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DRAFT FINAL REPORT:

Northern Beaches Council Stormwater Management Study

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Abbreviations

Alluvium	Alluvium Consulting Australia Pty Ltd
CVS	Confined Valley Settings
DPIE	NSW Department of Primary Industries and Environment (DPIE)
EES	Environment, Energy and Science (EES) Group of DPIE
GDE	Ground Dependent Ecosystems
HEV	High Ecological Value
MRA	Metropolitan Rural Area
NBC	Northern Beaches Council
LEP	Local Environmental Plan
LUV CC	Laterally unconfined valley setting – continuous channel
LGA	Local Government Area
DCP	Development Control Plan
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids

Glossary

Term	**Definition**
Waterway objectives	Objectives for waterway hydrology, water quality, riparian condition and physical condition to meet community environmental values and uses
Stormwater management targets	Stormwater flow and pollutant load management to meet waterway objectives

1 Introduction

Alluvium Consulting was engaged by the Northern Beaches Council to undertake a Stormwater Management Study for the LGA. The objective of the project was to develop a Stormwater Management Strategy and qualitative targets for stormwater quality and quantity for each catchment in the LGA in order to inform the Northern Beaches Council's Local Environmental Plans (LEP). It is intended that future investigation will be undertaken to quantify the stormwater quantity and quality targets.

This report documents the approach used to develop the Stormwater Management Strategy. A map has been produced to show how the strategy and targets apply across the LGA. It is proposed that the map and a summary of this report forms part of Northern Beaches Council LEP discussion paper for public exhibition.

2 Background

Urbanisation has an impact on both the quantity and quality of stormwater runoff that is generated from impervious surfaces. This can have an impact on the health of waterways by:

- Disrupting the natural water cycle, reducing water from infiltrating into the ground and reducing evapotranspiration.
    - Lower groundwater contributions to base flows in creeks means they are more likely to cease to flow in dry periods.
    - In coastal groundwater aquifers, this increases saltwater intrusion and impacts vegetation health.
- Increasing the frequency and volume of stormwater entering waterways from regular small storm events, as well as increasing peak flows in large storm events. This impacts waterway health by:
    - Degrading water quality (i.e. from pollutants and contaminants in stormwater)
    - Affecting the fauna community present (some require permanent water and others are naturally adapted to periods without flow, and it can impact lifecycle activities such as spawning)
    - Affecting aquatic and riparian vegetation condition
    - Affecting waterway physical condition (e.g. erosion/sedimentation)
    - Increasing flooding risk (a direct impact to the community).

It should be noted that detention measures manage peak flows (and therefore flooding risk) but alone do not have a significant impact in reducing the frequency and volume of stormwater runoff associated with regular small storm events which is a key pressure on waterway health.

2.1 Community environmental values and uses

The beaches, lagoons, creeks and estuaries of the Northern Beaches LGA are highly valued by the community for primary contact (swimming) and secondary contact (fishing, boating) recreation, and passive recreation (walking, picnics). Local tourism is heavily reliant on the waterways being healthy and having amenity. The waterways support many threatened ecological communities, including endangered species of flora and fauna. Some waterways support a thriving marine industry that includes commercial fishing.

The community environmental values and uses of the waterways in the Northern Beaches LGA are included in the Local Strategic Planning Statement (LSPS) as outlined in Figure 1 with definitions in Table 1. The NSW Government policy for managing water quality and waterway health is underpinned by the community environmental values and uses. The timeframes targeted to achieve the community environmental values and uses are also outlined in Figure 1 (i.e. maintain or improve existing condition, for achievement in 5-10 years, or for achievement in 10 years of more). It should be noted that the community environmental values and uses that are relevant to the Northern Beaches LGA are a subset of values and uses adopted by the NSW Government and are specified in the NSW Water Quality and River Flow Objectives (https://www.environment.nsw.gov.au/ieo/).

Table 1. Definition of community environmental values and uses

Community environmental values and uses	Definition
Aquatic ecosystems	Maintaining or improving the ecological condition of waterbodies and their riparian zones over the long term
Visual amenity (non-contact recreation)	Maintaining or improving the aesthetic qualities of waters
Secondary contact recreation	Maintaining or improving water quality for activities such as boating and wading, where there is a low probability of water being swallowed
Primary contact recreation	Maintaining or improving water quality for activities such as swimming in which there is a high probability of water being swallowed
Aquatic foods (to be cooked before eating)	Refers to protecting water quality so that it is suitable for the production of aquatic foods for human consumption and aquaculture activities.

2.2 Water Sensitive Urban Design (WSUD)

Waterway health impacts of urban development can be mitigated or avoided through the application of Water Sensitive Urban Design (WSUD) – an approach that:

- Aims to replicate the natural water cycle by targeting more balanced infiltration, evaporation and evapotranspiration.
- Improves water quality flowing into receiving waters
- Reduces reliance on potable water sources by providing alternate water supply.

Northern Beaches Council currently applies WSUD through its “Water Management for Development Policy”, which is referred to in all three DCPs. The Warringah and Manly LEPs refer specifically to WSUD, whilst the Pittwater LEP requires that development does not adversely impact on water quality. The current development controls for stormwater management in the Northern Beaches LGA generally allow developments to reduce the quality of stormwater, through the adoption of best practice targets requiring the removal of 80% of total suspended solids, 65% of phosphorus and 45% of nitrogen generated at the sites post-development. Typically, there is a shortfall between the export loads that are achieved at the site post-development and pre-development (e.g. for a site with existing imperviousness less than 10%). The controls also do not address stormwater quantity issues that affect waterway health i.e. frequency and volume of stormwater runoff associated with regular small storm events. However, there are requirements for on-site detention (OSD) which aims to reduce peak flows to assist with flood management.

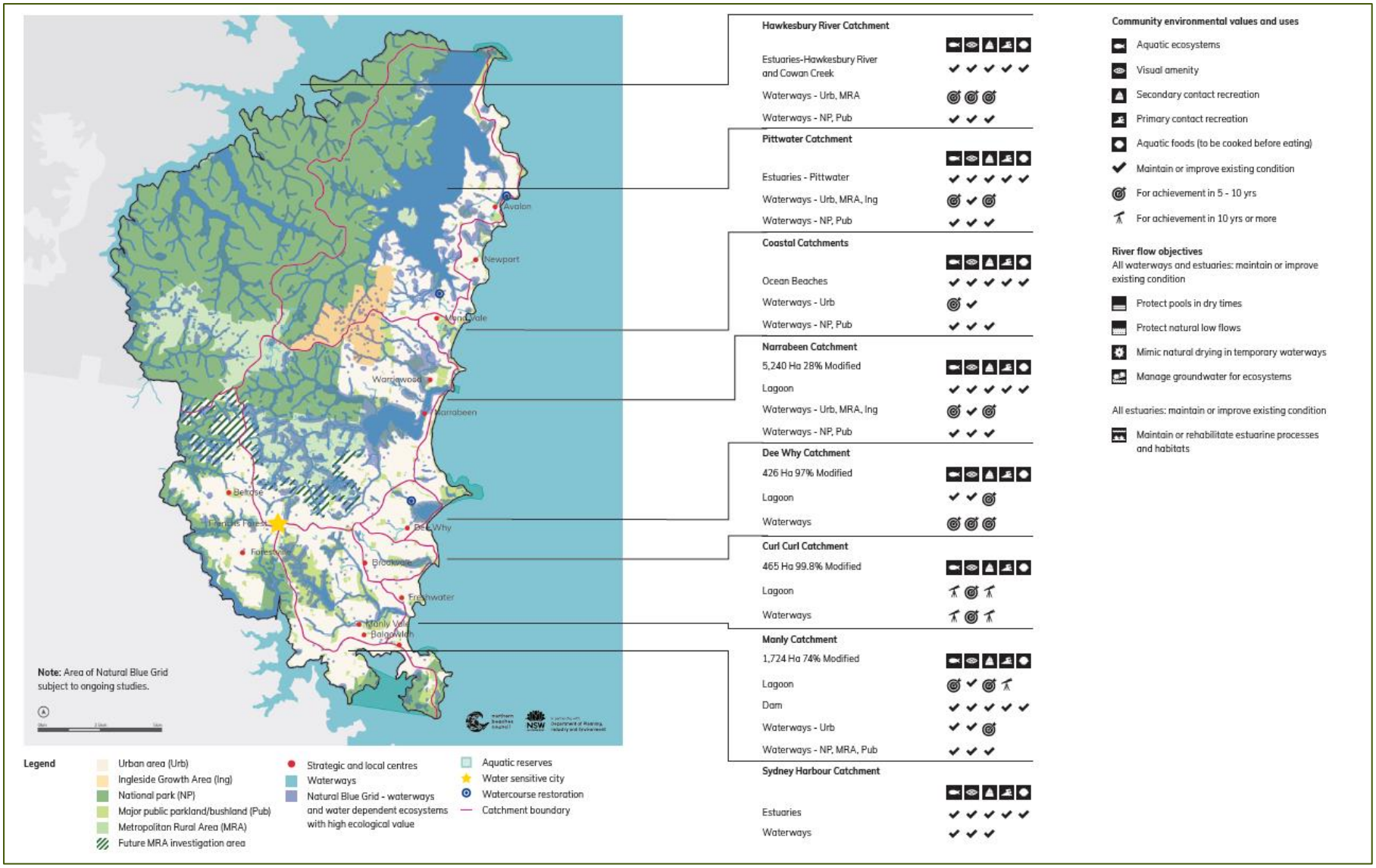


Figure 1. *Community environmental values and uses (Northern Beaches Council, Towards 2040: Local Strategic Planning Statement, 2020)*

2.3 Current stormwater management policy and practices

Stormwater quality
Under the Northern Beaches Council "Water Management for Development Policy", the general stormwater quality requirements (load reduction targets) outlined in Table 2 applies to sub-divisions resulting in:

- Creation of 2 lots (where the total post development imperviousness of the new lots exceeds 40%)
- Creation of 3 lots of more.

The "General stormwater quality requirements" also apply to residential flat buildings, multi-residential dwelling houses, commercial, mixed-use or industrial developments with a site area greater than 1000 m^2. A development that is less than 1000 m^2 and is not a sub-division is required to install a filtration device (catch pit) to remove organic matter and coarse sediments from stormwater if the development proposes to increase impervious area by more than 50 m^2.

However, if a development is proposed in "undeveloped land" in Wheeler Creek, Deep Creek and Oxford Creek catchments (termed as a high-quality catchments), the stormwater water quality management strategy is to have no impact on the waterway (Table 3). There is also a stormwater quantity (flow) target to *maintain* the natural flow regime. Undeveloped land is defined as land that has not been subject to prior development, or is in a state of nature, or with an impervious area of less than 10%. The same stormwater management strategy applies for land containing or adjoining wetlands, bushland and saltmarsh endangered ecological communities, and land adjacent to estuarine habitat and areas containing seagrass, and land within the riparian buffer of a Coastal Upland Swamp in the Sydney Basin Bioregion Endangered Ecological Community.

Table 2. General stormwater quality requirements (Northern Beaches Council, 2020)

Pollutant	Performance Requirements
Total Phosphorous	65% reduction in the post development mean annual load[1]
Total Nitrogen	45% reduction in the post development mean annual load[1]
Total Suspended Solids	85% reduction in the post development mean annual load[1]
Gross Pollutants	90% reduction in the post development mean annual load[1] (for pollutants greater than 5mm in diameter)
pH	6.5 - 8.5
Hydrology	The post-development peak discharge must not exceed the pre-development peak discharge for flows up to the 50% AEP

Table 3. Stormwater quality objectives e.g. for development in "undeveloped land" in a high-quality catchment or development in or in proximity of an ecologically sensitive area (Northern Beaches Council, 2020)

Criteria	Objectives
Stormwater Quality	Stormwater quality (temperature, salinity, chemical makeup and sediment loads) discharging from the development shall not impact the receiving waters. Reference shall be made to local data if available, including the Warringah Creek Management Study and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC), or other widely accepted guidelines. Stormwater and other drainage shall not be discharged into saltmarsh.
Sediment	Disturbance to stream and wetland sediments is to be minimised by regulated discharge of stormwater and dissipation of flows at discharge locations. Runoff from the development must be retained at natural discharge rates and sediments controlled at the source.
Hydrology	Stormwater and groundwater flow is to mimic natural conditions and ensure a dispersed pattern of flow, avoiding centralised or concentrated discharge points into the wetland or waterway. Natural flow regimes must be retained. The reduction or increase in flows, alteration in seasonality of flows, changes to the frequency, duration, magnitude, timing, predictability and variability of flow events, altering surface and subsurface water levels and changing the rate of rise or fall of water levels must be avoided.

2.4 Key aspects of Northern Beaches Council's LEPs and DCPs that need to be resolved

- The current LEPs and DCPs are similar in that no clear guidance is provided on how Water Sensitive Urban Design is to be implemented by development applicant.
- The controls for stormwater management principally focus on stormwater quality (the removal of pollutants) and not on Water Sensitive Urban Design (quality and quantity), leading to developments largely responding to this aspect of WSUD only and not stormwater flow management. This is despite Northern Beaches Council's "Water Management for Development Policy" having a stormwater quantity requirement for development to *maintain* the natural flow regime in high-quality catchments. Clear requirements for stormwater quantity management are therefore required to inform developers.
- The majority of developments use grey infrastructure solutions such as proprietary filtration cartridges to manage the removal of pollutants from stormwater rather than green infrastructure which includes filtration through planted gardens and wetlands. The controls fail to outline how developers must deliver WSUD outcomes when proprietary solutions are used.
- Targets for pollutant removal are inconsistent and based on differing methodologies. For instance, the previous Warringah LGA divides catchments into those that must achieve a neutral or beneficial impact (NorBE) on water quality and those that can apply stormwater quality targets that allow some deterioration in water quality of receiving waterways. This study was based on a comprehensive catchment study in 2004 (which has not been updated for current conditions). The previous Pittwater LGA simply notes the McCarrs Creek catchment (including Cicada Glen Creek) as a priority, but there is no supporting study.
- Targets for stormwater quality management are not related to the water quality objectives for waterways. The LSPS for instance notes that swimming is possible in Narrabeen Lagoon, which therefore requires water quality suitable for primary contact recreation, whereas swimming is less likely to be achieved in Curl Curl Lagoon due to existing poor water quality. The catchments therefore have very different objectives, yet a development in Narrabeen catchment has the same targets for pollutant removal as a development in the Curl Curl catchment.
- Stormwater and water cycle management is currently addressed via the recently adopted Water Management for Development Policy, with the DCP simply directing applicants to the policy.

2.5 Narrabeen Lagoon catchment pilot study

Northern Beaches Council is participating in a pilot study with the NSW Department of Planning, Industry and Environment (DPIE) and Alluvium Consulting to apply the *Risk-Based Framework for Considering Waterway Health Outcomes in Strategic Land-Use Planning Decisi*ons (Dela-Cruz et al., 2017) in the Narrabeen Lagoon catchment.

The Risk Based Framework is a protocol that has been developed to help decision makers such as councils, planners and environmental regulators manage the impact of land-use activities on the health of waterways in New South Wales. The benefit of the Risk-Based Framework is that it allows decision makers to determine management strategies (including stormwater management strategies) that meet waterway health outcomes and reflect the community's environmental values and uses of the waterways. By applying the steps in the Risk Based Framework (Figure 2) in the pilot study, there was a clear line of sight between the proposed stormwater management strategy and targets, waterway objectives, and the community environmental values and uses of the waterways.

The pilot study was completed in 2021 with a recommended stormwater management strategy and targets for the Narrabeen Lagoon catchment. In order to develop stormwater management strategy and targets across the LGA, the Risk-Based Framework was applied to the remaining catchments of the Northern Beaches Council as part of this project.

3 Methodology

This section outlines the approach undertaken to develop the Stormwater Management Strategy and targets for each catchment in the Northern Beaches LGA (Figure 3). The approach is based on a desktop assessment following the first three steps of the Risk-Based Framework (Figure 2).

As outlined in the background, stormwater quantity and quality both need to be managed to address the impact of stormwater runoff on the health of waterways. As such, it is important to define and establish a link between waterway health objectives and stormwater management strategy and targets.

Waterway objectives are established by considering:

- the "existing condition" of the waterway
- the "desired condition" of the waterway based on the community environmental values and uses as outlined in section 2.1
- risk of impacts on waterways including from current and future pressures.

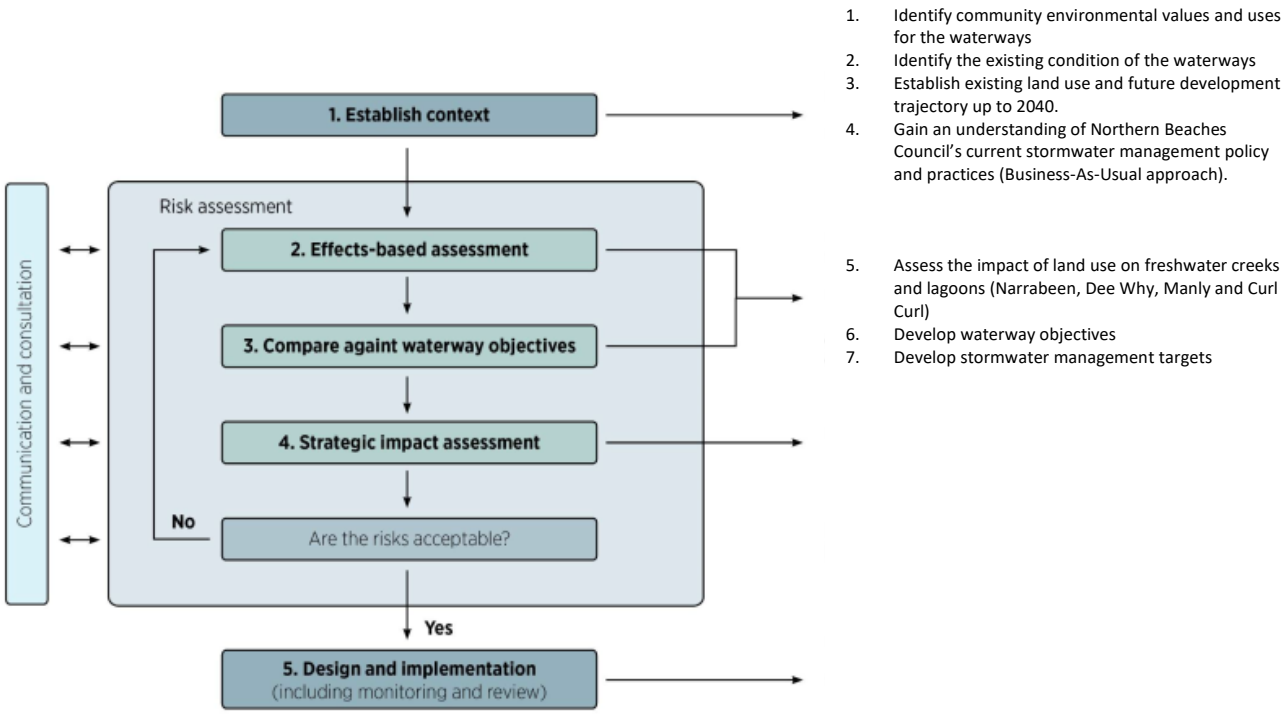


Figure 2. *Application of the Risk Based Framework in the Narrabeen Lagoon Catchment*

For this project, draft waterway objectives have been established from existing data, findings in previous studies and initial consultation with Northern Beaches Council. It is important to note that the waterway objectives from this study are in draft form as they have been established using limited recent local data and limited consultation. For a significant proportion of catchments data has been limited to remotely sensed data (not ground-truthed). It is recommended that additional consultation and field verification of the draft waterway objectives be undertaken with an initial focus on catchments with higher existing and anticipated future pressures.

To test the methodology, the steps above were applied for catchment case studies. The findings for the case studies are presented in section 4. The steps were then applied for remaining catchments (see Appendix A).

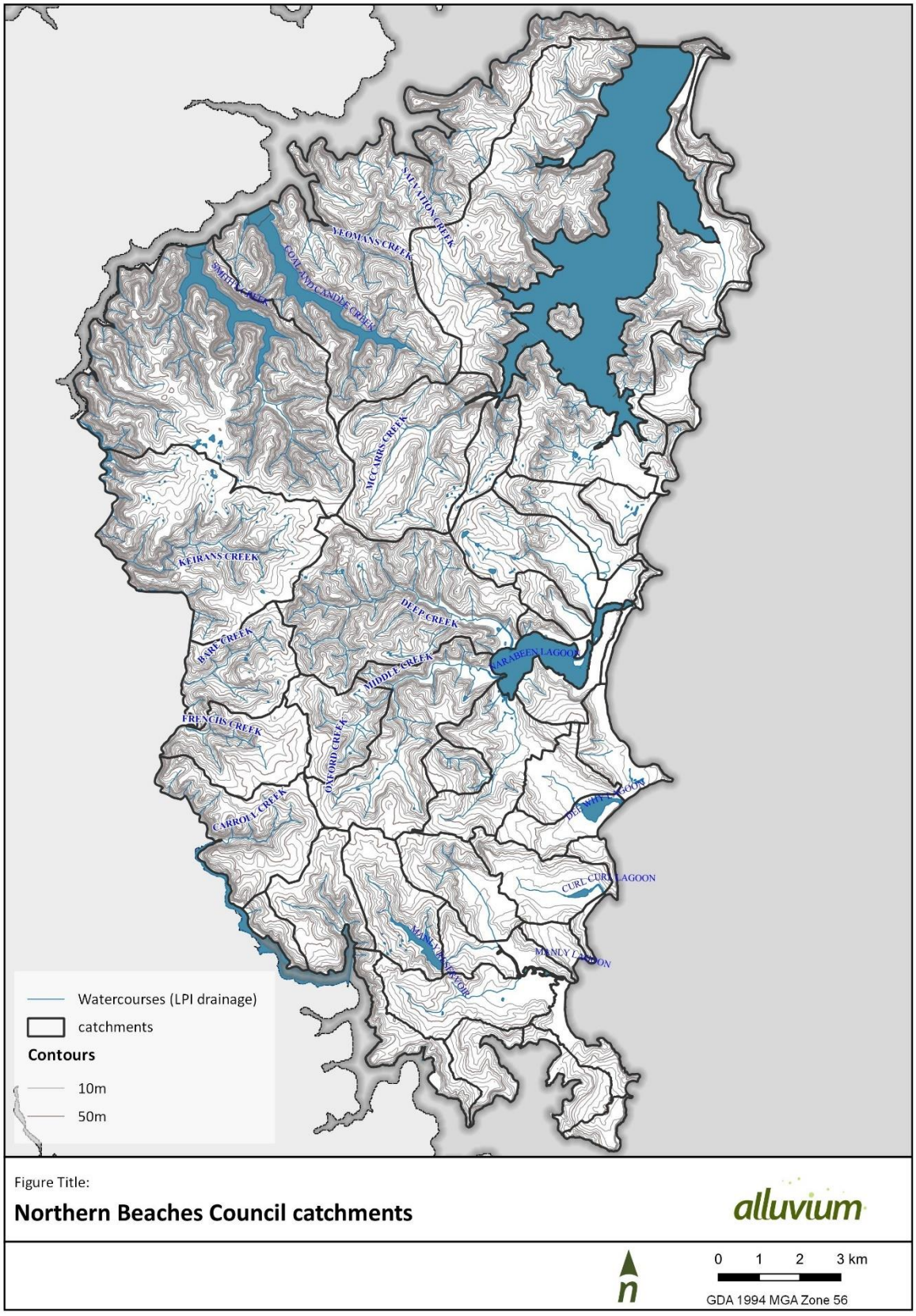


Figure 3. *Northern Beaches Council catchments*

Waterway condition and indicators
In this study, waterway condition has been assessed by investigating the following four conditions:

1. Hydrology
2. Water quality
3. Riparian vegetation
4. Physical form

The combined assessment of the four conditions (see Table 4 for definitions) provides an indication of the overall waterway condition. Indicators are identified which can be measured to provide useful information on the waterway condition. "Key indicators" have been selected for this project based on data available (see section 3.1). The four waterway conditions have also been mapped to show how they support community environmental values and uses (Table 5).

Table 4. Definition of four waterway conditions and indicators

Condition		Definition	Indicators
1.	Hydrology	Flow or water regime into, within and out of the waterway or receiving water is managed to support community environmental values and uses.	Catchment imperviousness, annual runoff volume, flow obstructions, flow diversions, flow extractions.
2.	Water quality	Water quality is managed to support community environmental values and uses:	
		Aquatic ecosystems	Turbidity, nutrients, macroinvertebrates, Chlorophyll-a
		Visual amenity (i.e. non-contact recreation)	Turbidity, litter, debris, nuisance organisms (e.g. phytoplankton scums, blue-green algae)
		Secondary contact recreation	Turbidity, litter, debris, nuisance organisms, surface films and microbial
		Primary contact recreation	Turbidity, litter, debris, nuisance organisms, surface films and microbial
		Aquatic foods	Algae, microbial
3.	Riparian vegetation	Riparian vegetation extent and quality is managed to support community environmental values and uses including aquatic habitat. • Extent refers to in-stream vegetation and stream side vegetation that support the health of the waterway. • Vegetation quality refers to the level vegetation is intact or disturbed.	Riparian vegetation extent and quality Extent of weed infestation
4.	Physical form	Physical form is managed to support community environmental values and values including aquatic habitat.	Geomorphic condition, shape and size, bed and bank stability, sedimentation, sand slugs, debris

Table 5. Condition attributes that support community environmental values and uses

Community environmental values and uses	Conditions that support values and uses
Aquatic ecosystems	Hydrology Water quality Riparian vegetation Physical form
Visual amenity	Hydrology Water quality Riparian vegetation Physical form
Secondary contact recreation	Water quality Physical form
Primary contact recreation	Water quality Physical form
Aquatic foods (to be cooked before eating)	Water quality

3.1 Data availability

We have reviewed existing data and previous studies to identify current understanding of catchment values, issues and pressures, and waterway existing condition and trajectory. These are summarised in the catchment summaries (section 4 and Appendix A).

Two reports were particularly useful as they applied a consistent methodology to assess a large number of waterways.

- Creek Management Study Warringah Council (MWH Australia Pty Ltd, 2004)
- Creek Monitoring, Evaluating and Reporting Project Spring 2015 and Autumn 2016 (NSW OEH, not dated).

The first study provided a useful historical summary of waterway values, issues and pressures, noting that the study was completed over 15 years ago. The second study provides data on water quality, macroinvertebrates diversity, and physical form but is only limited to four sampling events and assessment at one or two specific locations along each waterway.

Given data availability, we have selected key indicators to inform existing condition and trajectory of waterways (Table 6).

Table 6. Selected indicators

Conditions		Key indicators	Description	Data source
1.	Hydrology	Catchment imperviousness	Imperviousness represents the portion of the catchment that is impermeable as a result of hard surface such as roofs and roads. It provides an indication of the extent to which the waterway hydrology has been modified.	DPIE using a combination of "Buildings Geospaces" and NSW government land use layers
2.	Water quality	Turbidity, nutrients, macroinvertebrates, microbial	Turbidity, nutrients and macroinvertebrates provide an indication of the health of aquatic ecosystems. Microbial levels indicate suitability for secondary and primary contact.	Creek Management Study Warringah Council (MWH Australia Pty Ltd, 2004) Northern Beaches Council Creek Monitoring, Evaluating and Reporting Project Spring 2015 and Autumn 2016 (NSW OEH, undated) Mullet Creek Water Quality Monitoring Program and Design, Bio-analysis, 2010
3.	Riparian vegetation	Riparian vegetation extent and quality	Extent and quality of riparian vegetation: Category 1: Riparian Corridor that potentially supports relatively intact native vegetation and habitats within a nominated width measured from the channel Category 2: Riparian Corridor that potentially supports disturbed lands within a nominated width measured from the edge of the channel	Riparian Mapping Methodology for the Northern Beaches Council LEP and DCP, BMT, 2021
4.	Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Reach geomorphic type and condition Erosion issues and description	NSW River Styles Database Creek Management Study Warringah Council (MWH Australia Pty Ltd, 2004) Northern Beaches Council Creek Monitoring, Evaluating and Reporting Project Spring 2015 and Autumn 2016 (NSW OEH, undated). A variety of creek, lagoon, estuary and coastal management plans as documents in catchment summaries.

Key findings
A summary of the two studies is presented in Table 7. The key findings are:

- There is an apparent correlation between catchment imperviousness and macroinvertebrates diversity. For creeks where the number of macroinvertebrates groups collected is similar to those expected to be present (referred to as Band A), catchment imperviousness was observed to be less than 10%. For creeks where the number of macroinvertebrates groups collected is less than those expected to be present (referred to as Band B), catchment imperviousness was generally between 20% and 30%. For creeks where the number of macroinvertebrates groups collected is significant less than those expected to be present (referred to as Band C), catchment imperviousness generally exceeds 30%.

  Different macroinvertebrates can withstand different levels of pollution. Macroinvertebrate diversity is therefore a useful indicator for understanding the level of pollution and associated waterway health (a healthy waterway will contain diverse species of macroinvertebrates).

  The data suggests that there is a tipping point in macroinvertebrates diversity (i.e. from Band A to B) when the catchment imperviousness reaches between 10-20% and a tipping point to Band C when imperviousness reaches about 30%.

- Curl Curl Creek and Kierans Creek have lower water quality despite catchment imperviousness being less than 10%. This is attributed to a number of other pollution sources overriding stormwater pollution including on-site wastewater effluent, runoff from horse paddocks, landscape suppliers and nurseries for Kierans Creek, and polluted groundwater or fertiliser use resulting in high nitrogen levels for Curl Curl Creek. Despite the lower water quality, macroinvertebrates diversity is similar to those expected to be present (Band A) which was attributed to resilience and good physical form of the National Park or urban parkland reaches that would provide some buffering of water quality.

- Waterways with urbanised upper reaches and downstream reaches in National Park or large urban parklands can be characterised with degraded urban reaches which in turn affects the health of downstream reaches in terms of weed encroachment, water quality and macroinvertebrate diversity e.g. Frenchs Creek, Carroll Creek and Bates Creek all with catchment imperviousness exceeding 20%. For waterways with similar development characteristics but lower catchment imperviousness (e.g. Bare Creek and Oxford Creek), water quality and macroinvertebrate diversity in the downstream reaches has remained in good condition (noting however significant sand slugs in the downstream reaches of Oxford Creek).

- Turbidity was observed to be higher in catchments with lower imperviousness. This is possibly due to increased erosion associated with recent construction activity and soil disturbance, walking tracks and fire trails in close proximity to the waterways. It also suggests that sediment loads from catchments with higher imperviousness have stabilised. Although, the limited water quality data available makes it challenging to draw any definitive conclusions.

It should also be noted that there are no specific environmental flow studies undertaken for waterways or lagoons in the LGA which would have assisted in evaluating waterway existing hydrologic conditions in relation to flow indicators (e.g. wetting and drying patterns, frequency of low flows and over-bank flows, and baseflow). For this project, we have therefore relied primarily on catchment imperviousness to infer existing hydrology. Additional investigation is recommended in the future to define waterway flow objectives in order to quantify stormwater quantity (flow) targets.

Table 7. Summary of findings from key waterway assessment studies

Creek	Current estimated imperviousness (%)	Group*	Total Nitrogen score ** (1-5)	NOx score** (1-5)	Total Phosphorus score** (1-5)	Turbidity score** (1-5)	Macroinverte-brates band**	Physical form (100 m)**	Coliforms above trigger values*
Deep Creek (U/S)	3.4%	A	1	1	1	1	A	Excellent	No
Wheelers Creek	6.2%	A	1	1	1	2	B	Fair	Yes (D/S dev)
Bare Creek (D/S)	7.2%	B	2	1	1	1	A	Excellent	Not sampled
Kierans Creek	7.6%	B	5	4	5	3	A	Very good	Not reported
Curl Curl Creek	11.7%	A	3	1	2	2	A	Excellent	Not sampled
Oxford Creek	14.3%	B	1	1	1	3	A	Fair	Not sampled
Middle Creek (D/S)	16.8%	C	1	1	1	1	A	Very good	Not sampled
Middle Creek (U/S)	NA	C	3	2	3	2	B	Fair	Yes
Mullet Creek	19.8%		Inferred from separate study ***				***		
Bates Creek (Bantry Bay)	21.0%	C	3	2	2	1	B	Very good	Not sampled
Carroll Creek	24.2%	C	2	3	1	1	B	Very good	Not sampled
Frenchs Creek	24.2%	C	1	2	1	1	B	Very good	Not sampled
South Creek	32.2%	C	1	2	2	3	C	Fair	Yes
Brookvale Creek (D/S)	39.9%	C	5	5	2	1	C	Very good	Yes
Dee Why Creek	42.9%	C	4	4	3	1	C	Poor	Yes
Burnt Bridge Creek	43.8%	C	3	2	2	1	C	Very good	Yes

*Creek Management Study Warringah Council, MWH Australia Pty Ltd, 2004; ** Northern Beaches Council Creek Monitoring, Evaluating and Reporting Project Spring 2015 and Autumn 2016, NSW OEH, undated. Limited to four sampling events
*** Mullet Creek Water Quality Monitoring Program and Design, BioAnalysis Pty Ltd, 2010

Creek group:

Group A: Creeks unaffected by development

Group B: Creeks with highly modified reaches in urban and rural areas but good condition in National Parks

Group C: Creeks with significant and potentially irreversible changes to ecology and geomorphology

Macroinvertebrates Band

A – Number of macroinvertebrates groups collected is similar to those expected to be present; B – Number of macroinvertebrates groups collected is less than those expected to be present; C – Number of macroinvertebrates groups collected significantly less than those expected to be present

Water quality score categories

Category 1 to 5 represent how far the measured value is above the ANZECC guidelines trigger value with 5 being the furthest.

4 Catchment case studies

This section presents seven case studies (Table 8) with different receiving water environments for which existing waterway condition, trajectory and draft waterway objectives were established.

Summaries for remaining catchments are provided in Appendix A.

Table 8. Catchment case studies

Catchment case study	Downstream receiving waters	Estimated current imperviousness (%)	Potential increase in imperviousness over next 20 years (%)
Oxford Creek	Narrabeen Lagoon	14%	>10%
Carroll Creek	Middle Harbour Creek	24%	<3%
Dee Why Creek	Dee Why Lagoon	43%	<3%
Curl Curl Creek	Manly Dam	12%	<2%
Manly Beach	Ocean	32%	<2%
Manly Cove	Middle Harbour	24%	<2%
Careel Creek	Pittwater Estuary	28%	<4%

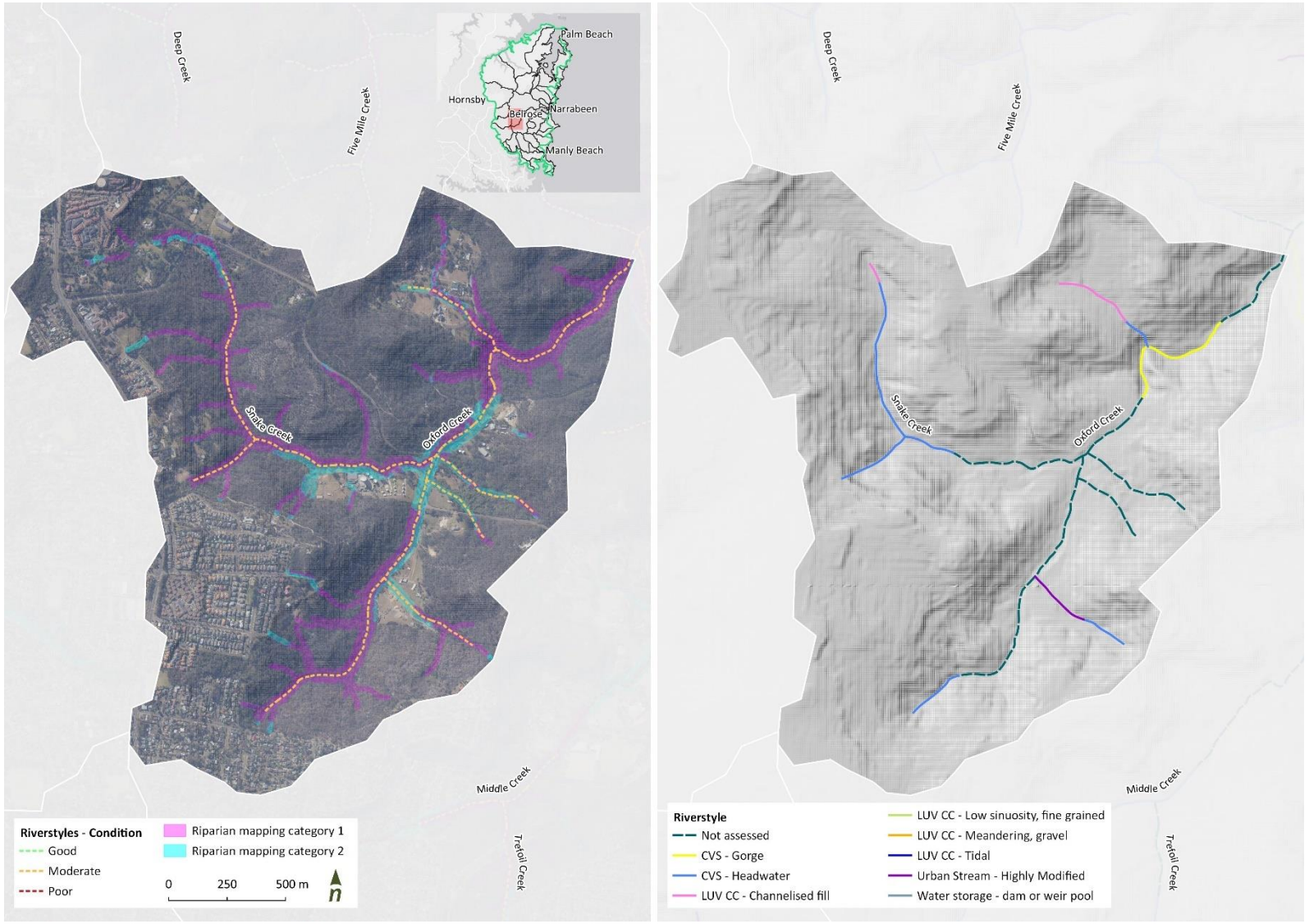
Current imperviousness in each catchment was estimated by DPIE-EES based on a combination of the commercially available layer "Buildings Geospaces" and the NSW government land use layer. The data captured roof surfaces, road pavement and car parks but not driveways and other outdoor paved areas on lots. As such, it is expected that the data underestimated imperviousness. However, given that the impervious surfaces captured by the data are directly connected to the stormwater network, it is expected that the imperviousness data is a reasonable estimate of Directly Connected Imperviousness (DCI) – a metric which has been established as a catchment indicator of waterway ecological condition.

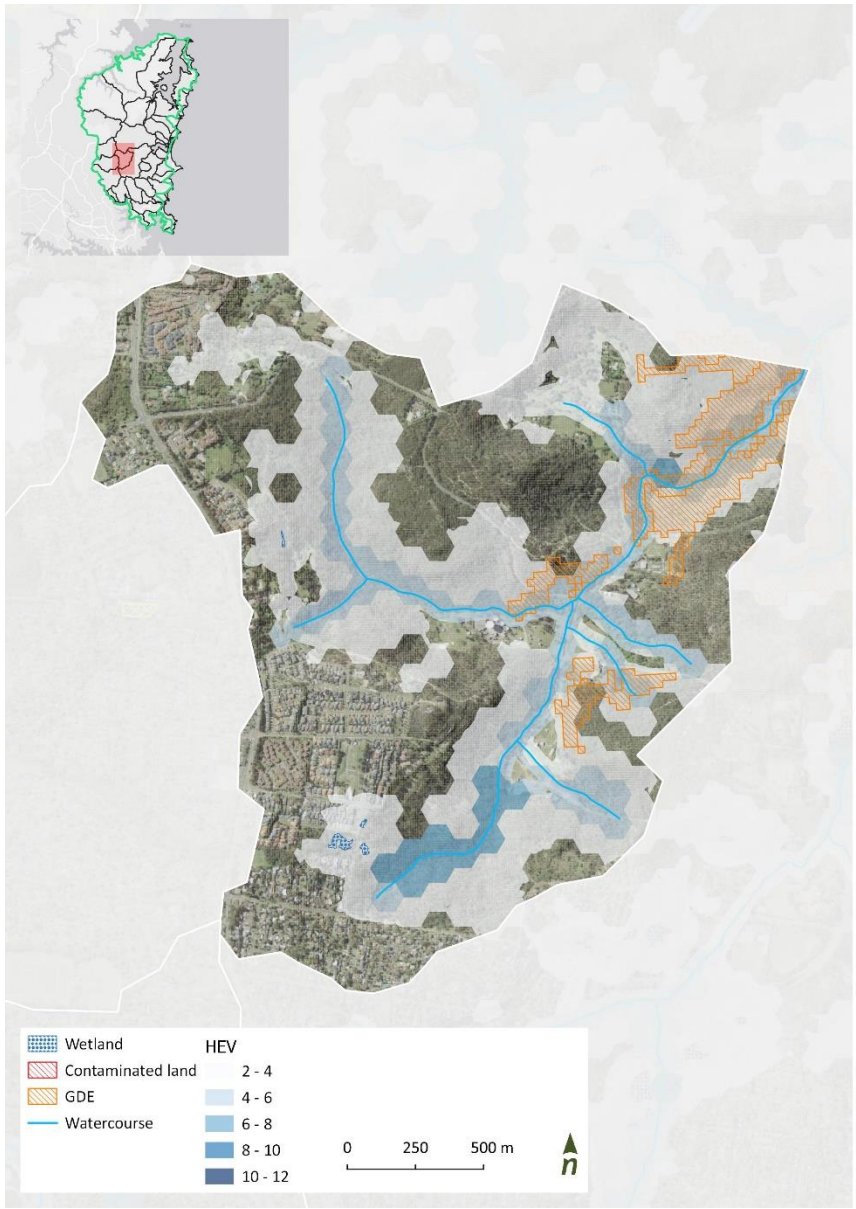
Potential increase in imperviousness within each catchment is based on assumed increases in imperviousness within future development areas in Northern Beaches LGA (Table 9).

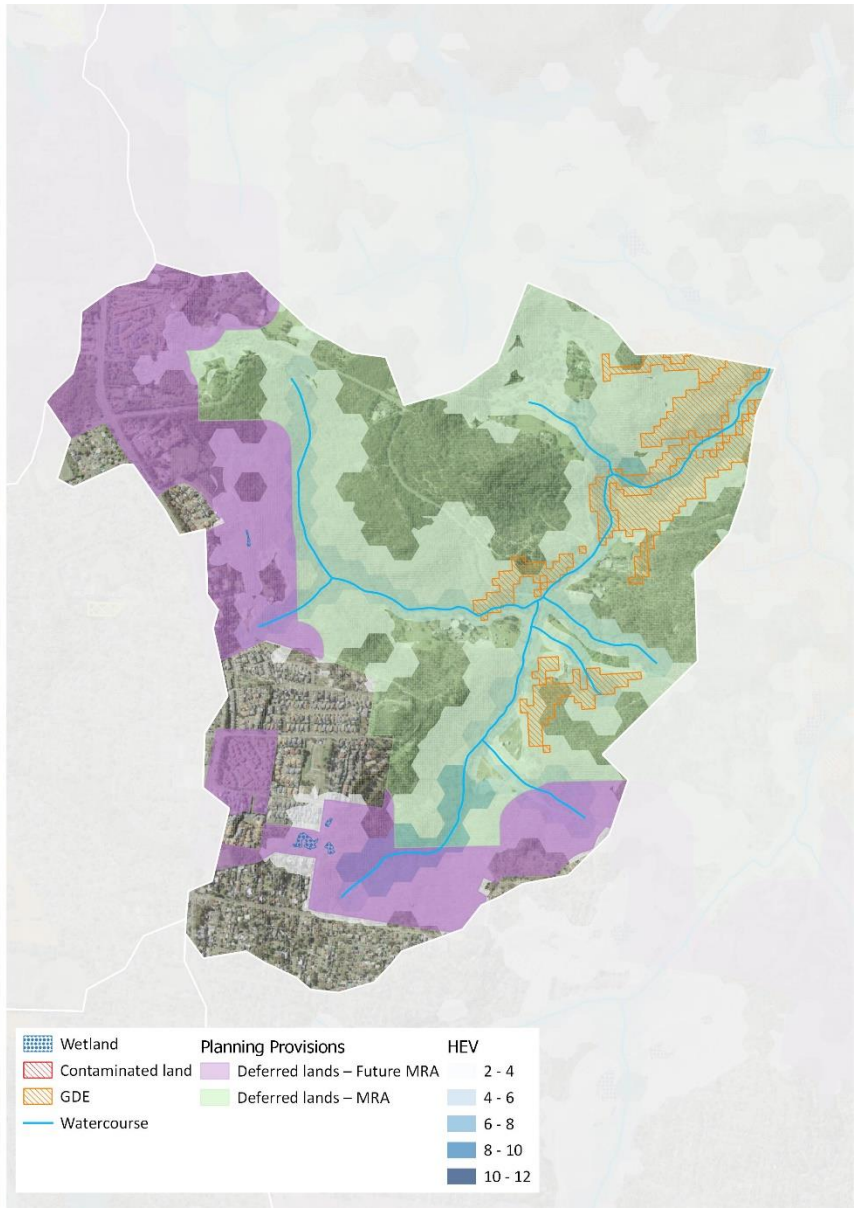
Table 9. Assumed increase in imperviousness within future development areas

Future development areas	Potential increase in imperviousness over next 20 years (%)
Centre Investigation Areas	20%
Frenchs Forest Release Area	30%
Housing Diversity Areas	20%
Ingleside Growth Area	50%
Warriewood Growth Area	50%

4.1 Oxford Creek



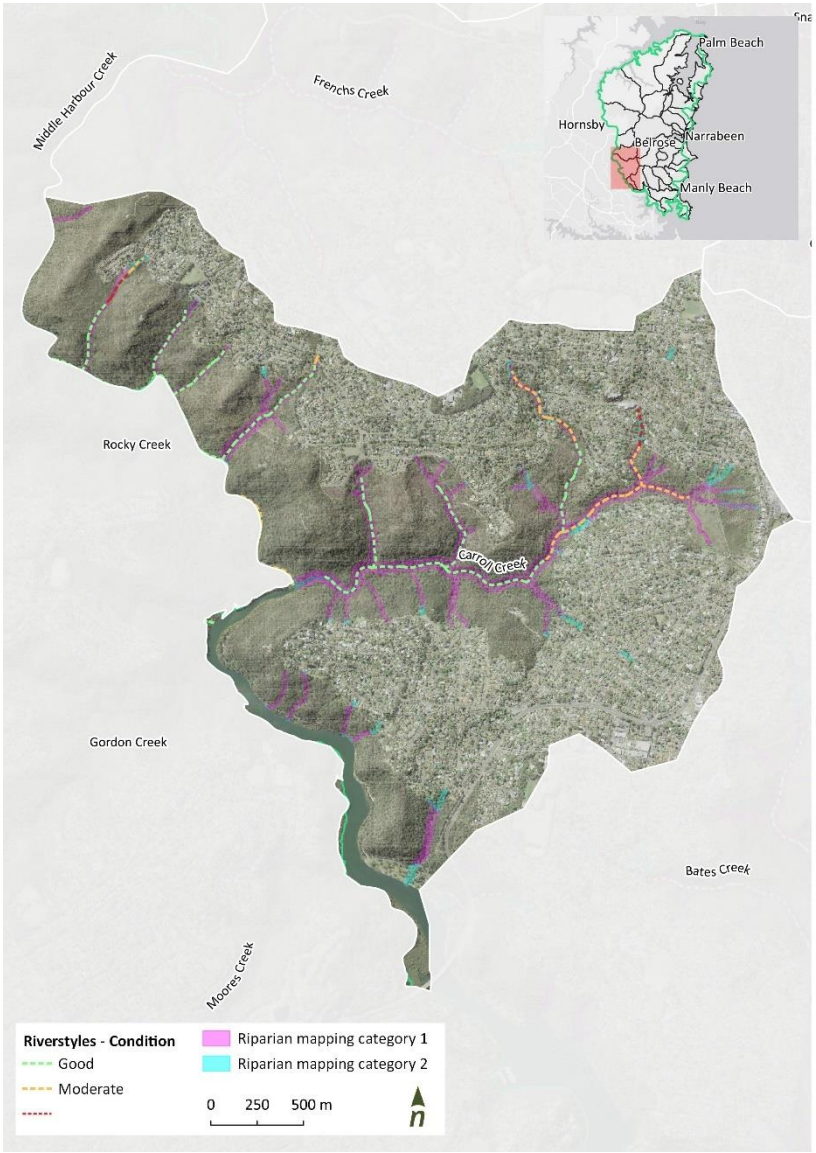

Wetland
Contaminated land
GDE
Watercourse
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0
250
500 m
n

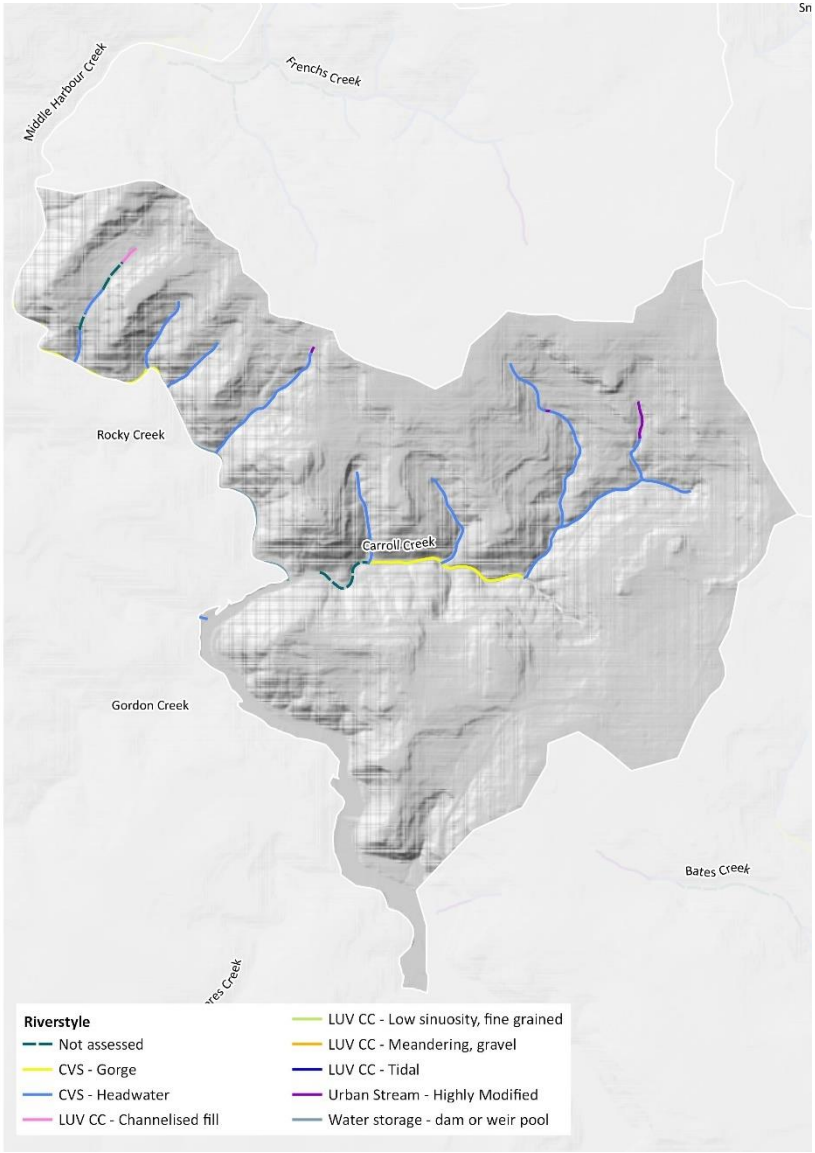

Wetland
Contaminated land
GDE
Watercourse
Planning Provisions
Deferred lands – Future MRA
Deferred lands – MRA
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

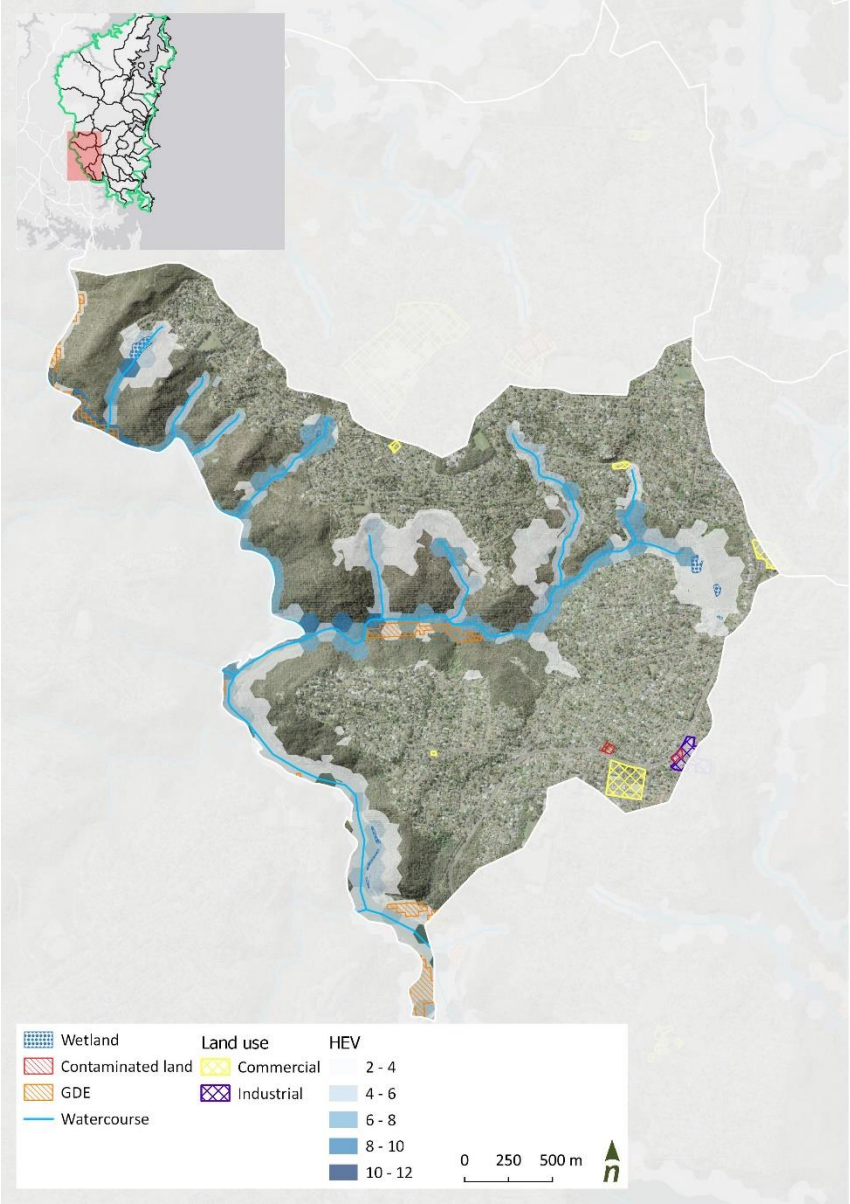
Oxford Creek	Current fraction imperviousness: 14 % (Potential increase>10%)			References
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for visual amenity; *Improve* condition for aquatic ecosystems and secondary contact recreation (5-10 year timeframe); *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	• Varies between reaches owing to weed infestation and cleared agricultural lands • High landscape value and fine example of streamside vegetation close to waterfall • In-stream biodiversity in good condition (similar to that expected to be present) • HEV score higher for upper reaches of Oxford Creek • GDE at lower reaches of Oxford Creek			Creek MER Assessment Report Card 2014-2015 Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016
Existing catchment pressures and stressors	• Urbanisation in upper parts of the catchment • Bank eroding in places • High sediment load enters the creeks during and after heavy rainfall (based on high turbidity measurements) • Weed invasion			Creek MER Assessment Report Card 2014-2015 Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objectives**
1. Hydrology	Imperviousness	Expected to be slightly to moderately modified (Imperviousness 14%)	Potential to decline given imperviousness can exceed 20% in the next 20 years	**Maintain condition**
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TN, NOx and TP at or just above trigger value for aquatic ecosystems (ANZECC Guidelines for NSW and Victoria lowland, east flowing coastal rivers). Macroinvertebrates diversity similar to that expected to be present Turbidity elevated possibly due to localised erosion and erosion of informal bike tracks and fire trails Sediment plumes have been observed at stormwater outlets	Potential to decline given imperviousness can exceed 20% in the next 20 years	**Maintain or improve condition** (e.g. improve condition in upper urban reaches)

3.Riparian vegetation	Riparian vegetation extent and quality, weed infestation.	- Category 1 riparian vegetation classified in the upper and lower reaches (BMT, 2021). Good connectivity and width maintained. - The mid reaches is significantly disturbed, with a narrow width limited by the road on the eastern side. Some natives in the canopy layer (approx. 50%), understory and ground cover primarily weeds. *Some weed infestation observed immediately downstream of outlets. Area is extending over time. Likely causes are higher wetting and nutrient inputs.*	- Invasive weeds disturbance to downstream likely Declining with development and potentially with climate change (higher flows exposing banks)	**Maintain condition** Potential to improve condition at stormwater outlets and at disturbed sites
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Upper reaches are steep and bedrock confined with moderate geomorphic condition. - The mid reaches (upstream of Oxford Falls Cascade) are partially confined with a relatively continuous but narrow floodplain on the eastern side. Some bedrock evident in the channel limiting vertical adjustment, banks are typically steep with some active erosion present but generally constrained by the road. A sand slug identified in this reach (NSW OEH, 2016). - The lower reaches flow through a confined gorge setting until its confluence with Middle Creek where significant sand slug has been identified. *Some widening and localised erosion observed*	- No significant lateral adjustment likely in confined upper reaches - Ongoing erosion possible through the partly confined mid reaches upstream of Oxford Falls Cascade - Ongoing aggradation in the channel around the confluence with Middle Creek	**Maintain condition**

4.2 Carroll Creek





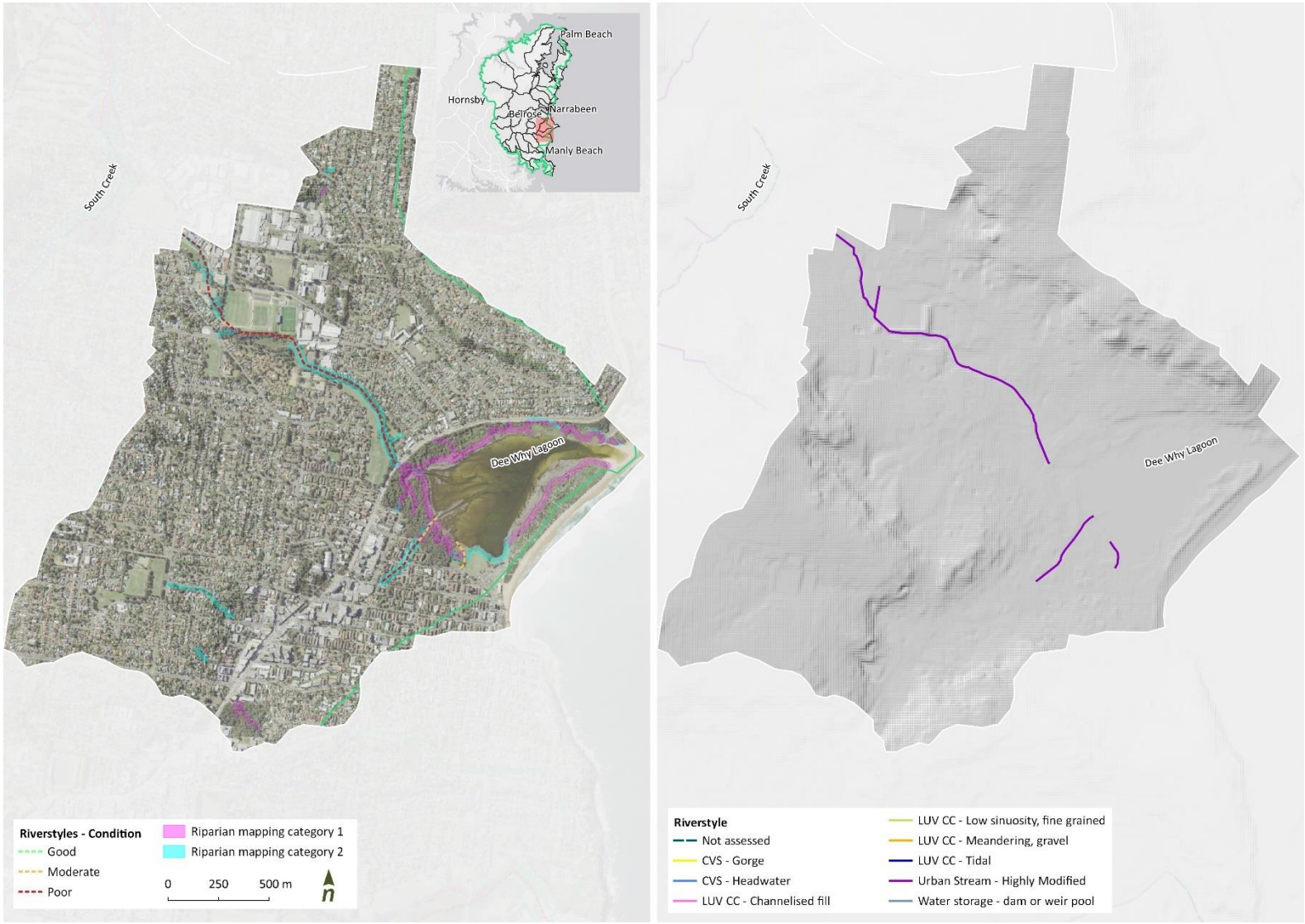

Wetland
Contaminated land
GDE
Watercourse
Land use
Commercial
Industrial
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0 250 500 m
n

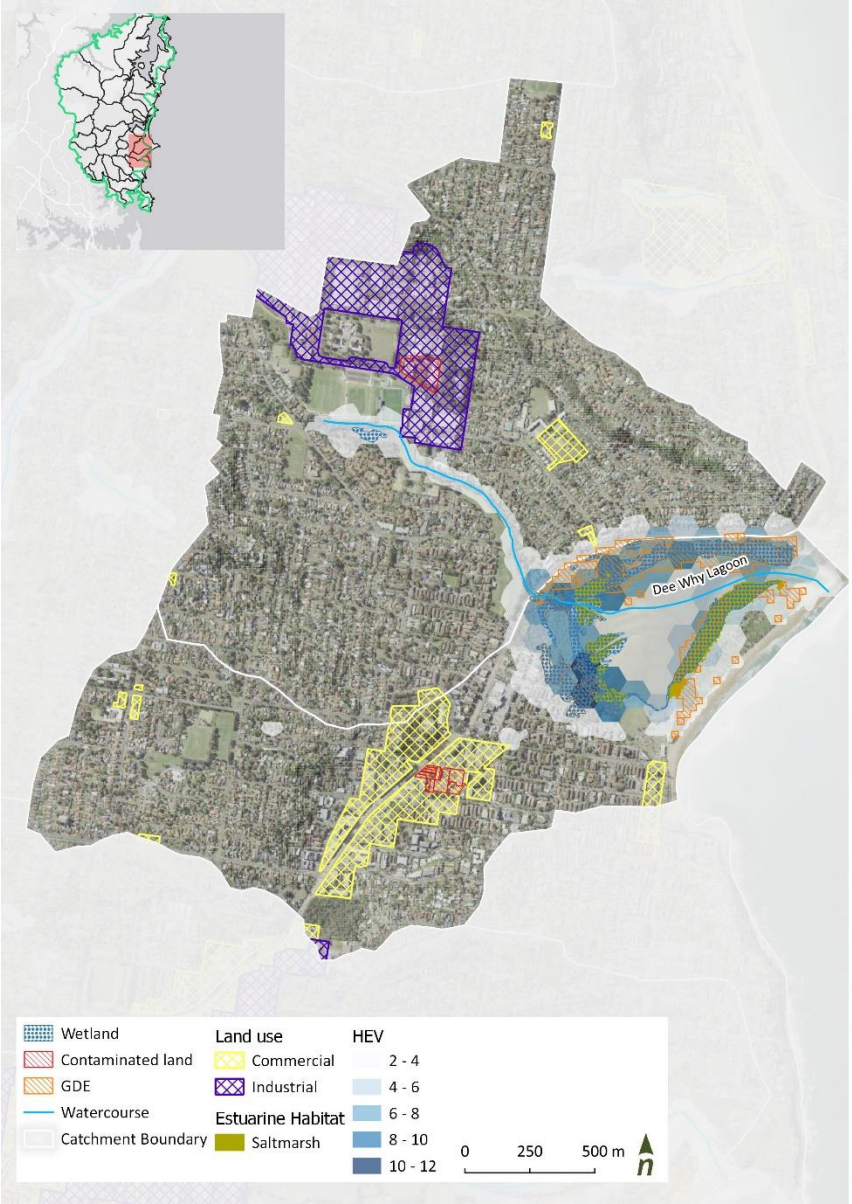

Wetland
Contaminated land
GDE
Watercourse
Land use
Commercial
Industrial
Planning Provisions
Centre Investigation Areas (800m R2)
Frenchs Forest Release Area
Housing Diversity Areas (400m R2)
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

Carroll Creek	Current fraction imperviousness: 24 % (potential increase <3%)			References
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems, visual amenity and secondary contact recreation; *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	• High native species richness immediately upstream of National Park with reasonable connectivity and habitat quality • Ecological value high both within and outside National Park • HEV score higher in National Park • GDE existing along main creek line.			Middle Harbour Catchment Stormwater Management Plan July 1999 Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016
Existing catchment pressures and stressors	• Polluted urban runoff. TN concentrations at Prahran Avenue poor. • Degradation of upstream reaches threatening high values downstream • Weeds encroachment in National Park resulting from uncontrolled invasion and deliberate cultivation of exotics in upstream urban reaches. • Land development, sediment input, nutrient input, freshwater input are catchment pressures to health of Middle Harbour. • *Old Sydney Water sewers – leaking, sewer overflows. Sydney Water improving system*. • *Warringah Rd impacts on from road runoff tyres, brakes, accidents*			Warringah Creek Management Study 2004 Estuary Health Assessment Clontarf Bantry Bay Final Report 2017
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objectives**
1. Hydrology	Imperviousness	Expected to be moderately modified	Stable with small increase in imperviousness expected in the next 20 years	**Maintain condition**
2. Water quality	Turbidity, nutrients, macroinvertebrates	TN, NOx above trigger value for aquatic ecosystems. TP at or just above trigger value for aquatic ecosystems (ANZECC Guidelines for NSW and Victoria lowland, east flowing coastal rivers). Macroinvertebrates diversity is less that expected to be present	Stable given small increase in imperviousness. Note: Sydney Water improving sewerage system.	**Improve condition** *noting multiple sources of pollution
3.Riparian vegetation	Riparian vegetation extent and quality, weed infestation	Local weed encroachment in National Park	Expect to decline. New DAs suggest that planting proposed	**Improve condition** along degraded reaches

			may incorporate more invasive species	
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Highly confined. Low turbidity – large urban development disturbance in the catchment have now been completed.	Stable	**Improve condition** along degraded reaches

4.3 Dee Why Creek




Dee Why Lagoon
Wetland
Contaminated land
GDE
Watercourse
Catchment Boundary
Land use
Commercial
Industrial
Estuarine Habitat
Saltmarsh
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0
250
500 m
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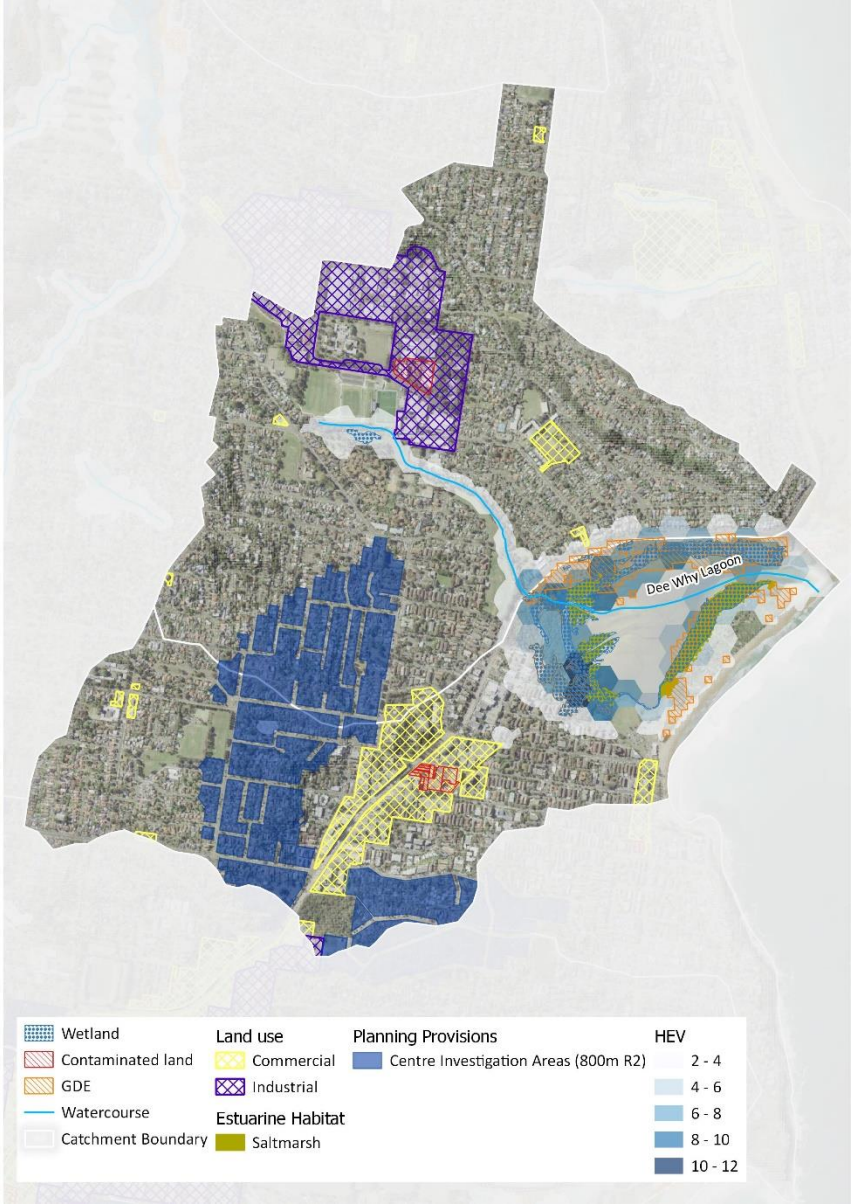
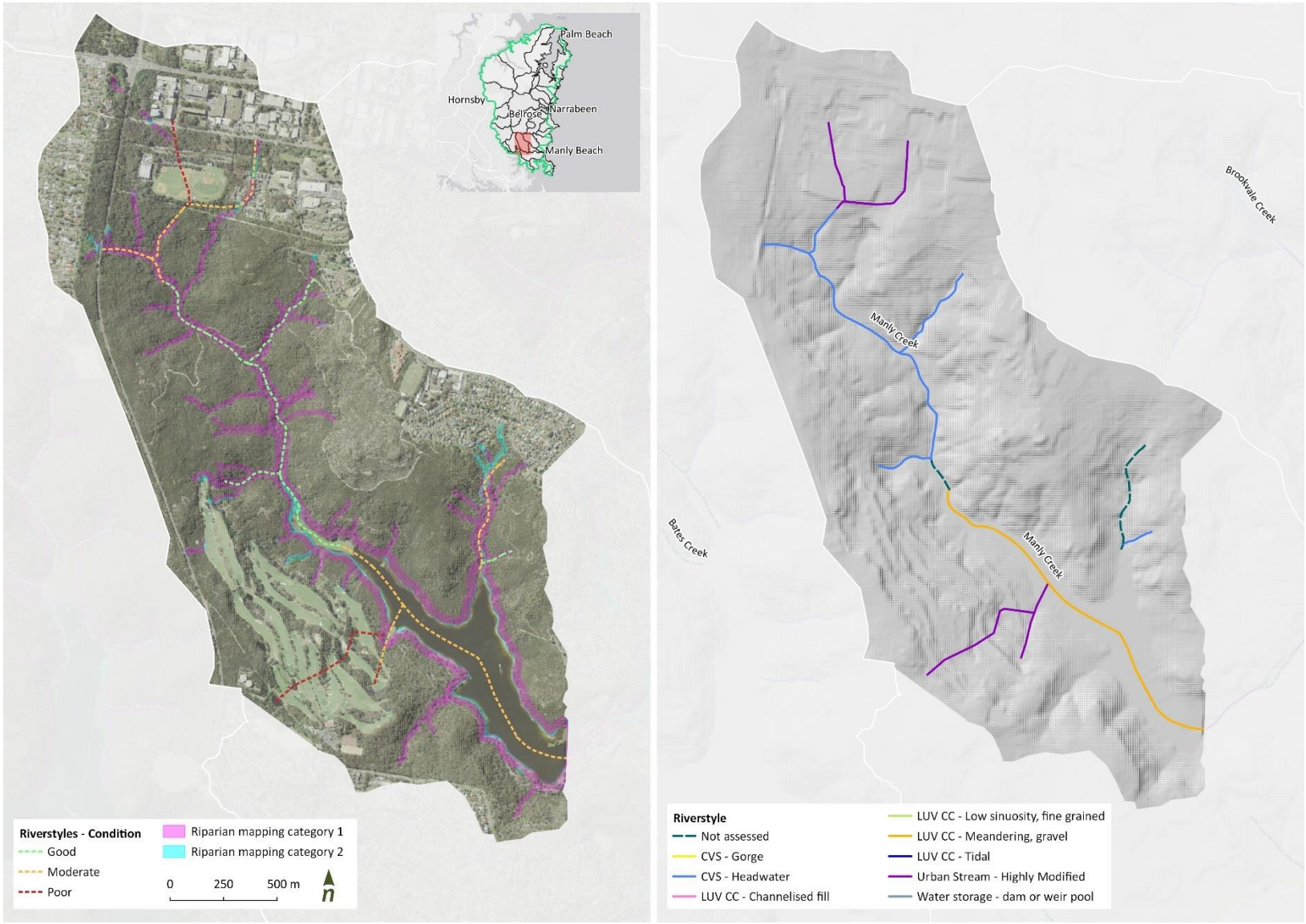
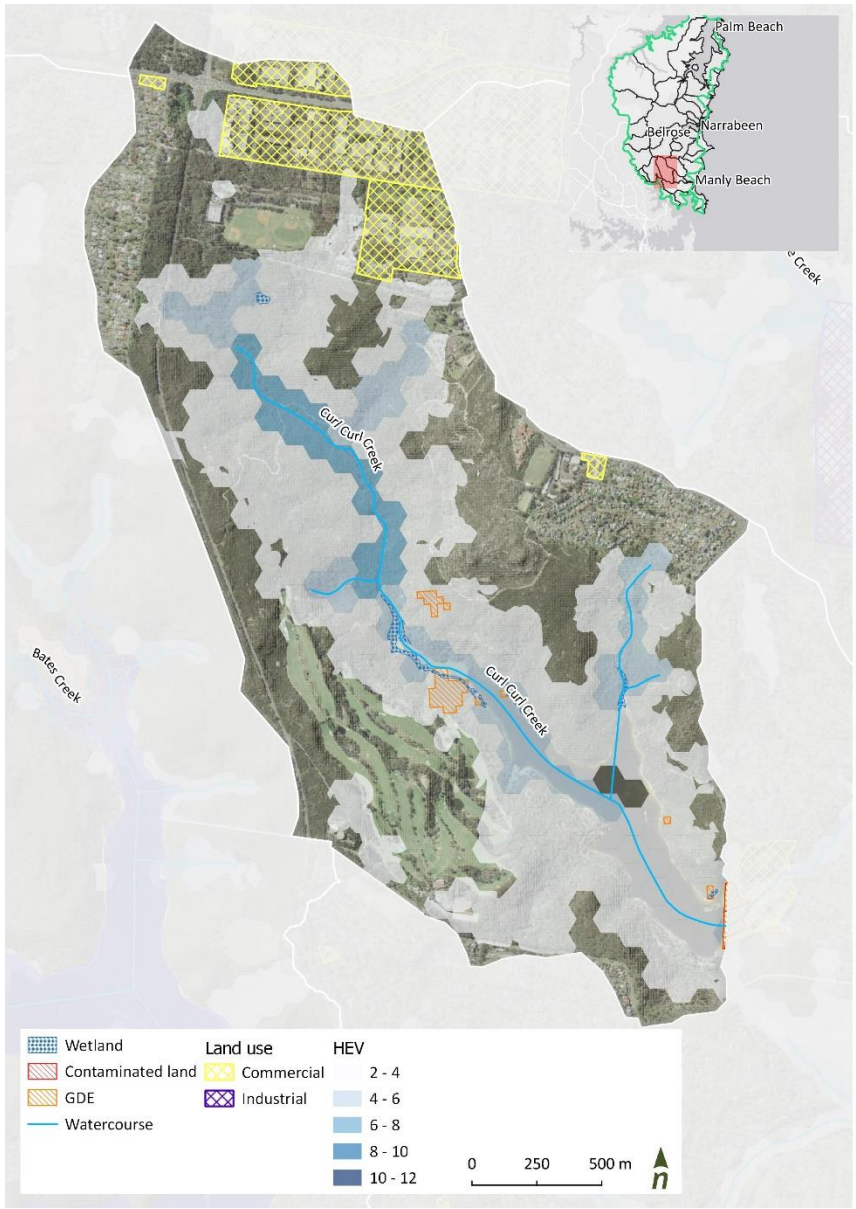

Dee Why Lagoon
Wetland
Contaminated land
GDE
Watercourse
Catchment Boundary
Land use
Commercial
Industrial
Estuarine Habitat
Saltmarsh
Planning Provisions
Centre Investigation Areas (800m R2)
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

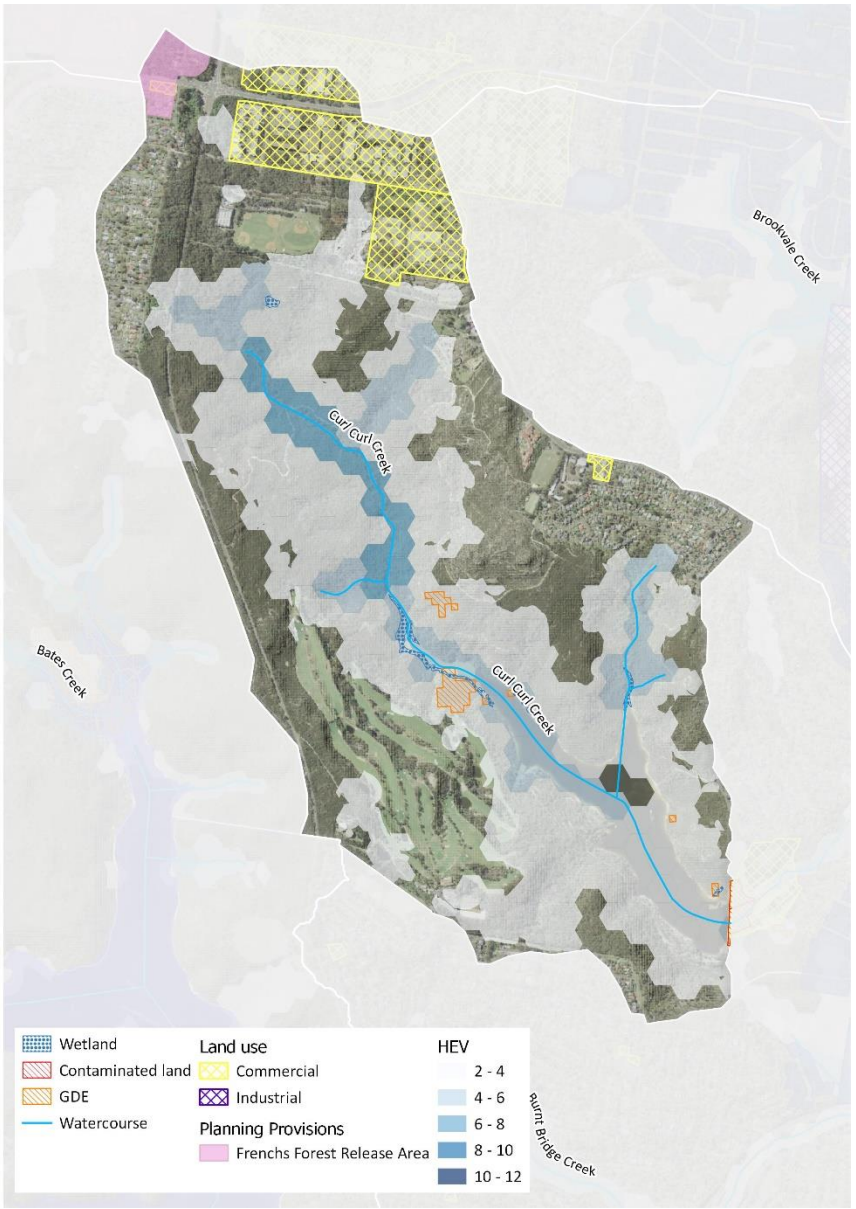
Dee Why Creek	Current fraction imperviousness: 43 % (Potential increase < 3%)	References:
Objectives and timeframe for community environmental values and uses	**Freshwater creeks**: *Improve* condition for aquatic ecosystems, visual amenity and secondary contact recreation (5-10 year timeframe). *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems. **Lagoon**: *Maintain or Improve* existing condition for aquatic ecosystems and visual amenity; *Improve* condition for secondary contact recreation (5-10 year timeframe)	Local Strategic Planning Statement (LSPS)
	Improve water quality in terms of managing inputs of sediments, nutrients and other contaminants	Dee Why Lagoon Estuary Management Plan 2004
Existing values	Dee Why Creek: • Low ecological value (bush regeneration activities) Dee Why Lagoon: • Waterbirds and small mammals • Recreational, educational, amenity • Saltmarsh	Dee Why Lagoon Estuary Management Plan 2004
Existing catchment pressures and stressors	**Dee Why Creek** • Weed infestation • Poor water quality including microbial levels • High flow velocities contributing to bank erosion and sediment deposition in D/S reaches • High levels of urbanisation • Cromer Industrial estate **Dee Why Lagoon** • Polluted runoff • Fair to good water quality (in terms of clarity and algae) • Frequent break-out assist with water quality • Infilling with sediment • Leachate from old tip sites • Weed invasion • Human impacts (sports, dredging)	Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016 Warringah Creek Management Study 2004

Conditions	Key indicators	Existing condition	Trajectory	Draft waterway objectives
1. Hydrology	Imperviousness	Expected to be highly disturbed	Stable – small change in imperviousness	**Maintain condition**
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	MER data suggest aquatic ecosystem indicators well above trigger values and macroinvertebrates diversity significantly less than that expected to be present	Stable given small increase in imperviousness.	**Improve condition**
3.Riparian vegetation	Riparian vegetation extent and quality, weed infestation	Significant weed infestation in upper reaches and wetland portions (NSW OEH, 2016)	Ongoing weed disturbance	**Improve condition**
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Upper reaches highly modified with evidence of sedimentation and channel chocked with aquatic weeds (NSW OEH, 2016) -poor geomorphic condition. - Mid reaches flow into wetland adjacent to Cromer park. - Lower reaches highly modified, low sinuosity, unconfined channel in poor geomorphic condition	Increased flows could increase erosion potential of lower reach	**Improve condition**

4.4 Curl Curl Creek



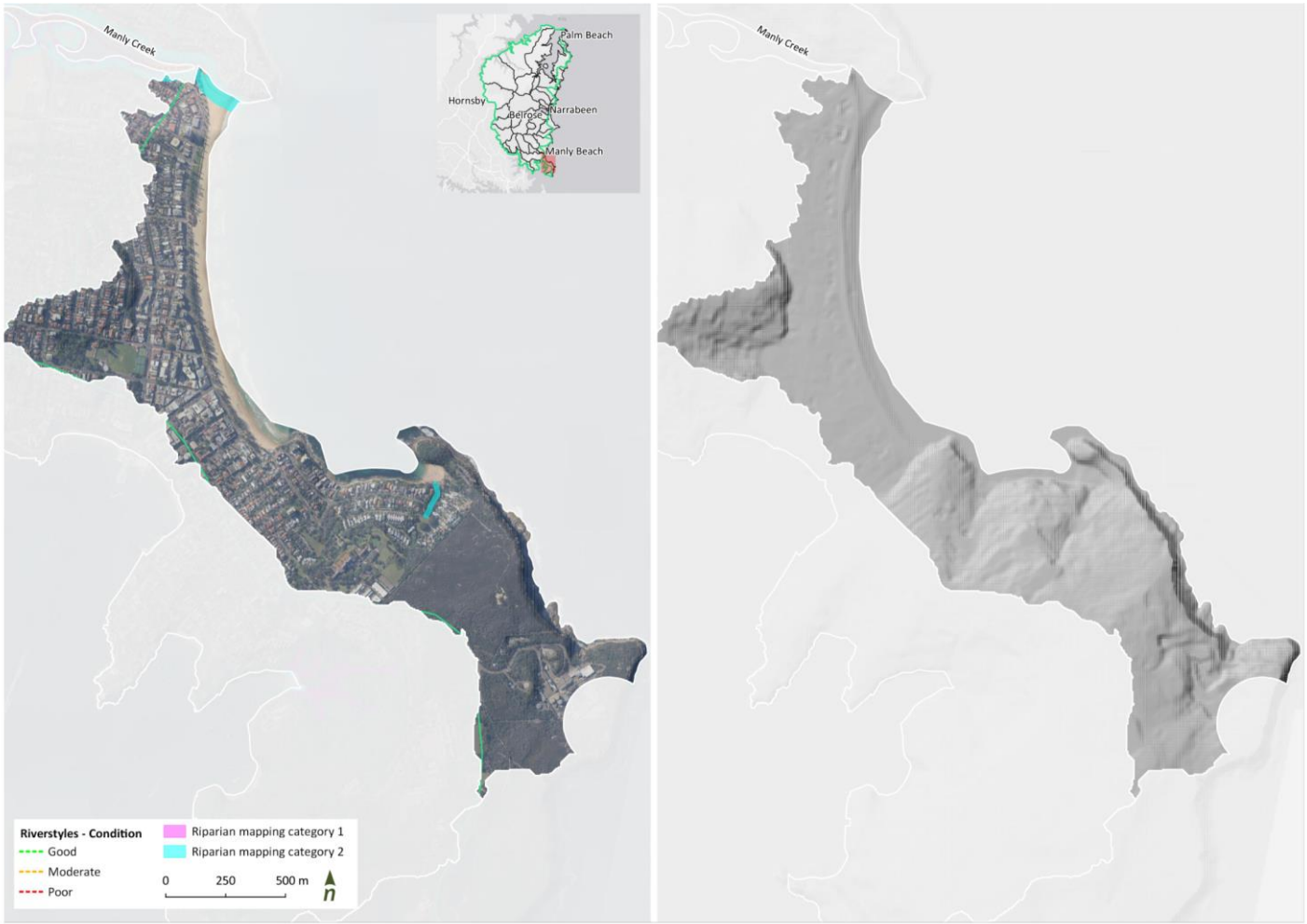

Palm Beach
Narrabeen
Belrose
Manly Beach
Curl Curl Creek
Curl Curl Creek
Bates Creek
Wetland
Contaminated land
GDE
Watercourse
Land use
Commercial
Industrial
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0
250
500 m
n

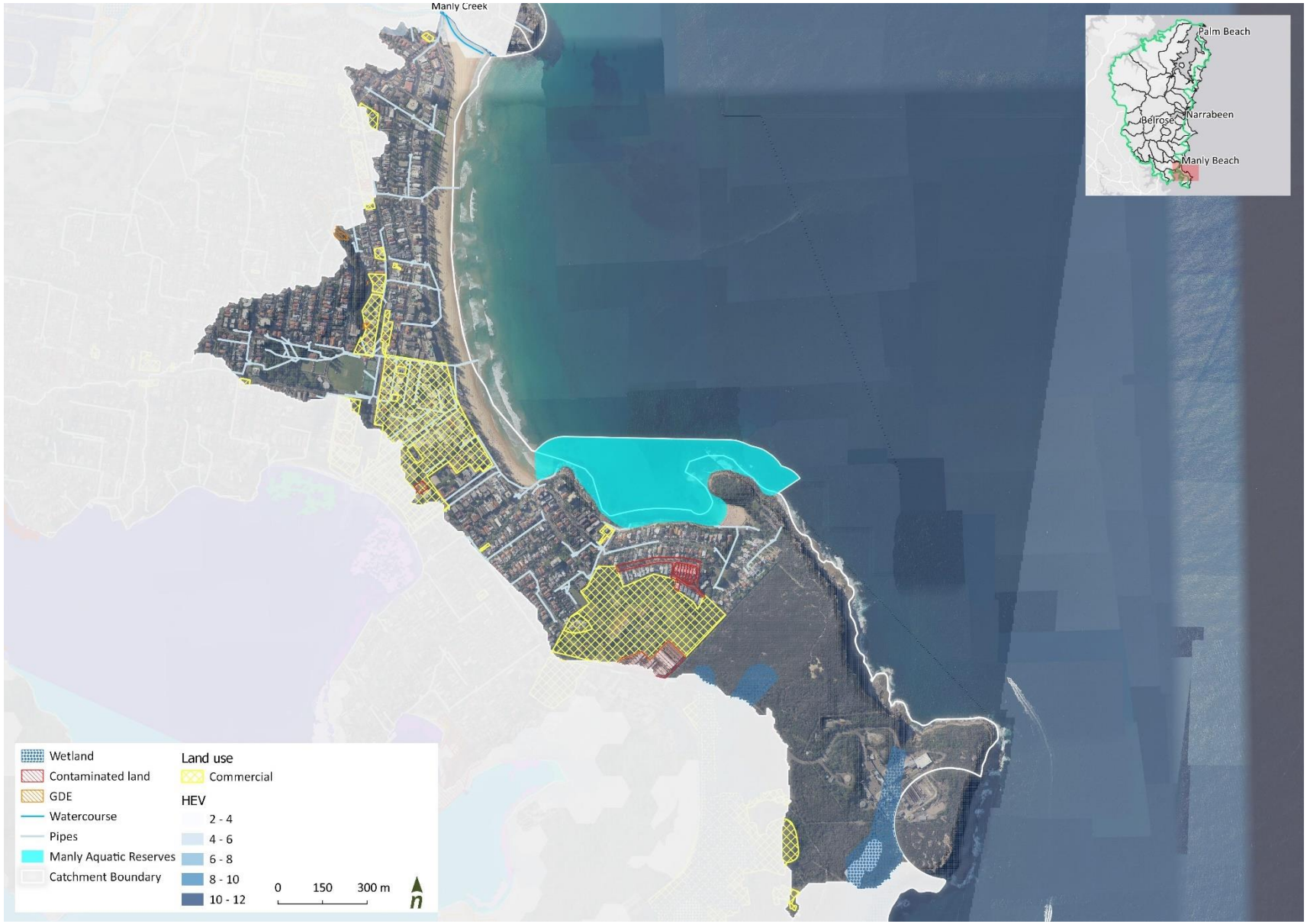

Brookvale Creek
Curl Curl Creek
Curl Curl Creek
Bates Creek
Burnt Bridge Creek
Wetland
Contaminated land
GDE
Watercourse
Land use
Commercial
Industrial
Planning Provisions
Frenchs Forest Release Area
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12

Curl Curl Creek	Current fraction imperviousness: 12 % (Potential increase <2%)			References
Objectives and timeframe for community environmental values and uses	**Freshwater creek**: *Maintain or Improve* condition for aquatic ecosystems, visual amenity and secondary contact recreation. *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems. **Dam**: *Maintain or Improve* existing condition for all environmental values and uses			Local Strategic Planning Statement (LSPS)
Existing values	• High ecological value • High recreational and scenic value • HEV score higher along main creek line upstream of dam			Monitoring Evaluating and Reporting (MER) Project 20152016
Existing catchment pressures and stressors	**Curl Curl Creek** • Poor water quality • Potentially polluted groundwater or fertiliser use resulting in high nitrogen levels • Elevated turbidity level points to soil disturbance in the catchment • Some weeds present **Manly Dam** • Wet weather increases nutrient flows to the dam which promote phytoplankton growth (e.g. in 2008). • Release of water from the dam which occurs occasionally and after major rainfall events flushes Cyanobacteria (and phytoplankton) improving water quality			Warringah Creek Management Study 2004 Manly Dam Water Quality Draft Report _1July_2010
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objectives**
1. Hydrology	Imperviousness	Expected to be slightly modified	Stable with small increase in imperviousness expected in the next 20 years	**Maintain condition**
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TP and TN above trigger value for aquatic ecosystems. NOx at or just above trigger value for aquatic ecosystems. Macroinvertebrates diversity is similar to that expected to be present	Stable with small increase in imperviousness expected in the next 20 years	**Improve condition** *noting multiple sources of pollution Address potential erosion issue in the catchment

		Elevated turbidity levels.		
3.Riparian vegetation	Riparian vegetation extent and quality, weed infestation	Riparian zone connected to good quality bushland, very few weeds and high conservation value (NSW OEH, 2016)	Stable	**Maintain condition**
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	-Upper reach (500m) highly modified urban stream -Mid to lower reaches (to Manly Dam) primarily confined by bedrock with boulders and cobbles in channel and pools, riffles and waterfalls. Good geomorphic condition	Stable	**Maintain condition**

4.5 Manly Beach

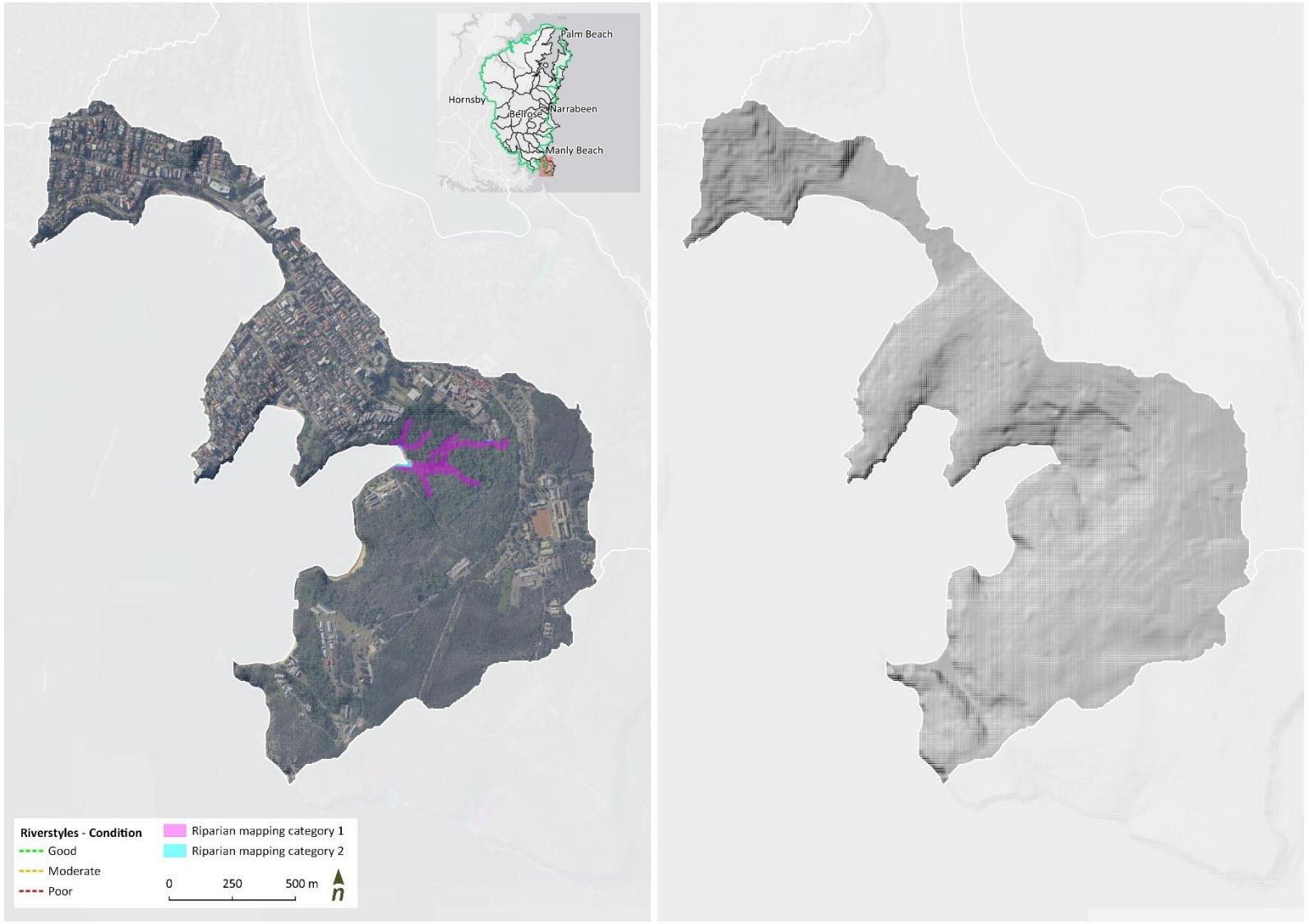


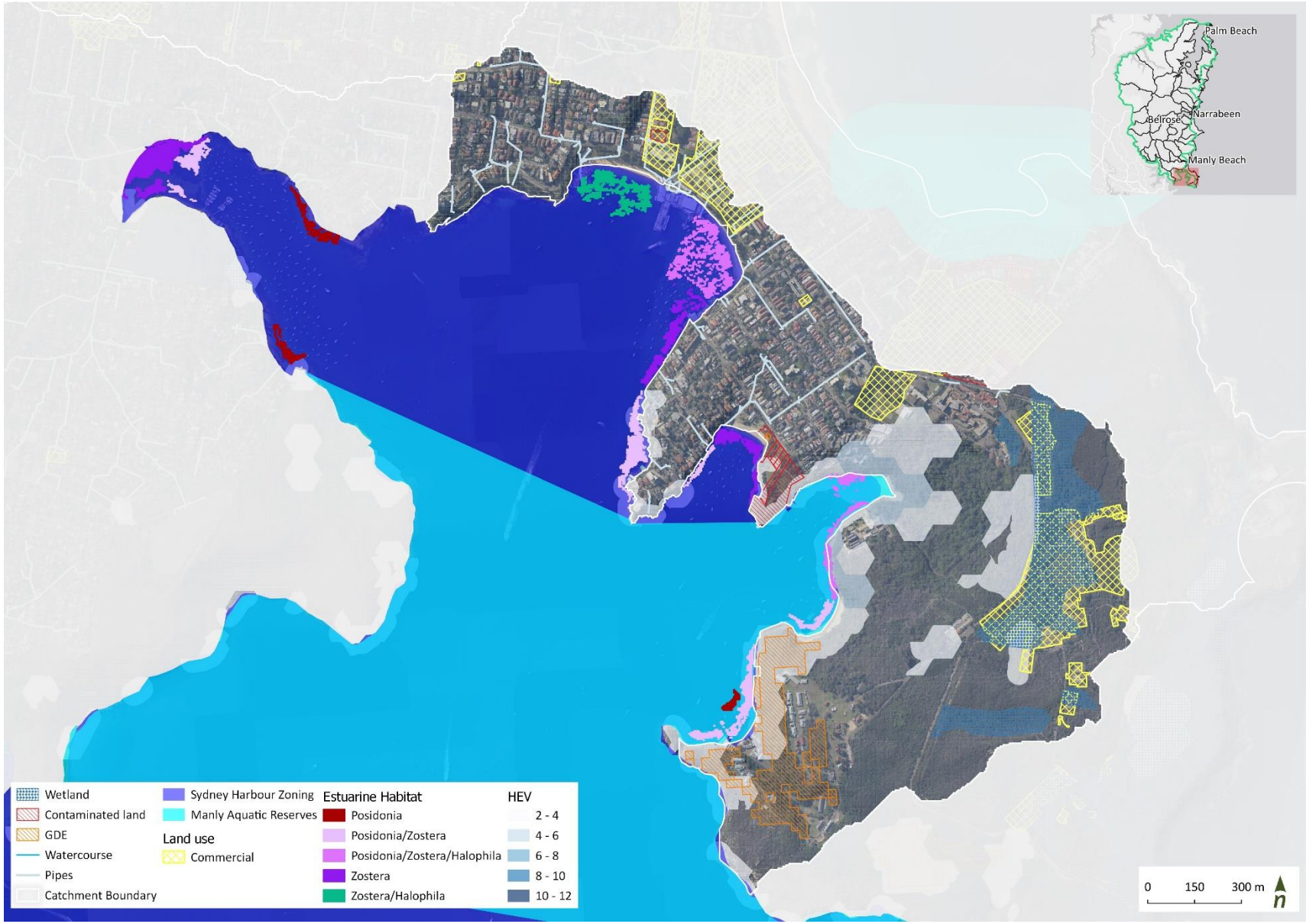

Manly Creek
Palm Beach
Belrose
Narrabeen
Manly Beach
Wetland
Contaminated land
GDE
Watercourse
Pipes
Manly Aquatic Reserves
Catchment Boundary
Land use
Commercial
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0
150
300 m
n

Manly Beach	Current fraction imperviousness: 32 % (Potential increase <2%)			References:
Objectives and timeframe for community environmental values and uses	**Ocean beaches:** *Maintain or Improve* existing condition for all environmental values and uses			Local Strategic Planning Statement (LSPS)
Existing values	High recreational value (swimming, boating and fishing) Fish, birds, seaweed, organisms within sediment, phytoplankton Aquatic reserve in proximity (kelp beds, seagrass, fish, invertebrates)			Manly Ocean Beach coastline management study 2008
Existing catchment pressures and stressors	• Beach erosion/shoreline recession (stormwater outlets, sea level rise) • Stormwater outlets impacting safety and amenity • Manly lagoon flood outlet affects amenity and water quality • Pollution from stormwater outlets and Manly Lagoon • Water quality is good during dry weather but declines following rainfall events • Faecal coliform and enterococci levels often exceed trigger values after rainfall events • High levels of urbanisation (flow rates and water quality) • Sea level rise • Beach activities (litter)			
Previously documented catchment objectives	• Ensure water quality meets the community's expectations and provides water quality suitable for swimming, boating and fishing • Manage beach erosion and shoreline recession in a manner that maintains or improves beach amenity • Ensure activities at Manly Ocean Beach are carried out in a manner that maintains or improves the ecological condition of aquatic habitats.			
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objectives**
1. Hydrology	Imperviousness	High levels of imperviousness (32%) with runoff discharged directly into ocean beach.	Stable	Reduce beach erosion at stormwater outlets
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	Faecal coliform and enterococci levels often exceed trigger values after rainfall events	Stable	**Maintain or improve condition**

3. Aquatic vegetation	Aquatic vegetation extent and quality e.g. seagrass	No data		**Maintain or improve condition**
4. Physical form	Shoreline erosion, recession, sand movement and volume	Local erosion at stormwater outlets	Stable	**Maintain or improve condition** (e.g. reduce erosion at stormwater outlets)

4.6 Manly Cove



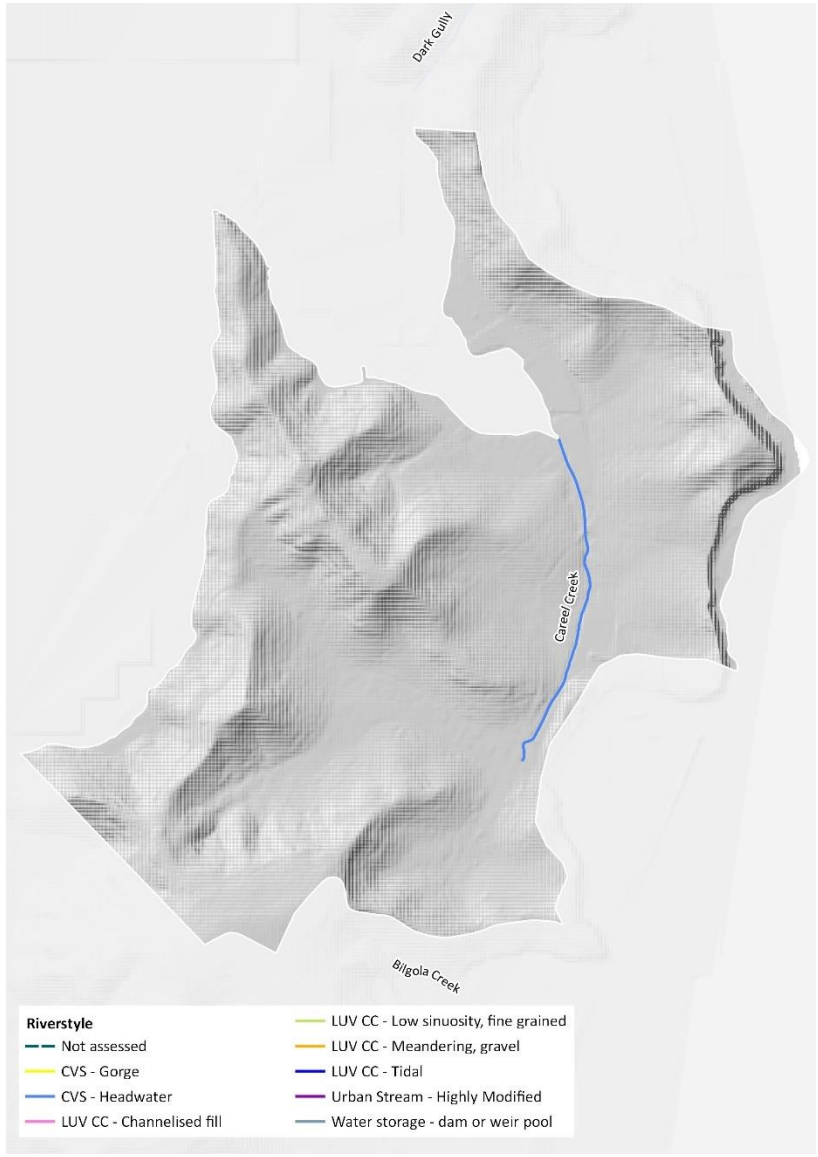

Palm Beach
Narrabeen
Belrose
Manly Beach
Wetland
Contaminated land
GDE
Watercourse
Pipes
Catchment Boundary
Sydney Harbour Zoning
Manly Aquatic Reserves
Land use
Commercial
Estuarine Habitat
Posidonia
Posidonia/Zostera
Posidonia/Zostera/Halophila
Zostera
Zostera/Halophila
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0
150
300 m
n

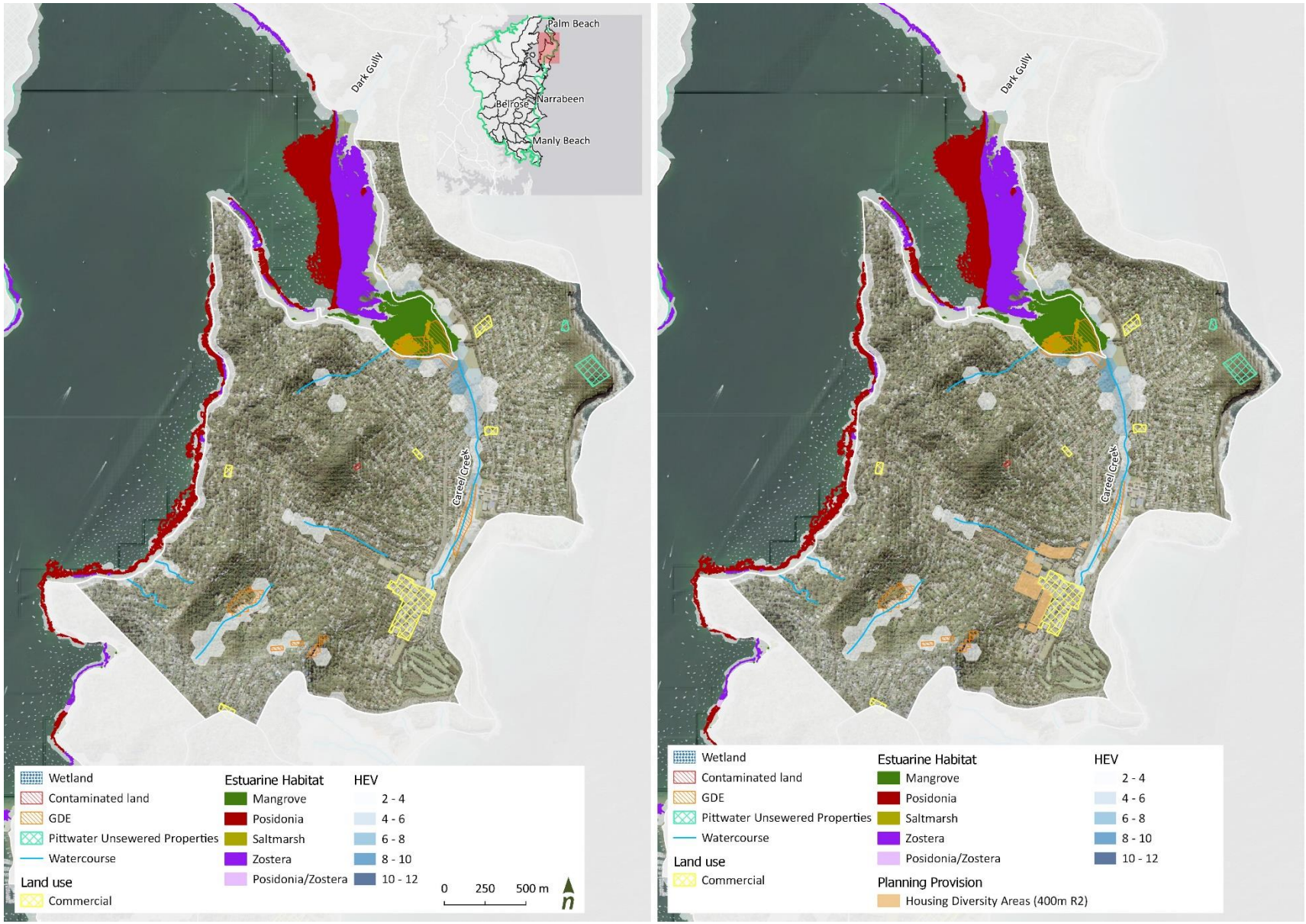
Manly Cove	**Current fraction imperviousness: 24 % (Potential increase < 2%)**	**References:**
Objectives and timeframe for community environmental values and uses	**Estuary**: *Maintain or Improve* existing condition for all environmental values and uses	Local Strategic Planning Statement (LSPS)
Existing values	Seagrass Fishing, boating, scuba diving, swimming in Middle Harbour	Middle Harbour Catchment Stormwater Management Plan July 1999 Estuary Health Assessment Clontarf Bantry Bay Final Report 2017
Existing catchment pressures and stressors	Erosion pushing seagrass from the beachfront arising from: • Boating activities/mooring • Stormwater outlets/sewerage pumping stations (quality and quantity of water) • Sediment loads from stormwater outlets Middle Harbour estuary: • Pollution from urbanised catchments. Estuary recovers 3 days after rainfall events (well flushed) • Estuary healthy based on Chlorophyll-a and turbidity sampling program • Extent of seagrass very poor. Loss of seagrass is continuing in recent years but could also be natural variation. • Direct discharge to foreshore resulting in nutrient loading and fast flows resulting in weeds and erosion at localised sites • High levels of urbanisation (flow and water quality, direct discharges) • Activities (boating/mooring)	
Previously documented catchment objectives	• Preserve sea grass bed	

Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objectives**
1. Hydrology	Imperviousness	High levels of imperviousness (24%) with runoff discharged directly into ocean beach.	Stable with small increase in imperviousness	Reduce beach erosion at stormwater outlets

2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	Direct discharge to foreshore resulting in nutrient loading and fast flows resulting in weeds and erosion at localised sites Estuary is healthy based on Chlorophyll-a and turbidity monitoring program. Estuary recovers from catchment pollution 3 days after rainfall events.	Stable with small increase in imperviousness	**Maintain or improve condition** (e.g. reduce litter, sediment loads, nutrient loads and weeds in order to protect sea grass in proximity of outlets).
3. Aquatic vegetation	Aquatic vegetation extent and quality e.g. seagrass	Extent of seagrass very poor	Seagrass declining or stable noting that observed decline in recent years may be natural variation	**Maintain or improve condition**
4. Physical form	Shoreline erosion, recession, sand movement and volume	Local erosion at stormwater outlets	Stable	**Maintain or improve condition** (e.g. reduce erosion at stormwater outlets)

4.7 Careel Creek




Palm Beach
Narrabeen
Belrose
Manly Beach
Dark Gully
Careel Creek
Wetland
Contaminated land
GDE
Pittwater Unsewered Properties
Watercourse
Land use
Commercial
Estuarine Habitat
Mangrove
Posidonia
Saltmarsh
Zostera
Posidonia/Zostera
HEV
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
0 250 500 m
Planning Provision
Housing Diversity Areas (400m R2)

Careel Creek	**Current fraction imperviousness: 25 % (Potential increase < 4%)**	
Objectives and timeframe for community environmental values and uses	**Freshwater creeks:** *Maintain or Improve* existing condition for visual amenity; *Improve* condition for aquatic ecosystems and secondary contact recreation (5-10 year timeframe); *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems. **Estuary (Careel Bay)**: *Maintain or Improve* existing condition for all environmental values and uses	Local Strategic Planning Statement (LSPS)
Existing values	**Careel Creek** • Substantially modified – large concrete channel • Low riparian vegetation along channel. Weeds present. • Endangered Ecological communities closer to Careel Bay **Careel Bay** • Wetland habitats (mangrove forest, saltmarsh, mudflats, seagrass beds) • Saltmarsh has decreased significantly since 1946 • Mangroves have spread over the saltmarsh	**References:** BMT-WBM Careel Creek Issues Paper Final - December 2010 FINAL REPORT Urban Sedimentation and Pollution Audit in the Pittwater Estuary - Environmental Investigation Report - AWC Consulting Sept 2012
Existing catchment pressures and stressors	**Careel Creek** • High volume of runoff and poor water quality • Gross pollutant/litter loads. Decaying organic matter source of odour • High tidal flow – flow can leave channel easily • High nutrient levels (decomposition of litter, stormwater input, sewer overflow) • Flooding (open channel has capacity up to 20% AEP) • Nutrient loads promoting weeds along creek line. Creek in turn contributing weeds to saltmarsh • High levels of urbanisation • Septic seepage **Careel Bay** • Poorly flushed bay. Stormwater inputs takes time to dissipate • Sewer overflows and stormwater inputs enhancing presence of mangroves • Sedimentation over saltmarsh enhances establishment of mangroves • Sediments are contaminated from boating, light industry and domestic activities • Faecal coliforms sometimes high especially in dry weather (septic seepage?) • Bike tracks affecting salt marsh area	
Previously documented catchment objectives	• Preserve sea grass bed	

Conditions	Key indicators	Existing condition	Trajectory	Draft waterway objectives
1. Hydrology	Imperviousness	Expected to be moderately to highly modified	Stable given small increase in imperviousness	**Improve condition** e.g. reduce runoff volume and flow rates to reduce flooding
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TP and TN expected to be above trigger value for aquatic ecosystems. Macroinvertebrates diversity likely to be less that expected to be present Microbial level expected to be above trigger values for secondary recreation.	Stable	**Improve condition**
3.Riparian vegetation	Riparian vegetation extent and quality	Very poor riparian condition upstream of Barrenjoey Road. Forested into estuarine wetlands in lower reaches - condition unknown	Stable	**Improve condition**
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Highly modified urban stream in upper and mid reaches (constructed concrete drain). Moderate geomorphic condition	Stable	**Improve condition where possible**

5 Estuary health risk

To understand the impact of land use on Narrabeen Lagoon Dee Why Lagoon, Curl Curl Lagoon and Manly Lagoon, EES developed an Estuary Health Risk map following the methods outlined in Dela-Cruz et al., 2019. The map identifies which sub-catchment pose the greatest risks of impacts on the health of estuaries to inform strategic priorities for managing nutrient and sediment runoff so that estuary health is protected, maintained and/or improved.

The data consists of likelihood scores, consequence scores and risk scores at a sub-catchment scale (see Table 10 and Table 11). Likelihood scores represent the extent and intensity of land-use pressure from each sub-catchment, with a score of 1 indicating the lowest likelihood of impact and a score of 4 the highest likelihood of impact on estuary health. Consequence scores represent the extent of impact on estuary health, with a score of 1 indicating the lowest chance of impact and a score of 4 indicating the highest chance of impact. Risk is a product of the likelihood and consequence scores (i.e. likelihood x consequence = risk), with a maximum score of 16 indicating the greatest risk and a score of 1 indicating the lowest risk.

The dataset is available for sub-catchments contributing to Narrabeen Lagoon, Dee Why Lagoon, Curl Curl Lagoon and Manly Lagoon (Figure 4).

Findings

Sub-catchments with the highest risk of impact on the lagoons can be interpreted as those with risk scores greater than 4 and those with the lowest risk of impact are those with risk scores ≤ 4. The risk scores show that the developed sub-catchments (i.e. existing urban areas) generally pose higher risk to the health of the estuaries (Narrabeen Lagoon, Dee Why Lagoon, Curl Curl Lagoon and Manly Lagoon) with risk scores generally > 4. This aligns with the findings for freshwater creeks (section 4 and Appendix A). For instance, the risk score for developed sub-catchments contributing to Manly Dam (or Curl Curl Creek) are > 4 whist the undeveloped sub-catchments contributing to Manly Dam are ≤ 4.

The risk scores also indicate areas which pose relatively higher risk to the health of the estuaries than others. For instance in the Narrabeen Lagoon catchment, the existing urban areas contributing to Middle Creek and South Creek pose a higher risk than existing urban areas contributing to Nareen Creek and Mullet Creek. Another observation is that the risk score for the sub-catchments covering the future Ingleside Growth Area has a maximum score of 16.

To integrate these results with the freshwater creek assessment in section 4 and Appendix A, the risk scores were categorised into two groups to correspond with a maintain or improve management objective:

- Maintain management objective – assigned to risk scores ≤ 4, and where nutrient and sediment loads to the lagoon should not exceed existing loads
- Improve management objective – assigned to risk scores > 4, and where nutrient and sediment loads to the lagoon should be reduced (i.e. less than existing loads).

The risk scores suggest that a suitable stormwater management strategy should aim to reduce nutrient and sediment loads from developed sub-catchments (i.e. existing urban areas). Priority can be placed on sub-catchments which pose a higher risk to the health of the estuaries.

Table 10. Likelihood scores define the chance that runoff from a sub-catchment will have an impact on the health of an estuary*

LIKELIHOOD	SCORE	DESCRIPTION
High	4	Health of estuaries has a high chance of impact from the sub-catchment because the per hectare surface flows, and TN, TP and TSS loads from a sub-catchment are large. Large inputs are those in the >75th percentile.
Moderate	3	Health of estuaries has a moderate chance of impact from the sub-catchment because the per hectare surface flows, and TN, TP and TSS loads from a sub-catchment are moderate. Moderate inputs are those in the >50th and ≤75th percentile.
Low	2	Health of estuaries has a low chance of impact from the sub-catchment because the per hectare surface flows, and TN, TP and TSS loads from a sub-catchment are relatively low. Low inputs are those in the ≥25th and <50th percentile.
Very Low	1	Health of estuaries has a very low chance of impact from the sub-catchment because the per hectare surface flows, and TN, TP and TSS loads from a sub-catchment are very low. Very low inputs are those in the <25th percentile.

*Adapted from Dela-Cruz et al., 2019

Table 11. Consequence scores define the magnitude of impact on the health of an estuary*

CONSEQUENCE	SCORE	DESCRIPTION
High	4	Impacts on the health of an estuary are high because the residence time, base exceedance, the extent of potential impact and the extent of high ecological value assets are in the >75th percentile.
Moderate	3	Impacts on the health of an estuary are moderate because the residence time, base exceedance, the extent of potential impact and the extent of high ecological value assets are in the >50th and ≤75th percentile.
Low	2	Impacts on the health of an estuary are low because the residence time, base exceedance, the extent of potential impact and the extent of high ecological value assets are in the >25th and ≤50th percentile.
Very Low	1	Impacts on the health of an estuary are very low because the residence time, base exceedance, the extent of potential impact and the extent of high ecological value assets are in the ≤25th percentile.

*Adapted from Dela-Cruz et al., 2019

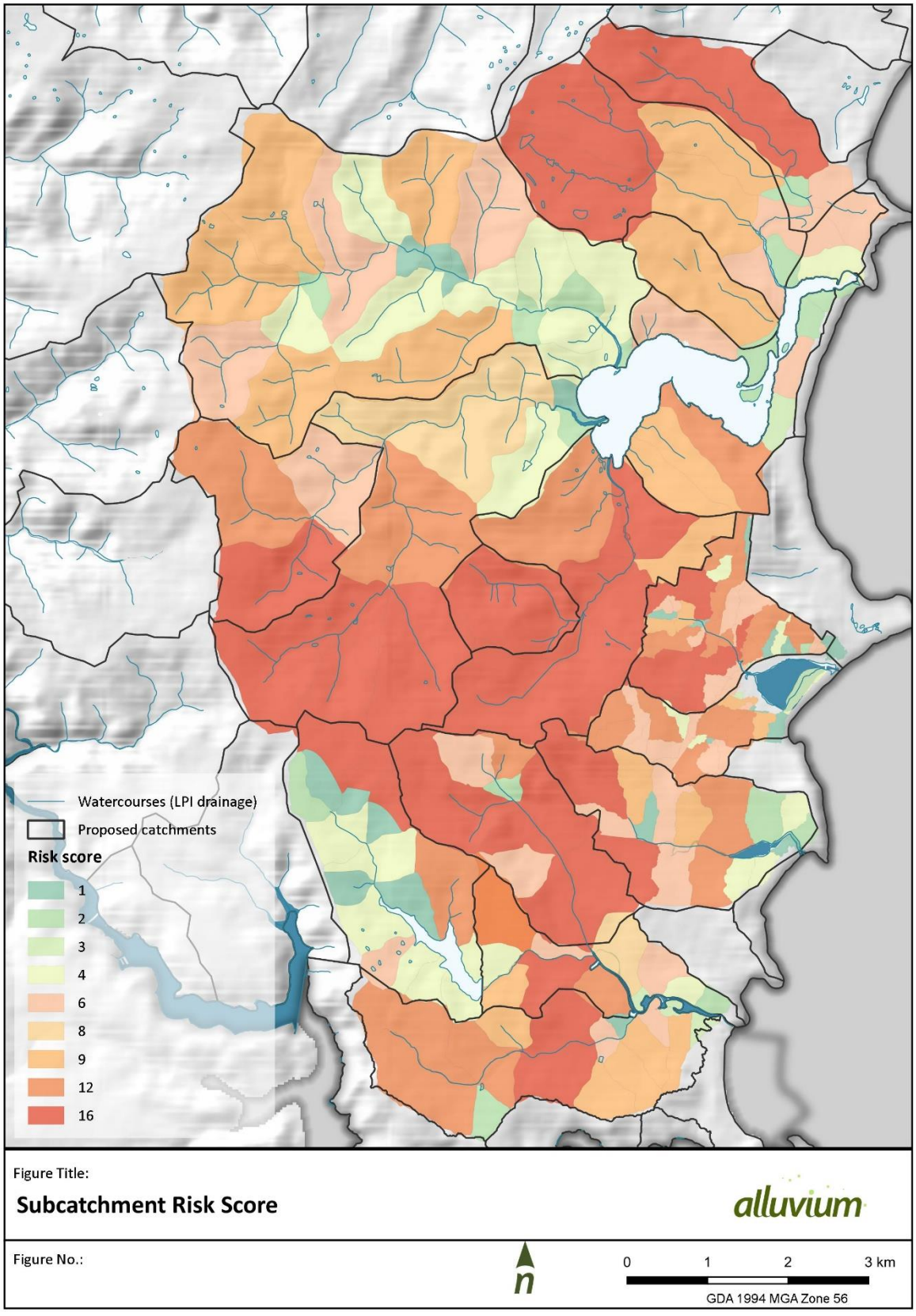


Figure 4. *Map ranking sub-catchment based on their relative risk of impact (risk score 1-16) on the ecological health of Narrabeen Lagoon, Dee Why Lagoon, Curl Curl Lagoon and Manly Lagoon (derived from Dela-Cruz, 2019).*

6 Stormwater Management Strategy and Targets

Based on the assessment of land use impact on freshwater creeks and lagoons in the Northern Beaches LGA, a Stormwater Management Strategy has been defined outlining stormwater management quantity and quality targets for each catchment (Figure 5, Table 12 and Table 13). The strategy addresses the risks of impacts to freshwater creeks and lagoons and is in line with the objectives and timeframe for community environmental values and uses as outlined in the LSPS. Targets have been identified for four catchment groups. Additional investigation is required to quantify the stormwater quantity and quality targets.

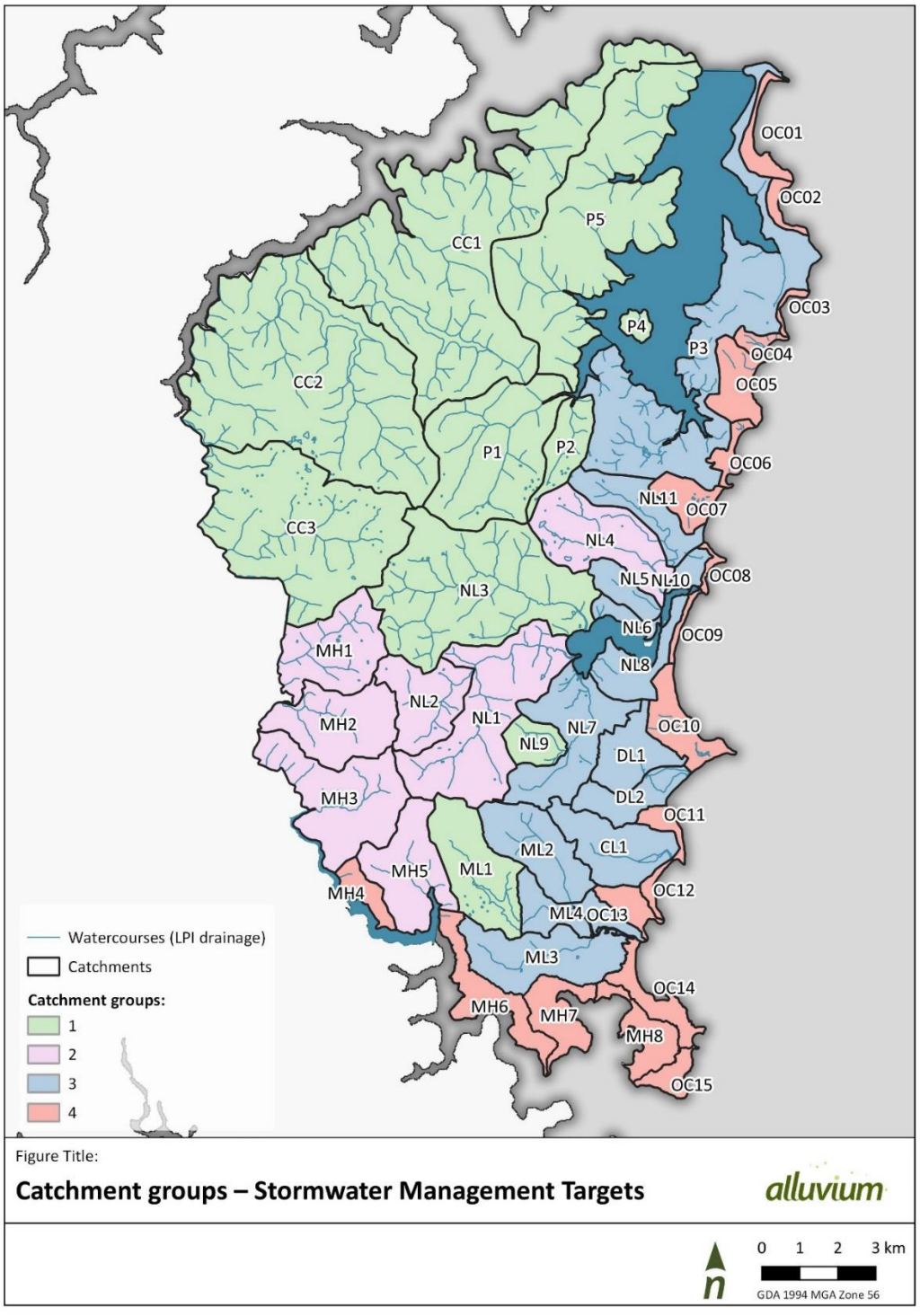


Figure 5. *Catchment groups in terms of stormwater management targets*

Table 12. Stormwater management strategy and targets

Group	Description	Catchments	Stormwater quantity target	Stormwater quality target
1	Creeks in National Park in catchments with very low existing imperviousness and low development pressure in the future OR creeks with high ecological value but slightly disturbed in catchments with existing imperviousness approximately 10% or lower with development pressure in the next 20 years likely to push imperviousness closer to or above 10%.	Smiths Creek, Coal and Candle Creek, and Salvation creek. McCarrs Creek, Cicada Glen Creek, Deep Creek, Wheelers Creek, Kierans Creek, Curl Curl Creek	Avoid impact to existing hydrological regime (e.g. to meet environmental flow targets or to avoid additional erosion)	Avoid increase in amount of stormwater pollution entering creek (compared to existing loads)
2	Creeks that are at the point where any increase in flows or pollutants from the catchment could result in significant deterioration OR creeks with highly disturbed reaches in urban and rural areas in catchments with existing imperviousness of 10-25% where an increase in flows or pollutants can further degrade downstream reaches and values.	Bare Creek, Frenchs Creek, Carroll Creek, Bates Creek, Middle Creek, Oxford Creek, Mullet Creek	Avoid impact to existing hydrological regime (e.g. to meet environmental flow targets or to avoid additional erosion)	**Existing urban areas**: Reduce amount of stormwater pollution entering creek (compared to existing loads) **Areas proposed for greenfield development**: Avoid increase in amount of stormwater pollution entering creek (compared to existing loads)
3	Creeks that are highly disturbed and in need of rehabilitation in catchments with existing imperviousness > 30 %.	Careel Creek, Cahill Creek, Brookvale Creek, Narrabeen Creek, Burnt Bridge Creek, Manly Creek, Greendale Creek, Dee Why Creek, and other southern catchment (unnamed) contributing to Dee Why Lagoon, Nareen Creek, South Creek, catchments NL6, NL8 and NL10.	Avoid or minimise impact to existing hydrological regime (e.g. to avoid additional erosion)	Reduce amount of stormwater pollution entering creek (compared to existing loads)
4	Catchments discharging directly into well flushed permanently open estuary or to the ocean	Catchments MH4, MH6, MH7 and MH8 and catchments OC1 to OC15		Reduce amount of stormwater pollution entering estuary or ocean (compared to existing loads focusing on litter and coarse sediments)

Table 13. Detailed summary

ID	Name	Ex. Imp (%)	↑ Imp (%)	Group	Draft waterway objectives				Stormwater management targets	
					Hydrology	Water quality	Riparian or aquatic Vegetation	Physical form	Quantity	Quality
CC1	Coal and Candle Creek	1%	<2%	1	Maintain	Maintain	Maintain	Maintain	Avoid impact to existing hydrological regime (e.g. to meet environmental flow targets or to avoid additional erosion)	Avoid increase in amount of stormwater pollution entering creek (compared to existing loads)
CC2	Smiths Creek	1%	<2%	1	Maintain	Maintain	Maintain	Maintain		
P4	Unnamed	18%	<2%	1	Maintain	Maintain	Maintain	Maintain		
P5	Salvation Creek	1%	<2%	1	Maintain	Maintain	Maintain	Maintain		
CC3	Kierans Creek	8%	<2%	1	Maintain	Improve (* note multiple sources)	Improve degraded reaches	Improve U/S where possible, otherwise maintain		
ML1	Curl Curl Creek	12%	<2%	1	Maintain	Improve (multiple sources)	Maintain	Maintain		
NL3	Deep Creek	3%	7%	1	Maintain	Improve in degraded reaches otherwise maintain	Maintain	Maintain		
NL9	Wheelers Creek	6%	>10 %	1	Maintain		Maintain	Maintain Improve D/S		
P1	McCarrs Creek	4%	>10 %	1	Maintain		Maintain	Maintain		
P2	Cicada Glen Creek	7%	>10 %	1	Maintain		Maintain	Maintain		

ID	Name	Ex. Imp (%)	↑ Imp (%)	Group	Draft waterway objectives				Stormwater management targets	
					Hydrology	Water quality	Riparian or aquatic Vegetation	Physical form	Quantity	Quality
MH1	Bare Creek	7%	>10 %	2	Maintain	Improve	Improve urban reaches	Improve urban reaches	Avoid impact to existing hydrological regime (e.g. to meet environmental flow targets or to avoid additional erosion)	**Existing urban areas**: Reduce amount of stormwater pollution entering creek (compared to existing loads) **Areas proposed for greenfield development**: Avoid increase in amount of stormwater pollution entering creek (compared to existing loads)
MH2	Frenchs Creek	24%	7%	2	Maintain	Improve	Improve urban reaches	Improve urban reaches		
MH3	Carroll Creek	24%	3%	2	Maintain	Improve	Improve urban reaches	Improve urban reaches		
MH5	Bates Creek	21%	3%	2	Maintain	Improve	Improve	Improve		
NL1	Middle Creek	17%	>10 %	2	Maintain	Improve	Improve	Improve		
NL2	Oxford Creek	14%	>10 %	2	Maintain	Improve	Maintain	Maintain		
NL4	Mullet Creek	20%	>10 %	2	Improve	Improve	Improve	Improve		

ID	Name	Ex. Imp (%)	↑ Imp (%)	Group	Draft waterway objectives				Stormwater management targets	
					Hydrology	Water quality	Riparian or aquatic Vegetation	Physical form	Quantity	Quality
CL1	Greendale Creek	42%	2%	3		Improve	Improve	Improve	Avoid or minimise impact to existing hydrological regime (e.g. to avoid additional erosion)	Reduce amount of stormwater pollution entering creek (compared to existing loads)
DL1	Dee Why Creek	43%	2%	3		Improve	Improve	Improve		
DL2	Unnamed	35%	4%	3		Improve	Improve	Improve		
ML2	Brookvale Creek	40%	6%			Improve	Maintain U/S Improve D/S	Maintain U/S Improve D/S		
ML3	Burnt Bridge Creek	44%	2%	3		Improve	Improve	Improve		
ML4	Manly Creek	38%	4%	3		Improve	Improve	Improve		
NL10	Unnamed	29%	<2%	3		Improve	Improve	Improve		
NL5	Nareen Creek	38%	<2%	3		Improve	Improve	Improve		
NL6	Unnamed	33%	<2%	3		Improve	Improve	Improve		
NL7	South Creek	32%	9%	3		Improve	Improve	Improve		
NL8	Unnamed	39%	<2%	3		Improve	Improve	Improve		
P3	Careel and Cahill creek	28%	4%	3		Improve	Improve	Improve		
NL11	Narrabeen Creek	31%	>10 %	3		Improve	Improve	Improve		

ID	Name	Ex. Imp (%)	↑ Imp (%)	Group	Draft waterway objectives				Stormwater management targets	
					Hydrology	Water quality	Riparian or aquatic Vegetation	Physical form	Quantity	Quality
MH4	Unnamed	26%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
MH6	Unnamed	34%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
MH7	Multiple Beaches	34%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
MH8	Multiple Beaches	24%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC01	North Palm Beach	25%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC02	Whale Beach	27%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC03	Avalon Beach	19%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC04	Bilgola Beach	27%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC05	Newport Beach	38%	2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC06	Bungan Beach	26%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC07	Mona Vale Beach	29%	4%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC08	Turimetta Beach	4%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC09	Narrabeen Beach	10%	3%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC10	Collaroy Beach	31%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC11	Unnamed	42%	2%	4		Maintain or improve	Maintain or improve	Maintain or improve		

Reduce amount of stormwater pollution entering estuary or ocean (compared to existing loads focusing on litter and coarse sediments)

ID	Name	Ex. Imp (%)	↑ Imp (%)	Group	Draft waterway objectives				Stormwater management targets	
					Hydrology	Water quality	Riparian or aquatic Vegetation	Physical form	Quantity	Quality
OC12	Curl Curl Beach	29%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC13	Freshwater Beach	45%	5%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC14	Multiple Beaches	32%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		
OC15	Unnamed	2%	<2%	4		Maintain or improve	Maintain or improve	Maintain or improve		

7 Summary and next steps

The objective of this project was to develop a Stormwater Management Strategy and qualitative targets for stormwater quality and quantity for each catchment in the LGA in order to inform the Northern Beaches Council's Local Environmental Plans (LEP). The Risk-Based Framework was adopted as the approach at it provides a clear line of sight between Stormwater Management Strategy and targets, waterway objectives and the community environmental values and uses of the waterways.

Draft waterway objectives were established for this project to assist in the development of the Stormwater Management Strategy and targets. Waterway objectives were established for four waterway conditions: hydrology, water quality, riparian vegetation and physical form. It is important to note that the waterway objectives for this study are in *draft form* as they have been established using limited recent local data and limited consultation. For a significant proportion of catchments data has been limited to remotely sensed data (not ground-truthed).

We undertook an assessment of land use impact on freshwater creeks and lagoons in the Northern Beaches LGA. The assessment was based on previous studies – in particular the Creek Management Study Warringah Council (MWH Australia Pty Ltd, 2004) and the Creek Monitoring, Evaluating and Reporting Project Spring 2015 and Autumn 2016 (NSW OEH, not dated) – as well as the Estuary Health Risk dataset by DPIE-EES (Dela-Cruz et al., 2019). Based on our understanding of land use impact on the waterways and the draft waterway objectives, a Stormwater Management Strategy was defined outlining stormwater management quantity and quality targets for each catchment with Northern Beaches LGA.

Based on the findings of this investigation, we recommend the following next steps for Northern Beaches Council:

- Develop waterway flow objectives to inform stormwater quantity (flow) targets that achieve the community environmental values and uses of the waterways.
- Improve knowledge including data collection on waterway:
    - Hydrology (e.g. flow studies to confirm waterway flow objectives)
    - Water quality including macroinvertebrates diversity
    - Physical form (e.g. field surveys to determine extent of erosion and to determine reaches where there is an erosion risk).
- Undertake additional consultation with Northern Beaches Council stakeholders and field verification to confirm the draft waterway objectives in this report. The initial focus can be on catchments with higher existing and anticipated future pressures.
- Complete the remaining steps (steps 4 and 5) of the Risk-Based Framework to assess effectiveness and cost-benefit analysis (feasibility) of stormwater management approaches/responses to achieve the proposed stormwater management strategy in this report
- Quantify stormwater management quality and quality targets for each catchment. These targets can form requirements to be met by developers.
- Begin a program of Council-funded stormwater quality improvement works in existing urban areas to improve condition of urban waterway reaches which also serves to protect downstream reaches and other receiving environments.
- Undertake additional consultation with Northern Beaches Council stakeholders and external stakeholders such as the community to prioritise catchments for Council-funded works for improving stormwater condition from existing urban areas.

8 References

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Hyder Consulting, 2008. 'Mullet Creek Rehabilitation Plan'. Prepared for Pittwater Council

NSW OEH, 2016. 'Northern Beaches Council Creek Monitoring Evaluating and Reporting Project'. Prepared for Northern Beaches Council.

Pietsch, T. 2018, *'Middle Creek Sediment Study – Middle Creek Floodplain sediment characterisation'.* Griffith University and NSW Soil Conservation.

Creek Management Study Warringah Council (MWH Australia Pty Ltd, 2004)

Northern Beaches Council Creek Monitoring, Evaluating and Reporting Project Spring 2015 and Autumn 2016 (NSW OEH, undated).

Mullet Creek Water Quality Monitoring Program and Design, Bio-analysis, 2010

Appendix A
Remaining catchment summaries

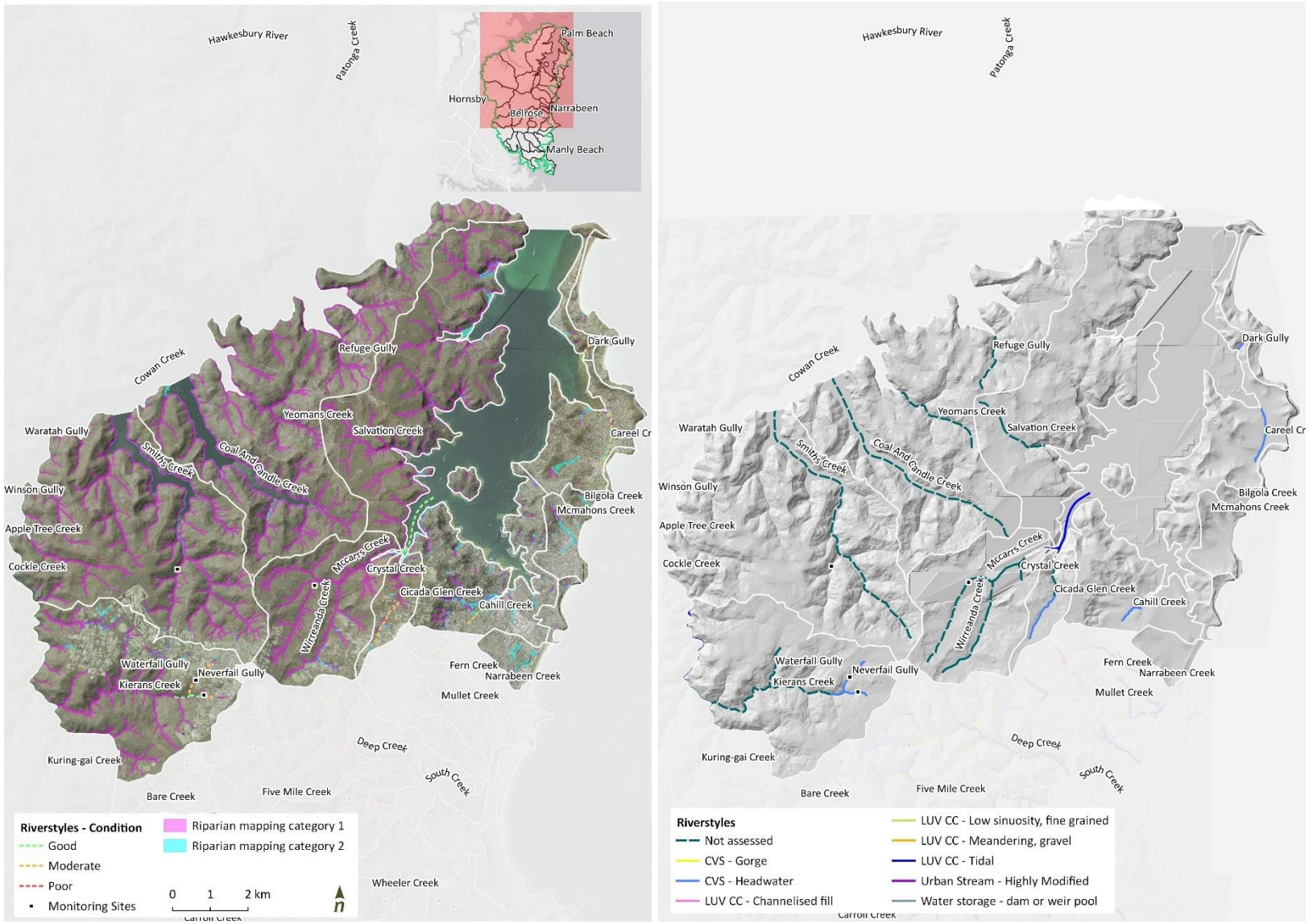

Figure 6. *Zone 1 waterway geomorphic type and condition*

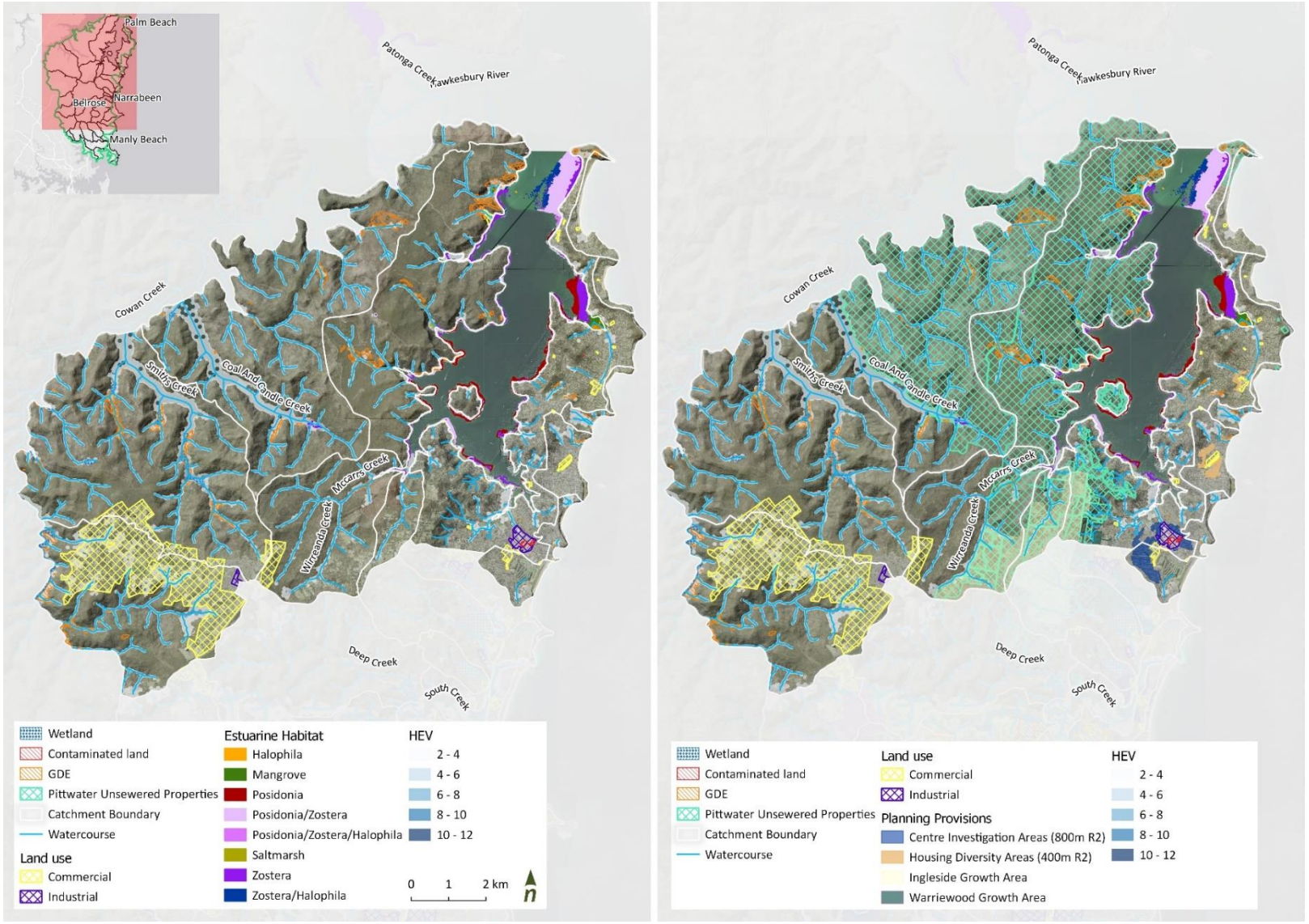

Figure 7. *Zone 1 Land use, High Ecological Values, and Planning Provisions*

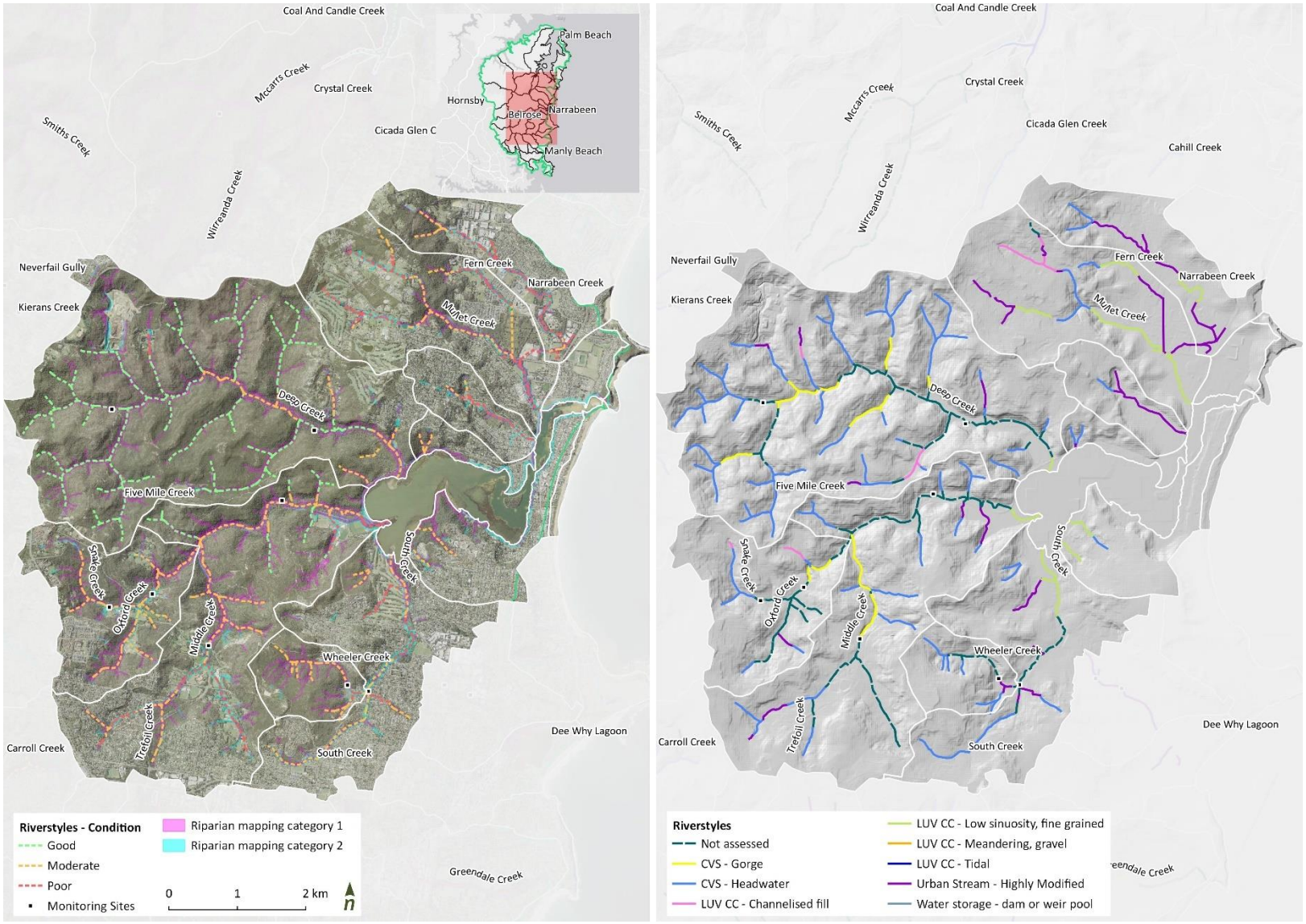

Figure 8. *Zone 2 waterway geomorphic type and condition*

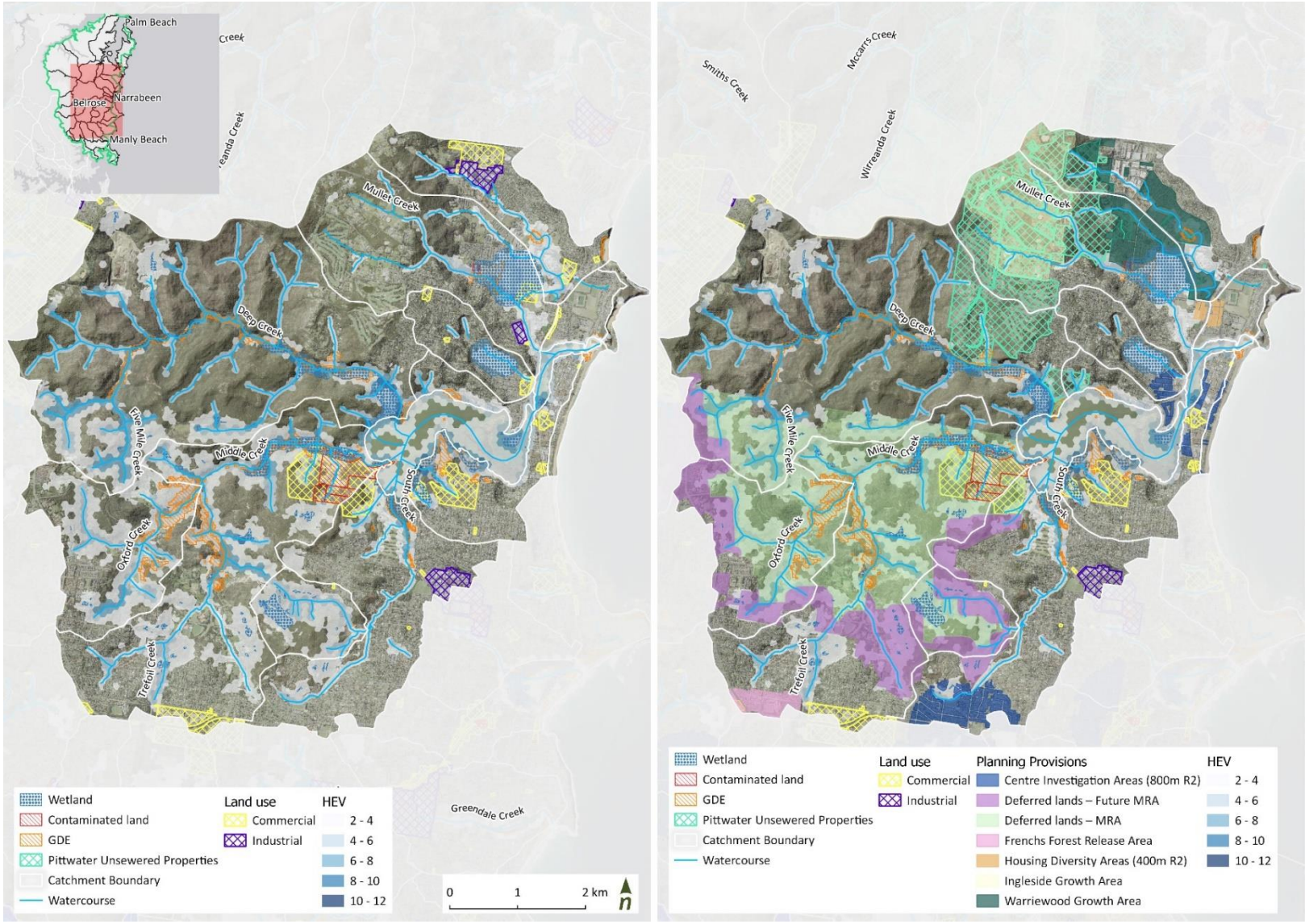

Figure 9. *Zone 2 Land use, High Ecological Values, and Planning Provisions*

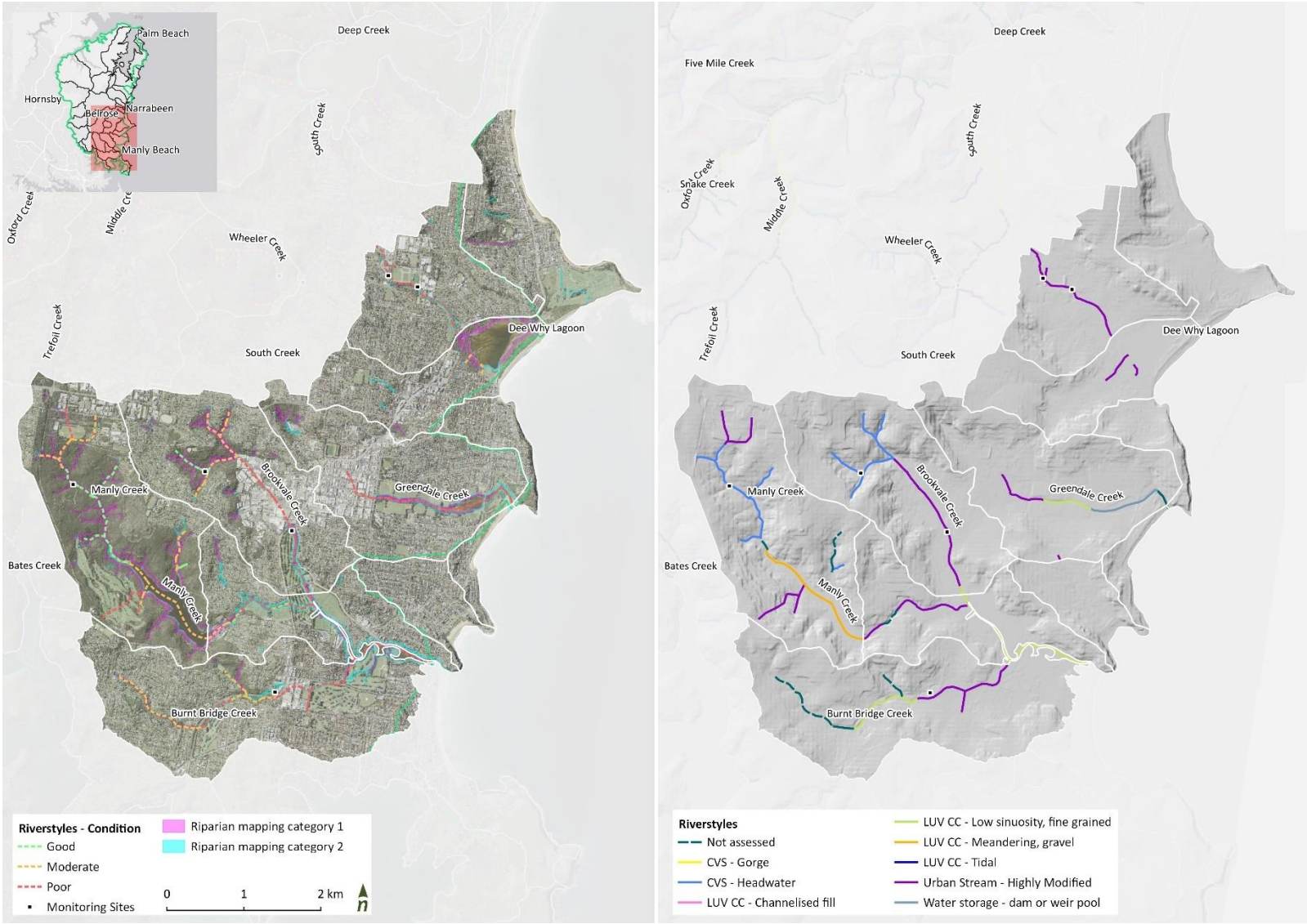

Figure 10. *Zone 3 waterway geomorphic type and condition*

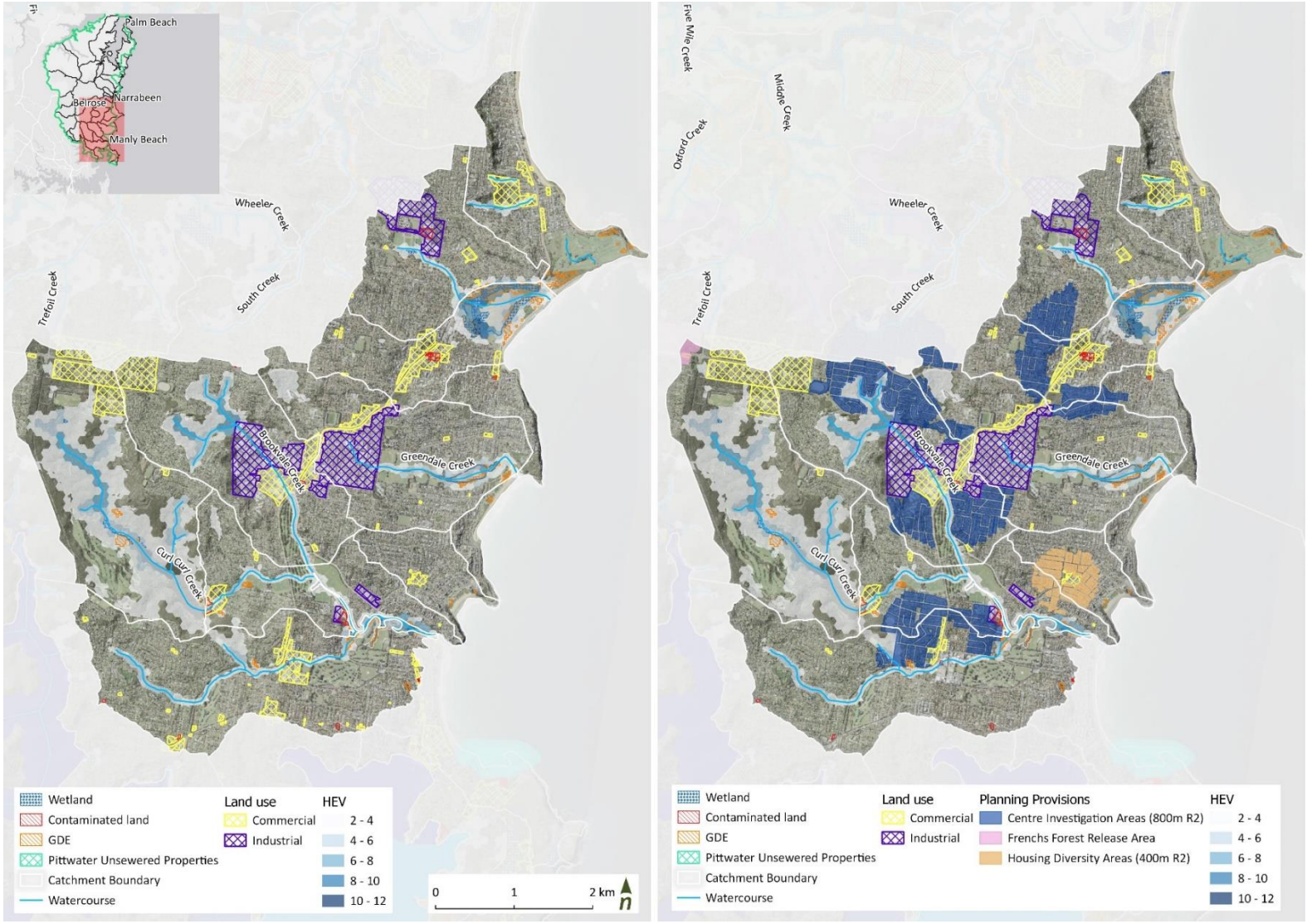

Figure 11. *Zone 3 Land use, High Ecological Values, and Planning Provisions*

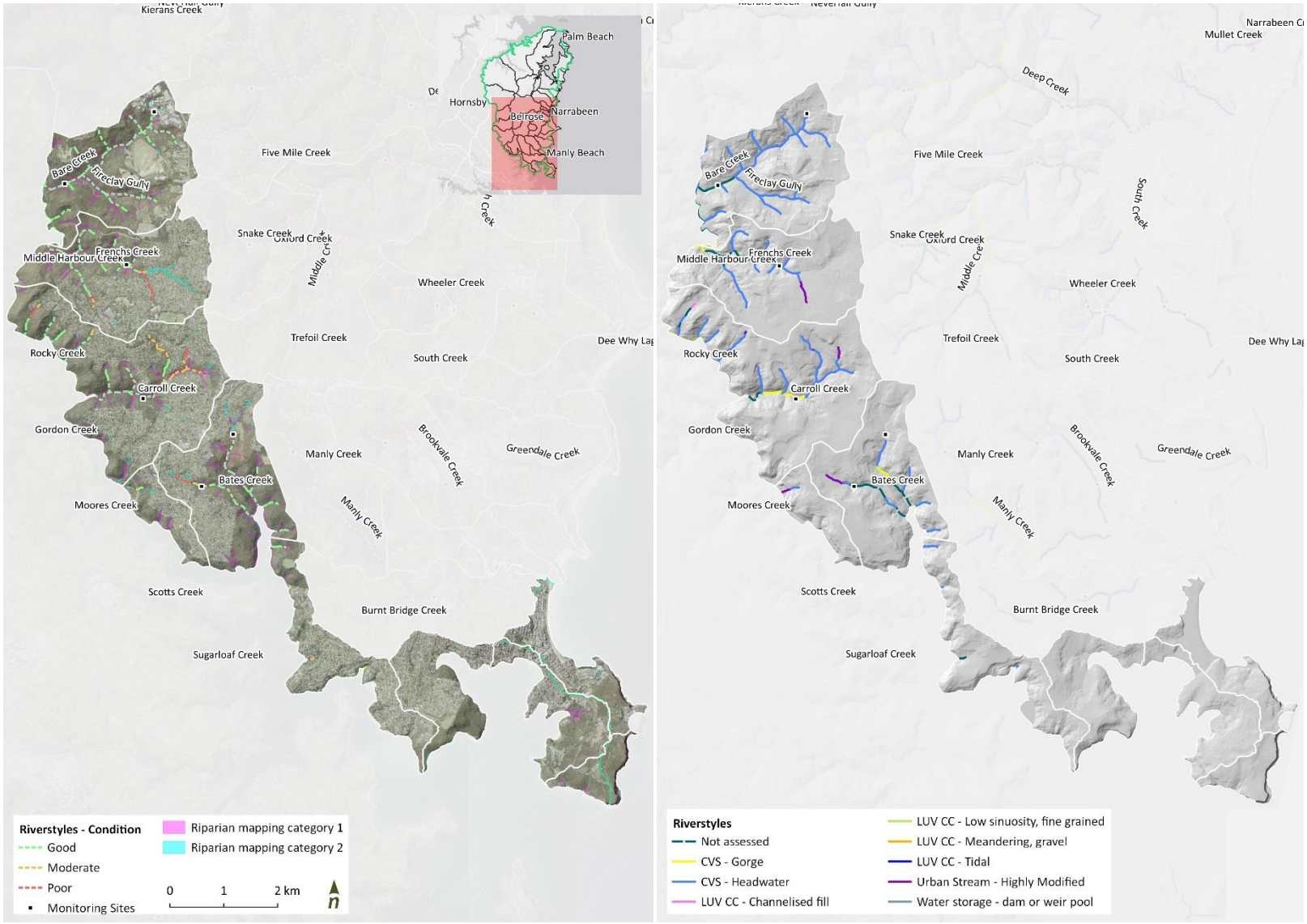

Figure 12. *Zone 4 waterway geomorphic type and condition*

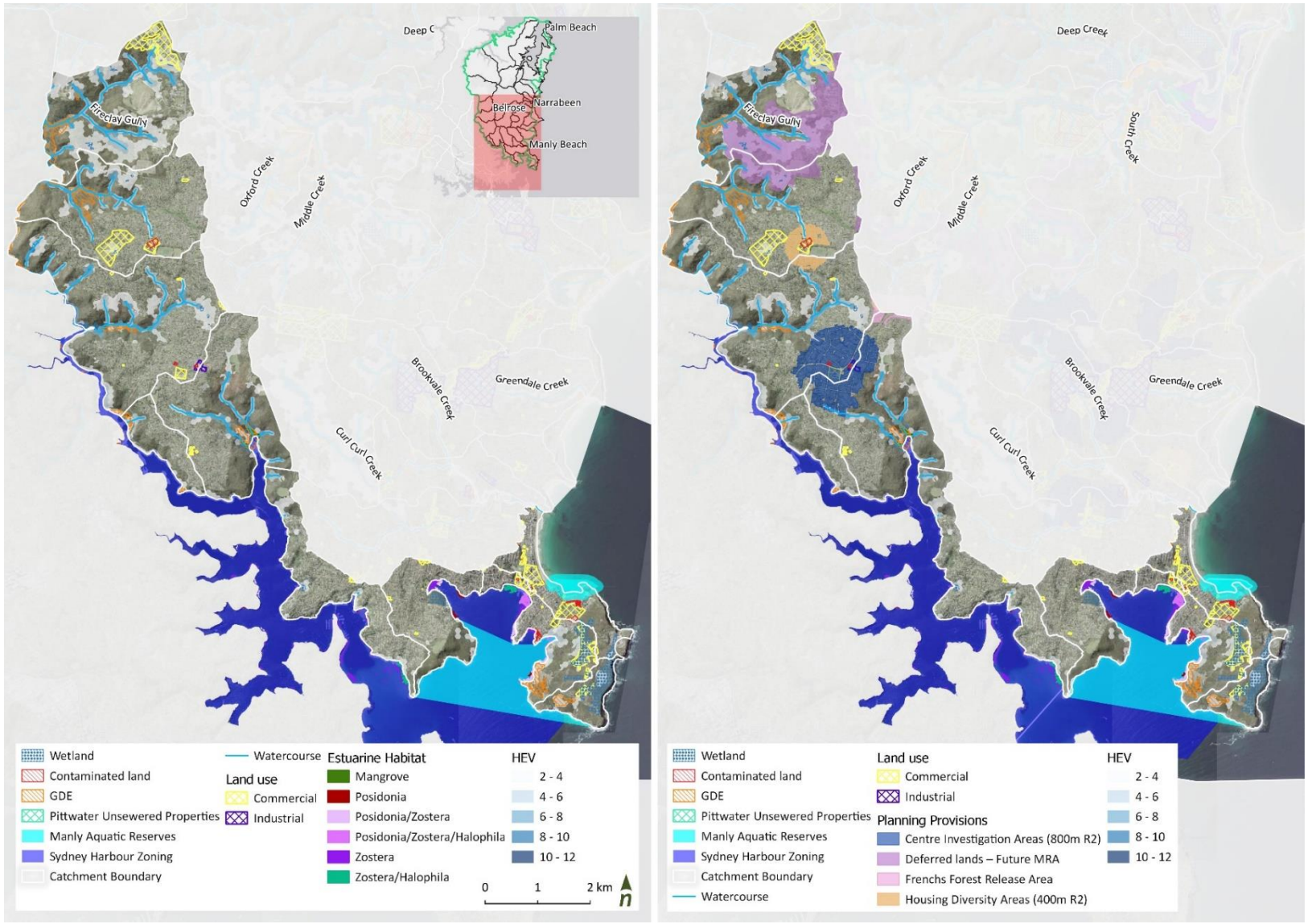

Figure 13. *Zone 4 Land use, High Ecological Values, and Planning Provisions*

9 Catchment summaries (Pittwater estuary)

9.1 McCarrs Creek

McCarrs Creek	**Current fraction imperviousness: 4 % (potential increase >10%)**			**References:**
Objectives and timeframe for community environmental values and uses	**Freshwater creeks:** *Maintain or Improve* existing condition for aquatic ecosystems, visual amenity and secondary contact recreation. *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems. **Estuary (Careel Bay)**: *Maintain or Improve* existing condition for all environmental values and uses			Local Strategic Planning Statement (LSPS)
Existing values	No information available			
Existing catchment pressures and stressors	• Land clearing and development in upper catchments • Runoff from development in upper catchments. • Monitoring of water quality shows pH rising in McCarrs Creek likely related to urbanisation in top of catchment (runoff over concrete). • Small amount of sewerage leakage from upper catchments/unsewered areas. • Pets and dog exercising areas. • Although not specific to McCarrs Creek, similar urbanisation pattern in upper catchments of Cowan Creek resulted in exotic species dominating the understorey of riparian zones.			Water Quality McCarrs Creek Cowan Lane Cove 2003
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be slightly modified	Potential to decline given imperviousness can exceed 10% in the next 20 years	Maintain condition
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TN, NOx and TP expected to be below trigger value for aquatic ecosystems Macroinvertebrates diversity likely to be similar	Potential to decline given imperviousness can exceed 10% in the next 20 years	Improve condition in degraded reaches otherwise maintain

		to that expected to be present		
3.Riparian vegetation	In-stream and stream side vegetation extent and quality	- Intact native vegetation, all within Ku-Ring-gai National Park. Good condition. Category 1 (BMT, 2021)	Potential to decline given imperviousness can exceed 10% in the next 20 years	Maintain condition
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Predominately shallow channel, bedrock controlled with narrow continuous floodplain (NSW OEH, 2016). Good geomorphic condition	Potential to decline given imperviousness can exceed 10% in the next 20 years	Maintain condition

9.2 Circada Glen Creek

Circada Glen Creek	Current fraction imperviousness: 7% (potential to increase by >10%)			References
Objectives and timeframe for community environmental values and uses	**Freshwater creeks:** *Maintain or Improve* existing condition for aquatic ecosystems, visual amenity and secondary contact recreation. *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems. **Estuary (Careel Bay)**: *Maintain or Improve* existing condition for all environmental values and uses			Local Strategic Planning Statement (LSPS)
Existing values	The lower part of Cicada Glen Creek runs through National Park and has excellent vegetation condition.			Northern Beaches Council input
Existing catchment pressures and stressors	• Land clearing and development in upper catchments • Light industry eg. nurseries, landscaping supplies in upper catchment • EC values in Cicada Glen Greek similar to urbanised creeks • 50th and 90th percentile nutrient concentrations for Circada Glen Greek exceeded guidelines. • Small disturbances to sandstone catchments can have large impact on water quality			Water Quality McCarrs Creek Cowan Lane Cove 2003 Northern Beaches Council input
Conditions	**Indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be slightly modified	Potential to decline given imperviousness can exceed 10% in the next 20 years	Maintain condition
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TN, NOx and TP expected at or just above trigger value for aquatic ecosystems Macroinvertebrates diversity likely to be similar to that expected to be present	Potential to decline given imperviousness can exceed 10% in the next 20 years	Improve condition in degraded reaches otherwise maintain
3.Riparian vegetation	In-stream and stream side vegetation extent and quality	Predominately Category 1 vegetation with isolated discontinuities	Increase weed disturbance possible	Maintain condition

4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Partly confined headwater stream in upper and mid reaches flowing into confined gorge in lower reaches. Bed/bank erosion unclear. Moderate geomorphic condition	Possible increase in erosion potential outside of confined areas	Maintain condition

9.3 Cahill Creek

Cahill Creek	Current fraction imperviousness: 28% (potential increase <3%)	References:
Objectives and timeframe for community environmental values and uses	**Freshwater creeks:** *Maintain or Improve* existing condition for visual amenity; *Improve* condition for aquatic ecosystems and secondary contact recreation (5-10 year timeframe); *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems. **Estuary (Careel Bay)**: *Maintain or Improve* existing condition for all environmental values and uses	Local Strategic Planning Statement (LSPS)
Existing values	No information	
Existing catchment pressures and stressors	• Lower reaches of all creeks in both the Careel and Winnererremy catchments exhibited exposed sections of embankments devoid of vegetation, slumping and vertically cut banks. However, little evidence of significant, current sources of sediments in streams and creeks. • Large organic matter load • Sedimentation of the poorly flushed embayments of Careel and Winnererremy Bays has been due to increased development in the area since the 1920's and insufficient tidal motions to move deposited sediment out of the bays, thus forming large alluvial deltas • TN and TP values within Winnererremy Bay catchment exceeded ANZECC guideline values. Sites, located within the golf course and industrial area showed higher TP concentrations. • High Enterococci values across sampling sites within Winnererremy Bay points to leaky sewer pipes, sewer pump station overflows and/or faecal matter deposition from domestic and non-domestic pets/ animals. • Golf course impacting creek in lower reach	FINAL REPORT Urban Sedimentation and Pol_ttwater Estuary - Environmental Investigation Report - AWC Consulting Sept 2012

Conditions	Indicators	Existing condition	Trajectory	Draft waterway objective
1. Hydrology	Imperviousness	Expected to be moderately to highly modified	Stable given small increase in imperviousness	

2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TP and TN expected to be above trigger value for aquatic ecosystems. Macroinvertebrates diversity likely to be less that expected to be present Microbial level expected to be above trigger values for secondary recreation.	Potential to decline further given increase in imperviousness	Improve condition
3.Riparian vegetation	Riparian vegetation extent and quality	Category 2 vegetation classification (BMT, 2021) Highly disturbed. Large discontinuities and very narrow width highly constrained by urban development in the upper reaches and limited through lower reaches (golf course)	Decline possible	Improve condition
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Highly modified urban stream in partly confined to unconfined setting. Moderate geomorphic condition	Decline possible	Improve condition where possible

10 Catchment Summaries (Cowan Creek)

10.1 Coal, Candle and Smith Creeks

Coal and Candle Creek, and Smith Creek have Intact native vegetation, all within Ku-Ring-gai National Park. The creeks are in good condition with category 1 riparian vegetation (BMT, 2021). Waterways are in confined headwater and gorge setting and in good geomorphic condition.

10.2 Kierans Creek

	Current fraction imperviousness: 8 % (potential increase <1%)	**Dominant land uses:**
Existing values	**National park reaches** • Native species diversity, habitat value good connectivity and retention of natural vegetation • High landscape/visual value in National Park • Recreational boating in Cowan Creek. • Fishing and oyster industries in Lower Hawkesbury	**References:** Cowan Creek Catchment Stormwater Management Plan June 1999
Existing catchment pressures and stressors	• Rural and urban developed areas and associated runoff • On-site wastewater effluent • Runoff from horse paddocks, landscape suppliers and nurseries • Stormwater fostering weed growth and infestation along riparian zones (nutrients and suspended solids Keirans creek is an anomaly with upstream section being weed infested and cleared in upper reaches with poor water quality, erosion and rubbish but nevertheless good fauna diversity (likely because of natural downstream conditions). This is similar as Neverfail Creek that has high nutrient levels but resilient fauna aided by fairly good in-channel condition and available habitat.	**References:** Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016
Previously documented catchment objectives		**References:**

Conditions	**Indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be slightly modified	Stable given small increase in imperviousness	Maintain condition

2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TP, TN and NOx are well above trigger value for aquatic ecosystems (pollution likely from multiple sources) Macroinvertebrates diversity similar to that expected to be present	Stable given small increase in imperviousness	Improve condition (noting multiple sources of pollution)
3.Riparian vegetation	Riparian vegetation extent and quality	- Upper reach has poor riparian vegetation including cleared areas as well as weed infestations including willows	Stable given small increase in imperviousness	Improve degraded reaches (weeds) along to a level that minimises the risk to natural habitats
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Upper reach (250m) - highly modified partly confined urban stream in moderate geomorphic condition. Where banks aren't armoured by bedrock they are undercut. - Mid and lower reaches are bedrock confined with a series of waterfalls, riffles, pools and runs in good geomorphic condition	Stable given small increase in imperviousness	Maintain condition downstream Improve geomorphic condition where possible upstream (Extent of channel erosion issues unknown)

11 Catchment Summaries (Middle Harbour)

11.1 Bare Creek

Bare Creek	**Current fraction imperviousness: 7 % (Potential to increase by >10%)**			**References:**
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems, visual amenity and secondary contact recreation; *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	In national park, creeks have high scenic value, swimming holes and used for fishing Large area of HEV with generally low score			Middle Harbour Catchment Stormwater Management Plan July 1999
Existing catchment pressures and stressors	• Most impact in section of creeks in the upper developed areas (urbanisation concentrated on flatter lands). • Reaches in Garigal National Park in good condition, However, weed infestation and accelerated sedimentation arises from upper developed areas. Condition of riparian reflect impact of development, wetting regime (wetter for longer promotes weeds), nutrient sources and disruption to natural channel. • One tributary in upper catchment next to commercial and industrial land uses in poor condition where nutrient pollution has been quite high on occasions. Small reach, lack of habitat and flow explain poor faunal diversity. • Land development, sediment input, nutrient input, freshwater input are catchment pressures to Estuary health.			Middle Harbour Catchment Stormwater Management Plan July 1999 Creek MER Assessment Report Card 2014-2015 Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016 Estuary Health Assessment Clontarf Bantry Bay Final Report 2017
Conditions	**Indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be slightly modified	Potential to decline given imperviousness can exceed 10% in the next 20 years	Maintain condition
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TP and NOx at or just above trigger value for aquatic ecosystems	Potential to decline given imperviousness can exceed 10% in the next 20 years	Improve condition (particularly downstream of urban areas)

		TN above trigger value for aquatic ecosystems Macroinvertebrates diversity similar to that expected to be present		
3.Riparian vegetation	In-stream and stream side vegetation extent and quality	Classified as category 1 (BMT, 2021) however weed disturbance noted in upper reaches (NSW OEH, 2016)	Ongoing weed disturbance likely	Improve degraded reaches (weeds) along to a level that minimises the risk to natural habitats
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Confined headwater stream in good geomorphic condition	Stable	Improve condition along degraded reaches

11.2 Frenchs Creek

Frenchs Creek	Current fraction imperviousness: 24 % (potential increase 7%)			References
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems, visual amenity and secondary contact recreation; *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	High native species richness immediately upstream of National Park with reasonable connectivity and habitat quality Ecological value high both within and outside National Park HEV score higher along main creek line. GDE existing along main creek line.			Middle Harbour Catchment Stormwater Management Plan July 1999 Final Report - Creek Monitoring Evaluating and Reporting (MER) Project 20152016
Existing catchment pressures and stressors	• Polluted urban runoff • Degradation of upstream reaches threatening high values downstream • Weeds encroachment in National park resulting from uncontrolled invasion and deliberate cultivation of exotics in upstream urban reaches. • Erosion along drainage lines as a result of a changed hydrologic regime although erosion process is likely to be completed now. • Sewage entering Frenchs Creek with discoloration of water for days after sewer overflows • Water quality: Poor EC. High concentration of nitrogen, phosphorus and suspended solids). • Land development, sediment input, nutrient input, freshwater input are catchment pressures to Estuary health.			Warringah Creek Management Study 2004 Estuary Health Assessment Clontarf Bantry Bay Final Report 2017
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be moderately modified	Potential to decline given new land development in Deferred lands – Future MRA	Maintain condition
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	NOx above trigger value for aquatic ecosystems. TP and TN at or just above trigger value for aquatic ecosystems.	Potential to decline given imperviousness can exceed 30% in the next 20 years.	Improve condition (particularly downstream of urban areas)

		Macroinvertebrates diversity is less that expected to be present		
3.Riparian vegetation	Riparian vegetation extent and quality	Predominately good riparian vegetation throughout however weeds present in upper reaches including 'Giant Reed'	Ongoing weed disturbance likely	Improve degraded reaches (weeds) along to a level that minimises the risk to natural habitats
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Upper reach (500 m) highly modified urban stream - poor geomorphic condition - Mid to lower reaches confined by bedrock, pools, riffles, runs, bedrock bars and waterfalls - good geomorphic condition	Stable	Improve condition along degraded reaches

11.3 Bates Creek

Bates Creek	Current fraction imperviousness: 21 % (potential increase <5%)			References
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems, visual amenity and secondary contact recreation; *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	Very popular walking track alongside both side of the creek and also in Garigal National Park			Northern Beaches Council input
Existing catchment pressures and stressors	• Accelerated erosion at stormwater outlets • Pollution evident in estuary following rainfall events • Tidal fluctuations and mixing with freshwater are extremely effective in flushing contaminants after rainfall. In periods of wet weather, the estuary can become stratified with the more buoyant fresh water sitting as a thin layer on the surface of the salt water. This stratification process aided in the rapid transportation of pollutants from their upstream source to the lower parts of the estuary where tidal flushing aided in dispersal of the pollutants. • Water quality has improved but pollution still evident from stormwater runoff. • Highly urbanised catchment results in concentration of stormwater flows through artificial drainage networks resulting in erosion at end of pipe which is often surrounded by soft surface material such as soil or sand that is easily eroded by large runoff volume and high flow rates. Major stormwater pipes extend right to Middle Harbour and discharge either onto the foreshore or directly into the estuary. • Land development, sediment input, nutrient input, freshwater input are catchment pressures to Estuary health.			**References:** Estuary Health Assessment Clontarf Bantry Bay Final Report 2017
Conditions	**Indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be moderately modified	Stable with small increase in imperviousness expected in the next 20 years	Maintain condition

2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TN, NOx and TP above trigger value for aquatic ecosystems. Macroinvertebrates diversity is less that expected to be present	Stable given small increase in imperviousness.	Improve condition
3.Riparian vegetation	Riparian vegetation extent and quality	Category 1 vegetation through Garigal National Park, weed disturbance noted (BMT, 2021)	Ongoing weed disturbance from urban areas	Improve degraded reaches along to a level that minimises the risk to natural habitats
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Upper reach (350 m) highly modified urban stream - poor geomorphic condition - Mid reaches partly confined by bedrock - good geomorphic condition - Lower reach confined - good geomorphic condition	Stable	Improve condition along degraded reaches

12 Catchment Summaries (Manly Lagoon)

12.1 Manly lagoon

Manly Lagoon	**Current fraction imperviousness: 38 % (potential increase < 5%)**	**References**
Objectives and timeframe for community environmental values and uses	**Lagoon**: *Maintain or Improve* existing condition visual amenity; *Improve* condition for aquatic ecosystem and secondary contact recreation (5-10 year timeframe); *Improve condition* for secondary contact recreation (10 years or more)	Local Strategic Planning Statement (LSPS)
Existing values	No information	Lagoon card
Existing catchment pressures and stressors	• Manly Lagoon had consistently high algae concentrations and water clarity was poor in the upper zones. This is a common characteristic for Manly as it suffers from high organic loading and is poorly flushed due to its shape and size. Council is investigating groundwater inputs and nutrient levels to better understand why the lagoon has such high algae concentrations. • Urban stormwater is a higher source of pollutants (sediment, phosphorous and Nitrogen) compared to sewerage overflows. • Contaminated groundwater	Manly Lagoon Pollutant and Sediment Load - Water Quality MUSIC Model
Previously documented catchment objectives	• Future works to improve the environmental condition in Manly Lagoon should focus on stormwater quality improvement	

12.2 Manly Creek

Manly Creek	**Current fraction imperviousness: 38 % (potential increase < 5%)**			**References:**
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems and visual amenity; *Improve* condition for secondary contact recreation (5-10 year timeframe). *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	Mermaid Pool – very popular walking location, waterfall. People used to swim there, no longer possible due to weeds (and probably water quality)			Northern Beaches Council input
Existing catchment pressures and stressors	Weed infestations No riparian vegetation through golf course. Poor quality vegetation and weeds through David Thomas and Millers Reserves. Flows regulated by releases from Manly Dam. Groundwater contamination Can be subject to major flooding if releases from the dam aren't managed well.			Northern Beaches Council input
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be highly modified	Stable with small increase in imperviousness expected in the next 20 years	Potential to manage volume and flow rates to reduce ongoing erosion if erosion issues are better understood.
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TP and TN expected to well exceed trigger values for aquatic ecosystems Macroinvertebrates diversity expected to be significantly less than those expected to be present.	Stable with small increase in imperviousness expected in the next 20 years	Improve condition
3.Riparian vegetation	Riparian vegetation extent and quality	Primarily Category 2 vegetation. Reasonable connectivity, however largely exotics (BMT, 2021) between dam and golf	Ongoing weed disturbance	Improve condition

		course with narrow riparian width. Weeds present throughout.		
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Partly confined immediately downstream of Manly Dam moderate to poor geomorphic condition. Bank erosion identified (Manly Creek Rapid assessment, 2017) - Unconfined, highly modified lower reach between Condamine St and Brookvale Creek confluence - poor geomorphic condition	Ongoing erosion likely through the partly confined to unconfined reaches	Reduce channel erosion (extent of channel erosion issues unknown)

12.3 Burnt Bridge Creek

Burnt Bridge creek	Current fraction imperviousness: 44 % (Potential increase of <3%)			References
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems and visual amenity; *Improve* condition for secondary contact recreation (5-10 year timeframe). *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	HEV has a low score Previously subject to a grant that improved riparian cover. Short section piped through Balgowlah.			Northern Beaches Council input HEV dataset
Existing catchment pressures and stressors	Future Beaches Link tunnel could significantly impact base flows due to loss of groundwater source. Maybe refer to future expansion of road networks? This will also reduce riparian for the creek as it is directly next to the Burnt Bridge Creek Deviation. Weeds Major issues with flooding in the lower reaches.			Northern Beaches Council input
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be highly modified	Stable with small increase in imperviousness expected in the next 20 years	Potential to manage volume and flow rates to reduce ongoing erosion if erosion issue is better understood.
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TN, NOx, and TP above trigger value for aquatic ecosystems. Macroinvertebrates diversity is significantly less that expected to be present	Stable with small increase in imperviousness expected in the next 20 years	Improve condition
3.Riparian vegetation	Riparian vegetation extent and quality	- Riparian zone highly disturbed, narrow and discontinuous. Ground and shrub layers dominated by weeds.	- Ongoing weed disturbance likely	Improve condition

4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	- Partly confined upper reaches flowing through dense urban area with moderate geomorphic condition - Mid reaches laterally unconfined, low sinuosity with poor geomorphic condition. Active bank erosion identified (NSW OEH, 2016) _ Lower reaches highly modified including piped and channelised sections connecting into Manly Creek	- Ongoing erosion likely through the partly confined to unconfined reaches	Reduce channel erosion (Extent of channel erosion issues unknown)

12.4 Brookvale Creek

Brookvale Creek	**Current fraction imperviousness: 40 % (potential increase in imperviousness >5%**			**References:**
Objectives and timeframe for community environmental values and uses	*Maintain or Improve* existing condition for aquatic ecosystems and visual amenity; *Improve* condition for secondary contact recreation (5-10 year timeframe). *Maintain or improve* existing condition for flows including 1) Protect pools in dry times; 2) Protect natural low flow; 3) Mimic natural drying in temporary waterways; and 4) Manage groundwater for ecosystems.			Local Strategic Planning Statement (LSPS)
Existing values	HEV has a larger extent in upper reaches but low score Very nice section in Allenby Park upstream Popular walking trails alongside and across lower sections in Nolan Reserve Golf Club Piped through Brookvale Must be a lot of fish because a lot died during a major pollution event after a fire			Northern Beaches Council input
Existing catchment pressures and stressors	Significant pollution from Commercial/Industrial area of Brookvale Large GPT immediately below Condamine Street			Northern Beaches Council input
Conditions	**Key indicators**	**Existing condition**	**Trajectory**	**Draft waterway objective**
1. Hydrology	Imperviousness	Expected to be moderately modified	Potential to decline further with a reasonable increase in imperviousness	
2. Water quality	Turbidity, nutrients, macroinvertebrates, microbial	TN and NOx well above trigger value for aquatic ecosystems. TP above trigger value for aquatic ecosystems. Macroinvertebrates diversity is significantly less that expected to be present	Potential to decline further with a reasonable increase in imperviousness	Improve condition
3.Riparian vegetation	Riparian vegetation extent and quality	Upper reaches contain good riparian vegetation with	- Stable upper reaches	Maintain condition in upper reaches

		high proportion of native species and is well connected to bushland and is of high value. - Highly disturbed mid and lower reaches (Piped network and modified through golf course to Manly Creek)		Improve condition (lower reaches)
4. Physical form	Geomorphic condition, bed and bank erosion, sedimentation, sand slugs	Upper reaches - confined headwater streams in moderate to good geomorphic condition. - Mid reaches Highly modified urban (piped or constructed channel) - poor geomorphic condition - Lower reaches highly modified urban stream flowing through golf course - poor geomorphic condition	- Stable upper reaches	Maintain condition in upper reaches Improve condition in lower reaches