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Environmental Impact Statement – Chapter 22: Soils

Warragamba Dam Raising

Reference No. 30012078
Prepared for WaterNSW
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SMEC INTERNAL REF. 30012078

Contents

List of Tables

List of Figures

22 Soils

This chapter provides an assessment of soils during construction and operation of the Warragamba Dam Raising. The relevant Secretary's Environmental Assessment Requirements (SEARs) are shown in Table 22-1.

Table 22-1. Secretary's Environmental Assessment Requirements: Soils

Desired performance outcomes	Secretary's Environmental Assessment Requirements[1]	Where addressed
15. Soils Desired performance outcome: The environmental values of land, including soils, subsoils and landforms, are protected. Risks arising from the disturbance and excavation of land and disposal of soil are minimised, including disturbance to acid sulfate soils and site contamination.	1. The Proponent must verify the risk of acid sulfate soils (Class 1, 2, 3 or 4 on the Acid Sulfate Soil Risk Map) within, and in the area likely to be impacted by the project.	Section 22.3.10
	2. The Proponent must assess the impact of the project on acid sulfate soils (including impacts of acidic runoff offsite) in accordance with the current guidelines.	Section 22.4.2 Section 22.5.2
	3. The Proponent must assess whether the land is likely to be contaminated and identify if remediation of the land is required, having regard to the ecological and human health risks posed by the contamination in the context of past, existing and future land uses. Where assessment and/or remediation is required, the Proponent must document how the assessment and/or remediation would be undertaken in accordance with current guidelines.	Section 22.3.12 Section 22.4.4 Section 22.6
	4. The Proponent must assess whether salinity is likely to be an issue and if so, determine the presence, extent and severity of soil salinity within the project area.	Section 22.4.3
	5. The Proponent must assess the impacts of the project on soil salinity and how it may affect groundwater resources and hydrology.	Section 22.4.3
	6. The Proponent must assess the impacts on soil and land resources (including erosion risk or hazard). Particular attention must be given to soil erosion and sediment transport consistent with the practices and principles in the current guidelines.	Sections 22.3.1 to 22.3.9 Section 22.5.1
	7. Attention must also be given to direct and indirect increase in erosion, siltation, impact on riparian vegetation of increased sediment loads and reduction in stability or river banks or water courses both upstream and downstream in the event of a flood. Consideration must be given to the amount of time areas are inundated	Section 22.5.1Chapters 8 and 9

Desired performance outcomes	Secretary's Environmental Assessment Requirements[1]	Where addressed
	and the impact of soil during and after these events.	
	8. Consideration should also be given to areas inundated by probable maximum flood levels and the potential for the project to impact how siltation remains deposited in these areas, as well as the potential impact on existing vegetation and changes in soil characteristics. The Proponent should detail, in the event that a probable maximum flood level event occurs, how soil and areas affected by changed hydrological regimes as a result of the project will be managed and/or remediated.	Section 22.5.1Chapters 8 and 9
	9. The Proponent must detail the capacity of the site to support the increased size of the structure.	Chapter 5

1. This chapter specifically addresses SEARs requirement 15 in addition to those general requirements of the SEARs applicable to all chapters and as identified as such in Chapter 1 (Section 1.5, Table 1-1).

This chapter is supported by detailed investigations which are documented in:

- Soils and contamination assessment report (Appendix N1)
- Geomorphology assessment report (Appendix N2).

The proposed management and mitigation measures in this chapter are collated in Chapter 29 (EIS synthesis, Project justification and conclusion).

22.1 Project overview

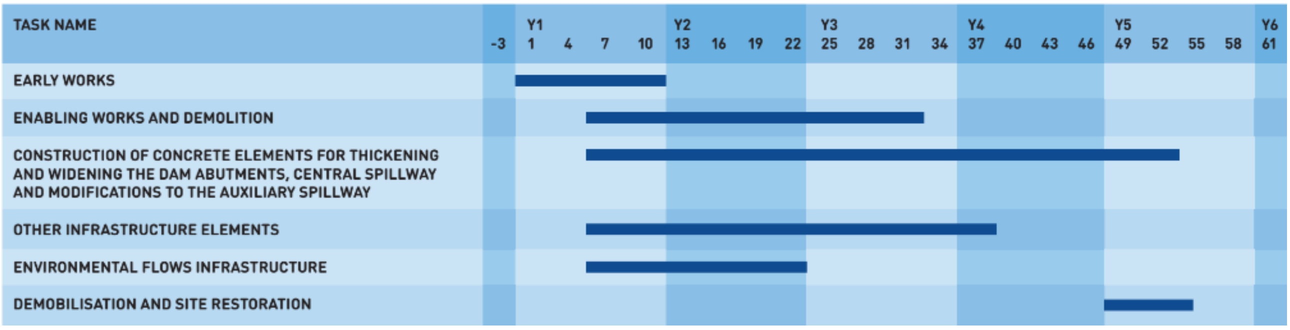
22.1.1 Project description

The Project is to provide additional capacity to facilitate flood mitigation (a flood mitigation zone or FMZ) by increasing the crest level of the central spillway by approximately 12 metres and the auxiliary spillway crest by around 14 metres above the existing full supply level for temporary storage of inflows. The spillway crest levels and outlets control the extent and duration of the temporary upstream inundation. There would be no change to the existing maximum volume of water stored for water supply. The current design includes raising the dam side walls and roadway by 17 metres to enable adaptation to projected climate change. The Project includes the following main activities and elements:

- demolition or removal of parts of the existing Warragamba Dam, including the existing drum and radial gates,
- thickening and raising of the dam abutments
- thickening and raising of the central spillway
- new gates or slots to control discharge of water from the FMZ
- modifications to the auxiliary spillway
- operation of the dam for flood mitigation
- environmental flow infrastructure.

A preliminary construction program is presented in Figure 22-1 with construction anticipated to be completed within four to five years.

Figure 22-1. Preliminary construction program



22.1.2 Operation of the dam for flood mitigation

Operational objectives in order of priority are to:

- maintain the structural integrity of the dam
- minimise risk to life
- maintain Sydney's water supply
- minimise downstream impact of flooding to properties
- minimise environmental impact
- minimise social impact.

There would be two different modes of operation for the Project: normal and flood operations. In both modes Warragamba Dam would continue to store and supply up to 80 percent of Sydney's drinking water. The storage capacity, which is the dam's FSL, would not change. The Project would delay downstream flooding, which would reduce current downstream flood peaks and increase the time taken for downstream water levels to recede. The dam would be subject to the following operational regimes, depending on the water level.

Normal operations

Normal operations would occur when the dam storage level is at or lower than FSL.

Normal operations mode for the modified dam would be essentially the same as current operations, apart from environmental flow releases. Inflows would be captured up to FSL, after which environmental flows releases would cease and flood operation procedures would be implemented..

Flood operations

During large rainfall events when the storage level rises above FSL, flood operations mode would commence. In this mode, inflows to Lake Burragorang would be captured and temporarily stored (increasing water levels in Lake Burragorang and upstream tributaries). The raised dam would provide capacity (i.e. the FMZ) to capture temporarily around 1,000 gigalitres of water during a flood event.

Water would be discharged in a controlled manner via the gated conduits or slots until the dam level returns to FSL. FMZ operating protocols would guide this process and be developed for approval by the relevant regulatory authorities.

The raised dam would not be able to fully capture inflows from all floods. For floods that exceed the capacity of the FMZ, water would spill firstly over the central spillway and then, depending on the size of the flood, the auxiliary spillway.

22.1.3 Project location and study area

The Hawkesbury-Nepean catchment is shown on Figure 22-2. The Hawkesbury-Nepean River drains a catchment of 22,000 square kilometres from the Great Dividing Range to the Pacific Ocean at Broken Bay. Warragamba Dam is located approximately 65 kilometres west of Sydney in a narrow gorge at the start of the Warragamba River, 3.3 kilometres before it joins the Nepean River. The Nepean River then becomes the Hawkesbury River at the junction of the Grose River at Yarramundi. The entire river is called the Hawkesbury-Nepean River. The area downstream of the dam supports several major population centres including the towns of Wallacia, Penrith, Richmond and Windsor.

The topography of the Hawkesbury-Nepean Valley varies from rugged and mountainous terrain, which covers nearly half of the area, to floodplains. The latter accounts for only a small percentage of the total area but contains most of the urban development. The catchment is generally aligned south to north, rising to 600 mAHD near the Avon River, 750 mAHD at the head of the Wollondilly River and about 1,200 mAHD on the Great Dividing Range at the head of the Kowmung River.

Warragamba Dam controls approximately 40 percent of the total area of the Hawkesbury-Nepean River catchment to the ocean and about 70 percent of the catchment at Windsor. There are four other major dams in the catchment upstream of Sackville on the Nepean River (Nepean, Avon, Cordeaux and Cataract dams). The total area controlled by other dams are a small proportion of the total catchment and have minimal impact on floods.

The township of Warragamba is located approximately one kilometre east of the dam wall. The upstream environment includes the reservoir formed by Warragamba Dam (Lake Burragorang) and its tributaries, and comprises about 5,280 hectares, broadly equating to the area between the existing FSL and the Project probable maximum flood (PMF) level. The downstream environment includes a short section of the Warragamba River, the Hawkesbury-Nepean River and its floodplain, and some of the tributaries of the Hawkesbury-Nepean River (such as South Creek) that experience backwater flooding effects.

The soils assessment study area is shown on Figure 22-3, Figure 22-4 and Figure 22-5 and comprises respectively:

- the dam construction area near the township of Warragamba, which broadly covers an area of approximately 105 hectares
- upstream flood affected areas up to the Project PMF
- downstream flood affected areas up to the PMF (note that the Project PMF would be less than the existing PMF).

Figure 22-2. Hawkesbury-Nepean catchment

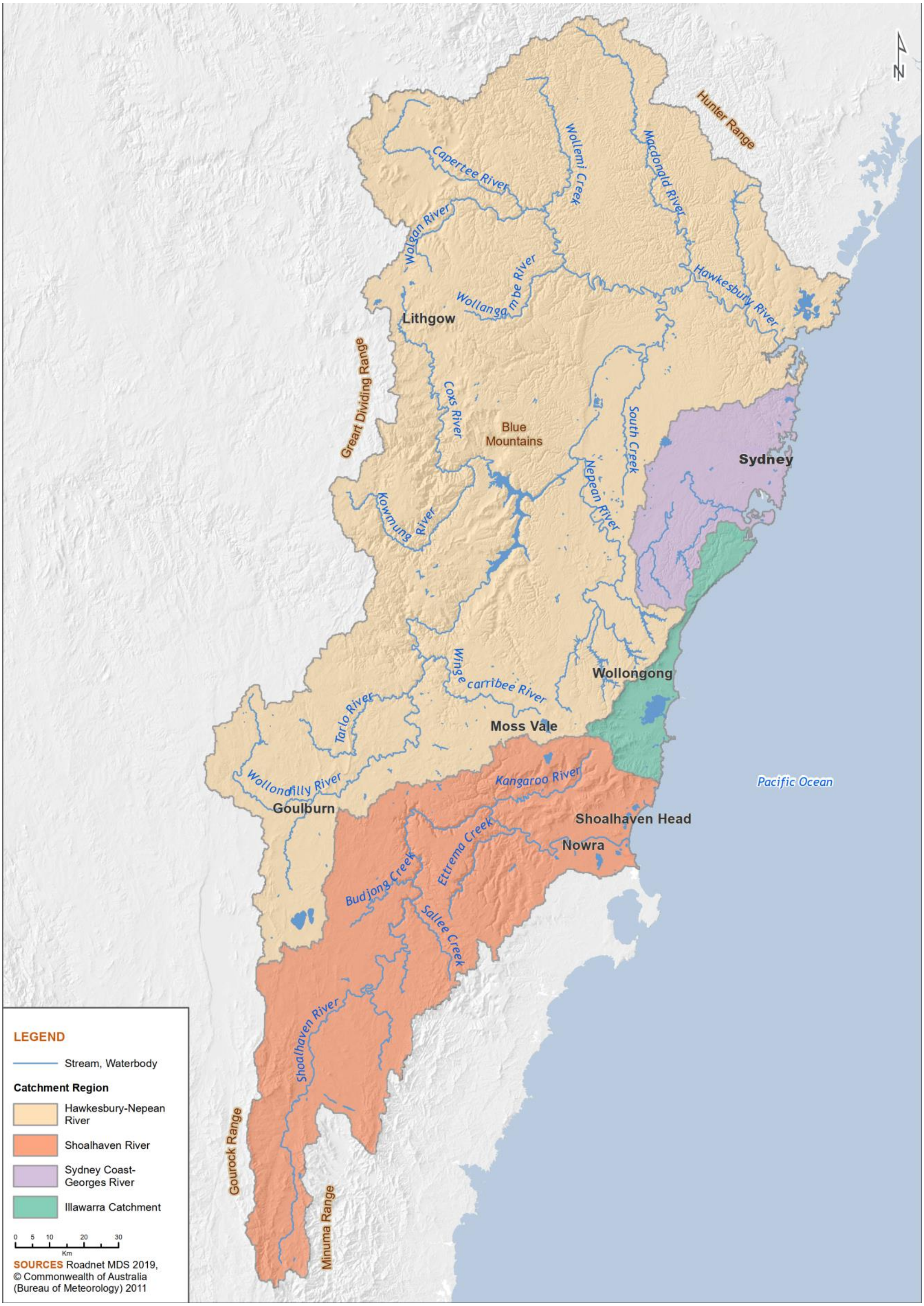


Figure 22-3. Construction study area

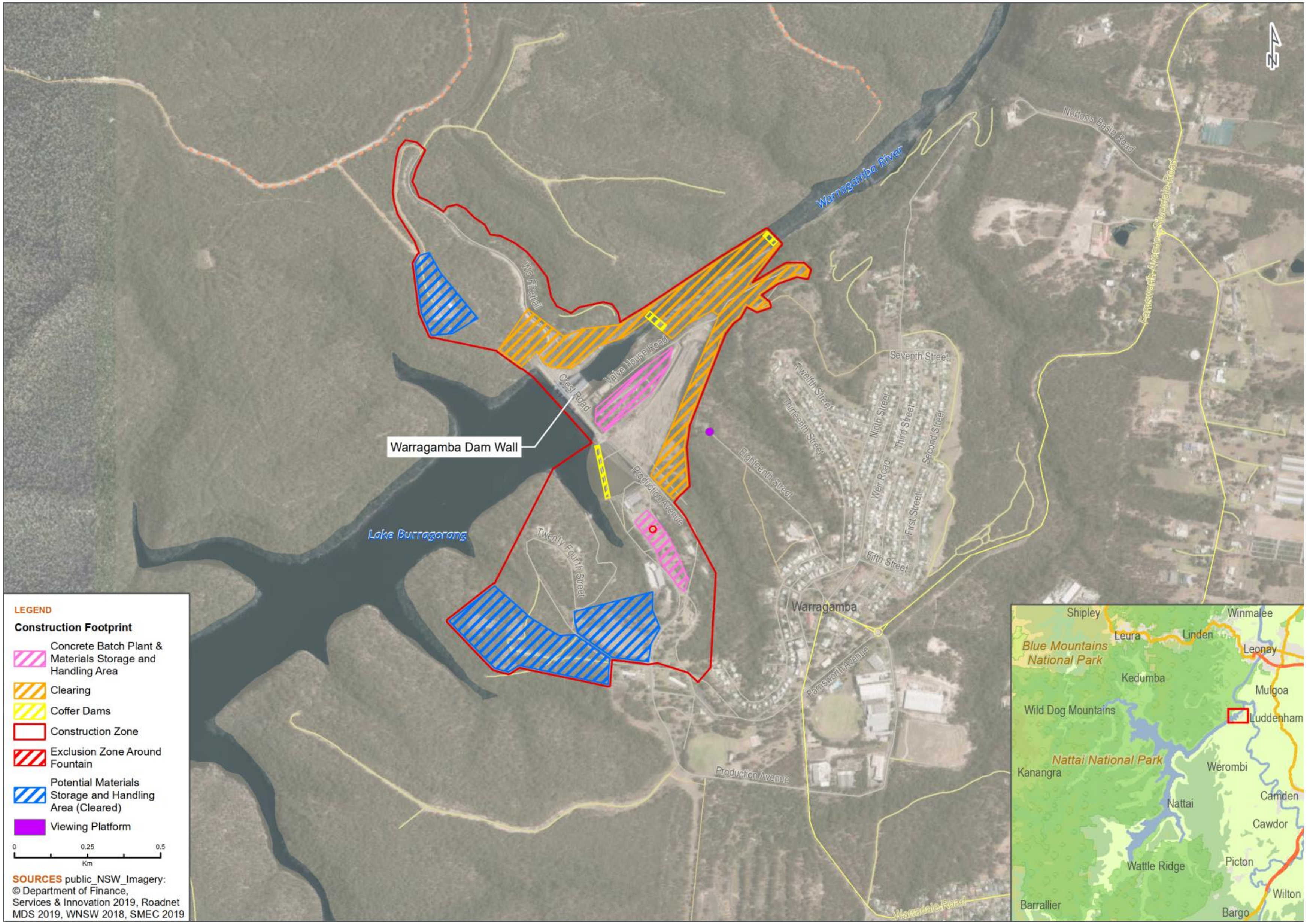


Figure 22-4. Upstream study area

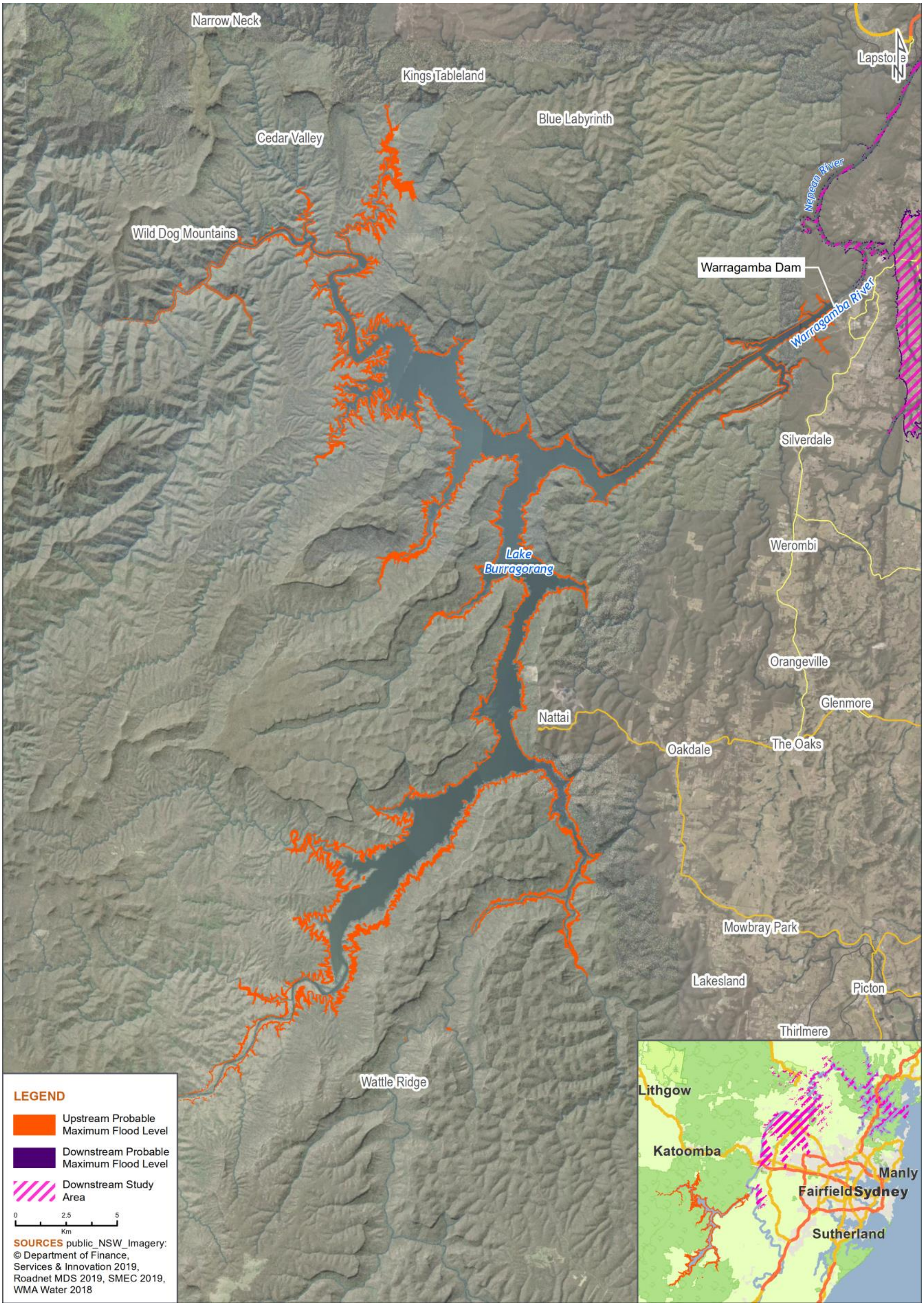
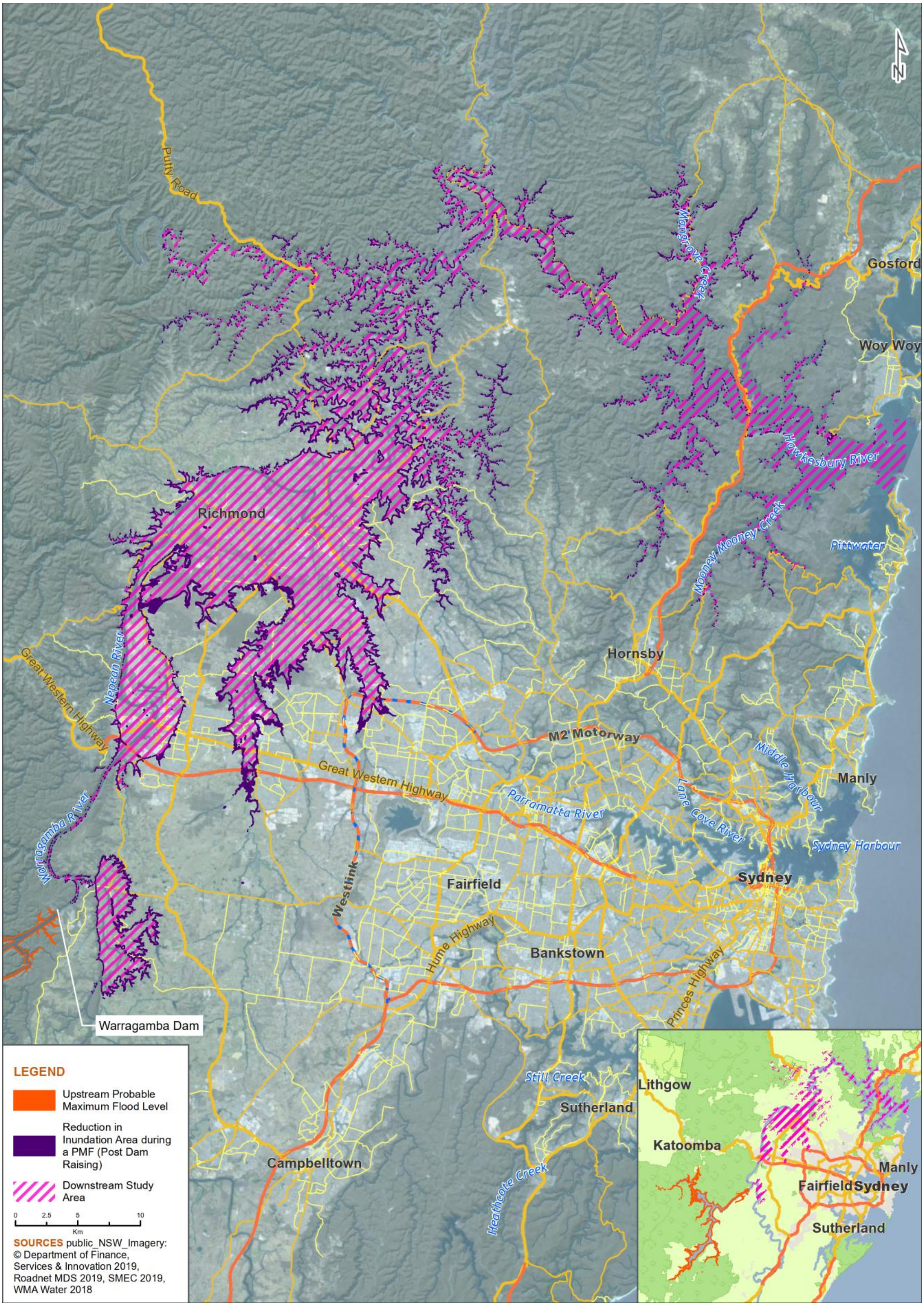


Figure 22-5. Downstream study area



22.2 Study methodology

22.2.1 Geology and land use

Land use and soils mapping for the study area was available from:

- Department of Planning, Industry and Environment (DPIE)
- Local environment plans for local government areas that the study area overlaps
- geological mapping for the area.

22.2.2 Geomorphology

Geomorphology aspects, including soils, siltation and erosion, are assessed in Appendix N2 (Geomorphology assessment report). The assessment methodology is discussed in Appendix N2 (Section 2.1) and was structured to:

- identify and describe baseline conditions through a combination of desktop information and site-based observations
- analyse physical process change and describe sensitive environmental values/receptors
- describe potential adverse and beneficial impacts of the Project on the environmental values/receptors
- identify risk of these impacts occurring (significance vs likelihood)
- identify mitigation measures to reduce the identified impacts/risk.

The assessment covered:

- Consideration of relevant guidelines
- Desktop review of relevant mapping and publicly available literature
- Field surveys
- Impact assessment.

Further detail is provided as follows.

Consideration of relevant guidelines

The assessment was prepared in accordance with the following relevant Commonwealth and NSW legislation and guidelines:

- ANZECC Guidelines and Water Quality Objectives in NSW (DEC 2006)
- *A Rehabilitation Manual for Australian Streams* (Cooperative Research Centre for Catchment Hydrology 2000)
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000, revised 2018)
- Guidelines for Controlled Activities on Waterfront Land (DPI 2012)
- Guidelines of Ecologically Sustainable Management of Rivers and Riparian Vegetation (Land and Water Resources Research and Development Corporation 1995)
- NSW State Rivers and Estuary Policy 1993
- NSW Government Water Quality and River Flow Objectives 2006. Available at: http://www.environment.nsw.gov.au/ieo/
- *Managing Urban Stormwater: Soils and Construction* Volume 1 (Landcom 2004)
- The River Styles Framework. Available online at: https://riverstyles.com/
- *Water Management Act 2000.*

Desktop review

This comprised a review of relevant mapping and literature as summarised in Table 22-2.

Table 22-2. Data sources

Assessment type	Data source/s	Application to this assessment
Aerial photography	Nearmap 2019	Illustrate channel planform movements visually Quantify nett sediment input/export areas Determine lateral accretion (downstream or upstream) in geomorphic features
Data request	SMEC/WaterNSW/WMA Water	Targeted data request capturing knowledge from the analysis behind other EIS chapters
Literature review	Multiple sources – search using Google, Google Scholar and ResearchGate	Review of locally relevant ecological and water quality environmental values Locally relevant hydrological and geomorphological features
Longitudinal profiles	Nearmap 2019	Changes in gradient at incremental distances along watercourse (Wollondilly River only) Changes in gradient for entire watercourse (all other major creeks/rivers in GIA)
Meteorological data	WaterNSW 2019	Generation of wave height dataset for Lake Burragorang Interpretation of sediment dataset
River Styles™ framework	NSW Office of Water (2012)	Catchment-scale classifications
Sediment concentrations and flow data	WaterNSW 2019	Sediment load calculations for the Coxs, Nattai and Wollondilly Rivers Temporal and spatial variation in sediment concentrations in both the Upstream and Downstream Zone rivers and for Lake Burragorang Variation of sediment with depth in Lake Burragorang
Topographic survey of Lake Burragorang	WaterNSW 2019	Input dataset for the Erosion Hotspot Model Sediment deposition features in Lake Burragorang
Turbidity level long-profile of Hawkesbury-Nepean River	DECC 2009	Input to floodplain sedimentation from out of bank flows

Field surveys

Field surveys were conducted over five days and comprised:

- assessment of bank strengths
- a rapid geomorphology survey that included:
  - conveyance and channel adjustment characteristics
  - erosion mechanisms and depositional features
  - floodplain geomorphology
  - river character and behaviour based on bed and bank sediment information.
- Sediment deposition potential, including:
  - potential accumulation of sediment mass on floodplain banks during inundation events
  - particle size composition of deposited sediments.

Impact assessment

Potential erosion and sediment transport impacts were assessed using semi-quantitative impact assessment analyses of collated desktop and site investigations data for the upstream, lake and downstream environments. These are summarised in Table 22-3. Of note is that the differences observed in the hydrological modelling performed for the Project could not be related solely to the dam development.

Table 22-3. Geomorphology impact assessment methodology

Location	Assessment approach	Application to assessment
Upstream	▪ bank erosion data (spatial variation) ▪ erosion hotspot model ▪ Hjulström Curve sensitivity analysis ▪ literature review ▪ site walkover observations. Potential Project changes were modelled for the Coxs River, Kedumba River, Kowmung River, Nattai River and Wollondilly River. Modelling was done for a range of floods including the 1 in 5, 1 in 10 and 1 in 100 chance in a year events, and the PMF.	Used to assess potential for out of bank erosion, translocation of sediment features upstream and in channel sediment deposition.
Lake Burragorang	▪ bank erosion data (spatial variation) ▪ erosion hotspot model ▪ literature review ▪ site walkover observations.	Used to assess potential for out of shoreline erosion, elevated erosion of shoreline banks, deposition of sediments on sensitive receptors during inundation events and change in circulation patterns causing sediment redistribution.
Downstream	▪ bank erosion data (spatial variation) ▪ Bank Erosion Index ▪ literature review ▪ Hicken Curve motion analysis ▪ site walkover observations ▪ turbidity levels overlain on FMZ discharge flood extent and critical infrastructure land use mapping.	Used to assess potential for cumulative bank erosion impact caused by prolonged FMZ flows, increased fine sediment content in Hawkesbury-Nepean river channel and floodplain sedimentation from out of bank flows.

22.2.3 Acid sulfate soils, salinity and contaminated land

Acid sulfate soils, salinity and contaminated land issues are addressed in Appendix N1 (Soils and contamination assessment report). Due to the large area involved and availability of relevant baseline data, it was assessed that Project risks can be adequately addressed without additional intrusive soils surveys. Subject to detailed design and construction layouts, some contaminated site surveys may be required on the construction site and this is covered in the proposed mitigation measures.

22.2.3.1 Acid sulfate soils

The potential presence of acid sulfate soil and acid runoff in the study area was assessed through a review of available mapping comprising:

- acid sulfate soil risk maps (eSPADE)
- acid sulfate soil class mapping (Environmental Planning Instrument – Acid Sulfate Soils)
- *Atlas of Australian Acid Sulfate Soils* (CSIRO) (Fitzpatrick, Powell and Marvanek 2011)
- geological maps.

Land use and soils mapping for the study area was available from:

- Department of Planning, Industry and Environment (DPIE)
- Local environment plans for local government areas that the study area overlaps

- geological mapping for the area.

The assessment considered the risk of presence of acid sulfate soil classes 1 to 5, in accordance with the class descriptions detailed in Table 22-4.

Table 22-4. Acid sulfate soils classes

Acid sulfate soil class	Description
Class 1	Acid sulfate soils in a class 1 area are likely to be found on or below the natural ground surface
Class 2	Acid sulfate soils in a class 2 area are likely to be found below the natural ground surface
Class 3	Acid sulfate soils in a class 3 area are likely to be found beyond 1 metre below the natural ground surface
Class 4	Acid sulfate soils in a class 4 area are likely to be found beyond 2 metres below the natural ground surface
Class 5	Acid sulfate soils are not typically found in class 5 areas. Areas classified as Class 5 are located within 500 metres on adjacent class 1, 2, 3 or 4 areas

The potential presence of 'inland', as opposed to coastal, acid sulfate soils was determined from the *CSIRO Atlas of Australian Acid Sulfate Soils* and the *Coastal Acid Sulfate Soils Mapping*. The *CSIRO Atlas of Australian Acid Sulfate Soils* uses a provisional acid sulfate soils classification inferred from national and state soils, hydrography and landscape coverages. The definitions for 'inland' and 'coastal' acid sulfate soils are provided in Section 22.3.10.

22.2.3.2 Salinity risk

Salinity risk was identified through an assessment of mapping available through DPIE.

22.2.3.3 Contaminated land

The potential presence of contaminated land in the construction area was determined through an assessment of previous reports relating to the area, including:

- *Warragamba Dam – Explosives Store and Vehicle Refuelling Area – Left Bank: Remediation Action Plan* (Sinclair Knight Merz 1998)
- *Warragamba Dam Auxiliary Spillway Environmental Management Plan: Remediation of Proposed Truck Maintenance and Explosive Storage Area* (Carey Constructions Ltd 1998)
- *Remedial Action Plan: Former Workshop Yard, Farnsworth Avenue, Warragamba, NSW, 2752*. Prepared for Sydney Catchment Authority (IT Environmental 2004)
- *Hazardous Materials Survey Report: Warragamba Dam, Warragamba, NSW*. Prepared for Sydney Catchment Authority (ADE Consulting Group 2014)
- *Additional Site Investigation: Megaritty's Creek, Weir Road, Warragamba, NSW* (JBS&G 2017a)
- *Assessment of Remedial Options - Megaritty's Creek, Weir Road, Warragamba, NSW* (JBS&G 2017b).

The potential presence of contaminated land in the upstream, construction and downstream study areas was assessed through review of publicly available records and databases, including:

- list of contaminated sites notified to EPA
- EPA Contaminated Land Record of Notices
- *Protection of the Environment Operations Act 1997* Register
- National Pollutant Inventory
- unlicensed premises regulated by the EPA
- a review of the Record of Waste Management Facilities (Geoscience Australia)
- a review of the NSW Government Mine View Mining Data.

22.3 Existing environment

22.3.1 Reference chapters

The existing environment of the upstream and downstream study areas is addressed in relevant chapters. This section provides a summary, as well as additional information related specifically to soils and potential impacts. Relevant chapters are:

- Chapter 8: Upstream biodiversity assessment
- Chapter 9: Downstream biodiversity assessment
- Chapter 10: Construction biodiversity assessment
- Chapter 11: Aquatic ecology
- Chapter 12: Matters of National Environmental Significance
- Chapter 15: Flooding and hydrology
- Chapter 27: Water quality.

22.3.2 Topography and landforms

22.3.2.1 Upstream topography and landform

Topography and landform of the upstream study area is shown on Figure 22-6. Most of the upstream study area is within the steep slopes of the Burragorang Valley. The landscape surrounding the upstream study area is dominated by rugged topography where, over geological timescales, the highlands of a vast plateau have been incised by rivers to form steep valleys, rocky outcrops, sheer cliffs and escarpments. The ridges and peaks surrounding the western extent of the upstream study area, above the Burragorang Valley reach elevations of up to 640 metres AHD, rapidly decreasing to around 117 metres AHD at Lake Burragorang.

Warragamba Dam was built across the Warragamba Gorge, about 3.5 kilometres upstream of the confluence of the Warragamba River and Nepean River. The gorge is 160 metres deep, 30 metres wide at the base, and about 450 metres wide at the edge of the plateau.

22.3.2.2 Downstream topography and landform

Topography and landforms of the downstream study area is shown on Figure 22-7. The topography of the downstream study area, near the confluence of the Warragamba River and Nepean River comprises of densely forested undulating hills with a maximum elevation of 200 metres AHD. At Leonay/Regentville, the landscape flattens into a floodplain environment with a typical elevation of 20 to 40 metres AHD. Between Emu Plains and Castlereagh, the Nepean River is flanked to the west by the steep slopes of the eastern extent of the Blue Mountains National Park.

At Ebenezer/Cattai, the topography starts to gently undulate as the Hawkesbury River flows north toward the Parr Conservation Park. From the confluences of the Colo and Macdonald Rivers with the Hawkesbury River, at Lower Portland/Webbs Creek, to the Tasman Sea, the topography comprises narrow flat floodplain immediately adjacent to the river with undulating hills of the Dharug National Park, Marramarra National Park and Brisbane Water National Parks adjacent.

Figure 22-6. Topography and landforms – upstream study area

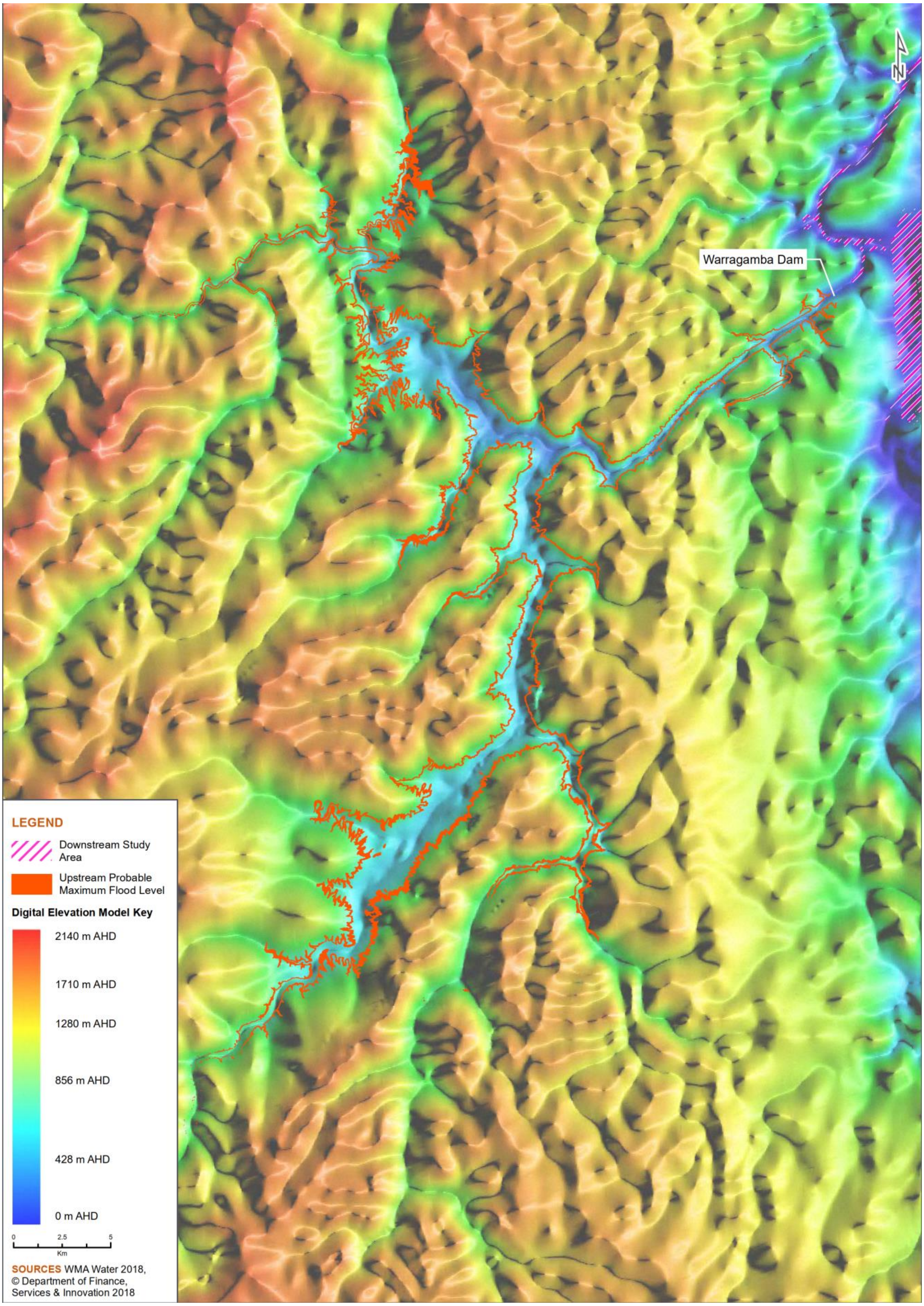
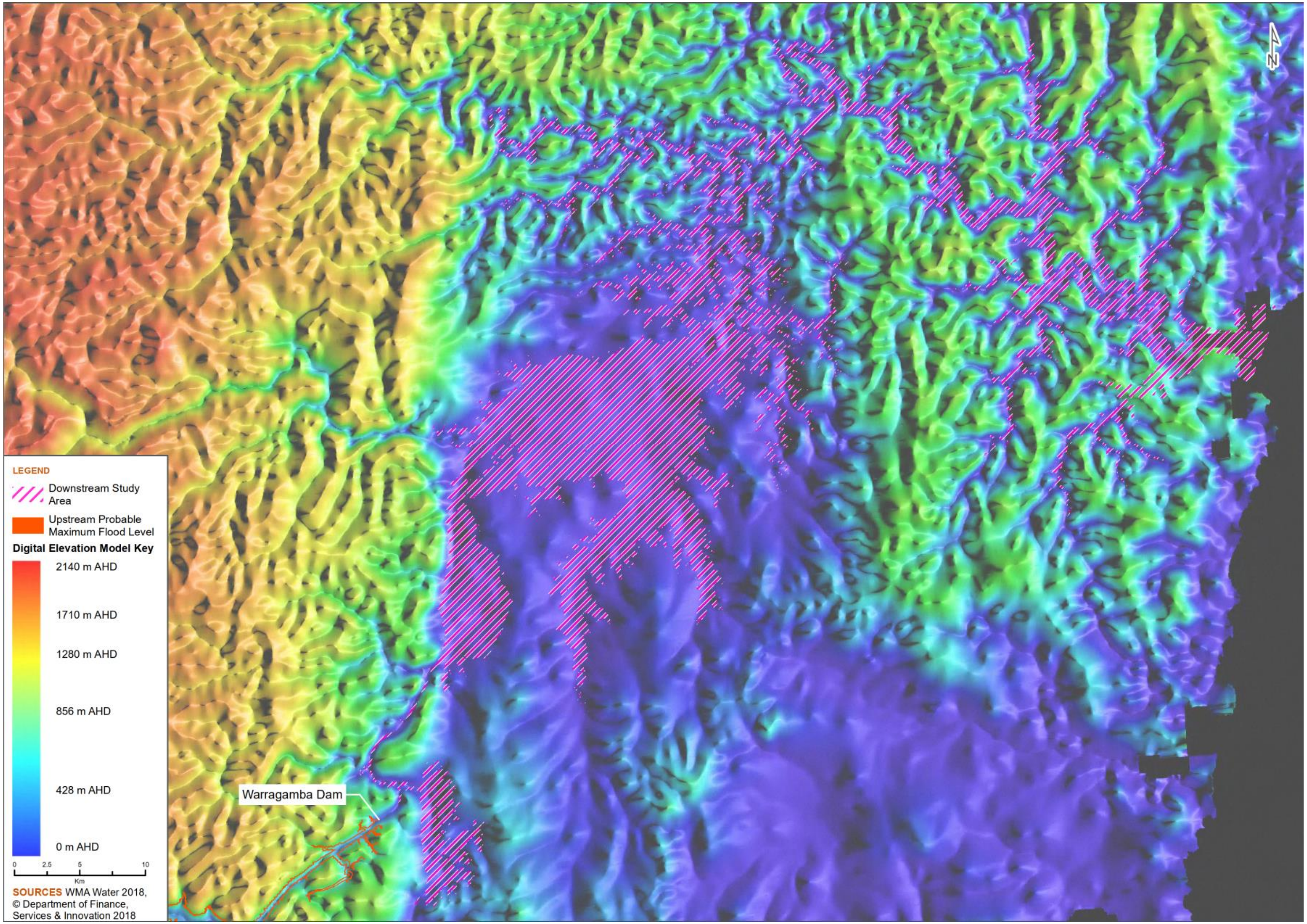


Figure 22-7. Topography and landform – downstream study area



22.3.3 Geology

Upstream geology

Geological mapping for the upstream study area is shown on Figure 22-8.

The flooded base and sides of the Burragorang Valley are made up of the Berry Siltstone (Shoalhaven Group) comprising mid to dark grey siltstone to very-fine grained sandstone (Colquhoun et al. 2015). The western extent of Burragorang valley is dominated by the Illawarra Coal Measures comprising shale, quartz-lithic sandstone, conglomerate, chert, sporadically carbonaceous mudstone, coal and torbanite seams. The topographically elevated escarpments and ridges above the Burragorang Valley generally comprise of Triassic sedimentary rocks including quartz-lithic to quartz-rich sandstone (including the Hawkesbury Sandstone) with conglomerate, mudstone and siltstone.

The base and sides of the Burragorang Valley comprises the Wentworth Clay Member, Burralow Formation and Banks Wall Sandstone (all components of the Narrabeen Group). The Narrabeen Group tapers approximately two kilometres upstream of the dam from which point Hawkesbury Sandstone dominates the landscape. The Hawkesbury Sandstone comprises horizontally-bedded medium to coarse grained quartz sandstone with minor shale and laminate lenses. The northwest and southwest extents of the study area are underlain by quartz rich sandstones and pebbly conglomerate units as well as sandstone, siltstone and mudstone.

Downstream geology

Geological mapping for the downstream study area is shown on Figure 22-9. From Warragamba Dam and the Lapstone local area, Hawkesbury Sandstone (Tuth) dominates the geology. From Lapstone to Maraylya, the dominant geological formation is the Wianamatta Group comprising the Ashfield and Bringelly Shales, the remainder of the downstream study area from Maraylya east to the coast is underlain by Hawkesbury Sandstone and the Burralow Formation.

The floodplain suburbs of Emu Plains, Penrith, Castlereagh, Agnes Banks, Richmond, Lowlands and Cornwallis are underlain by quaternary sediments including channel and floodplain alluvium comprising gravel, sand, silt and clay. The floodplain suburbs of Londonderry, Richmond, Clarendon, Bligh Park, Windsor Downs and Pitt Town are underlain by undifferentiated consolidated Cenozoic sedimentary rocks comprising sandstone, limestone, conglomerate, siltstone, duricrust; commonly ferruginous or silicified.

Figure 22-8. Geology – upstream study area

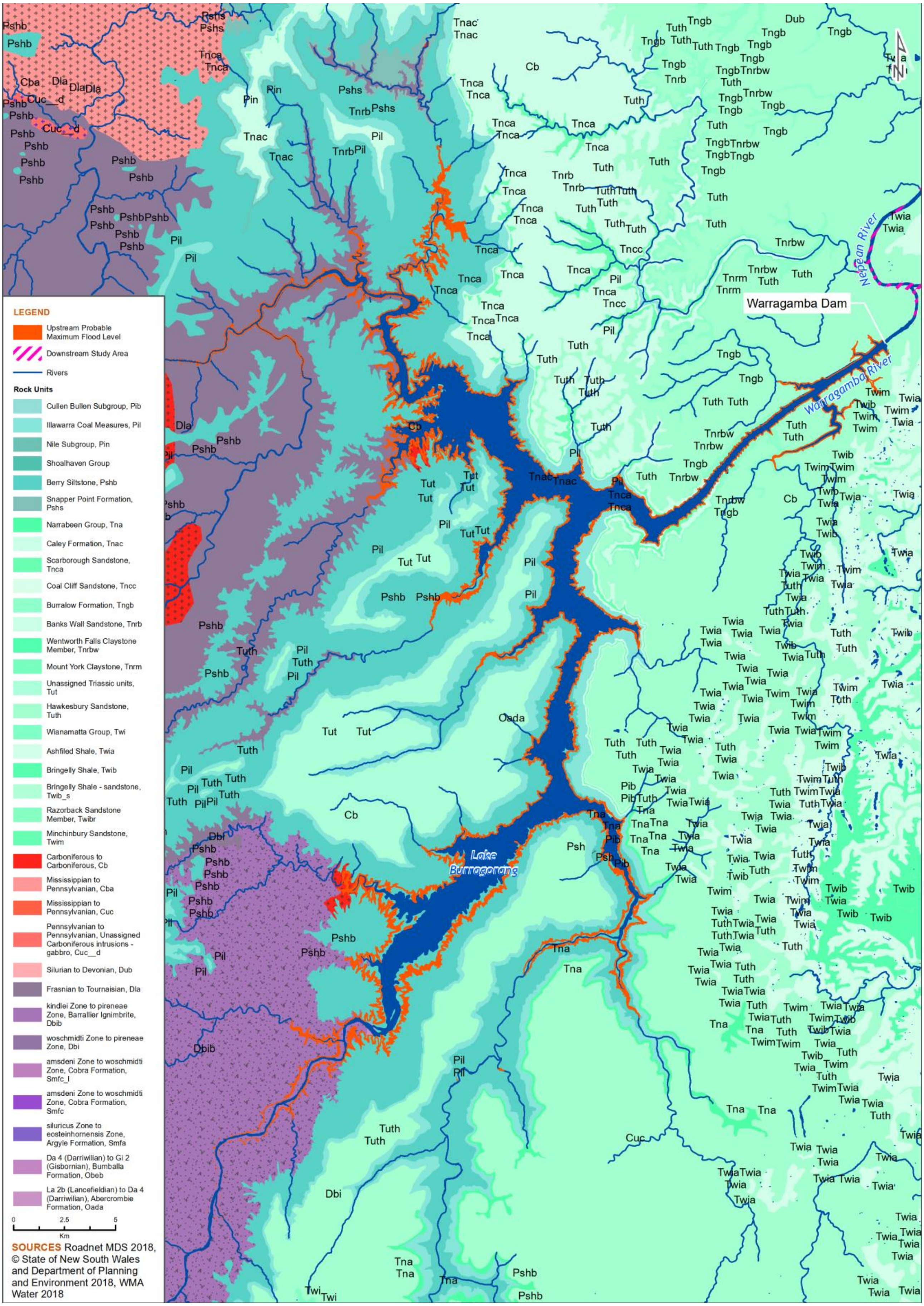
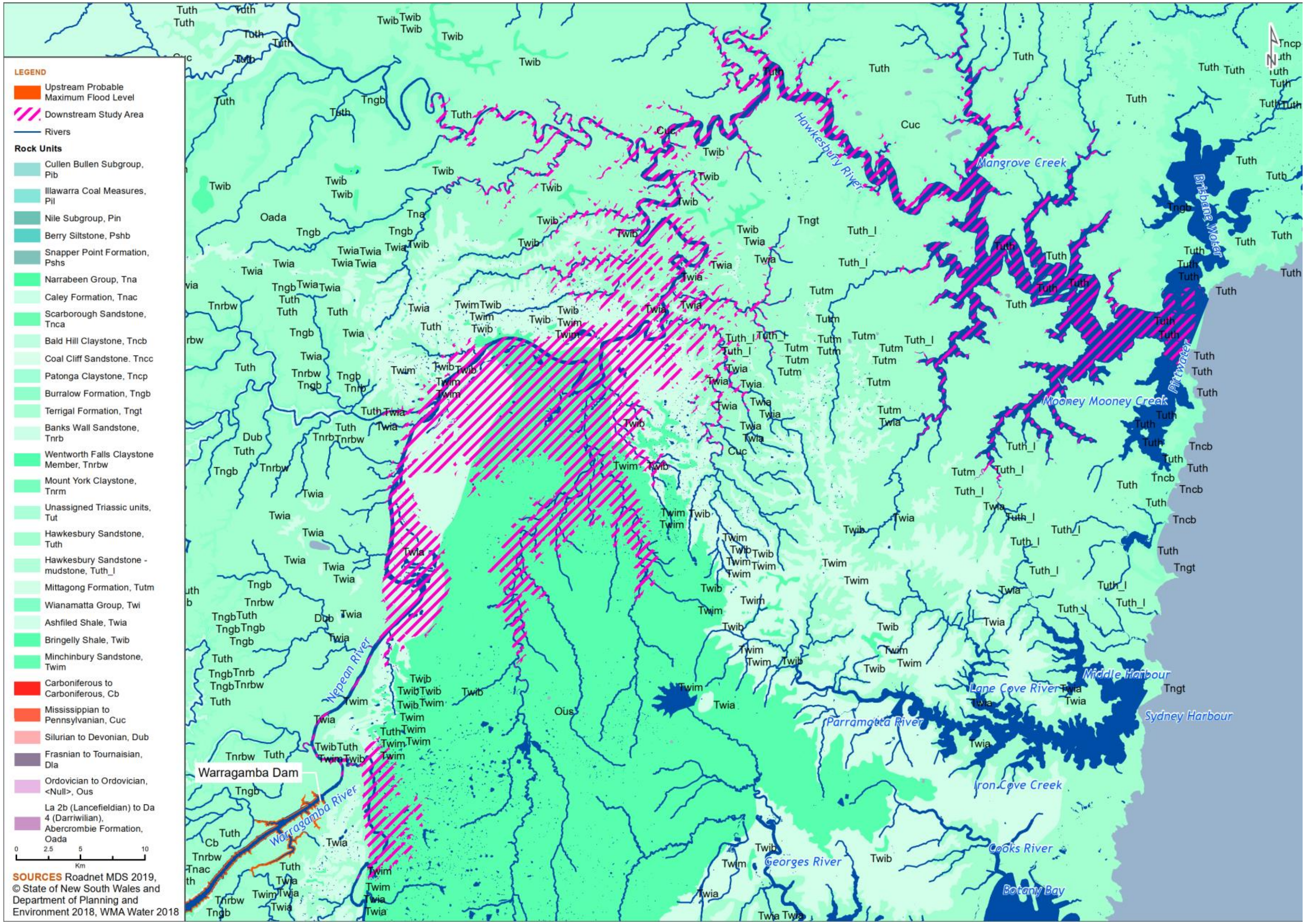


Figure 22-9. Geology – downstream study area



22.3.4 Land use

Upstream land use

Land zoning within the upstream catchment is shown on Figure 22-10. Land cover is predominantly pasture and woody vegetation. About 47 percent of the Lake Burragorang catchment remains as forest and woodland, mainly concentrated in the lower Coxs and Nattai catchments. These include the Nattai and Burragorang State Conservation Areas to the south and east of Lake Burragorang, and Yerranderie State Conservation Area and Blue Mountains National Park to the west and north of Lake Burragorang. Most of the cleared land is in the relatively low gradient parts of the Wollondilly and Upper Coxs' catchments. Cleared areas are mainly grassland with areas of open Eucalyptus also used for grazing. Urban areas occupy about 3 percent of the catchment and a similar area is used for plantations and horticulture. Mining activities occur in 1 percent of the catchment but can have a disproportionate impact on sediment generation.

Almost all land within the study area is covered with natural vegetation, with small areas categorised as cleared-modified land and exposed rock. Vegetation is typically associated with dry sclerophyll forest of shrubby sub-formation, as well as areas of wet sclerophyll forest, dry rainforest, warm temperate rainforest, grassy woodlands, and forested wetlands. Historical and current land use practices provide context to historical and current contamination and erosion risks.

Downstream land use

Land zoning within the downstream catchment is shown on Figure 22-11 and summarised in Table 22-5. Thirty-two land zones are represented within the downstream study area, with most of these comprising primary production and rural land uses.

Almost one million people reside in the Hawkesbury-Nepean catchment with most of these living in the lower catchment. Approximately 134,000 people live in the probable maximum flood extent of the Hawkesbury-Nepean River (INSW 2017). National parks are located on the western and northern borders of the study area and within the sub-catchments of the Grose, Colo, and Macdonald Rivers. A large urban area is centred around Penrith on the eastern side of the Hawkesbury-Nepean River, with numerous smaller urban areas along the length of the river to Pitt Town. Between these centres are agricultural areas, which occur on both sides of the Hawkesbury-Nepean River and in the sub-catchments of South Creek and Cattai Creek.

River reaches downstream of Warragamba Dam have been significantly modified since pre-European settlement. The impact of urbanisation along the river and land use changes across the floodplain have altered geomorphic features and river flow characteristics. Between Yarramundi and Windsor, the Hawkesbury River is wide and shallow with numerous shoals restricting navigability. This segment of river is also notably straighter than the other downstream river reaches and includes numerous lagoons and wetlands across the floodplain and lowlands. Further downstream, between Cattai and Wisemans Ferry, the floodplain is narrow (typically less than 400 metres wide) and mostly non-existent where the river channel is bedrock-controlled and characterised by steep sandstone gorges.

Construction area

The construction area covers approximately 105 hectares, of which approximately 53 percent (55.23 hectares) comprises native vegetation. The remainder of the area is extensively modified and comprises the dam wall, and ancillary structures.

Table 22-5. Land zoning composition of the downstream study area

Land zone code	Land zone class	Approx. area covered (ha)	Approx. percentage of area covered (%)
B1	Neighbourhood Centre	27	0.05
B2	Local Centre	76	0.13
B3	Commercial Core	25	0.04
B4	Mixed Use	35	0.06
B5	Business Development	113	0.19
B6	Enterprise Corridor	14	0.02
B7	Business Park	50	0.09
DM	Deferred Matter	2,357	4.04
E1	National Park and Nature Reserve	3,690	6.33
E2	Environmental Conservation	4,056	6.96
E3	Environmental Management	1,101	1.89
E4	Environmental Living	3,378	5.79
IN1	General Industrial	836	1.43
IN2	Light Industrial	100	0.17
IN4	Working Waterfront	2	0.00
R1	General Residential	99	0.17
R2	Low Density Residential	1,765	3.03
R3	Medium Density Residential	442	0.76
R4	High Density Residential	76	0.13
R5	Large Lot Residential	590	1.01
RE1	Public Recreation	1,153	1.98
RE2	Private Recreation	598	1.03
RU1	Primary Production	6,002	10.30
RU2	Rural Landscape	8,872	15.22
RU4	Primary Production Small Lots	7,332	12.58
RU5	Village	204	0.35
RU6	Transition	561	0.96
SP1	Special Activities	1,992	3.42
SP2	Infrastructure	1,167	2.00
SP3	Tourist	108	0.19
W1	Natural Waterways	4,067	6.98
W2	Recreational Waterways	6,423	11.02
-	Miscellaneous	987	1.69
Total		58,298	100.00

Figure 22-10. Upstream land zoning

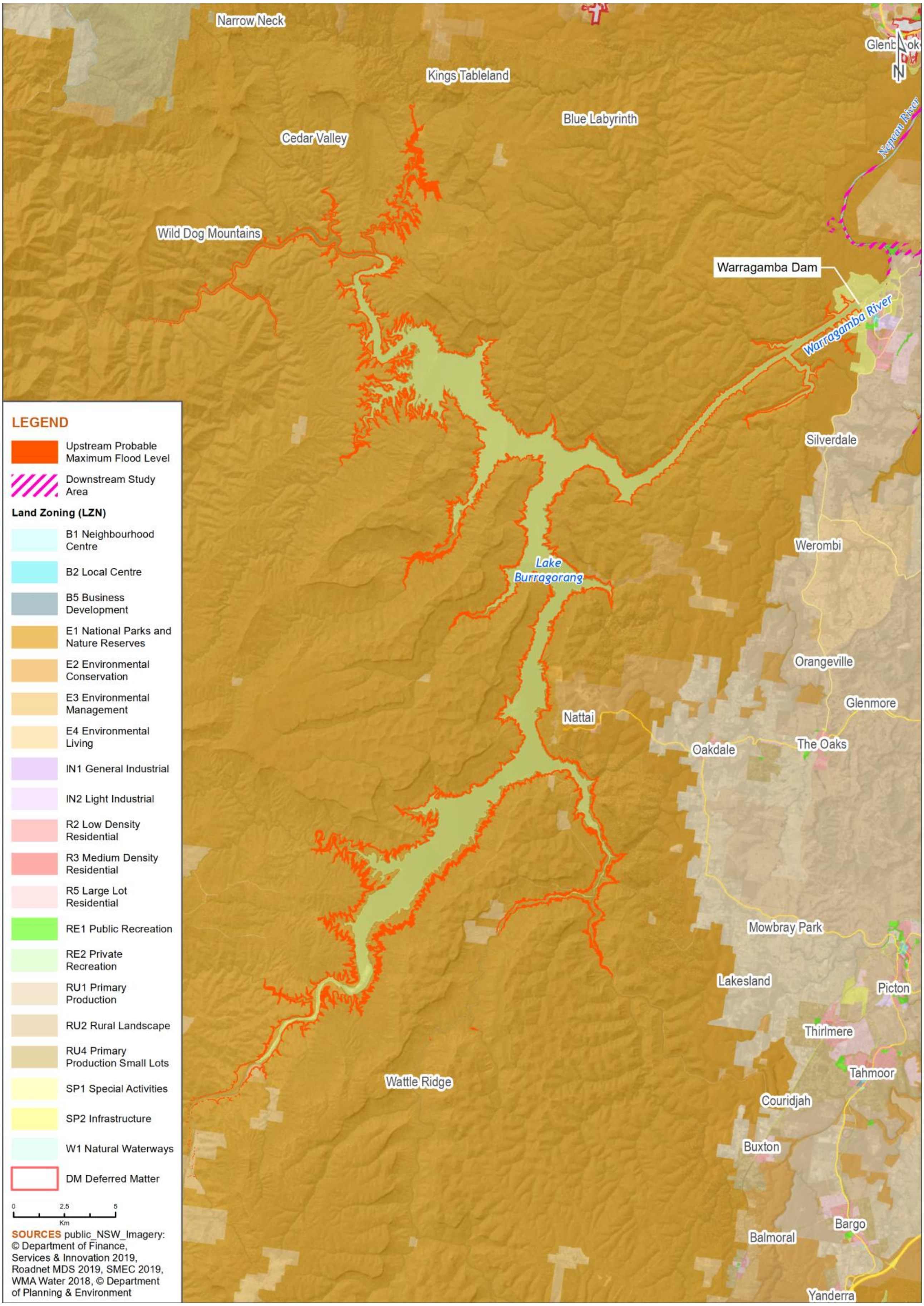
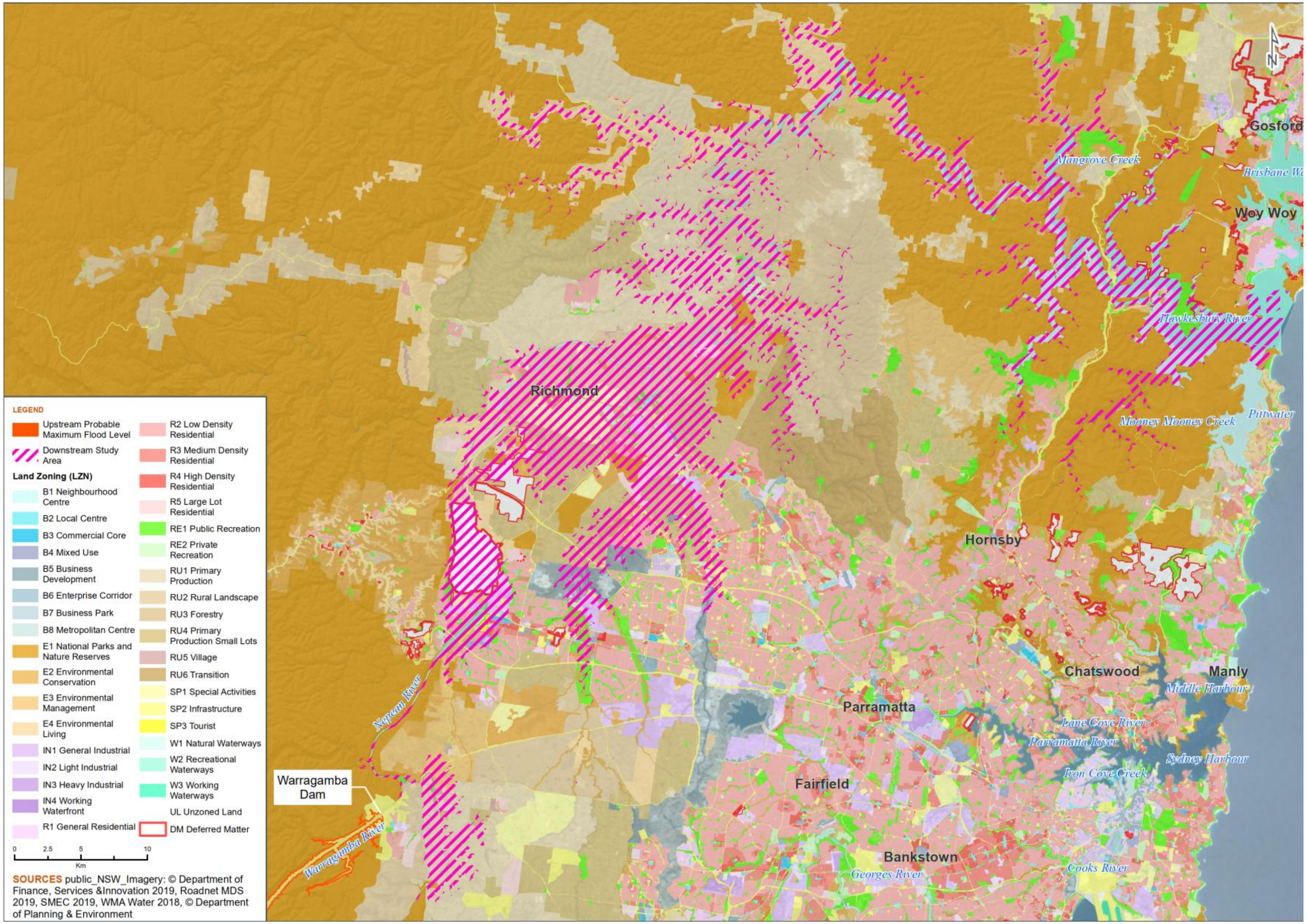


Figure 22-11. Downstream land zoning



22.3.5 Hydrology and Hydrological characteristics

22.3.5.1 Rainfall

Rainfall is influenced by the southern extensions of tropical low-pressure systems while convective storms can result in localised short-duration, high intensity falls that deliver larger proportions of the annual rainfall in one event (Fredericks 1994). Highest rainfall generally occurs in the highest parts of the catchment, notably on the high plateaus in the Coxs catchment (e.g. approximately 1,400 mm at Katoomba) and the Southern Highlands near Moss Vale. Conversely, the lowest rainfall area occurs on the middle to lower Wollondilly Catchment (for example, approximately 500 millimetres at Goulburn). Thunderstorms often originate in response to daily heating of hills slopes to the west of Sydney in unstable air flows before drifting over adjacent lowlands and coastal areas to the east. These thunderstorms are neither spatially nor temporally uniform (Rasuly 1996).

The implications of this rainfall pattern are rapid hydrological responses to events in the northern, Sydney Metropolitan (also due to local convection patterns and high impermeable area) and western sub-catchments. Rainfall erosivity is also highest in the northern and western parts of the catchment where the mean annual rainfall is highest. In the drier parts of the catchment gradual hillslope erosion is the dominant source of sediments to the channels.

22.3.5.2 Hydrology

Upstream: The upstream catchment is shown on Figure 22-12. Lake Burragorang has a catchment area of approximately 9,050 square kilometres and includes State Conservation Areas, National Parks and areas of the Greater Blue Mountains World Heritage Area. The main tributaries are summarised below.

- The catchment extends to the south near Lake Bathurst, where rainfall is comparatively low, and drains to Mulwaree Ponds near Goulburn and then to the Wollondilly River, which flows north-east to Lake Burragorang. A major tributary of the Wollondilly River is the Wingecarribee River, which rises in an area of high rainfall near Bowral to the east.
- The Coxs River extends as far north as Ben Bullen and flows north of Lake Burragorang along the western edge of the Great Dividing Range. The Coxs River has been dammed and the mid reaches of the catchment cleared to supply water and land for power generation, coal mining and agriculture.
- Other important but smaller waterways include the Kowmung River, Kedumba River and Nattai River, which generally drain heavily vegetated areas within the National Parks.

Downstream: The downstream catchment is shown on Figure 22-13. The downstream environment includes the freshwater and estuarine reaches of the river system between the dam wall and Brooklyn. Also included are local creeks, riparian zone and floodplain and wetland waterbodies adjacent to the main rivers. Topography of the Hawkesbury-Nepean Valley varies from flat floodplains to mountainous terrain that covers almost 50 percent of the catchment. Floodplains account for a small percentage of the total catchment area, however they contain most of the urban development. The main tributaries are summarised below.

- The Nepean catchment at its junction with the Warragamba River is approximately 20 percent of the size of the upstream Warragamba catchment, however the river drains a region of high rainfall along the top of the Illawarra escarpment and its contribution to downstream flows is significant. During high rainfall, substantial flows from the Warragamba catchment into the Nepean River and the narrow Fairlight Gorge causes existing upstream flows in the river to back up and cause localised flooding in the floodplain at Wallacia.
- Downstream of the junction, the Nepean River flows through a narrow gorge until it emerges into more open country immediately upstream of Penrith. Floodplain elevation near Penrith, including Emu Plains and the Penrith Lakes Scheme, is relatively high and does not convey floodwaters until floods almost reach the magnitude of a 1 in 100 chance in a year event. However, once water starts flowing over the flood plain, downstream flows are partially restricted by the Castlereagh Gorge, which is located just upstream of the Grose River junction.
- Downstream of Penrith the Grose River joins the Hawkesbury-Nepean River and flows through the Richmond/Windsor lowlands. These are extensive floodplains inundated by minor and moderate flooding. The main towns in the area, Richmond and Windsor, are in the most part elevated above smaller floods but are seriously affected by floods above the 1 in 50 chance in a year event.
- South Creek joins the river just below Windsor, and although the creek is not a major contributor to flood flows it has a large floodplain that is inundated by backwater from the Hawkesbury River. Below Wilberforce, Cattai Creek joins the river prior to it entering the Hawkesbury gorge, which extends for over 100 kilometres to the ocean at Broken Bay. Other major tributaries to join the Hawkesbury-Nepean River are the Colo River at Lower

Portland and Macdonald River at Wisemans Ferry. The gorge at Sackville presents a significant constriction to flood flow, causing flooding of the Windsor and Richmond areas. This restriction results in a substantial difference of approximately nine metres between the 1 in 100 chance in a year flood level and the PMF, which compares to approximately two metres for other rivers in NSW.

22.3.5.3 Hydrogeology

Hydrogeological characteristics are shown on Figure 22-14 and Figure 22-15. Aquifer types comprise:

- unconsolidated sediment aquifers; for example, surficial sediment aquifers underlying the suburbs of Richmond and Penrith and proximal to Hawkesbury River throughout the downstream component of the study area
- porous rock aquifers. For example, Hawkesbury Sandstone Formation and Narrabeen Group Sandstones
- fractured rock aquifers. For example, the Palaeozoic and Pre-Cambrian Fractured Rock that encompasses most of the upstream component of the study area (Groundwater in the Sydney Basin, Milne-Home 2009).

Figure 22-12. Upstream catchments

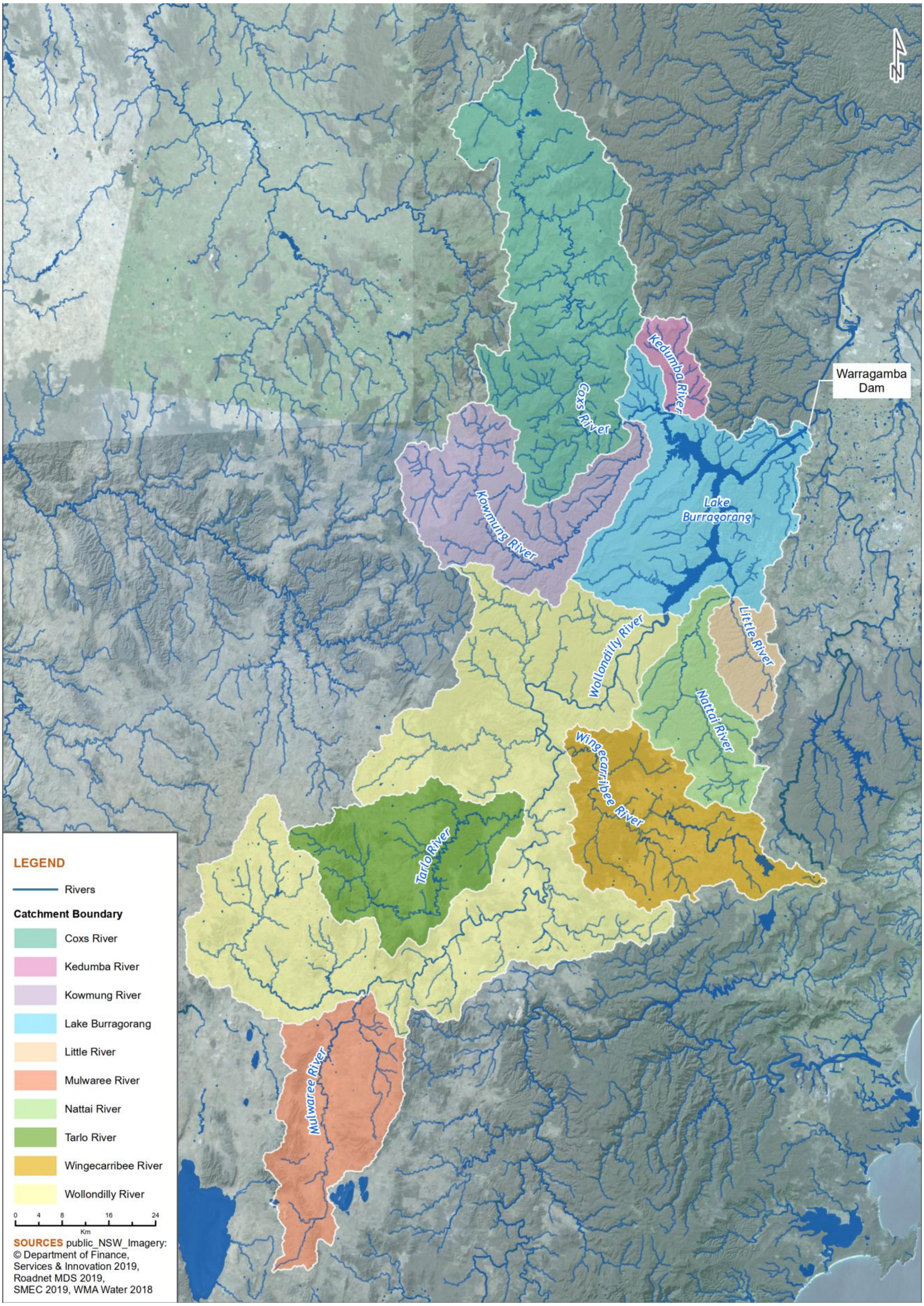


Figure 22-13. Downstream catchments

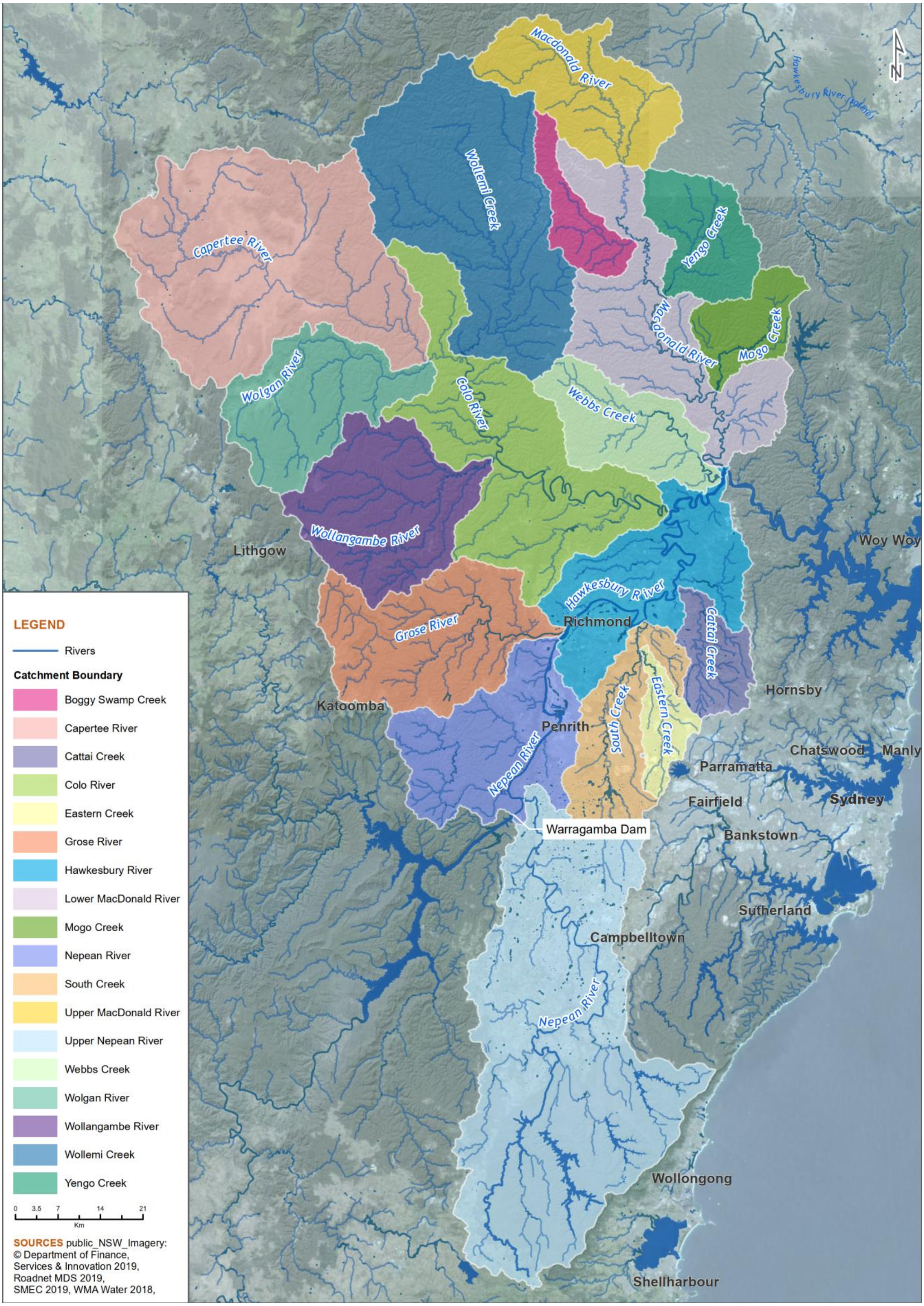


Figure 22-14. Hydrogeology – upstream study area

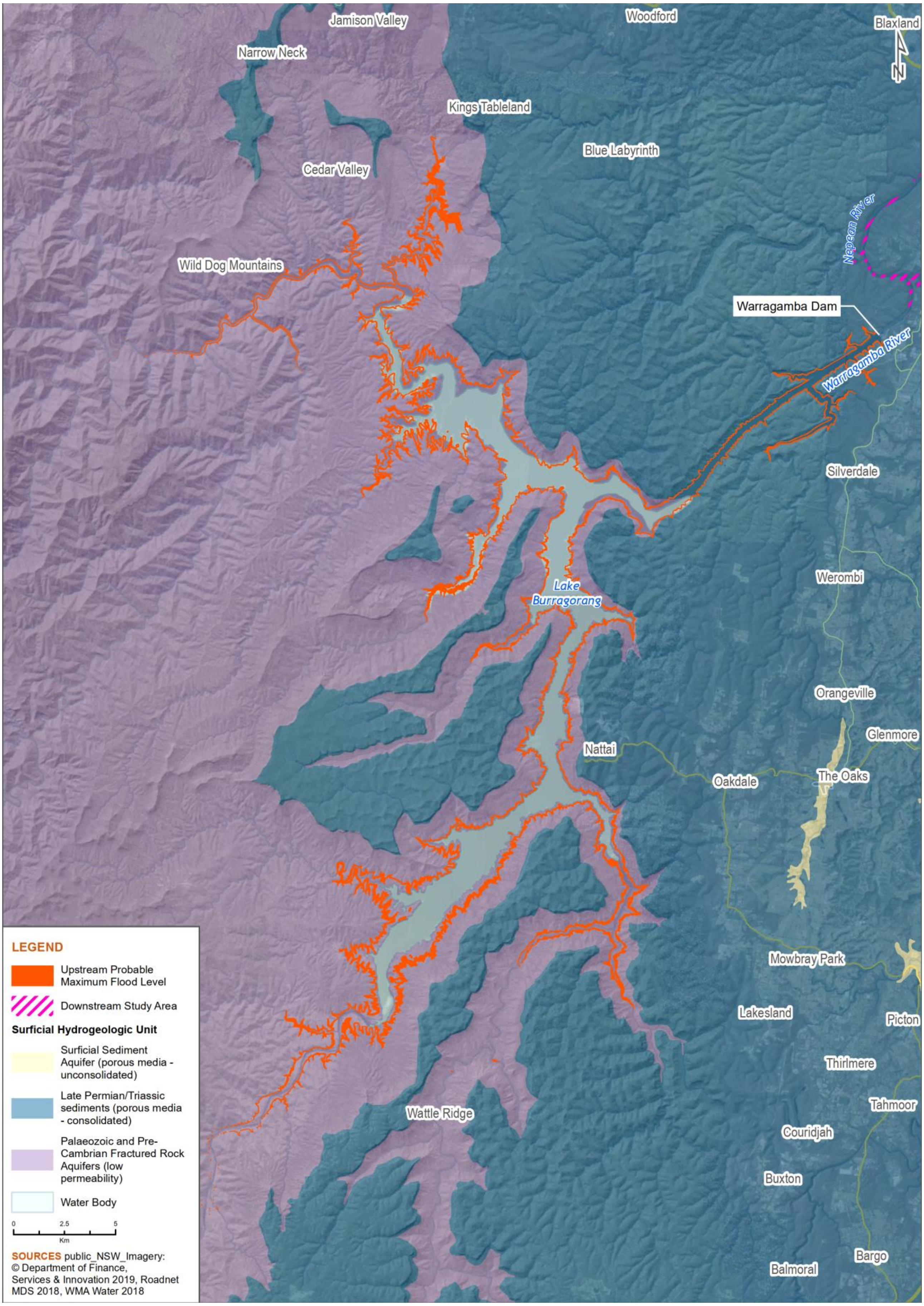
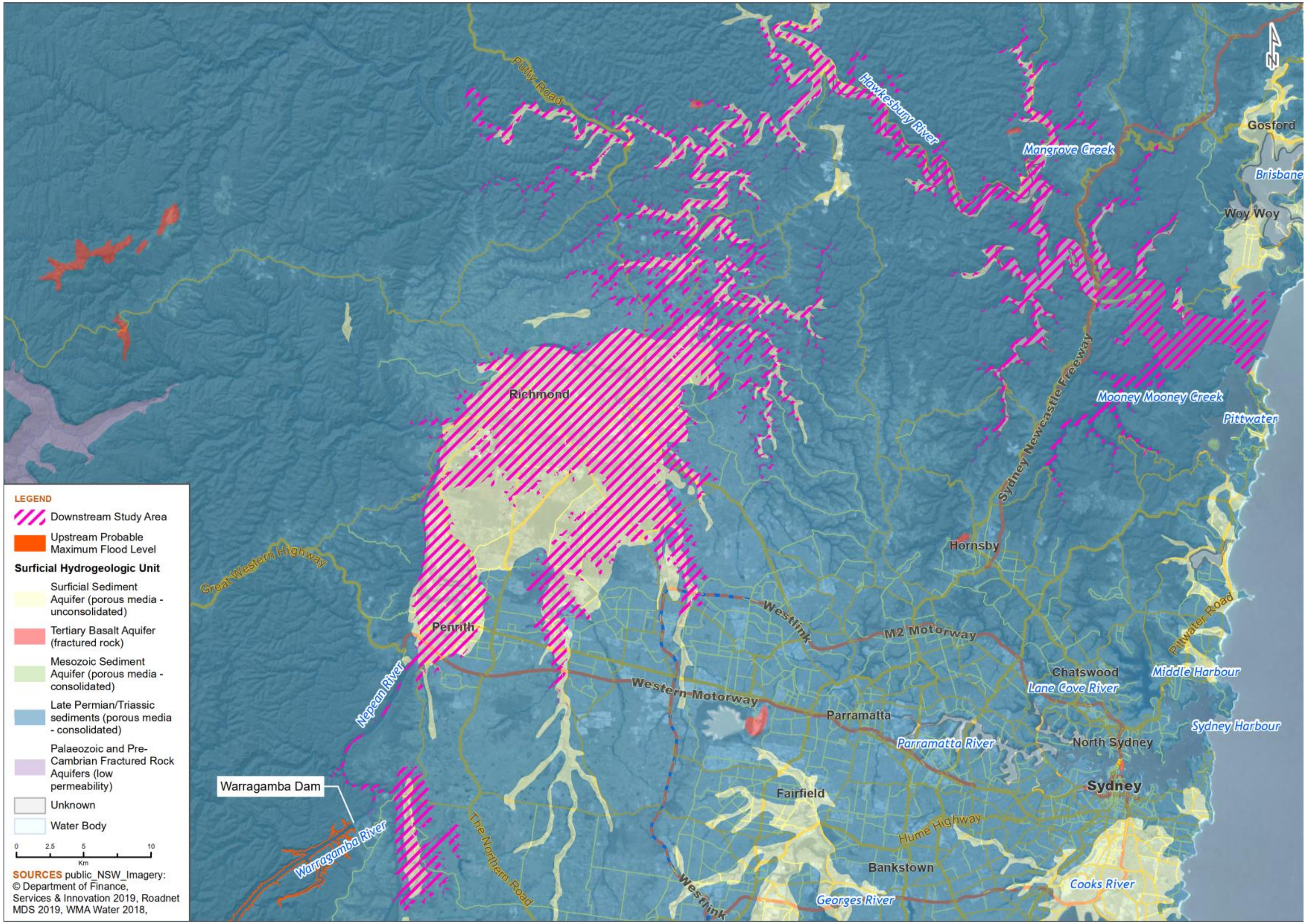


Figure 22-15. Hydrogeology – downstream study area



22.3.6 Aerial photography and slope analysis

Historic aerial images of selected sites within the study area are provided in Appendix N2 (Geomorphology assessment report, Appendix C). Selected sites are shown on Figure 22-16 and a summary of changes to the geomorphological structure summarised in Table 22-6, Table 22-7 and Table 22-8.

Table 22-6. Upstream: Changes in geomorphology

Site code[1]	Observations
Wollondilly River	
US-01	2009 onwards – Sediments of left bank pool with increasing vegetation cover in 2015-2016
US-02	Removal of vegetation and sediment deposition on left hand bank in 2014 and again in 2016 following regrowth
US-03	No changes observed over timeframe
US-04	No changes observed over timeframe
US-05	2018 re-vegetation of extensive delta
Nattai River	
US-06	No changes observed over timeframe
US-07	Extensive reworking of channel on braided floodplain with eyots forming. Inundation of levee in 2013.
US-08	Transport of sand in channel evident 2006 – 2010.
Coxs River	
US-09	Partial vegetation of in-channel fill in 2012 that subsequently is eroded
US-10	Partial non-vegetated sand bar deposited in the channel which appears to be either inundated or eroded downstream in 2012.
Reedy Creek	
US-11	No changes observed over timeframe
Kedumba River	
US-13	Poor resolution but a sand bar has been deposited in the downstream reach in the 2017 image.
US-14	No changes observed over timeframe clear. Vegetation partially masks channel structure.
Cedar Creek	
US-16	No changes observed over timeframe

1. See Appendix N2.

Table 22-7. Lake Burragorang

Site code[1]	Observations
R-01	Form of inlet to south remains stable. Main shoreline appears non-vegetated but progressive re-vegetation to 2019. Some rill erosion evident.
R-02	Exposed foreshore evident in 2010 and 2019 but inundated in 2013 and 2016. Vegetation evident in 2010 has disappeared. Rill erosion evident in swash zone.
R-03	Sand bypass channel in 2006 has been re-vegetated in successive 2012, 2014 and 2016 images.
R-04	No changes observed over timeframe
R-05	No changes observed over timeframe
R-06	Mud deposits along cliff-face emanating from southern inflow in 2015. These appear to be in suspension. Other tributaries in area also appear to contain silt deposits.

1. See Appendix N2.

Table 22-8. Downstream: Changes in geomorphology

Site code[1]	Observations
Warragamba River	
DS-01	Vegetation of mid-channel bar between 2014 and 2018.
DS-02	Highly turbid water in 2007 (fine sediments) and 2009 (algae) appear to be sourced from upstream Nepean, rather than from Warragamba. No change to channel structure.
Nepean River	
DS-03	Channel inflow on left hand bank evident in 2016. Revegetation in other years.
DS-04	No changes observed over timeframe.

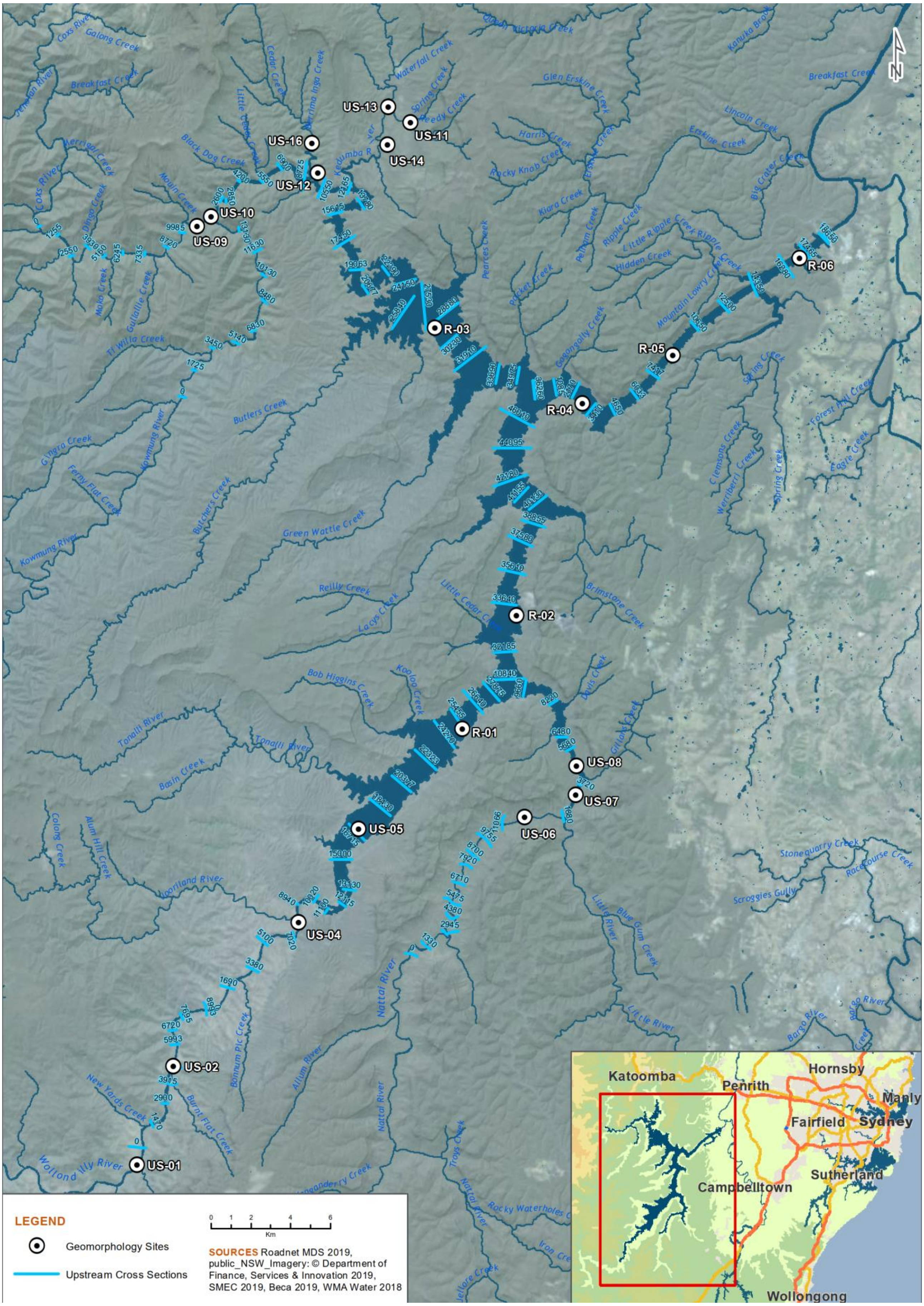
1. See Appendix N2.

Watercourse gradients are important when analysing potential erosion impacts and can be classified as follows:

- Low slope (0-10 percent)
- Medium slope (11-20 percent)
- High slope (>20% percent).

Water course slopes are given in Appendix N2 (Geomorphology assessment report, Table 8). Most of the short creeks that flow into Lake Burragorang have high slopes, while the Coxs, Nattai and Wollondilly Rivers have low slopes. Most of the downstream rivers have low slope, except for the Grose River, which has a high slope.

Figure 22-16. Selected geomorphological sites (refer Appendix N2)



22.3.7 River Styles framework

The Water Division of NSW Department of Planning, Industry and Environment (DPIE) and Macquarie University developed the NSW River Styles Database. Classifications found within the upstream and downstream study areas are presented for the following parameters:

- River Style classifications (Figure 22-17)
- Fragility (Figure 22-18)
- Recovery potential (Figure 22-19)
- Stream condition (Figure 22-20).

A detailed breakdown of these attributes for watercourses and a literature review of geomorphological conditions are provided in Appendix N2 (Geomorphology assessment report, Section 3.1.4 and Appendix E).

22.3.7.1 Lake morphology

The morphology of Lake Burragorang is dominated by the flooded V-shaped river channel remnants primarily of the Coxs and Wollondilly Rivers. This is discussed in Appendix N2 (Geomorphology assessment report, Section 3.1.5) and summarised below:

- There are numerous incisions in the steep sides of the gorge and other steep sections of the lake, most likely the result of minor faults or joints in the underlying sandstone that have been exploited by natural drainage over time to form these small-scale erosional features (MGS 2014).
- There are numerous fluvial-type depositional and erosion features on the lake floor in many of the shallower reaches of the lake including a network of braided channels, sediment bars and point bars. These are indicative of an area of sediment deposition on the valley floor prior to the construction of the dam wall.
- Remnants of landslides/slumping and drowned roadways from pre-dam land use are evident.
- Several raised plateau features were noted in the moderately shallow to shallow sections of the Lake, in the Junction and lower reaches of the Coxs and Wollondilly Rivers. These features are believed to be remnants of fluvial channel bars that were formed prior to the construction of the dam. The sedimentary nature of these fluvial features is evidenced by the presence of slumps/slope failures along their margins.

22.3.8 Soil erosion and sediment transport

22.3.8.1 Catchment sediment loads and turbidity

Appendix N2 (Geomorphology assessment report, Section 3.1.6 and 3.1.7) provides detailed information on catchment sediment loads and turbidity profile of the Hawkesbury-Nepean River. Estimated sediment loads are summarised in Table 22-9 and the turbidity profile for the Hawkesbury-Nepean River shown on Figure 22-21.

Table 22-9. Estimated suspended sediment loads for rivers in the Lake Burragorang catchment

River	Suspended sediment load (tonnes/annum)	Catchment area (km^2)	Catchment factored load (tonnes/annum/km^2)
Coxs	54,822	2,630	21
Nattai	154	446	0.3
Wollondilly	496,983	2,699	184

Long-term median turbidity levels generally remain relatively low in the freshwater section between Penrith and North Richmond. These levels are below the minimum ANZG 2018 guidance level for lowland rivers (South Australia, including NSW, aquatic ecosystem generic guideline) and could be due to lack of sediment supply caused by the dam and/or the depositional conditions in the area. Between Cornwallis and Ebenezer where the Rickabys and South Creek confluences enter the Hawkesbury, there is a peak in turbidity medians. Following this, a gradual reduction back to low levels occurs close to the mouth of the Hawkesbury River.

Figure 22-17. River Styles – Classification (refer Appendix N2)

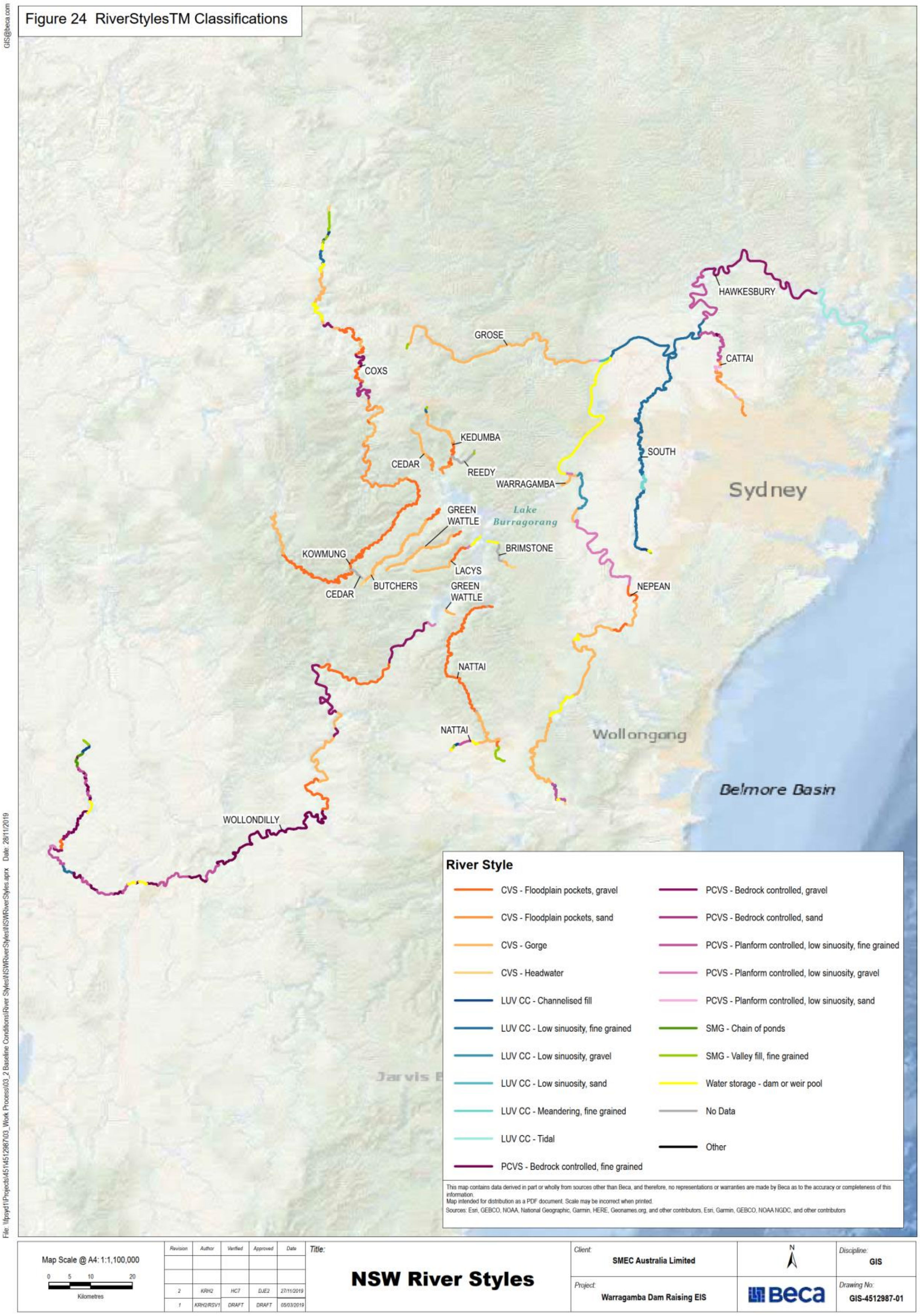


Figure 22-18. River Styles – Fragility (refer Appendix N2)

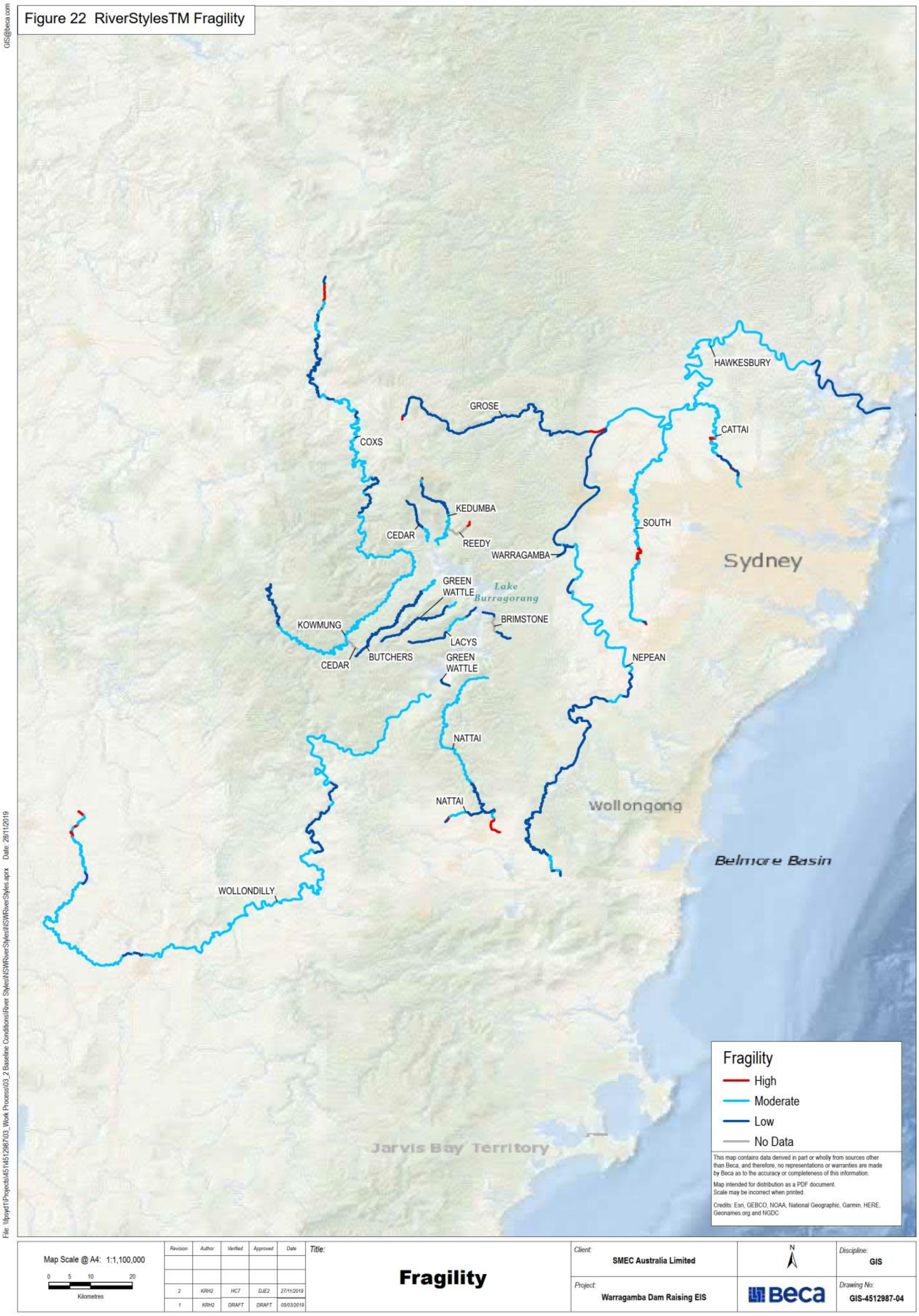


Figure 22-19. River Styles – Recovery potential (refer Appendix N2)

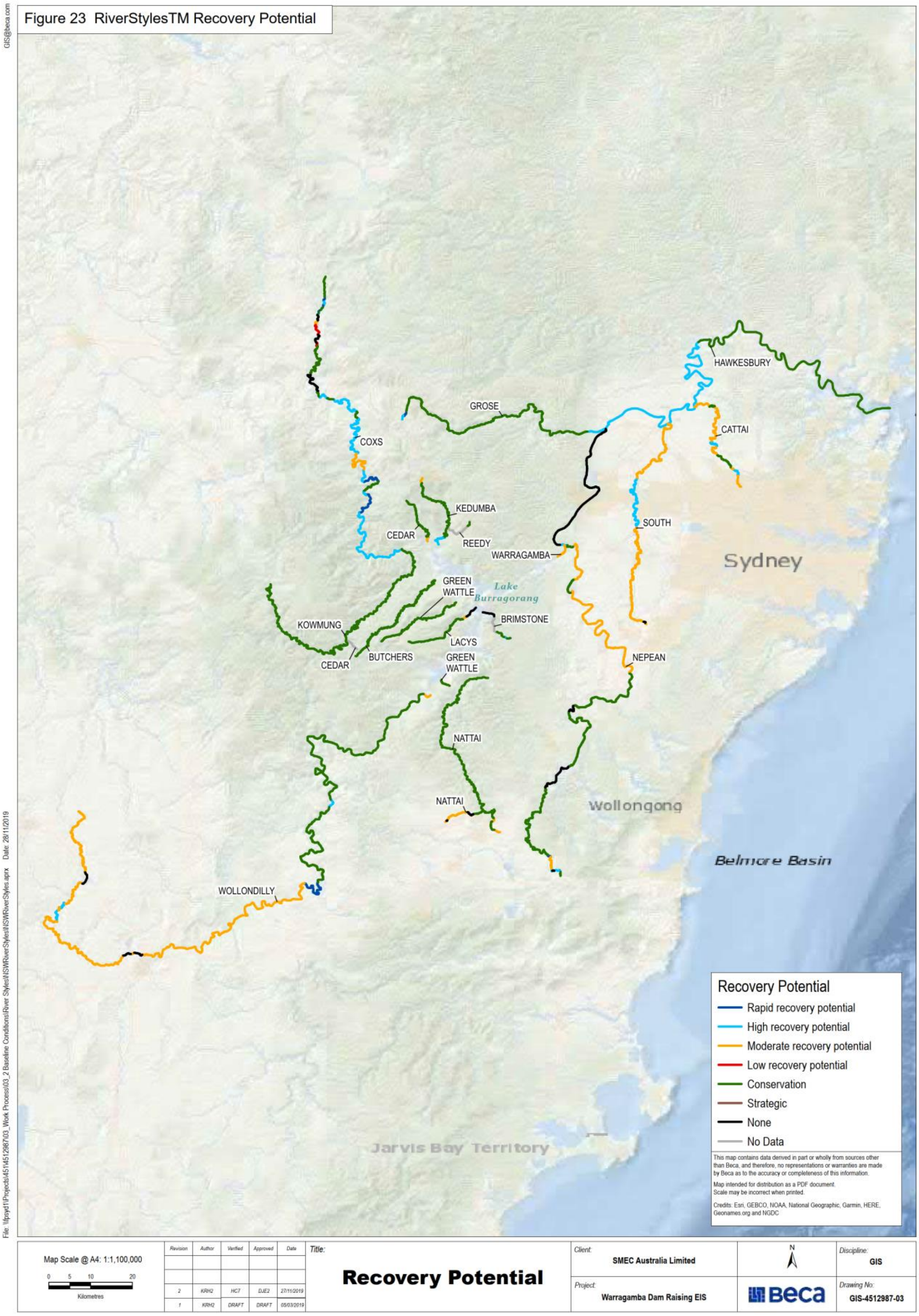
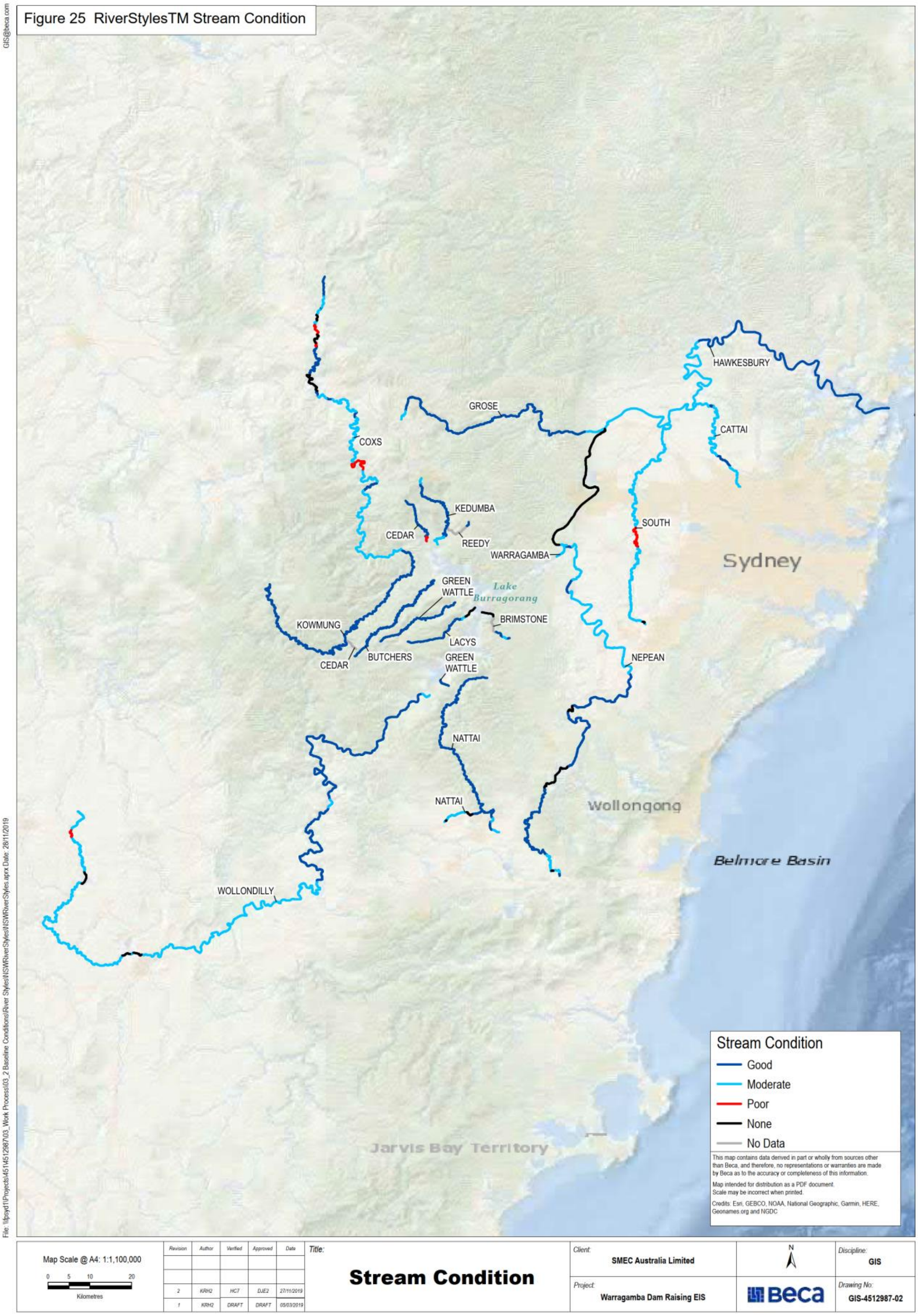


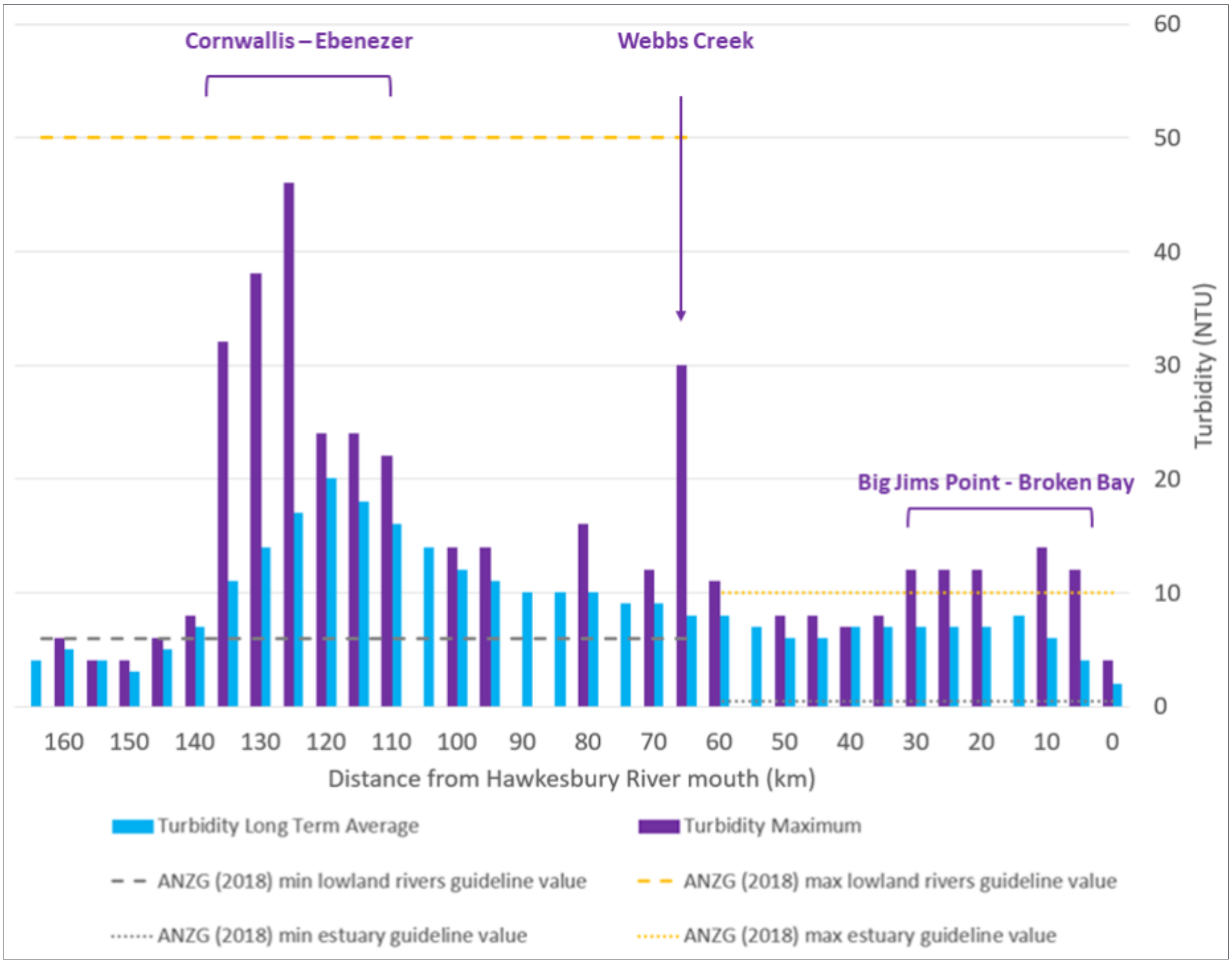
Figure 22-20. River Styles – Stream condition (refer Appendix N2)



There are two exceptions to this pattern of decreasing turbidity in the Hawkesbury River towards the Tasman Sea:

- elevated turbidity at Webbs Creek. This 'turbidity maximum' occurs in many coastal waterways, caused by the trapping and flocculation of sediment at the wedge (e.g. salinity discontinuity) between freshwater and seawater (Jassby *et al*. 1995, Uncles *et al*. 2002)
- consistent maximum levels above the ANZG (2018) estuary guidelines between Big Jims Point and Broken Bay. Tide-dominated coastal waterways are naturally turbid because strong tidal currents resuspend fine sediment (Heap et al. 2001; Porter-Smith *et al*. 2004). Tidal currents have the capacity to mobilise fine sediments and turbidity levels can vary considerably due to the spring-neap cycle of high and low tidal ranges and the daily cycle of high and low tides.

Figure 22-21. Hawkesbury-Nepean River turbidity profile (ref. Appendix N2)



22.3.8.2 Hot spot modelling

Results from the hot spot modelling (see Section 22.2.2) are summarised as follows:

- erosion risk classifications were categorised from negligible to high. Most of the land in the upstream study area is categorised as 'slight' (41 to 72 percent of total land area) and 'low' (27 to 47 percent of total land area). Only up to 11.2 percent of land was classified intermediate erosion risk, and up to 0.4 percent high risk or greater
- creeks flowing into the lake from the east and south (for example, Little River, Nattai River, Werriberri Creek and Wollondilly River) have a similar erosion range to the north-east arm of Lake Burragorang, with slight to low erosion risk predominating. However, the creeks to the west of Lake Burragorang (for example, Cedars

Creek, Coxs River, Kedumba River and Kowmung River) have higher erosion risk, with the intermediate category predominating. This could be due to increased land gradient in this area

- a large volume of sediment has accumulated in the Wollondilly River above its gorge reach, approximately 25 kilometres from Lake Burragorang. These deposits have persisted as stable sediment storage sites (away from the banks) for decades following their deposition, with many being revegetated with grass and riparian vegetation. Despite this long-term stability, there remains the potential for these sediment deposits to be destabilised during large floods and made available for downstream transport
- the Wollondilly River is also characterised by large delta deposits where the river enters the lake. This stretches for almost five kilometres, from three kilometres within the lake itself to two kilometres up the river to an abrupt meander bend, which is likely to be the limit of further deposition
- there has been a dramatic reduction in sediment deposition across the catchment over the past 20 to 40 years and sediment yields in the major river systems have declined substantially below their initial post-settlement peak (Wasson *et al*. 1998; Olley & Wasson 2003). Better management of vegetation cover is also likely to be influencing lowered sediment yields today compared to a century ago
- further up the Kedumba River the presence of levees suggest that bank overtopping is a common occurrence, however sediment deposition was assessed to be small
- sediment transport into Lake Burragorang was dominated by the Wollondilly River with Coxs and Nattai Rivers delivering successively lower loads.

22.3.9 Water and adjacent land environmental values

22.3.9.1 Upstream

Important aquatic and terrestrial habitats within the upstream study area are discussed in Chapter 8 (Upstream Biodiversity), Chapter 11 (Aquatic ecology) and Chapter 12 (Matters of national environmental significance).

Upstream vegetation mapping is shown on Figure 22-22. Vegetation within the study area is aligned with 18 Plant Community Types (PCTs), which are defined within the Vegetation Information System (VIS) Classification Database. Most of the study area (99.7 percent) is covered with native vegetation, with small areas classified as cleared-modified land and exposed rock. Eleven (11) vegetation classes are identified (Keith 2004), these being:

- Northern Warm Temperate Rainforests
- Central Gorge Dry Sclerophyll Forests
- Sydney Sand Flats Dry Sclerophyll Forests
- Dry Rainforests
- Coastal Floodplain Wetlands
- Sydney Hinterland Dry Sclerophyll Forests
- Sydney Coastal Dry Sclerophyll Forests
- Eastern Riverine Forests
- North Coast Wet Sclerophyll Forests
- Western Slopes Grassy Woodlands
- Northern Hinterland Wet Sclerophyll Forests.

The study area is centred around Lake Burragorang, which was created following construction of Warragamba Dam in 1960. Consequently, vegetation surrounding Lake Burragorang is not typical riparian or flood plain vegetation but is composed of vegetation characteristic of ridgetops on skeletal soils and valley slopes. Most of the study area supports dry sclerophyll forest of shrubby sub-formation, as well as areas of wet sclerophyll forest, dry rainforest, warm temperate rainforest, grassy woodlands, and forested wetlands.

There are several important wetlands within the Lake Burragorang catchment, of which four are considered nationally significant. However, none of these wetlands occur within the upstream study area.

The channels upstream and downstream of the dam provide valuable aquatic and terrestrial habitat with broad environmental value, while Lake Burragorang supports an abundance of aquatic flora and fauna including macroinvertebrates, molluscs, fish, reptiles and mammals.

22.3.9.2 Downstream

Important aquatic and terrestrial habitats within the downstream study area are discussed in Chapter 9 (Downstream Biodiversity), Chapter 9 (Construction area Biodiversity), Chapter 11 (Aquatic ecology) and Chapter 12 (Matters of national environmental significance).

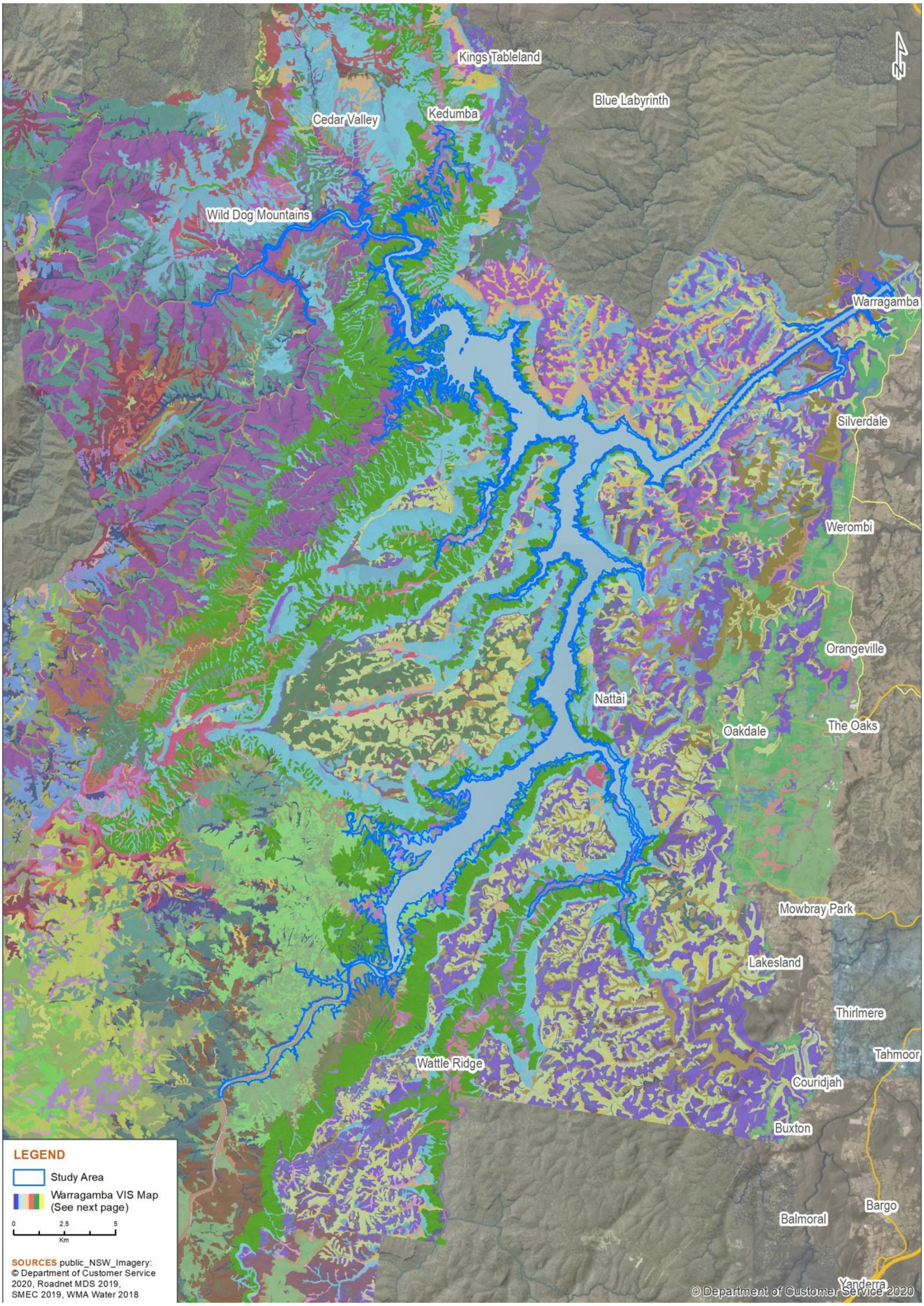
Downstream vegetation mapping is shown on Figure 22-23. Important wetland areas are shown on Figure 22-24. Vegetation and habitat across the study area varies significantly in its structure, floristics, and condition. Within the Cumberland lowlands, much of the vegetation has been subject to clearing and disturbance due to historical land use practices such as agriculture and, more recently, urban development. Consequently, most the intact native vegetation is found within national parks, conservation reserves, council managed land and small remnant patches in farm paddocks. Approximately 73 percent of the study area has been previously cleared, disturbed or dominated by exotic vegetation.

The downstream river system includes both freshwater and estuarine waters between the Warragamba River directly downstream of the dam wall and Wisemans Ferry (Figure 22-24). Features include upland lakes, wetlands, coastal swamps and coastal floodplains. Wetlands listed in the Directory as Important Wetlands in Australia include Pitt Town Lagoon located off Bardenarang Gully and Longneck Lagoon located off Longneck Creek near Pitt Town. No Ramsar or coastal wetlands are located within the downstream study area.

The downstream environment includes waterways and their associated riparian zones as well as floodplain and wetland waterbodies adjacent to the main rivers. Wetlands in the region are in poor condition overall (DECCW 2010c), due to altered hydrology and disturbance. These floodplain wetlands include flood lakes, backswamps, ponded tributaries and creek swamps. They provide important habitat for migratory water birds. While they are predominantly invaded by carp, they have potential to provide native fish habitat (BMT WBM 2014a).

Wetland mapping studies show 50 floodplain wetlands with regional conservation significance associated with the Hawkesbury-Nepean River downstream of Pheasants Nest and Broughtons Pass Weirs to the confluence of the Colo River, with the majority found from Richmond to Wisemans Ferry. Other floodplain wetlands exist on the Richmond Lowlands including Irwins Swamp, Yarramundi Lagoon, Bakers and Triangle Lane Lagoons (both in private ownership), and Pughs and Bushells Lagoons spanning both public and private property. There are several threatened aquatic species present in the study area.

Figure 22-22. Vegetation – Upstream



LEGEND

warragamba_VISmap_2380

- 1 Sandstone Warm Temperate Rainforest
- 10 Sheltered Sandstone Smooth-barked Apple Forest
- 11 Sheltered Sandstone Blue-leaved Stringybark Forest
- 12 Escarpment Mountain Grey Gum Forest
- 13 Sheltered Escarpment Blue Gum Forest
- 14 Escarpment Grey Gum Forest
- 15 Highlands Gorge River Peppermint Forest
- 16 Bindook Highlands Open Forest
- 17 Yerranderie White-topped Box Forest
- 18 Sheltered Porphyry Forest
- 2 Montane Cool - Warm Temperate Rainforest
- 20 Montane Sheltered Narrow-leaved Peppermint Forest
- 21 Kanangra Gorge Sheltered Grey Gum Forest
- 22 Oakdale Blackbutt Gully Forest
- 23 Burragorang River Flat Forest
- 24 Highlands Sandstone Dry Shrub Forest
- 25 Blue Mountains Sandstone Dry Shrub Forest
- 26 Nattai Sandstone Dry Shrub Forest
- 27 Burragorang Sandstone Dry Shrub Forest
- 28 Kowmung Sheltered Red Gum Forest
- 29 Exposed Devonian Grey Gum Forest
- 3 Grey Myrtle Dry Rainforest
- 31 Highlands Slopes Grey Gum - Stringybark Forest
- 32 Permian Footslopes Grassy Grey Box Forest
- 33 Tonalli Escarpment Dry Shrub Forest
- 34 Montane Sandstone Silvertop Ash Shrub Forest
- 35 Montane Exposed Silvertop Ash Forest
- 36 Montane Slopes Stringybark Forest
- 37 Montane Sandstone Dry Shrub Forest
- 38 Oakdale Alluvial Rough-barked Apple Forest
- 39 Tablelands River Oak Forest
- 4 Kowmung Dry Rainforest
- 40 Exposed Blue Mountains Sandstone Woodland
- 41 Exposed Burragorang Sandstone Shrub Woodland
- 42 Rocky Sandstone Heath Woodland
- 46 Kanangra Gorge Narrow-leaved Ironbark Woodland
- 47 Exposed Permian Sandstone Woodland
- 48 Escarpment Slopes Dry Ironbark Woodland
- 49 Dry Alluvial Paperbark Woodland
- 5 Highlands Basalt Acacia Scrub
- 50 Douglas Scarp Woodland
- 51 Devonian Red Gum - Yellow Box Woodland
- 52 Devonian Red Gum - Ironbark Woodland
- 53 Devonian Red Gum - Grey Box Woodland
- 55 Highlands Transitional Shale Woodland
- 56 Cumberland Plain Shale Sandstone Transition Forest (Low Sandstone Influence)
- 57 Cumberland Plain Shale Sandstone Transition Forest (High Sandstone Influence)
- 58 Cumberland Plain Alluvial Woodland
- 59 Cumberland Plain Shale Hills Woodland
- 6 Sandstone Riparian Scrub
- 60 Cumberland Plain Shale Plains Woodland
- 61 Rock Plate Heath-Mallee
- 62 Montane Heath-Mallee
- 64 Rosy Paperbark Heath
- 66 Kowmung Acacia Scrub
- 67 Regenerating Vegetation
- 68 Highlands Peat Swamp
- 69 Highlands Swamp Gum - Tea Tree Heath-Woodland
- 7 Montane Gully Brown Barrel Forest
- 70 Montane Sedgeland Heath
- 71 Upland Swamps Cyperoid Heath
- 72 Upland Swamps Tea Tree Thicket
- 73 Sandstone Brittle Gum Swamp Woodland
- 74 Thirlmere Sand Swamp Woodland
- 75 Lepironia Freshwater Wetland
- 76 Bindook Highlands Grassland
- 77 Exposed Rock
- 78 Cleared-Modified Land
- 79 Water Bodies
- 8 Sandstone Moist Blue Gum Forest
- 9 Sheltered Sandstone Intermediate Blue Gum Forest

Figure 22-23. Vegetation mapping – Downstream

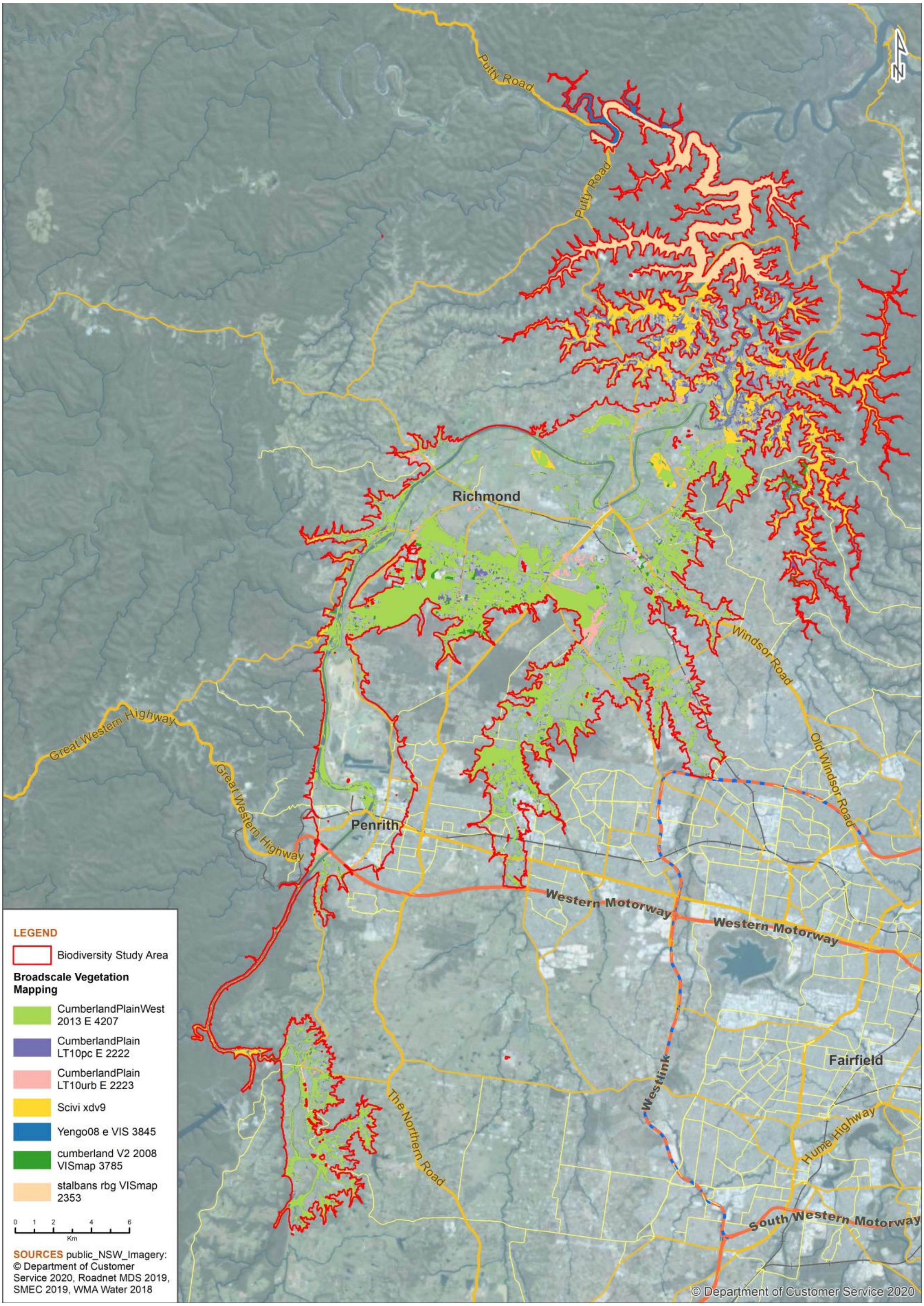
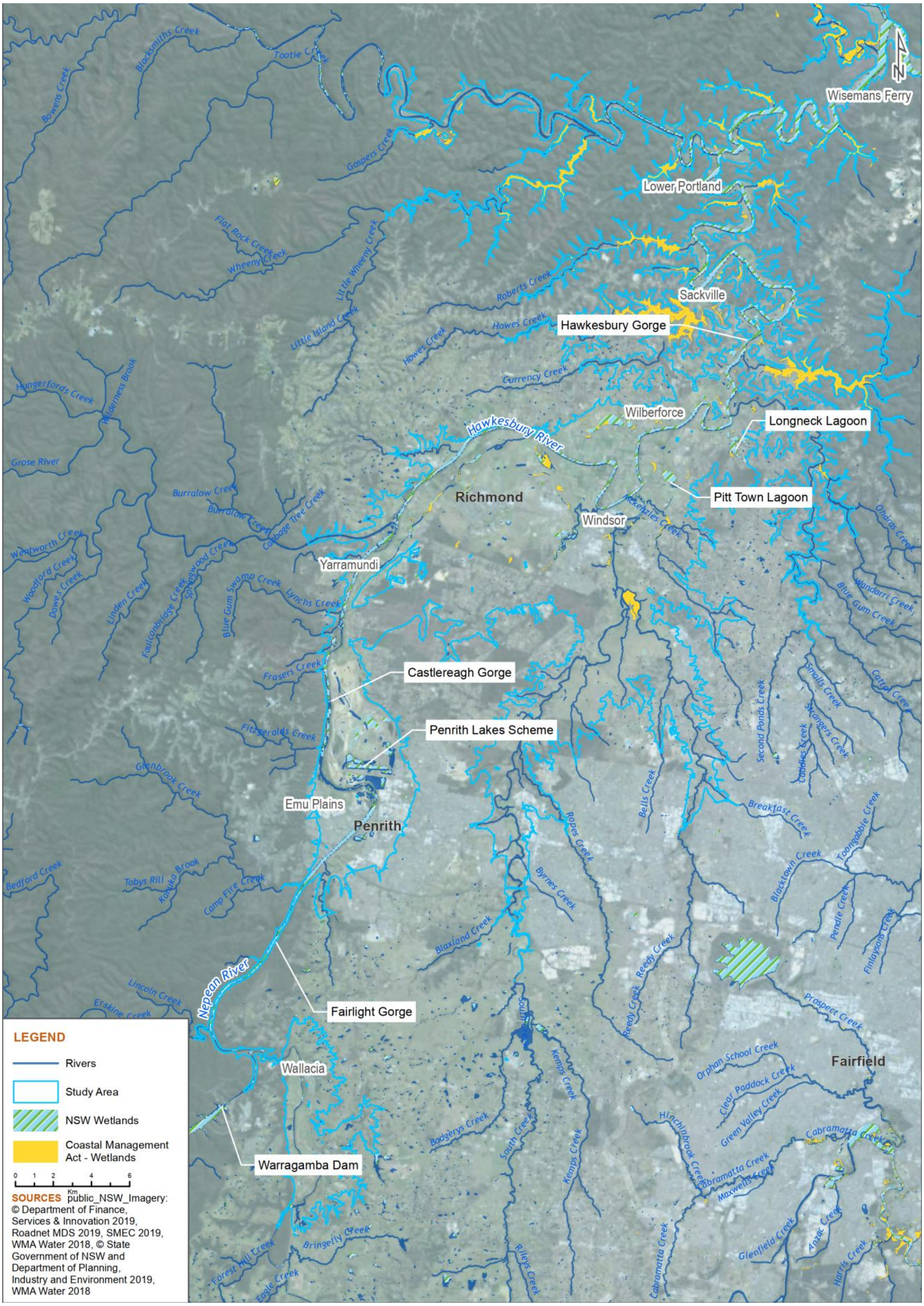


Figure 22-24. Wetlands – Downstream



22.3.10 Acid sulfate soils

Acid sulfate soil mapping and classes are discussed in Section 22.2.3. Acid sulfate soils can generally be described as:

- **coastal acid sulfate soils**: occur in coastal areas at elevations typically less than five metres AHD
- **inland acid sulfate soils**: less common, but can occur on inland waterways, wetlands and drainage channels where the right conditions, such as waterlogged saline areas with anaerobic conditions, have existed to aid the formation of iron sulfides.

22.3.10.1 Upstream

Acid sulfate risk and probability of occurrence in the upstream study area are shown in Figure 22-25 and Figure 22-26 respectively. Some areas immediately surrounding Lake Burragorang are mapped 'high probability of occurrence' of acid sulfate soils. This is likely associated with bottom sediments in low velocity flow environments. These areas occur in a relatively narrow band as land areas further adjacent to Lake Burragorang are mapped 'low probability' or 'extremely low probability' of occurrence of acid sulfate soils. There are no class 5 acid sulfate soils.

22.3.10.2 Downstream

Acid sulfate risk and probability of occurrence in the downstream study area are shown on Figure 22-27 and Figure 22-28 respectively.

The downstream study extends from Warragamba Dam to the mouth of the Hawkesbury River, and all acid sulfate soil classes occur within this area. This comprises:

- Class 1, areas along the:
  - Hawkesbury River and tributaries to as far west as about Mount White
  - Hawkesbury River from Mount White to about Lower Portland.
- Class 2, areas along:
  - Mangrove Creek to the extent of the probable maximum flood (PMF)
  - Adjacent the Hawkesbury River from Mount White to about Lower Portland, including Webbs Creek and areas of the Colo River near the confluence with the Hawkesbury River.
- Class 3, areas:
  - along the Hawkesbury River from about Gunderman to the confluence with the Nepean river
  - along the Nepean River from the confluence with the Hawkesbury River to Pitt Town
  - the floodplains of Richmond, Windsor and Pitt Town.
- Class 4, areas:
  - along the Hawkesbury River and minor tributaries from about Mount White with the confluence of the Nepean River
  - along the Nepean River and minor tributaries from the confluence with the Hawkesbury River to Pitt Town
  - the floodplains of Richmond, Windsor and Pitt Town.
- Class 5, areas: small localised thin wedge areas adjoining Classes 1 to 5.

These areas also coincide with those areas of acid sulfate soils mapped as high probability to low probability of acid sulfate soils nominally representing class 1 to class 5 respectively.

22.3.10.3 Construction area

The construction study area is not in an area mapped as acid sulfate soils potential or risk by either the acid sulfate soil class mapping (Environmental Planning Instrument – Acid Sulfate Soils) or eSPADE 2.0.

Figure 22-25. Acid sulfate soils risk – upstream study area

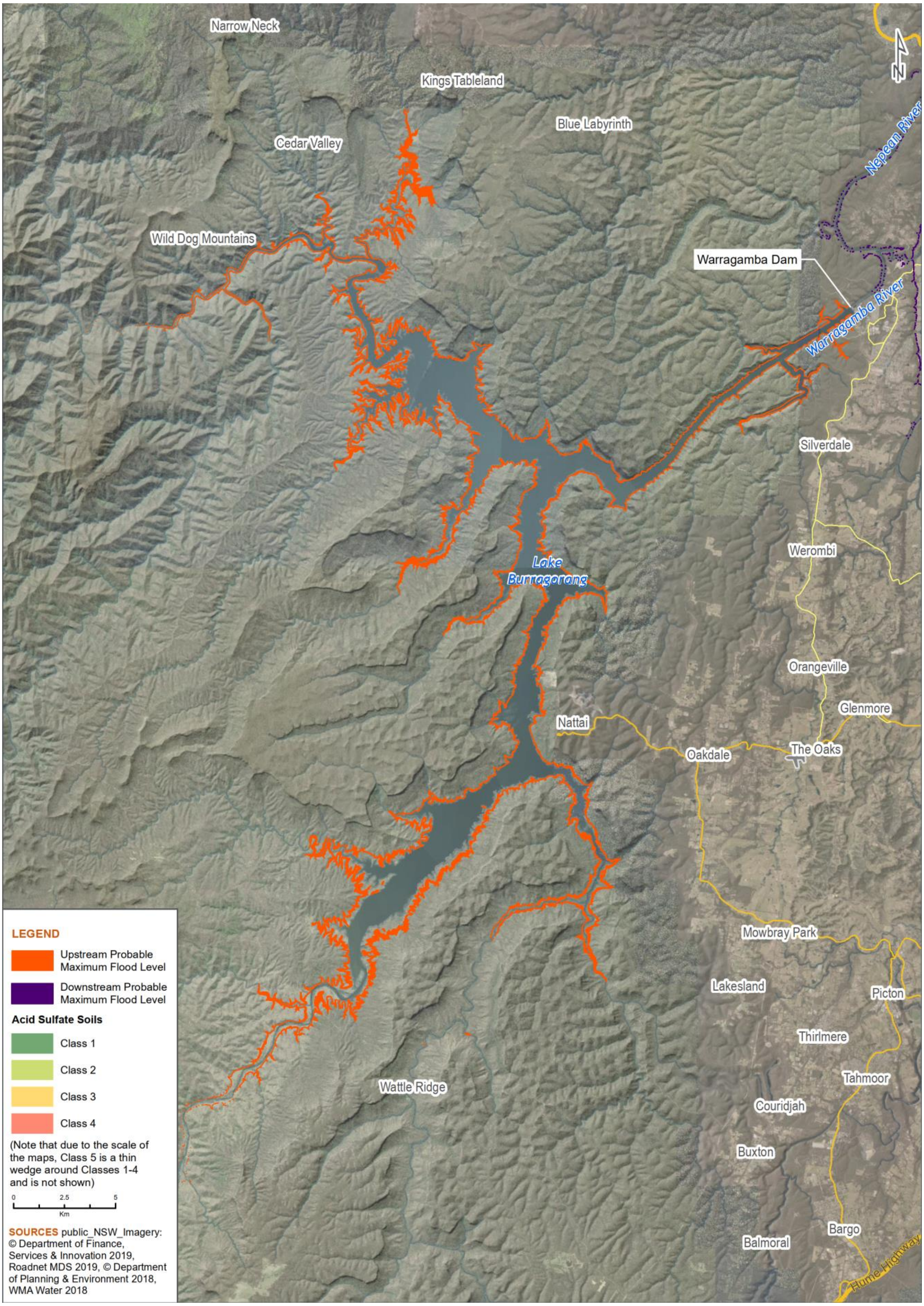


Figure 22-26. Acid sulfate soil probability – upstream study area

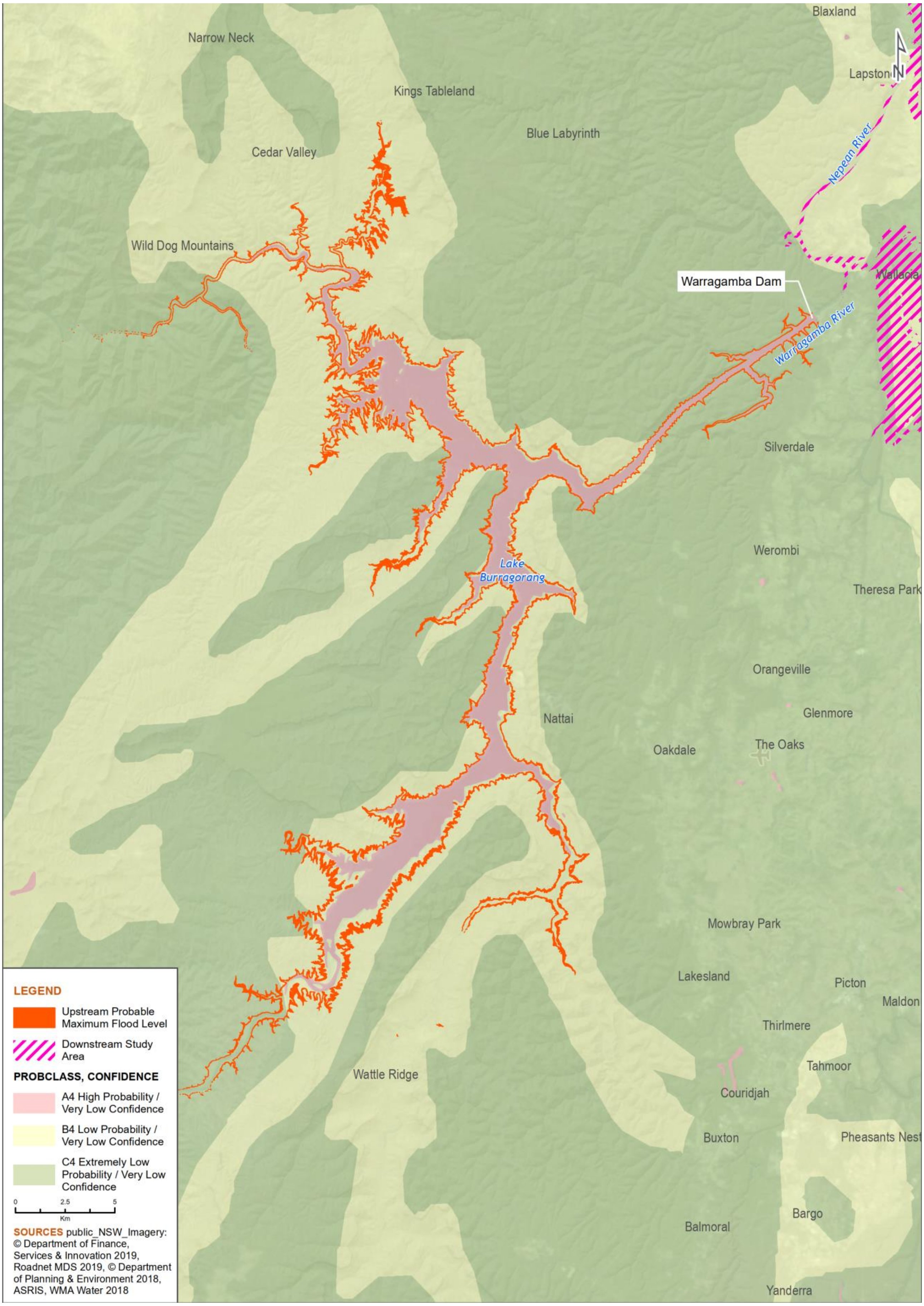


Figure 22-27. Acid sulfate soil risk – downstream study area

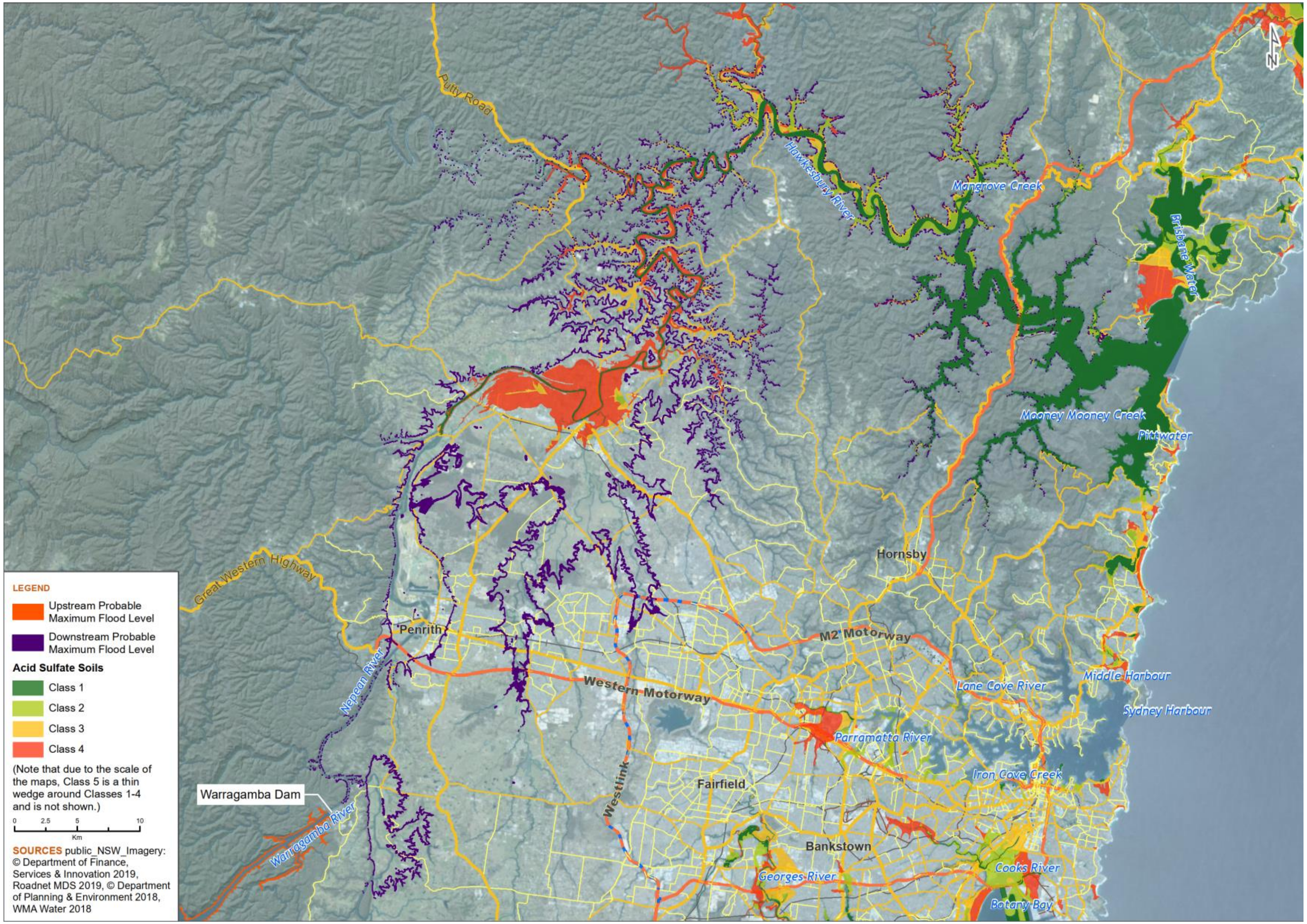
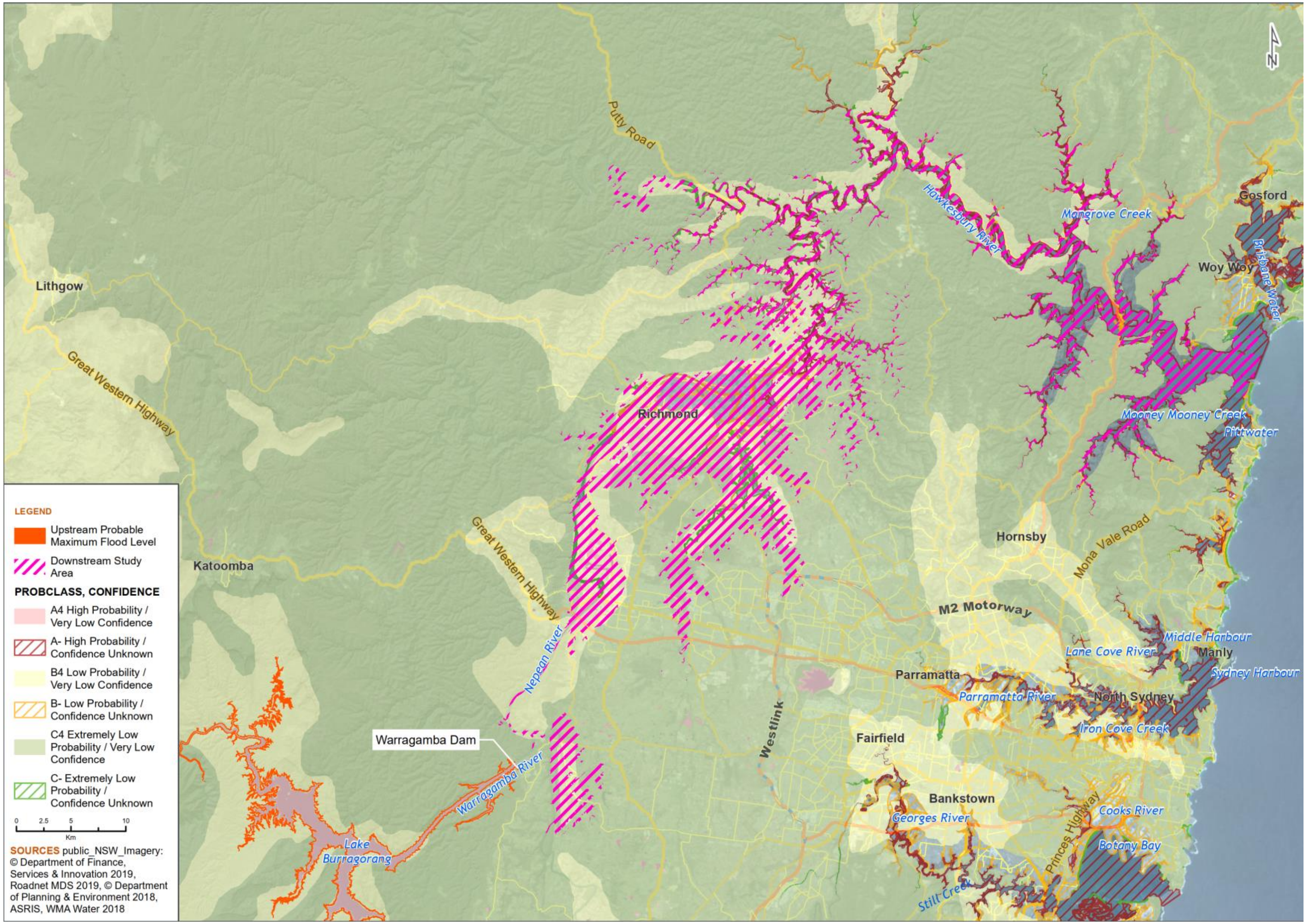


Figure 22-28. Acid sulfate soil probability – downstream study area



22.3.11 Salinity

The hydrogeological landscape (HGL) influences salinisation, as different HGLs have varying ability to store and make available salts. HGL maps show the relatively consistent formations in the upper catchment and the diverse and complex formations in the lower catchment.

Salinity risk is the likelihood of the salinity hazard being realised. It is determined by overlaying salinity hazard with conditions affecting salinity processes that can change over time. This provides a good indication of whether salinisation would occur, and the potential location, severity and extent that might be expected. Salinity risk factors include:

- short-term extreme climatic events
- land use
- condition of vegetation
- condition of soil.

22.3.11.1 Upstream

The HGL map for the upstream catchment is shown on Figure 22-29, which shows relatively consistent formations. The upstream geology consists mainly of porous or fractured rock aquifers that are of low salinity. There is limited available mapping of the salinity potential for the upstream study area. Salinity risk for the upstream study area is shown on Figure 22-30, which shows a portion of the study area as very low risk. The remainder of the non-mapped area is of similar geology and is likely to have a similar very low salinity risk.

22.3.11.2 Downstream

The HGL map for the downstream catchment is shown on Figure 22-31, which shows diverse and complex formations. Salinity potential for the downstream study area is shown on Figure 22-32, which indicates that most of the western suburbs of Sydney (for example Richmond, Penrith and Windsor), are underlain by soils categorised as having a 'moderate salinity potential'. Areas of 'high and known salinity potential' typically occur in proximity to the Nepean and Hawkesbury rivers. This association is due to the predominant geology, shallow groundwater tables and dissolved salts in these areas. A summary of salinity categories is presented in Appendix N1 (Soils and contamination assessment report).

The HGLs intercepted by the downstream study area and their overall salinity hazard is summarised in Table 22-10. Downstream salinity risk is shown on Figure 22-33. Key findings are:

- very high salinity risk area extends east across the downstream Project area, from Glenmore Park to Glendenning, and south from Vineyard to St Clair
- high risk area is around Oakville and Riverstone
- moderate salinity risk area is mapped across Penrith, Goulburn, Richmond and Pitt Town.

Table 22-10. Summary of existing hydrogeological landscape hazard rating

HGL	Land salinity impacts	Water EC impacts	Salt store	Salt availability	Impact[1]	Likelihood	Overall hazard
Agnes Banks Sands	Low	Low	Low	Low	Limited	Low	Low
Kurrajong	Moderate	Low	Moderate	Low	Limited	Moderate	Low
Currency Creek	Moderate	Moderate	Moderate	Low	Significant	Low	Low
Richmond Lowlands	Moderate	Moderate	Moderate	Moderate	Significant	Moderate	Moderate
Londonderry	Low	Moderate	Moderate	Moderate	Significant	Moderate	Moderate
Ropes Crossing	High	High	High	High	Severe	High	Very High
Box Hill	High	Moderate	Moderate	Moderate	Significant	High	High

HGL	Land salinity impacts	Water EC impacts	Salt store	Salt availability	Impact[1]	Likelihood	Overall hazard
Shale Plains	High	High	High	High	Severe	High	Very High
Upper South Creek	High	High	High	Moderate	Severe	High	Very High
Mulgoa	Moderate	Moderate	High	Moderate	Significant	Moderate	Moderate
Hawkesbury	Low	Low	Low	High	Limited	Low	Very Low
Greendale	Moderate	Moderate	Moderate	Moderate	Significant	High	High
Shanes Park	Moderate	Moderate	Moderate	Moderate	Significant	Moderate	Moderate

1. Impact rating relates to existing potential impacts arising from salinity, and is not related to the Project.

22.3.11.3 Construction area

The construction area falls within the upstream catchment HGL (Figure 22-29 and salinity risk Figure 22-30) figures. The construction area is likely to have a low salinity risk.

Figure 22-29. Hydrogeological landscape – upstream study area

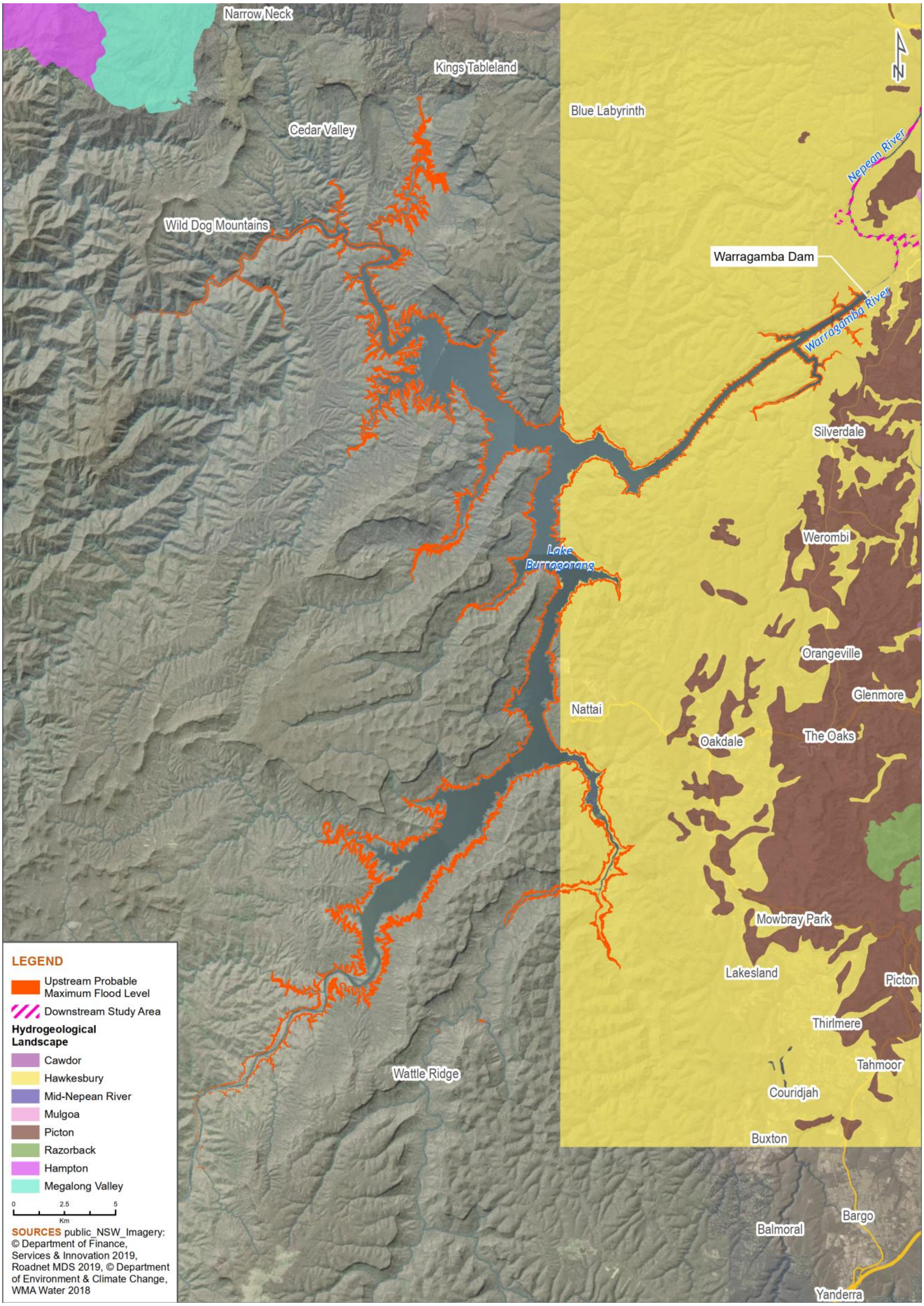


Figure 22-30. Salinity risk - upstream study area

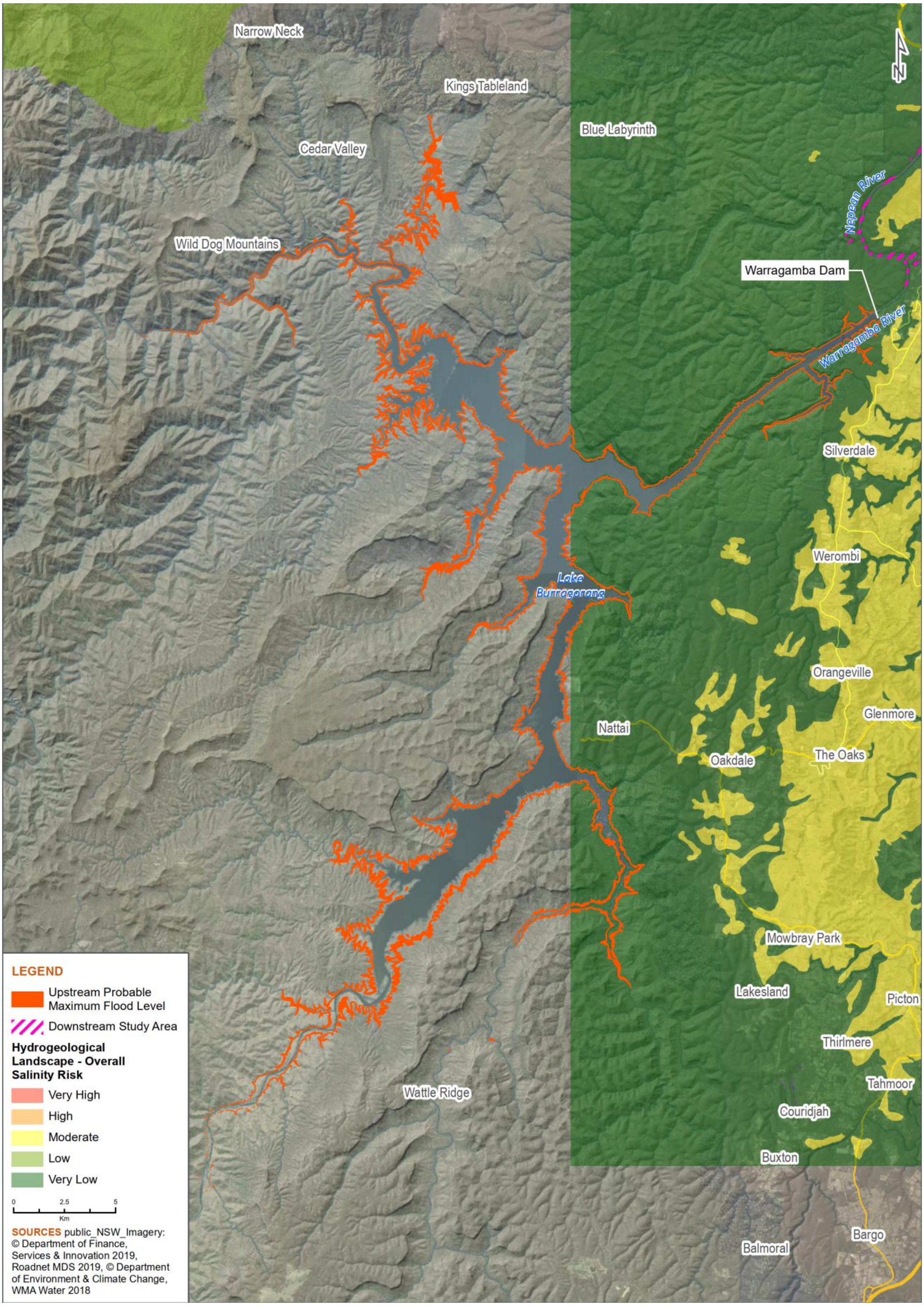


Figure 22-31. Hydrogeological landscape – downstream study area

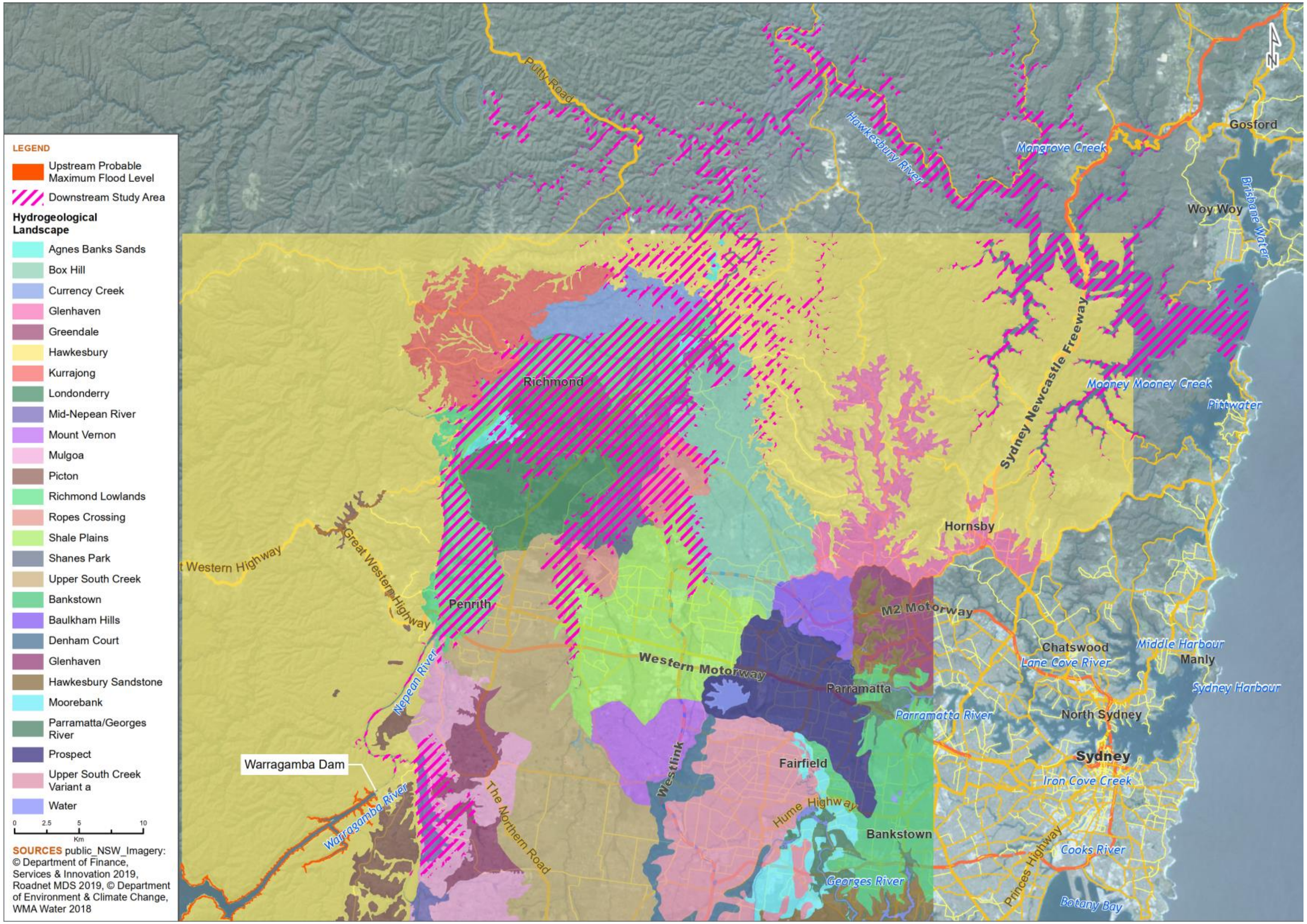


Figure 22-32. Salinity potential – downstream study area

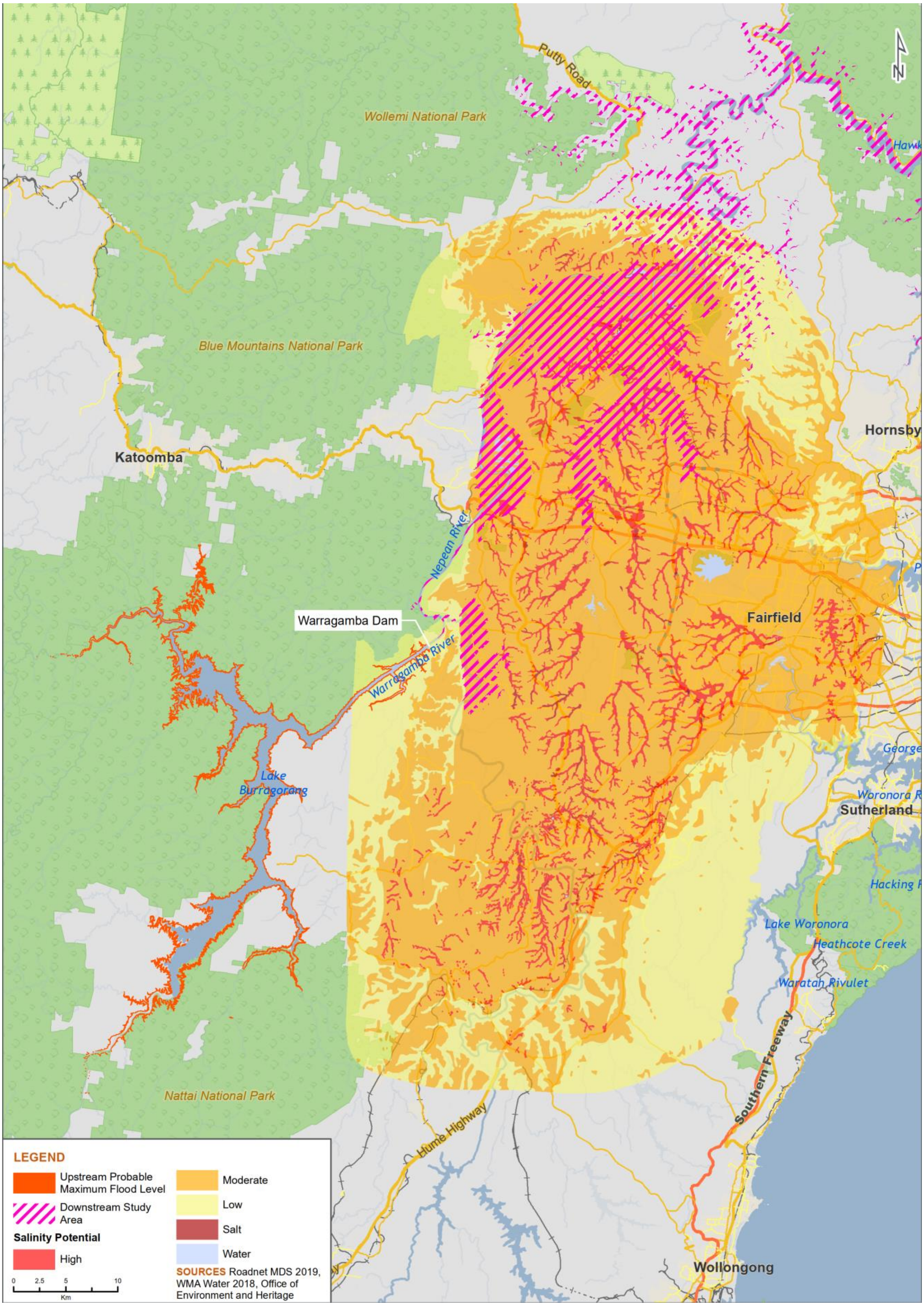
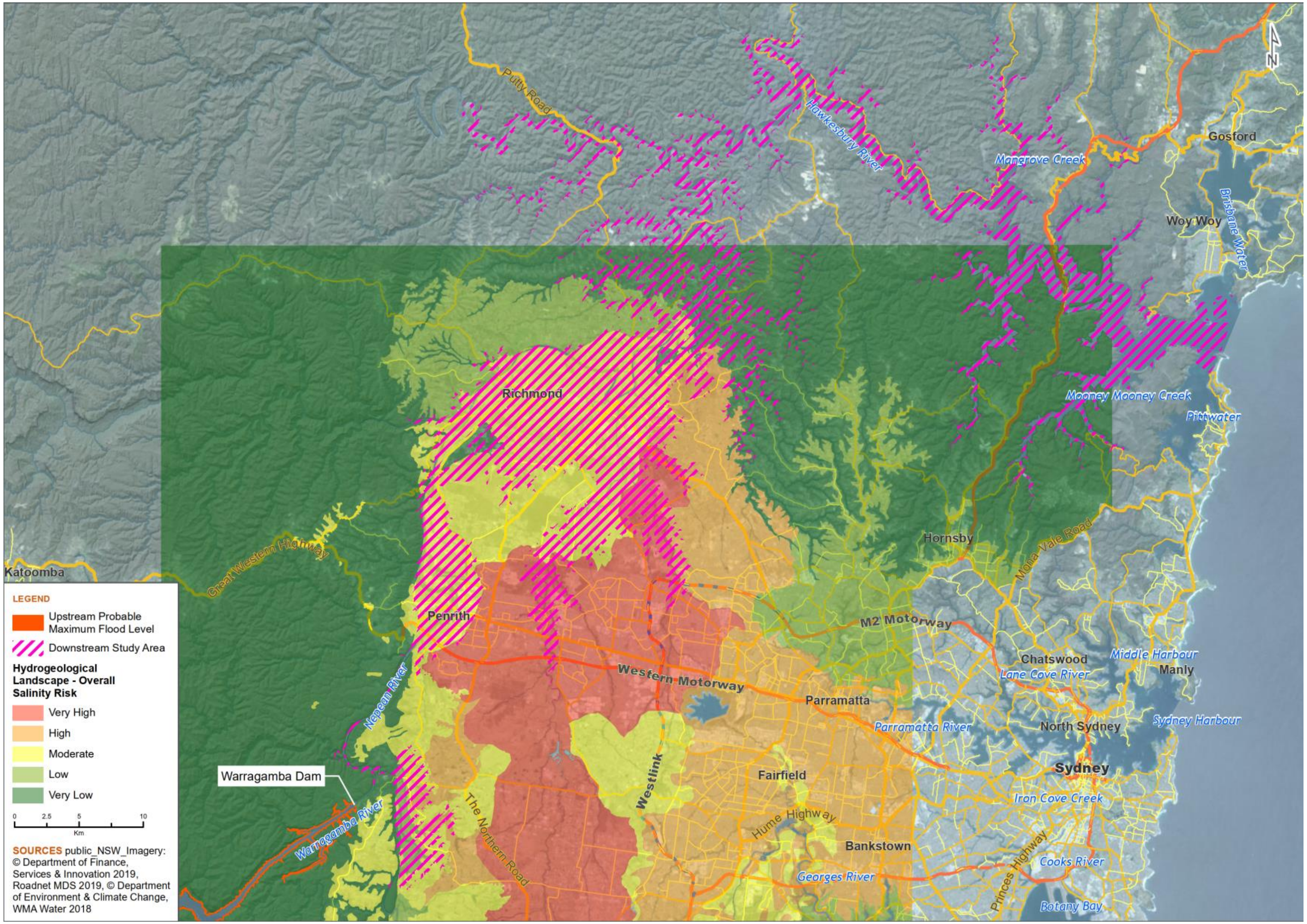


Figure 22-33. Salinity risk - downstream study area



22.3.12 Contaminated land

22.3.12.1 Upstream area

Historical industrial activities in the upstream study area included mining and agriculture, both activities that have the potential to lead to land contamination. The study found:

- a search of the *List of Contaminated Sites Notified to EPA* identified two sites; however, neither were noted as requiring regulation by the Environmental Protection Authority (EPA)
- no sites were listed on the EPA Contaminated Land Record of Notices
- no sites were listed on the National Pollutant Inventory (NPI)
- no recorded unlicensed premises regulated by the EPA.

22.3.12.2 Construction area

Several sites and buildings within the construction area have previously been identified as contaminated. These are shown on Figure 22-34 and include:

- explosives store and vehicle refuelling area (Site A)
- former workshop yard on Farnsworth Avenue (Site B)
- various commercial properties (Site C and Site D)
- some portions of land around Megaritty's Creek, Weir Road, Warragamba (Site E)
- the Warragamba Dam viewing platform at Eighteenth Street (Site F).

Previous investigations indicate that soils on the sites listed above may have:

- significant soil contamination of copper, lead and zinc
- contamination by petroleum hydrocarbons and polychlorinated biphenyls (PCBs).

The available reports suggest that the areas were remediated by burying and containing soils contaminated with heavy metals in a purpose-built disposal cell, and bioremediation of soils contaminated with petroleum hydrocarbons and PCBs.

The Warragamba Dam viewing platform is listed on the List of Contaminated Sites Notified to EPA; however, it is listed under the EPA site management class as 'Regulation under CLM Act not required'. 'Regulation under the CLM Act not required' identifies that the EPA has completed an assessment of the contamination at this site and decided that regulation under the CLM Act is not required. Contamination may still exist at the Warragamba Dam viewing platform, but the EPA has determined that it does not need to be managed under the CLM act.

A number of NPI sites categorised as 'sewerage and drainage services' and 'water supply' were identified in or near the construction area, which are shown on Figure 22-35.

22.3.12.3 Downstream area

A search of the *List of Contaminated Sites Notified to EPA* identified 30 sites in the downstream study area, many of which were listed as service stations. Of these, three sites were noted as being under regulation by the EPA – a former service station, a metal industry, and a former drum re-conditioner.

There were no sites in the downstream study area listed on the EPA Contaminated Land Record of Notices. A search of public registers under Section 308 of the *Protection of the Environment Operations Act 1997* identified over 200 sites within the downstream study area, which are identified in Appendix N1 (Soils and contamination assessment report).

Other potential sources of contamination in the downstream study area are:

- a number of NPI sites categorised as 'sewerage and drainage services' and 'water supply' were identified in the downstream study area (Figure 22-35)
- waste management facilities (Figure 22-36)
- numerous recorded unlicensed premises regulated by the EPA which are described in Appendix N1 (Soils and contamination assessment report).

Figure 22-34. Potentially contaminated sites – construction study area

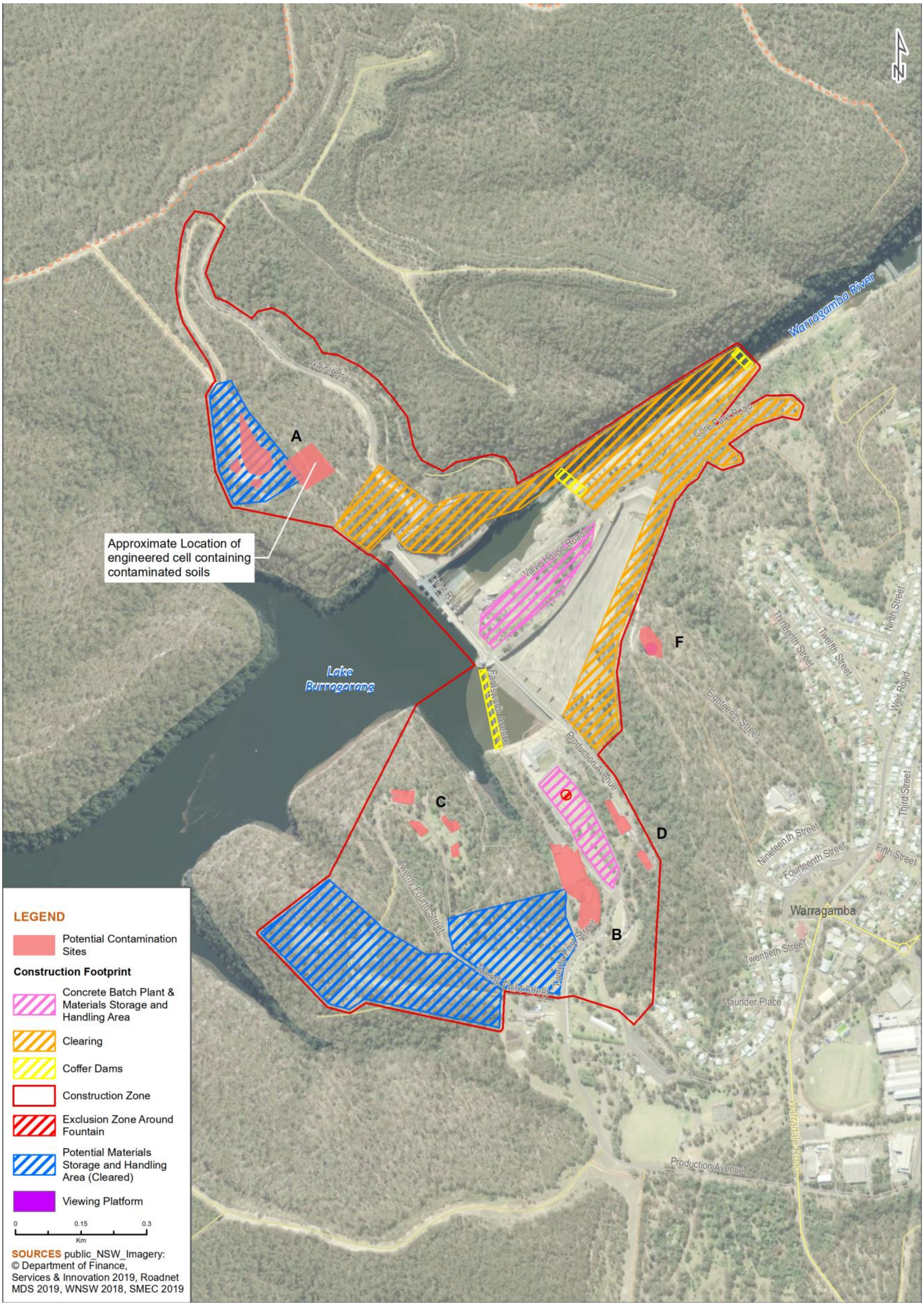


Figure 22-35. NPI sites – construction and downstream study areas

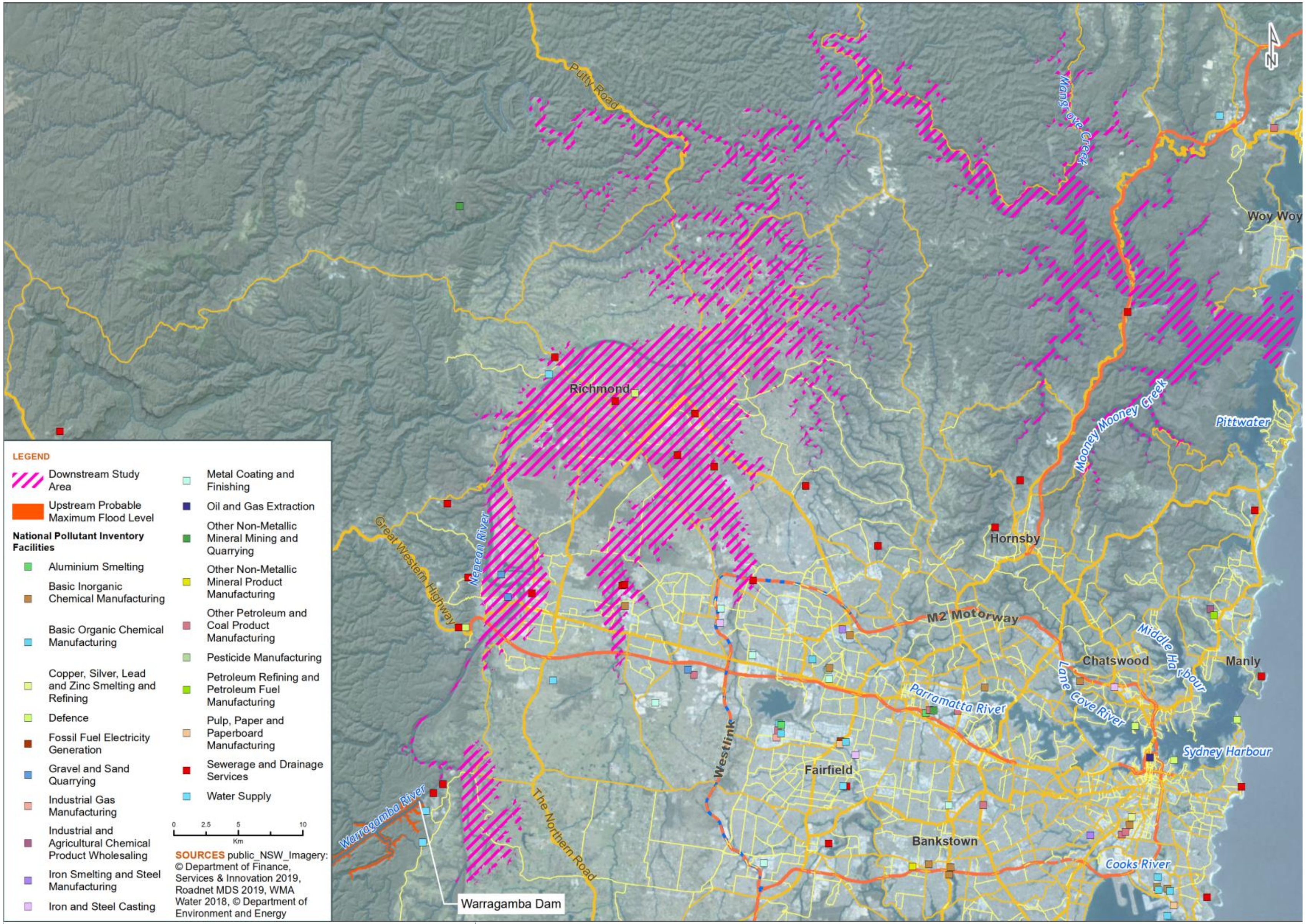
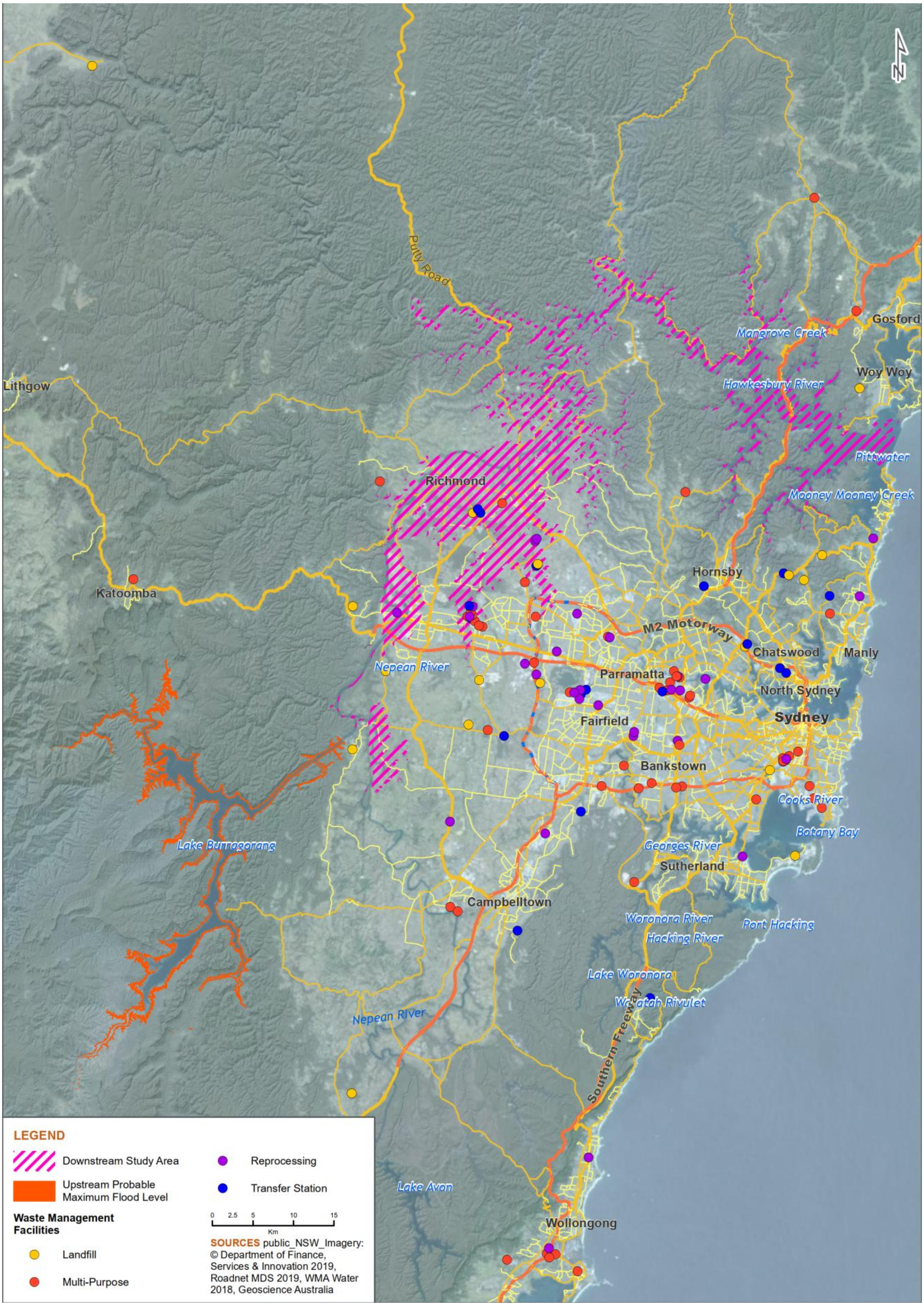


Figure 22-36. Waste management facilities: downstream study area



22.4 Construction area impacts

22.4.1 Soil erosion and sediment transport

Soil erosion and sediment transport risks during construction largely relate to construction activities. These include erosion and sediment transport from areas cleared for construction purposes. Temporary in-stream structures required to allow construction of the dam should not exacerbate existing erosion or sediment transport risk. However, should a significant rainfall event occur during construction, erosion and sediment transport impacts downstream may occur.

22.4.2 Acid sulfate soils

Acid sulfate soil risk mapping indicates that the proposed construction area for the dam and associated laydown areas that surround it are not located in or in proximity to areas mapped with acid sulfate soils risk classes (1-4) (see Figure 22-25). Due to the relatively high elevation of the area, it is considered that acid sulfate soils would not be disturbed as part of the works and therefore not impacted.

22.4.3 Salinity

Construction activities would be confined to the construction study area. Existing flows are not anticipated to change significantly during construction and construction activities are not expected to adversely impact on salinity.

22.4.4 Contaminated land

There is potential for land contamination within or near the proposed construction site and laydown areas. These are shown in Figure 22-34 (see Section 22.3.12) and described below.

Site A – Former explosives store and vehicle re-fuelling area/painters workshop/workshop shed

Available reports suggest that contamination identified in soil at this site was remediated through excavation and on-site burial in a clay lined pit. A formal validation report was not sighted, but a supplementary letter was provided by Ken Holmes (the Environmental Management Representative at the time) confirming the works were completed as per the approved remediation action plan.

This site is situated in the boundary of one of the proposed laydown areas; however, the likelihood of contamination remaining at the surface at concentrations that would cause adverse impacts is considered to be low. Assuming no physical ground disturbance is required at the laydown area, the potential for disturbing residual contamination is considered to be low.

Site B – Former Workshop yard, Farnsworth Avenue, Warragamba, NSW

Available reports suggest soil contamination at the Former Workshop Yard was remediated. This site is in the proposed construction zone but outside areas designated for disturbance. Residual impacts, if any, are likely to be low and can be managed as part of the construction works, or as a precursor to works if ground disturbance is required.

Sites C and D – Selected existing structures

Previous hazardous materials surveys of selected buildings within the construction study area have noted hazardous materials such as asbestos within sites C and D. Disturbance or demolition of the buildings or structures referenced in the *Hazardous Materials Survey Report: Warragamba Dam, Warragamba, NSW* (ADE Consulting Group 2014) is not proposed as part of the Project.

Due to the age of the dam and ancillary services, not all hazardous materials may have been assessed during previous surveys. Areas of the dam that are to be disturbed as part of the construction works should be assessed for hazardous building materials prior to commencing works. A protocol for managing unexpected finds of hazardous materials should be included in the construction environmental management plan (CEPM).

Site F – Warragamba dam viewing platform

The Warragamba Dam viewing platform is recorded on the NSW EPA list of contaminated sites. The platform is listed as ‘not requiring regulation’ by NSW EPA, but contamination may still be present. Details of the contamination are not known. This site is outside the construction zone and not likely to be influenced or disturbed by the Project.

Should construction work impact on this structure then management of hazardous materials would need to be managed through appropriate controls in accordance with state and national guidelines and codes of practice.

Other areas

Documentation of the contamination status of other areas of the Warragamba Dam construction area were not available at the time of preparation of this EIS, and therefore the assessment could not determine the presence or absence of contamination in these areas. Sydney Catchment Authority (now WaterNSW) has undertaken a program of managing legacy contamination. The extent of the program was not able to be judged for this assessment. Areas within the proposed construction zone/laydown area also fall within or close to former construction zones and former construction camps. Potential contamination sources could exist in these areas, including hazardous building materials (such as lead paint and asbestos) from former demolished structures or older pipework/conduits or associated infrastructure.

Most of the construction works for raising the dam would occur on the existing wall, with some disturbance of adjacent areas required for ancillary works. The likelihood of widespread contamination is low based on the reviewed documents.

22.5 Operational impacts

22.5.1 Soil erosion and sediment transport

Impact summary

The methodology for assessing potential Project impacts on soil erosion and sediment transport is summarised in Table 22-3 (Section 22.2.2). This includes hotspot modelling for upstream and lake areas, and bank erosion index and sediment motion analysis for downstream areas. Detailed data analysis and impact assessment is provided in Appendix N2 (Geomorphology assessment report, Section 5) and summarised below. These impacts are presented as potential risks, which were determined in accordance with the methodology and definitions outlined in Section 22.7 (Risk assessment).

Potential Project impacts (residual risks) are shown in Figure 22-37. In summary, there are likely to be unavoidable geomorphological impact with regard to the risk of bank erosion in the system; however, the impacts associated with elevated sediment deposition in the upstream zone and on floodplains in the downstream zone when flows are backed up appears low. Constraining flows within the downstream channel would lead to a net reduction in overbank flows in the downstream rivers, leading to a reduced likelihood of sediment deposition. There would be a transition towards deposition conditions during flood storage events (upstream) and flood mitigation zone discharges (downstream). The long-term effect of these events; however, appear to be short-lived and covering a limited spatial scale. Specific impacts and risks are discussed as follows.

Detailed risk assessment (Appendix N2, Section 5.4)

A detailed geomorphology risk assessment is presented in Appendix N2 (Geomorphology assessment report, Section 5.4.2, Table 15) and includes risk assessment before and after (residual risk) the application of mitigation measures.

A total of 16 potential impacts from the Project were identified. These include four potential impacts in the Upstream study area, four potential impacts in the Lake area and eight potential impacts in the Downstream study area. Findings are summarised in Figure 22-37 and Table 22-11, and are as follows:

- risks prior to mitigation: Four **Low**, eight **Medium** and four **High** risks were identified
- residual risks after mitigation: Mitigation can effectively reduce potential impacts to five **Medium**, nine **Low** and two **Negligible** residual risks.

Figure 22-37. Project soil and erosion risks

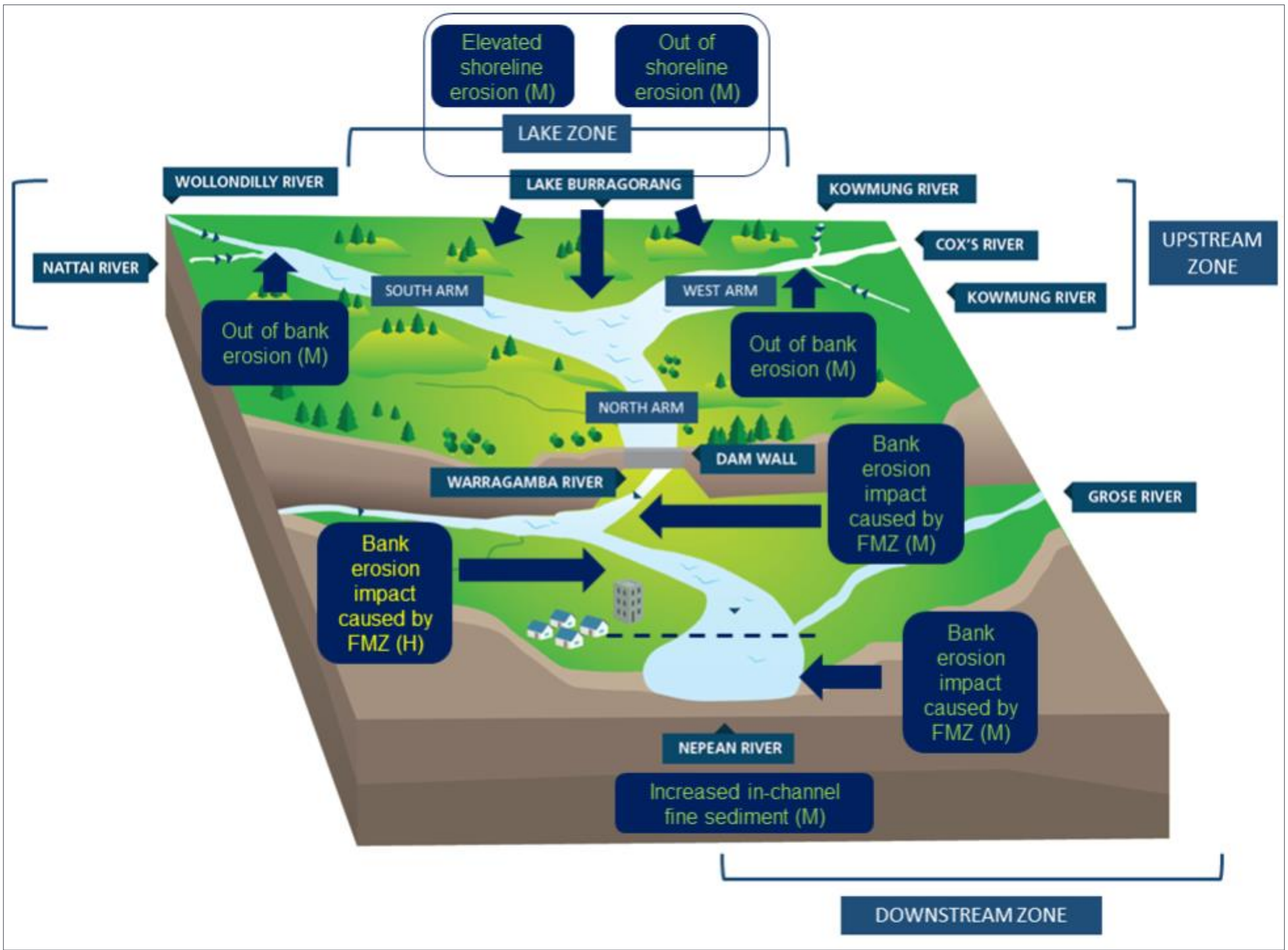


Table 22-11. Geomorphology risk assessment

Risk assessment and mitigation (see Appendix N2, Geomorphology assessment report, Section 5.4.2)	
Risk assessment: **Without mitigation (see Appendix N2, Table 15)**	**Residual risk assessment:** **With mitigation (see Appendix N2, Appendix L – Mitigation measures)**
Low risk	**Low risk**
Upstream: 1. translocation of sediment features upstream – Coxs and Wollondilly Rivers 2. floodplain sediment deposition – Kedumba and Wollondilly Rivers *Lake Burragorang:* 3. deposition of sediments on sensitive ecological/heritage receptors during inundation events – Lake Burragorang North, South and West arms 4. change in Lake Burragorang circulation patterns causing sediment redistribution.	*Lake Burragorang:* 1. deposition of sediments on sensitive ecological/heritage receptors during inundation events – North 2. change in circulation patterns causing sediment redistribution *Downstream:* 3. cumulative bank erosion impact caused by prolonged FMZ flows - Warragamba River, Dam to Nepean River confluence - Nepean River, Warragamba River confluence to Fairlight Gorge 4. cumulative bank erosion impact caused by prolonged FMZ flows - Nepean River, Devlins Road to Grose Confluence - Hawkesbury River, Windsor to Colo River 5. cumulative bank erosion impact caused by prolonged FMZ flows - Nepean River, Fairlight Gorge to Penrith Weir 6. cumulative bank erosion impact caused by prolonged FMZ flows - Hawkesbury River, Grose River to Windsor 7. cumulative bank erosion impact caused by prolonged FMZ flows - Hawkesbury River, Colo River to Wisemans Ferry 8. cumulative bank erosion impact caused by prolonged FMZ flows (including damage to existing erosion protection measures) - Nepean River, Penrith Weir to Devlins Road 9. floodplain sedimentation from out of bank flows

<table>
<tr><th colspan="2">Risk assessment and mitigation (see Appendix N2, Geomorphology assessment report, Section 5.4.2)</th></tr>
<tr><td>Medium risk</td><td>Medium risk</td></tr>
<tr><td>Upstream:
1. out of bank erosion – Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River
Lake Burragorang:
2. out of shoreline erosion – Lake Burragorang North, South and West Arms
Downstream:
3. cumulative bank erosion impact caused by prolonged FMZ flows
- Warragamba River, Dam to Nepean River confluence
- Nepean River, Warragamba River confluence to Fairlight Gorge
4. cumulative bank erosion impact caused by prolonged FMZ flows
- Nepean River, Devlins Road to Grose Confluence
- Hawkesbury River, Windsor to Colo River
5. cumulative bank erosion impact caused by prolonged FMZ flows
- Nepean River, Fairlight Gorge to Penrith Weir
6. cumulative bank erosion impact caused by prolonged FMZ flows
- Hawkesbury River, Colo River to Wisemans Ferry
7. increased fine sediment content in Hawkesbury-Nepean River channel
8. floodplain sedimentation from out of bank flows in the Downstream Zone</td><td>Upstream:
1. out of bank erosion in the Upstream Zone, including Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River
2. out of bank erosion in the Upstream Zone, including Butchers Creek, Coxs River, Kedumba River, Kowmung River (lower), Laceys Creek
Lake Burragorang:
3. out of shoreline erosion – Central, South and West Arms
4. elevated erosion of shoreline banks – North, South and West Arms
Downstream:
5. Increased fine sediment content in Hawkesbury-Nepean River channel</td></tr>
<tr><td>High risk</td><td>High risk</td></tr>
<tr><td>Upstream:
1. out of bank erosion in the Upstream Zone
Lake Burragorang:
2. elevated erosion of shoreline banks in the Lake Zone
Downstream:
3. Cumulative bank erosion impact caused by prolonged FMZ flows
- Hawkesbury River, Grose River to Windsor
4. Cumulative bank erosion impact caused by prolonged FMZ flows (including damage to existing erosion protection measures)
- Nepean River, Penrith Weir to Devlins Road</td><td></td></tr>
</table>

22.5.2 Acid sulfate soils

The Project would not impact on known areas of known coastal acid sulfate soils. However, CSIRO mapping suggests there are potential 'high probability' areas of inland acid sulfate soils within Lake Burragorang. The potential for inland acid sulfate soils has not been verified. However, even if present, the temporary increase in water levels during a flood event is unlikely to constitute a material change from existing conditions.

Acid sulfate soils classes 1-4 with a range of probability of occurrence are mapped only in downstream areas commencing about 40 kilometres downstream of Warragamba Dam. Flood modelling indicates that the dam raising generally results in a decrease in the inundation of downstream areas (in various annual exceedance probability scenarios, including the PMF). Modelling of flood velocities indicates that Project flood waters at a given location and flow rate would comprise similar velocity distributions to the existing conditions. However, due to the increased attenuation and management of flood waters associated with the Project, the exposure to peak flood velocities would be reduced, which would result in an associated reduction of flood hazard. When the FMZ is emptied, the Project would result in an increase in the duration of sustained bank-full velocities associated with the steady FMZ release rate of 100 gigalitres per day (see EIS Chapter 15 – Flooding and hydrology). Given there would be no increase in overall or peak flood velocities, impacts to acid sulfate soils (that is, disturbance) are not considered likely.

22.5.3 Salinity

The mobilisation of salinity can be caused by changes in the existing water cycle through water use or climate changes. In urban areas, the processes that cause salinity can be intensified by increased volumes of water being added to the natural system, through changes to the groundwater flow regimes and exposure of freshly cut saline soils to the weathering process. More specifically, salinity is associated with several issues such as:

- degradation of water quality resulting in decreasing plant growth, in lower crop yields and degraded stock water supplies
- reducing overall soil health, resulting in reduced productivity
- changes in soil chemistry reducing soil stability resulting in increased erosion, soil loss, and effects on slope stability
- increased volume (load) and/or concentration (electrical conductivity) of salinity in creeks and streams can degrade water supplies, affect irrigated agriculture and horticulture and adversely impact river ecosystems
- salinity has the potential to damage infrastructure, for example, buildings, roads and pipes.

The upstream study area would be subject to an increased frequency of temporary inundation over limited periods, resulting in increasing recharge of the submerged geology and subsequent discharges as the level in the dam reduces. While this process is likely to increase the mobilisation of saline components contained in the soils and geological formations, the predominant soil and subsoil formations are expected to contain and release only low salinity levels. Initial electrical conductivity spikes in the dam water close to the freshly inundated areas may be expected after the first few inundations. The overall water quality of the dam water is unlikely to be affected.

Given the short inundation periods and the predominantly low permeability of the rock formations in the upstream study area, impacts on the upstream groundwater regime and quality are considered to be insignificant.

The decreasing footprint (area) and increasing duration of flooding events in the downstream areas would have:

- minimal impact on groundwater recharge/discharge across most of the flooded areas, where groundwater is within two metres of the surface
- minor impact on groundwater recharge/discharge in the small areas where the groundwater table is more than two metres below the surface.

The impact in such areas would be either flushing of slightly more salt from the historically pre-leached soil profile due to slightly longer flood duration, or slightly elevated salt loads due to water logging and evaporative processes. This is likely to be the case for known 'high' and 'moderate' salinity risk potential areas as the proposed changes from the current flow regime are only minor and other factors contributing to land salinisation remain principally unchanged. However, potential land use changes as part of adaptation to the new flooding regime may impact on the salinity regime through changes in anthropogenic responses, such as increased irrigation, use of fertilisers or general urban and agricultural development of land previously at higher risk of flooding.

As there is limited information on the salinity regimes and changes to the regimes since settlement and since the operation of the reservoir in its current form, it would be difficult to distinguish changes to the soil, surface water and/or groundwater salinisation as a direct result of raising the dam versus the initial dam construction, as well as changes due to changing land use practices as a result of the raising versus potential changes due to the altered inundation regime directly.

As saline water from areas affected by salinity flows into creeks and rivers, the electrical conductivity (EC) concentration and volume (load) of salt increases. Over time, as salinity within catchments worsens and the quality of river water declines. Many factors influence EC, but salt load is driven by the volume of water flow. Therefore, routine emptying of water volumes from Warragamba Dam may impact EC concentration in the Nepean and Hawkesbury Rivers. However, water quality in rivers is largely a function of land use and catchment geology, as well as in-stream processes such as tidal influence, barriers and interferences.

22.5.4 Contaminated land

The assessment of potential contamination risk and impact associated with the Project considered source(s), pathway(s) and ecological/human receptor(s) linkages. The contaminated land assessment did not identify any sites in the upstream study area with contamination or evidence of contaminating activities that would be influenced by construction or operation of the Project. Note, however, that not all sites with contamination issues can be identified through the searches that were carried out for this assessment.

The downstream study area is large, comprising agricultural-recreational land and several suburbs along the Nepean and Hawkesbury River systems. A review of publicly available information suggests there are many sites within the downstream study area that could have site contamination issues and could be exposure sources, such as service stations, industrial facilities, commercial premises etc. The presence of existing contamination is not the primary focus of this assessment but, rather, whether additional interference of existing contamination during construction or operation of the Project could create additional pathways and exposure. Relevant to typical contaminated site scenarios it is considered that the likelihood of changes in the contamination status of downstream properties due to the slightly increased period of inundation by flood waters, and any subsequent additional exposure risk would be low. If anything, the risk of exposure to contamination is likely to be improved, as the downstream inundation footprint is considerably smaller compared to the pre-Project conditions.

It is generally concluded that the existing contamination source-pathway-receptor linkages would not be changed due to the Project.

22.6 Environmental management measures

Safeguards and management measures have been developed to avoid, minimise or manage potential risks. Relevant management and mitigation measures are detailed in Table 22-12. These mitigation and management measures have been incorporated in the Environmental Management measures in Chapter 29 (EIS synthesis, Project justification and conclusion).

Appendix N2 (Geomorphology assessment report, Appendix L) provides a range of recommended mitigation measures to address potential Project erosion and sedimentation impacts. These include measures that WaterNSW does not have responsibility for (‘Outside scope mitigation measures’) and do not form part of the mitigation measures for the Project. Some recommended mitigation measures are captured through existing management measures carried out by WaterNSW and other agencies, and through mitigation and management measures identified in other investigations carried out for the Project and documented in relevant chapters such as Chapter 8 (Biodiversity – upstream) and Chapter 9 (Biodiversity – Downstream). Other relevant chapters are noted in Section 22.3.1. Many of these measures would be further investigated and consolidated in the Environmental Management Plan (EMP), which would be prepared under the Water NSW Act (refer Chapter 8: Biodiversity - Upstream, Sections 8.7.2 and 8.15).

The recommended mitigation measures in Appendix N2 (Geomorphology assessment report, Appendix L) include a number of measures related to downstream cumulative bank erosion impacts that may result from FMZ flows (Appendix N2, Appendix L: recommended measures MM48, MM49, MM51, MM52, MM56 and MM57). A practical issue with these recommended mitigation measures is isolating the effects of the Project from all the other influences in the downstream catchment that collectively contribute to the risk of bank erosion (and which is acknowledged in the Geomorphology assessment report). Further, erosion and deposition are natural features of a river system and there would likely be substantial challenges in accurately allowing for this. In view of these issues, it is considered that these recommended measures would not be reasonable or feasible, and it is not proposed to implement these as stated.

Table 22-12. Safeguards and management measures

Impact	ID	Environmental management measure	Responsibility	Timing
Impacts on site workers and/or local community through disturbance of known or potential contaminated land(s) or material.	S1	Prior to ground disturbance, further investigations are recommended to assess and manage potential contamination risk. Any contamination would be managed through implementation of an unexpected finds protocol, as discussed below. Site works should be managed to avoid disturbance of known buried contamination (identified as Site A', which is within the boundary of one of the proposed laydown areas) through implementation of adequate protocols to ensure restrictions on ground disturbance in potentially affected areas. The location of this area will be identified on design drawings. Further investigations and management of potential contamination will be undertaken in accordance with NSW regulatory provisions and NSW Environment Protection Authority (EPA) endorsed guidelines, such as (but not limited to): ▪ National Environment Protection (Assessment of Site Contamination) Measure 1999 (April 2013), EPHC 2013, Canberra ▪ NSW EPA Waste Guidelines ▪ Contaminated Land Guidelines - Consultants Reporting on Contaminated Land (NSW EPA 2020) ▪ Managing Land Contamination: Planning Guidelines SEPP 55 – Remediation of Land (DUAP 1998)	Construction contractor	Construction
	S2	Should demolition of existing structures within the construction footprint be required then management of hazardous materials would need to be managed through appropriate controls in accordance NSW regulatory provisions, NSW EPA and SafeWork NSW guidelines such as (but not limited to): ▪ Code of Practice – How to Safely Remove Asbestos (SafeWork NSW 2019) ▪ Code of Practice – How to Manage and Control Asbestos in the Workplace (SafeWork NSW 2019) ▪ Construction and demolition waste: A management toolkit, EPA, 2020 ▪ NSW EPA Waste Guidelines ▪ NSW Health and Safety Act and Regulations ▪ *Protection of the Environment and Operations Act 1997* These controls should be detailed in the appropriate construction management plan (CEMP).	Construction contractor	Pre-construction

Impact	ID	Environmental management measure	Responsibility	Timing
		A hazardous materials assessment will be carried out prior to and during the demolition of buildings. Demolition works will be undertaken in accordance with the relevant Australian Standards and relevant NSW WorkCover Codes of Practice, including the Work Health and Safety Regulation 2017 (NSW). Due to the age of the dam and ancillary services, not all hazardous materials may have been assessed during previous surveys. Areas of the dam that are to be disturbed as part of the construction works should be assessed for hazardous building materials prior to commencing works. A protocol for managing unexpected finds of hazardous materials should be included in the construction environmental management plan (CEMP).		
	S3	Areas of contamination, if they were to be uncovered during site works could be managed through implementation of an unexpected finds protocol, otherwise initial intrusive assessments could be carried out to gain a better understanding of the potential for contamination to exist in areas that will be disturbed. Soil contamination if identified is likely to be able to be managed through either offsite disposal or on site capping and management. The protocol would include: ▪ cease work in the vicinity ▪ initial assessment by an appropriately qualified professional ▪ further assessment and management of contamination, if confirmed, in accordance with section 105 of the *Contaminated Land Management Act 1997*.	Construction contractor	Pre-construction Construction
	S4	Potentially contaminated areas directly affected by the Project would be investigated and managed in accordance with section 105 of the *Contaminated Land Management Act 1997*.	Construction contractor	Pre-construction Construction
	S5	Asbestos handling and management will be undertaken in accordance with an Asbestos Management Plan (as part of the CEMP).	Construction contractor	Pre-construction Construction
Unexpected Finds	S6	Any unexpected contamination finds would be managed through an unexpected finds protocol which would be detailed within the CEMP.	Construction contractor	Pre-construction Construction
Accidental spills during construction	S7	Procedures to address spills, leaks will be developed as part of the CEMP and implemented during construction of the Project.	Construction contractor	Pre-construction Construction
Impacts to soil and water quality	S8	Measures will be implemented to appropriately store dangerous goods and reduce the potential for environmental contamination due to spills and leaks.	Construction contractor	Pre-construction Construction

Impact	ID	Environmental management measure	Responsibility	Timing
	S9	A construction soil and water management plan will be prepared for the Project including procedures to manage potentially contaminated stormwater runoff.	Construction contractor	Pre-construction Construction
	S10	An operational protocol that balances the multiple objectives from the flood mitigation zone, upstream inundation, environmental flows and downstream riverine requirements. The outcome will be to minimise as much as possible the inundation durations in upstream areas and reduce downstream flooding.	WaterNSW	Operation

22.7 Risk assessment

An environmental risk assessment was carried out in accordance with the SEARs, using the methodology provided in Appendix C (Risk assessment procedure). A Project risk matrix was developed and risk ranking evaluated by considering:

- the likelihood (L) of an impact occurring
- the severity or consequence (C) of the impact in a biophysical and/or socio-economic context, with consideration of:
  - whether the impact will be in breach of regulatory or policy requirements
  - the sensitivity of receptors
  - duration of impact, that is, whether the impact is permanent or temporary
  - the areal extent of the impact and/or the magnitude of the impact on receptors.

The likelihood and consequence matrix is shown on Figure 22-38.

Once the consequence and likelihood of an impact are assessed, the risk matrix provides an associated ranking of risk significance: **Low**; **Medium**; **High** or **Extreme,** as shown in Table 22-13. The residual risk was determined after the application of proposed mitigation measures.

The risk analysis for potential soils impacts is provided in Table 22-14. This includes the residual risk of the potential impact after the implementation of mitigation measures.

It should be noted that a separate detailed geomorphology risk assessment is provided in Appendix N2 (Geomorphology assessment report, Section 5). This risk assessment generally follows the methodology described in Appendix C (Risk assessment procedure). Results are discussed in Section 22.5.1 and summarised in Table 22-15.

Table 22-13. Risk ranking definitions

Risk definitions	
Extreme 21 – 25	Widespread and diverse primary and secondary impacts with significant long-term effects on the environment, livelihood, and quality of life. Those affected will have irreparable impacts on livelihoods and quality of life.
High 15 – 20	Significant resources and/or Project modification would be required to manage potential environmental damage. These risks can be accommodated in a Project of this size, however comprehensive and effective monitoring measures would need to be employed such that Project activities are halted and/or appropriately moderated. Those impacted may be able to adapt to change and regain their livelihoods and quality of life with a degree of difficulty.
Medium 9 – 14	Risk is tolerable if mitigation measures are in place, however management procedures will need to ensure necessary actions are quickly taken in response to perceived or actual environmental damage. Those impacted will be able to adapt to changes.
Low 1 – 8	On-going monitoring is required however resources allocation and responses would have low priority compared to higher ranked risks. Those impacted will be able to adapt to change with relative ease.

Figure 22-38. Risk matrix

		Consequence				
		Negligible	**Minor**	**Medium**	**Major**	**Extreme**
	LEGAL	No legal consequences	No legal consequences	Incident potentially causing breach of licence conditions	Breach of licence conditions	Breach of licence conditions resulting in shutdown of Project operations.
	SOCIO-ECONOMIC	Impacts that are practically indistinguishable from the social baseline, or consist of solely localised or temporary/short-term effects with no consequences on livelihoods and quality of life.	Short-term or temporary impacts with limited consequences on livelihoods and quality of life. Those affected will be able to adapt to the changes with relative ease and regain their pre-impact livelihoods and quality of life.	Primary and secondary impacts with moderate effects on livelihoods and quality of life. Will be able to adapt to the changes with some difficulty and regain their pre-impact livelihoods and quality of life.	Widespread and diverse primary and secondary impacts with significant long-term effects on livelihoods and quality of life. Those affected may be able to adapt to changes with a degree of difficulty and regain their pre-impact livelihoods and quality of life.	Widespread and diverse primary and secondary impacts with irreparable impacts on livelihoods and quality of life and no possibility to restore livelihoods.
	HEALTH	No health consequences	Accident or illness with little or no impact on ability to function. Medical treatment required is limited or unnecessary.	Accident or illness leading to mild to moderate functional impairment requiring medical treatment.	Accident or illness leading to permanent disability or requiring a high level of medical treatment or management.	Accident, serious illness or chronic exposure resulting in fatality.
	ENVIRONMENT	Localised (on-site), short-term impact on habitat, species or environmental media	Localised or widespread medium-term impact to habitat, species or environmental media	Localised degradation of sensitive habitat or widespread long-term impacts on habitat, species or environmental media. Possible contribution to cumulative impacts.	Widespread and long-term changes to sensitive habitat, species diversity or abundance or environmental media. Temporary loss of ecosystem function at landscape scale. Moderate contribution to cumulative impacts.	Loss of a nationally or internationally recognised threatened species or vegetation community. Permanent loss of ecosystem function on a landscape scale. Major contribution to cumulative effects
		A - negligible	**B** - minor	**C** - medium	**D** - major	**E** - extreme
Expected to occur during the Project or beyond the Project	**a** - expected	13	14	20	24	25
May occur during the Project or beyond the Project	**b** - may	8	12	19	22	23
Possible under exceptional circumstances	**c** - possible	6	7	11	18	21
Unlikely to occur during the Project	**d** - unlikely	4	5	10	16	17
Rare or previously unknown to occur	**e** - rare	1	2	3	9	15

Risk Definition (see Table 22-13)	**Low**	**Medium**	**High**	**Extreme**

Table 22-14. Soils risk assessment

<table>
<tr><th rowspan="2">Key impacts</th><th colspan="3">Risk before mitigation</th><th rowspan="2">Mitigation and management</th><th colspan="3">Risk after mitigation</th><th rowspan="2">Residual risk</th></tr>
<tr><th>L</th><th>C</th><th>R</th><th>L</th><th>C</th><th>R</th></tr>
<tr><td colspan="9">Construction</td></tr>
<tr><td>Most construction works will occur at the existing wall, with some disturbance of adjacent areas required for ancillary works. Potential soil impacts are:
▪ presence of soil contamination
▪ soil erosion and sedimentation of receiving waters.</td><td>b</td><td>C</td><td>19</td><td>S1, S2, S3, S4, S5, S6, S7, S8, S9</td><td>b</td><td>B</td><td>12</td><td>Historic activities have resulted in contaminated soils in and around the construction site, however a review of available information shows that these areas have been remediated and there is no known remaining contamination. However, there remains a likelihood that contaminated soil may be uncovered during construction, resulting in localised degradation and licence non-compliance, resulting in a High risk.
Mitigation can reduce this to a Medium residual risk by quick identification of possible contamination and specific guidelines for its management, including remediation or disposal.</td></tr>
<tr><td colspan="9">Operation</td></tr>
<tr><td>1. Potential soil impacts may occur due to inundation and scouring of soils causing:
▪ soil water-logging
▪ acid mobilisation from interference with acid sulfate soils
▪ increased salinity from interference with saline soils</td><td>b</td><td>C</td><td>19</td><td>S10</td><td>b</td><td>B</td><td>12</td><td>Infrequent and temporary upstream inundation is not expected to significantly change long-term soil moisture characteristics or negatively impact on water quality because of the potential presence of acid sulfate and saline soils. Similarly, a reduction in downstream flooding would not significantly affect soil characteristics or water quality. However, the risk is assessed as High should upstream flood retention and downstream FMZ flows not be carefully managed.
This risk can be reduced to a Medium residual risk by implementing a Project operational protocol designed to manage upstream flood retention and FMZ flows so that an incremental increase in inundation does not significantly change current acid sulfate and saline soil characteristics.</td></tr>
</table>

<table>
<tr><th rowspan="2">Key impacts</th><th colspan="3">Risk before mitigation</th><th rowspan="2">Mitigation and management</th><th colspan="3">Risk after mitigation</th><th rowspan="2">Residual risk</th></tr>
<tr><th>L</th><th>C</th><th>R</th><th>L</th><th>C</th><th>R</th></tr>
<tr><td>2. Potential geomorphology impacts causing erosion and scouring of the upstream and downstream operational areas.
Refer Section 22.5.1 and Table 22-15.</td><td colspan="3">Refer Table 22-15</td><td>See Appendix N2 (Geomorphology assessment report, Appendix L)</td><td colspan="3">Refer Table 22-15</td><td>A detailed risk assessment is provided in Appendix N2 (Geomorphology assessment report, Section 5) and summarised in Section 22.5.1. Mitigation can effectively reduce potential risks to five Medium residual risks
Upstream:
▪ out of bank erosion in the Upstream Zone, including Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River
▪ out of bank erosion in the Upstream Zone, including Butchers Creek, Coxs River, Kedumba River, Kowmung River (lower), Laceys Creek
Lake Burragorang:
▪ out of shoreline erosion – Central, South and West Arms
▪ Elevated erosion of shoreline banks – North, South and West Arms
Downstream:
▪ Downstream: Increased fine sediment content in Hawkesbury-Nepean River channel</td></tr>
</table>

Table 22-15. Detailed soil erosion risk matrix (see Geomorphology assessment report: Appendix N2, Section5.4)

Zone	Potential impact	Pre-mitigation			Mitigation measure/s (see Appendix L)	Post-mitigation		
		Likelihood	Significance	Risk		Likelihood	Significance	Risk
Upstream	Out of bank erosion – Brimstone Creek, Green Wattle Creek, Nattai River, Tonalli Creek, Wollondilly River	P	Mo	M	• Existing mitigation measures • National Parks EMP	P	Mo	M
Upstream	Out of bank erosion – Butchers Creek, Coxs River, Kedumba River, Kowmung River (lower), Laceys Creek	HL	Mo	H	• Existing mitigation measures • National Parks EMP	L	Mo	M
Upstream	Translocation of sediment features upstream – Coxs and Wollondilly Rivers	HL	N	L	• National Parks EMP	L	N	N
Upstream	Floodplain sediment deposition – Kedumba and Wollondilly Rivers	HL	N	L	• Existing mitigation measures • Outside scope mitigation measures	L	N	N
Lake Burragorang	Out of shoreline erosion – Central, South and West Arms	L	Mo	M	• Existing mitigation measures • Outside scope mitigation measures	P	Mo	M
Lake Burragorang	Elevated erosion of shoreline banks – North, South and West Arms	HL	Mo	H	• Existing mitigation measures • National Parks EMP	L	Mo	M
Lake Burragorang	Deposition of sediments on sensitive ecological / heritage receptors during inundation events - North, South and West Arms	HL	N	L	• Existing mitigation measures • Outside scope mitigation measures	HL	N	L
Lake Burragorang	Change in circulation patterns causing sediment redistribution	HL	N	L	• Mitigation measures - Water Quality	H	N	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Warragamba River, Dam to Nepean River confluence - Nepean River, Warragamba River confluence to Fairlight Gorge	HL	Mi	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Nepean River, Devlins Road to Grose Confluence - Hawkesbury River, Windsor to Colo River	L	Mo	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Nepean River, Fairlight Gorge to Penrith Weir	P	Mo	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Hawkesbury River, Grose River to Windsor	HL	Mo	H	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows - Hawkesbury River, Colo River to Wisemans Ferry	Po	Mo	M	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Cumulative bank erosion impact caused by prolonged FMZ flows (including damage to existing erosion protection measures) - Nepean River, Penrith Weir to Devlins Road	HL	Mo	H	• Audit and investigation used to direct erosion mitigation measures	U	Mi	L
Downstream	Increased fine sediment content in Hawkesbury-Nepean River channel	P	H	M	• Mitigation measures - Water Quality • Outside scope mitigation measures	P	H	M
Downstream	Floodplain sedimentation from out of bank flows	L	Mo	M	• Mitigation measures - Ecology • Mitigation measures - Heritage • Outside scope mitigation measures	U	Mi	L

For Likelihood; U = Unlikely; P = Possible; L = Likely; HL = Highly Likely / For Significance; N = Negligible, Mi = Minor, Mo = Moderate; H = High; VH = Very High / For Risk;

N = Negligible	L = Low	M = Medium	H = High	Ex = Extreme

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