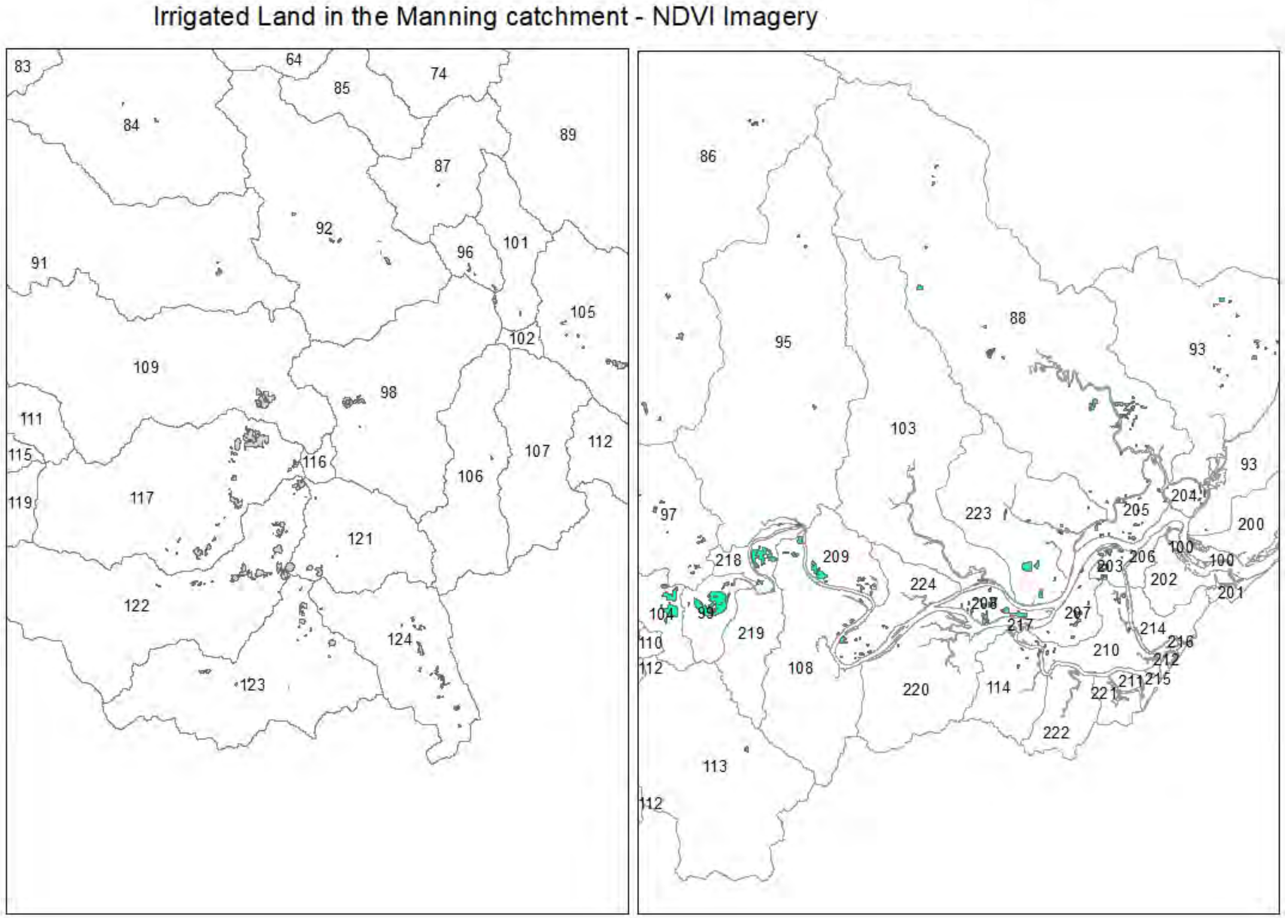
Land Use	TSS mg/L	TP mg/L	TN mg/L
Grazing Native Vegetation	12	0.16	1.39
Grazing Modified Pasture – Type 1	140	0.21	1.58
Grazing Modified Pasture – Type 2	140	0.27	1.8
Grazing Modified Pasture – Type 3	75	3.6	5.2
Irrigated Modified Pasture	500	4.5	10.45

Table A1 - 5 Other land use classes were assigned the following EMCs from Table A1-2 (unaltered unless otherwise stated) in the updated Estuary Health Risk Map for the Manning River Estuary

Land Use (Alum – tertiary level)	EMC Broad LU-category (Table A1-2)
Cropping (dryland)	Crops
Cropping (irrigated)	Irrigated Pastures (TSS – 500mg/L)
Intensive Animal Production Dairy sheds/yards, Cattle feedlots, Piggeries	Irrigated Horticulture (to reflect high N relative to P, in animal waste). Very high TSS (2972 mg/L) retained due to likely high loads TSS in wash down
Intensive Animal Production Poultry sheds and yards	Irrigated pasture (to reflect higher levels of phosphorous in poultry waste Very high TSS (2972 mg/L retained due to likely high loads TSS in wash down)
Rural residential	Rural residential
Forest	Forest
Forestry (all)	Forestry
Roads	Road
Cleared	Cleared
Dry horticulture	Dry horticulture
Irrigated horticulture	Irrigated horticulture
Urban residential	Urban residential
Commercial	Commercial
Industrial	Industrial
Waterways	Other



Map A1 - 1 **Mapped irrigated lands in the Manning Catchment in October 2013 based on Landsat imagery and NDVI thresholding – provided by Water Group, Department Planning, Industry and Environment (Reinfelds et al.). See Map A1-2 for further detail of the estuary and upper catchment**



Map A1 - 2 **The irrigated areas mapped for the Manning Estuary Tributaries Water Source and the main irrigation areas in Gloucester, Barrington, Bowman and Manning River water sources (Reinfelds et al.).**

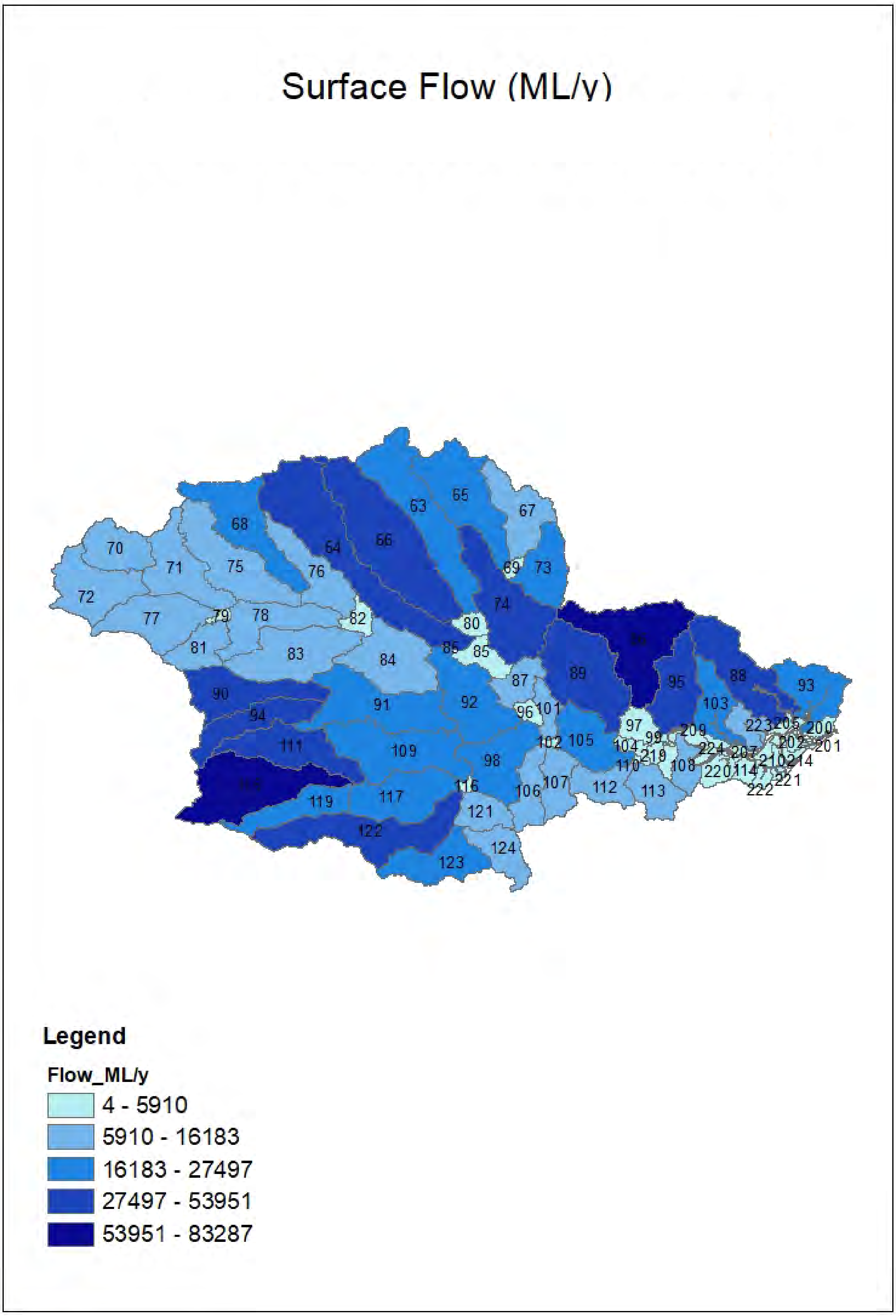
Appendix 2 - Updated Estuary Health Risk Map

Catchment model

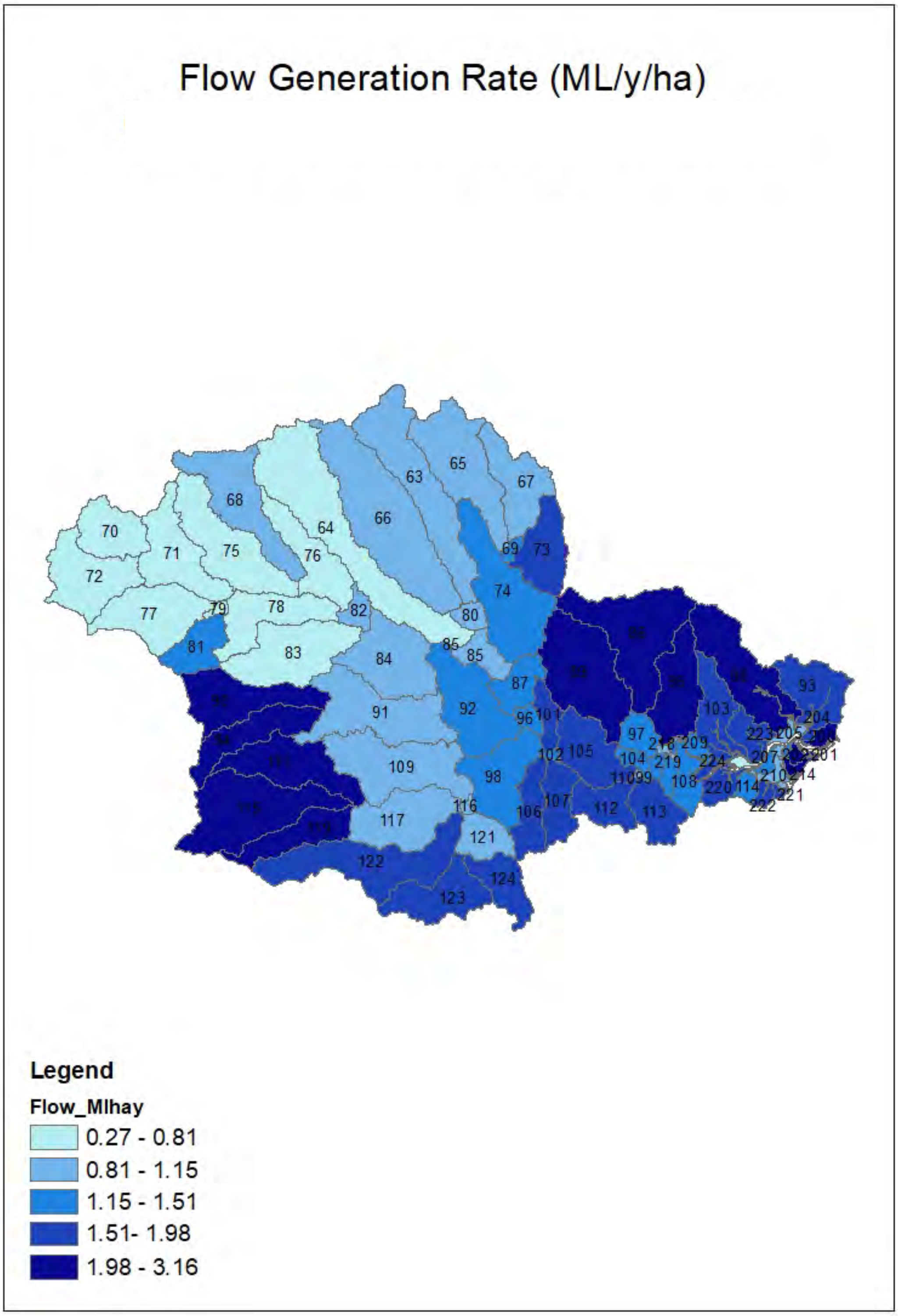
Catchment model outputs

Loads are total flow or amount of pollutants in surface runoff exported from the subcatchment per year (ML/y – Map A2-1, kg/y – Maps A2-3, A2-5, A2-7). Generation rates are flows (ML/ha/y - Map A2-2) or pollutants loads per hectare of subcatchment area (kg/ha/y - A2-4, A2-6, A2-8). Generation rates are a better reflection of the intensity of pollutants exported from the subcatchment to receiving waters and should be used to identify hotspots for pollution. Loads and generation rates for each pollutant for each subcatchment are shown in Table A2-1.

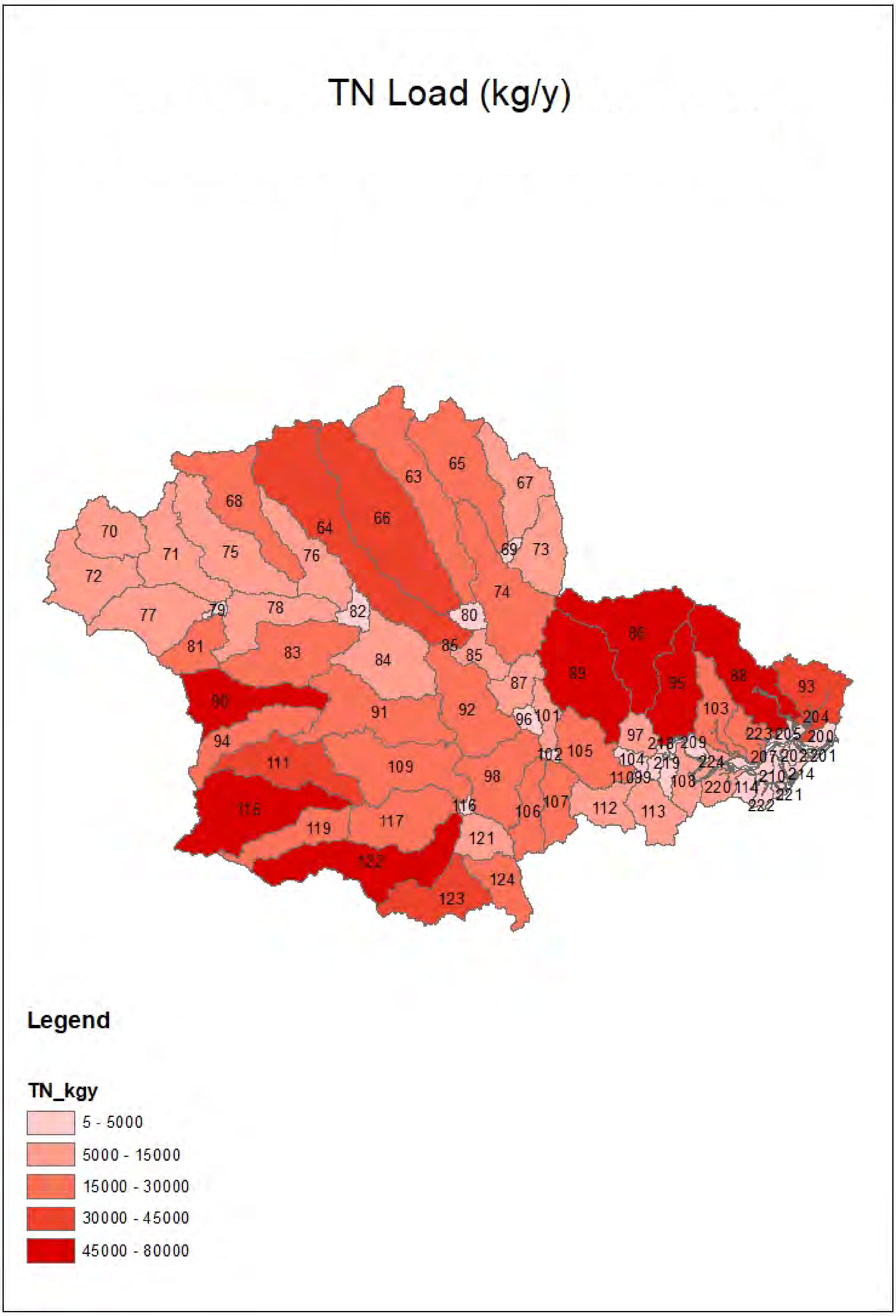
Generation rates for surface flow (ML/ha/y), total nitrogen (kg/ha/y), total phosphorous (kg/ha/y) and total suspended solids (kg/ha/y) were used as likelihood criteria in the updated Estuary Health Risk Map.



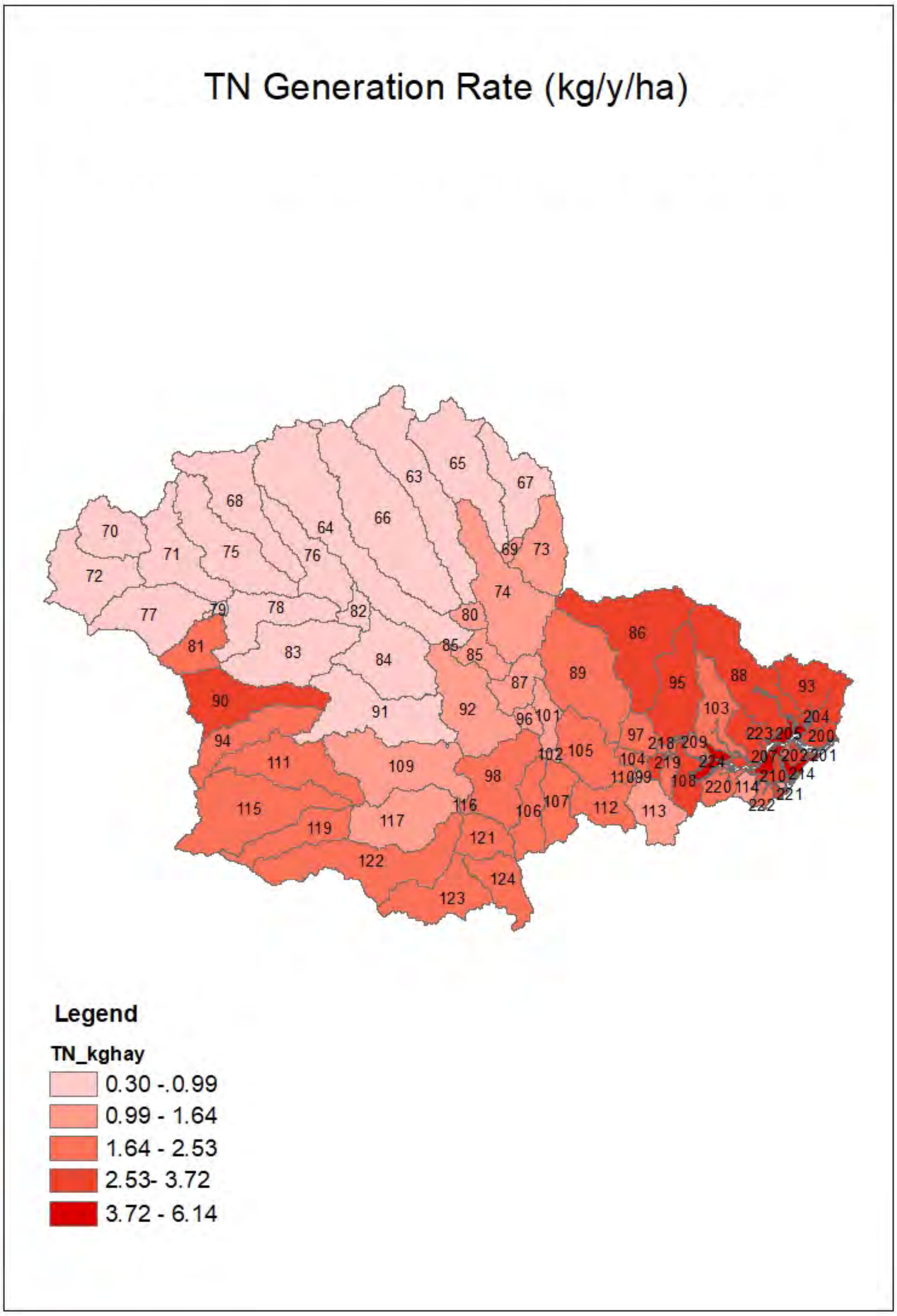
Map A2 - 1 Surface Flow (ML/y) from each subcatchment of the Manning River Estuary – outputs (result) from the Catchment Model



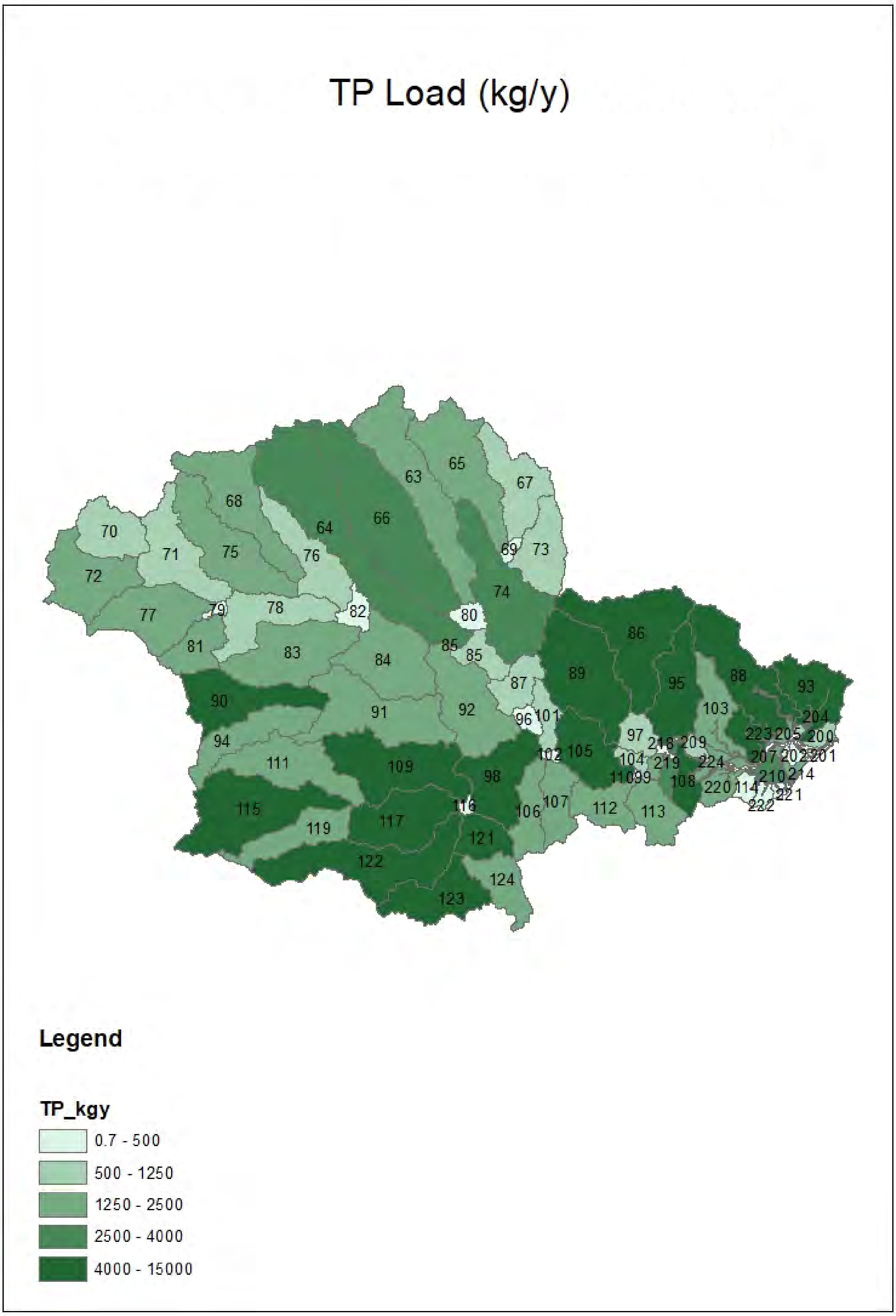
Map A2 - 2 **Surface Flow Generation Rate (ML/ha/y) from each subcatchment in the Manning River catchment – outputs (result) from the Catchment Model used in the updated Estuary Health Risk Map. Generation rate is the average surface flow from 1 hectare of the subcatchment per year**



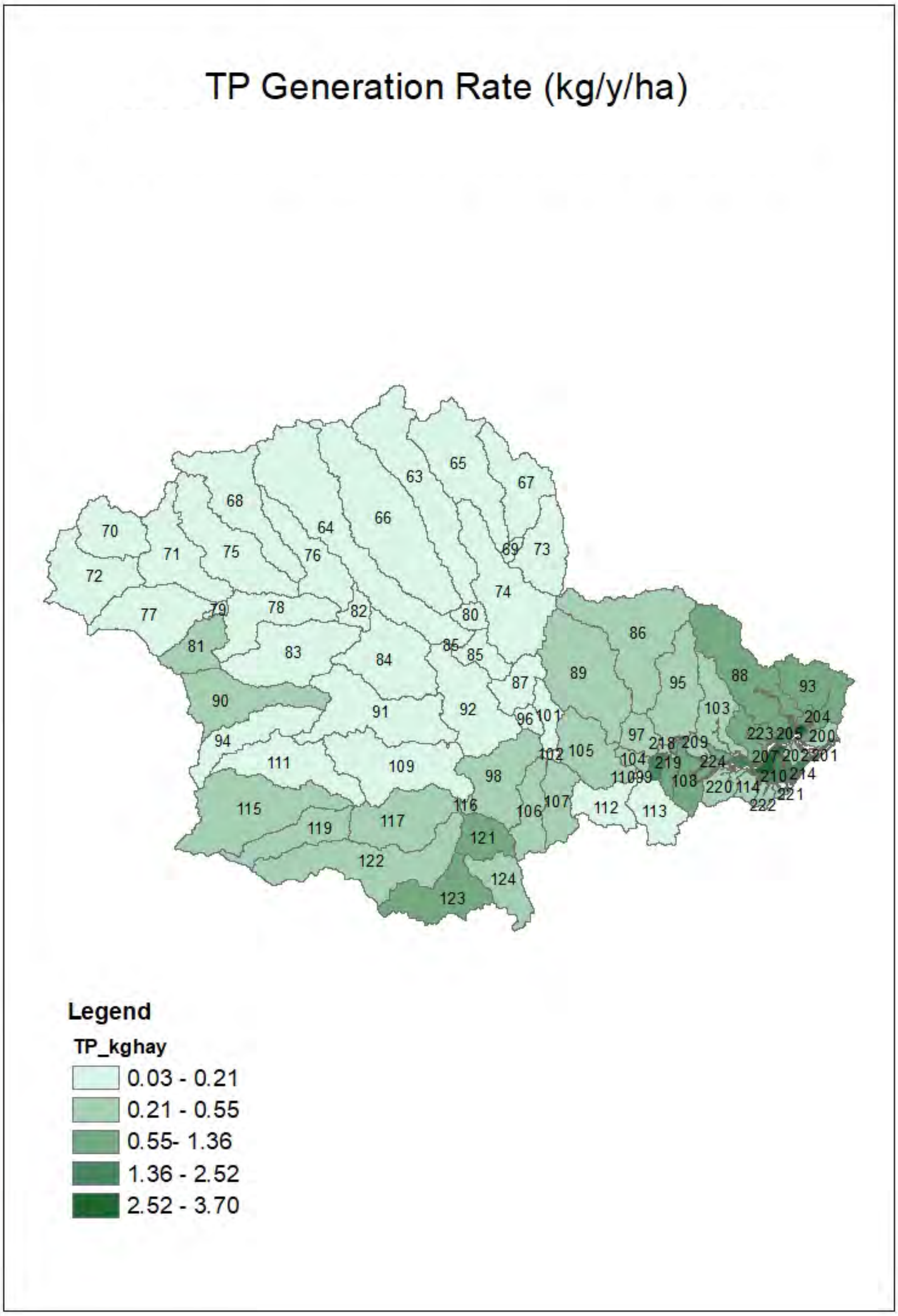
Map A2 - 3 **TN load (kg/y) from each subcatchment in the Manning River catchment – outputs (results) from the Catchment Model**



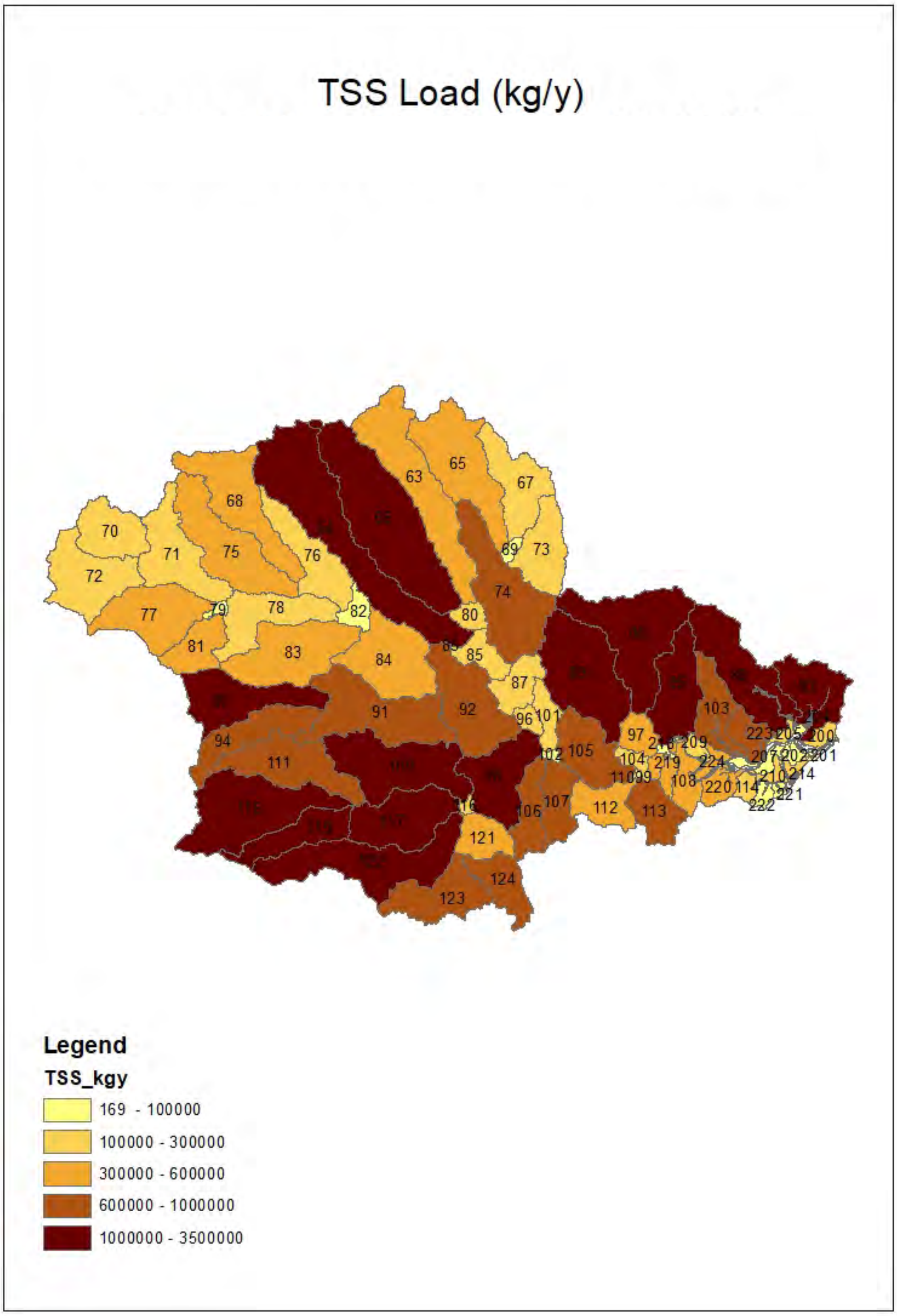
Map A2 - 4 TN generation rate (kg/ha/y) from each subcatchment in the Manning River catchment - outputs (result) from the Catchment Model used in the updated Estuary Health Risk Map. Generation rate is the average export of TN (kg) from 1 hectare of the subcatchment per year.



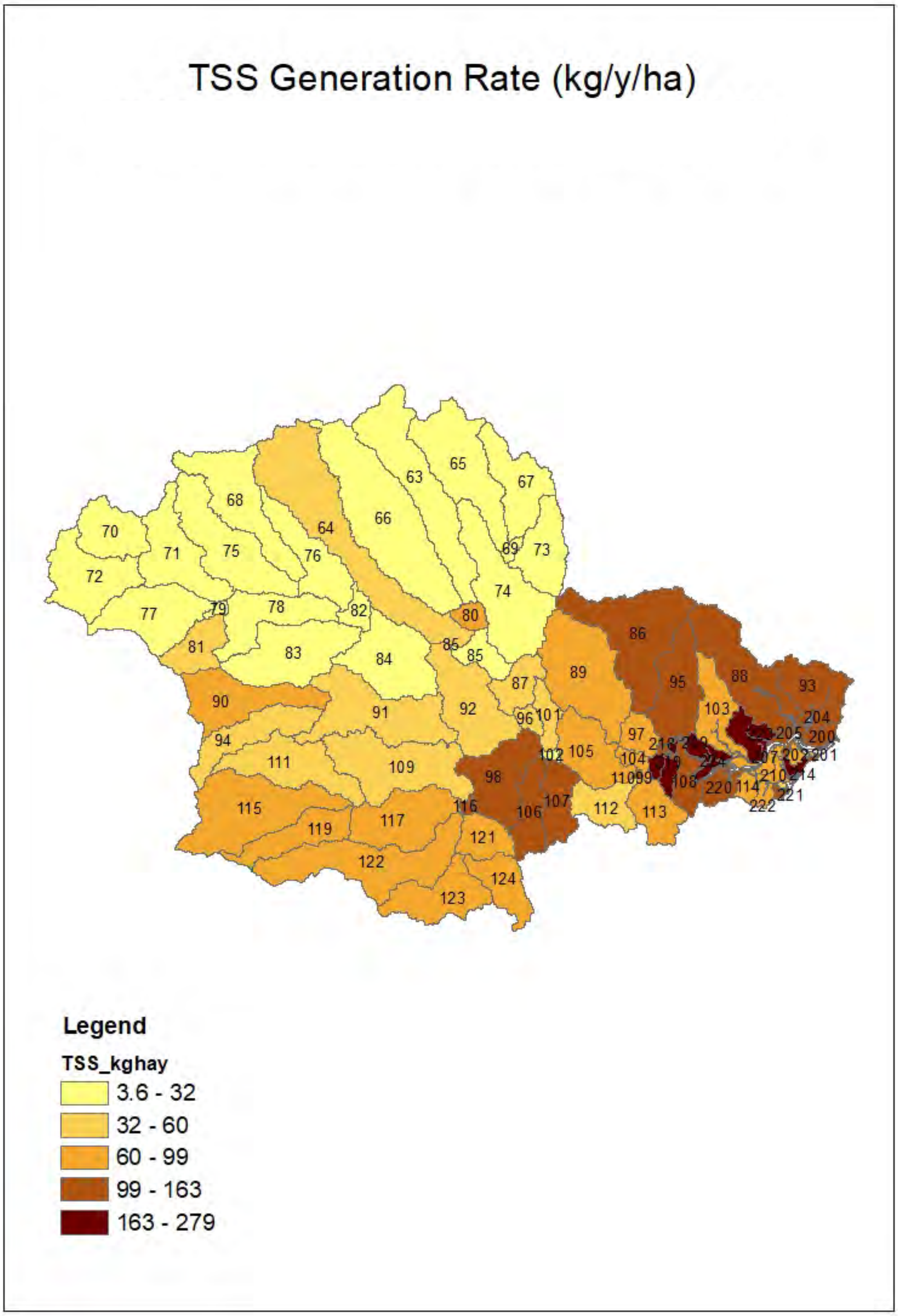
Map A2 - 5 **TP load (kg/y) from each subcatchment in the Manning River catchment – outputs from the Catchment Model**



Map A2 - 6 **TP generation rate (kg/ha/y of each subcatchment in the Manning River catchment - outputs (result) from the Catchment Model used in the updated Estuary Health Risk Map. Generation rate is the average export of TP (kg) from 1 hectare of the subcatchment per year.**



Map A2 - 7 **TSS load (kg/y) from each subcatchment in the Manning River catchment – outputs from the catchment model**



Map A2 - 8 TSS generation rate (kg/ha/y) from each subcatchment in the Manning River catchment - outputs (result) from the Catchment Model used in the updated Estuary Health Risk Map. Generation rate is the average export of TSS (kg) from 1 hectare of the subcatchment per year.

Table A2 - 1 **Catchment model outputs – loads (L/y, Kg/y) and generation rates (L/ha/y) for surface flow (SF), total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS) from each subcatchment**

SubcatchID	SF L/ha/y	SF L/y	TN kg/ha/y	TN kg/y	TP kg/ha/y	TP kg/y	TSS kg/ha/y	TSS kg/y
63	1.03E+06	2.75E+10	0.78	20685	0.06	1582	17.65	470291
64	8.09E+05	3.19E+10	0.88	34597	0.10	3925	36.76	1449204
65	1.05E+06	2.36E+10	0.76	17015	0.06	1288	16.20	363504
66	9.60E+05	3.68E+10	0.92	35169	0.09	3592	32.02	1227807
67	1.06E+06	1.47E+10	0.79	10974	0.07	1004	16.07	222858
68	8.88E+05	1.77E+10	0.80	15959	0.09	1863	27.60	550357
69	1.24E+06	1.29E+09	1.33	1384	0.14	140	15.44	16006
70	7.93E+05	8.85E+09	0.68	7635	0.06	681	17.07	190503
71	5.64E+05	9.34E+09	0.42	6979	0.03	533	8.55	141604
72	7.11E+05	1.2E+10	0.80	13530	0.09	1456	12.21	206655
73	1.67E+06	1.98E+10	1.21	14303	0.09	1032	24.36	287853
74	1.35E+06	3.25E+10	1.16	28005	0.12	2842	30.22	728057
75	6.93E+05	1.49E+10	0.63	13578	0.09	1847	19.27	412998
76	8.10E+05	1.09E+10	0.69	9319	0.06	821	20.70	277912
77	5.18E+05	8.92E+09	0.80	13708	0.14	2370	26.08	449410
78	5.10E+05	7.24E+09	0.43	6103	0.04	525	8.00	113471
79	2.80E+05	2.22E+08	0.30	240	0.03	25	3.59	2844
80	1.15E+06	3.01E+09	1.33	3492	0.15	393	68.88	180977
81	1.51E+06	1.24E+10	2.14	17554	0.26	2120	37.91	310982
82	9.07E+05	2.75E+09	0.82	2478	0.08	229	18.78	56935
83	7.35E+05	1.51E+10	0.75	15531	0.08	1595	23.62	486498
84	8.59E+05	1.62E+10	0.77	14588	0.07	1402	25.58	482145
85	1.14E+06	5.75E+09	1.13	5711	0.15	753	29.42	148772
86	3.16E+06	8.33E+10	2.90	76425	0.36	9553	129.77	3419353
87	1.32E+06	8.79E+09	1.21	8068	0.12	767	36.53	242770
88	2.27E+06	4.53E+10	2.82	56326	0.69	13743	135.99	2713666
89	2.17E+06	5.4E+10	2.13	52957	0.24	5994	80.21	1995144
90	2.61E+06	4.33E+10	3.08	50921	0.56	9224	65.31	1080863
91	1.05E+06	2.46E+10	0.99	23303	0.10	2344	34.80	815186
92	1.18E+06	2.22E+10	1.09	20483	0.13	2407	43.13	812694
93	1.85E+06	2.27E+10	3.02	37106	1.19	14572	105.76	1299682
94	2.83E+06	3.55E+10	2.22	27893	0.18	2247	53.63	674490
95	2.36E+06	3.38E+10	3.15	45095	0.42	6027	149.99	2148826
96	1.23E+06	2.37E+09	1.37	2646	0.15	295	53.89	104362
97	1.21E+06	5.31E+09	1.87	8178	0.28	1239	87.64	383373
98	1.26E+06	1.93E+10	1.81	27636	0.28	4294	115.50	1766284
99	1.22E+06	1.45E+09	2.82	3344	1.64	1941	278.65	329976
100	6.06E+05	60322992	0.58	58	0.08	8	47.19	4694
101	1.98E+06	8.11E+09	1.55	6369	0.13	524	45.19	185630
102	1.22E+06	6.89E+08	1.35	762	0.14	77	28.07	15801
103	1.83E+06	1.74E+10	2.09	19792	0.23	2204	91.68	867095

104	1.20E+06	2.42E+09	1.88	3791	0.38	774	94.50	190815
105	1.54E+06	1.94E+10	2.00	25230	0.49	6121	79.34	998403
106	1.65E+06	1.34E+10	2.32	18880	0.29	2330	105.09	855491
107	1.91E+06	1.5E+10	2.54	20001	0.32	2497	120.94	952980
108	1.48E+06	7.26E+09	2.69	13197	0.96	4683	114.83	562741
109	1.15E+06	2.67E+10	1.23	28497	0.21	4865	59.96	1385232
110	1.03E+06	2.36E+08	1.57	361	0.20	47	107.23	24612
111	2.40E+06	4.08E+10	1.84	31171	0.15	2460	50.14	850146
112	1.70E+06	1.35E+10	1.83	14553	0.19	1532	58.10	461039
113	1.74E+06	1.45E+10	1.65	13791	0.18	1488	78.58	657820
114	1.30E+06	2.36E+09	1.56	2825	0.24	429	83.52	151079
115	2.49E+06	6.58E+10	2.17	57414	0.36	9401	66.21	1751403
116	1.10E+06	7.26E+08	1.98	1302	0.29	193	162.57	107045
117	1.04E+06	1.74E+10	1.54	25901	0.34	5648	88.04	1477227
119	2.31E+06	2.53E+10	2.25	24644	0.23	2486	96.95	1059961
121	1.11E+06	7.57E+09	2.08	14230	0.65	4412	72.34	493898
122	1.78E+06	4.52E+10	2.09	53197	0.41	10505	92.09	2345432
123	1.58E+06	2.13E+10	2.38	32027	0.82	11067	69.96	939526
124	1.56E+06	1.35E+10	1.86	16107	0.27	2331	77.97	675790
200	2.59E+06	4.34E+09	2.84	4760	0.30	506	116.87	196155
201	1.98E+06	4.29E+08	4.38	948	1.98	427	112.85	24420
202	2.18E+06	2.09E+09	2.88	2746	0.41	389	98.63	94199
203	1.05E+06	3.57E+08	5.35	1816	3.71	1260	90.33	30678
204	1.12E+06	3.78E+08	5.23	1758	3.62	1216	121.57	40842
205	1.13E+06	1.06E+09	4.15	3882	2.52	2357	145.02	135532
206	1.44E+06	4.66E+08	1.98	643	0.24	79	117.98	38310
207	1.18E+06	1.12E+09	4.76	4510	3.02	2858	83.75	79339
208	8.10E+05	5.03E+08	3.72	2311	2.50	1555	71.55	44417
209	1.21E+06	1.76E+09	2.48	3616	0.51	745	186.10	271342
210	1.02E+06	1.51E+09	3.25	4810	1.83	2705	76.15	112643
211	9.09E+05	1.35E+08	1.26	188	0.15	22	37.28	5555
212	9.52E+05	86409829	1.24	112	0.16	14	103.87	9425
214	2.58E+06	2.22E+09	5.73	4937	2.35	2021	176.26	151868
215	1.47E+06	9010000	6.14	38	0.71	4	53.03	324
216	9.49E+05	16066666	1.16	20	0.13	2	10.01	169
217	3.94E+05	4083000	0.52	5	0.07	1	45.68	473
218	1.11E+06	5.62E+08	1.85	938	0.23	116	105.01	53167
219	1.33E+06	2.8E+09	2.33	4910	1.37	2880	219.10	461191
220	1.56E+06	5.91E+09	2.11	8004	0.52	1977	110.74	419864
221	1.78E+06	8.42E+08	2.81	1326	0.33	158	138.09	65292
222	1.88E+06	2.56E+09	2.20	2985	0.23	309	68.17	92666
223	1.70E+06	8.45E+09	3.60	17875	1.12	5553	183.52	912029
224	1.93E+06	3.21E+09	4.23	7027	1.06	1758	232.01	385222
225	2.86E+06	11385000	3.69	15	0.44	2	215.25	857

Testing catchment model loads against observed water quality data

The major input to the catchment model is land use class. The model uses event mean concentrations (EMCs) for TN, TP, TSS for each land use class (from literature) to predict the pollutant loads (TN, TP, TSS – kg/y) in surface flow runoff from each land use class in the catchment. It is standard process that during model development, modelled outputs are compared to observed data collected in the catchment. A coarse validation of the catchment model outputs was undertaken through testing of modelled outputs (TN, TP, TSS loads) against existing (observed) water quality data collected in the freshwater catchment by MidCoast Water from 2001 – 2019 (Table A2 – 2).

Validation / box-whisker charts explained

Freshwater catchment

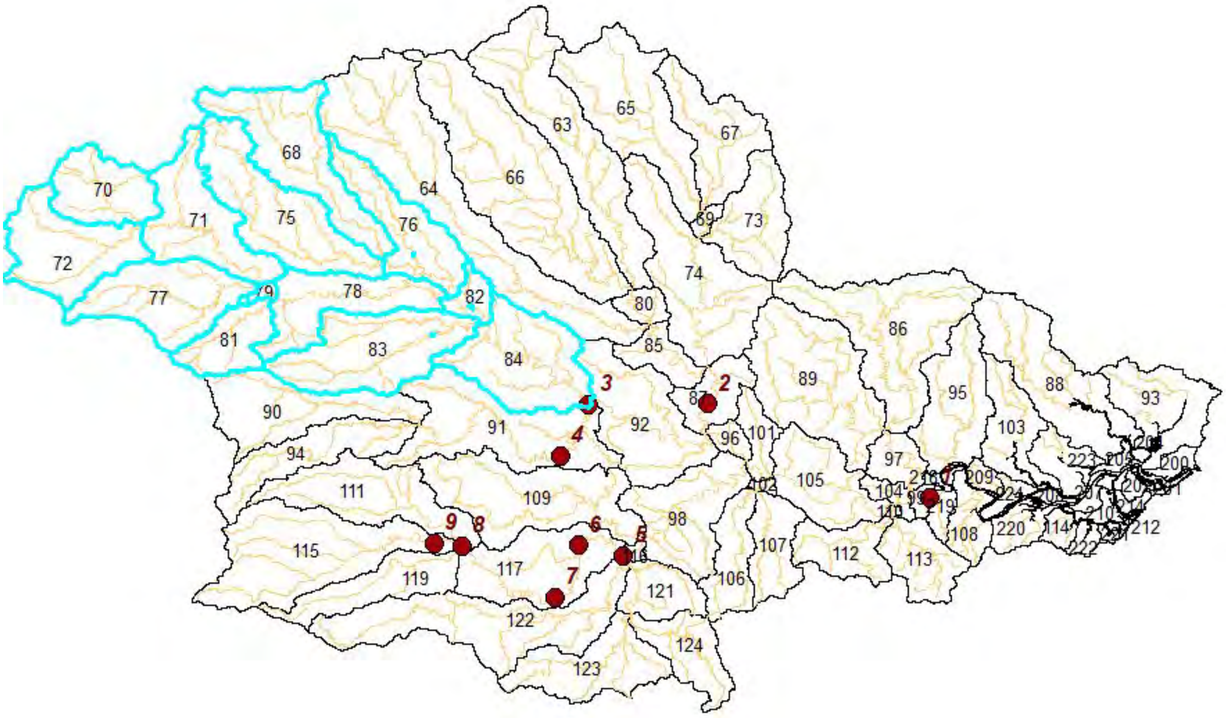
For each water quality monitoring site, the modelled pollutant loads (TN, TP or TSS kg/y) from adjacent and upstream catchments were summed to reflect the total load contributing to the water quality at that site (Table A2-3, Map A2-9). The total load (modelled outputs, summed) determined the order of sites on the x-axis, that is, monitoring site 8 (MCW8) had the lowest total TN load and is first on the x-axis, while site 1 (MCW1) had the highest total TN load and is last on the x-axis. The total load for the site is shown on each graph under the box/whiskers (Graph A2-1, Table A2-3).

All available water quality data from each site was plotted (log (x+1)) in box and whisker charts (Table A2-2, Graph A2-1 – A2-3). Box and whisker charts show the distribution of data into quartiles, highlighting the mean (line) and outliers (dots). “Whiskers” indicate variability outside the upper and lower quartiles, and any point outside those lines or whiskers is considered an outlier.

The outliers represent the very high concentrations of TN, TP, TSS which occur in receiving waters after heavy rainfall or extended wet periods. The outliers (or upper whisker) are the focus of the model validation as they occur after overland flow delivers pollutants in the surface runoff from adjacent and upstream catchments. The catchment model estimates the concentration of pollutants (that is, EMCs) entering the waterways in surface runoff from different land use.

Table A2 - 2   MidCoast Water water quality sampling locations and frequency

Location	Site Code	Time period of data (sampling frequency)
Manning River (Bootawa Dam Offtake)	MCW1	2001 - 2019 (fortnightly)
Nowendoc River at Caffrey’s Flat	MCW2	2010 - 2019 (monthly)
Barnard River at Bretti	MCW3	2010 - 2019 (monthly)
Little Manning at Gloryvale Reserve	MCW4	2010 - 2019 (monthly)
Gloucester Water Supply Offtake	MCW5	2017 - 2019 (weekly)
Barrington River at Rocky Crossing	MCW6	2009 - 2019 (monthly)
Barrington River at Barrington Bridge	MCW7	2010- 2019 (monthly)
Cobark River - Griffith Bridge	MCW8	2009 - 2011 (monthly)
Barrington River at Landers Bridge	MCW9	2009 - 2011 (monthly)



Map A2 - 9 **MidCoast Water sampling site locations (1-9) in freshwater catchment showing adjacent and upstream subcatchments (see Table A2-3). Map also shows all subcatchments (blue border) draining to MCW Water quality monitoring site 3. Total loads (kg/y, modelled) from these subcatchments were added together for comparison to observed water quality at site 3. See text and Table A2-2 for further explanation**

Table A2 - 3 **MidCoast Water water quality monitoring sites - contributing loads from adjacent and upstream subcatchments used to validate second pass catchment model (See Map A2-9)**

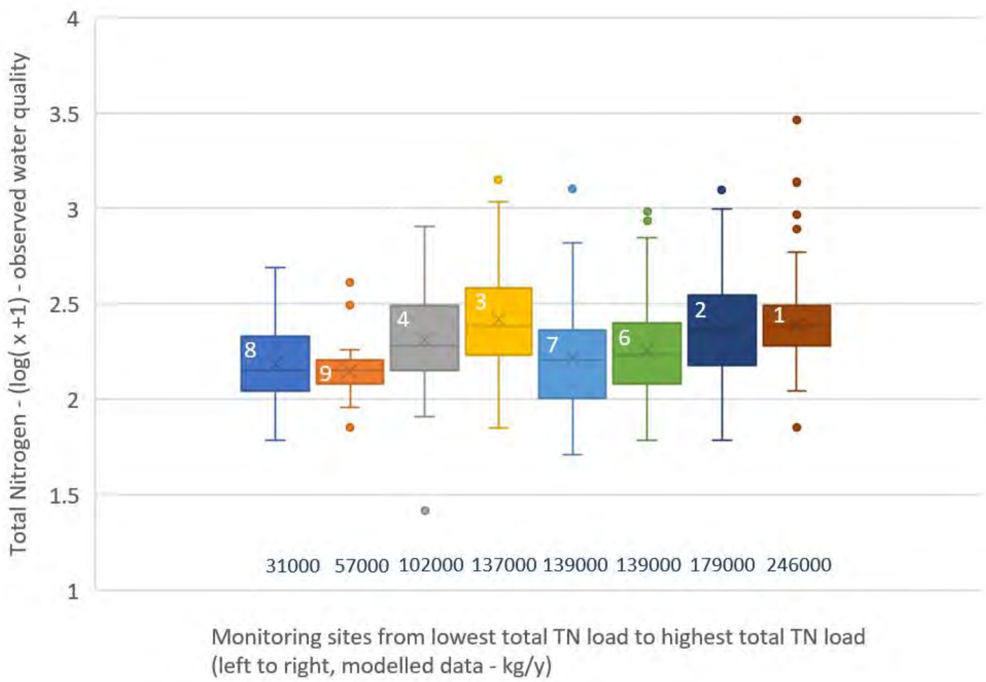
Site	Sum TN load (kg/y)	Sum TP load (kg/y)	Sum TSS load (kg/y)	Primary and upstream catchments
MCW1	246220	35639	11197612	99, 104, 105, 101, 96, 98, 102, 106, 107, 97, 86, 89
MCW2	179401	17318	5338100	87, 85, 80,66, 63, 64, 74, 65, 73, 69, 67
MCW3	137202	15467	3682313	84, 82, 78, 81, 83, 79, 71, 70, 72, 77, 75, 76, 68
MCW4	102117	13815	2570539	91, 90, 94
MCW5	139131	19996	5138737	117, 119, 115, 111
MCW6	139131	19996	5138737	117, 119, 115, 111
MCW7	139131	19996	5138737	117, 119, 115, 111
MCW8	31171	2460	850146	111
MCW9	57414	9401	1751403	115

Observed TN concentrations are plotted in Graph A2-1 with sites plotted on the x-axis in order of increasing modelled TN loads draining to the site. The monitoring site number is shown inside the box (white number). Observed maximum TN concentrations (outliers) increase with increasing TN load to the site.

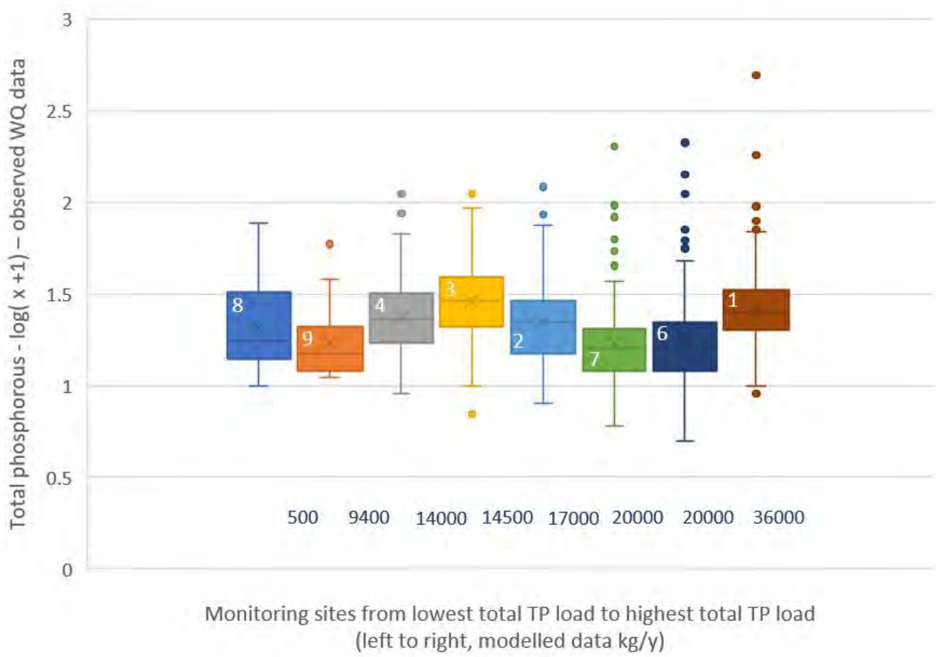
Observed TP concentrations are plotted in Graph A2-2 with sites ordered on the x-axis according to increased modelled TP loads draining to the site. Observed maximum TP concentrations (outliers) increase with increasing TP load to the site.

TN and TP concentration maxima observed at freshwater monitoring locations match well with the modelled TN and TP loads (Graphs A2-1,2). Maximum observed concentrations of TN and TP were strongly correlated with total TN and TP (modelled) loads (TN correlation = 0.97, TP correlation = 0.93). The observed data therefore provides a good fit for modelled outputs for TN and TP (kg/y).

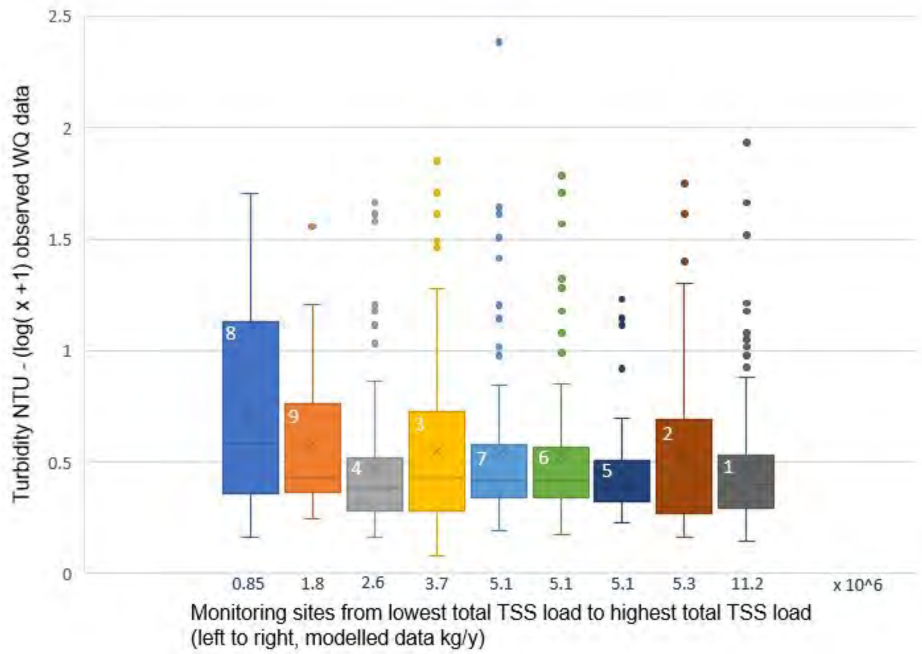
Observed turbidity maxima data at freshwater sites did not increase with increasing modelled TSS loads (Graph A2-3) but this can be explained by other significant inputs of TSS to freshwater streams during rain events such as from hillslope erosion and streambank/streambed erosion.



Graph A2 - 1 Water quality data (TN ug/L, observed data on y axis) from monitoring sites in the freshwater catchment (MCW, white numbers in box) ordered along the x-axis from lowest to highest TN loads (modelled data). Note observed maximum concentrations of TN increase as total TN modelled loads (draining to site) increase.



Graph A2 - 2 Water quality data (TP ug/L, observed data on y axis) from monitoring sites in the freshwater catchment (MCW, white numbers in box) ordered along the x-axis from lowest to highest TP loads (modelled data). Note observed maximum concentrations of TP increase as total TP modelled loads (draining to site) increase.



Graph A2 - 3 Water quality data (turbidity NTU, observed data on y axis) from monitoring sites in the freshwater catchment (MCW, white numbers in box) ordered along the x-axis from lowest to highest TSS loads (modelled data). Note observed maximum turbidity does not increase with increased TSS load draining to site. See text for further explanation

Estuary

A robust validation of the catchment model in the estuary was not possible as it requires catchment modelled data to be compared to 'observed' water quality data at 'pour points' where catchment runoff from creeks/rivers enters the main estuary. EES water quality monitoring sites were not located at the model input locations.

Estuary (Hydrodynamic) Model

1D Branched Models were developed for NSW Estuary Health Risk Maps (Dela-Cruz et al. 2019) for estuaries classified as barrier rivers, including the Manning River. This type of model treats the main estuary branch as a linear representation of the estuary, but also include multiple tributaries joining the main branch to create a simple and accurate representation of the more complex system. The 1D-Branched Models consider how nutrient and sediment inputs from the heads of the main branch and tributaries are transported due to the advection of catchment runoff (moving downstream) and the propagation of the tides (moving upstream/ downstream).

The models also account for friction along the estuary floor (bottom friction), which allows for accurate dissipation of tidal energy and vertical mixing in the water column. This interaction of catchment runoff, tides and bottom friction provide a reliable estimate of the upstream transport of brackish water and downstream transport of freshwater. This results in metrics for estimating the residence times or flushing times as a function of distance along the estuary, which is a one of the drivers of primary production in estuary systems.

For the estuary risk maps, the 1D Branched Models were run to produce two metrics: base exceedance and extent of potential impact. TN (or TP, TSS) loads arising from small rainfall events (i.e. 1 year ARI) were used as inputs to the 1D Branched Model on the assumption that the catchment runoff from these small, but frequent events will be retained within the estuary and hence pose the greatest risk of impacts on estuary health. Graph A2-4 shows the volume transport due to tides that were used in the hydrodynamic model. Note that the second entrance at Farquhar is closed in the hydrodynamic model for the Manning Estuary (Graph A2 – 4).

Base exceedance was determined for each subcatchment, by increasing the total TN loads for one subcatchment by 20% and re-running the model. The increase in TN concentrations within the estuary relative to the base or ambient TN concentrations (i.e. base exceedance) provide a relative measure of the magnitude of impact of that one subcatchment. The extent of potential impact determines if the exported pollutants remain localised near the input point or are transported to other parts of the estuary. Guidance on how to interpret the hydrodynamic output maps is given below.

The hydrodynamic model was run separately for TN, TP and TSS for updated estuary risk map at the request of Council. There were minor differences in the base exceedance outputs for TN (Map A2-10), TP (Map A2-13) and TSS (Map A2-14) but there was virtually no difference in the 'extent of potential impact' outputs from each run so only the 'extent of potential impact' output for TN is shown (Maps A2-11,12). This is because the model is a simple particle tracking model and does not account for settling of particles such as suspended solids.

Interpretation of base exceedance and extent of potential impact maps

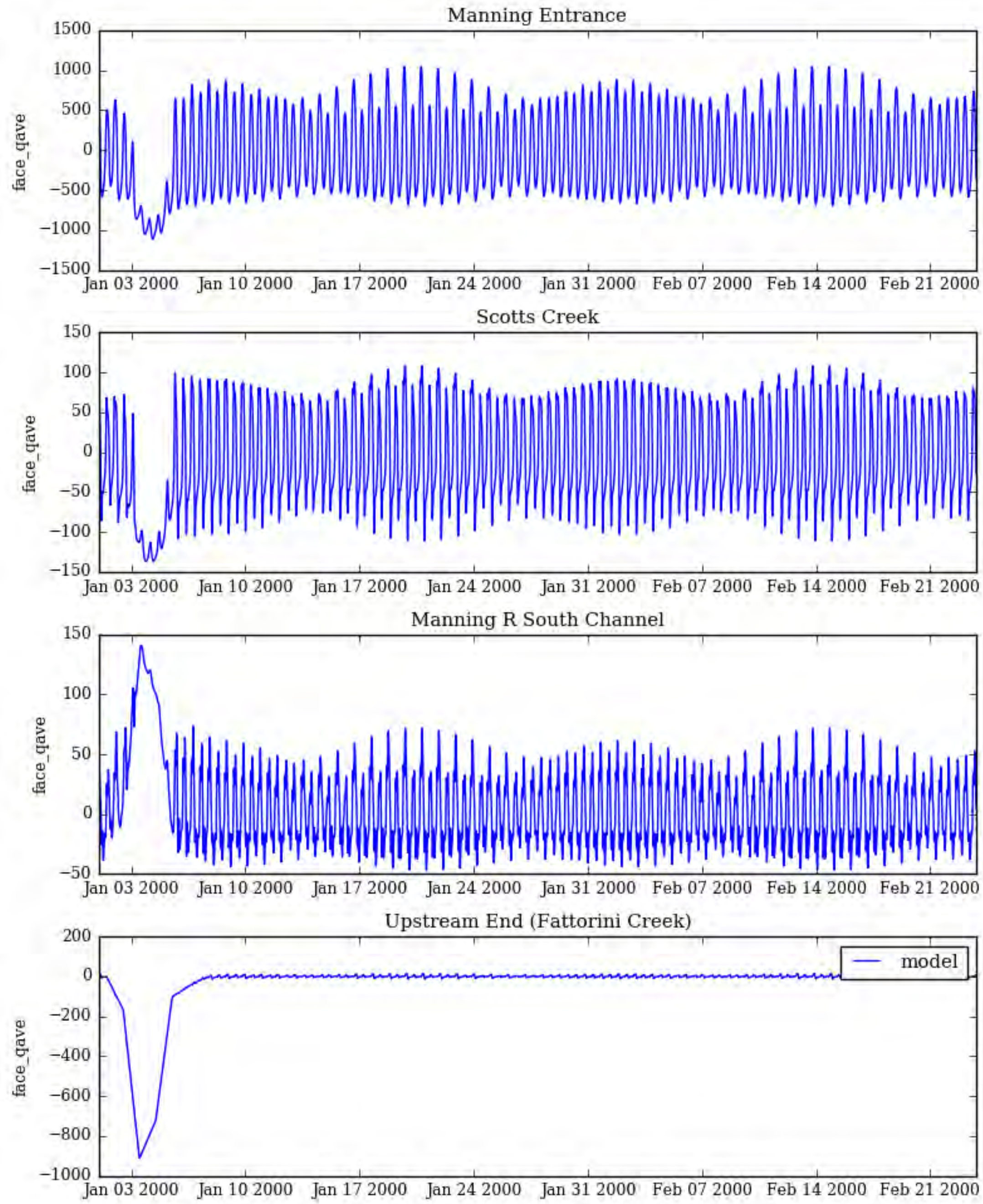
Both the base exceedance and extent of potential impact are expressed as percentages, ranging from 0 to 100 (Maps A2-10 – 15). A base exceedance of 100% indicates a doubling of the base or ambient TN concentrations in the estuary. Similarly, if the extent of potential impact is 100%, then the TN loads from the subcatchment are transported to all areas of the estuary. Map A2-10 shows that subcatchment 88 has the greatest base exceedance (100%) and would pose the greatest risk of impact, if this metric was considered alone. Maps A2-11, 12 however show that extent of potential impact (i.e. transport of runoff in the estuary) of pollutants from subcatchment 88 is localised, with 20-30% extent of potential impact (green subcatchments) 'relative' to subcatchments with maximum extent of impact (red subcatchments). In comparison, an increase of 20% in TN loads in subcatchment 86 will result in 30-40% exceedance of ambient TN concentrations across the estuary (Map A2-10, light green) but will have a systemic impact because the runoff/pollutants from these subcatchments is transported throughout all the estuary (Map A2-11, 100%, red). Meanwhile, an increase of 20% in TN loads from subcatchments 103, 223, and 93 will cause 50-60% exceedance of base conditions (Map A2-10, beige subcatchments) but the extent of potential impact will be more localised as indicated by blue – green shading of these subcatchments (Maps A2-11, A2-12).

Note that in the updated Estuary Health Risk Map, the two outputs from the hydrodynamic model were multiplied together, into a single volume-based index, before categorising into quantiles and attributing a consequence score. In the first pass model each output was scored separately and then averaged for the final consequence score. The volumetric index output for TN from the hydrodynamic model are shown in Map A2-15. Even though the volumetric (combined) index was used for the risk assessment, both maps of hydrodynamic outputs (base exceedance and extent of potential impact) should be viewed to fully interpret the 'consequence' of increased loads from individual subcatchments.

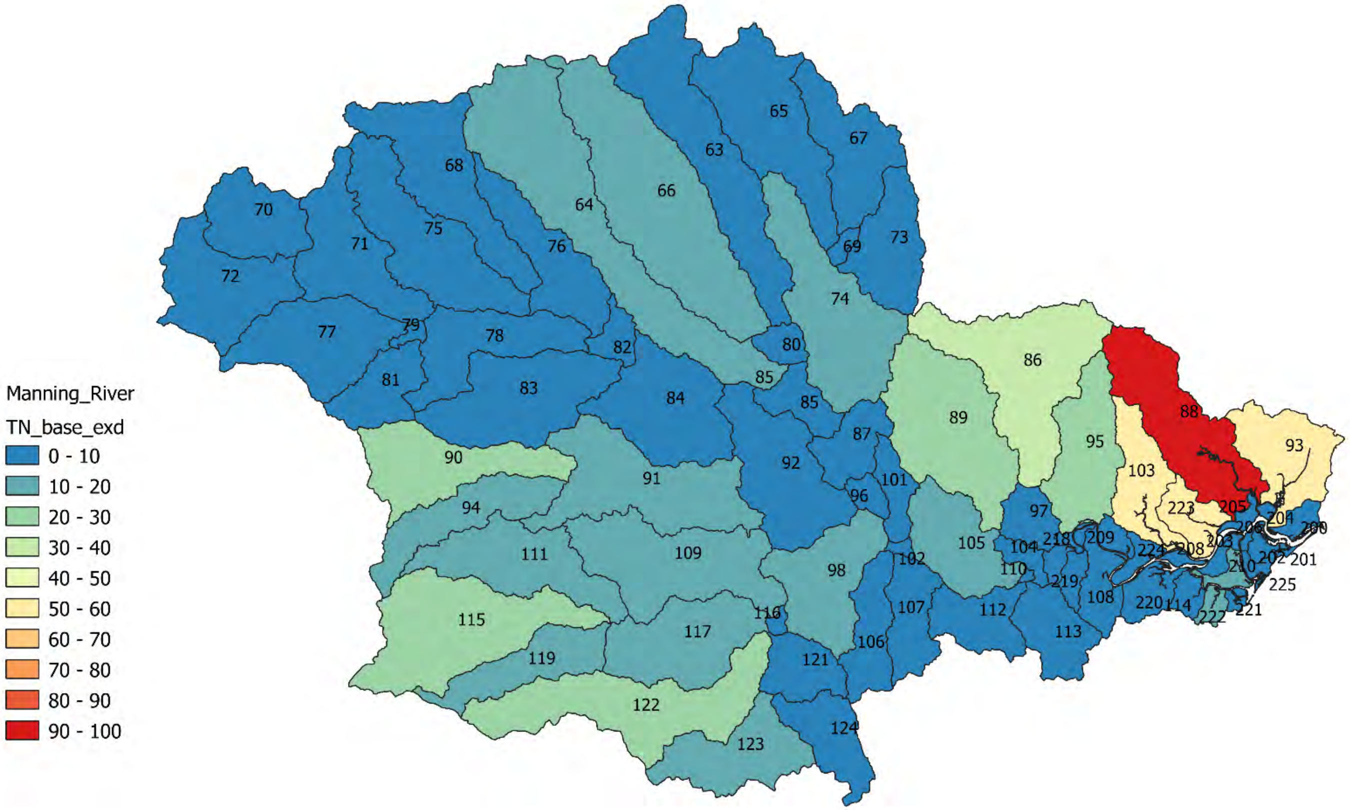
Risk assessment without proximity

A risk assessment was undertaken using only the generation rate outputs from the catchment model (SF, TN, TP and TSS; kg/ha/y) as likelihood criteria without including proximity (upon request from Council). Hydrodynamic model outputs (base exceedance and extent of potential impact) were used as consequence criteria in the risk matrix. The estuary risk map without proximity included is shown in Map A2-16. Excluding proximity from the risk assessment results in an increased Risk level assigned to some subcatchments in the upper catchment (e.g. 81, 90, 94,111) compared to when proximity is included in the risk assessment (Map 2). Subcatchments in the lower catchment however still pose the highest 'relative' risk to the estuary when proximity is excluded from the assessment, as they have the highest generation rates for pollutants. Subcatchments 88, 95, 223 and 86 (and 90) were assigned the highest Risk Level of 16 when 'proximity' was excluded from the likelihood criteria, compared to a Risk Level of 16 or 12 in the risk assessment which included proximity. That is, the same set of subcatchments were identified as Very High or High Risk to estuary health, when proximity was or was not included in the risk assessment.

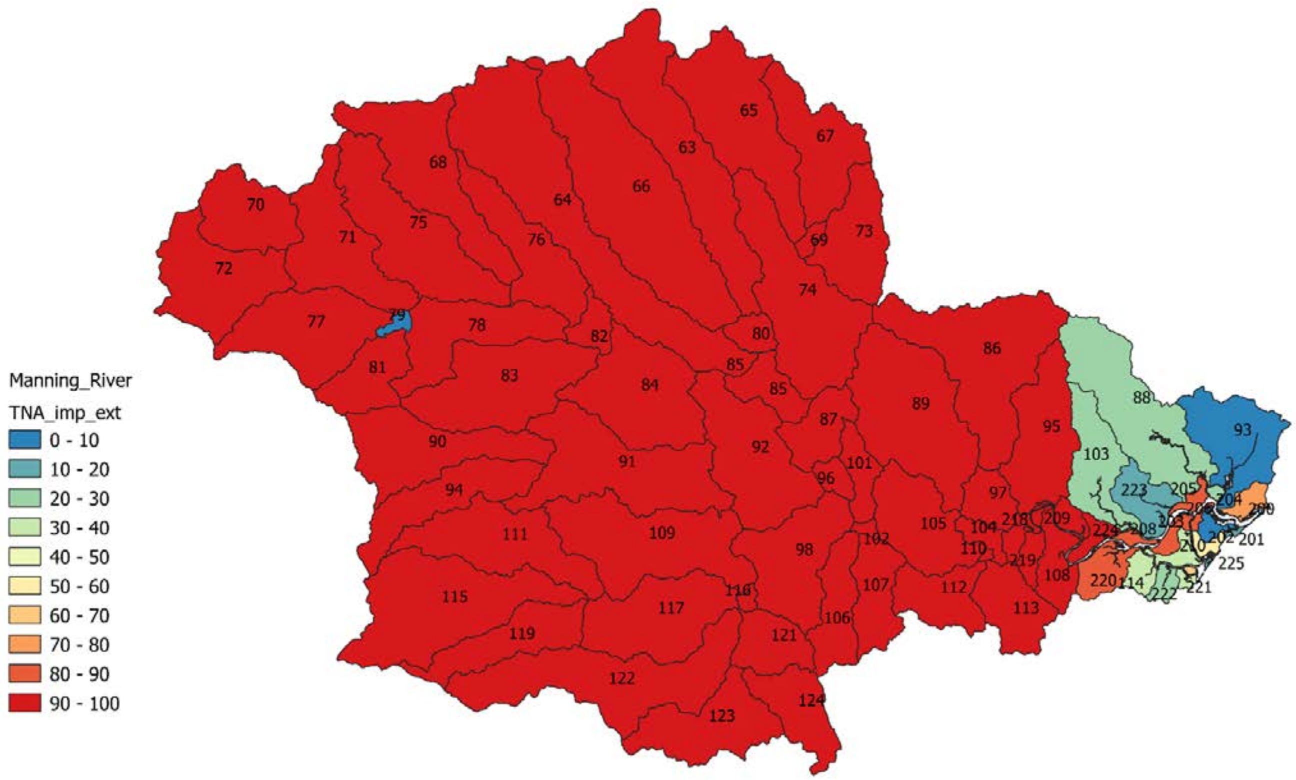
The Estuary Health Risk Map from Stage 1 Scoping Study 2018 is shown in Map A2-17 for comparison. There is limited difference between the 2018 risk map (Map A2-7) and the updated Estuary Health Risk Map (Map 2)



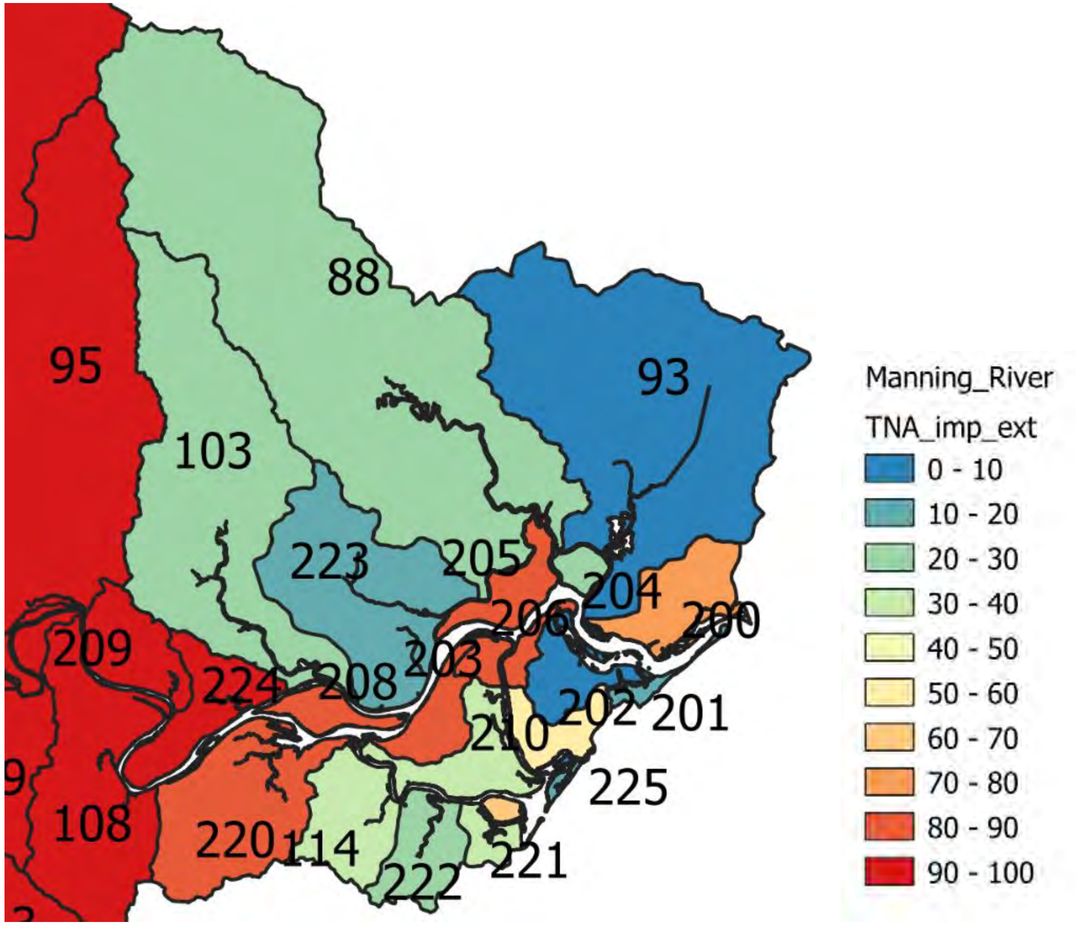
Graph A2 - 4 **Graphs showing the volume transport component of the hydrodynamic (estuary) model at different locations in the estuary. Scott's Creek flows between Oxley Island (subcatchment 203/210) and Mitchells Island (subcatchments 206/214). Monitoring site R24 is located in the Manning River South Channel. Note the different scale of y-axes in each graph and the lower volume transport from tides in the South Channel (entrance at Farquhar is closed in the hydrodynamic model). Fattorini Creek is located upstream of the tidal limit.**



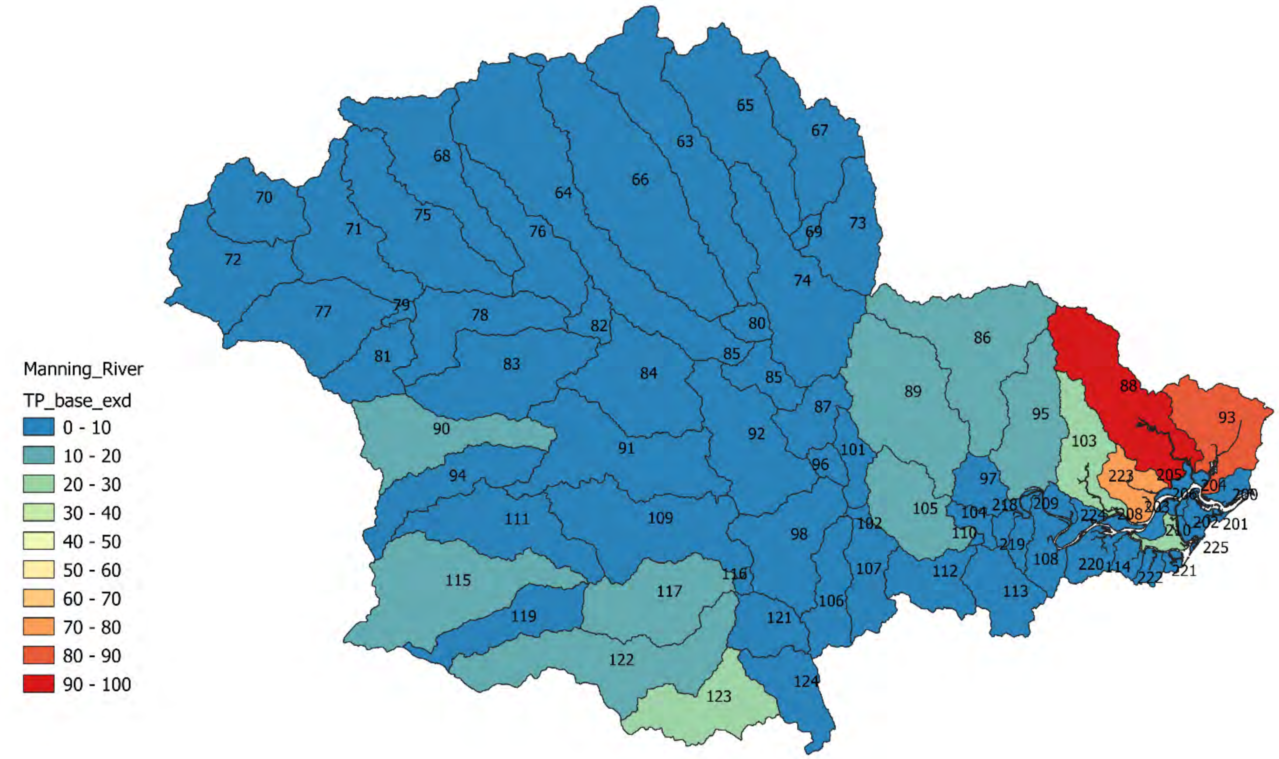
Map A2 - 10 **Hydrodynamic Model, output – TN base exceedance. A base exceedance of 100% indicates a doubling of the base or ambient TN concentrations in the estuary when TN load is increased by 20%. See text on pg 83-84 for map interpretation.**



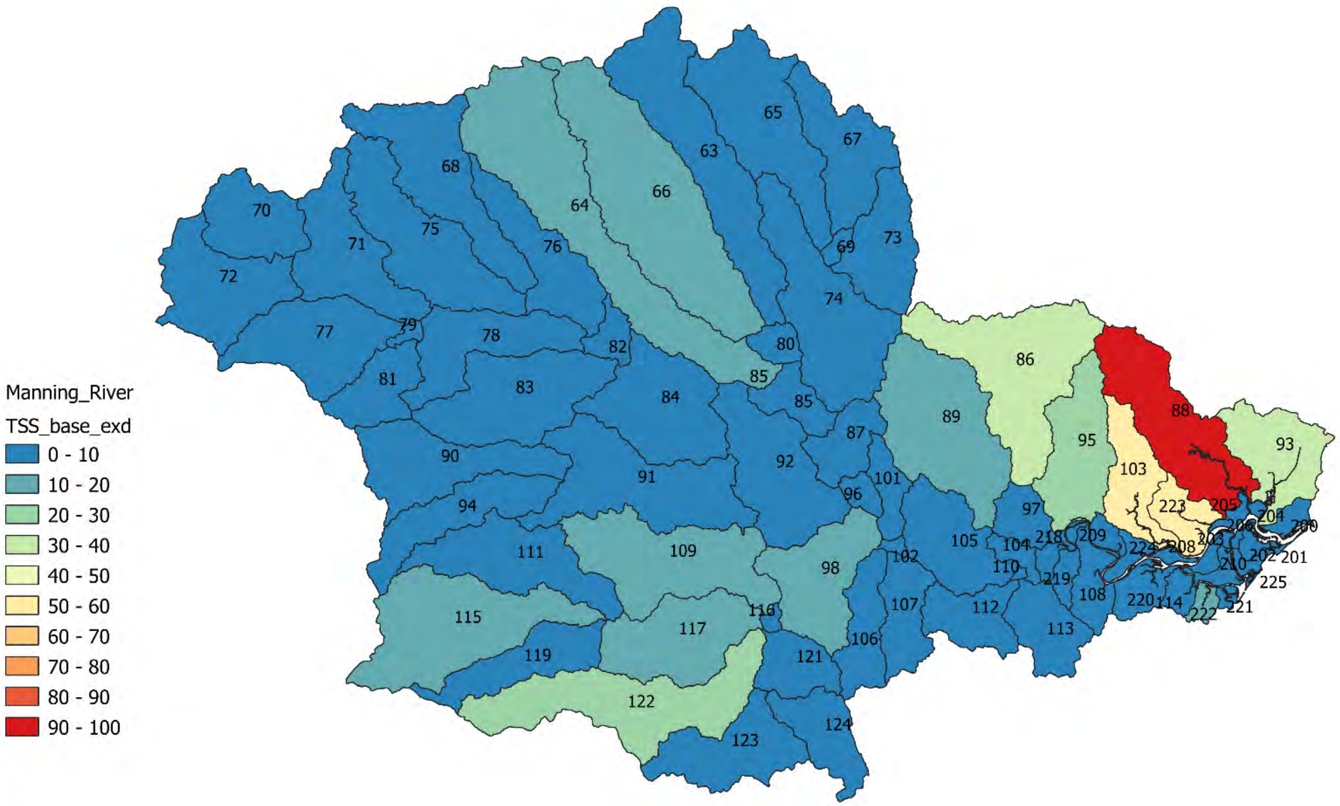
Map A2 - 11 **Hydrodynamic Model, output TN 'Extent of Potential Impact'. If the extent of potential impact is 100%, then the TN loads from the subcatchment are transported to all areas of the estuary. Note only output for TN shown as results essentially the same for TP and TSS. See Map A2-12 for more detailed view of lower estuary. See text on pg 83-84 for map interpretation. Note subcatchment 79 is blue because it was not included in the hydrodynamic model (if it was included in the model it would be red like the rest of the upper catchment)**



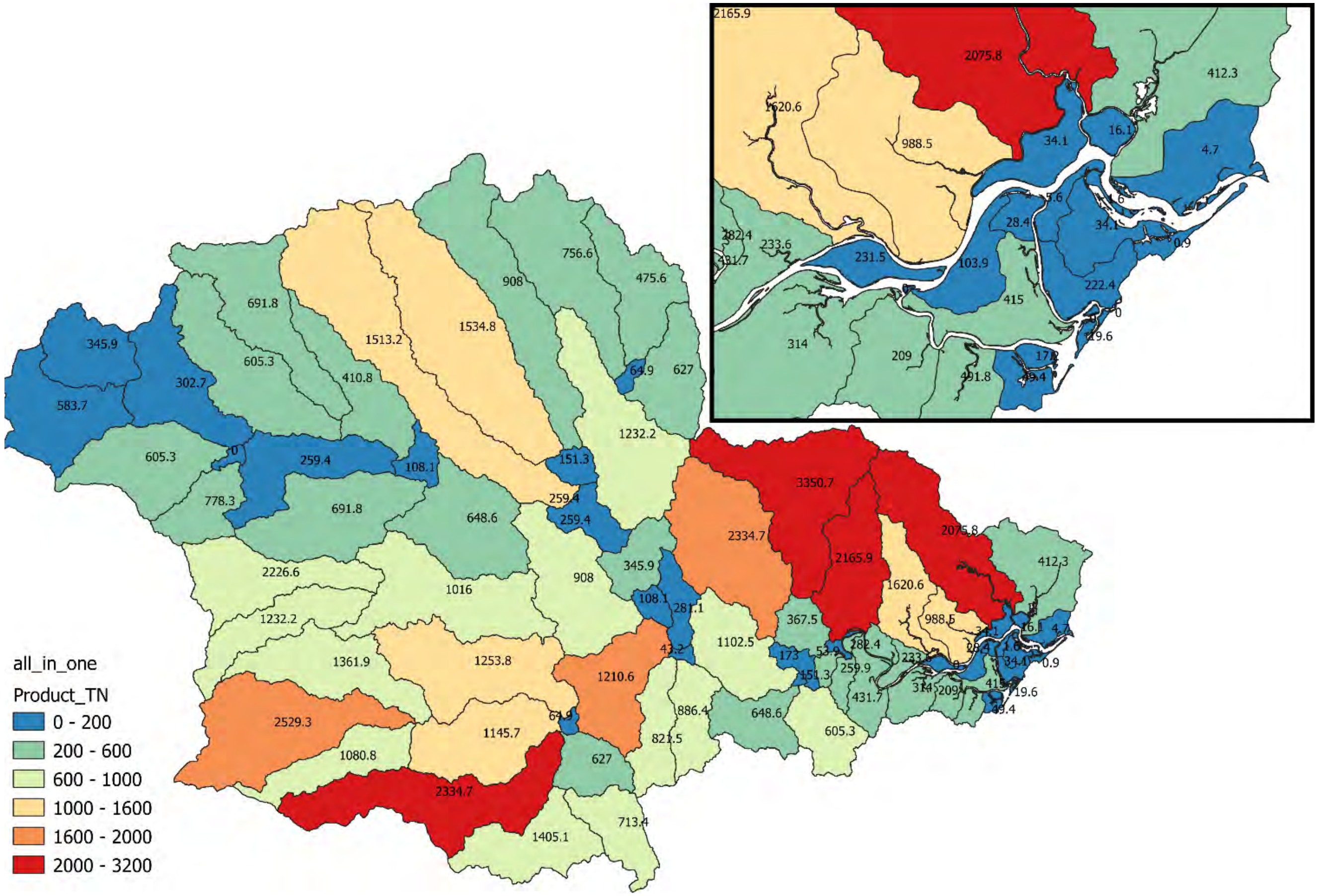
Map A2 - 12 Hydrodynamic Model, output - TN 'Extent of Potential Impact'. If the extent of potential impact is 100%, then the TN loads from the subcatchment are transported to all areas of the estuary. Note only output for TN shown as results essentially the same for TP and TSS. See text on pg 83-84 for map interpretation.



Map A2 - 13 **Hydrodynamic Model, output – TP base exceedance. A base exceedance of 100% indicates a doubling of the base or ambient TP concentrations in the estuary. See text on pg 83-84 for map interpretation.**

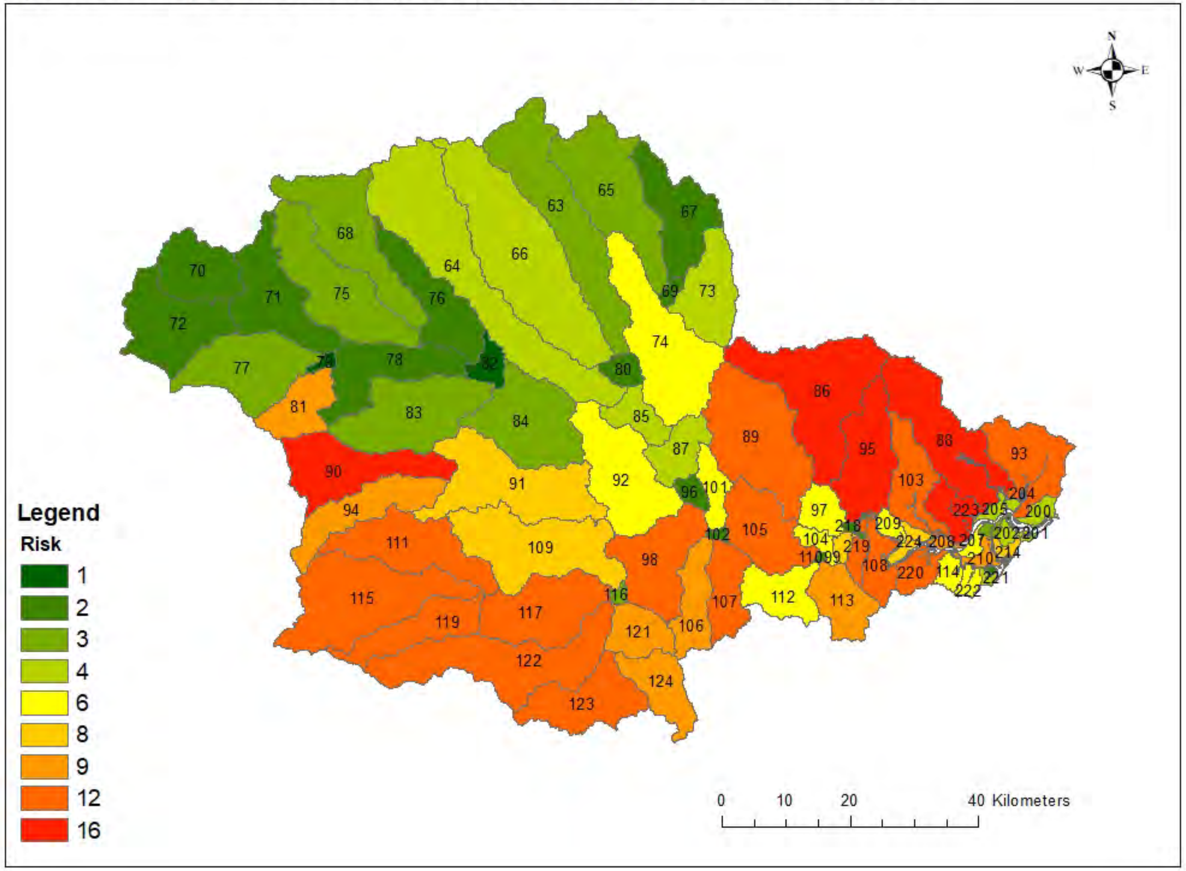


Map A2 - 14 **Hydrodynamic Model, output – TSS base exceedance. A base exceedance of 100% indicates a doubling of the base or ambient TSS concentrations in the estuary. See text on pg 83-84 for map interpretation.**

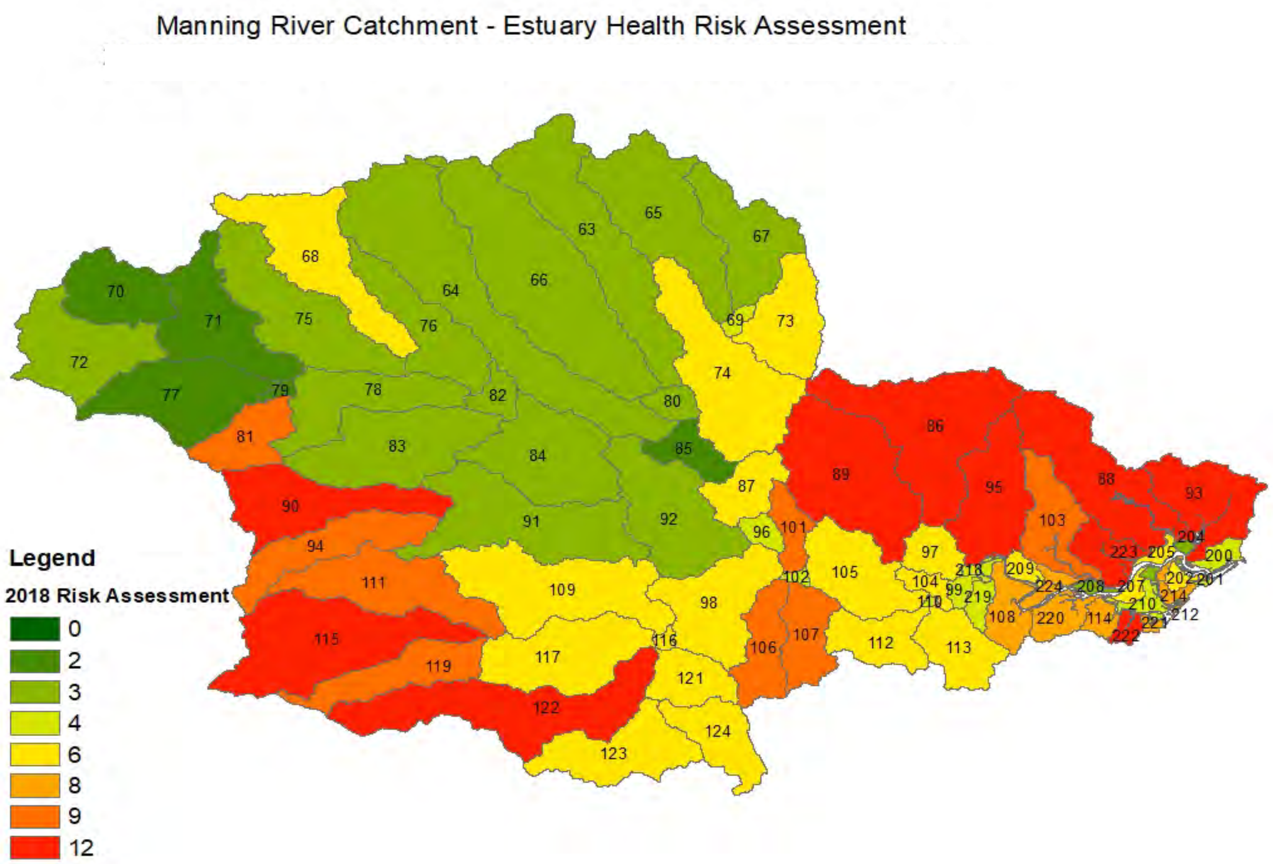


Map A2 - 15 Combined single output from hydrodynamic model for TN (Base exceedance X extent of potential impact = volumetric index). TP and TSS single output from hydrodynamic model were very similar so only volumetric index for TN is shown. See text on pg 83-84 for map interpretation.

Updated Estuary Health Risk Map excluding Proximity from Likelihood Criteria



Map A2 - 16 **Updated Estuary Health Risk Map using only generation rates for surface flow (SF), total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS) as likelihood criteria (proximity excluded). Hydrodynamic model outputs were used as consequence criteria.**



Map A2 - 17 **The Estuary Health Risk Map from Stage 1 Scoping Study for CMP (MCC 2018) showing overall risk that subcatchments pose to estuary health with all generation rates and proximity used for likelihood criteria and hydrodynamic model outputs as consequence criteria.**

Ground-truthing updated Estuary Health Risk Map

Existing water quality data

The major input to the catchment model is land use type. The model uses event mean concentrations (EMCs) for TN, TP, TSS for each land use type taken from the literature to predict the pollutant loads (TN, TP, TSS – kg/y) in surface flow runoff from each land use category. A coarse validation of the catchment model outputs was undertaken through testing of modelled outputs (TN, TP, TSS loads) against existing (observed) water quality data from the freshwater catchment (MidCoast Water, Graphs A2-1 - A2-3).

Modelled TN and TP loads outputs were strongly correlated with maximum concentrations of TN and TP in the freshwater catchment. Modelled TSS data outputs were not correlated with maximum concentrations of TSS in the freshwater catchment however this is not surprising considering that significant sediment inputs from hillslope erosion and streambank erosion contribute to measured TSS concentrations in waterways.

Rapid Site Assessments

Land Use Site Scores - Overview

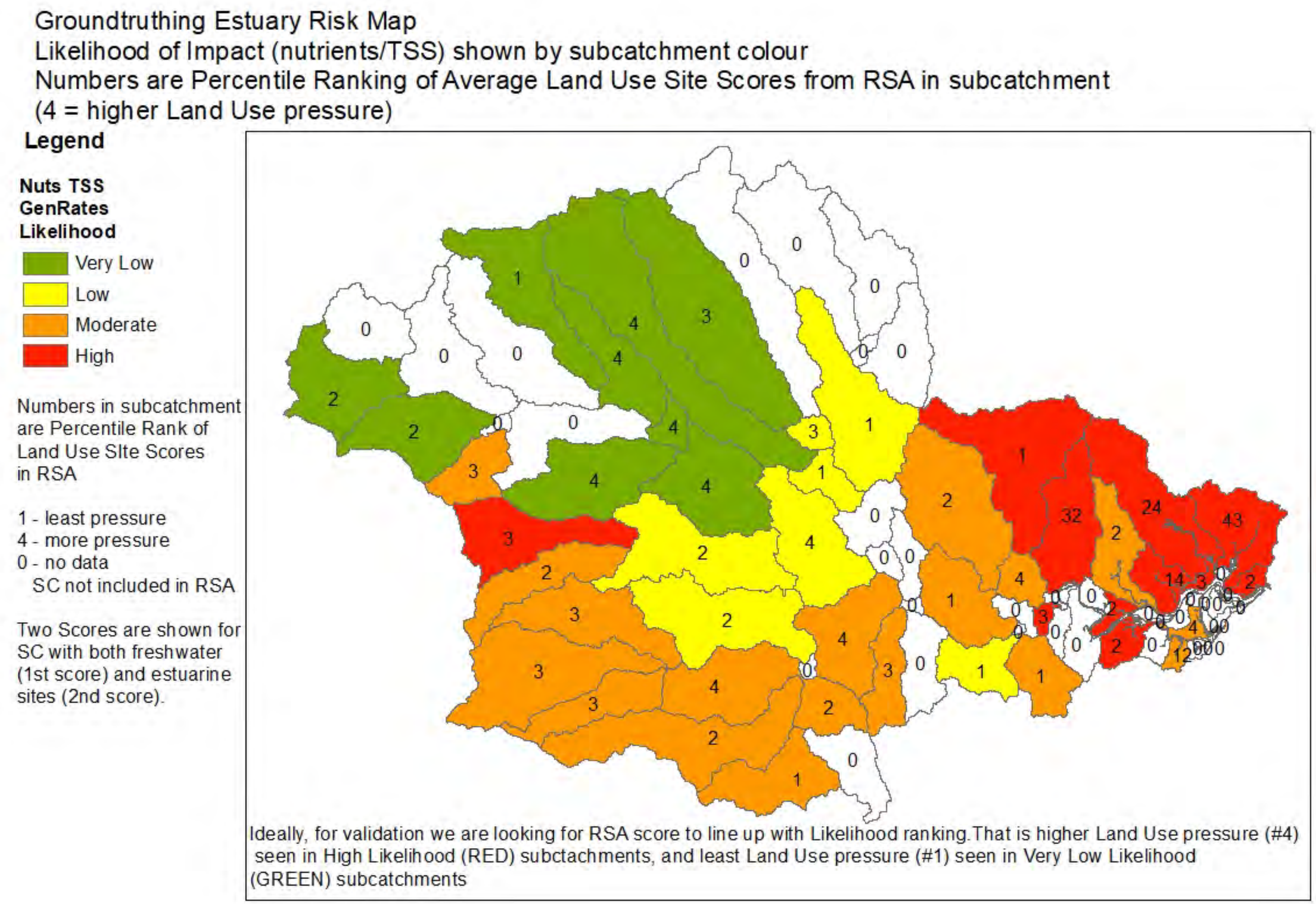
Diffuse runoff from agricultural and urban areas delivers high nutrient loads to receiving waters, with a higher proportion of bioavailable dissolved inorganic forms than would occur in runoff from natural forested areas (Harris 2001; Bartley et al. 2012). The land use category in the Rapid Site Assessments (RSA) recorded land use at the site, with the lowest score of 1 given for intensive land use (e.g., dairies), 2 for grazing, through to 5 for forested areas. The Land Use site score should therefore reflect intensity of land use and associated pollutant exports.

Grazing was the dominant land use at sites surveyed by Rapid Site Assessment. Grazing land use was targeted based on the Estuary Health Risk Map from Stage 1, which suggested that agricultural land use posed the highest relative risk to estuary health. Sites with different land use were also included to assess if land use affected riparian and stream condition.

Stock impact on the riparian zone was assessed if grazing or dairy was selected as the primary land use at the site. Further, if grazing or dairy was selected it was noted whether adjacent land use was irrigated or fertilised to capture the level of intensity of grazing/farming near the site. Land Use Site Score included land use class, stock impact if any, fertilisation and irrigation in surrounding land use. Lower Land Use Site Scores indicate more intense land use, from which high pollutant loads (TN, TP, TSS) are predicted (modelled) to occur in surface runoff.

Land Use Scores - Subcatchment Average

The average Land Use score for each subcatchment were calculated and ranked into percentiles with '1' representing least pressure from land use and '4' representing the highest intensive land use pressure. The land use 'ranking' was compared to Likelihood Scores from the catchment model that were used to produce the updated Estuary Health Risk Map (Map 2). The Likelihood Scores were based on the average generation rate of TN, TP TSS and surface flow in each subcatchment, ranked into percentiles with '1' representing the lowest risk and '4' representing the highest risk due to higher generation rates of pollutants. Map A2-18 shows the Likelihood Scores from the catchment model represented only by the colour of the subcatchment (1 = very low likelihood, GREEN; 2 = low likelihood, YELLOW; 3 = moderate likelihood, ORANGE; 4 = high likelihood, RED). The average Land Use Site score



Map A2 - 18 Ground-truthing Likelihood Scores from the catchment model represented only by the colour of the subcatchment (1 = very low likelihood, GREEN; 2 = low likelihood, YELLOW; 3 = moderate likelihood, ORANGE; 4 = high likelihood, RED). The average Land Use score ranked from 1 – 4 are shown as numbers in the subcatchment.

ranked from 1 – 4 are shown as numbers in the subcatchment. Ideally, for validation we are looking for alignment of Likelihood Scores with the Land Use score, that is moderate-high likelihood subcatchments (ORANGE, RED) would have higher scores (3,4) and vice versa for lower risk subcatchments. Instead a range of Land Use scores (1 – 4) occurred in very low, low, moderate and high likelihood subcatchments (Map A2-18). However, there was good alignment of Likelihood Scores with Land Use scores in the high risk estuarine subcatchments, more so for the estuarine sites (second score in map) than freshwater sites (first score). The freshwater sites in the predominantly estuarine subcatchments (Lansdowne 88,223; Cedar Party Creek 95, 93 were typically in better condition than the estuarine sites as freshwater sites were located upstream in forested areas.

The poor alignment off Likelihood Scores with Land Use cores across the wider catchment is not surprising given the range of condition of sites assessed in each subcatchment and the small number of sites assessed. Assessing many more sites per subcatchment may have resulted in a better alignment of modelled data and field data. Further analyses of field data collected from individual sites was done to ground-truth the catchment model inputs to the updated Estuary Health Risk Map.

Land Use Scores and Water Quality (chlorophyll-a and turbidity)

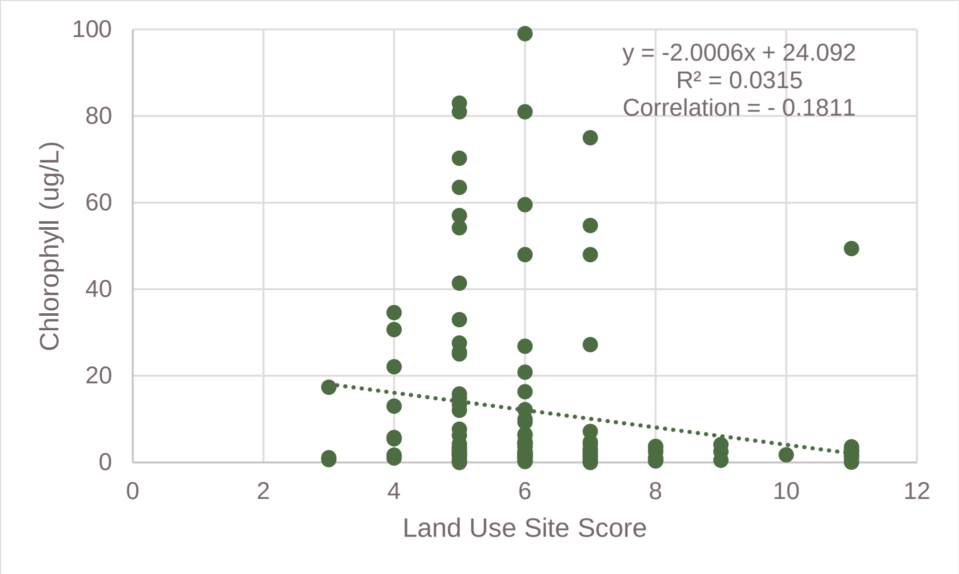
Turbidity and chlorophyll-a are appropriate measures of ecological health of estuaries as they are indicators of ecosystem performance in response to catchment pressure (Scanes et al. 2007). The concentration of chlorophyll-a in the water column is a biological indicator reflecting phytoplankton biomass, and typically reflects the nutrient load entering the waterway. Turbidity measurements indicate water clarity where high turbidity can result in a reduction of light available for photosynthesis, limiting algal and seagrass growth. These indicators are consistent with the NSW Natural Resources Monitoring, Evaluation and Reporting (MER) Program (Roper et al. 2011). Turbidity and chlorophyll-a can also be used as indicators of ecological health of freshwater systems (ANZECC and ARCMANZ 2000).

Freshwater Sites

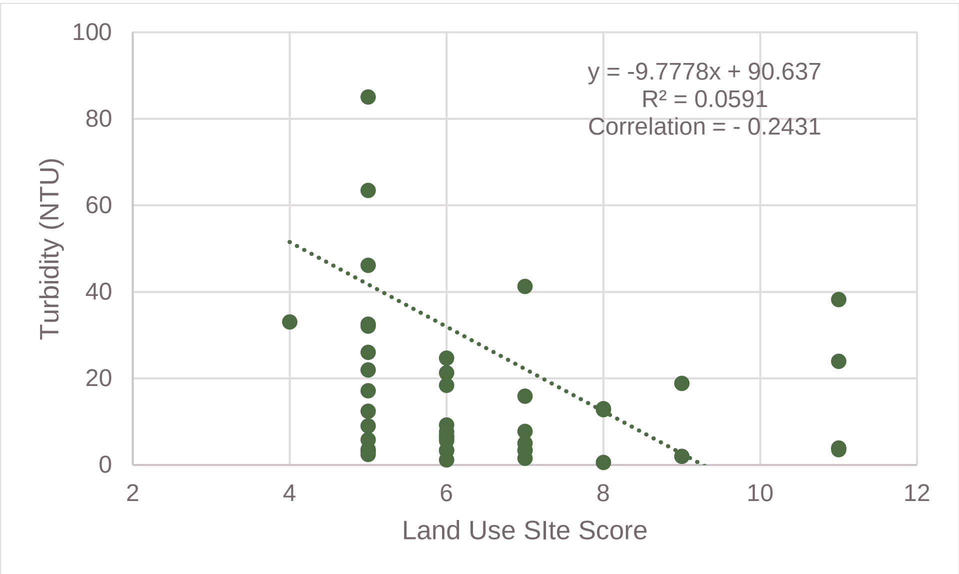
Water quality is affected by adjacent land use. Poor water quality (high chlorophyll, a lot of algal growth, poor water clarity) is indicative of high nutrients and sediment inputs in surface runoff.

Water quality was recorded at freshwater sites but was not scored as part of the in-stream condition score primarily because waterbodies assessed were not comparable (e.g. flowing streams versus isolated pools, Swanson 2019). Water quality data from freshwater sites was however still used for ground-truthing purposes.

Turbidity and chlorophyll data collected at freshwater sites was compared to Land Use Site Score. Negative trends are apparent despite the high variation in data, with higher turbidity and chlorophyll observed at sites with lower Land Use scores (lower scores indicate more intensive land use, Graphs A2-5, A2-6). Chlorophyll in freshwater streams/pools showed a significant negative correlation (correlation = - 0.18, significant [slope of zero rejected]) with Land Use score (Graph A2-5), and turbidity also showed a negative trend (correlation = - 0.14). Chlorophyll in isolated freshwater pools showed a negative trend (correlation = -0.24) with Land Use score, and turbidity also showed a negative trend (correlation = -0.24, Graph A2-6).



Graph A2 - 5 **Land Use score (includes Land Use type, stock impact, irrigation/fertilisation) for all freshwater sites from Rapid Site Assessments and corresponding chlorophyll in stream or isolated pool. Null hypothesis that slope is zero was rejected.**



Graph A2 - 6 **Land Use score (includes Land Use category, stock impact) for freshwater sites from Rapid Site Assessments and corresponding turbidity in isolated pools**

These analyses support the premise of all catchment models, that is, that highly modified land use generates more pollutant loads which in turn affects water quality of receiving waters. The data shows that land use intensity affects water quality. Negative trends were observed with higher chlorophyll/turbidity measured at sites with lower Land Use scores (Graphs A2-5, A2-6). Water quality in flowing streams was very good at many sites due to no recent inputs of nutrients/TSS in surface runoff from adjacent land use (RSA occurred in drought conditions).

Given the dry conditions, water in isolated pools either originated from groundwater springs or irrigation. Water quality of isolated pools did often reflect adjacent land use with poor water quality (e.g. high chlorophyll, turbidity) in areas of intensive land use reflecting nutrient runoff during irrigation or from nutrient rich groundwater.

Modelled Loads V Water Quality – turbidity and chlorophyll

Modelled catchment loads (TN, TP, TSS) for the subcatchments were compared against water quality data collected at sites in the subcatchment. Chlorophyll concentrations showed a negative trend with modelled TN loads (correlation = -0.13) rather than an expected positive relationship of higher chlorophyll concentrations with increasing loads in the subcatchment (Graph A2-7). Results for TP Load and chlorophyll showed a similar pattern (correlation statistic = -0.07). Modelled TSS load was compared to turbidity data collected at freshwater sites and there was no relationship (correlation = -0.01).

Water quality data collected during the RSA was highly variable with good water quality usually recorded in perennial streams and poorer water quality in isolated pools. Good water quality data collected in the perennial streams reflects drought conditions, that is, no recent inputs of pollutants from overland flow.

Estuarine Sites

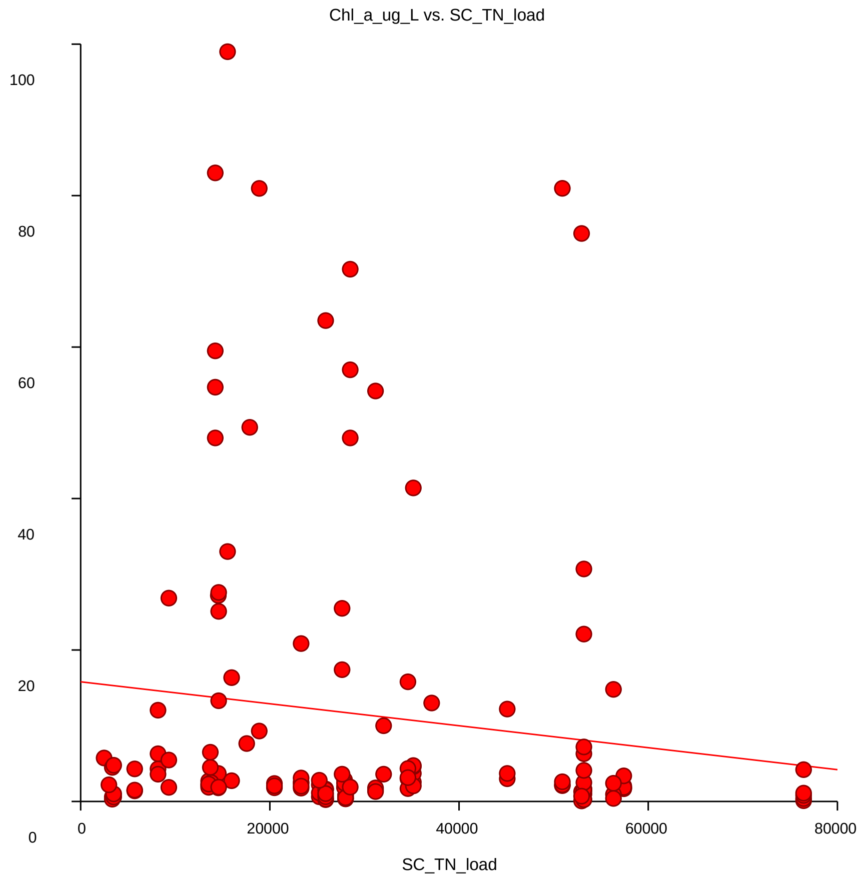
Modelled Loads V Water Quality

Modelled catchment loads (TN, TP, TSS) for the subcatchments were compared against water quality data collected at estuarine sites in the subcatchment to see if water quality data collected in RSA correlates with modelled loads. For estuarine sites, chlorophyll concentrations showed a positive trend with modelled TP (A2-8, correlation = 0.32) and modelled TN load (correlation = 0.17) for the subcatchment, in line with expectations. No trend was observed with turbidity data and modelled TSS loads (correlation = 0.03). Sediment from streambank erosion is likely to contribute to turbidity in estuarine waters.

Modelled Loads V Instream Condition Scores

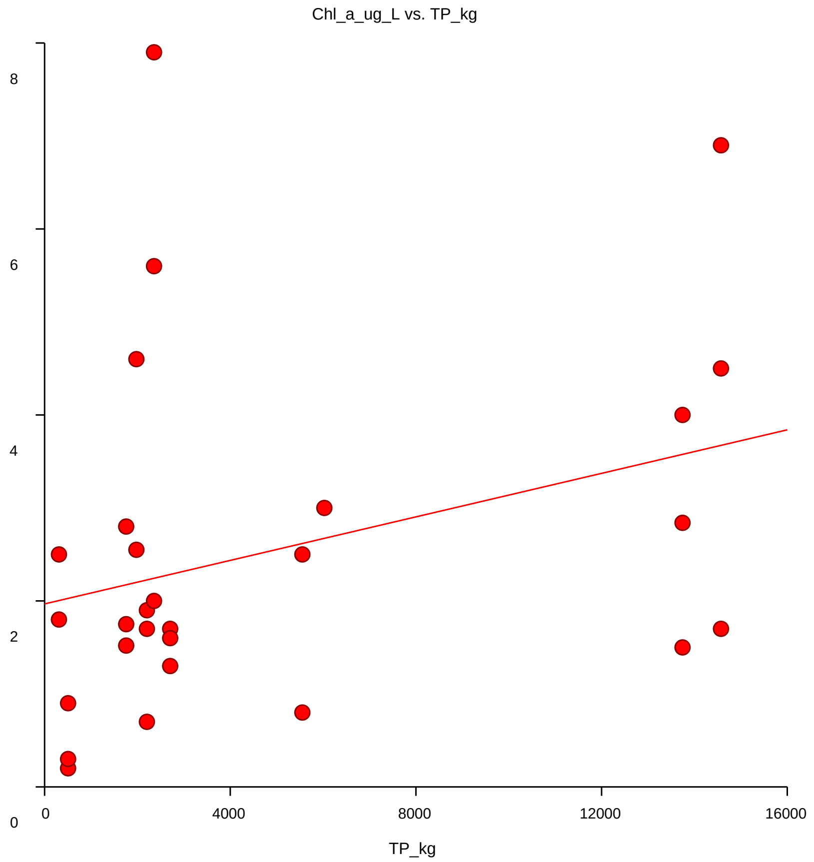
Instream Condition from RSA at estuarine sites included a score for chlorophyll and turbidity but also includes scoring for presence of macrophytes. The health of macrophytes like seagrass are affected by high loads of TN, TP and TSS to estuarine waters. Modelled loads for estuarine subcatchments are compared to the Instream Site Score for sites in those subcatchments

In line with expectations, Instream Condition showed a negative correlation with: 1) modelled TP load (kg/y) of subcatchment where the site was located (correlation = - 0.50, Graph A2-9), 2) modelled TN load (correlation = - 0.38, Graph A2-10) and modelled TSS load (correlation = -0.36, Graph A2-11).

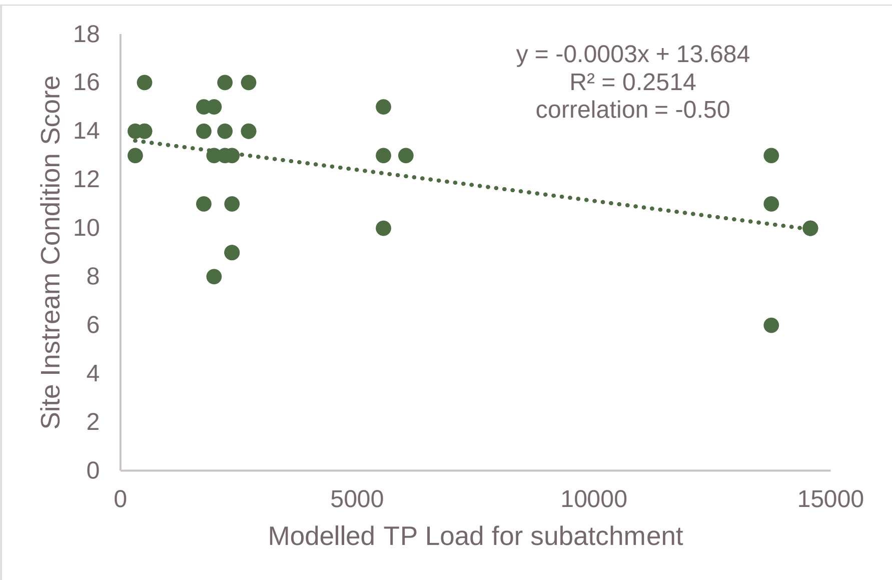


Graph A2 - 7 **Chlorophyll data collected at freshwater sites plotted against modelled TN load for the subcatchment the site is located in. Correlation = - 0.13. Note that the negative trend observed is not in line with expectations.**

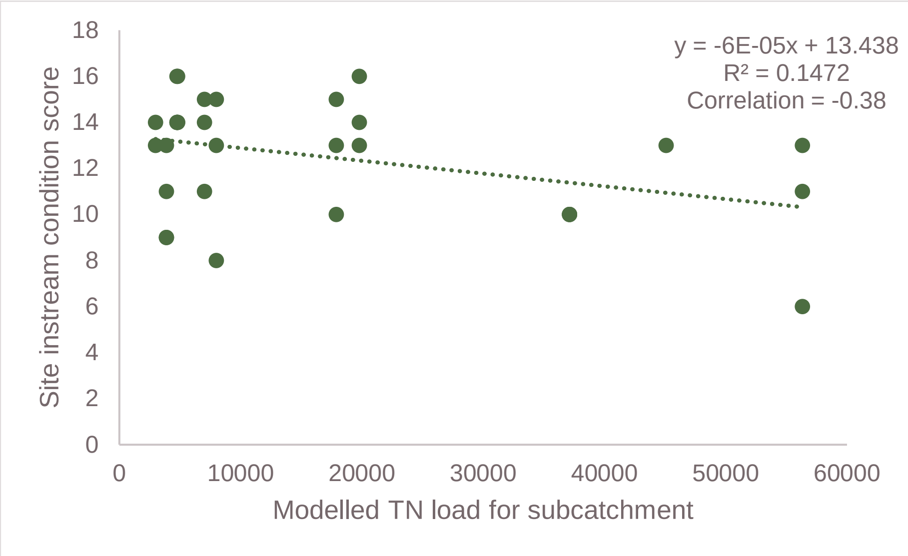
Conclusion – Water quality data collected during the Rapid Site Assessments (RSA) shows expected trends with modelled pollutant loads used to produce the updated Estuary Health Risk Map (Map 2) for estuarine sites only. Water quality recorded across the freshwater catchment reflected the current extended drought more so than estuarine sites. If the surveys occurred during a wetter period, it is likely that water quality data collected during the RSA would better reflect the modelled pollutants loads from the catchment.



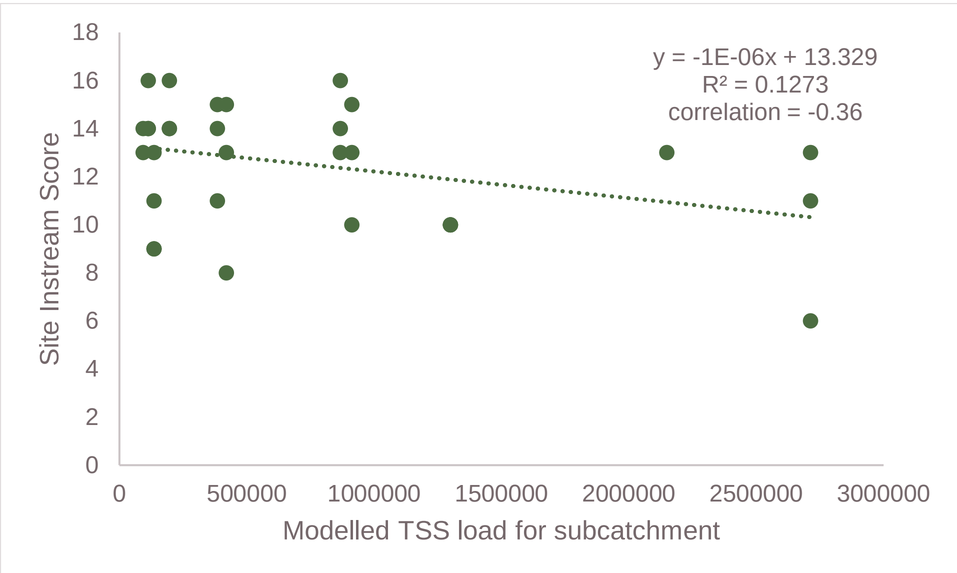
Graph A2 - 8 **Chlorophyll data collected at estuarine sites plotted against modelled TP load for the subcatchment the site is located in. Correlation = 0.32. Note that the positive trend observed is in line with expectations.**



Graph A2 - 9 **Modelled TP load vs Instream Condition score (water quality, presence of macrophytes, rubbish/grease/oil). Note higher scores indicate better instream condition so the negative trend observed is in line with expectations.**



Graph A2 - 10 Modelled TN load vs Instream Condition score (water quality, presence of macrophytes, rubbish/grease/oil). Note higher scores indicate better instream condition so the negative trend observed is in line with expectations.



Graph A2 - 11 Modelled TSS load vs Instream Condition score (water quality, presence of macrophytes, rubbish/grease/oil). Note higher scores indicate better instream condition so the negative trend observed is in line with expectations.

Appendix 3 – Pathogen Risk

Pathogen Risk from Stock

Stock and Poultry

The Stock Intensity Likelihood Scores shown in Map 7 were developed from averaging Likelihood Scores from two separate layers (A3-9):

- Total stock per subcatchment layer (A3-1) and a
- Stocking density layer (A3-9) based on
    - o stocking density per holding area (A3-3 – A3-5) and the number of properties with stocking intensity (>0.5 stock per hectare) located on 5th order streams (A3-6)
    - o the presence of large poultry farms (Map A3-7, A3-8)

Total stock per subcatchment layer

Total stock per subcatchment was calculated from the average of stock returns for 2009 – 2018 (Map A3-1). If holdings crossed two (or more) subcatchments, stock numbers were attributed to both subcatchments as it is likely that stock occupy the whole holding area over time. In the case of very large properties (with thousands of cattle) falling across multiple subcatchments, stock numbers were divided between the subcatchments. Stock divisions were informed by desktop review Nearmap / Google Earth imagery, and field observations during ground-truthing survey.

Stock per holding

Total number of stock per holding is shown in Map A3-2. This map also shows the extent of the holdings data in the upper catchment. Other blank areas in the catchment are forested areas or holdings that are less than 20 hectares.

Stocking density per holding

Stocking density per hectare holding area was calculated and is presented as percentiles in Map A3-3. Median stocking density was 0.5 stock per hectare of holding, and 95th percentile of stocking density was 2.1 animals per hectare of holding. More detail of stocking density in upper and lower catchment are shown in Maps A3-4, A3-5). Stocking density per holding layer was intersected with 5th order streams (and above, River Styles spatial layer) to show properties with moderate to high (>0.5 stock per ha) stocking densities on major waterways (Map A3-6).

Total poultry per subcatchment

Total poultry per subcatchment was calculated from the average of stock returns for 2009 – 2018 are shown in Map A3-7.

Poultry density per holding

Total number of chickens per holding is shown in Map A3-8.

Stock intensity layer (= Likelihood Score)

The stock intensity layer is based on total stock numbers in each subcatchment, and the stocking density of stock and poultry in farms in each subcatchment.

Total number of stock per subcatchment – Likelihood score

Subcatchments with <1000 stock (average 2009-2018) were assigned a Score of 1.
Subcatchments with 1001 - 3000 stock (average 2009-2018) were assigned a Score of 2.
Subcatchments with 3001 - 6000 stock (average 2009-2018) were assigned a Score of 3.
Subcatchments with 6001 - 10000 stock (average 2009-2018) were assigned a Score of 4.

Likelihood scores for total stock per subcatchment are shown in Map A3-9 (top left inset map).

Stock density – Likelihood score

Maps of stocking density per hectare holding in each subcatchment, and the intersection of properties with moderate-high stocking density with 5th order streams were interrogated to calculate Likelihood Scores for each subcatchment.

Subcatchments with majority of properties with stocking density of 0.25 stock per ha holding (25th percentile) were assigned a score of 1.

Subcatchments with majority of properties with stocking density <0.25 stock per ha holding (25th percentile) and 0.25 – 0.5 stock per ha holding (median) were assigned a score of 2.

Subcatchments with high proportion of properties with a moderate stocking density >0.5 stock located on 5th order streams, or adjacent to estuary were assigned a score of 3.

Subcatchments with the highest proportion of properties with a moderate stocking density and high stocking density >2 stock per hectare (>95th percentile) located on 5th order streams, or adjacent to estuary, were assigned a score of 4.

Likelihood scores for stocking density in each subcatchment are shown in Map A3-9 (bottom left inset map).

Stock intensity (including poultry) – Likelihood Score

Likelihood scores for total stock numbers and stock density were averaged to get the Stock Intensity Likelihood Scores used in the pathogen risk assessments (Map A3-9 – main map, Map 7).

Any subcatchment with large poultry farms (>50,000 chickens) were upgraded to score of 4 if they were not already assigned 4. Only one subcatchment had to be upgraded from score of 3 to 4 (SC 86), all other subcatchments with large poultry farms (SC 88, 95, 122, 123) were already assigned a score of 4 due to stock densities.

Ground-truthing Stock Intensity layer

Observed stocking rates in catchment

Field staff noted stock numbers observed in pastures while on route to sites for Rapid Site Assessments. Observations were restricted to stock visible from public roads, except when driving through private property. Observations of stocking rates were averaged for the subcatchment and are compared to Stock Intensity Likelihood Scores in Map A3-10 represented by colour (1 = very low likelihood, GREEN; 2 = low likelihood, YELLOW; 3 = moderate likelihood, ORANGE; 4 = high likelihood, RED). Note that the Stock Intensity

Likelihood in Map A3-10 is for stock only (no poultry) and differs (only) slightly from Map A3-9 (which includes poultry).

Generally low stocking rates were observed throughout most of the catchment during the ground-truthing program (with a few exceptions) as farmers have de-stocked due to the ongoing drought. Field observations were restricted to stock observed in pastures from the road while driving between sites. Stock Intensity likelihood ratings were based on average stocking rates from last 10 years of annual returns to LLS-Hunter, which includes stocking rates from non-drought years. Stocking rate observations align reasonably well with the Likelihood Scores considering the likely influence of the drought reducing stock numbers. Low stocking rates (or no stock) were observed in subcatchments with very low or low stocking intensity except for subcatchment 66-Nowendoc where moderate stocking rates were observed (yellow subcatchment in upper catchment). Moderate stocking rates were observed in subcatchments 117-Barrington (orange, moderate likelihood), 122-Gloucester and 88-Lansdowne (red, high likelihood). Low stocking rate was observed in 95-Cedar Party Creek although this subcatchment was rated Stock Intensity of High likelihood.

Rapid Site Assessments

Stock impact scores – subcatchment average

Stock access to sites were assessed during Rapid Site Assessments (RSA) by noting the level of impact of stock in the riparian zone and on streambanks. Stock Impact Scores were based on sightings of manure, pugging on the banks, no understory/grazed *Lomandra* etc and sightings of cows in the stream /riparian zone at the time of the RSA. Note that lower scores for Stock Impact in RSA indicates *more* impact. This scoring needed to be reversed to compared to Likelihood Scores where higher scores indicates more impact. The average Stock impact score for sites in each subcatchment was calculated and reversed (ie., 4 becomes 1, 2 becomes 3, and vice versa) and the reversed score is shown in the subcatchment. Stock impact scores are compared o Stock Intensity Likelihood represented by colour (1 = very low likelihood, GREEN; 2 = low likelihood, YELLOW; 3 = moderate likelihood, ORANGE; 4 = high likelihood, RED) in Map A3-11.

Stock impact score only measures direct impact on the riparian zone/streambank whereas the stock intensity likelihood score is a combination of total stocking numbers in the subcatchment, stocking density per holding and number of properties of moderate to high stocking density located on waterways. For these reasons, it is not surprising that there is not a great alignment of Stock Impact scores with the Stock Intensity Likelihood rating. However, this map provides an overview of stock impact in each subcatchment with over half subcatchment averages scoring 3 or 4, revealing the large extent of stock impact on riparian zones/streambanks at sites assessed in those subcatchments. Subcatchments with the lowest Stock Intensity Likelihood rating (GREEN, YELLOW subcatchments) scored poorly for Stock Impact as cattle frequently accessing riparian zones.

Stock impact scores – water quality

Stock Impact Scores from freshwater sites were compared to turbidity and chlorophyll data to see if there was a relationship between stock access to waterways and water quality. Note that lower scores for Stock Impact indicate *more* impact. There was a weak but significant negative correlation between stock impact scores and water quality (turbidity, correlation = -0.17; chlorophyll concentrations, correlation = -0.27). That is, there was trend of poorer water quality (i.e., higher turbidity and chlorophyll concentrations) in streams with higher levels of stock access to a site (as indicated by a lower Stock Impact Score).

Conclusion

Observations of stocking rates across the catchment showed reasonable alignment with stocking intensity Likelihood Scores considering that drought has led to de-stocking across the catchment. Stock Intensity Likelihood Scores were based on average stocking rates over the last 10 years which included non-drought years. Observations of stocking rates were also restricted to stock visible from the road and may have been underestimated. Stock Impact scores from Rapid Site Assessments did not match that well with the Stocking Intensity Likelihood Scores probably because Stock impact scores were purely related to cattle access to streams, whereas the Stock Intensity Likelihood Scores takes into account other factors relating to total stock numbers and stocking density. There was a weak correlation between poor water quality data and stock impact scores in the Rapid Site Assessments at freshwater sites. Cattle were frequently observed in riparian zones across the catchment and are a contributing factor to poor water quality.

Drinking water quality monitoring program

Escherichia coli

Escherichia coli is a normal inhabitant of the intestine and is present in high numbers in faeces from humans and other warm-blooded animals. *E. coli* generally does not grow in natural waters and is the most specific indicator of recent faecal contamination (because generally it is not capable of growth in the environment). While most *E. coli* are non-pathogenic, there are some pathogenic subtypes that can cause enteric illness, including enteropathogenic, enteroinvasive, enterotoxigenic and enterohaemorrhagic strains (Bopp 1999). Protecting source waters from contamination by human and livestock waste will reduce the potential presence of pathogenic *E. coli* (NHMRC, NRMMC 2011).

E. coli should not be present in any 100 mL sample of drinking water however there are no guidelines for *E. coli* in the water supply to be used for drinking water. All *E. coli* strains are highly sensitive to disinfection (NHMRC, NRMMC 2011)

MidCoast Water Services (MCW) monitor *E.coli* at the Gloucester Water Supply offtake (MCW5) and Manning River Offtake to Bootawa Dam (MCW1) as part of their Drinking Water Quality Monitoring Program on a weekly to fortnightly basis (MidCoast Water Services 2018). *E. coli* data is summarised in Table A3-1 along with Stocking Intensity Likelihood and Risk scores allocated to the subcatchment in which monitoring site is located.

Total faecal coliforms

Total faecal coliforms includes *E. coli* strains and other bacteria of faecal origin. MidCoast Water Services monitor total faecal coliforms (FC) at monitoring sites MCW7 – MCW2 on a monthly basis but do not monitor total faecal coliforms at MCW1 (only *E. coli*). A summary of FC data is shown in Table A3-2 (FC data for MCW9-8 is from 2009 -2011).

E. coli and faecal coliform data (95th percentile) are shown in Maps A3-12, A3-13 in context of stocking density of holdings upstream of the monitoring site/offtake locations.

The *E. coli* and faecal coliform data collected at each monitoring site are generally in line with the Stock intensity layer likelihood scores for the subcatchment (Tables A3-1, A3-2) except for the very high counts at MCW5. Subcatchment 117 was assigned a Likelihood Score of 3 based on the stocking density across the whole subcatchment. Subcatchment 117 was deemed as high risk to drinking water in the pathogen risk assessment with a risk level of 12 (Map 9) because the highest Consequence Score or 4 was applied to 117.

Gloucester offtake location (MCW5) – E. coli and faecal coliform data

E.coli counts in offtake water for Gloucester water supply (Table A3-1) suggest that faecal contamination of the water supply is a constant pressure on delivering drinking water to the community of the appropriate standard (zero *E. coli* should be present in drinking water). Disinfection of the water supply kills E. coli and other pathogens before it enters the drinking water supply.

The source of the faecal contamination is from intensive farming that occurs on the Barrington River upstream of the offtake location. *E.coli* data is only available for MCW5 in the Barrington River catchment however total faecal coliform data is available from upstream sites MCW7 and MCW6 (Table A3-2). Looking at median FC concentrations there is a large increase in FC at MCW5 (3100 cfu/100ml) compared to upstream sites MCW 7 (3100 cfu/100ml) and MCW6 (3100 cfu/100ml, Table A3-2) which suggests the main contamination is coming from properties between Sites MCW6 and the offtake site (MCW5, Map A3-13).

There are a number of properties with moderate to high stocking density in this reach of river that are immediately upstream of the offtake (Maps A3-14). The holding shown in red upstream of MCW5 (Map A3-14) has a very high stocking density of 3.2 stock per hectare of holding (holding ID - 107155798). Another property farther upstream is Rosemary's property (117-05, Map A3-14), a large dairy farm where hundreds of cattle cross the river twice daily for milking. *Note this property is approximately 6 km upstream of offtake however in previous correspondence with Council this property was said to be 600m upstream of offtake location*.

The offtake location (MCW5) is approximately 200m upstream of the confluence with the Gloucester River (Maps A3-14). The Avon River and Gloucester River merge approximately 1 km upstream of the confluence with the Barrington River. These two rivers pass through kilometres of intensive farming land. Given the close proximity of the confluence of the two rivers with the offtake location, could it be possible that under some conditions (low flow Barrington/high flow in Gloucester, or high winds) that some water from the Gloucester River could be entering the offtake supply in the Barrington? Or is the large spike in FC counts at MCW5 (relative to MCW6) due only to the properties on the Barrington River immediately upstream of the offtake? The source of the faecal contamination at MCW5 needs further investigation for the risk it poses to drinking water quality.

It should be noted that human waste may also be contributing to the bacterial counts. Gloucester township has a reticulated sewage system but unsewered properties occur in the rest of the surrounding areas. Given the intensity of farming in the area it is most likely that the majority of the faecal contamination in the rivers is from stock.

Total phosphorous in Abbotts Rd Offtake (Bootawa Dam water supply)

Intensive farming in the drinking water catchment leads to high levels of Total Phosphorous (TP) in the water supply. MidCoast Water Services uses monthly 50th percentile data for TP as a guide for cease-to pump response at Abbots rd offtake in Manning River. Monthly 50th percentile concentrations range from the low 30s (µg/L) in the summer months to 14-17 *u*g/L in the winter months. TP concentrations in offtake water at MCW1 are plotted with 50th percentile concentrations data in Graph A3-1. TP concentrations at the offtake location regularly exceed 50th percentile concentrations and often by a large amount (Graph A3-1).

Secondary Recreation Risk Assessment

The bacterial data presented in the previous section is not only a risk to drinking water quality but also poses a potential human health risk to the community using the waterway for secondary recreation. Relf's Landing (site 117-04, Map A3-14) is just upstream of the Gloucester offtake location where high *E. coli* counts are common (Table A3-1, median concentration *E. coli* 190 cfu/100ml). Relf's Landing is a popular launch site for kayaking and is also a popular fishing and swimming location (primary recreation, pers. Comm. Mark Tull - MCC). There is another kayaking route upstream between Rocky Crossing (MCW7) and Barrington Bridge (MCW6) but faecal contamination is lower in this reach.

Subcatchment 117 was assigned the highest Consequence Score of 4 in the pathogen risk assessment for secondary recreation resulting in a risk level of 12. Further investigation and on-ground works to reduce the pathogen risk to water quality in the downstream end of Barrington River (117).

Aquaculture

The NSW Food Authority monitors water quality (salinity, total faecal coliforms) in the vicinity of the oyster farms for a quality assurance program. Median concentrations of faecal coliforms were typically less than 5 cfu/100ml with 95th percentile concentrations typically under 100 cfu/100ml (Table A3-3). Incoming clean oceanic water and the larger volume of water in the estuary help to dilute bacterial counts. The faecal coliforms in estuary waters are likely to originate from stock as well as human sources with many of the surrounding subcatchments being unsewered.

Subcatchments 203, 204 and 205 were deemed to be high risk to aquaculture with respect to stock derived pathogens. The highest median counts of faecal coliforms were recorded at site 13 where Scotts Creek/Manning River confluence (subcatchment 203).

Table A3 - 1 E.coli data (CFU/100ml) from Gloucester water supply offtake (MCW5) and Manning River offtake (MCW1) for Bootawa Dam, showing the subcatchment offtake is located in and subcatchment Likelihood (Like'd) and Risk scores from the risk assessment.

Site (SC)	Like'd score	Risk score	Ecoli_ Median	Ecoli_ Ave	Ecoli_ Max	Ecoli_ Range	Ecoli_ 80th	Ecoli_ 95th
MCW5 (117)	3	12	190	301	2000	1977	442	942
MCW1 (99)	3	12	65.5	136	7700	7700	120	308

Table A3 - 2 Faecal coliform (FC, CFU/100ml) data from MCW monitoring sites (Map A2-1). FC data from sites 9 and 8 is from 2009-2011, other datasets are from 2009/10 to 2019. Likelihood and Risk scores (for the subcatchment (SC) that monitoring site is located in) from the risk assessment are also shown.

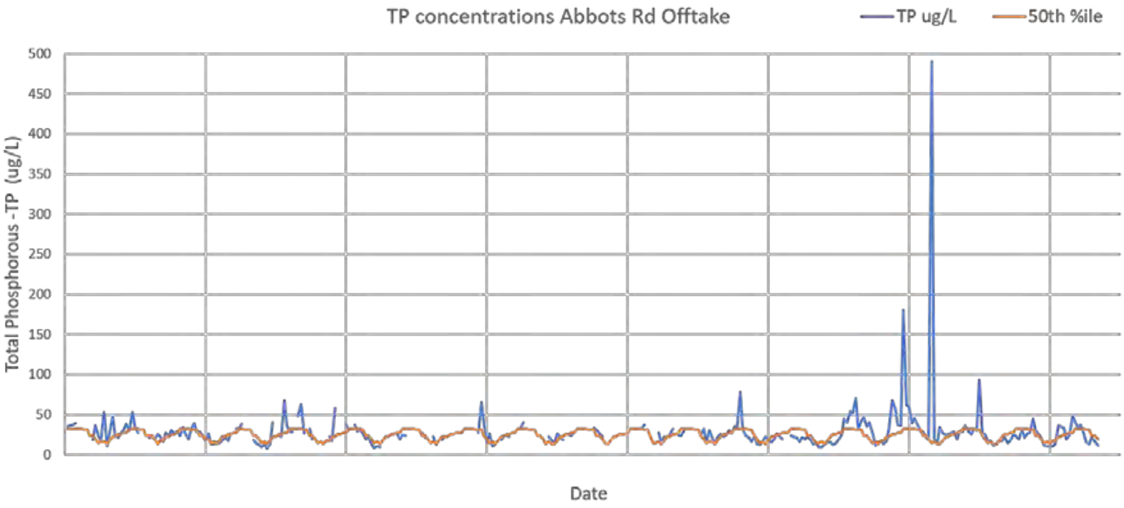
Site (SC)	Like'd score	Risk Score	FC_ Median	FC_Ave	FC_Max	FC_80th	FC_95th
MCW9(111)	2	8	64	93	530	130	178
MCW8(115)	2	8	85.5	209	2500	142	316
MCW7(117)	3	12	70	203	8100	104	146
MCW6(117)	3	12	92	225	6000	144	537
MCW5(117)	3	12	3100	4275	48000	4900	9625
MCW4(91)	2	6	58	101	1000	77	207
MCW3(84)	1	4	59	141	3600	242	878
MCW2(87)	2	8	24	60	1200	28	76

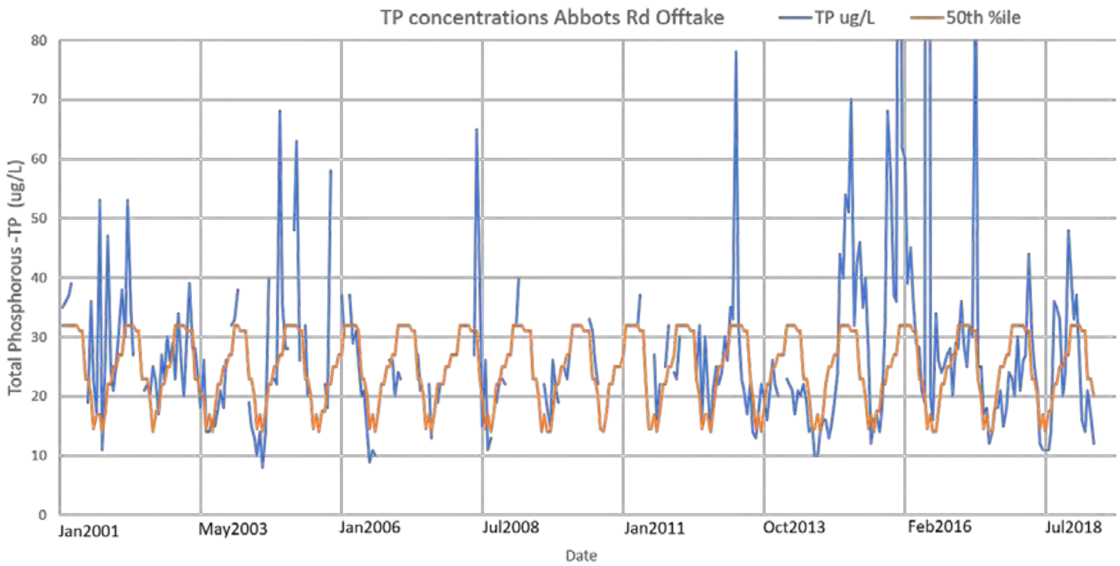
Table A3 - 3 Total faecal coliform data collected by NSW Food Authority for Manning River Shellfish Quality Assurance Program. Data was collected on an 'as needs' basis from 2003 – 2019. Sites 01 – 22 are shown on Map A3-4

Site	01	02	03	04	05	06	08	09	10
average	28	36	19	30	28	22	30	30	40
median	4	5	4	7	4	4	6	6	5
95th percentile	53	81	47	87	47	50	71	79	71

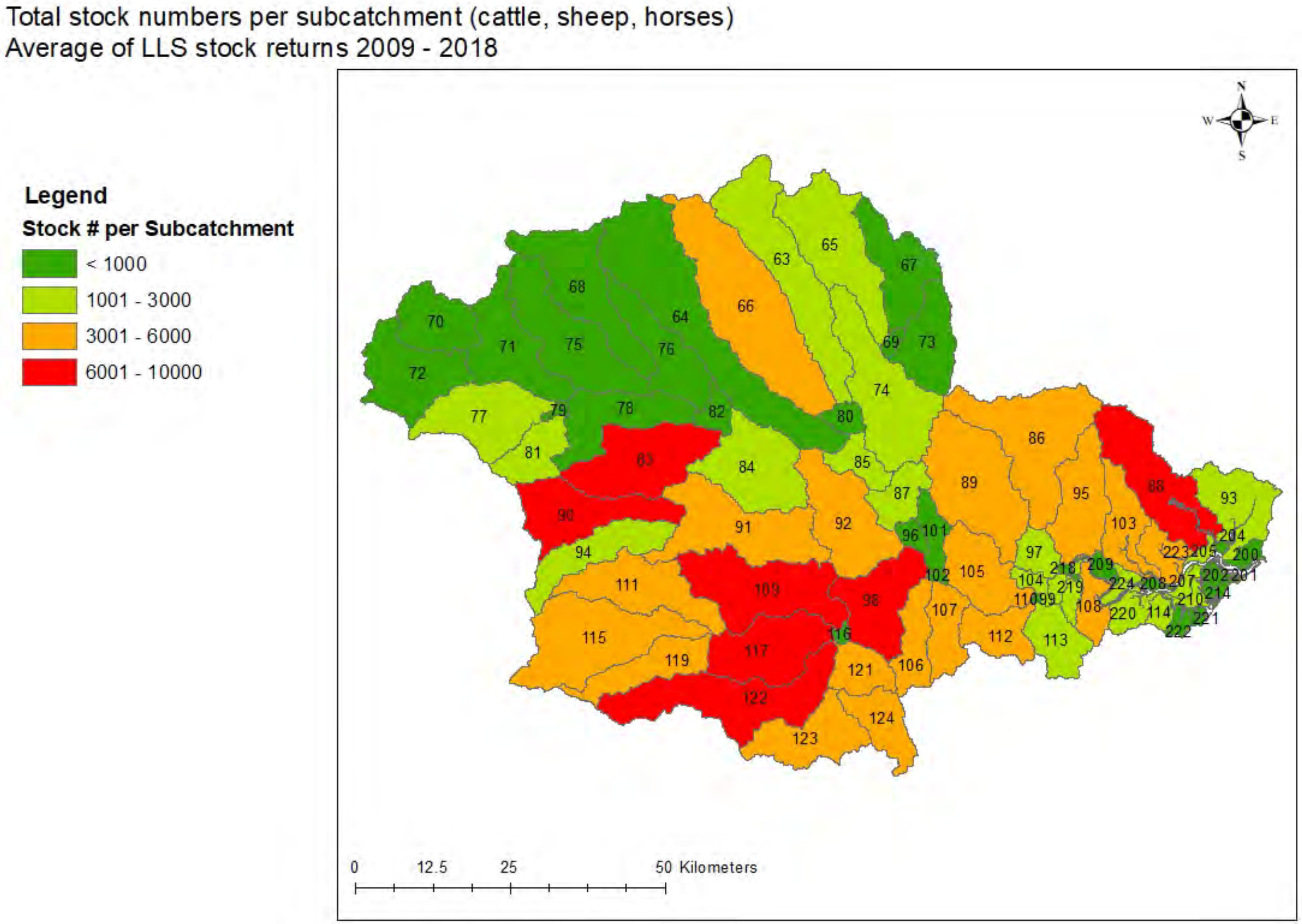
Site	11A	12	13	14	15	16	17	18	20
average	18	28	32	44	23	31	27	31	63
median	6	6	7	6	6	4	4	4	3
95th percentile	52	72	59	69	64	90	100	83	124

Site	21	22	42	45	47	48
average	58	53	13	25	14	12
median	4	4	3	4.5	3	6
95th percentile	120	108	43	161	48	28

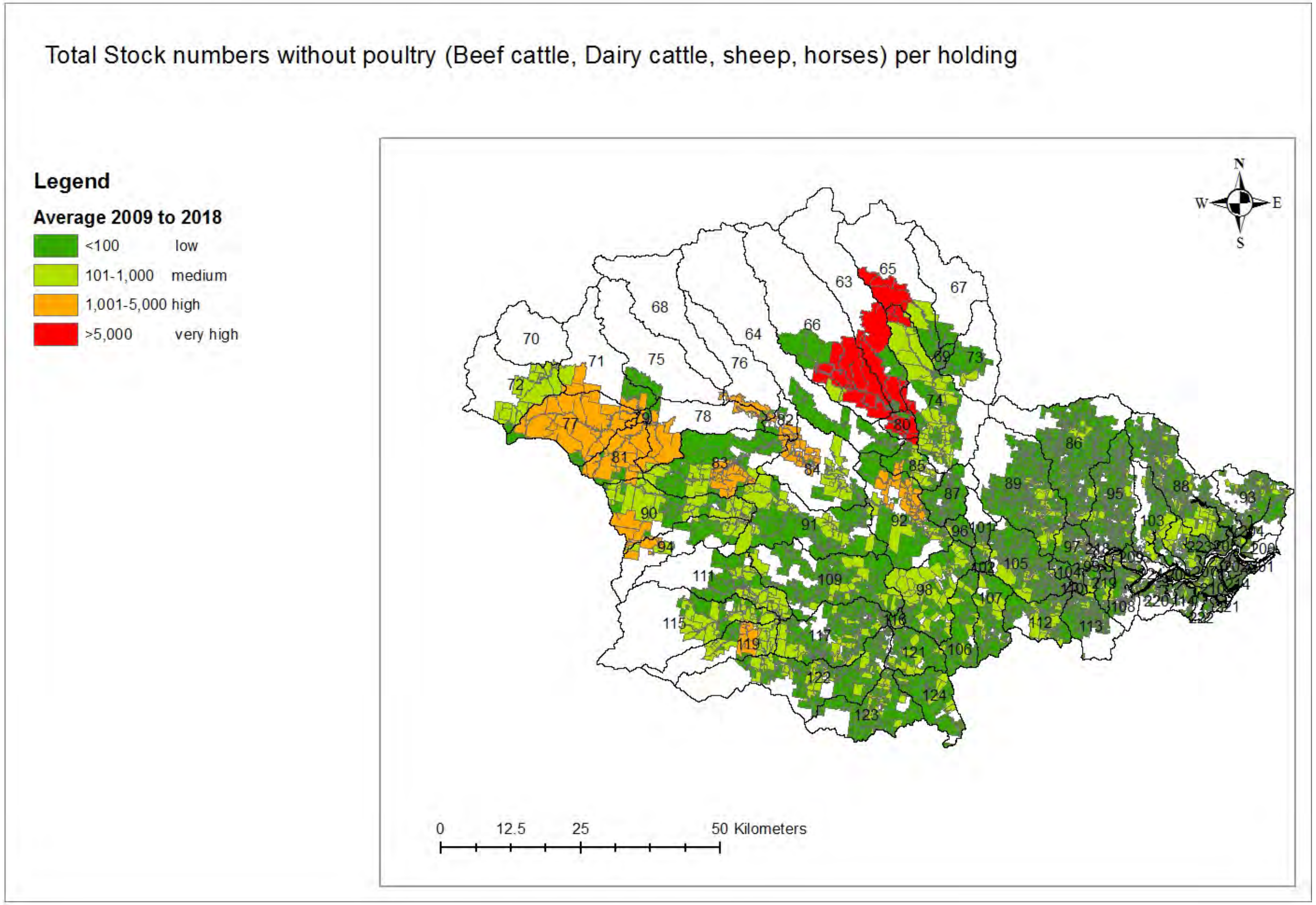




Graph A3 - 1 Total phosphorous concentrations in Manning River at Abbots Rd Offtake for Bootawa Dam (Taree and Forster water supply). The Orange Line represents 50th percentile TP concentrations for each month based on all data collected. The blue line is TP concentrations in Manning River.

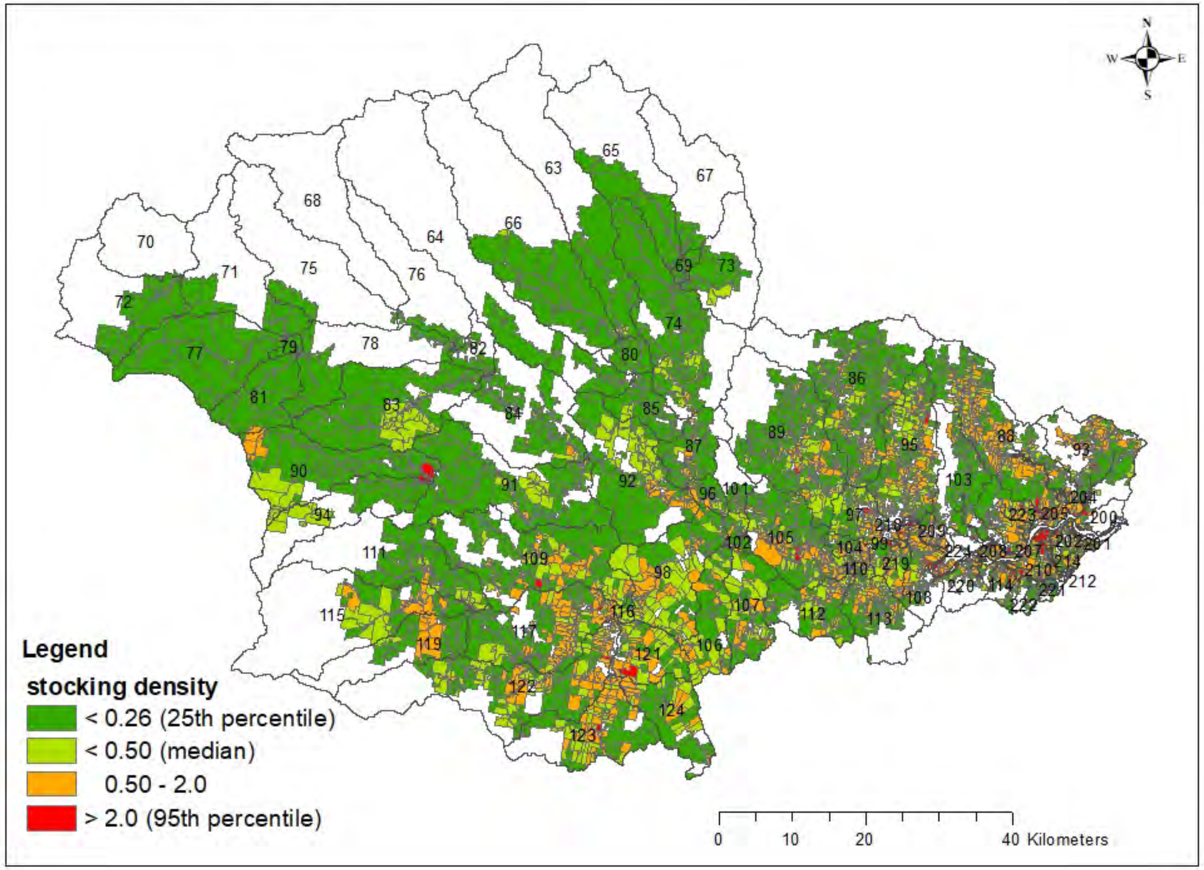


Map A3 - 1 **Average total stock numbers (cattle, horses, sheep) in each subcatchment based on Annual Stock returns 2009-2018 provided to LLS-Hunter.**



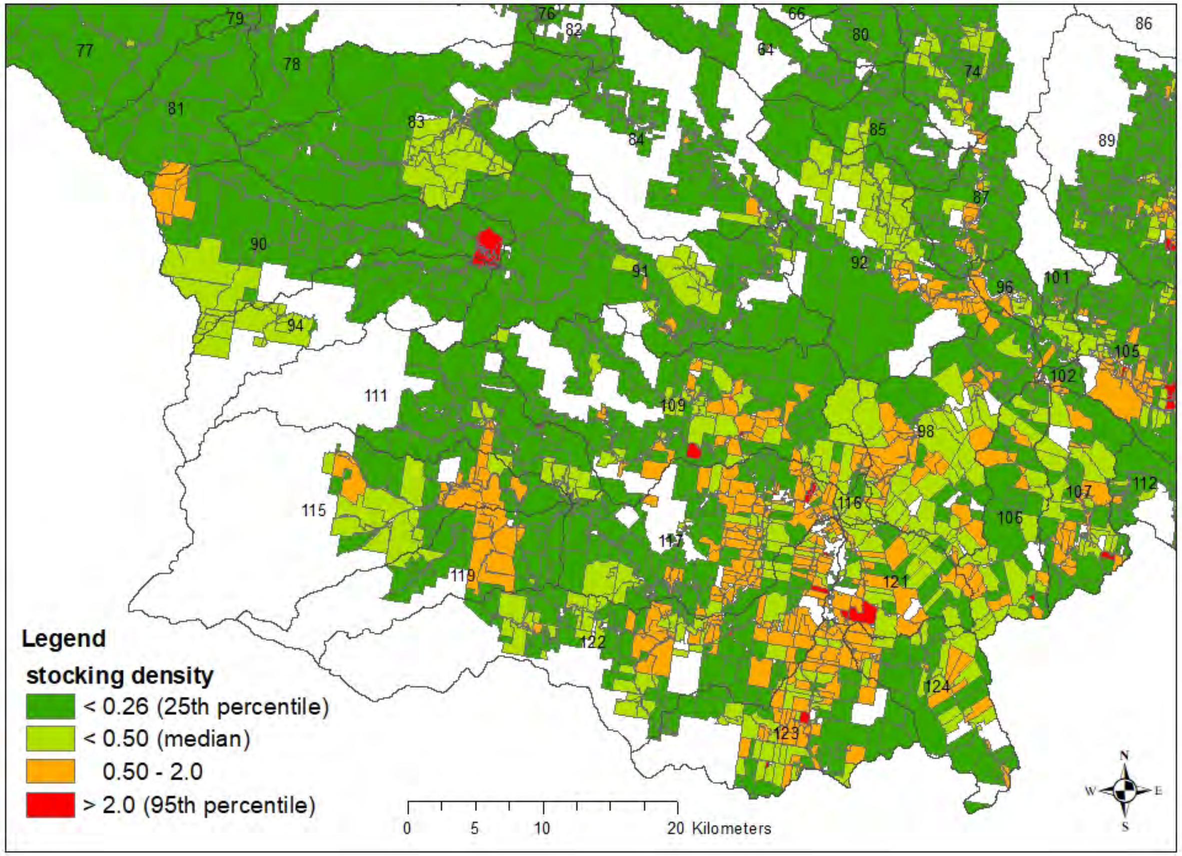
Map A3 - 2 **Total stock per holding. Also shows extent of stocking data for upper catchment. Large Red and Orange holdings (subcatchment 77, 81) are one property**

Stocking density - stock numbers per area of holding
Average of LLS stock returns 2009 - 2018

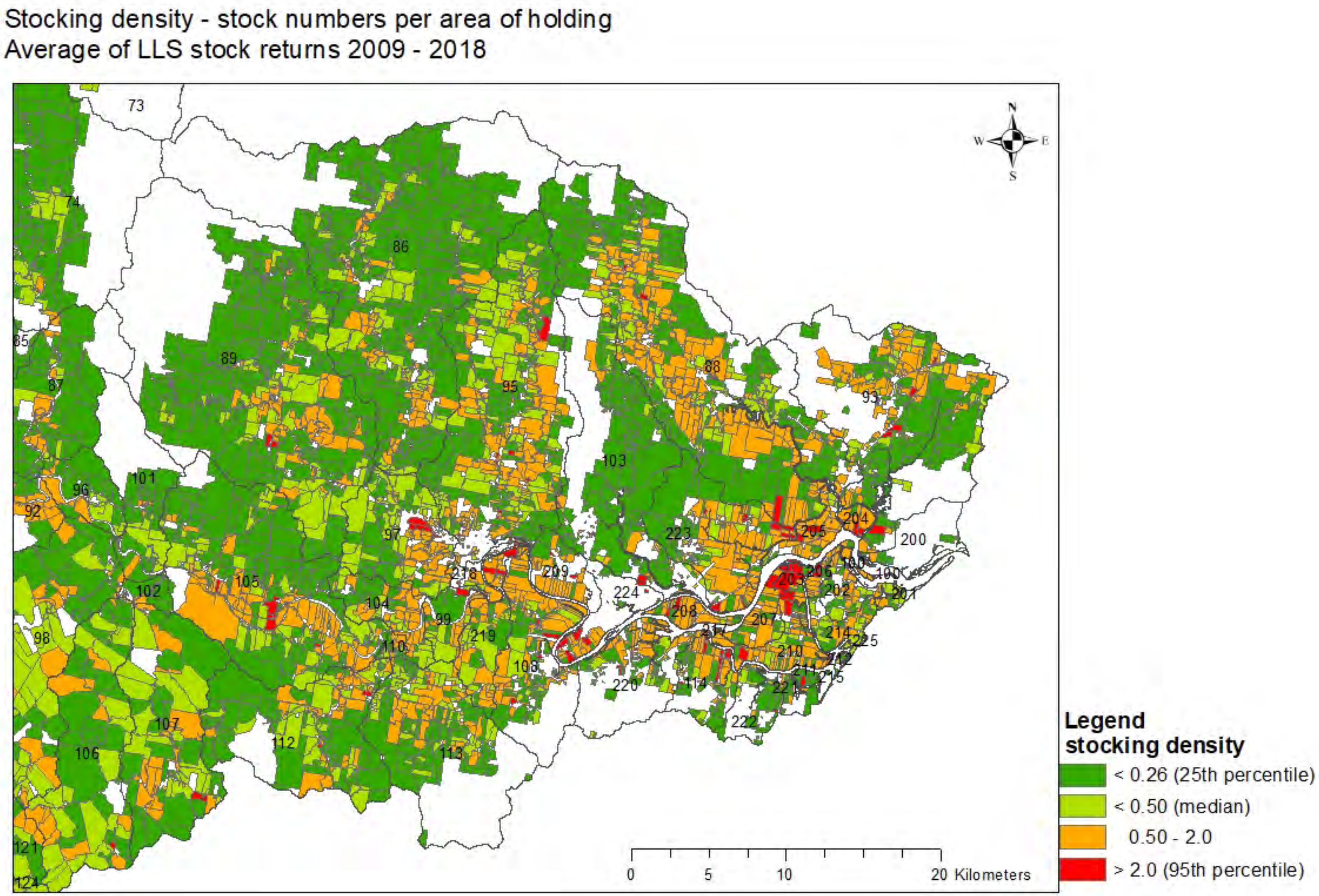


Map A3 - 3 **Stocking density (number of stock per hectare of holding). See Maps A3-3 and A3-4 for more detail of holdings density in upper and lower catchment**

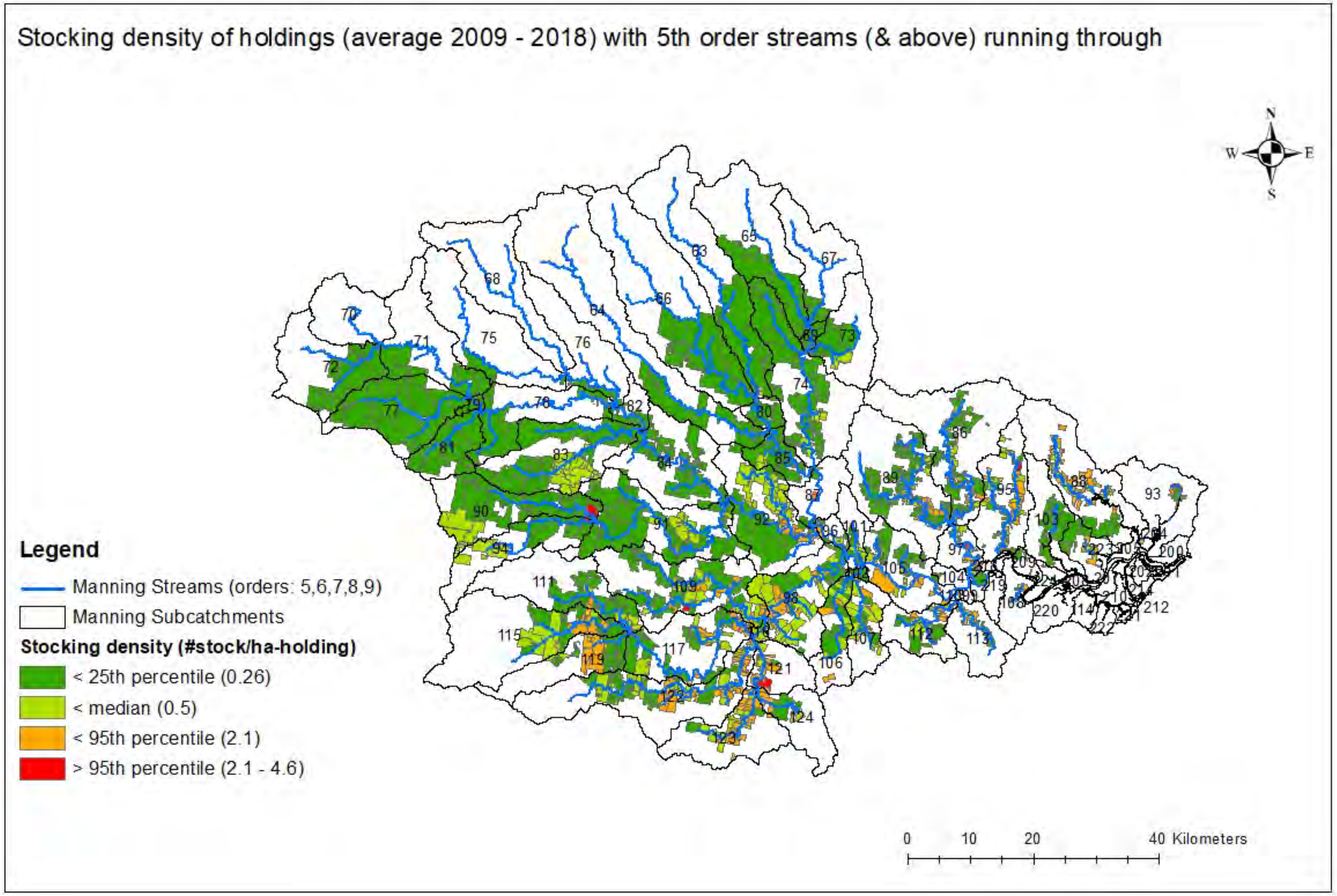
Stocking density - stock numbers per area of holding
Average of LLS stock returns 2009 - 2018



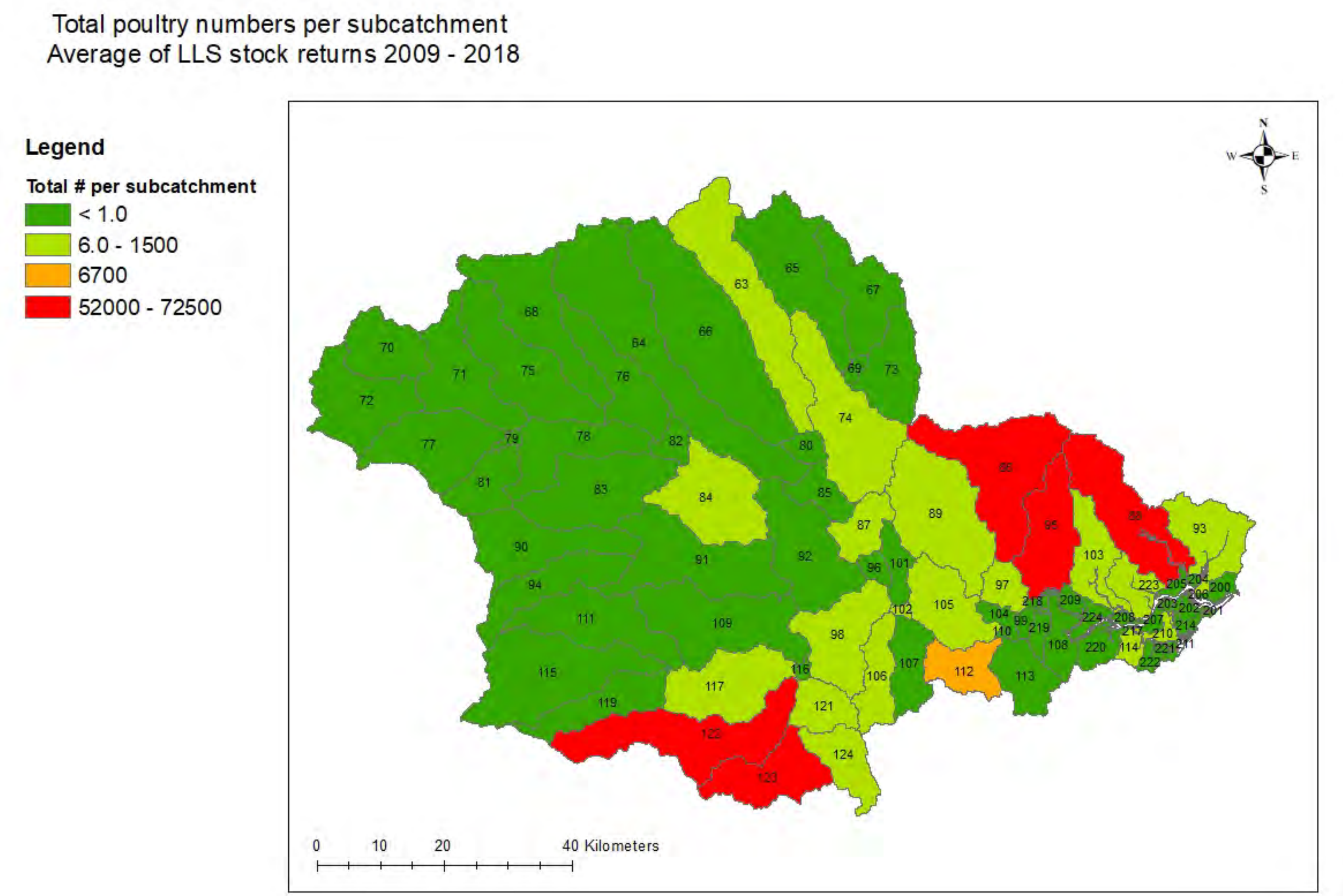
Map A3 - 4 **Stocking density (number of stock per hectare of holding) in the upper catchment**



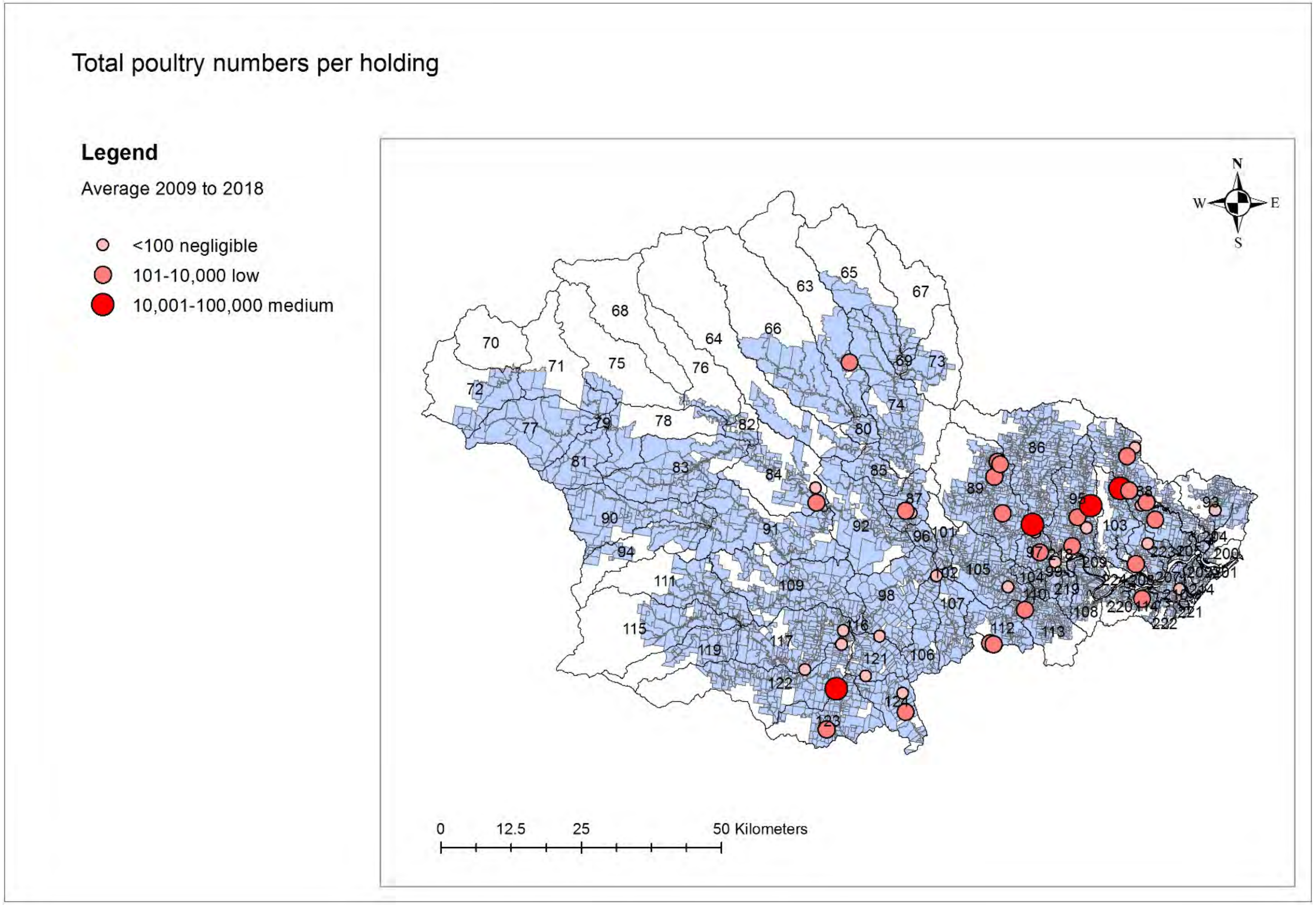
Map A3 - 5 Stocking density (number of stock per hectare of holding) in the lower catchment



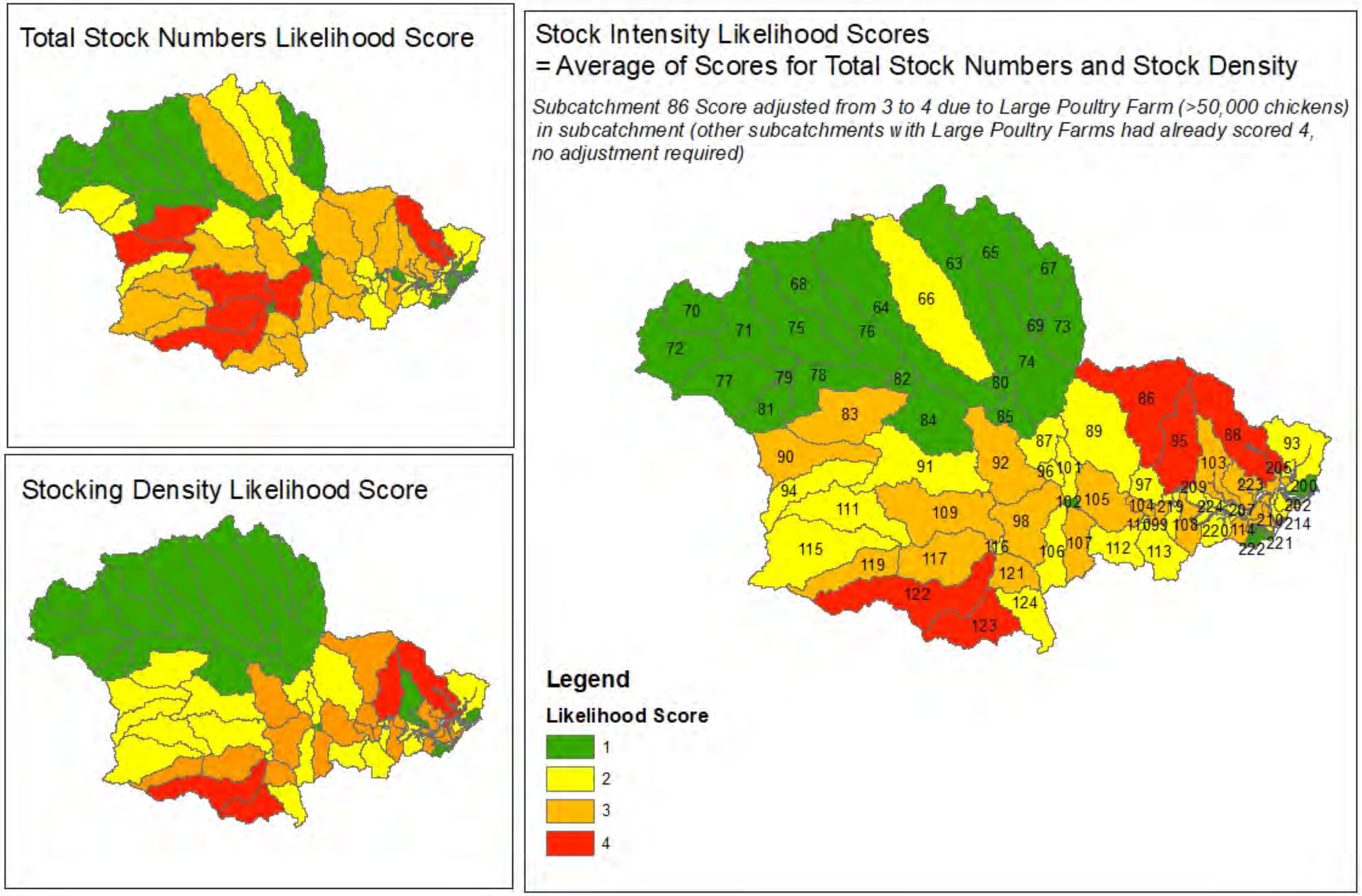
Map A3 - 6 **Intersection of stocking density map and 5th order streams (River Styles). Note this map only shows holding situated on 5th order streams (and above)**



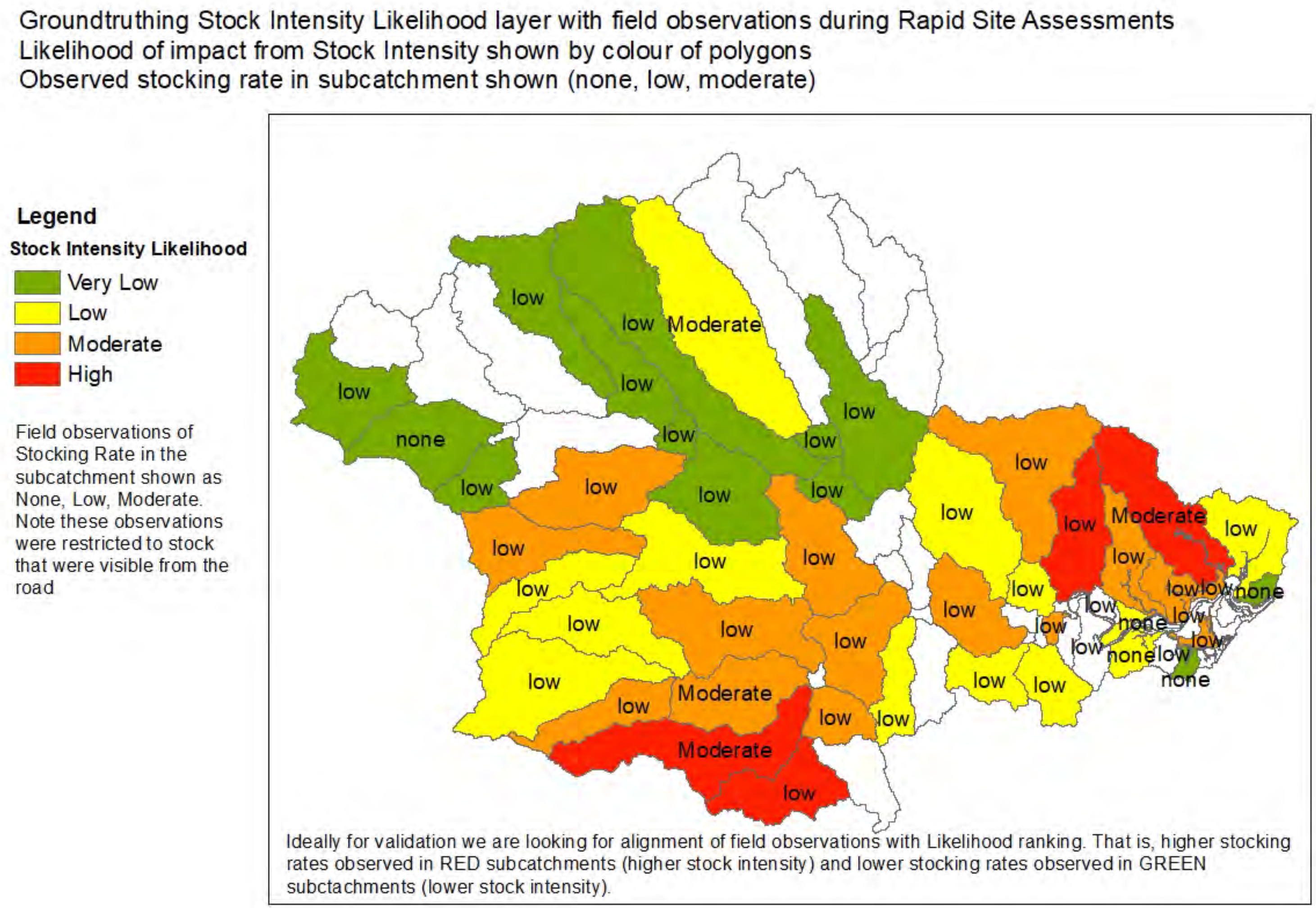
Map A3 - 7 Average total number of poultry in each subcatchment based on Annual Stock returns 2009-2018 provided to LLS-Hunter



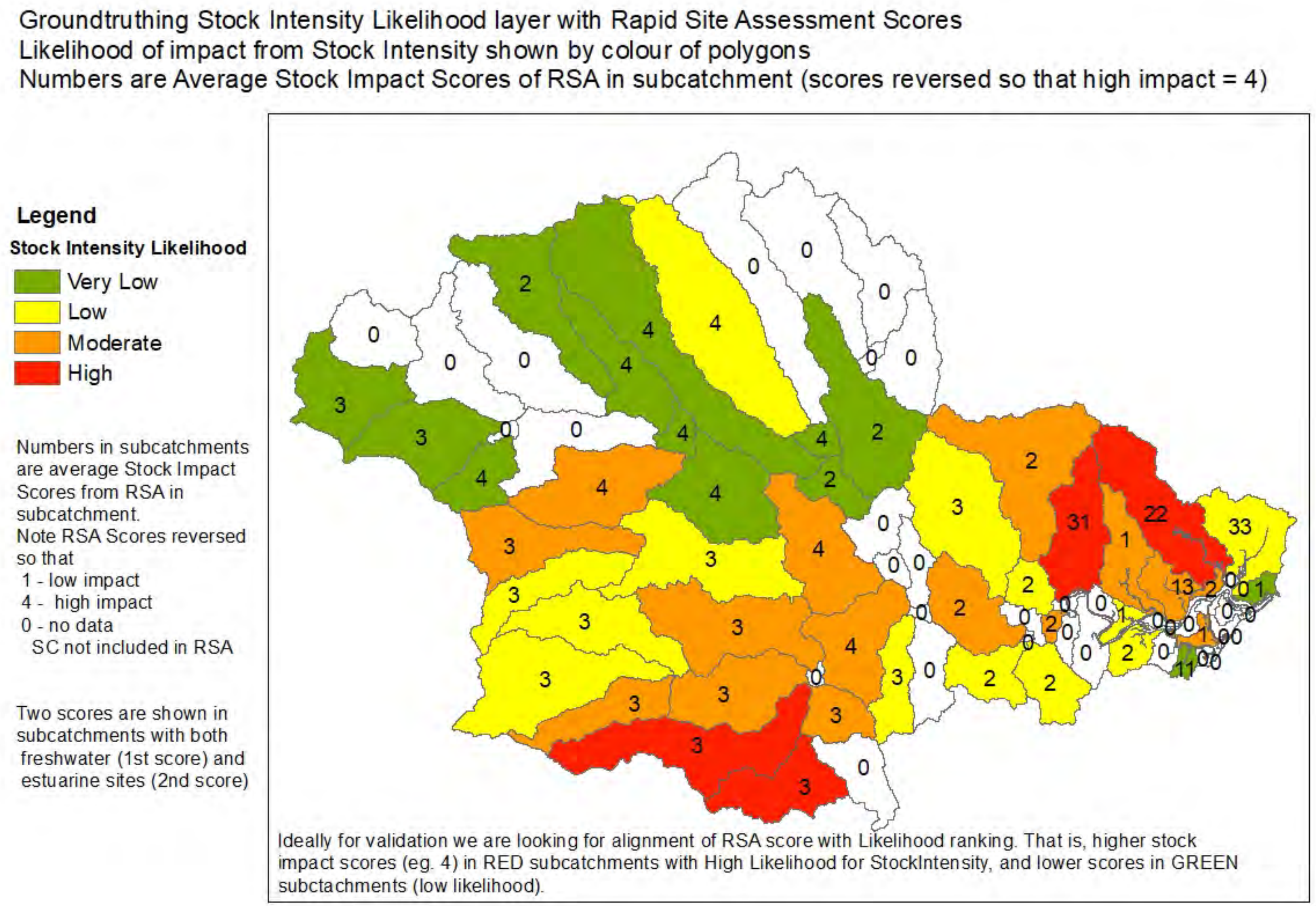
Map A3 - 8 Total poultry per holding (average of Annual Stock Returns 2009-2018 provided to LLS-Hunter)



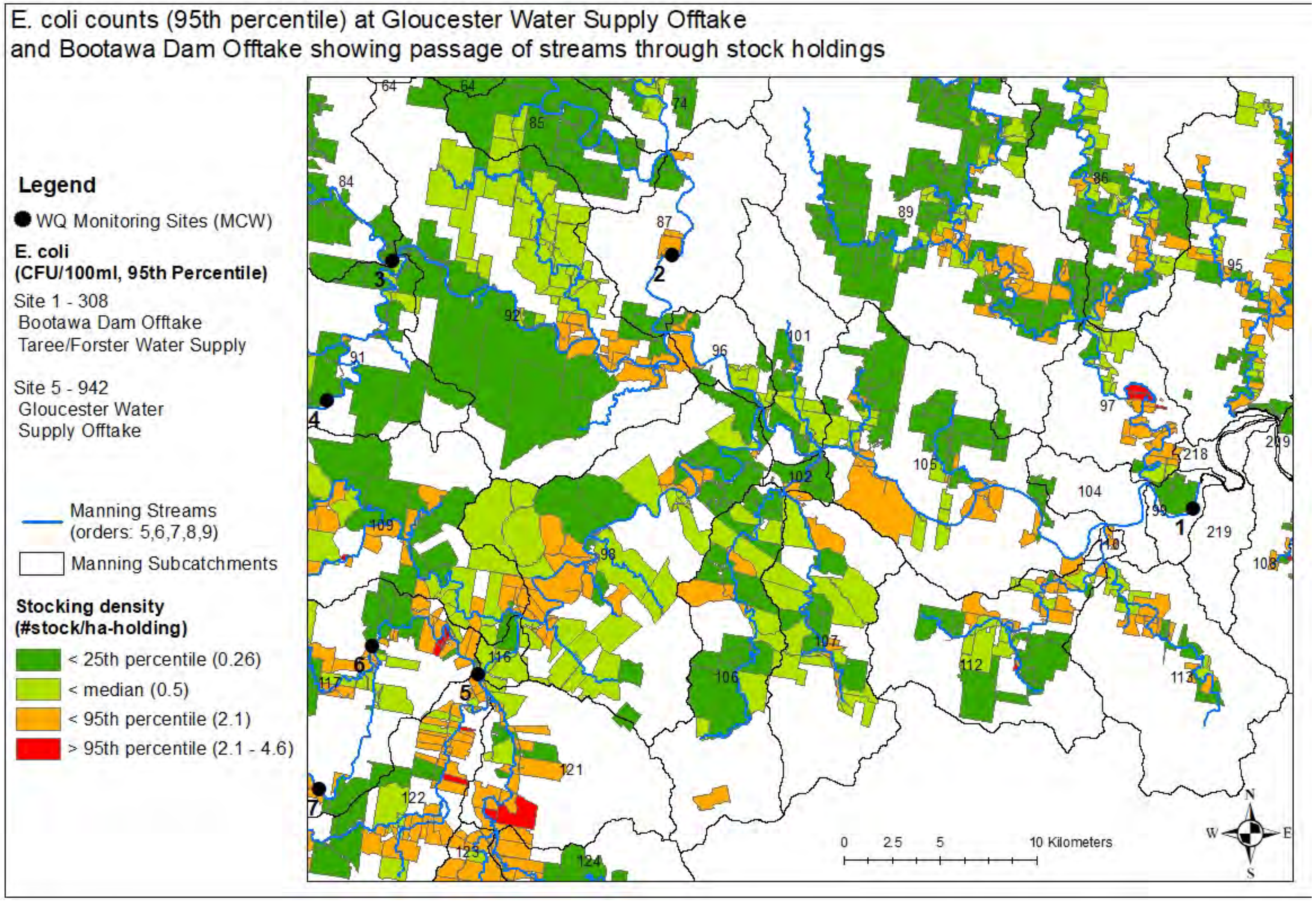
Map A3 - 9 **Derivation of Stock Intensity Likelihood Score from the Average of Total Stock Numbers (Likelihood Score) and Stock Density (Likelihood Score)**



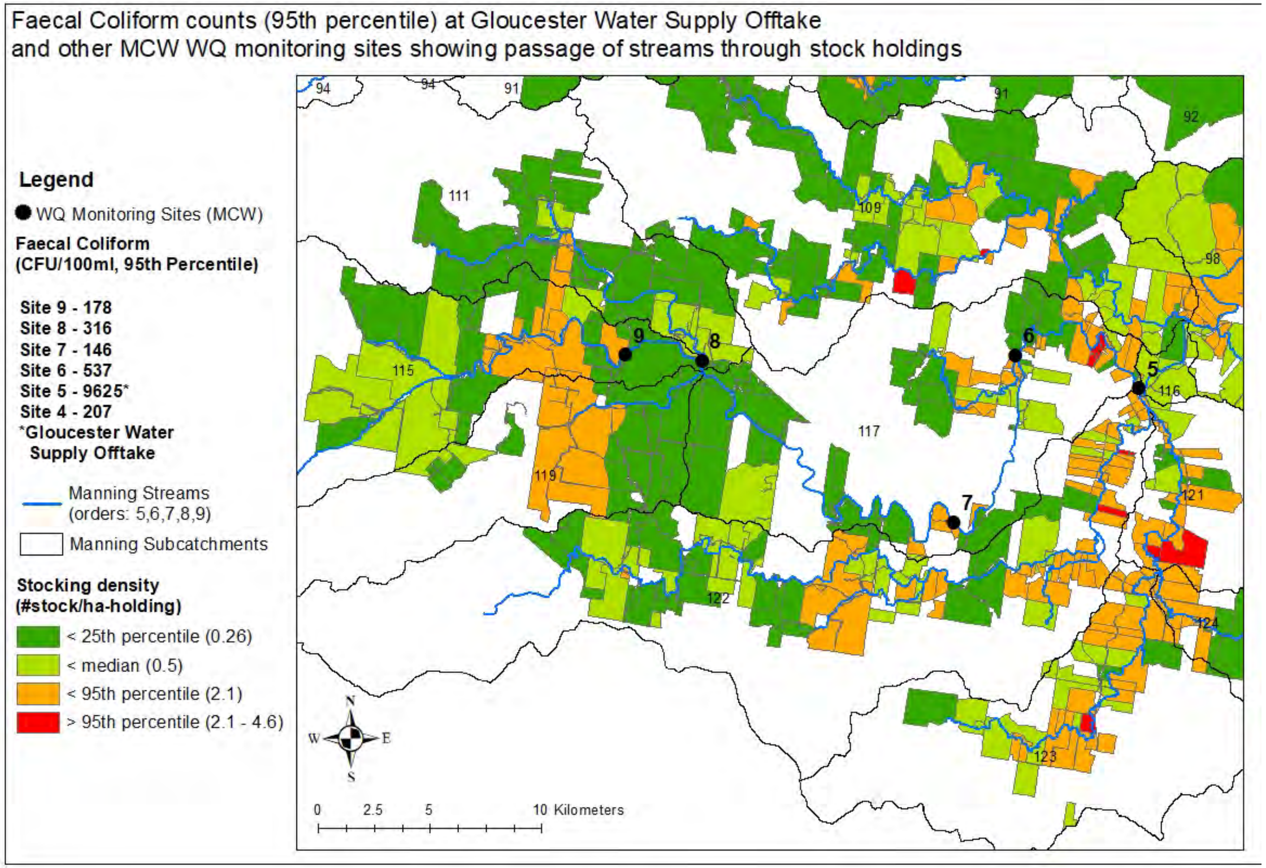
Map A3 - 10 **Observations of stocking rates were averaged for the subcatchment are compared to Stock Intensity Likelihood Scores represented by colour (1 = very low likelihood, GREEN; 2 = low likelihood, YELLOW; 3 = moderate likelihood, ORANGE; 4 = high likelihood, RED).**



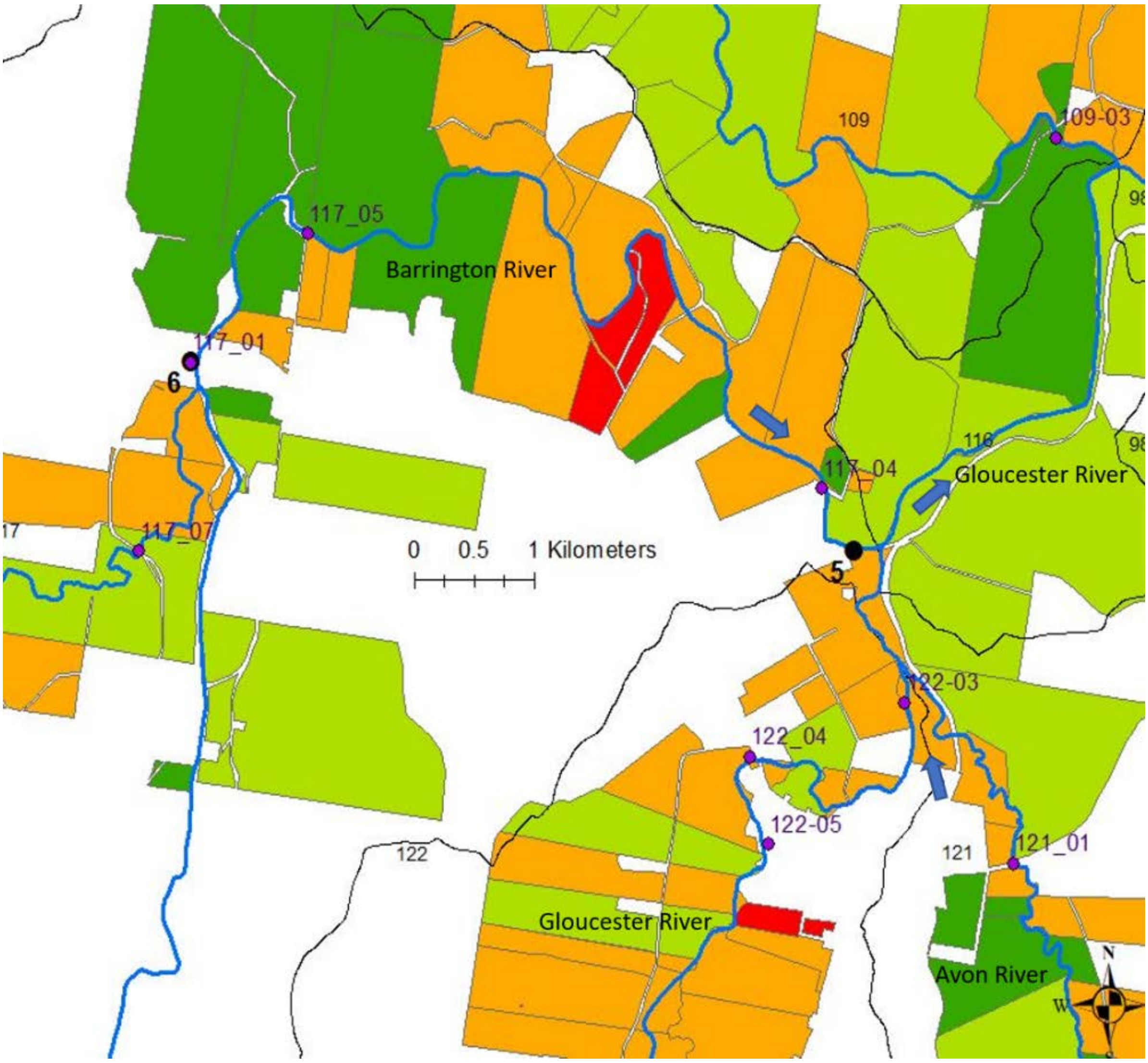
Map A3 - 11 **Subcatchment averaged Stock Impact scores (ranked by percentiles, 4 = most impact) compared to Stock Intensity Likelihood Scores represented by colour (1 = very low likelihood, GREEN; 2 = low likelihood, YELLOW; 3 = moderate likelihood, ORANGE; 4 = high likelihood, RED).**



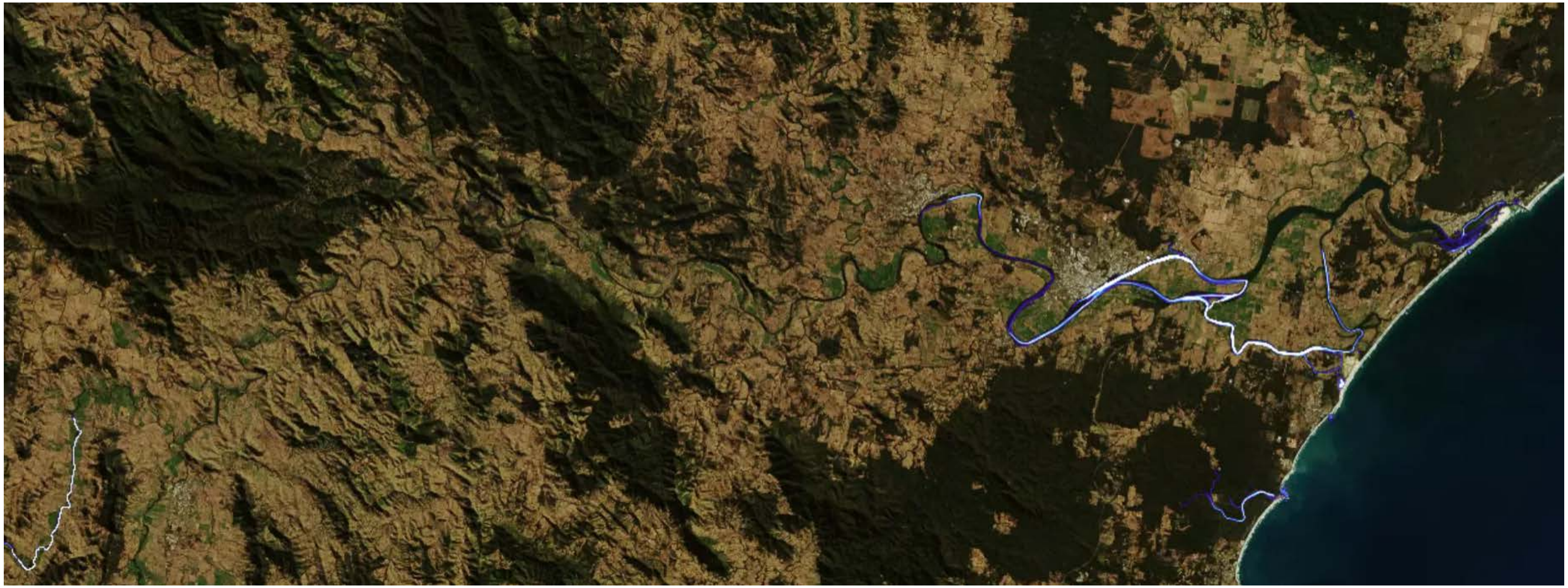
Map A3 - 12 **Location of MCW monitoring locations and stock density per holdings in the vicinity. *E. coli* are monitored at offtakes for water supply (site 5 – Gloucester water supply, Site 1 – Bootawa Dam, water supply for Taree and Forster) and 95th percentile concentrations are shown in Legend**



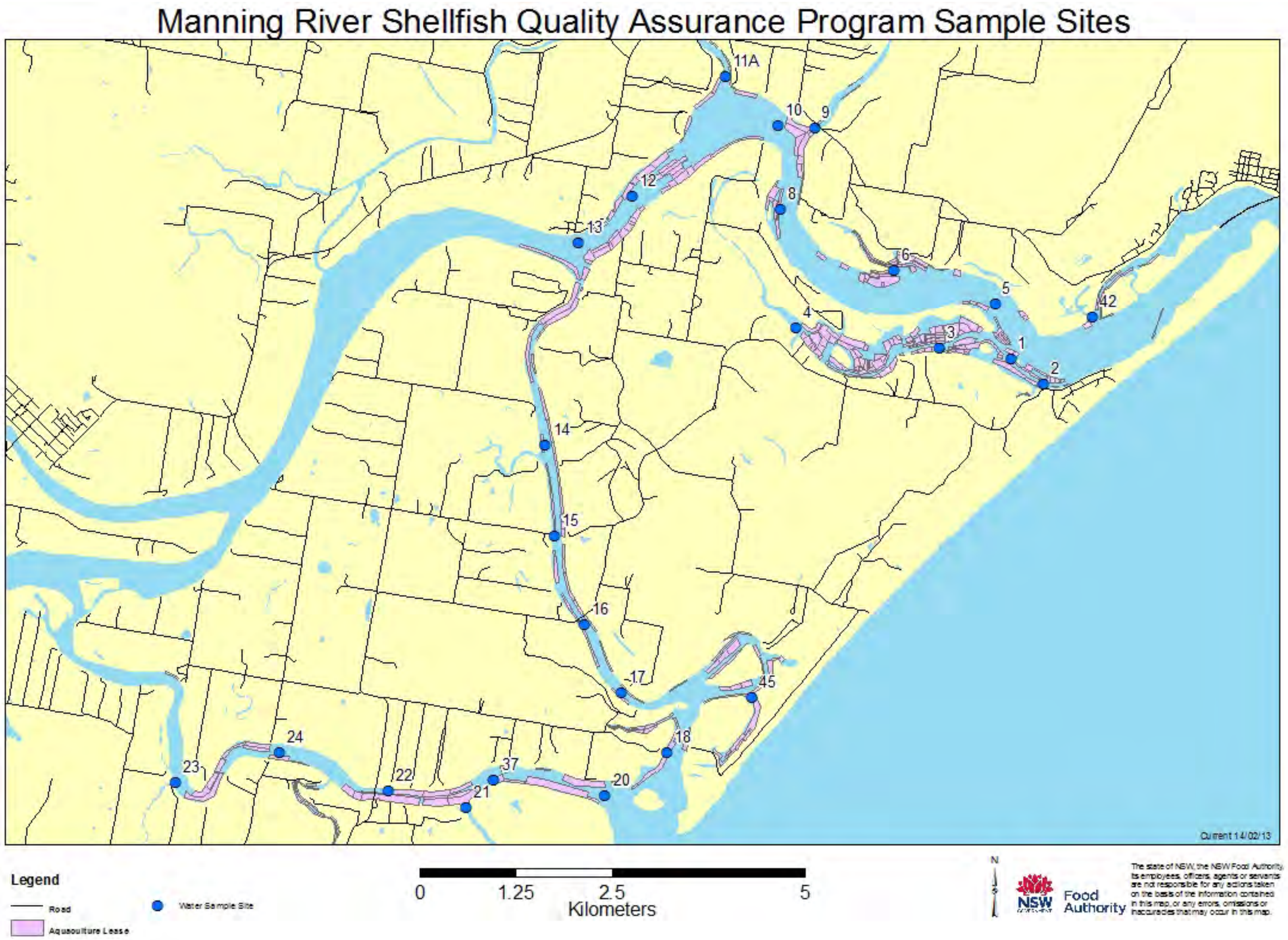
Map A3 - 13 Location of MCW monitoring locations and stock density per holdings in the vicinity. ***Faecal coliforms*** **are monitored at all sites except for Site 1. Faecal coliform (95th percentile, cfu/100ml) data are shown in Legend. Note the very high readings at site 5.**



Map A3 - 14 **Maps showing the location of Gloucester water supply offtake (black dot, 5) on the Barrington River, approximately 200 m upstream of confluence with Gloucester River. Very high *E. coli* counts are regularly recorded at Gloucester offtake (Map A3-10, 11; Table A3-2). *E. coli* are used as an indicator of recent faecal contamination Map shows the upstream path of Barrington River through farms of moderate – high stocking density. Several sites surveyed on Barrington River and Gloucester River during ground-truthing program (purple dots) are shown e.g., 117-05 (Rosemary) – a large dairy where hundreds of cattle cross the river twice daily for milking*. 117-04 is Relf's Landing, a popular kayaking launch site, also used for swimming and fishing. 122-03 is the Gloucester STP.**



Map A3 - 15 **Strava - a social fitness network where community upload information on where they are recreating. This map shows locations of secondary recreation – kayaking, canoeing – in the Manning Estuary and at Barrington River (subcatchment 117). Note this popular location for kayaking (bottom left corner of image) is upstream of intensive farming (shown as large green areas to north of where white line stops). The kayaking route does go past a number of large farms (green areas either side of white line) of low stocking density. The kayaking route is between monitoring sites 7 and 6 shown in Map A3-11.**



Map A3 - 16 **Locations of water quality monitoring by NSW Food Authority as part of the Manning River Shellfish Quality Assurance Program (total faecal coliform data shown in Table A3-3)**

Appendix 4 - Erosion Risk

Hillslope Erosion Likelihood Scores

Hillslope erosion risk was used as a Likelihood (pressure) criterion in the risk assessment (combined with Fragility score - below). Hillslope erosion was calculated from a spatial layer of modelled data (Yang 2019 *in press*, Map A4-1). Mean rates of hillslope erosion for each grid cell of land in the subcatchment were summed to get total hillslope erosion for the subcatchment and categorised into quantiles. Subcatchments were attributed with a score of 1 if erosion rates were ≤ 25th percentile, a score 2 if they were >25th and ≤ 50th percentile, a score of 3 if they were > 50th and ≤ 75th percentile or a score of 4 if they were > 75th percentile (Map A4-1).

Streambank/streambed erosion

Fragility (River Styles) was used as a likelihood criterion (pressure) in the risk assessment (averaged with hillslope erosion score). The score was based on the proportion of low, moderate & high Fragility streams in each subcatchment. The proportion of each fragility class (low, moderate, high) in each subcatchment was calculated based on the length of each fragility class and total length of that stream in the subcatchment. A heavier weighting was placed on those streams with moderate and high fragility. Proportions of each fragility class were then summed together for each subcatchment and rounded to the nearest whole number. This resulted in Fragility scores of 1, 2, 3. Other likelihood criteria have scoring of 1, 2, 3, 4 with 4 being the highest risk. Fragility scores of 3 were changed to a score of 4 to represent the highest risk, resulting in Fragility Likelihood Scores of 1, 2, 4 (Map A4-2)

Combined Erosion Risk Scores

The Hillslope Erosion Risk and Fragility Risk Scores were averaged for the Combined Erosion Risk score shown in Map18.

Riparian Vegetation layer (Consequence criterion)

Riparian vegetation layer is included in the risk assessment as a consequence criterion. The ‘proportion of trees >2m’ in the riparian zone (1 km reach assessed) was the attribute used to score the asset. The proportion of trees was averaged across the subcatchment and categorised into quantiles. A Consequence Score of 4 was assigned if they were ≤ 25th percentile (lower proportion of >2m trees, higher chance/risk of loss), a score of 3 was assigned if they were >25th and ≤ 50th percentile, a score of 2 if they were > 50th and ≤ 75th percentile or a score of 1 if they were > 75th percentiles (highest proportion of trees. Subcatchments outside the LGA were assigned a score of 0 for no data. The scores allocated to Riparian Vegetation layer are shown in Map 19.

Alternate method / consequence layer

The alternate method follows NRM philosophy to protect assets in good condition. A Consequence Score of 1 was assigned if they were ≤ 25th percentile (lower proportion of >2m trees), a score of 2 was assigned if they were >25th and ≤ 50th percentile, a score of 3 if they were > 50th and ≤ 75th percentile or a score of 4 if they were > 75th percentiles (highest proportion of trees). Subcatchments outside the LGA were assigned a score of 0 for no data. The scores allocated to Riparian Vegetation Consequence layer using the alternate scoring method are shown in Map A4-6.

The decision on which consequence layer to choose will depend on the management approach that Council chooses to adopt in relation to riparian vegetation and erosion risk

Risk Assessment – version 2

High risk subcatchments in version 1 of the erosion risk assessment were 105, 92, 96, 76, and 82).

The second risk assessment used alternate scoring for the Consequence layer (described above) to reflect overarching NRM philosophy which is to prioritise protection of assets in good condition. If Council wishes to take this approach, then Risk Assessment – Version 2 (Map A4-7) should be used to help guide decision making

Ground-truthing layers

Two types of erosion risk, hillslope erosion and Fragility (River Styles), were combined to form the combined erosion likelihood layer used in erosion risk assessments. The hillslope erosion and Fragility layers were ground-truthed separately as they refer to different types of erosion

Hillslope erosion

Visual observations of Hillslope erosion across the catchment

Hillslope erosion was noted and photographed by field teams during the ground-truthing program. Steep hills with minimal groundcover due to clearing and extended drought conditions were very common across the catchment. High hillslope erosion risk was noted in subcatchments 82, 90, 91, 92, 94 and 98. Active erosion, bare steep hills and gully erosion were noted in high risk subcatchments (e.g. 74, 85, 105, 117; Photographs A4-1 – A4-3).

Field observations of hillslope erosion risk show good alignment with hillslope erosion risk Likelihood ratings which were based on modelled data (Yang 2019).

Hillslope erosion - subcatchment average for stream bed condition

Hillslope erosion can have detrimental effects on streambed condition through the deposition of fine sediments which can alter flow regimes when large sediment slugs form. Over time, the accumulation of fine sediments can alter contours of the stream bed leading to less variation in types of habitats in the stream (pools, riffles etc.). Fine sediments also smother aquatic organisms, fill interstitial spaces in the substrate altering benthic communities.

Hillslope erosion risk (Likelihood Scores) was ground-truthed with average scores for Streambed Condition attributes from the Geomorphic Condition component of the Rapid Site Assessments (Map A4-9). The Streambed attributes that were used were dominant substrate percent cover, riffle pool sequences and channel sediment accumulation. The scores were averaged for the subcatchment and then subcatchment averages were ranked by percentiles with better scores assigned rank of ‘1’ representing better condition. An alignment of hillslope erosion risk of Very Low or Low Likelihood with lower scores (percentile ranking) for Streambed Condition, and vice versa (Hillslope erosion risk of moderate, high Likelihood with higher Streambed Condition scores) would result mean the layer was validated but this did not occur. A range of Streambed Condition scores (1-4) occurred in subcatchments with Very Low, Low, Moderate and High Likelihood of Hillslope erosion risk (Map A4-10).

Fragility

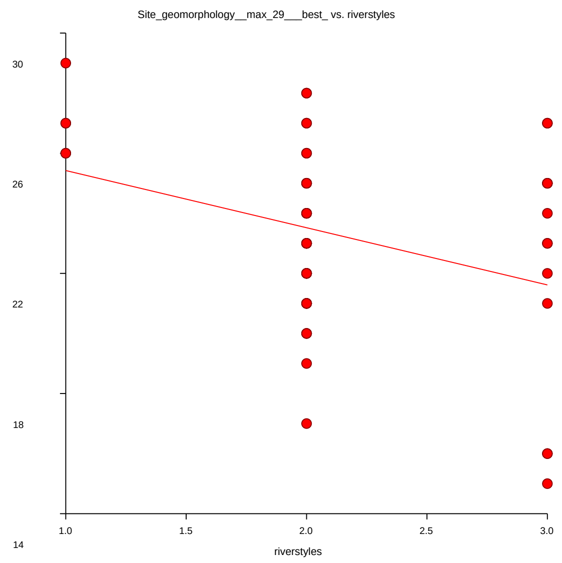
The Rapid Site Assessments (RSA) scored several geomorphic attributes for an overall Geomorphic Condition score. Higher scores reflect 'better' Geomorphic Condition in the RSA. Most streams in the catchment are rated Moderate Fragility (River Styles, Map A4-3) and most sites in the Rapid Site Assessments were of Moderate Fragility (n = 157, 90% of sites). Five sites with Low Fragility and 13 sites with High Fragility were assessed in the RSA.

Fragility – subcatchment average for geomorphic condition

The Fragility rating (averaged for streams in the subcatchment) was compared to the average Geomorphic Condition score for sites in the subcatchment. The scores were averaged for the subcatchment and then subcatchment averages were ranked by percentiles with better scores assigned rank of '1' representing better condition. An alignment of Fragility rating or low-moderate with lower Geomorphic Condition Scores, and vice versa (Fragility rating or moderate-high with higher Geomorphic Condition Scores) was sought but did not occur. A range of Geomorphic Condition scores (1-4) occurred in subcatchments with either low-moderate Fragility and moderate-high fragility (Map A4-10)

Fragility – individual site data for geomorphic condition

There was a weak correlation of Fragility rating (1 – low, 2 – moderate, 3 – high) of the stream with the (original) Geomorphic Condition score for the site (higher score = better condition) in the RSA (correlation - 0.34, significant, Graph A4- 1) but only if a random selection of 20 sites of Moderate fragility were included in the analysis. Including all sites rated as Moderate fragility resulted in a non-significant relationship due to the variation of condition and over representation of sites with Moderate Fragility (90% of sites).



Graph A4 - 1 Site Geomorphic Condition score plotted against Fragility rating of the stream (River Styles). X-axis, 1=Low Fragility, 2 = Moderate Fragility, 3 = High Fragility (correlation = -0.34, significant, but only if a random slection of 20 sites with moderate Fragility rating. 90% of sites assessed were of moderate Fragilty)

Photograph A4-1 Subcatchment 74 – Cells Rd, steep bare hills pose a high erosion risk

Photograph A4-2 Active erosion in subcatchment 85

Photograph A4-3 Hillslope erosion, erosion gullies and no riparian vegetation (subcatchment 105)

Riparian Vegetation – subcatchment average for selected riparian zone attributes

Riparian vegetation in the Manning River catchment (MidCoast LGA) was mapped by Griffith University (Pietsch 2019, Map A4-5). The proportion of trees >2m tall in the riparian zone (1 km reaches) was averaged across each subcatchment (Map A4-5), ranked into percentiles and used for the Consequence Scores (1 - 4) in the Riparian Vegetation layer (Map 19). Several attributes of the riparian zone were recorded as part of the Riparian Condition component of the Rapid Site Assessments (RSA). The riparian vegetation layer was compared to a selection of riparian zone attributes for ground-truthing. The following riparian zone attributes were selected as they relate most to the characteristic which defined the riparian vegetation layer (i.e., the proportion of trees in a specified area ~ 1 km of riparian zone); Longitudinal continuity, width of riparian zone and disturbance to the riparian zone. The scores for each of these attributes were summed for each site and the subcatchment average was calculated. The subcatchment average scores were then ranked into percentiles with '1' assigned to the highest RSA scores which represented best condition. Map A4-11 shows these scores overlayed on the Riparian Vegetation layer.

For ground-truthing, alignment of subcatchments with higher proportion of tall trees (green, yellow subcatchments) with lower scores for riparian zone attributes in RSA, and vice versa, was sought. There was reasonable alignment of the riparian vegetation layer with RSA scores. Green subcatchments (highest proportion of tall trees in the riparian zone) were assigned a rank of 1 or 2 for subcatchment averaged scores for riparian zone attributes (Map A4-11). Most orange and red subcatchments (lower proportion of tall trees in the riparian zone) were assigned a rank of 3 or 4 for subcatchment averaged scores for riparian zone attributes (Map A4-11).

Riparian Vegetation – proportion of trees and riparian zone attributes

The proportion of trees >2m tall in the riparian zone (1 km reaches), averaged across each subcatchment (Map A4-5), were compared against the RSA Scores for related Riparian Vegetation attributes (higher score, better condition) at sites in the subcatchment.

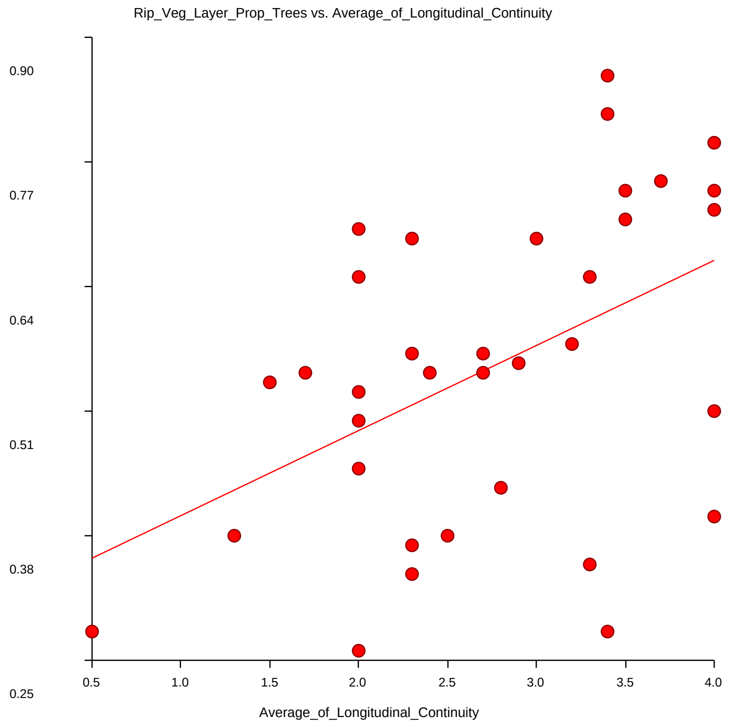
There were good correlations between the mapped data (proportion of trees) and scores for attributes of the Riparian Zone in the RSA:

- Longitudinal continuity (correlation 0.47, significant, Graph A4-2)
- Riparian Disturbance (correlation 0.52, significant)
- Canopy Layer % cover (correlation 0.56, significant, Graph A4-3)
- Shrub Layer % intact (correlation 0.38, significant)

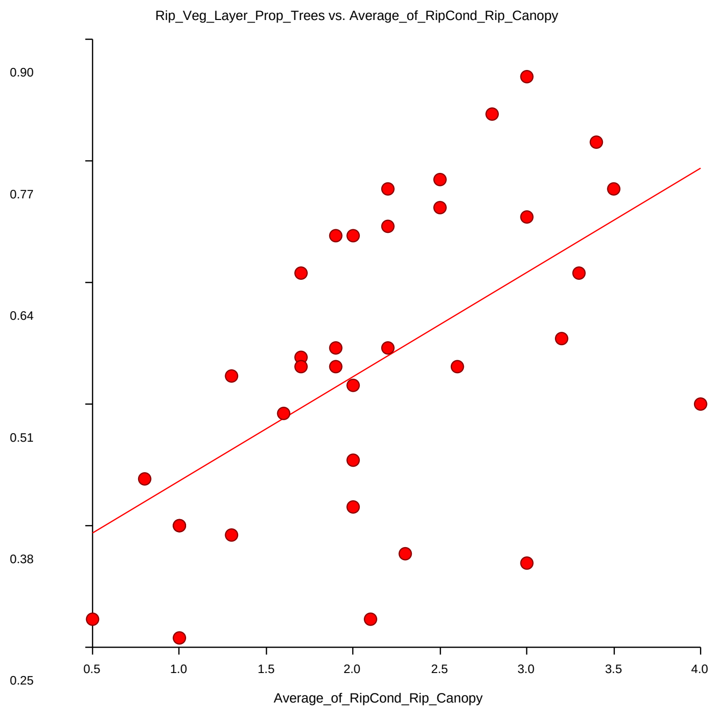
Riparian Vegetation – proportion of trees and bank structure

There was weak positive trend of higher proportions of trees >2m tall in the riparian zone (1 km reaches) with the average score for bank structure at sites in the subcatchment (Graph A4-4). Scoring that applied to the condition of bank structure is shown in the table below

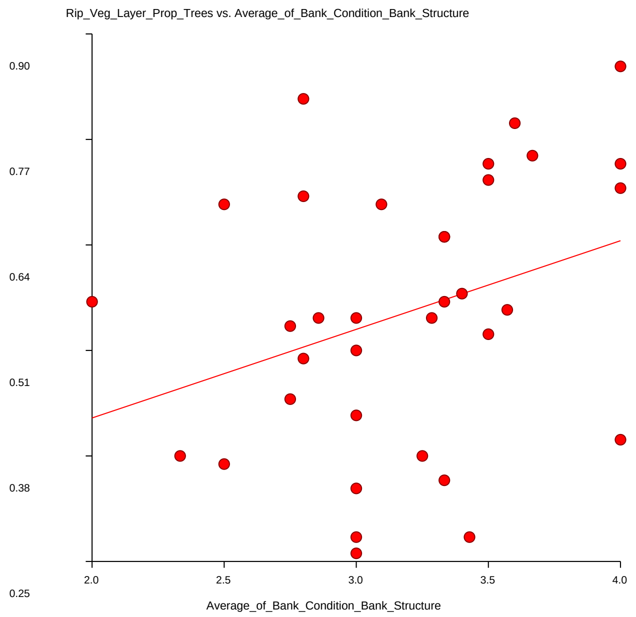
Bank structure		***Score***
General assessment of bank structure across site	Banks fully stabilised by trees, shrubs etc	4
	Banks firm but held mainly by grass and herbs	3
	Banks loose, partly held by sparse grass etc	2
	Banks unstable, mainly loose sand or soil	1



Graph A4 – 2 Proportion of riparian vegetation >2m tall in the subcatchment plotted against average score for longitudinal continuity from Rapid Site Assessments in the subcatchment (correlation 0.47, significant)



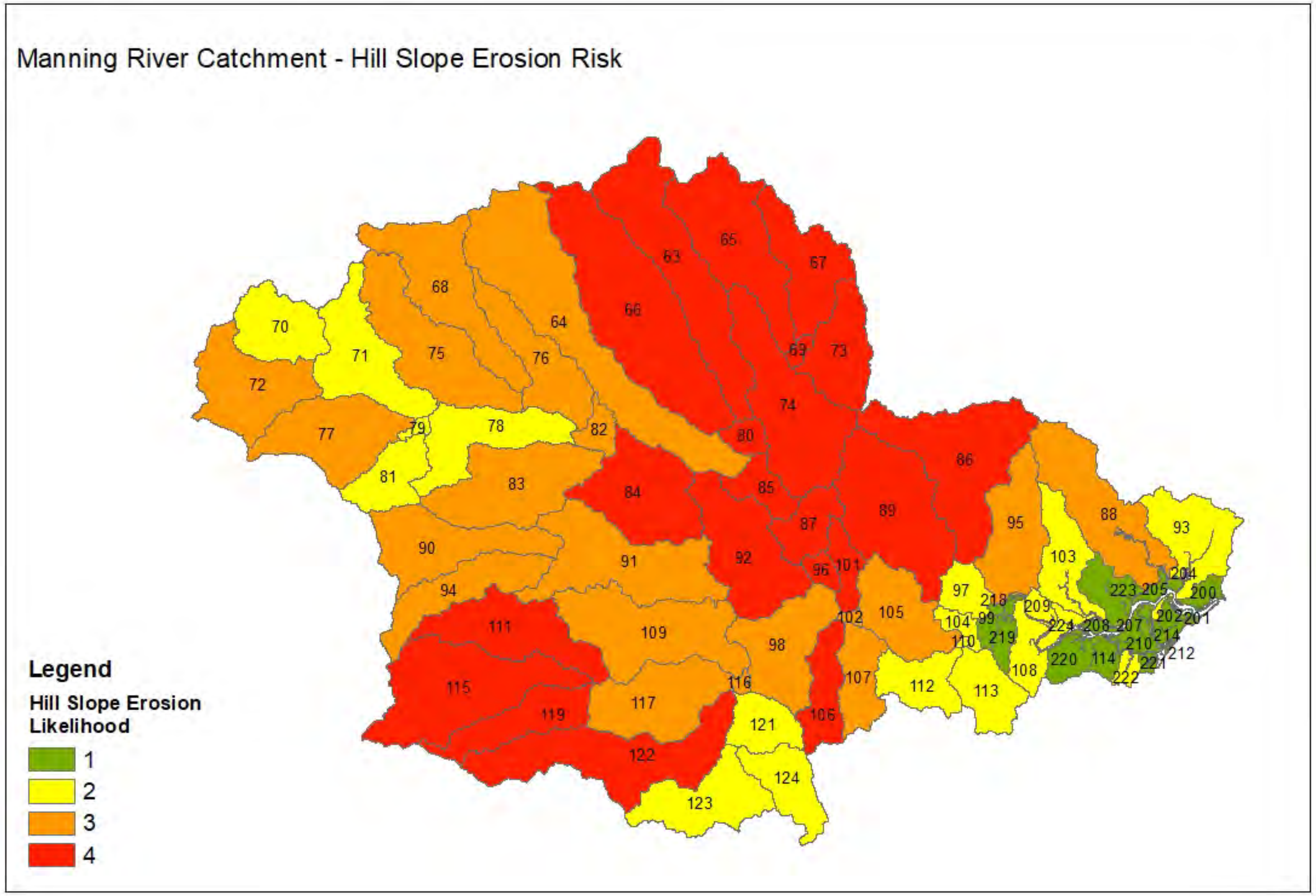
Graph A4 - 3 Proportion of riparian vegetation >2m tall in the subcatchment plotted against average score for longitudinal continuity from Rapid Site Assessments in the subcatchment (correlation 0.56, significant)



Graph A4 - 4 Proportion of riparian vegetation >2m tall in riparian zone (averaged for subcatchment) plotted against average bank structure score for the sites in the subcatchment

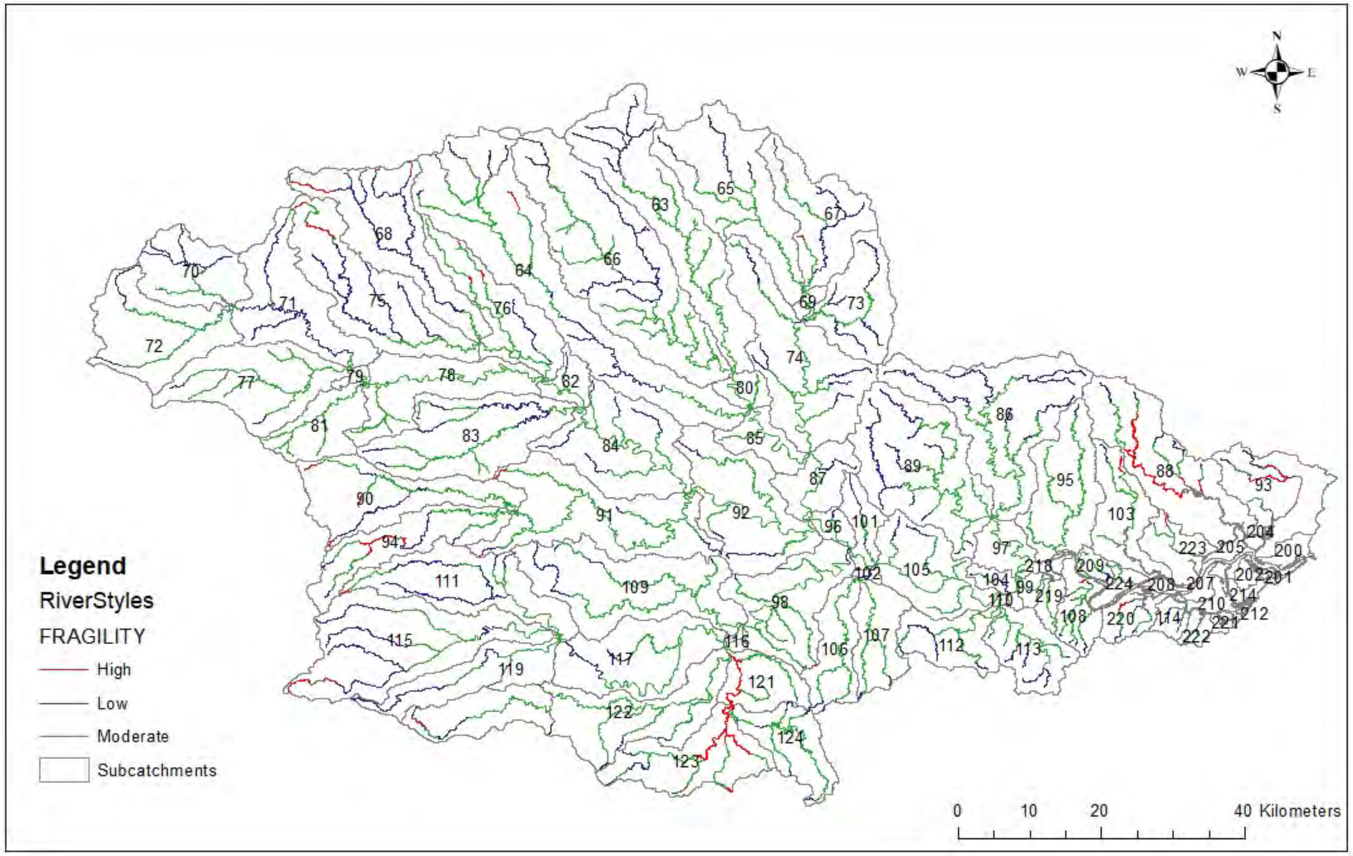
Conclusion - The RSA data collected in the riparian zone has validated the mapping data used for the Riparian Vegetation ‘Consequence’ layer in the erosion risk assessments.

Map A4 - 1 **Modelled hillslope erosion in the Manning River catchment (Yang 2019). Likelihood Scores for hilslope erosion were generated from total erosion data for each subcatchment**

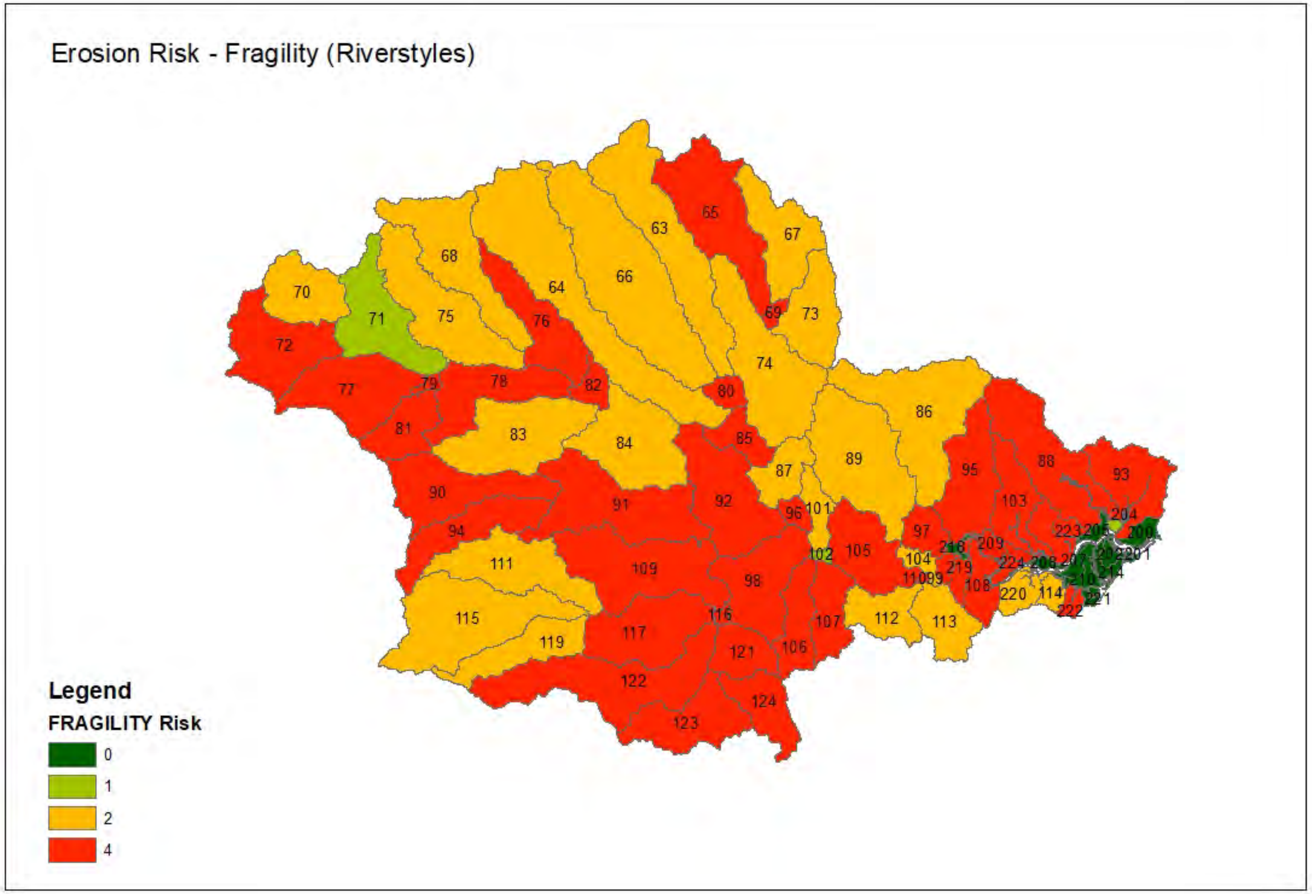


Map A4 - 2 Likelihood Scores for Hillslope Erosion Risk based on mean hillslope erosion rates in spatial layer in Map A4-1

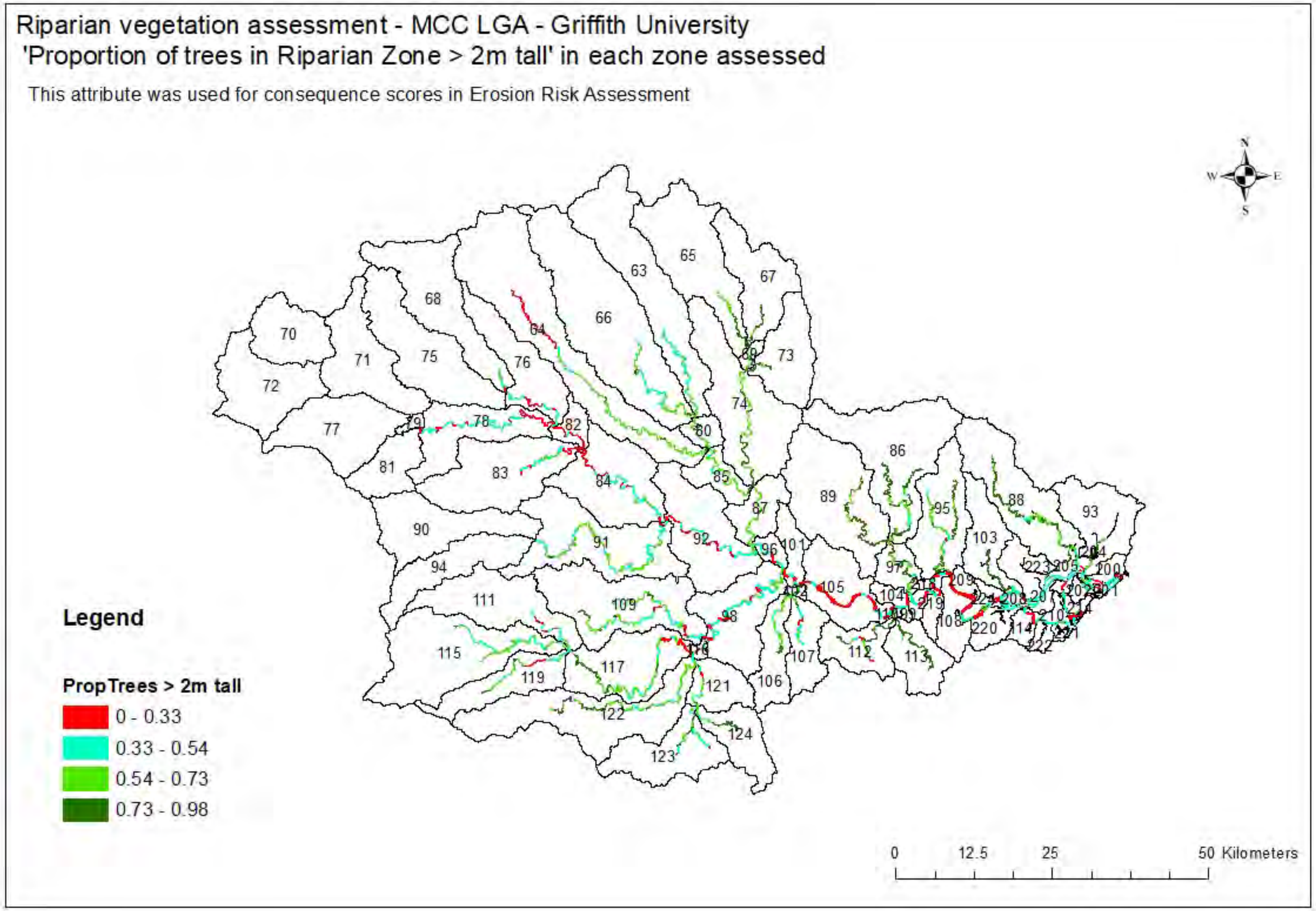
Riverstyles Fragility Rating for Freshwater Streams
used to represent streambank/streambed erosion risk



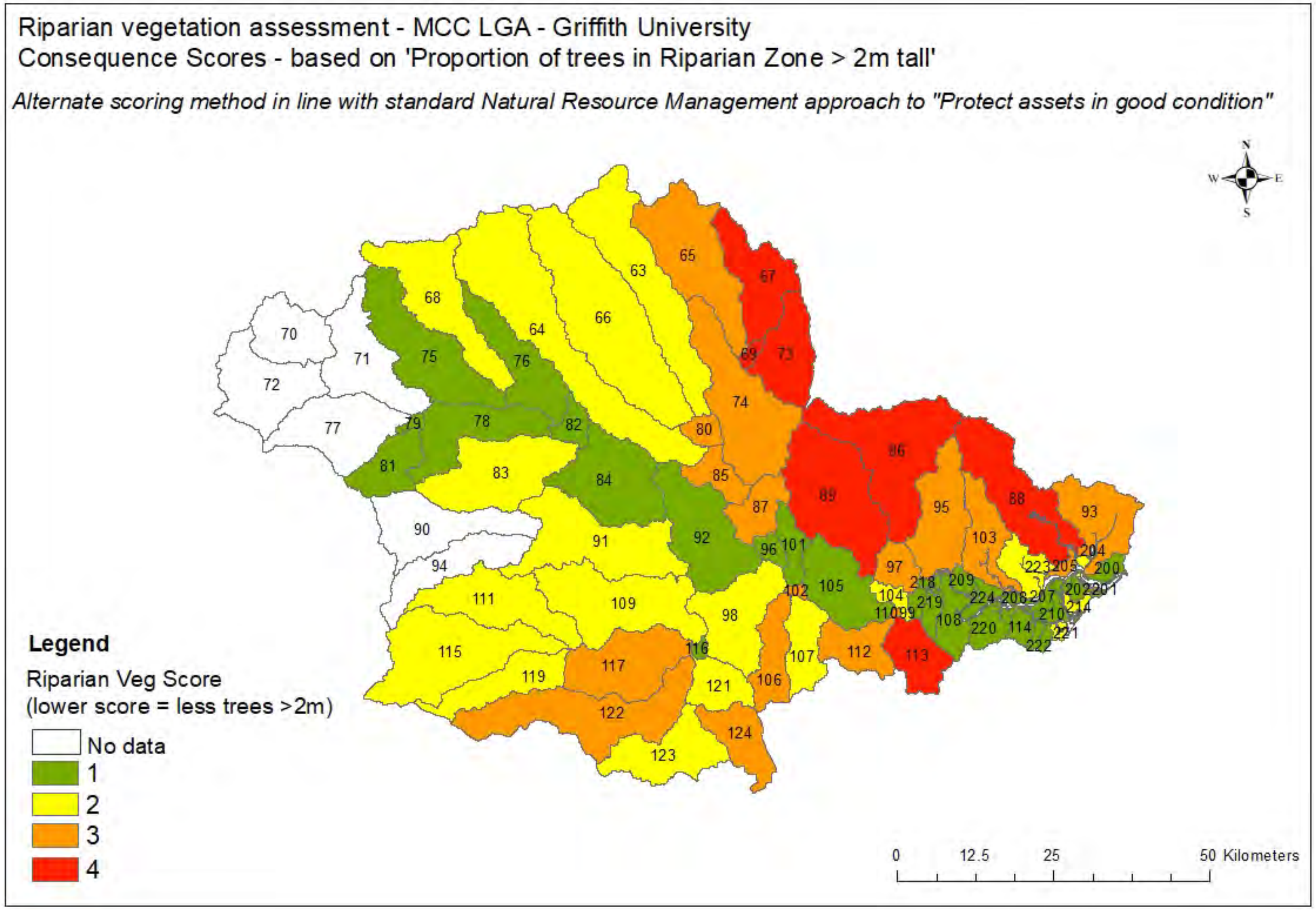
Map A4 - 3 **Fragility rating (Low, Miderate, High) of streams in Manning catchment from River Styles assessment. The majority of streams are rated as Moderate Fragility (green)**



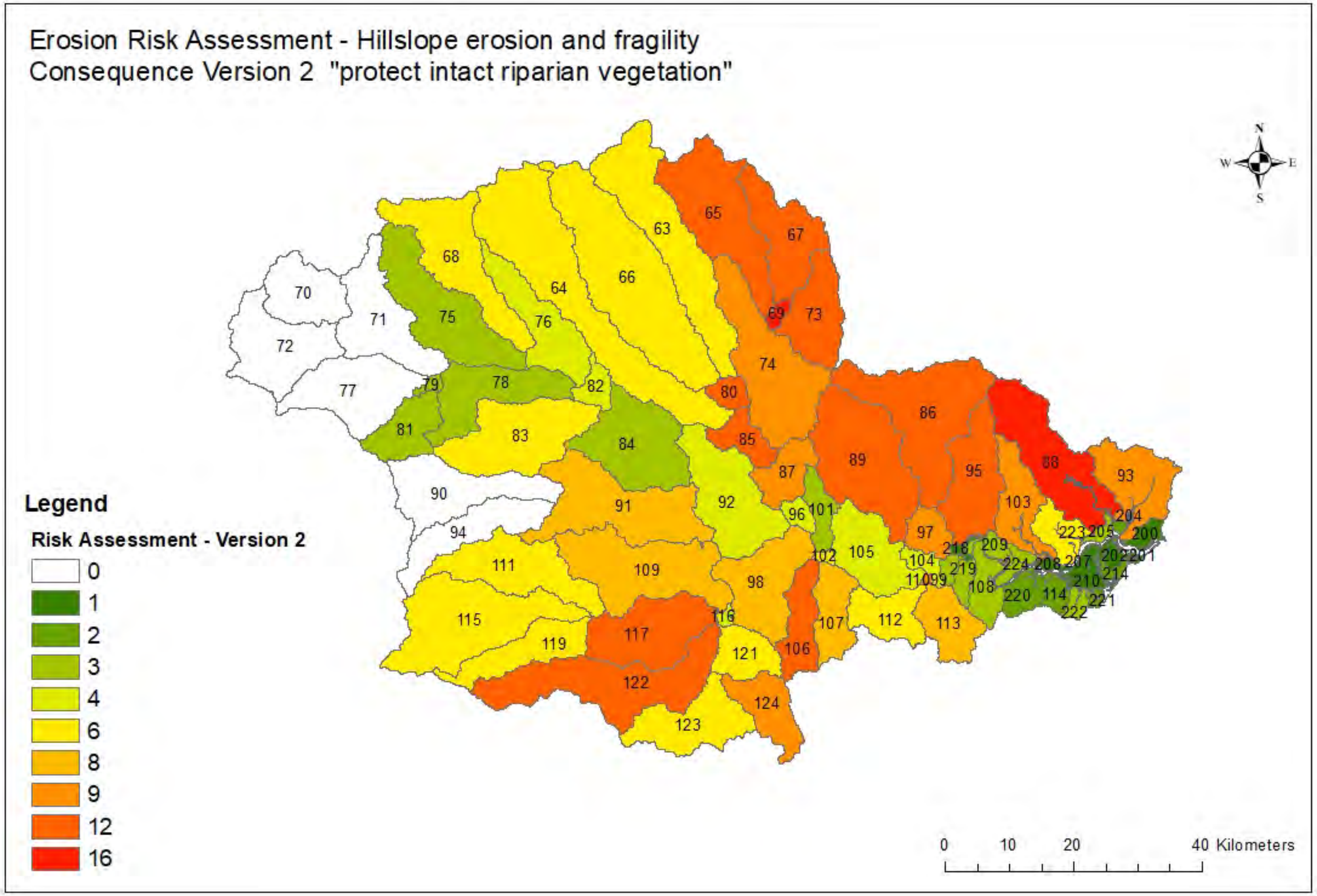
Map A4 - 4 **Likelihood Scores for Fragility of streams in the Manning catchment. Likelihood Scores were based on the proportion of Low/Moderate/High Fragility streams in each subcatchment with higher weighting given to streams of Moderate and High Fragility**



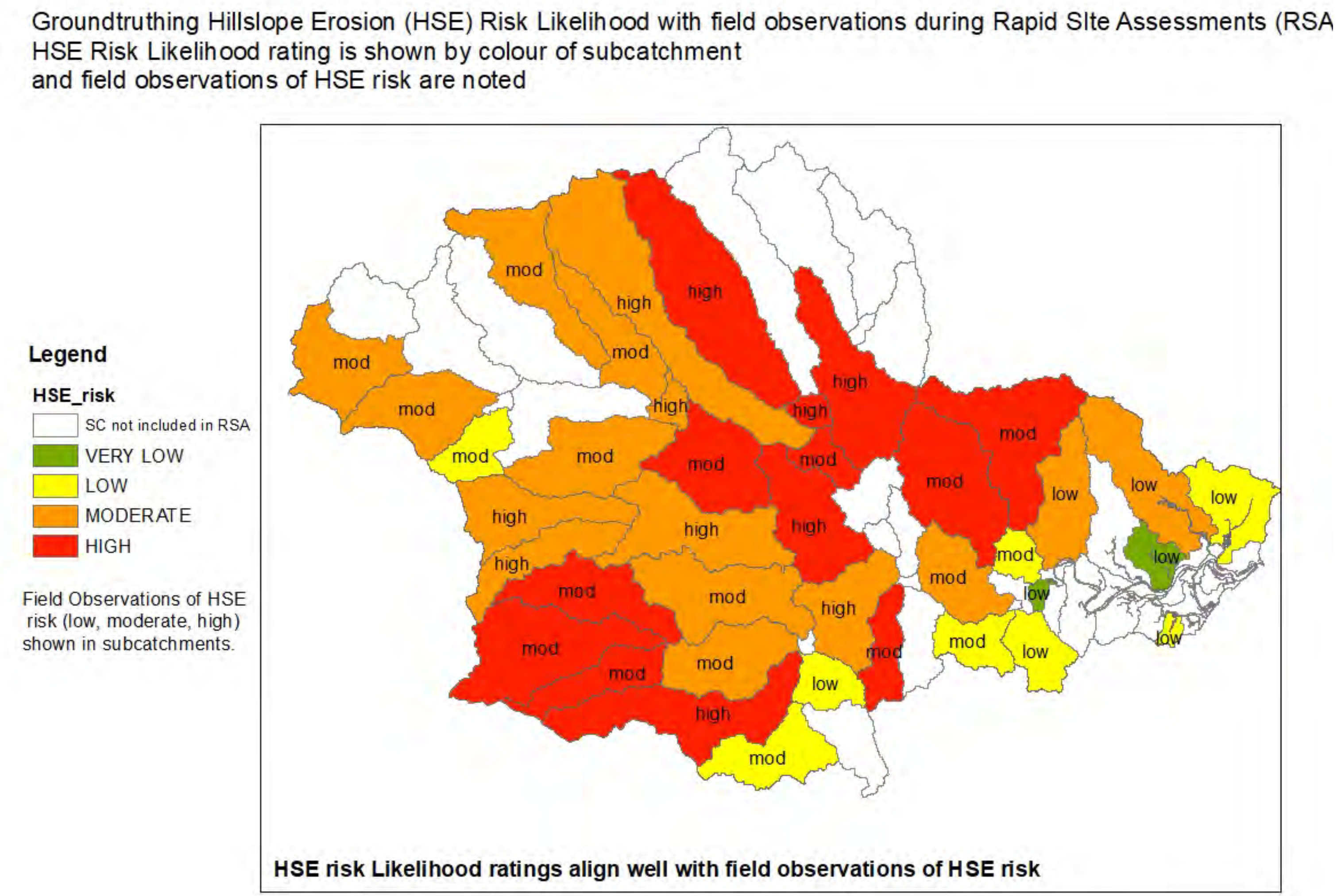
Map A4 - 5 **Riparian Vegetation mapping of the Manning River catchment (MidCoast Council LGA) by Griffith University (Pietsch 2019) showing the proportion of trees (in each reach surveyed) over 2 m tall. This data was used to develop the Consequence Scores for Riparian Vegetation (Version 1 – Map 19, Version 2 – Map A4-6)**



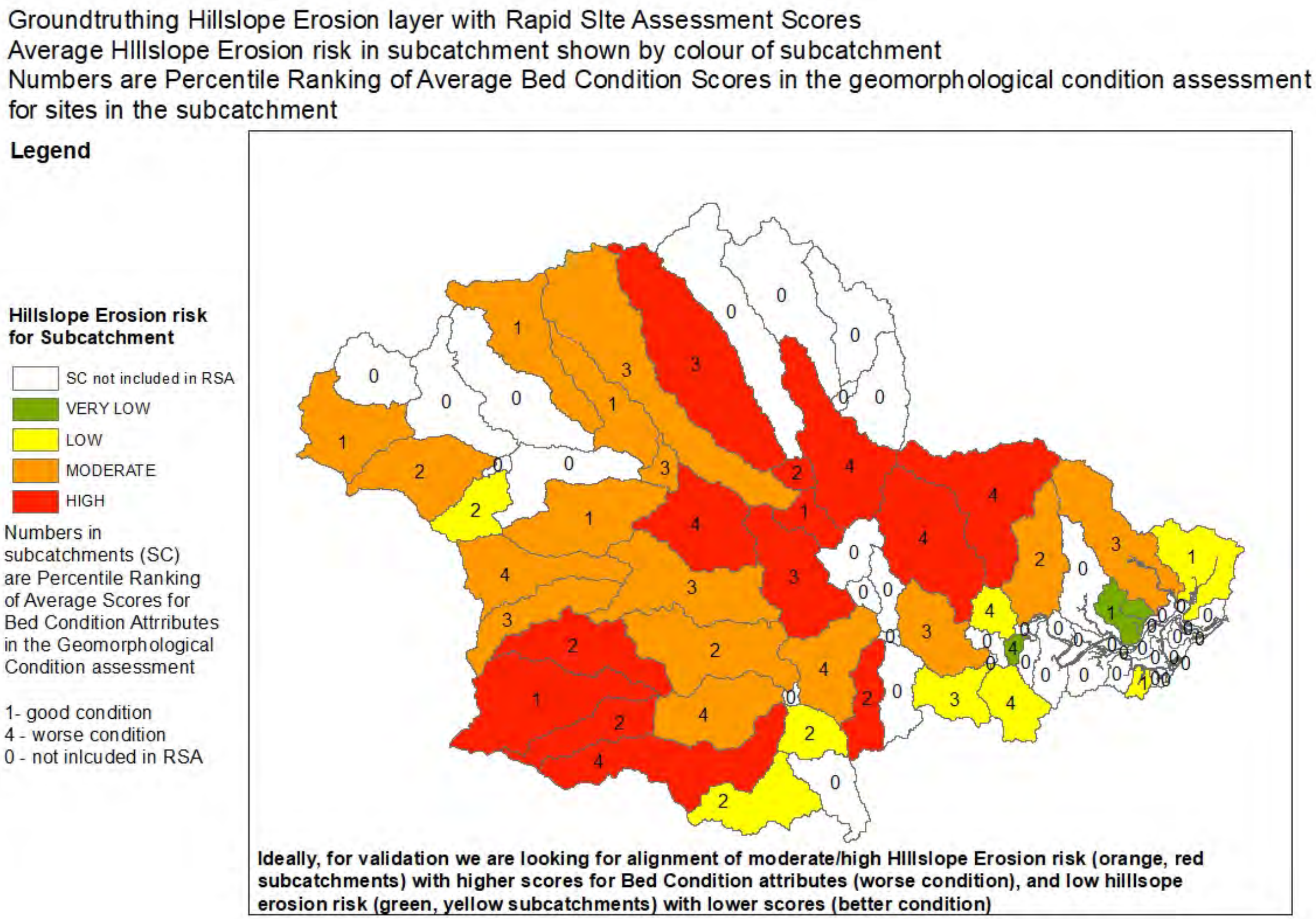
Map A4 - 6 **Consequence Scores for Riparian Vegetation using the alternate scoring method (Version 2) whereby subcatchment with the highest proportion of tall trees were scored '4' in line with NRM philosophy to first protect assets in good condition.**



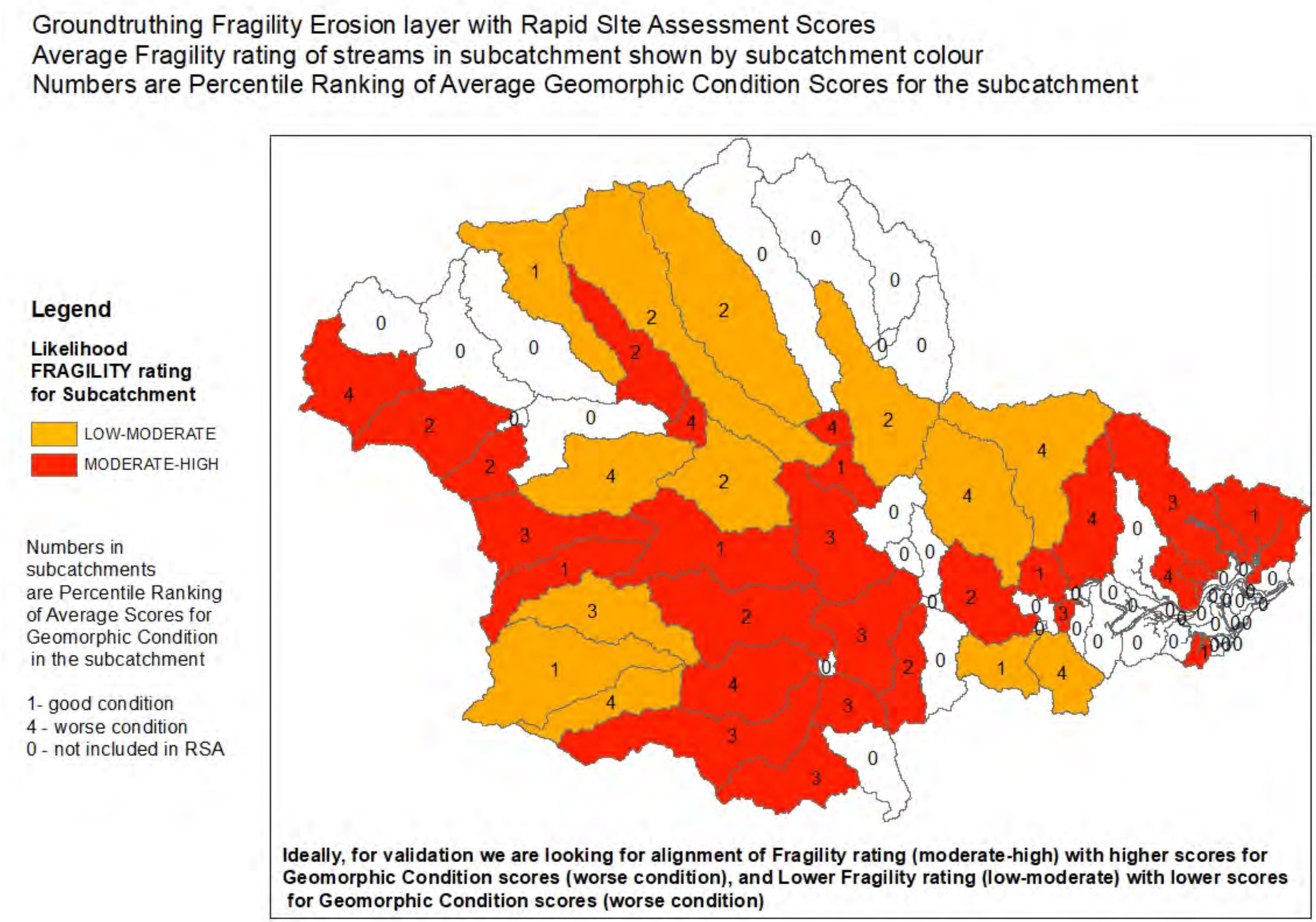
Map A4 - 7 **Erosion Risk Assessment Version 2 using Consequences Scores (Version 2, Map A4-6). This risk assessment prioritises the protection of riparian vegetation in good condition. Council can use this Erosion Risk Assessment or the Erosion Risk Assessment in Map 20 (Version 1 - which prioritises protection and restoration of Riparian Vegetation in poor condition)**



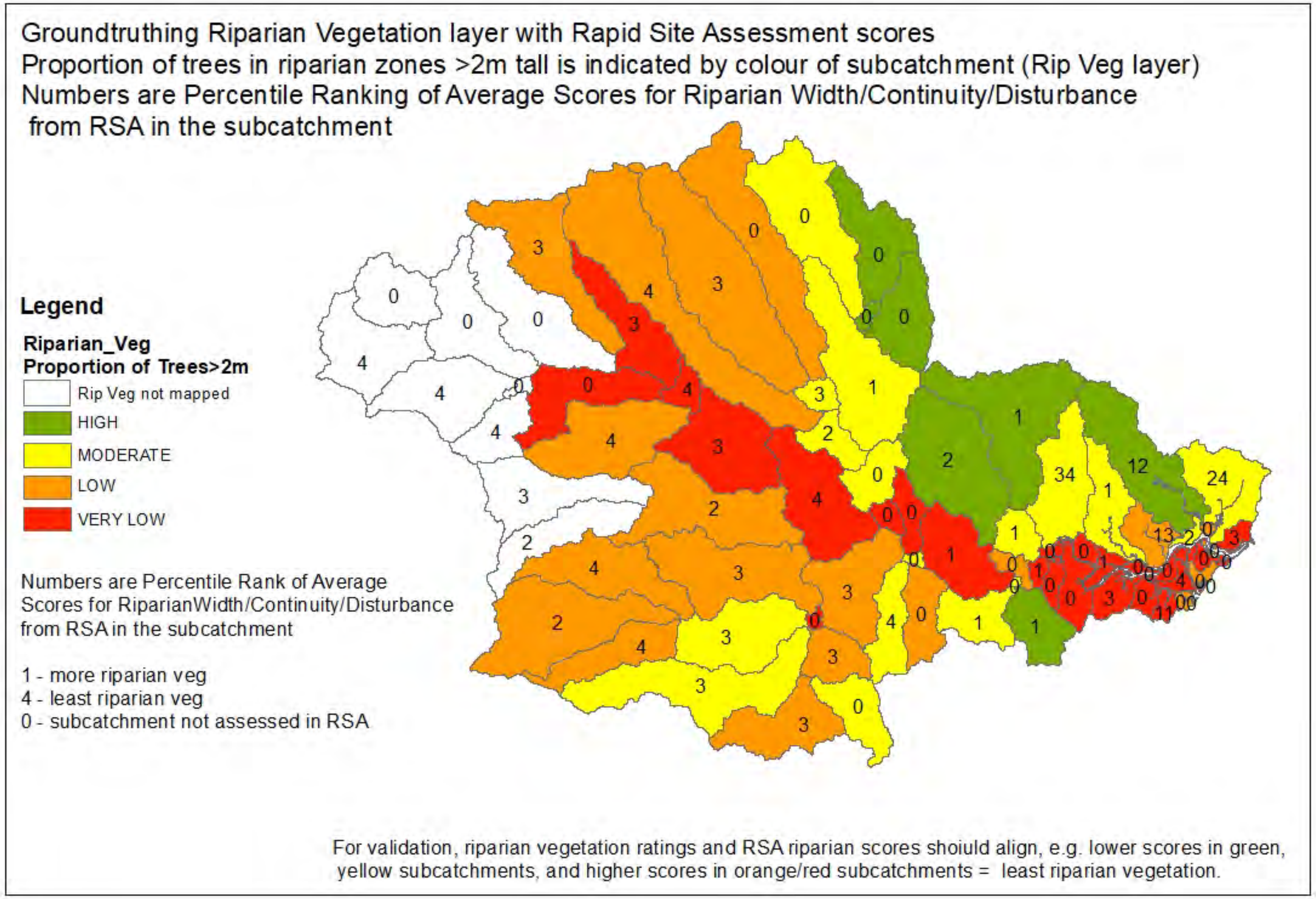
Map A4 - 8 Ground-truthing of Hillslope Erosion (HSE) Likelihood Scores with observations of hillslope erosion risk across the catchment during Rapid Site Assessments. Good alignment of HSE risk rating with field observations of HSE risk.



Map A4 - 9 **Ground-truthing of Hillslope Erosion Likelihood Scores with subcatchment averaged score (ranked by percentiles) for Streambed Condition attributes in the Geomorphic Condition component of the Rapid Site Assessments. Streambed condition attributes were selected (rather than total Geomorphic Condition score) as hillslope erosion influences streambed condition more so than bank condition, the other component of the geomorphic condition assessment.**



Map A4 - 10 **Ground-truthing of Fragility (River Styles) of streams (Likelihood) with average scores for Geomorphic Condition (ranked by percentiles) in the Rapid Site Assessments. Fragility rating is linked to both streambed condition and streambank condition, which together form the Geomorphic Condition score.**



Map A4 - 11 **Ground-truthing of the Riparian Vegetation layer used in erosion risk assessment (Version 1). The riparian vegetation Likelihood Score is represented by colour to compare to subcatchment averaged scores (ranked by percentile) for riparian width, continuity and disturbance (freshwater) or similar attributes at estuarine sites, from Rapid Site Assessments (4 = low amount of riparian vegetation).**