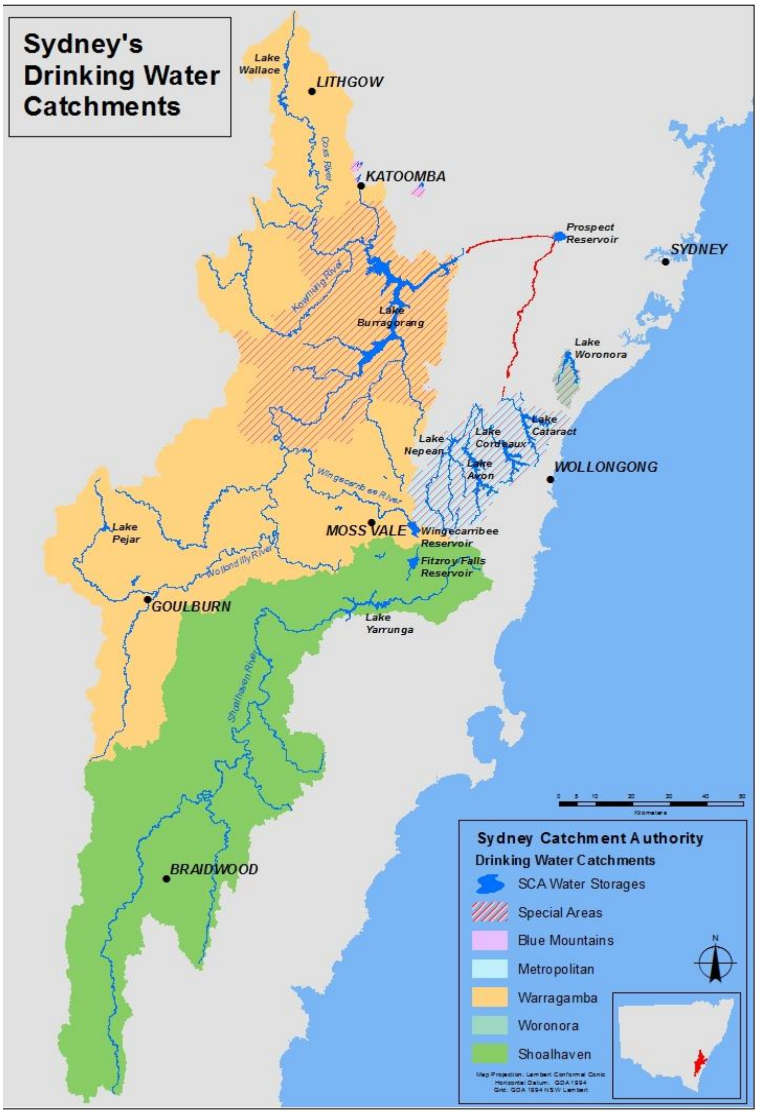

2013 Audit of the Sydney Drinking Water Catchment

Volume 1 - Main Report

November 2013

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Executive summary

The *Sydney Water Catchment Management Act (SWCMA) 1998* (the Act) is the legislation that defines the roles, functions and objectives of the Sydney Catchment Authority (SCA). The *SWCMA 1998* requires an audit of the state of the land of the Sydney's Drinking Water Catchment (the Catchment) be undertaken every three years, and that a report on this audit be submitted to the Minister responsible. GHD Pty Ltd was commissioned to undertake the 2013 Audit covering the period 1 July 2010 to 30 June 2013.

The Audit focused on the eighteen gazetted Catchment Health Indicators (NOW 2009) and used a reporting format consistent with current methods for State of the Environment (SoE) utilising a *Pressure-State-Response* (PSR) model. The indicators were grouped into four broad themes, given below:

- Land Use and Human Settlements;
- Biodiversity and Habitats;
- Water Availability; and
- Water Quality.

The audit collected data and information relevant to the audit period from the SCA and other relevant stakeholders, and sought submissions from the public via newspaper advertisements and letters to stakeholders. For a description of Audit methodology, synthesis of submissions and information received see Volume 2 Appendices A-H. To ensure adequate stakeholder engagement and information gathering the audit process would benefit from a minimum of 6 months to complete.

Further integration of information databases between government agencies would significantly enhance the opportunity for information exchange and synthesis. Coordination and leveraging of monitoring programs to maximise the range of biodiversity indicators collected at sites would enable Catchment Health outcomes to be evaluated more holistically.

The SCA could lead the implementation of an integrated ecosystem health database to collate and maintain information for the catchment with support from OEH and other government agencies. The spatial database should contain all data and metadata required for the assessment of the gazetted Catchment health indicators (see **Recommendation 1**).

The Catchment comprises 27 sub-catchments; comprehensive information and data analyses were compiled for each sub-catchment. Results of the data analyses and information (Volume 3 Appendix I) provide useful 'snapshots' of the current conditions in the sub-catchments and the pressures on them, although some indicators did not have sufficient spatial resolution or updated information to report at the sub-catchment scale.

In conducting the Audit it was apparent that additional information and insight could be gained if further analysis criteria were specified. For example, the Macroinvertebrate Indicator is currently limited to AUSRIVAS, although the same data can be used to generate a SIGNAL2 score and these were available and reported annually by both the SCA and NSW Office of Environment and Heritage (OEH). As it is five years since the Catchment Health Indicators were gazetted, it would be useful for NSW Office of Water (NOW) to review the gazetted criteria prior to the next audit.

Overview of Catchment Health Indicators

The demand to develop land continues to be high throughout the Catchment, particularly in existing urban areas and in the Sydney to Canberra corridor. The interest in mining underground resources, particularly coal resources, is an ongoing pressure on the Catchment.

Mining in the Catchment is perhaps the most significant issue identified by this audit, and by previous audits, requiring management to protect water resources. The 2013 Audit documents various impacts that have occurred. These impacts were largely related to geological impacts (such as fracturing, subsidence and cracking, as a result of longwall mining), which may affect surface water flows, water quality and potentially groundwater.

Unless well managed, mining developments represent a potential risk to water quality, ecosystem health and land condition in the Catchment. The data and information assessed indicates that the Catchment Management Authorities (CMA's), mainly, the SCA, Hawkesbury Nepean NCMA, Southern Rivers CMA, OEH and Department of Planning and Infrastructure (DP&I) are engaged in promoting management practices and guidelines to mitigate the potential impacts of developments in the Catchment.

To effectively manage the impacts of mining in the Special Areas of the Catchment the SCA shall continue to recommend approval conditions for mining within the Special Areas which are consistent with their Principles for Managing Mining and CSG impacts (see **Recommendation 2**).

The 2013 Audit found that impacts of longwall mining on aquatic or terrestrial biota were not well documented. However, the reviews of data and information from previous studies and reports indicated that sensitive ecological communities, such as upland swamps, were negatively impacted by longwall mining. Limited site inspections, conducted during the current Audit, confirmed these findings. Sensitive, upland swamps in some sub-catchments, affected by longwall mining, have begun to show deterioration in condition, particularly of native vegetation and surface water availability. Hence, the precautionary principle should apply in these areas until more data are collected and clear management guidelines are implemented. The Auditor recommends OEH should finalise the Upland Swamp Environmental Assessment Guideline for whole of Government consideration and endorsement. The Guideline should provide clear and robust measures of swamp significance and impact (see **Recommendation 3**).

The Auditor recommends that the DP&I approval conditions should be set considering risk management zones around ecological features, such as streams and swamps that have 'special significance status'. Risk management should aim to achieve nil or negligible impact to 'significant' features. Where the conditions required to achieve nil or negligible impact cannot be determined then mining should be excluded by a lateral distance of 400 m on each side of the feature or, if greater, by a 40° projection angle from the vertical down to the coal seam which is proposed to be extracted, as detailed in the Strategic Review (DoP 2008a) (see **Recommendation 4**).

Proper assessment of mining impacts, particularly, long-term and cumulative impacts, is crucial for the future management of the Drinking Water Catchment, to safeguard the water resources, as well as the public's trust in catchment management stakeholders. The SCA in consultation with OEH, DPI, DP&I, NOW and Sydney Water assess the potential cumulative impacts of all mining activities within the designated Special Areas (see previous audit recommendation). In addition, the DPI, SCA, OEH, NOW, DP&I and Sydney Water should collaborate to develop a risk assessment methodology to assess the impacts of mining, CSG and industrial developments on water resources in the catchment (**Recommendation 5**).

Many industries have undertaken positive steps to reduce discharges into waterways, implementing pollution reduction programs. The SCA has also improved its awareness of sites and areas of potential pollution impacts within the Catchment through the development of the Pollution Source Assessment Tool (PSAT).

The SCA, in partnership with Local Councils and NOW, have funded the upgrade of a number of Sewage Treatment Plants (STPs) through the Accelerated Sewerage Program. This program has significantly reduced the frequency, volume, and load of pollutants discharged to waterways within the Catchment over the last eight years.

The NSW Environment Protection Authority (EPA) continues to monitor sites across the Catchment, and enforce conditions to mitigate pollution and improve catchment protection practices through Environment Protection Licences (EPLs). Enforcement of EPLs by EPA will continue to drive improvement for licenced premises however collaboration between CMAs and Local Councils will be required to motivate reduced pollution discharges from non-licensed premises. The Auditor also recommends Sydney Water reviews their Catchment to Tap risk assessments for the Blue Mountains to ensure that dry weather sewer overflow discharges are minimised (see **Recommendation 6**).

Some areas of erosion control and riparian rehabilitation have significantly improved condition in the Catchment. The continued support of these rehabilitation programs will enable further improvement in Catchment water quality (particularly nutrients and sediment) and support sustainable land use. Monitoring the progress of the rehabilitation would be improved by mapping of the extent of streambank erosion in selected sub-drainage units in the Catchment prior to the next audit.

The Catchment population increased slightly (4%) during the Audit period and the relevant agencies had appropriate processes in place to monitor and plan for predicted future population growth. Community attitudes, aspirations, and engagement were high with many community members and landholders in the Catchment becoming involved in catchment management programs and projects throughout the Catchment. The Audit found increasing efforts being made by the appropriate agencies to engage with and support Landcare and other groups, including indigenous groups. The Auditor endorses continued prioritisation of soil erosion and water quality issues for community engagement and capacity building programs.

There were increased environmental flows released from the nominated SCA storages during this audit period. Increased daily flows were recorded through most flow monitor gauges with some exceptions. Nine locations had reduced flows less than the long term medians and at only one location flows had declined greater than 50%. Integration of dam storage levels, catchment rainfall volumes and the assessment of volumes that are extracted by current water entitlements into a single spatial meta-database would improve the ability of stakeholders to access and manage surface water information.

Analyses of long term groundwater level trends at ten locations within the Catchment showed that most declining groundwater level trends could be attributed to rainfall trends and seasonal groundwater abstraction, presumably from irrigation/farming activities, and not to mining abstraction. Fluctuations in groundwater levels were seasonal, or short term, which indicated natural seasonal trends, and/or possible, interactions with seasonal groundwater users for irrigation, stock or domestic purposes. There was insufficient data available to assess groundwater quality changes within the Catchment.

The Auditor recommends that NOW should extend existing monitoring to include groundwater quality data as well as groundwater levels to establish a baseline for groundwater resources in the Catchment (see **Recommendation 7**).

The ecosystem health and condition of the Catchment's streams and storages (based on macroinvertebrates, fish, native vegetation, and riparian vegetation indicators) was generally good, or had not significantly changed in many areas of the Catchment.

There were some areas, which were degraded, or under considerable pressure, from developments and land use activities. Water quality parameters, including nutrients (N and P), either occasionally, or regularly, exceeded benchmarks at various sites (primarily those with significant agricultural or urban development). Water quality in waterways or storages, located in sub-catchments with more natural characteristics, including vegetation cover (e.g. Woronora River, Cordeaux River, Nepean River) was noticeably better than catchments with human development (e.g. Wollondilly River, Wingecarribee River, Shoalhaven River), which highlights the important function of Special Areas in protecting water quality.

Protozoan pathogens - *Cryptosporidium* and *Giardia* (oo)cysts were detected infrequently at low concentrations at some catchment sites. Occasionally, elevated concentrations of pathogens were found at a few Catchment sites. The Auditor recommends the SCA should refine investigation of hotspots of sporadic *Cryptosporidium* contamination to sites not proximate to STPs to determine the sources, genotypes and potential human health risks of such contamination (see **Recommendation 8**).

The level of compliance of point source inputs (STPs) with their respective EPLs was variable. Most non-compliances were related to nutrient loads, pH and volumes discharged (particularly, under wet conditions) and monitoring requirements. However all of the STPs in the Catchment have made significant improvements in performance which will contribute to improved catchment health. The data and information, available to the SCA or OEH were not adequate to characterise diffuse sources of pollution across the Catchment. None of the previous modelling efforts have been adequately ground-truthed with sub-catchment water quality or flow data, even for relatively small drainage units. The SCA's existing PSAT was demonstrated as a useful method to identify priority drainage areas. Further improvements to the PSAT modules were in progress, and would enhance the SCA's capacity to identify problem areas, which are sources of diffuse nutrient pollution. The Auditor recommends that the SCA use the existing data (including PSAT) to develop a predictive tool to evaluate catchment management scenarios for the reduction of diffuse sources of nutrient pollution (see **Recommendation 9**).

Water quality at catchment sites, as well as in storages varied with regard to phytoplankton (and cyanobacterial) growth. However, the quality of water in the storages was generally good during the audit period and posed no threat to drinking water supplies in terms of cyanobacterial blooms, or to recreational users or ecological communities, according to ANZECC benchmarks. The Auditor notes the significant progress made by SCA in understanding the risks to water quality in the catchment streams and storages, posed by cyanobacteria and for initiating pre-emptive planning to manage those risks, should they re-occur at a future date.

Long-term water quality datasets from monitored sites are extremely valuable for the on-going management of the Catchment. The examination of the SCA's long-term water quality data from catchment sites and storages using statistical techniques, indicated that several important parameters (such as Chl-a, EC, TN and TP) showed significant, increasing or decreasing trends in the sub-catchments. For instance, TN concentrations were detected to be decreasing by 0.22 mg/L in Farmers Creek and by 0.298 mg/L in Gibbergunyah Creek in the Warragamba Catchment. In contrast, the most notable increasing TN trends were in the Gillamatong Creek (Shoalhaven Catchment) and in the Nepean River (Upper Nepean Catchment), where concentrations were detected to be increasing by 0.016 and 0.014 mg/L/year, respectively.

To measure economic, social and environmental effectiveness of Current Recommended Practices the Auditor recommends the SCA undertake targeted projects to ground-truth the effectiveness of Catchment improvement activities at a drainage unit scale to verify the prioritisation of on-ground works via PSAT and use this information as feedback to the Land Management Database (see **Recommendation 10**).

No new native vegetation condition information was available for the 2013 Audit, which constrained the assessment of any changes over time, or emerging issues related to native vegetation cover and condition. Information on the extents of weeds, or levels of weed infestations, was also not readily available on a sub-catchment basis.

The Audit makes a recommendation for OEH and CMAs to investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period (**Recommendation 11**).

The majority of the Catchment land use is classed as conservation or natural environment however 37.6% is cleared and several sub-catchments have poor native vegetation cover (i.e. Upper Wollondilly River - 16.3 %; and Mulwaree River - 28.8 % cover). In contrast, each of the Little River, Lower Coxs River, and Endrick River sub-catchments has greater than 90% cover of native vegetation. The Audit documented many programs in sub-catchments, implemented by various stakeholders, which continue to reduce the pressure of weeds and improve the condition of native vegetation.

Although new riparian data was limited it was apparent that there had been a high level of investment by the SCA, CMAs, and Local Councils in protecting and rehabilitating riparian vegetation in the Catchment. These programs include native vegetation protection under conservation agreements, limiting stock access, and removing weeds from riparian zones, contributing to improved health of riparian zones and protection of water quality. The CMAs, SCA, OEH, and other stakeholders would benefit from integrating riparian condition monitoring into a broader catchment-wide ecosystem monitoring program.

A Riverstyles assessment indicated that 57% of stream reaches within the Catchment were in either good condition, or in a protected area; these were mainly in Endrick River, Bungonia Creek, Kangaroo River and Upper Shoalhaven River sub-catchments. However, 39 % of reaches (mainly in the Upper Wollondilly River, Mulwaree River, Boro Creek, Braidwood Creek and Back and Round Mountain Creek sub-catchments) were in moderate or poor condition.

The assessment of the recovery potential of streams within the Catchment to categories of reaches with high, moderate or low potential, has allowed stakeholders to prioritise future works, and plan according to the specific needs of reaches (i.e. either immediate protection strategies, or phased rehabilitation.

Wetland mapping in the Catchment has not occurred at a frequency which enables changes in wetland extent or condition to be assessed. Furthermore, there is presently no standardised procedure for assessing the condition of wetlands. The Auditor recommends OEH, SCA, CMAs and other relevant agencies collaborate to develop and apply a standardised procedure for assessing the extent and condition of wetlands in the Catchment (see **Recommendation 12)**.

Long-term data and information on the condition of wetland types in the Catchment were only available for individual swamps (e.g. Wingecarribee Swamp). Positive catchment protection outcomes include swamp restoration works at several major wetlands in the Catchment, which have been completed, or were in progress. There were, however, continued impacts from longwall mining to upland swamps, particularly in the Metropolitan and Woronora Special Areas.

There was an increase in native fish species collected from the Catchment's waterways during 2010-13 compared with previous fish surveys. The greatest diversity of fish species were found in the sub-catchments of Bungonia Creek, Kangaroo River, Upper Nepean River, and the Wollondilly River. Waterways in many other sub-catchments remained low in species diversity.

The Audit revealed a lack of geographical site coordination between monitoring programs for various Catchment Health Indicators due to the programs being administered by different government agencies. Hence, the Auditor recommends SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (**Recommendation 1**) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection (see **Recommendation 13**).

The Audit found a decrease in the condition of macroinvertebrates at a significant number of sites in the Catchment during the current Audit period. The decline was most notable in the southern part of the Catchment, including Bungonia Creek, Upper and Mid Shoalhaven River, Kangaroo River, Endrick River, Mongarlowe River (see **Recommendation 14**).

Less than 10% of the Catchment has been burnt since the last major events in 2000-2003, either by bushfire or prescribed fire. This has resulted in widespread fuel accumulation to high levels across more than 90% of native vegetation areas in the Catchment. Without either major bushfires, or substantial increases in prescribed burning programs, these fuel loads are likely to increase to very high levels in future years. In 2012/13, an eight-fold increase in prescribed burning in the Catchment compared to the previous year was achieved.

In its annual integration of fire history datasets the RFS needs to review reported fire data to ensure that actual burn areas are reported to facilitate pro-active fire management between relevant government agencies.

Recommendation 1:

The SCA lead the implementation of an integrated ecosystem health database to collate and maintain information for the catchment with support from OEH and other government agencies. The spatial database should contain all data and metadata required for the assessment of the gazetted Catchment health indicators.

Recommendation 2:

In the management of the Special Areas the SCA shall continue to make recommendations to the DP&I, which are commensurate with their Principles for Managing Mining and CSG impacts.

Recommendation 3:

OEH should finalise the Upland Swamp Environmental Assessment Guideline and provide clear measures of impact and clarity around the determination of the severity of such impacts.

Recommendation 4:

DP&I approval conditions should be set considering risk management zones around ecological features, such as streams and swamps that have ‘special significance status’. These risk management zones should be extended a lateral distance of 400 m on each side of the feature or, if greater, by a 40° projection angle from the vertical down to the coal seam which is proposed to be extracted, as recommended in the Strategic Review (DoP 2008a).

Recommendation 5:

DPI, SCA, OEH, NOW, DP&I and Sydney Water should collaborate to develop a risk assessment methodology to assess the impacts of mining, CSG and industrial developments on water resources in the catchment.

Recommendation 6:

Sydney Water reviews their Catchment to Tap risk assessments for the Blue Mountains to ensure that dry weather sewer overflow discharges are minimised.

Recommendation 7:

NOW should extend existing monitoring to include groundwater quality data as well as groundwater levels to establish a baseline for groundwater resources in the Catchment.

Recommendation 8:

The SCA should refine investigation of hotspots of sporadic *Cryptosporidium* contamination to sites not proximate to STPs to determine the sources, genotypes, and potential human health risks.

Recommendation 9

The SCA use the existing data (including PSAT) to develop a predictive tool to evaluate catchment management scenarios for the reduction of diffuse sources of nutrient pollution.

Recommendation 10:

The SCA undertake targeted projects to ground-truth the effectiveness of Catchment improvement activities at a drainage unit scale to verify the prioritisation of on-ground works via PSAT and use this information as feedback to the Land Management Database.

Recommendation 11:

OEH and CMAs should investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period.

Recommendation 12:

OEH, SCA, CMAs and other relevant agencies collaborate to develop and apply a standardised procedure for assessing the extent and condition of wetlands in the Catchment.

Recommendation 13

The SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (**Recommendation 1**) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection.

Recommendation 14

The SCA and OEH should investigate the causes of the decline in the condition of macroinvertebrates at core sites in the Catchment.

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Abbreviations

AEMR	Annual Environmental Management Reports
Al	Aluminium
Alk	Alkalinity
ANOSIM	Analysis of similarity
ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resources Management Council of Australia and New Zealand
AUSRIVAS	Australian River Assessment System
AWA	Australian Water Association
BMCC	Blue Mountains City Council
BMP	Best Management Practice
BOD	Biological Oxygen Demand
BoM	Bureau of Meteorology
BWSAs	Bulk Water Supply Agreements
CAP	Catchment Action Plan
CDSS	Catchment Decision Support System
Chl-a	Chlorophyll-a
cm	Centimetre
CMA	Catchment Management Authority
CPS	Catchment Protection Scheme
CRP	Current Recommended Practices
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DA	Development Applications
DEC	Department of Environment and Conservation
DECC	Department of Environment and Climate Change
DECCW	Department of Environment, Climate Change and Water
DO	Dissolved oxygen
DoH	NSW Department of Health
DoP	Department of Planning
DP&I	Department of Planning and Infrastructure
DPI	NSW Department of Primary Industries
DPW	NSW Department of Public Works
DSC	Dam Safety Committee
DTIRIS	Department of Trade and Investment, Regional Infrastructure and Services
DWE	Department of Water and Energy
EC	Electrical conductivity
EEC	Endangered Ecological Community
EIS	Environmental Impact Statements

EOAM	Environmental Outcomes Assessment Methodology
EP	Equivalent Persons
EPA	Environment Protection Authority (NSW)
EP&A	Environmental Planning and Assessment Act
EPBC	Environment Protection and Biodiversity Conservation Act
GDE	Groundwater Dependent Ecosystems
GIP	Grazing Incentives Program
GL	Gigalitres
GMC	Goulburn Mulwaree Council
HNCMA	Hawkesbury–Nepean Catchment Management Authority
Ha	Hectare
hr	Hour
IDEA	Intermittently Decanted Extended Aeration
kg	Kilogram
km	Kilometre
KMC	Kiama Municipal Council
L	Litre
LEP	Local Environmental Plans
LiDAR	Light Detection and Ranging
LMDB	Land Management Database
LOR	Limit of reporting
LTAAEL	Long term average annual extraction limits
m	Metre
MDS	Multi-dimensional scaling
MERI	Monitoring, Evaluation, Reporting and Improvement
mg	Milligram
ML	Megalitre
mm	Millimetre
N	Nitrogen
NCC	Nature Conservation Council
NHMRC	National Health and Medical Research Council
Ni	Nickel
NorBE	Neutral or Beneficial Effect
NOW	NSW Office of Water
NPWS	National Parks and Wildlife
NRM	Natural Resource Management
NTU	Nephelometric turbidity unit
NWC	National Water Commission
OEH	NSW Office of Environment and Heritage
P	Phosphorus
PAC	Planning Assessment Commission
PCA	Principal Component analysis

POEO Act	Protection of the Environment Operations Act 1997
PRP	Pollution Reduction Programs
PSAT	Pollution Source Assessment Tool
RACC	Regional Algal Coordinating Committee
RCI	River Condition Index
RFS	NSW Rural Fire Service
RMAP	Riparian Management and Assistance Program
RVI	Riparian Vegetation Index
SCA	Sydney Catchment Authority
SEPP	State Environmental Planning Policy
SGP	Sustainable Grazing Program
SIGNAL 2	Stream Invertebrate Grade Number Average Level - Version 2
SOC	Synthetic Organic Compounds
SoE	State of the Environment
SOWCA	Save our Water Catchments Alliance
sp.	Species
SRCMA	Southern Rivers Catchment Management Authority
SS	Suspended solids
SSD	State Significant Developments
SSI	State Significant Infrastructure
STP	Sewage Treatment Plant
SWC	Sydney Water Corporation
SWCMA	Sydney Water Catchment Management Act 1998
Temp	Temperature
TN	Total nitrogen
TOC	Total organic carbon
ToR	Terms of Reference
TP	Total phosphorus
TSC Act	Threatened Species Conservation Act 1995
TSS	Total suspended solids
Turb	Turbidity
ULSC	Upper Lachlan Shire Council
WCC	Wollongong City Council
WFP	Water Filtration Plants
WSC	Wingecarribee Shire Council
WSP	Water Sharing Plan
Zn	Zinc
°C	Degree Celsius
µm	Micrometre
µS	Microsiemens

1. Introduction

The Sydney Catchment Authority (SCA) was established in 1999 under the *Sydney Water Catchment Management Act 1998* (the Act). Section 14(1) of the Act states that the SCA must '…ensure that water supplied by it complies with appropriate standards of water quality…' To meet this objective, the SCA manages the Catchment area of over 16,000 km^2, which extends from north of Lithgow in the upper Blue Mountains, to the source of the Shoalhaven River near Cooma in the south (see Figure 1-1).

The multi-barrier approach to controlling water quality risks for drinking water supplies emphasises the importance of providing good quality raw water. The elements required to achieve this include protection of catchments and effective management of catchment activities, water storage and delivery systems. Hence, the SCA undertakes extensive monitoring within its catchments, storages and raw water supply system and in rivers downstream of storages - to assist in meeting this objective.

Section 42A of the *Sydney Water Catchment Management Act 1998* (SWCM Act) requires the Minister to appoint a public authority or person to conduct an audit (a catchment audit) of the catchment health of Sydney's drinking water catchment and present a report on the audit to the Minister. Section 42 of the SWCM Act requires the audit to be undertaken every two years. However, this requirement was amended in 2010 for the audit to be undertaken at least every three years, in line with NSW State of the Environment (SoE) reporting (*Sydney Water Catchment Management Amendment Act 2007 No 83*).

Previous audits of the drinking water catchments for Sydney, the Illawarra, Blue Mountains, Southern Highlands and Shoalhaven ('the Catchments') were undertaken in 1999 and 2002 by the *Commonwealth Scientific and Industrial Research Organisation* (CSIRO).

In 2003, the *Environment Protection Authority* (EPA) performed the audit of the Catchment. Subsequent audits, in 2005, 2007 and 2010, were undertaken by the EPA's successor organisations, the *Department of Environment and Conservation* (DEC), the *Department of Environment and Climate Change* (DECC), and the *Department of Environment, Climate Change and Water* (DECCW), respectively (DECCW 2010a).

In July 2013, GHD Pty Ltd. was appointed by the Minister to conduct the 2013 catchment audit. The 2013 audit is required to assess the state of the SCA managed catchments, using the catchment health indicators, approved and gazetted under Section 42 of the SWCM Act.

1.1 Overview of the 2013 Audit

As with the previous audits, the primary purpose of the 2013 audit is to collate, analyse and provide information about the state of the Catchment during the period from 1 July 2010 to 30 June 2013. This information is provided on the approved suite of catchment health indicators, which can be used to assess the pressures on, and changes in, the state of the Catchment over time, by identifying trends in selected indicators where possible.

The Terms of Reference (ToR) for the 2013 audit were as follows:

- The Catchment audit is required to assess the state of the Catchment having regard to the Catchment Health Indicators approved under section 42 of the SWCM Act 1998;
- Consultation must be undertaken with stakeholders inside and outside the Catchment to seek information and data that may assist with the audit and to seek comments relating to the state of the Catchment;
- Undertake detailed information and analysis on long term trends and impacts of mining activities in the catchment, as part of the assessment of Land Use practices in the catchment;
- Conduct estimates of nutrient loads from diffuse sources of pollution in the catchment, in order to understand the full context of nutrient loading and to evaluate the effectiveness of catchment interventions; this is in response to the 2010 Catchment Audit recommendation 2010/21;
- Cover the period from 1 July 2010 to 30 June 2013 in the audit, and also include long term trend analysis; and
- Produce the 2013 Audit report to be consistent with the 2010 Audit Report (DECCW 2010a; 2010b), allowing continuity in the data analysis, style of reporting, and comparison of audit findings.

1.2 Sydney's Drinking Water Catchment - an overview

The Sydney Drinking Water Catchment (the Catchment) collects and stores up to 2.6 million mega litres (ML) of water to supply Sydney, the Blue Mountains, the Illawarra, the Southern Highlands and parts of the Shoalhaven area with between an average of 1000 and 1500 ML of water every day (SCA 2012a; 2013a). The Catchment is extensive, covering parts of the hydrologic catchments of the Hawkesbury–Nepean, Shoalhaven and Woronora rivers and extending over 16,000 square kilometres. It consists of five areas (see Figure 1-1):

- Warragamba catchment;
- Blue Mountains catchment;
- Upper Nepean catchment;
- Woronora catchment; and
- Shoalhaven catchment.

The Catchment extends from north of Lithgow on the Coxs River, from the head of the Shoalhaven River in the south near Cooma, and from the Woronora River in the east to the source of the Wollondilly River west of Goulburn.

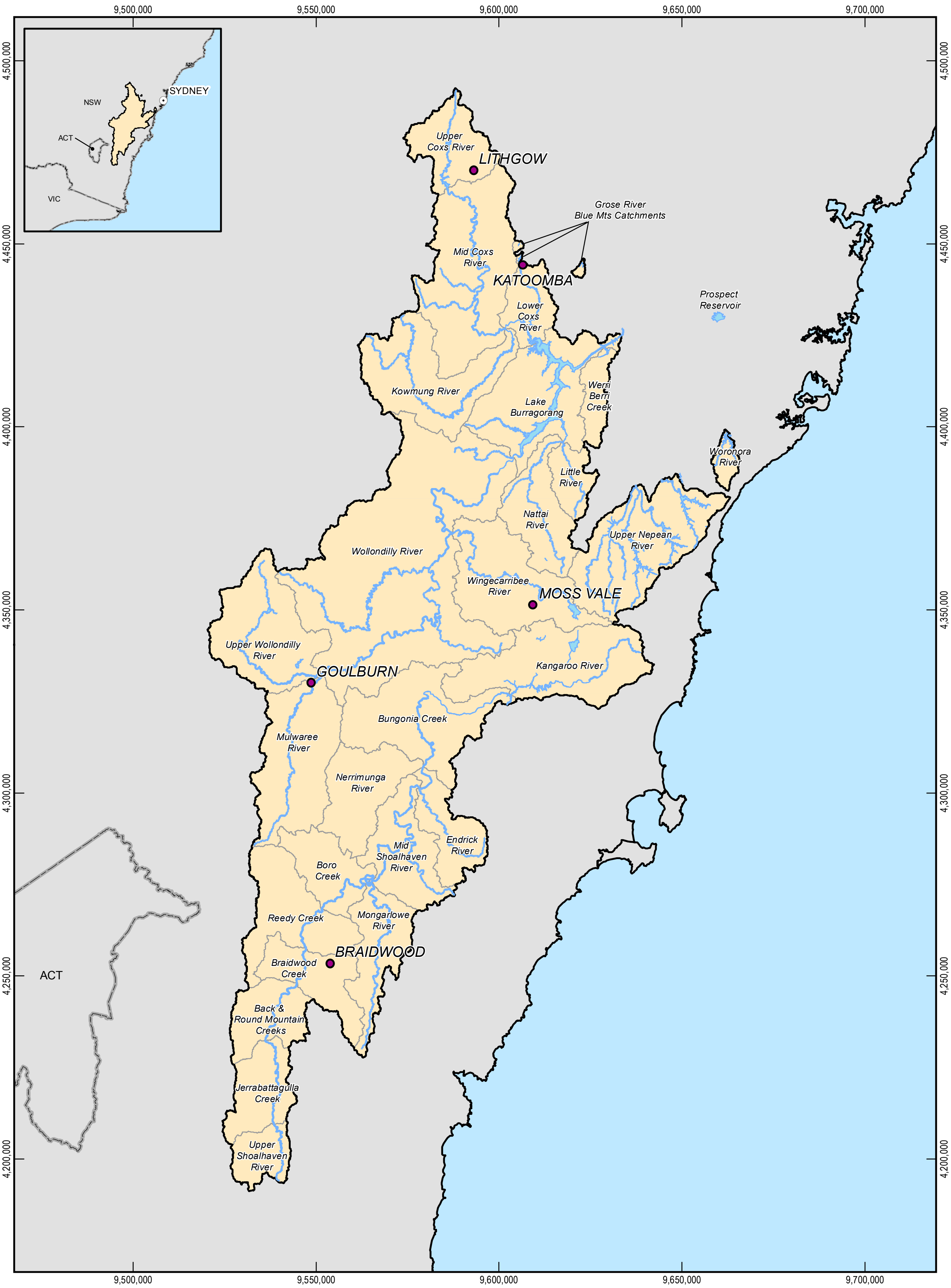
In particular, it covers the entire catchment area upstream of Warragamba Dam, including the Coxs, Kowmung, Nattai, Wollondilly and Wingecarribee River sub-catchments and their tributaries. It also covers the upper Nepean catchment upstream of the Nepean Dam and upstream of the Pheasants Nest and Broughtons Pass Weirs, and the small catchments of the Greaves Creek, Cascade, and Woodford Dams in the Blue Mountains.

Outside of the Hawkesbury-Nepean Basin, the Catchment includes the catchment of the Woronora River upstream of Woronora Dam, and the catchments of the Shoalhaven and Kangaroo Rivers, upstream of Tallowa Dam (SCA 2007a). The 2013 Audit includes the hydrologic catchment of the Prospect Reservoir in Western Sydney.

Overall, the Catchment comprises 27 sub-catchments as listed in Table 1-1. The sub-catchments drain into 11 major dams that store 'raw water', which has not been treated at Water Filtration Plants (WFPs). The SCA manages these water sources in the sub-catchments, and release the water via a network of rivers, pipes and canals to WFPs, where it is treated and delivered to customers.

Table 1-1 Sydney Catchment Authority - Sub-catchments

Catchment	Sub-catchment
Warragamba (12 sub-catchments)	• Upper Coxs River • Mid Coxs River • Lower Coxs River • Kowmung River • Werriberri Creek • Lake Burragorang • Little River • Nattai River • Wingecarribee River • Wollondilly River; • Upper Wollondilly River • Mulwaree River
Blue Mountains	• Grose River
Upper Nepean	• Upper Nepean River
Woronora	• Woronora River
Shoalhaven (12 sub-catchments)	• Kangaroo River • Bungonia Creek • Nerrimunga Creek • Endrick River • Mid Shoalhaven River • Boro Creek • Reedy Creek • Mongarlowe River • Braidwood • Black & Round Mountain Creek • Jerrabattgulla Creek • Upper Shoalhaven River



LEGEND

- Town
- Drainage
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary
- State boundary

Page Size A4

0 10 20 30

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Job Number 2314960
Revision 0
Date 26 Nov 2013

Sydney drinking water catchment and sub-catchment boundaries

Figure 1.1

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013). Created by: KP

The SWCM Act (s3) formally defines catchment health as follows: *'catchment health, in relation to the catchment area, means the condition of ecosystems and systems of management (such as sewerage and stormwater systems) in that catchment that protect water quality'.*

The ecosystems include both the aquatic and terrestrial ecosystems found within the sub-catchments, and the whole catchment area.

1.2.1 Priority sub-catchments

Previous audit ToR required the audit to focus on a set of priority sub-catchments, which had been identified by the SCA, in relation to the water quality risks to reservoir water quality, and stream health. These sub-catchments were:

- Kangaroo River;
- Mulwaree River;
- Werriberri Creek;
- Wingecarribee River;
- Lower Coxs River;
- Mid Coxs River; Upper Coxs River;
- Wollondilly River; and
- Upper Wollondilly River.

The SCA has since updated its assessment of risk, based on their *Catchment Decision Support System* (CDSS) (SCA 2009a).

The ToR for the 2010 audit and this audit, do not specifically require a focus on 'priority' sub-catchments. However, these sub-catchments are the most important areas for management and protection, in terms of raw water quality for drinking water. The Auditor is also of the view that it is reasonable to focus on the quality of these sub-catchments in the current Audit, as they are of strategic value in the Catchment.

Assessing the quality of the other sub-catchments in a more general sense is also regarded as important, as it provides a snapshot of various catchment pressures, how they impact on catchment health, and the effectiveness of catchment management actions.

1.2.2 Approach to drinking water quality management

The management of drinking water quality in the Catchment follows a multiple barrier approach (NHMRC 2008). The strength of the multiple barrier approach is that a failure of one barrier may be compensated by effective operation of the remaining barriers, thereby minimising the likelihood of contaminants passing through the entire treatment system and being present in sufficient amounts to cause harm to consumers. Traditional preventive measures are incorporated within a number of barriers, which include the following:

- Catchment management and source water protection;
- Detention in protected reservoirs or storages;
- Extraction management;
- Coagulation, flocculation, sedimentation and filtration;
- Disinfection; and
- Protection and maintenance of the distribution system.

1.2.3 Catchment management

Catchment management is the first barrier for the protection of water quality. By decreasing contamination of the source water, the level of water treatment required can be reduced. Catchment management is achieved collaboratively by the participation of a number of agencies. These include: the SCA, the NSW Office of Water (NOW), the NSW Office of Environment and Heritage (OEH), Catchment Management Authorities (CMAs) (primarily, the Hawkesbury–Nepean CMA and Southern Rivers CMA), and several Local Councils, representing Local Government Areas. The roles and responsibilities of these and other agencies are outlined in Volume 2 Appendix A of this Report.

The SCA seeks to provide leadership in catchment protection through a set of tools including regulatory powers, policy development, inter-agency cooperation, research, community education and funding of catchment improvements (SCA 2010a; 2012b; 2013a). The SCA operates as an owner, regulator and partner in the management of catchment lands. The Catchment has Special Areas around the water storages, where access and usage are restricted to protect them. The outer catchment areas include a variety of land uses such as urban development, mining, agriculture and industrial activities.

The sub-catchment lands are managed to promote water quality and quantity and to maintain their ecological integrity. There is sufficient science to suggest that robust ecological systems contribute to improved water quality outcomes. The SCA's land management programs, such as fire management, pest and weed control, and soil erosion and access controls, contribute to these outcomes. Protecting these landscapes is regarded as very important to protecting the drinking water supplies. A significant issue in the management of Special Areas is the recent expansion in long-wall mining operations under these otherwise protected areas.

1.2.4 Storage and extraction management

The SCA's primary activities in storage management are the selection of water from different storages and from different levels in the storages to meet water quantity and quality requirements, destratification of storages, where this is necessary, and monitoring of water quality for a range of parameters (SCA 2010b).

The detention of water in reservoirs can reduce the number of faecal microorganisms through settling and inactivation and allow other suspended material to settle. Where a number of water sources are available, there may be flexibility in the selection of water for treatment and supply. Within a single water body, selective use of multiple extraction points can provide protection against localised contamination either horizontally or vertically through the water column.

1.2.5 Water treatment and distribution

Sydney Water and Local Councils are largely responsible for water treatment and distribution. Waterborne pathogens can cause outbreaks of illness, affecting a high proportion of the community, and in extreme cases, causing death (NHMRC 2011). How much treatment is required depends on the level of protection of water supplies, the quality of raw water and the level of treatment available.

2. Audit methodology

2.1 Overview

The ToR for this audit required that the current methods used for State of the Environment (SoE) reporting be used. This focuses on stating the current 'condition' of the environment, as well as annotating the 'pressures' human activity have on shaping the current environmental state, and will have on the environmental state in the future.

The methodology relies on an audit of available information, obtained from a range of stakeholders, and reporting on gazetted catchment health indicators to demonstrate the condition of the catchment and its health.

To formalise the methodology for the audit, along with meeting the style of reporting requirements, the audit methodology followed in 2013 is consistent with the requirements of ISO 19011 '*Guidelines for quality or environmental management systems reporting*'. ISO 14001 provides a systematic approach to defining the scope of the audit, planning, interpreting and objectively assessing evidence and report in a clear and accurate manner.

As in previous audits, the 2013 Audit applied the 'Pressure-State-Response' (PSR) Model as the basis for understanding the pressures and conditions in the Catchment, and how collective and individual responses may affect the on-going state of the Catchment. This Model (Figure 2-1), has formed the basis for SoE reporting in NSW, and is briefly discussed below.

2.2 'Pressure-State-Response' (PSR) model

The PSR model, initially developed by the *Organisation for Economic Cooperation and Developments* (OECD) in 1993, provides a structure that links environmental policies to environmental monitoring and reporting (OECD 1993).

The model considers that: human activities exert pressures on the environment and affect its quality and the quantity of natural resources ('State'); society responds to these changes through environmental, general economic and sectoral policies and through changes in awareness and behaviour ('societal response').

It highlights cause-effect relationships, and helps decision makers and the public see environmental, economic, and other issues as inter-connected. This helps to select and organise indicators of the state of the environment in a way that is useful for decision-makers and the public, and to ensure that nothing important has been overlooked.

The PSR model has the advantage of being one of the easiest frameworks to understand and use, and of being neutral in the sense that it shows which linkages exist, and not whether these have negative or positive impacts. This should, however, not obscure the view of more complex relationships, which exist in ecosystems, and in environment-economy and environment-social interactions. Environmental 'pressures' in the PSR Model describe pressures from human activities exerted on the environment, including natural resources. 'Pressures' cover underlying or indirect pressures (i.e. human activities, and trends and patterns of environmental significance), as well as direct pressures (i.e. the use of resources, and the discharge of pollutants and waste materials).

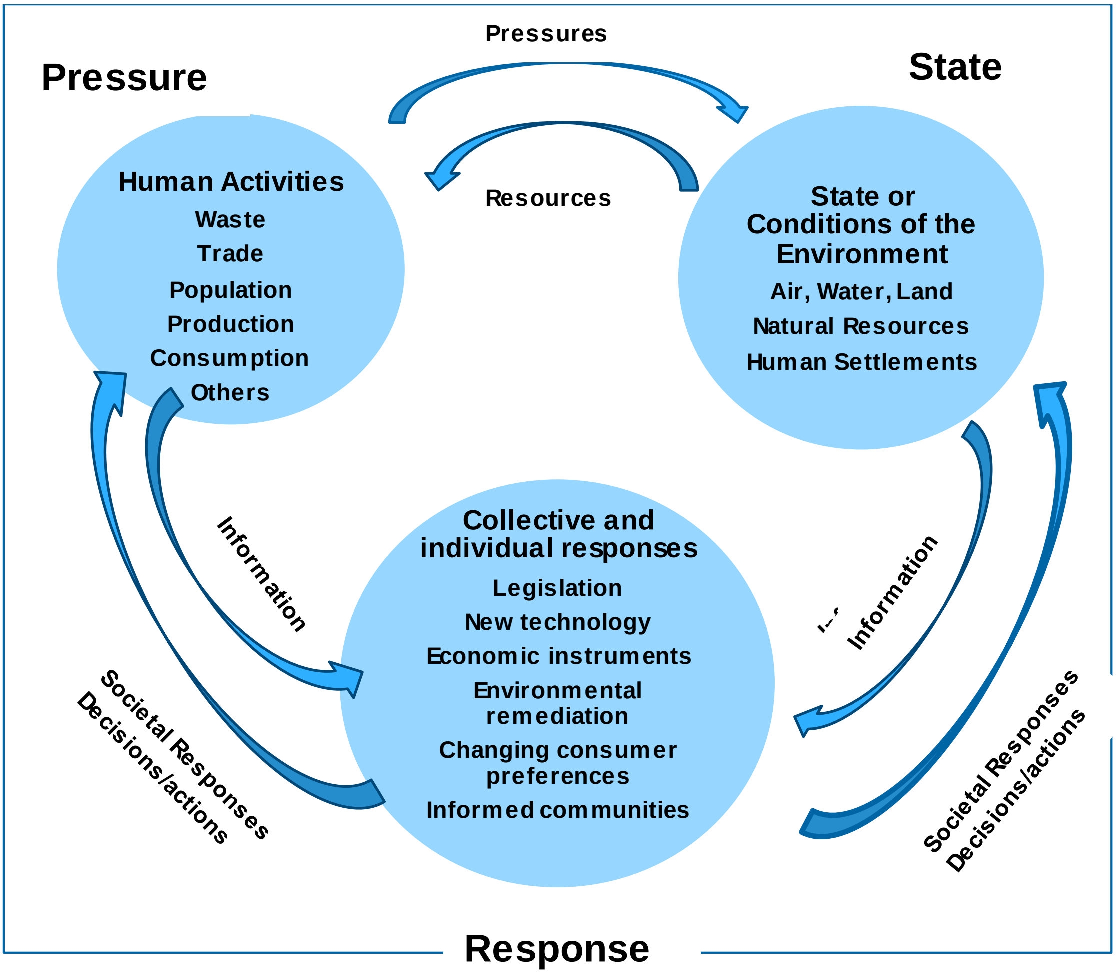


Figure 2-1 A simplified representation of the PSR Model

Indicators of environmental pressures are closely related to production and consumption patterns; they often reflect emission or resource use intensities, along with related trends and changes over a given period. They can be used to show progress in decoupling economic activities from related environmental pressures, or in meeting national objectives and international commitments (e.g. emission reduction targets).

Environmental 'conditions' relate to the quality of the environment and the quality and quantity of natural resources. As such, they reflect the ultimate objective of environmental policies. Indicators of environmental conditions give an overview of the situation (the 'state') of the environment, and its development over time. Examples of such indicators are: concentration of pollutants in the environment; exceedance of critical loads; population exposure to certain levels of pollution or degraded environmental quality and related effects on health; the status of wildlife and ecosystems and of natural resource stocks. In practice, measuring environmental conditions can be difficult or very costly. Therefore, environmental pressures are often measured instead, as a substitute.

Societal responses show the extent to which society responds to environmental concerns. They refer to individual and collective actions and reactions, intended to:

- Mitigate, adapt to or prevent human-induced negative effects on the environment;
- Halt or reverse environmental damage already inflicted; and
- Preserve and conserve nature and natural resources.

2.3 Audit indicators

Eighteen catchment health indicators (Table 2-1) were developed in 2009 by the then Department of Water and Energy (DWE), presently NOW, in consultation with various stakeholders (NOW 2009).

The indicators selected provide a coherent understanding of the condition of the Catchment, based on the primary objectives of protecting water quality and ecosystem health. They are also measurable, with the available data, and are a tool for effective information gathering and analysis, which then guides the management of the drinking water catchments.

The indicators were approved by the Director General of DWE and published in the *NSW Government Gazette* on 19th December 2008 (DWE 2008; NOW 2009).

Table 2-1 2013 Audit Gazetted Indicators

Theme	Indicator	Type of Indicator
1. Land Use & Human Settlements	1.1 Land use	Pressure
	1.2 Sites of pollution & potential contamination	Pressure
	1.3 Soil erosion	State
	1.4 Population settlements and patterns	Pressure
	1.5 Community attitudes, aspirations and engagement	Response
2. Biodiversity and Habitats	2.1 Macroinvertebrates	State
	2.2 Fish	State
	2.3 Riparian vegetation	State
	2.4 Native vegetation	State
	2.5 Fire	Pressure
	2.6 Wetlands	State
	2.7 Physical Form	State
3. Water Availability	3.1 Surface water flow	Pressure and State
	3.2 Environmental flows	Pressure and Response
	3.3 Groundwater availability	Pressure
4. Water Quality	4.1 Ecosystems and raw water quality	State
	4.2 Nutrient loads	Pressure
	4.3 Cyanobacterial blooms	State

2.4 Audit arrangements

The audit commenced with the Minister for Primary Industries commissioning GHD to conduct the audit. The contract was signed with SCA on 11 July 2013. The agreement documented the ToR, budget, key milestones, obligations, and undertakings of both the parties.

Following an inception meeting on 17 July 2013 primary points of contacts between the two parties were established.

2.5 Audit Team

The Audit Team members are outlined in Table 2-2. The Team, deliverables and outcomes were managed under GHD's quality management, project management, financial management, and health & safety management systems.

Table 2-2 Audit Team

Theme/Role	Core Audit Team
Project Director	Dr. Christobel Ferguson
Project Manager/Lead Auditor	Maurice Pignatelli
Technical Lead & Coordinator	Dr. Nimal Chandrasena
1. Land Use & Human Settlements	Danielle Baker
2. Biodiversity and Habitats	Dr. Sonia Claus
3. Water Availability	Matt Presswell
4. Water Quality	Dr. Nimal Chandrasena

2.6 The Audit report

As required by the ToR, the 2013 Audit Report has been produced essentially in the same format as in previous audits. It comprises of three volumes, as given below:

- **Volume 1 - Main Report**: This Report provides the results and conclusions of the audit assessment. It includes an Executive Summary and Section Summaries on each indicator, key discussions and audit findings.
- **Volume 2 - Appendices A-H** - Audit processes and compilation of stakeholder submissions. Provides further details of the audit processes, and a compilation of stakeholder submissions; it also provides details of all data that were analysed to support the findings.
- **Volume 3 - Appendix I** - Provides sub-catchment summaries.

There is no longer a requirement to present the findings separately for priority sub-catchments. It was agreed in 2010 that presentation of information by sub-catchment would provide a valuable reference tool. This reporting style was retained and presented in an Appendix to the Main Report (**Volume 3 - Appendix I**). Reporting on the sub-catchments was also referred to in the discussions for sub-themes and indicators.

In this **Main Report**, the Auditor has followed a format that is compatible with standard SoE reporting and presentation of results for each audit indicator. This includes a summary of findings using a traffic light style as well as in-depth SoE style reporting, with graphical and tabulated information to support the communication of the results.

In the **Main Report**, individual sections on each indicator are arranged as follows:

Each section starts with a summary of the section with key highlights, assessment criteria used in the determination of the state of the catchment health indicators (see assessment framework given below in Table 2-3), audit findings against assessment criteria and comments on progress against previous recommendations (whether completed, in progress, or not). This is followed by background information, management and surveillance information, methodology, findings of the current audit period with relevant discussions and finally recommendations requiring action.

To improve the transparency of the audit process, the Auditor developed and reported against performance-based assessment criteria for each of the gazetted Catchment Health indicators. These assessment criteria articulate audit considerations, and are phrased as statements of achievement, which assist in communicating the state of the Catchment against the gazetted indicators.

A traffic light framework was used to report results for this audit (Table 2-3) and the previous audit's recommendations (see Table 2-4).

Table 2-3 Framework and colour codes used to indicate performance against assessment criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Opportunity for improvement	Recommendations provided
3	**Does not meet expectations**	Recommendations provided

Table 2-4 Framework used to indicate status of actions against previous audit recommendations

Prior Recommendations	Remedial action	Status
No prior recommendations	NA	NA
State the Recommendation	Explain actions (i.e. adequately completed)	Closed
State the Recommendation	Explain actions (i.e. in progress or inadequately completed)	Opportunity for improvement
State the Recommendation	No actions	No progress

2.6.1 Audit recommendations

During the audit process, the data and information available for each indicator were objectively assessed and reviewed in the context of the ToR.

Recommendations were developed with the aim of providing constructive information for the relevant stakeholders to enable them to engage in the audit process and to assess catchment condition, and/or catchment health. Given that multiple stakeholders are involved in managing the Catchment, the recommendations were discussed with relevant agencies. This was undertaken to better understand:

- Constraints that may delay implementing some of the recommendations;
- The implications of each of the recommendations; and
- The practicalities of implementation.

Recommendations by the key agencies will further improve the 'knowledge base' available to effectively manage drinking water quality and maintain ecosystem health of the Catchment.

The key recommendations for action are highlighted in bold text in the Recommendations section for each Catchment Health Indicator and summarised in Section 7.3.

2.6.2 Review and submission of the Audit report

As required by the ToR, the Audit Report, reviewed by the major stakeholders, was submitted to the Minister in November 2013. The major stakeholders who reviewed the Audit Report and provided feedback are listed below:

- Sydney Catchment Authority (SCA)
- Office of Environment and Heritage (OEH)
- Hawkesbury-Nepean CMA (HNCMA)
- Southern Rivers CMA (SRCMA)
- NSW Office of Water (NOW)
- NSW Department of Primary Industries (DPI) – Division of Fisheries
- Environment Protection Authority (EPA)
- NSW Department of Planning and Infrastructure (DP&I)
- Rural Fire Service
- Sydney Water.

The Auditor reviewed and considered all comments made by the major stakeholders on the draft report and where considered appropriate, amended the audit report accordingly.

3. Land Use and Human Settlements

3.1 Land use

3.1.1 Summary

Land use within the Catchment covers a total area of 1,565,367 ha of which over 50% is classed as conservation and natural environments. The SCA has a responsibility to set the strategic direction for protecting the Catchment and works collaboratively to manage the land accordingly. The major policy that sets management requirements is the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011)* (NSW Government 2011a).

It is necessary to monitor long-term change in land use, to understand how and if such changes can place pressure on water quality and quality, or the ecological integrity of the Special Areas. There were minor changes in land use between 2010 and 2012. There was a noticeable difference in the reduction of 'dryland agriculture and plantations' (-3,171 ha) which was offset by an increase in 'water' (3,715 ha). This change likely reflects an increase in the number and extent of farm dams since the land use layer uses a static full supply level for all dams. Intensive uses declined by approximately 640 ha. This overall decline reduces pressure on the Catchment; given intensive animal production is one of the most significant pollution sources. The SCA maintained approximately 93,000 ha of Special Areas land in the more sensitive areas of the Catchment. The Special Areas is used to provide a buffer to pollutants and is considered a crucial part of the multi-barrier approach to protect water quality (SCA 2012a).

Long-term land changes reflected an increase in grazing, intensive animal production and residential land uses. These changes are likely to apply additional pressure on the water resources of the Catchment, with the increasing land uses of grazing, intensive animal production and residential use considered to contribute to priority pollution.

The management and surveillance of the bulk of the Catchment land is implemented in conjunction with Local Councils and other agencies. Collectively they undertook a number of activities to monitor, influence and mitigate pressures from land uses that have the potential to impact on water quality. Development Applications (DAs) were required to demonstrate a Neutral or Beneficial Effect (NorBE) on water quality under the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (SEPP)*. This was applicable for large developments through to small developments routinely approved by Council. During the audit period the SCA assessed a total of 686 DAs for NorBE water quality outcomes with many additional DAs also being assessed directly by Councils for compliance with NorBE.

During the current audit period a total of 46 major project applications were received with 29 of them related to Mining and associated industries. The SCA provided advice to proponents and the Department of Planning and Infrastructure (DP&I) on these projects to ensure appropriate conditions were put in place for the protection of water quality. The nature of the major projects means there could be significant water quality impacts due to their location within the Catchment unless appropriate conditions are imposed and adhered to.

The Catchment is situated in regions with growth strategies that are focused on providing new urban development in existing regional centres and additional land to support economic growth. As such there is a substantial expected population increase in the future which needs to be managed. The introduction of the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (SEPP)* provision and the NorBE tool provides the capacity for this management.

Assessment Criteria

Criteria

1. Current information on land use type, extent and changes over the audit period are analysed.
2. The extent and land use of the Special Areas is monitored.
3. Development in the Catchment meets NorBE.
4. Future development is surveyed and appropriately assessed.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil
3	Meets Expectation	Nil
4	Meets expectation	Nil

Prior Recommendations

There were no prior recommendations on the type and extent of land use apart from those that relate to mining.

3.1.2 Background

The Greater Sydney Drinking Water Catchment includes the Warragamba, Upper Nepean, Blue Mountains, Shoalhaven, and Woronora River Systems and covers an area of more than 1,565,367 ha, contains 11 major reservoirs and is the source of drinking water for around 4.5 million people. The SCA works collaboratively with other government agencies, industry and the community to set the strategic direction for protecting the Catchment and works collaboratively to manage the land accordingly.

The SCA manages Special Areas within the Catchment which encompass 364,889 ha of mostly native bushland. Land use in these areas is not expected to change however they need to be monitored for ecological integrity and their beneficial effects in protecting water quality.

The previous audit noted that ‘land use mapping of the entire Catchment is not currently undertaken at a frequency which enables an assessment of land use change at three-year audit intervals. Further, land use changes over a three-year audit period are likely to be relatively minor on a Catchment-wide scale. The assessment of land use change at a Catchment-wide scale is therefore a more useful longer term measure of the pressures on land condition’ (DECCW 2010a). Analysis for this audit confirms that land use change from 2010-12 was relatively minor, however during the audit period the SCA completed a trend analysis of land use change over the period 2000 to 2012, providing a better long-term assessment.

New planning policies and strategies have been implemented during the Audit period with regard to development applications, standard instruments for Local Environmental Plans (LEPs) and major project applications. These policies and strategies have implications for the way in which government agencies, the SCA and Local Councils manage planning and land use policies within the Catchment. Both planning changes and long-term trend analysis are further discussed below.

3.1.3 Management and Surveillance

Within the SCA Catchment area, the SCA owns and manages approximately 69,000 ha of land in the northern part of the Catchment and a further 23,547 ha in the southern region around Braidwood. The SCA has an Asset Management Strategy which outlines the principles and objectives by which this land must be managed. Under the *Sydney Water Catchment Management Act 1998*, public access and activities are restricted within Special Areas to protect water quality. Land contained within these Special Areas is a buffer to pollutants and is considered a crucial part of the multi-barrier approach to protect water quality (SCA 2012a).

Of the 24,000 ha of land within the Braidwood region, some land is privately leased for farming with management plans in place to ensure the land is managed accordingly to maintain good water quality and environmental outcomes.

However, the management and surveillance of land in the bulk of the Catchment is implemented in conjunction with Councils and other agencies. Collectively, they undertake a number of activities to monitor, influence, and mitigate pressures from land uses that have the potential to impact on water quality and yield. A number of policies and strategies are in place to guide land use management including the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (SEPP)* and the SCA's Current Recommended Practices (CRPs).

3.1.4 Findings

Current land use

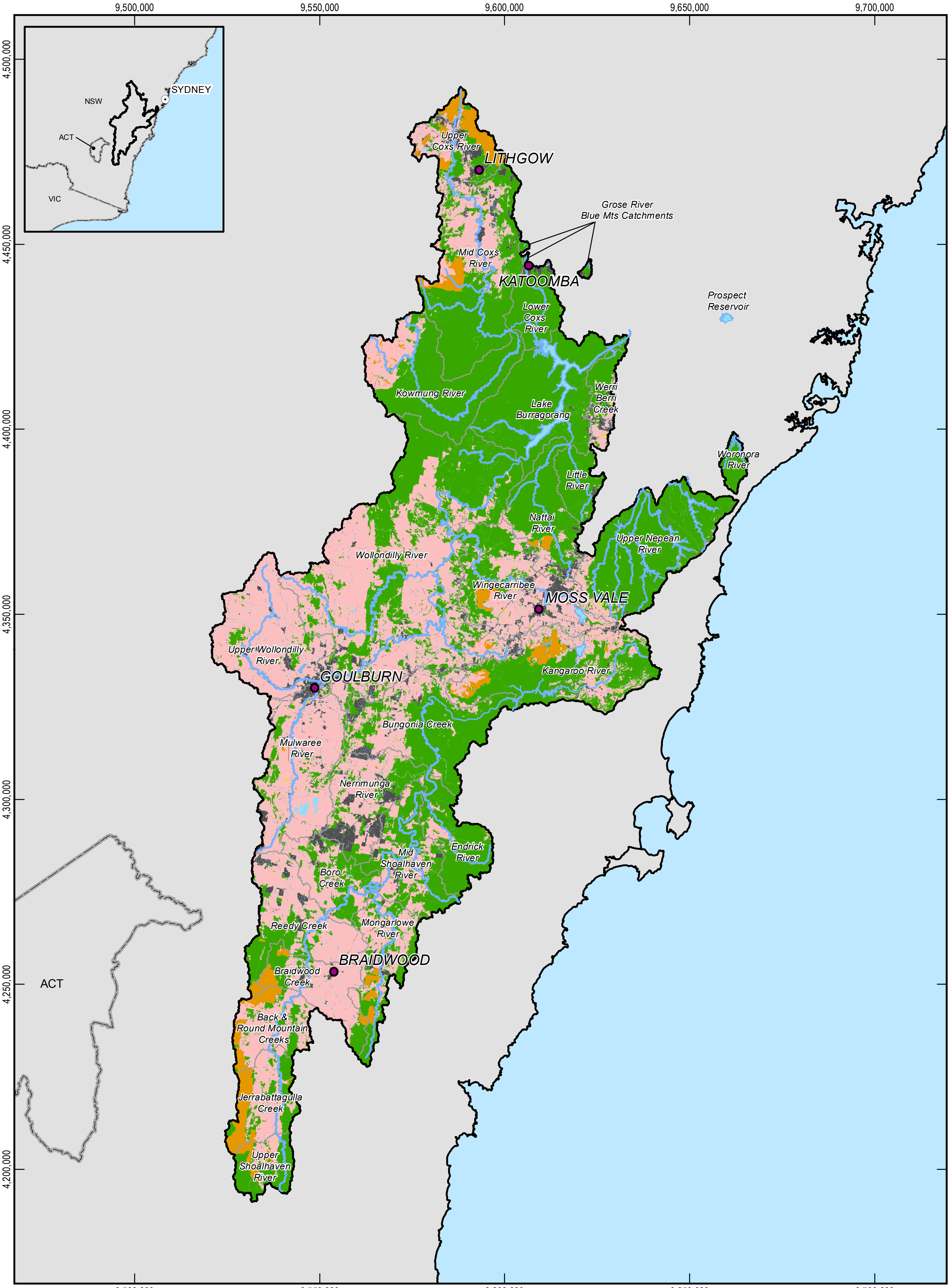
The land use categorisation data provided for 2012 is based on version 7 of the Australian Land Use and Management (ALUM 7) Classification system. Land use change since 2010 was analysed, although the 2010 data is based on ALUM 6 land use categories which vary slightly from ALUM 7. As a result there is no direct comparison of land use change; however ALUM 6 categories were reallocated to the most appropriate ALUM 7 categories to facilitate the analysis. The area of the various land use classes for 2012 and the changes compared to 2010 are shown in Table 3-1 with a map of the distribution of the six major ALUM 7 land use categories shown in Figure 3-1. Over half of the Catchment is classified as conservation and natural environments (50.2%) with almost half of this land use located in the northern half of the Catchment and within five main sub-catchments (see Figure 3-2). Dryland agriculture and plantations comprises 39.4% of land use with the Southern Highlands, Goulburn and Braidwood regions predominating.

Intensive land uses account for 4.9% of the total land with residential and farm infrastructure the major component. The largest area of intensive animal husbandry is in the Wingecarribee River sub-catchment which covers the majority of the Southern Highlands region where there are a number of equine and poultry enterprises covering an area of 1,354 ha.

Mining comprises 0.2% of the surface of the Catchment with the largest mining area (938 ha) in the Upper Coxs River sub-catchment concentrated around the power generation enterprises at Lithgow. Over half of the residential and farm infrastructure is concentrated in the following five sub-catchments of Nerrimunga River, Wollondilly River, Wingecarribee River, Mid-Coxs River and Bungonia Creek. Nerrimunga River and Wollondilly River sub-catchments also have large areas of rural residential as shown in Figure 3-2.

Table 3-1 Catchment land use area and land use change 2010 and 2012

ALUM 7 Class/ Tertiary Class - Code	ALUM 7 Class/Tertiary Class - Description	Total Area (ha) ALUM 7 - 2012	Total Area (%)	Total Area (ha) ALUM 6 - 2010	Change in land use from 2010 – 2012 (ha)
1.0.0	**Conservation and Natural Environments**	**785,551**	**50.2%**	**785,480**	**70**
1.1.0	Nature conservation	414,487	26.5%	414,501	-14
1.2.0	Managed resource protection	109,223	7.0%	109,238	-15
1.3.0	Other minimal use	261,840	16.7%	261,741	99
2.0.0	**Production from Relatively Natural Environments**	**53,340**	**3.4%**	**53,348**	**-9**
2.1.0	Grazing native vegetation	138	0.0%	138	0
2.2.0	Production forestry	53,201	3.4%	53,210	-9
3.0.0	**Production from Dryland Agriculture and Plantations**	**617,373**	**39.4%**	**620,545**	**-3171**
3.1.0	Plantation forestry	35,497	2.3%	35,533	-36
3.2.0	Grazing modified pastures	564,174	36.0%	567,389	-3215
3.3.0	Cropping	919	0.1%	943	-24
3.4.0	Perennial horticulture	316	0.0%	198	119
3.5.0	Seasonal horticulture	330	0.0%	305	24
3.6.0	Land in transition	16,138	1.0%	16,177	-39
4.0.0	**Production from Irrigated Agriculture and Plantations**	**2,811**	**0.2%**	**2,777**	**34**
4.1.0	Irrigated plantation forestry	17	0.0%	18	0
4.2.0	Grazing irrigated modified pastures	1,477	0.1%	1,499	-22
4.3.0	Irrigated cropping	6	0.0%	0	6
4.4.0	Irrigated perennial horticulture	1,059	0.1%	1,050	10
4.5.0	Irrigated seasonal horticulture	249	0.0%	209	40
4.6.0	Irrigated land in transition	1	0.0%	1	0
5.0.0	**Intensive Uses**	**76,316**	**4.9%**	**76,956**	**-640**
5.1.0	Intensive horticulture	55	0.0%	56	-1
5.2.0	Intensive animal husbandry	3,185	0.2%	3,187	-2
5.3.0	Manufacturing and industrial	286	0.0%	292	-7
5.4.0	Residential and farm infrastructure	51,084	3.3%	51,740	-656
5.5.0	Services	5,900	0.4%	5,914	-14
5.6.0	Utilities	2,218	0.1%	2,227	-9
5.7.0	Transport and communication	10,132	0.6%	10,140	-7
5.8.0	Mining	2,986	0.2%	2,915	71
5.9.0	Waste treatment and disposal	470	0.0%	485	-15
6.0.0	**Water**	**29,977**	**1.9%**	**26,261**	**3715**
6.1.0	Lake	1,331	0.1%	1,342	-11
6.2.0	Reservoir	18,667	1.2%	14,911	3757
6.3.0	River	9,138	0.6%	9,146	-8
6.4.0	Channel/aqueduct	1	0.0%	1	0
6.5.0	Marsh/wetland	839	0.1%	861	-22
	Totals	**1,565,367**		**1,565,367**	**0**



LEGEND

- Town
- Drainage
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary
- State boundary

ALUM7 Landuse classes

- Production from Dryland Agriculture and Plantations
- Production from Relatively Natural Environments
- Production of Irrigated Agriculture and Plantations
- Conservation and Natural Environments
- Intensive Uses
- Water

Page Size A4

0 10 20 30

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

SCA Landuse Cover
ALUM7 Classes

Job Number	2314960
Revision	0
Date	26 Nov 2013

Figure 3.1

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** ptamail@ghd.com **W** www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013). Created by: KP

The major urban centres within the Catchment are located at Lithgow (Upper Coxs River sub-catchment), Katoomba (Lower Coxs River sub-catchment), Moss Vale, Mittagong and Bowral (Wingecarribee River sub-catchment), Goulburn (Mulwaree and Upper Wollondilly River sub-catchment) and Braidwood (Braidwood sub-catchment). Population associated with these major urban centres is further discussed in Section 3.5.

Production from relatively natural environments covers an area of 53,340 ha (3.4%) with the majority of this being related to production forestry (53,201 ha) concentrated in the Upper Coxs River, Mid Cox River, Wingecarribee, Back and Round Mountain Creeks, Jerrabattagulla, Mongarlowe and Upper Shoalhaven River sub-catchments.

Land use change since 2010

The Figure 3-2 shows catchment-wide change in land use from 2010-12 while Table 3-2 shows changes at the sub-catchment level.

Since the 2010 audit, there was a modest net increase of 70.34 ha of Conservation and Natural Environments category across the catchment. All sub-catchments recorded a small decrease in this land use with the exception of Wollondilly River sub-catchment which recorded an increase of 191.50 ha.

There was a minor decrease of 9 ha for production from relatively natural environments, while production from irrigated agriculture and plantations had a net increase of 34 ha with the two largest increases occurring in the Kangaroo River (35 ha) and Wollondilly River (21 ha) sub-catchments. Production from dryland agriculture and plantations decreased by 3,171 ha since the last audit period with the five main decreases being recorded in the Wollondilly River (724 ha), Upper Wollondilly River (371 ha), Wingecarribee River (346 ha), Mulwaree River (220 ha) and Kangaroo River (193 ha) sub-catchments. Decreases in this land use category were recorded across nearly all the sub-catchments for this audit period and correspond with an increase in reservoir levels. There is a general lack of cropping within the Catchment and therefore ‘plantation’ may describe the bushland surrounding the reservoirs.

Intensive uses also had a net decline in land area by approximately 640 ha with a decrease of 324 ha recorded in the Wollondilly sub-catchment and an increase of 117 ha in the Upper Nepean River sub-catchment. This overall decline reduces pressure on the Catchment; given intensive animal production is one of the most significant pollution sources for the Catchment.

The Water classification increased by 3,715 ha over the period with the largest increases in the Wollondilly River (836 ha), Upper Wollondilly River (411 ha) and Wingecarribee River (392 ha) sub-catchments. This increase is likely to be due to increased number of farm dams.

Long-term change 2000 to 2012

SCA undertook a trend analysis of land uses over the period 2000 to 2012, based on updated catchment land use maps. The SCA used a combination of high resolution aerial photography and satellite imagery followed by field validation in order to obtain information on current land uses. The resulting information was used by SCA to:

- Assess the potential risk from different land use and management practices using the Pollution Source Assessment Tool (PSAT);
- Plan and implement catchment intervention programs set out in the Healthy Catchments Strategy; and
- Identify trends in land uses that may impact on water quality and quantity (SCA 2013a).

This analysis was released in the Catchment Management Report 2011-12 and noted that over the 12 years the following changes have occurred:

- Grazing (mostly cattle and sheep) within the catchment increased by 19,387 ha or 4%;
- Dairies declined in number from 28 to 23, with the majority concentrated in the Southern Highlands and Kangaroo Valley;
- Intensive animal production including horse studs increased by 180 ha;
- Piggeries and poultry production remained stable;
- Intensive and perennial horticulture (olives and viticulture) increased by 79 ha;
- Open-cut quarries increased in area by 185 ha;
- Rural residential areas increased by 5,246 ha (11%), while urban residential increased by 1,534 ha (19%); and
- Reserved areas in the Catchment increased by 81,334 ha (17%) as a result of transfer of land to create special conservation areas (SCA 2013a).

The implications arising from extensive agricultural operations and intensive animal operations are further discussed in Section 3.3. Overall, these changes in landuse are likely to apply additional pressure on the water resources of the Catchment, with the increasing land uses of grazing, intensive animal production and residential use considered to contribute to priority pollution.

Local Development

All development within the Catchment is controlled by the responsible Local Councils or, for major developments, by the State Significant Developments (SSD) provisions within the *Environmental Planning and Assessment Act 1979* (EP&A Act). The DP&I and the Planning Assessment Commission (PAC) have responsibility for major developments.

In the evaluation of Development Applications (DAs), under Local Environmental Plans (LEPs), Local Council's must not grant consent unless the development demonstrates a Neutral or Beneficial effect (NorBE) on water quality. Under section 34B of the EP&A Act (1979) provision for this is made via the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011 (SEPP)*. The aims of the SEPP are to:

- Provide for healthy water catchments that will deliver high quality water while permitting development that is compatible with that goal;
- Provide that a consent authority must not grant consent to a proposed development unless it is satisfied that the proposed development will demonstrate NorBE; and
- Support the maintenance or achievement of the water quality objectives for the Catchment.

The policy which took effect from March 1, 2011 applies to land within the Catchment and ensures that any development or activity proposed to be carried out within the Catchment '*should incorporate the Authority's current recommended practices and standards*.'

This SEPP replaced the previous Regional Environmental Plan (REP) and enables Councils to assess applications in the Catchment for NorBE, and incorporate best practices or performance standards to achieve those outcomes (DP&I 2013a).

Under these arrangements Local Councils now undertake the NorBE assessments for less complex developments and refer more complex development proposals to the SCA for specialist assessment. The SCA has ensured that the Councils are trained in undertaking NorBE assessments by providing tools, guidelines, and training.

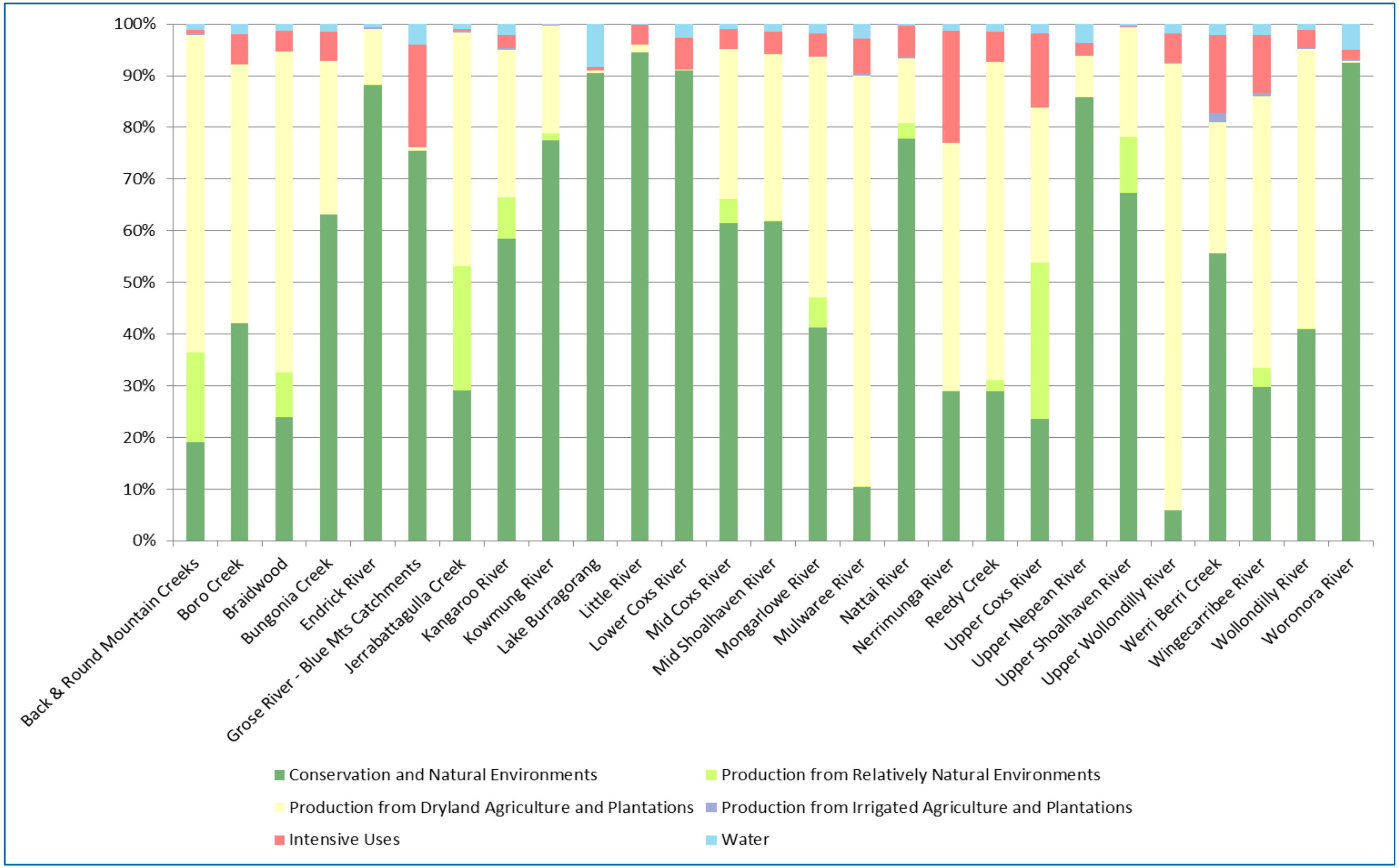


Figure 3-2 Land use in the sub-catchments 2012

Table 3-2 Sub-catchment scale change - difference (ha) of land use classes between ALUM6 (2010) and ALUM7 (2012)

Sub-catchment	Conservation and Natural Environments	Production from Relatively Natural Environments	Production from Dryland Agriculture and Plantations	Production from Irrigated Agriculture and Plantations	Intensive Uses	Water
Back & Round Mountain Creeks	-1.86	-0.08	-67.12	0.93	-0.20	68.33
Boro Creek	-8.94	0.00	-74.41	0.00	-14.90	98.25
Braidwood	-1.98	0.00	-110.53	0.00	-6.51	119.02
Bungonia Creek	-13.75	0.00	-142.61	1.19	-22.71	177.88
Endrick River	-1.72	0.00	-9.96	-0.04	-0.04	11.76
Grose River - Blue Mountains Catchments	-0.03	0.00	0.00	0.00	0.00	0.03
Jerrabattagulla Creek	-1.17	-0.10	-44.67	-0.41	-0.06	46.41
Kangaroo River	-11.96	-0.14	-192.62	35.54	-13.09	182.27
Kowmung River	-1.16	-1.15	-33.62	0.00	-0.04	35.98
Lake Burragorang	-4.07	0.00	-5.68	-0.08	-7.26	17.09
Little River	-0.54	0.00	-4.93	-0.02	-6.53	12.01
Lower Coxs River	-1.93	0.00	0.00	0.00	-2.63	4.57
Mid Coxs River	-5.70	-0.06	-90.31	-12.57	-29.27	137.91
Mid Shoalhaven River	-7.12	0.00	-39.57	-0.16	-12.09	58.94
Mongarlowe River	-4.52	-0.18	-56.46	0.00	-7.84	69.00
Mulwaree River	-7.89	0.00	-219.81	-3.56	-40.33	271.59
Nattai River	-9.49	-0.04	-36.25	-1.09	-4.08	50.95
Nerrimunga River	-7.71	0.00	-132.45	0.00	-78.01	218.17
Reedy Creek	-13.53	0.00	-180.08	2.78	-21.16	211.98
Upper Coxs River	-2.11	-6.90	-62.83	0.00	-45.92	117.76
Upper Nepean River	-3.76	0.00	-159.62	-1.50	117.29	47.59
Upper Shoalhaven River	-0.29	0.00	-12.57	0.00	-0.04	12.90
Upper Wollondilly River	-1.44	0.00	-371.74	-0.28	-37.10	410.56
Werriberri Creek	-1.89	0.00	-52.93	-1.99	-47.85	104.66
Wingecarribee River	-5.97	-0.10	-346.31	-5.11	-34.12	391.61
Wollondilly River	191.50	0.00	-723.88	20.74	-324.26	835.96
Woronora River	-0.61	0.00	-0.20	-0.38	-0.98	2.17
Grand Total	**70.34**	**-8.76**	**-3171.17**	**33.98**	**-639.69**	**3715.34**

Strategic Land and Water Capability Assessment

During this audit period the SCA also developed a number of web-based tools to assist these assessments. The SCA developed a Strategic Land and Water Capability Assessment (SLWCA) tool, which is designed to assist in the review and development of LEPs.

The SLWCA shows the level of risk to water quality from various land uses within the Catchment through examining inputs such as slope, vegetation, proximity to watercourses and soil type. Councils are required to take the outcomes of the SLWCA into consideration when they deal with planning proposals within the Catchment.

During the audit period, a total of 686 DAs had concurrence granted. The highest numbers were in the Wingecarribee LGA (276), Lithgow LGA (112) and Goulburn-Mulwaree LGA (108). The Table 3-3 shows the different categories of DAs (Modules) with concurrence.

A total of 250 development activities were granted concurrence for 'Module 3 - Rural Dwelling / Dual Occupancy Unsewered'. A further 257 were granted for 'Others (Industrial, Commercial, etc)', with the largest number of DA's in each category arising from the Wingecarribee LGA which includes the towns of Mittagong, Moss Vale and Bowral. Wingecarribee LGA had 31 DAs for 'Module 4 - Rural Subdivision – Unsewered' 31 between 2012 and 2013 compared with 63 for the previous audit. Development activity in the three LGAs with the highest DAs has declined since the last audit.

During the current audit period, 250 DAs for 'Rural Dwelling / Dual Occupancy Unsewered' were submitted. Of the 250 DAs in this module, 178 were in 2010-11, 38 in 2011-12 and 34 in 2012-13. During the current audit period, there was 107 DA's lodged in Wingecarribee LGA for Rural Dwelling / Dual Occupancy Unsewered, Lithgow (44) and Goulburn-Mulwaree (29). In the previous audit, Shoalhaven had the highest number of DA's for this category, however only 17 DA's were received for the Shoalhaven during the current audit period.

In summary, there was a decline in DAs when compared to the previous audit period. This reflects a slowing in new developments and projects across NSW. The decrease applications for in unsewered sub-division indicates a slowing of population movement just outside the major townships and represents a slight reprieve for the Catchment, given on-site wastewater systems are considered one of the significant pollution sources.

Table 3-3 DAs assessed for NorBE by SCA within Catchment LGA's (2012-13)

	Module 1 - Urban Dwelling Sewered	Module 2 - Rural Dwelling / Dual Occupancy Unsewered	Module 3 - Urban Subdivision / Multi Dwelling Sewered	Module 4 - Rural Subdivision - Unsewered	Module 5 - Others (Industrial, Commercial)	TOTAL
Blue Mountains	2	6	6	0	26	**40**
Goulburn Mulwaree	4	29	26	6	43	**108**
Kiama	0	0	0	0	1	**1**
Lithgow	2	44	5	16	45	**112**
Oberon	0	1	0	0	0	**1**
Palerang	0	28	2	15	7	**52**
Shoalhaven	0	17	2	5	13	**37**
Upper Lachlan	0	12	1	3	5	**21**
Wingecarribee	2	107	47	31	89	**276**
Wollondilly	0	6	1	3	26	**36**
Wollongong	0	0	0	0	2	**2**
Total	**10**	**250**	**90**	**79**	**257**	**686**

Major Developments Project Applications

During this audit period, the NSW Government repealed Part 3A of the EP&A Act, which was used to deal with major projects and was previously determined by the Minister for Planning. This system was replaced by the State Significant Development and Infrastructure Assessment System, which commenced on 1 October 2011.

State Significant Developments (SSD) are determined if they are over a certain size or located in a sensitive environmental area and can include a range of developments such as mines and manufacturing plants, warehousing, waste, energy, tourist, education and hospital facilities. State Significant Infrastructure (SSI) Developments include major infrastructure proposals, which could cross multiple Council boundaries and could include roads, railway lines or pipelines. Any major project that could have a significant environmental impact would also be considered as an SSI development project.

The Figure 3-3 shows the major project applications received during the current audit period. A total of 46 applications were received with 29 of them related to Mining and related industries intended for the Upper Coxs Catchment, Wingecarribee Special Areas and Metropolitan Special Areas. SCA provided advice to proponents, the DP&I and the PAC on these projects. DP&I is currently assessing a DA for an underground mine in the Catchment and Director-General's Requirements for environmental impact statements (EIS) have been issued for a further three DAs (DP&I 2013a).

A complete summary of the major projects is included in Volume 2 (Appendix E) of this Report.

Other applications were for transport, communications, energy and water infrastructure projects including wind farms, energy infrastructure, a major rail project in the Metropolitan Special Area, and development next to the Prospect Reservoir and Warragamba Pipeline.

The nature of the above projects means there could be significant water quality impacts due to their location within the Catchment unless appropriate conditions are imposed and adhered to. The SEPP does not apply to SSD, however the SCA and DP&I have a protocol to ensure that the SCA is consulted regarding SSD applications and will include requirements for NorBE in the DP&I requirements for EIS's for SSDs.

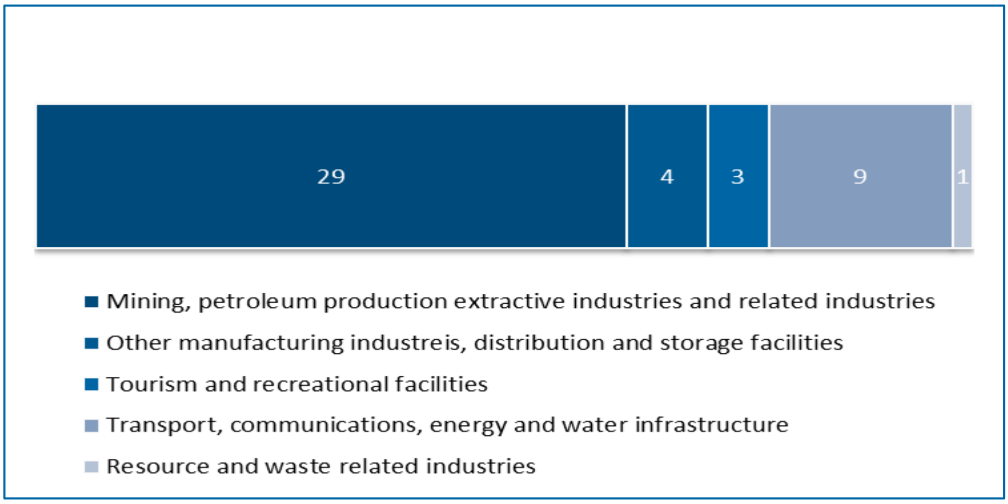


Figure 3-3 Major project applications 2010-13

Case Study - Renwick Estate Mittagong

Renwick Estate is currently being developed on what was previously grazing land in Mittagong. The development of Renwick incorporates 600 proposed lots on 116 ha. Planning for the development occurred under the SEPP (Sydney Drinking Water Catchment) 2011, thus requiring the need to demonstrate NorBE and compliance with the CRPs endorsed by SCA.

The development proposal was referred by the Council to the SCA for specialist assessment. The relevant tools and CRPs used in the development and the review of NorBE included:

- Model for Urban Stormwater Improvement Conceptualisation (MUSIC); and
- Developments in Sydney's Drinking Water Catchment – Water Quality Information Requirements.

The site includes Water Sensitive Urban Design (WSUD) features including swales (Figure 3-4), bioretention (Figure 3-5), rain gardens and attenuation devices (Landcom 2009). In addition re-vegetation and stream bed stabilisations works are proposed, given the degraded state of the land under the previous grazing use. The outcomes of this development indicate that implementation of the new planning tools has the potential to manage land use change to support beneficial water quality outcomes in the Catchment.

Figure 3-4 Renwick Estate sedimentation pond and WSUD grassed swale

Figure 3-5 Renwick Estate WSUD vegetated bioretention

Future Development

The Sydney-Canberra Corridor Regional Strategy (DP&I 2011) is a 25 year land use strategy, which aims to provide up to 25,200 new homes and 46,350 additional people by 2031, focusing on new urban development in existing regional centres, and providing suitable land to support economic growth. The strategy aims to guide local planning in six LGAs of which four are within the Catchment (Wingecarribee, Goulburn-Mulwaree, Upper Lachlan and Palerang).

The Illawarra and South Coast Regional Strategies also apply geographically to the Catchment. The Illawarra Regional Strategy is set to have an expected population increase of 47,600 with a further 38,000 new dwellings. The South Coast Regional Strategy will have a population increase of 36% and 45,600 new homes, although only some of this growth will be within the Catchment area.

In March 2012, Wollondilly LEP 2012 was amended which allowed for the rezoning of 15 ha from RU2 Rural Landscape to R2 Low Density Residential which allowed for a further 100 low density residential lots. Wingecarribee LEP 2010 accommodates for up to 3,600 new dwellings in areas north of Mittagong, around Moss Vale, while a further 570 ha of land at Moss Vale was zoned industrial (DP&I 2013b).

Since the last audit, a number of the LGAs are in the process of reviewing their Local Environmental Plans (LEPs) in order to bring them in line with the new standard instrument and in some instances have rezoned land for environmental protection purposes and reviewed minimum lot sizes.

Blue Mountains City Council (BMCC) is currently translating and amalgamating LEP 1991 and LEP 2005 into the standard instrument format, while Wollondilly LEP 2011 is a translation LEP, which updated the controls within Wollondilly LEP 1991 into a standard instrument.

A number of smaller villages that fall within the Catchment have traditionally relied on septic tanks adjacent to dwellings. The SCA considers sewage and stormwater to be among the top five sources of priority pollutants in the Catchment (SCA 2013d).

A number of these un-sewered townships were sewered, or were planned to be sewered. The SCA spent $3 million on priority pollutant grants to assist with building new sewerage and stormwater infrastructure during 2010-13.

The Township of Taralga (featured below) was sewered during this time. Also during the audit period, Shoalhaven City Council constructed a new Sewerage Treatment Plant (STP) for Kangaroo Valley in the Kangaroo River sub-catchment. The $18 million project was funded by the NSW Government (Country Towns Water Supply and Sewerage Program), Shoalhaven City Council and the SCA and will irrigate high quality effluent (EPA 2013a). In addition, Wingecarribee Shire Council was in the process of constructing the Robertson Sewerage Scheme, which involved the construction of a 25 km underground sewerage reticulation pipe network, a new sewerage pump station and an STP. This scheme was finalised in 2013.

Case Study -Taralga STP

Figure 3-6 Taralga STP commissioning testing 2011

The Upper Lachlan Shire Council has recently constructed a sewerage scheme for the village of Taralga (Figure 3-6), a $7.5 million project that connects all the properties within the village involving the construction of 11 km of sewer mains to service the village, together with a 400 Equivalent Person (EP) Intermittently Decanted Extended Aeration (IDEA) Sewage Treatment Plant (STP) and effluent storage and irrigation area.

This project was completed in 2011 (Upper Lachlan Shire 2013). All on-site septic systems were decommissioned and Upper Lachlan Shire reports the STP is working well and no discharges of treated effluent (or bypasses) have been required. The project is expected to have improved water quality in the local waterway as a result of eliminating discharges from poorly operated septic systems and absorption trenches. Visual observation of on-site system failure included hydraulic overload and absorption trench failure; particularly from the aged care home and dwellings with higher flows (submission from Upper Lachlan Shire Council).

3.1.5 Recommendations

Characterising land use across the Catchment is important in assessing what the likely impacts this change will have on the water resources within the Catchment. The SCA has continued to monitor land use change, introduce additional management requirements in the Special Areas, ensure that DAs appropriately consider impacts on water quality and support the upgrade of sewerage and wastewater infrastructure in response to an increasing population and economic activity. However, in order to continue to ensure the quality of water in the Catchment is protected, the following suggestions are provided:

- Continue to monitor land use change, but in future more clearly demonstrate linkages between land use and indicators of water quality health;
- Ensure that the extent and land use of the Special Areas is maintained or increased, with SCA reporting on the extent and land use within Special Areas and on changes to land use categories;
- The SCA should review some developments where concurrence was assumed, in order to establish that the training and tools provided to Councils are sufficient to achieve the desired outcomes; and
- Local Councils and the DP&I should continue to ensure that future needs for sewerage schemes are anticipated to support expected population increases, economic activity and land use change.

3.2 Mining Impacts

3.2.1 Summary

Mining was previously explored under the landuse indicator of 'type and extent of landuse'. There is no set measure for mining; however in the previous audit it was recommended that there be a detailed consideration of the potential cumulative impacts of all mining activities within the SCA Special Areas.

Both coal mining and Coal Seam Gas (CSG) were topics of interest with stakeholders and the community during the audit period and both are considered relevant for discussion due to the long history of coal mining, the development driver to extract high quality coal from the Southern Coalfields and for the newly emerging development pressure of CSG extraction.

There was an increase, not only in community interest, but the volume of mine related activity in the Catchment in recent years. There are nine active underground coal mines in the Catchment, five in the Southern Coalfields and four in the Western Coalfields. Five of the Southern Coalfields mines are active within the Special Areas.

A review of the Annual Environmental Management Reports (AEMRs) and End of Longwall Reports was undertaken for these mines, to detail the impacts and trends associated with mining in the Special Areas. Additional studies, dealing with the cumulative impacts of this mining, as identified by various agencies, provide a holistic review of activity and information new to the audit period. A study of the Thirlmere Lakes, and the Dendrobium Swamps and Sandy Creek was provided to present a further understanding of the impacts of mining on ecological communities, as determined by agencies external to the mines. In the case of the Dendrobium Swamps, the agency reports present a different view to those of the mine reports.

A review of non-conformance with Environment Protection Licences (EPLs) highlighted common pollution incidents for the surface workings of mine sites. This trend, related to water discharges arising from heavy rainfall and equipment malfunctions, was evident for coal and other types of mining. Geological impacts (fracturing, subsidence and cracking) are an inevitable trend in longwall mining. There is evidence that some changes to surface water flow and quality, and groundwater levels have occurred due to current or past mining activities. This trend is apparent across coal mines. The geological impacts of longwall mining do not appear to cause major damage to aquatic or terrestrial biota, based on the findings of the reports generated by mines.

These reports describe impacts in accordance with the development approvals for the mines. The alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands by mining is listed by the NSW Scientific Committee as a key threatening process under the *Threatened Species Conservation Act 1995*. In 2012 the Committee listed upland swamps as an Endangered Ecological Community (EEC).

Upland Swamps were found to be impacted in reports determined by external agencies, including OEH, and several recommendations were made with respect to these. The OEH report describes impacts considering instances of environmental change and therefore differs in its findings when compared to the mine reports. The ecological impacts of mining were observed to be present prior to, and occurring during the audit period. It was a previous audit recommendation that these types of mining impacts should be remediated.

A recommendation was made on addressing the impacts on features that have 'special significance status' through the approvals process. A further recommendation was made on providing methodology guidance on the determination of mine impacts on ecological communities, in order to better the balance between mining activities and the ecological integrity of the Special Areas. The recommended tasks will help to address the differences between the impacts reported by the mines and other agencies.

CSG approvals were sought for exploration within the Catchment. A review of the approvals process was presented to describe the current state of affairs and the stakeholder concerns for this activity.

Assessment Criteria

Criteria

1. Development within the Special Areas protects the infrastructure, yield, water quality and ecological integrity of the Special Areas.
2. Long term trends and the cumulative impacts of mining are understood.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Opportunity for improvement	The SCA shall continue to recommend approval conditions for mining within the Special Areas which are consistent with their Principles for Managing Mining and CSG impacts. OEH should finalise the Upland Swamp Environmental Assessment Guideline for whole of Government consideration and endorsement. The Guideline should provide clear and robust measures of swamp significance and impact. DPI, SCA, OEH, NOW, DP&I and Sydney Water should collaborate to develop a risk assessment methodology to assess the impacts of mining, CSG and industrial developments on water resources in the catchment.
2	Opportunity for improvement	DP&I approval conditions should be set considering risk management zones around ecological features, such as streams and swamps that have 'special significance status'. Risk management should aim to achieve nil or negligible impact to 'significant' features. Where the conditions required to achieve nil or negligible impact cannot be determined then mining should be excluded by a lateral distance of 400 m on each side of the feature or, if greater, by a 40° projection angle from the vertical down to the coal seam which is proposed to be extracted, as detailed in the Strategic Review (DoP 2008a).

Prior Recommendations

Prior Recommendations	Remedial action	Status
The Department of Planning should undertake detailed consideration of the potential cumulative impacts of all mining activities within the SCA Special Areas.	The DP&I in consultation with OEH, DPI, SCA, NOW and Sydney Water assess the potential cumulative impacts of all mining activities within the designated Special Areas. At present the DP&I is preparing a cumulative risk assessment methodology for mining and CSG projects (SCA 2013a; DP&I 2013e). The cumulative impact assessment should detail surface water, groundwater and ecological impacts in the context of all catchment inputs and outputs.	Opportunity for improvement
Where significant streams and wetlands in the Catchment are impacted by longwall mining there should be a requirement that impacts are remediated at the expense of the mining company.	Active mines are remediating natural features where development conditions have been breached.	In progress

3.2.2 Background

Mining was previously explored under the landuse indicator of 'type and extent of landuse'. There is no set measure for mining; however in the previous audit it was recommended that there be a detailed consideration of the potential cumulative impacts of all mining activities within the Special Areas.

Both coal mining and CSG were topics of interest with stakeholders and the community during the audit period and both are considered relevant for discussion due to the long history of coal mining and the development driver to extract high quality coal from the Southern Coalfields, along with the newly emerging development pressure of Coal Seam Gas (CSG) extraction.

Coal and more recently longwall coal mining has occurred in the Upper Nepean, Woronora and Warragamba catchments. The discrete and cumulative impacts of these mines have been documented through individual investigations and through cumulative impact assessments by the SCA (Jankowski 2010a; b) and OEH (Krogh 2012)

These assessments detail impacts to site geology, surface and groundwater quantity and quality, and changes to ecological features. The alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands by mining is listed by the NSW Scientific Committee as a key threatening process under the *Threatened Species Conservation Act 1995*. In 2012 the Committee listed upland swamps as an Endangered Ecological Community (EEC).

This may be applied to the impacts of mining observed to be present prior to, and occurring during the audit period. It was a previous recommendation that these types of mining impacts should be remediated. The state of current remediation will be discussed.

The driver to continue longwall mining in the Catchment results from the high quality coal available in the Wongawilli and Bulli seams that supplies the domestic and international market and is used to produce steel. The economic benefit generated by BHP Billiton alone is 4.7% of NSW household income, represents 2000 direct jobs, and supports up to 400 small and medium businesses (BHP 2013b). In total the catchment mines produced 20 million tonnes of coal in 2011 (DP&I 2013a).

CSG production is a newly emerging issue within the catchment areas and NSW as a whole. The Camden Gas Project, proximate to the upper canal is the only active large scale production project fully operating in NSW and provides for 5% of the state's gas (SCA 2012h). However, activities have been and continue to be proposed in the Catchment, including the Special Areas. Continued pressure is expected due to the depletion in conventional gas resources and the economic viability of extracting CSG.

3.2.3 Management and Surveillance

The assessment of mining activities in NSW is the responsibility of the Department of Planning and Infrastructure (DP&I), the Planning Assessment Commission (PAC) and the Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS). The decision on particular activities rests with the Minister for Planning (including delegates such as the PAC) and DTIRIS. The SCA provides advice to the assessing bodies on how activities may affect stored water, water supply infrastructure and the catchment before consent is granted (SCA 2013e).

Coal seam gas exploration, assessment, or production are the responsibility of the Office of Coal Seam Gas (OCSG) or the DP&I (EPA 2013a).

To guide the assessment and provision of advice to DP&I on proposed activities in the Catchment, the SCA developed a set of principles for managing mining and CSG impacts.

The principles are summarised as follows:

1. Mining and coal seam gas activities must not result in a reduction in the quantity of surface and groundwater inflows to storages or loss of water from storages or their catchments.
2. Mining and coal seam gas activities must not result in a reduction in the quality of surface and ground water inflows to storages.
3. Mining and coal seam gas activities must not pose increased risks to human health as a result of using water from the drinking water catchments.
4. The integrity of the SCA's water supply infrastructure must not be compromised.
5. The ecological integrity of the Special Areas must be maintained and protected.
6. Information provided by proponents, including environmental impact assessments for proposed mining and coal seam gas activities, must be detailed, thorough, scientifically robust and holistic. The potential cumulative impacts must be comprehensively addressed (SCA 2012g).

Once operating, mining and CSG operations are subject to the conditions of their development consent and mining or petroleum lease, as well as a number of government approvals including environment protection licences, with the EPA who are responsible for the administration of these licences which address mining impacts (EPA 2013a). The past and potential environmental impacts of mining were a driver in legislative reforms including the:

- *Dams Safety Act*, 1978;
- The Renyolds Inquiry Into Coal Mining Under Stored Waters which was completed in 1977*;* and the
- *Mine Subsidence Compensation Act*, 1961.

The DSC has statutory functions under the *Mining Act 1992* that allow for the DSC to provide advice to the Minister regarding development applications that involve activities, including mining below or near dam structures and their reservoirs. The DSC also performs a risk management and monitoring role to confirm that mining companies are adhering to established requirements for the protection of dams and stored waters.

The DSC's role is to advise on mining regulation without unnecessarily restricting the extraction of coal resources (DSC 2012). The DSC fulfils this role through the provision of guidance sheets, endorsing (or otherwise) proposed mining plans, involvement with the subsidence management planning process, monitoring and understanding risk. The notification area for which the DSC has responsibility were established under the *Dams Safety Act*, 1978 as investigation areas for careful assessment and regulation of mining (DP&I 2013d). These notification areas can be increased based on an understanding of the extent of ground movements experienced or newly predicted (DSC 2012).

The SCA is a member of the interagency committee that provides advice on the DTIRIS-Division of Resources and Energy (DRE) assessment of subsidence management plans.

3.2.4 Findings

Mining is an established industry within the Catchment which is subject to a large number of coal, mineral and petroleum mine titles. A total catchment area of 45% is licenced; Table 3-4 and Figure 3-7 presents the current mining titles within the catchment.

The Catchment is subject to the pressures of past, current, and future mining which can pose a risk to the natural environment including a risk to water quality, quantity and the ecosystems that rely on these. This same mining presents an economic benefit to the communities of the Catchment, and through export, to the Australian economy.

There has been an increase, not only in community interest, but the volume of mine related activity in the Catchment in recent years. During 2011-12, mining in the DSC Notification Areas across NSW, including parts of the Southern and Western Coalfields, produced 20.7 million tonnes of coal extracted from near or under storages, including drinking water and other storage dams, which represented a 10% increase over the previous year and over 40 times the tonnage extracted 10 year prior (DSC 2012). Mining approvals involving Notification Areas across NSW increased (Figure 3-8), as did approvals of active and monitored coal mining in the Catchment.

Figure 3-9 summarises the approvals for mining granted by the Minister for Planning and Infrastructure under the *EP&A ACT 1979* within the Catchment during the audit period. A full list of applications for mining activities reviewed under the Ministerial approvals process for state significant developments is presented in Volume 2, Appendix E. The majority of the applications for mining received between 2010 and 2013 were related to coal mining in the Woronora, Metropolitan and Wingecarribee Special Areas and in the Upper Cox's Catchment.

There are nine active underground coal mines in the Catchment, five in the Southern Coalfields and four in the Western Coalfields. Five of the Southern Coalfields mines are active within the Special Areas. There are mines that are proximate to the Catchment but not identified by SCA as being active within the Catchment during the audit period. These are the Tahmoor mine in the Southern Coalfields and the Invincible and Cullen Valley mines in the Western Coalfields. Further to this the Bulli Seam Operations at Appin and West Cliff in the Southern Coalfields is acknowledged as being proximate to the Upper Canal but otherwise not active within the Catchment.

CSG mining is not yet fully active within the Catchment, with modifications and works on hold for a single approval; however there is increased activity, with approvals sought during the audit period adjacent to the Upper Canal catchment.

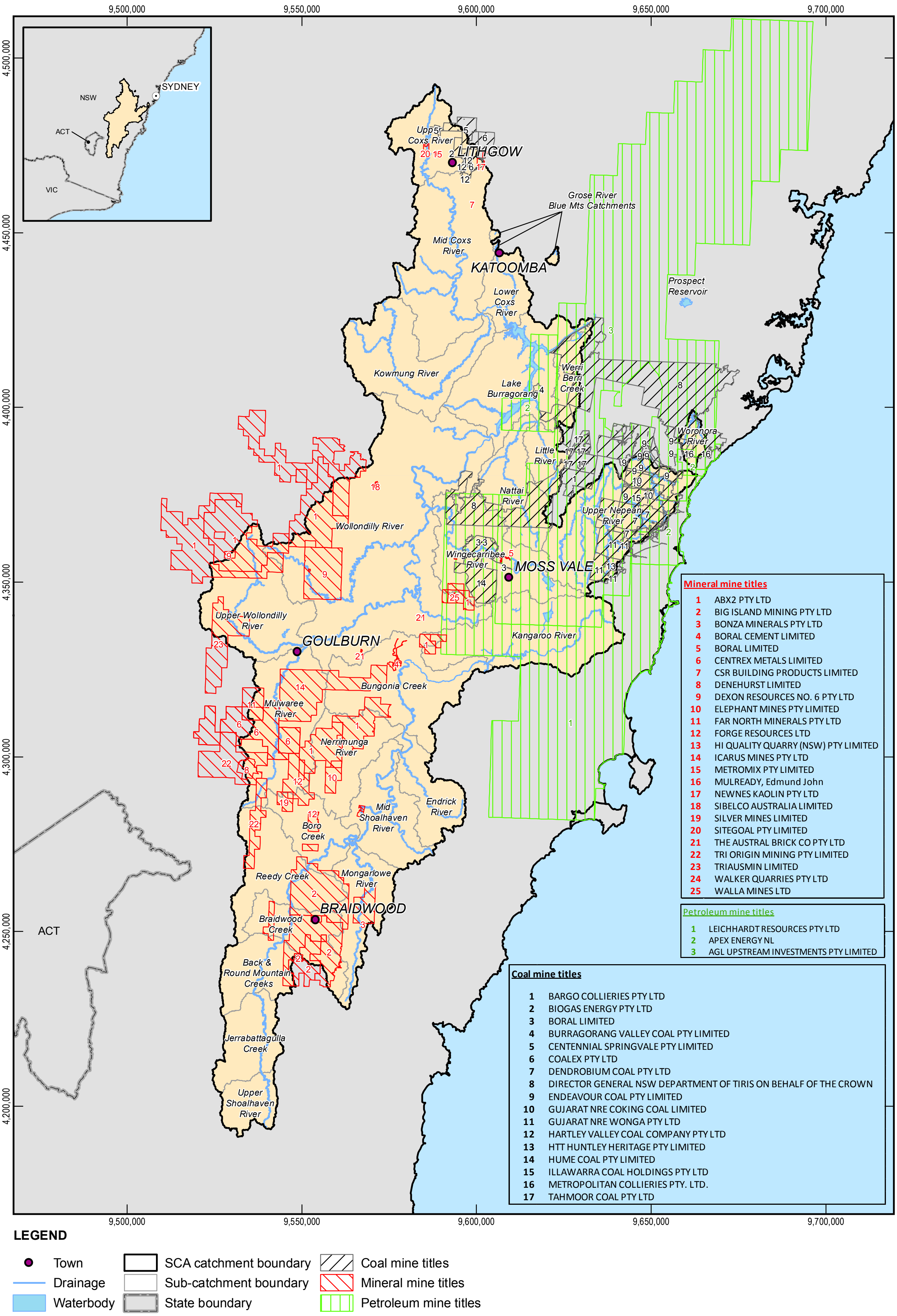
The following sections present the state of coal, mineral and CSG mining within the Catchment, along with an exploration of their known cumulative impacts.

The ToR for this Audit is that '*the catchment audit must include detailed information and analysis on the long term trends and impacts of mining activities in the catchment*'. A previous recommendation indicated that there should be a detailed consideration of the potential cumulative impacts of all mining activities within the SCA Special Areas. There has been no such assessment undertaken during the audit period.

The Southern Coalfield Inquiry of 2008 (DoP 2008a) presented a discussion of cumulative impacts and this was summarised in the previous audit. There has been no further documentation of the cumulative impacts and long term trends of mining within the Special Areas or the Catchment. This has limited the presentation of new material in this report.

Table 3-4 Mining Titles

Mining Titles	Area in Catchment (Ha)	Proportion of Catchment
Coal mining	146633	9%
Mineral	234202	15%
Petroleum	339288	21%



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0 10 20 30 Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

Sydney Catchment Authority
Catchment Audit 2013

Mining titles in the Catchment

Job Number	2314960
Revision	0
Date	26 Nov 2013

Figure 3.7

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); NSW TIRE: mining titles accessed 28/9/13. Created by: KP

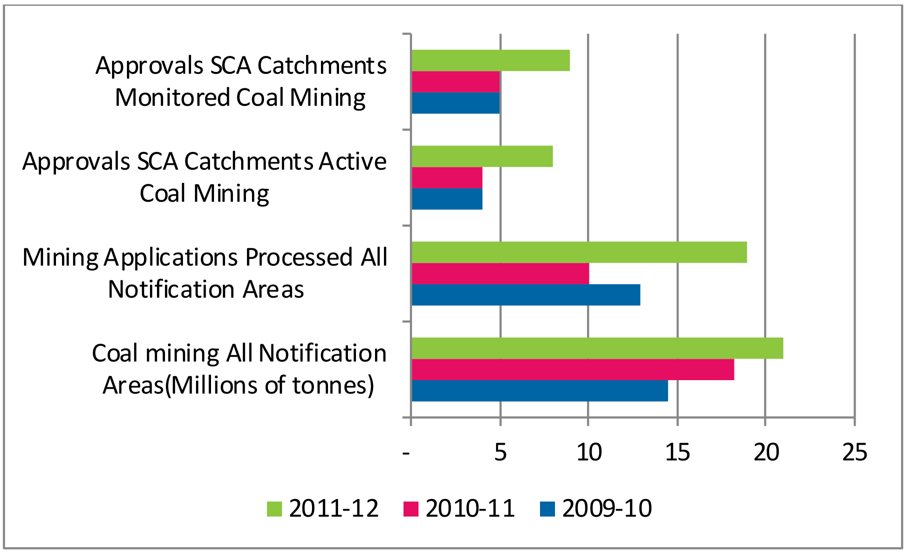


Figure 3-8 Mining trends for DSC Notification Areas, information sourced from the DSC Annual Reports for 2010-12

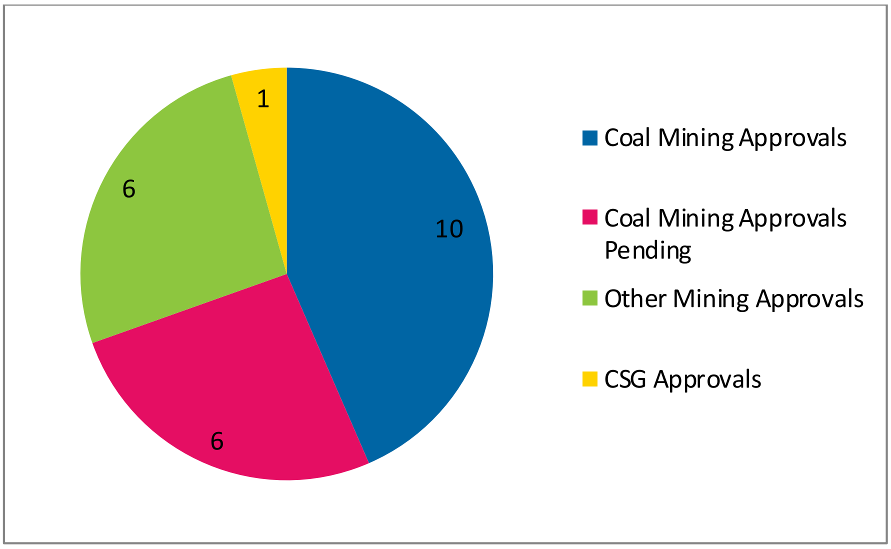


Figure 3-9 Mining approvals for 2010-13

Environment Protection Licence Compliance

Mining is a scheduled activity in accordance with the *Protection of the Environment Operations Act 1997* (NSW) and therefore, an Environmental Protection Licence issued by the NSW EPA is required. These licences list administrative, operational, environmental monitoring and reporting conditions for the site in order to ensure that the mining operations are conducted in a manner that minimises its adverse impact on the environment.

Table 3-5 and Table 3-6 summarise the non-compliances for the coal and mineral mines within the 2010-13 period. Note that as reporting periods differ from site to site, some of the non-compliances listed may have occurred outside the reporting period of this audit. Most of the non-compliances were exceedances of limit and these exceedances were usually caused by heavy rainfall, or equipment malfunction. These issues were usually rectified by the licensee, dealt with in a Pollution Reduction Program (PRP); or negotiated with NSW EPA to change to licence conditions. Only one penalty notice and one clean up notice were issued within the auditing period.

Monitoring and recording conditions non-compliances are usually caused by loss of data, failure of equipment, lack of access to sampling points, monitoring equipment failure, and human, laboratory and sampling error. Again, these issues are usually rectified by the licensee, dealt with in a Pollution Reduction Program, or negotiated with NSW EPA to change to licence conditions.

On November the 5th, 2012, Clarence Colliery was issued with a penalty notice for an exceedance in manganese concentration at the discharge to Clarence Colliery main mine dam, which overflows into the Wollangambe River. This incident was deemed by the EPA to be a licence exceedance but with no damage to the environment. An investigation to its cause was conducted and mitigation measures put in place to prevent future exceedances.

Unity Mining was issued with a clean-up notice by the NSW EPA on the 27th of February 2013 for the discharge of sediment laden water to Spring Creek and Majors Creek. The cause of this discharge was due to the heavy rainfall over three days which caused the sediment basin to overflow. Two Pollution Reduction Programs were included in Unity Mining's Environment Protection Licence No. 20095 (EPA 2013b):

- Ambient Water Quality Assessment for the Receiving Waters of the Compensatory Flow Discharge Point; and
- Site Assessment, Stabilisation, and Rehabilitation after Rain Events 2013.

Overall, the review of the non-conformances highlighted common pollution incidents for the surface workings of mine sites. This trend, related to water discharges arising from heavy rainfall and equipment malfunctions, was evident across coal and other types of mining; however there were a higher number of incidents for coal mining. A further discussion of the Western Coalfields pollution impacts is presented in Section 3.3.

Coal mining

Approximately 25% of the Metropolitan and Woronora special areas has been mined for coal (SCA 2012h). Longwall mining leads to levels of subsidence dependant on the width and spacing of the panels mined. The DSC has estimated a rule of thumb to be subsidence up to half of the thickness of coal removed which can be in excess of a metre in the Metropolitan Special Areas. Mining and this subsequent subsidence can therefore result in impacts to groundwater throughout the geological stratum, and impacts to surface water and associated ecosystems where cracking and connectivity occurs.

A review of the cumulative impacts for the Catchment, including the Special Areas, included groundwater and surface water yield and quality, as well as biota and infrastructure impacts. The following sections present information for the audit period relative to these impacts.

The Southern Coalfield inquiry lists the observed impacts to the Catchment as 'changes to stream bed and bank profiles, cracking of a watercourse bed and the creation or destruction of ponds' with the 'potential to impact on the flow regime, leakage losses via subsurface cracking, stream water quality, fauna and flora, archaeological features, and amenity' (DoP 2008a). The tables presented in this section detail the new impacts reported for 2010-13, sourced from annual reports and separately end of panel reports for active mines in the Catchment.

Table 3-5 Number of EPA non-compliances for coal mines in 2010-13

Coal Mine	Limit Conditions	Operating Conditions	Monitoring and Recording Conditions	Pollution Studies and Reduction Programs		Penalty Notices	Clean up notices
				Completed	In Progress		
BHP – Appin Colliery, Appin West Colliery, West Cliff and North Cliff Collieries	36	1	10	1 (Appin West Colliery)	3	0	0
BHP – Dendrobium Mine	1	0	8	3	0	0	0
Peabody – Metropolitan Colliery	4	0	4	0	1	0	0
Gujarat – NRE Wongawilli Colliery	4	0	0	1	2	0	0
Centennial Coal – Angus Place Colliery	13	0	2	0	1	0	0
Centennial Coal – Springvale Colliery	54	2	9	0	3	0	0
Centennial Coal – Clarence	11	2	0	0	1	1	0
The Wallerawang Collieries Ltd – Baal Bone Colliery	3	0	14	0	0	0	0
Boral – Berrima Colliery	0	0	0	2	4	0	0
Xstrata Tahmoor Coal – Tahmoor Colliery*	69	0	0	8	2	0	0

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

Table 3-6 Number of EPA non-compliances for mineral mines in 2010-13

Mineral Mines	Limit Conditions	Operating Conditions	Monitoring and Recording Conditions	Pollution Studies and Reduction Programs		Penalty Notices	Clean up notices
				Completed	In progress		
Boral – Peppertree Quarry	0	0	1	0	0	0	0
Boral – Marulan South Limestone Mine / Plant	0	0	0	0	0	0	0
Unity – Dargues Gold Mine	0	0	0	0	2	0	1
The Austral Brick Co – Bowral Brickworks	4	0	0	0	0	0	0
Hi-Quality Quarry – Ofallon Ford Quarry	0	0	4	0	0	0	0
Holcim – Marulan Quarry	0	0	0	0	0	0	0
Walker Quarries – Wallerawang Quarry	1	0	0	0	0	0	0
Metro mix –Quarries	0	0	0	0	0	0	0

Groundwater and Surface Water Impacts

One of the conditions of the mining leases is to prepare, in accordance with the *Guidelines to the Mining, Rehabilitation and Environmental Management Process* (DTIRE 2006), an Annual Environmental Management Report (AEMR). This report should detail the:

- Current status of approvals, leases, licences and strategies;
- Mining activities, rehabilitation, monitoring data, environmental performance and community liaison for the past 12 months; and
- Proposed improvements to environmental performance and management systems, mitigation measures and any environmental and rehabilitation targets for the next 12 months.

Table 3-7, Table 3-9, and Table 3-11 summarises a number of environmental impacts that may be attributable to mining for the audit period - 2010-13. Note that Boral's Berrima Colliery is not included in the tables due to the lack of access to the mine's AEMR.

A number of mines produced end of panel reports once a particular longwall extraction has been completed. These reports are prepared as part of the mine's Subsidence Management Plan approval conditions. These reports compare predicted and observed impacts of the longwall on the environment and man-made infrastructure. Both the AMER and end of panel reports describe impacts in accordance with the development approvals for the mines.

Table 3-8, Table 3-10, and Table 3-12 summarise the impacts found in the end of panel reports, which are publicly available.

In general, based on the AEMR reports, geological impacts (fracturing, subsidence and cracking) are an inevitable trend in longwall mining. There is evidence, in both the AEMRs and end of panel reports that some changes to surface water flow, water quality and groundwater levels have occurred due to current or past mining activities. This trend is apparent across coal mines. It is also worth noting that there is evidence that subsidence and fracturing continue to take place for a short period after the completion of extraction.

Case Study - The Waratah Rivulet

Water quality in the surface waterways downstream of areas impacted by subsidence can be altered through changed surface water/groundwater interactions. Cracking can result in both loss of yield to creeks and water quality change through the mechanism of interaction with fresh rock and the associated mineral leaching that can result.

These chemical reactions can include the dissolution of carbonate minerals, reductive dissolution of metal oxides/hydroxides and oxidation of metal-sulfur minerals, which mobilise cations, anions and metals from rock strata (Jankowski and Spies 2007; Jankowski and Knight 2010) and the discharge of groundwater rich in iron and manganese to the stream causing the development of thick mats of iron/manganese-oxides/hydroxides, together with large quantities of iron oxidising bacteria (Jankowski et al. 2010).

Table 3-7 Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
BHP - Appin Mine (Area 7 Longwalls 705-710) 2012/13	Fracturing observed in a tributary of the Nepean River adjacent to the commencing end of Longwall 704. No surface water present at inspection, however no baseline data is available due to the landholder denying access to the property at the time.	No mining induced springs have been identified. A spring with iron staining was observed in the upper reaches of a tributary of the Nepean River adjacent to the commencing end of Longwall 704. This spring was similar to others in the area where there has been no mining. As there is no baseline data due to restricted access to the area it is unable to be determine if the spring is associated with mining. Due to the minor nature of the spring it is not considered a mining impact.	The AEMR does not comment on any impact on groundwater due to mining activities.	BHP 2012a
BHP - West Cliff Colliery (Area 5 Longwalls 34-36) 2012/13	Fracturing and uplift observed on some rock bars and in some pools of the Georges River. Some associated minor flow diversion observed, no reduction in pool water level when comparing to baseline conditions. Fracturing and minor uplift and soil cracking observed within Mallaty Creek. Reduction in pool water level (not conclusive if mining related).	Minor flow diversions, no loss of flow or reduction in pool water level when comparing to baseline conditions. Gas releases observed in some pools. No iron staining greater than pre-mining conditions.	The two closest boreholes (27 and 28) have shown no significant change over LW35. There has been a reduction with no appreciable recovery in BH28 (impacted by previous mining).	BHP 2012b
BHP - Dendrobium (Area 3B Longwall 9) 2012/13	Some fracturing in exposed bedrock and tension cracks observed on or near fire tracks.	Some surface water flow diversion observed in WC17 and SC10C.	No comment on drawdowns during Longwall 9 extraction.	BHP 2012c; 2013a; b; c; d
Gujarat – NRE Wongawilli Colliery 2011/12	The AEMR does not comment on any impact on geology due to mining activities.	The AEMR does not comment on any impact on watercourse flow due to mining activities.	No evidence of adverse impact due to mining activities.	Gujarat 2011; 2012a; b; c; 2013

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
Peabody Energy - Metropolitan Mine 2010 - 12	Minor surface cracking of exposed sandstone outcrops was observed in several swamps where vegetation has opportunistically grown, for example Swamps 17 and 23; and rock displacement has been recorded in the lower end of Swamp 24 within a drainage channel. 2010 - max 43 mm at Line 9C and Line 9C West 2011 - Line 9C - Small vertical movements extend several hundred metres to the north of Longwall 20 and may be the result of redistribution of in-situ stresses due to the extraction of Longwall 20.	During the reporting period, visual inspections were conducted along the Waratah Rivulet in July 2010. Slight movement along an existing north-south joint was noted at the seep area located immediately downstream of Flat Rock Crossing. The subsidence crack was closed and consisted of slight flaking along a north-south joint. No strike slip or vertical displacement of the stream bedrock was evident. No additional subsidence impacts, such as cracking or gas releases were observed during the visual inspections. Stream bed cracking was observed in two sections of the Waratah Rivulet, namely, between Flat Rock Crossing and the rock bar of Pool H, and at the rock bar of Pool N (located between Longwalls 21 and 22). Both areas were affected by surface tension being proximal to secondary extraction.	No evidence of adverse impact due to mining activities.	Peabody 2010; 2011; 2012

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
Peabody Energy - Metropolitan Mine 2010 - 12 (continued)	A surface tension crack has recently been recorded above Longwall 18 (Plates 1 and 2). The tension crack is located sub-parallel to the gate roads, directly above mining and at a distance of approximately 50 m from the goaf edge. The tension crack extends semi-continuously over a length of approximately 200 m. The width of the tension crack is typically less than 10 mm, with a maximum width of 40 mm. Cracking of streamside rocky areas was observed during the autumn 2011 survey at the downstream end of MRIP01. A short length of cracking was observed on the western bank above the water level at the time of inspection. No dieback of vegetation was observed in areas adjacent to the cracked bedrock. The maximum observed incremental subsidence and tilt along D Line are greater than predicted. However, these movements occur above the previously extracted Longwall 18 and are likely to be the result of residual subsidence due to Longwall 18, which occurs over time following the completion of a longwall.	The crack at rock bar H, as at end May 2012, had dimensions, 16 m long and 30 mm wide. The crack has progressively lengthened and widened during the extraction of Longwall 21. Water flow does not appear to have been affected by the crack as evidenced by continuous overflow of water over the rock bar and retention of ponded water on the surface of the rock bar. At rock bar N, the crack orientations are consistent with a compression of the rock bar across the valley characteristic of the 'valley closure' mechanism. The closure mechanism results in a variety of individual crack orientations and crack dimensions. The shear fractures generally run along the axis of the rivulet and dip at shallow (<30°) angles perpendicular to the axis of the rivulet. On the surface of the rock bar the shear fractures appear as cracks running generally along the axis of the rivulet. The orientation of the surface cracks are influenced by localised features such as jointing. The cracks range in width from hairline to up to 20 mm. The depth of the cracking is approximately 1.5 m. The advancing Longwall 21 may have caused tensional surficial cracks, known elsewhere at the Metropolitan Mine to extend to 10-20 m depth, which have opened up the low permeability fine-sandstone base that supports the monitored perched sandstone water table at Swamp 20. Water has been lost to the immediately underlying unsaturated zone and will have caused a rise in the elevation of the underlying perched or regional (unmonitored) water table.		Peabody 2010; 2011; 2012

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
Peabody Energy - Metropolitan Mine 2010 - 12 (continued)	The maximum observed tensile and compressive strains occur within the valley of the Waratah Rivulet which experienced significant valley closure movement during the extraction of Longwalls 1 to 18 and these strains may be the result of reactivation of these movements. The small vertical movements extending to the south of Longwall 20 are likely to be the result of reactivation of the goaf due to Longwalls 1 to 18 These small vertical movements extend several hundred metres to the north of Longwalls 20 and 21 and may be the result of redistribution of in situ stresses due to the extraction of Longwall 20.	At Swamp 20, water appears to be infiltrating downwards to a series of perched water tables monitored by sandstone piezometers at 4 m depth and 10 m depth. The sandstone water levels remained stable during the review period until April 2012 when the deepest piezometer reacted to the approach and passage of the Longwall 21 mining face. The water level dropped suddenly by 1.8 m, then rose by 2.8 m, then declined by about 5 m at the end of the review period. The upper two piezometers (one sandstone and one swamp substrate) showed no effect but there is evidence of a slight decline in the final month of the review period. Whether this is a climatic effect or a mining effect cannot be answered at this time. This appears to have occurred selectively at Swamp 16 but not at Swamp 17, which is consistent with the expected randomness of crack locations. However, if the minor post-mining breach at Swamp 17 is a mining effect, this could be explained by the occurrence of tensional surficial cracks at Swamp 17 after the longwall face has passed.		Peabody 2010; 2011; 2012

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
Xstrata - Tahmoor (LW 27) 2010 – 12*	During the reporting period minor surface cracking and near surface unconformities occurred in isolated locations during the extraction of Longwall 26. These resulted in some local irregularities to the ground surface around semi-rural and urban properties. Restoration and rehabilitation of the land to the satisfaction of the property owners was undertaken.	Although minor creek bed cracking was observed due to extraction of Longwall 26, no adverse effects have been observed on the stream bed, bank stability or water quality during the monitoring period.	No evidence of adverse impact due to mining activities.	Xstrata 2010; 2011a; b; 2012; 2013a; b; GeoTerra 2011
Xstrata - Baal Bone Colliery 2010 - 12	2010: >200 mm width tension crack around the start of Longwall 30 (Wolgarn Escarpment). Identified as a significant unpredicted subsidence. There were no subsidence impacts observed outside the nominated angle of draw.	2010: minor impact on surface watercourses, potential bed damage in a watercourse where water was seen to disappear due to subsidence at the start of Longwall 30. Weekly visual monitoring indicated that on the 23 July width of the crack had developed and triggered a TARP. Creek is usually dry and subsidence event occurred after heavy rainfall event.	2010: no indication of mining related impacts to groundwater in proximity to Coxs River Swamp. 2011: Groundwater levels were within normal background levels and no anomalous trends are considered to have occurred in 2011.	Wallerawang Collieries 2010; 2011; 2013
	2011: mining undertaken at Longwalls 30 and 31. Minor cracking occurred parallel to gate roads associated with Longwall 31. Notification of exceedance provided to DPI. A remediation program was developed.	There were no subsidence impacts observed outside the nominated angle of draw.	pH levels for all groundwater monitoring piezometers were above the TARP major trigger values for 2011 except for BBPB6.	

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
	Longwall 30 start line cracking undertook remediation works which were completed on 24 February 2011.	2011: A repair to creek not undertaken due to ephemeral nature of the creek, and it does not hold any significant ecosystems or endangered flora and fauna. No current proposal for rehabilitation, as over time creek may self-rehabilitate due to silty stream bed Baal Bone continue subsidence monitoring with additional observation points until Longwall 31 complete and reassess subsidence impacts and/or required remediation at this stage.	Iron levels at BBPB3 exceeded the major exceedance trigger level from march to July 2011. Moderate exceedances occurred from October to December 2011. Increase in iron concentrations corresponded with a rise in groundwater levels and an increase in pH above 6.0. Rising groundwater interacted with soil high in iron causing oxidation and release into the groundwater. Zinc exceeded minor and major impact trigger levels in January, February, August, November and December 2011. This was attributed to natural variability, and reported to DPI.	
	Longwall 31 cracking had increased in size (post mining) in 2012. Notification provided to DTIRIS. Surface above Longwall 29-31 inspected for cracking in late February 2012. Risk assessment conducted to determine remediation methods. Repairs to subsidence to commence in February 2013.		2012: no significant changes in groundwater level pH levels were above the minor and major impact trigger levels for 2012 except bores BBPB2 and BBPB6; Copper levels in BBPB4 (background bore) exceeded the major impact trigger level in January 2012 and July to October 2012. Copper levels were found to increase in spring each year, suggesting a biological process. notification submitted to DPI	

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
			Zinc levels at BBPB3 exceeded the minor and major impact trigger levels for 5 consecutive months between August to December 2012. There were no obvious reasons for the increase.	
Centennial Coal - Angus Place Colliery 2011 - 12	Minor cracking identified along a section of kangaroo Creek Road on 28 July 2011 and attributable to Longwall 960. Sedimentation filled the cracks by December 2011. 2012: Longwall 970 cracking observed in the western end, 20 m from Kangaroo Creek Road. Four cracks (largest 18.2 m long) identified as having a minor impact.	The AEMR does not comment on any impact on watercourse flow due to mining activities.	2011: Monitoring of dewatering bores indicate no issues with contamination (hydrocarbons) from underground sources Kangaroo Creek: Groundwater level at bore labelled KC1 is influenced by previous mining activities. An underground lateral flow through mining-induced cracks is assumed to be occurring at the site causing the groundwater level to remain at the base of the bore. West Wolgan Seamp: Groundwater fluctuations largely influenced by rainfall patterns. Narrow Swamp Groundwater trends consistent with natural variability.	Centennial Coal 2012a; 2013a
			2012: Fluctuations in groundwater levels attributable to natural climatic events	

Table 3-7 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the AEMRs for 2010-13

Mines	Geological impact	Watercourse flow impact	Groundwater	Reference
Centennial Coal - Springvale Colliery 2012	No evidence of adverse impact due to mining activities.	The AEMR does not comment on any impact on watercourse flow due to mining activities.	Extraction limit at pit top bore exceeded by 349 ML for the 2011-2012 reporting period. Attributed to management of old Renown Colliery to maintain acceptable level of inrush protection	Centennial Coal 2012c
Centennial - Clarence Colliery 2011 - 12	All subsidence monitoring results for 2011 and 2012 were within the 100 mm maximum predicted in the SMP for all panels relevant to the 700 Area, Outbye Areas and 314/316 panels and within the elastic limit of the overburden strata (100 ± 2 5 mm, Strata Engineering Australia 2005).	The AEMR does not comment on any impact on watercourse flow due to mining activities.	No evidence of adverse impact due to mining activities.	Centennial Coal 2012b; 2013b

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

Table 3-8 Coal mining impacts as stated on geological, watercourse, and groundwater in the end of panel reports

Mines	Completion date	Geological impact	Watercourse flow impact	Groundwater	References
BHP - West Cliff Colliery (Longwall 34)	14/09/2011	A zone of fracturing was observed near Rockbar 41 (near Cardno Ecology Lab aquatic ecology monitoring Site 7) (ICEFT 2011). Recent areas of fracturing and uplift in the Georges River have been observed downstream of Pool 43 (ICEFT 2011b).	One small pool in Mallaty Creek (MC109) now drains more rapidly after rain due to fracturing. A number of other pools up and downstream have not lost water.	Drop of 6 m in GR28. Borehole water level is recovering during recharge events.	BHP 2012b
BHP - Appin Mine (Area 7 Longwalls 701-704)	28/07/2012	Subsidence induced fracturing was observed at two sites within a tributary of Nepean River (Lyrebird Creek).	No evidence of adverse impact due to mining activities.	Interconnection between aquifers and aquitards has been observed within 20 m of the surface over Longwall 703 in the Boustani and Nahkle private bores. An increased rate of recharge into the western plateau has been observed in both BHPBIC piezometers and the Nahkle bore. Temporary lowering of piezometric surface by up to 10 m observed.	BHP 2012b
BHP - Dendrobium (Area 3A Longwall 7)	23/01/2012	Fracturing of bedrock on a step within swamp 12. Fracturing resulting in water loss from some permanent pools has been observed in WC17 and SC10C.	Some surface water flow diversion into dilated strata observed in WC17 and SC10C.	Drawdown levels were as predicted.	BHP 2012c; 2013a; b; c; d

Table 3-8 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the end of panel reports

Mines	Completion date	Geological impact	Watercourse flow impact	Groundwater	References
BHP - Dendrobium (Area 3A Longwall 8)	29/12/2012	Some additional fracturing was observed along watercourses WC17 and SC10C where previous impacts were reported during the extraction of Longwall 7.	Pool water level loss due to fracturing of the bedrock at WC17 and SC10C.	4 to 20 m reductions of head were observed during Longwall 7 extraction. During Longwall 8 extraction, additional reductions of 1 to 10 m were observed. In general, drawdown levels were as predicted. During Longwall 8 extraction, the drawdown extent was observed to move farther into Area 3B. The expected propagation to the south has not occurred to any significant extent.	
Xstrata - Tahmoor (LW 26)	15/10/2012	Following the mining of Longwalls 24A and 25, increased subsidence has been observed above the southern end of Longwall 26. Maximum observed incremental subsidence from the mining of Longwall 26 was 893 mm, which was almost one and a half times the maximum predicted subsidence of approximately 640 mm. While observed tilts and curvature were also substantially greater than predicted, observed ground strains were generally within the normal range.	No evidence of adverse impact due to mining activities.	Lowering of piezometric surface by up to 8.9 m in piezometer P2. Groundwater levels in P2 recovered by approximately 8.6 m from their lowest point.	Xstrata 2010; 2011a; b; 2012; 2013a; b

Table 3-8 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the end of panel reports

Mines	Completion date	Geological impact	Watercourse flow impact	Groundwater	References
Xstrata - Tahmoor (LW 25)	21/02/2011	Following the mining of Longwall 24A, substantially increased subsidence has been observed above the southern end of Longwall 25. Maximum observed incremental subsidence from the mining of Longwall 25 was 1234 mm, which was almost double the maximum predicted subsidence of approximately 740 mm. While observed tilts and curvature were also substantially greater than predicted, observed ground strains were generally within the normal range.	Although isolated areas of exposed sandstone cracking / sloughing have occurred, there has been no adverse effect on overall plateau stream flow.	Lowering of piezometric surface by up to 8.9 m in piezometer P2 and up to 5.25 m in P3 has been observed. The groundwater level in P2 is approximately 4.9 m lower than the start of Longwall 25, whilst P3 exceeds its pre LW25 level by approximately 6.9 m.	Xstrata 2010; 2011a; b; 2012; 2013a; b
Gujarat – NRE Wongawilli Colliery (Longwall 11)	13/5/2011	Maximum observed total subsidence and tilt due to mining was greater than predicted.	No evidence of adverse impact due to mining activities.	Monitoring of groundwater has identified the groundwater level within the Hawkesbury Sandstone fell by 8.92 m in open piezometer EGW3 (over Longwall 11) as a result of the extraction of Longwall 11.	Gujarat 2011; 2012a; b; c; 2013
Gujarat – NRE Wongawilli Colliery (Longwall 19)	20/11/2011	Maximum observed total subsidence and tilt due to mining was less than predicted. Some increased subsidence has occurred away from the point of maximum subsidence, over the previously extracted Longwall 17. The increased subsidence in this area may be due to the reactivation of the Longwall 17 goaf.	No evidence of adverse impact due to mining activities.	Monitoring of groundwater has identified the groundwater level within the Hawkesbury Sandstone fell by 8.92 m since June 2010 in open piezometer EGW3 (over Longwall 11) as a result of the extraction of Longwall 11. To date the EGW3 water level has not recovered and the other EGW water levels have remained static to slightly rising during extraction of Longwalls 19 and 20.	Gujarat 2011; 2012a; b; c; 2013

Table 3-8 (cont.) Coal mining impacts as stated on geological, watercourse, and groundwater in the end of panel reports

Mines	Completion date	Geological impact	Watercourse flow impact	Groundwater	References
Gujarat – NRE Wongawilli Colliery (Longwall 20)	11/4/2012	Maximum observed total subsidence and tilt due to mining was greater than predicted.	No evidence of adverse impact due to mining activities.	Monitoring of groundwater has identified the groundwater level within the Hawkesbury Sandstone fell by 8.92 m since June 2010 in open piezometer EGW3 (over Longwall 11) as a result of the extraction of Longwall 11. To date the EGW3 water level has not recovered and the other EGW water levels have remained static to slightly rising during extraction of Longwalls 19 and 20.	Gujarat 2011; 2012a; b; c; 2013
Gujarat – NRE Wongawilli Colliery (Longwall 15)	6/11/2012	There are no subsidence survey lines installed in the surface area above Longwall 15. As such, subsidence survey data is not available for Longwall 15. No major surface cracking (>10 mm) was observed in the Mining Area above Longwall 15 during longwall extraction.	No evidence of adverse impact due to mining activities.	Monitoring of groundwater has identified the groundwater level within the Hawkesbury Sandstone fell by 8.92 m since June 2010 in open piezometer EGW3 (over Longwall 11) as a result of the extraction of Longwall 11. To date the EGW3 water level has not recovered and the other EGW water levels have remained static to slightly rising during extraction of Longwalls 15, 19 and 20.	Gujarat 2011; 2012a; b; c; 2013

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

This type of water quality impact is possible for approved longwall mining operations within the catchment and has been observed within the Special Areas. One such example of an observed surface water impact is the Waratah Rivulet in the Woronora Catchment. This, and the remediation of the cracking of this waterway by the Peabody Metropolitan Mine, was discussed in the previous audit report. A three year study, published in 2010 addressed the loss of yield and ground-surface water connectivity for the mining impacted section of this creek, as understood through isotopic and applied tracer studies (McLean et al. 2010).

The studies concluded that cracking / subsidence has enhanced permeability resulting in a loss of flow in low-flow conditions, 1300 m of dry streambed (Jankowski et al. 2010)and a re-routing of flow during high-flow conditions without ultimate loss (Jankowski and Spies 2007). This tracer study prompted the SCA to explore the development of an integrated surface and groundwater model. The SCA has used modelling to estimate the loss of groundwater to mine workings as 3 GL per annum across the Catchment (SCA 2013g). Note that some of this groundwater would not have otherwise been captured in the storages. This is not the overall impact of mining, which is expected to be far greater and too difficult to estimate (SCA 2013g). Loss can be estimated for specific sites, as is the case for the Waratah Rivulet where the SCA estimates the loss to be 3% of the flow (SCA 2013g). The results of 2011-12 modelling and tracer studies indicate this may be due to inter-catchment groundwater flow (SCA 2012c).

One of the reasons the impacts on this site and in general the cumulative impacts of mining are hard to quantify, and in this case required tracer studies is due to the inadequacy of baseline information prior to monitoring. Historically baseline monitoring has been negligible and ongoing monitoring has often been insufficient in duration or spatial density to support a determination (Jankowski and Madden 2009). This has resulted in the SCA developing guiding principles for the collection of baseline information and the listing of this as a mining principle.

Conditions are now being set for more comprehensive baseline monitoring and monitoring post mining, as demonstrated in the Dendrobium Area 3 determination (DoP 2008b) and the Metroploitan mine determination (DoP 2009). These reflect the findings of the Southern Coalfields enquiry to incorporate 2 years baseline and 2 years post mine monitoring (DoP 2008a). The ministerial acknowledgement and support of this through the setting of approval conditions which meet these requirements will support a finer determination of mining impact.

Remediation and monitoring of remediation works for this site continued during the audit period. This work included remediation through the drilling of holes and the injection of grout (polyurethane resin) into sub-surface fractures at two pools on the Waratah Rivulet. Monitoring activities have included the mobilisation, placement and operation of monitoring equipment and water quality monitoring.

Ecological Impacts

Table 3-9 summarises a number of adverse environmental impacts that may be attributable to mining for the audit period - 2010-13. Table 3-12 summarise the impacts found in the end of panel reports. Within the audit period, a penalty notice was issued by DESWPaC to Centennial Coal in 2011 for causing a significant impact on the endangered Temperate highland peat swamps on sandstone ecological community (DSEWPaC 2011). It should be noted that much of this mine is located just outside of the Catchment.

The media release on the 21st of October, 2011 stated that:

'The mining activities caused a loss of ecosystem function shown by loss of peat, erosion, and vegetation dieback and weed invasion in three swamps. They also caused the formation of a large slump hole, several metres wide and more than one metre deep, at the East Wolgan swamp. These changes mean the swamps can no longer serve their important hydrological role of acting as water filters and releasing water slowly to downstream watercourses.

Centennial Coal will pay $1.45 million towards a research program to ‘provide valuable knowledge to protect temperate highland peat swamps on sandstone and to promote land management practices that minimise impacts on these swamps’.

Although this highlights the possible adverse effects that longwall mining can have on the environment, this severity of the impact is not reflected in the AEMR documents reviewed. The Auditor notes that this is one limitation of presenting the cumulative impacts of mining through the use of mine reports and that this further justifies the need for a cumulative impact study to be developed that considers holistic sources of information. This will help to address the differences between the impacts reported by the mines and other agencies, due to different reporting focuses.

According to the AMER reports, the geological impacts of longwall mining do not appear to cause major damage to aquatic or terrestrial biota. The main adverse impact appears to be the discharge of water outside of the EPL limits for the Clarence mine.

A review of the Thirlmere Lakes, and the Dendrobium Swamps and Sandy Creek is provided to present a further understanding of the impact of mining on ecological communities, as determined by agencies external to the mines, including the OEH. In the case of the Dendrobium Swamps the agency reports present a markedly different view. This is because the OEH report describes instances of environmental change and therefore differs in its findings when compared to the mine reports.

The Thirlmere Lakes

The Thirlmere Lakes Inquiry in 2013 presented new information on the impacts on an ecological system thought to be connected to mining near the Warragamba Catchment. In 2010, the NSW Office of Water released the report Thirlmere Lakes groundwater assessment (Russell et al 2010). This report concluded drier than normal weather, and reduced groundwater levels were resulting in a decline of the water levels in the Thirlmere Lakes system. The report concluded that that ‘there was no evidence to suggest that mine fracturing or subsidence has affected the water levels in Thirlmere Lakes in any substantial way’ (Russell et al 2010). In 2011, Pells Consulting produced modelling and a report that noted that reduced water levels in the Lakes corresponds with a net deficit in rainfall (Pells Consulting 2011).

The accompanying modelling indicated that mining activities may have changed the groundwater flow pattern. The report postulated that longwall mining at the Xstrata Tahmoor Mines has caused an increase in ‘deep recharge’ as water is moved downwards to replace that removed in mine dewatering, but that there is insufficient data to determine the change in quantity of groundwater flow from the lakes (NSW Chief Scientist and Engineer 2013a; b).

The NSW Office of Water subsequently released the Thirlmere Lakes drilling report (Russell 2012), which aimed to fill previous knowledge gaps. Two further reports were produced by Gilbert and Associates Pty Ltd (2012) and Heritage Computing (2012), and all of these reports were used in the inquiry determination.

Gilbert and Associates (2012) found that a lack of level information, including baseline information resulted in model uncertainty and therefore uncertain findings. In this work, the conclusion was that ‘While it is possible that mining could have had a marginal effect on groundwater levels beneath the lakes, there is no definitive evidence that this has occurred. On the other hand, there is clear evidence for the drying of the lakes being coincident with a severe drought’ (Heritage Consulting 2012).

Table 3-9 Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the AEMRs for 2010-13

Mines	Water quality impact	Aquatic biota	Terrestrial biota
BHP - Appin Mine (Area 7 Longwalls 705-710) 2012/13	Four new gas releases have been identified. A spring with iron staining was observed in the upper reaches of a tributary of the Nepean River adjacent to the commencing end of Longwall 704. This spring was similar to others in the area where there has been no mining. As there is no baseline data due to restricted access to the area it is unable to be determine if the spring is associated with mining. Due to the minor nature of the spring it is not considered a mining impact.	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.
BHP - West Cliff Colliery (Area 5 Longwalls 34-36) 2012/13	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.
BHP - Dendrobium (Area 3B Longwall 9) 2012/13	Some changes in water appearance.	Loss of aquatic habitat and potentially biota appear to be confined to areas affected by fracturing and are relatively minor in a local and regional context.	No comment on Longwall 9's impacts.
Gujarat – NRE Wongawilli Colliery 2011/12	No evidence of adverse impact due to mining activities.	The AEMR does not comment on any impact on aquatic biota due to mining activities.	No evidence of adverse impact due to mining activities.

Table 3-9 (cont.) Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the AEMRs for 2010-13

Mines	Water quality impact	Aquatic biota	Terrestrial biota
Peabody Energy - Metropolitan Mine 2010 - 12	2010 - The spikes in dissolved iron on Waratah Rivulet may be associated with mining effects however they appear to be both isolated (localised) and transient – and have not been detected at the downstream sampling site WRWQ9. A gas release from Pool H on the Waratah Rivulet was identified on 5 January 2011. The gas release is not an exceedance of Metropolitan Coal's performance measures which allow for 'minimal' gas release downstream of Pool P.	No evidence of adverse impact due to mining activities.	2011 - For autumn 2010 the differences in riparian vegetation cover between baseline and post-mining are most likely attributable to track establishment through the longwall sites impacting vegetation cover (e.g. MRIP01, MRIP05, MRIP06), and the variable impacts of flooding along all riparian sites during spring 2010 and autumn 2011.
	Dissolved Fe at WRWQ9 exceeded the baseline mean plus one standard deviation in June and July 2011, and there was not a similar increase in the same measure at the control site. However, there is little evidence to conclude that the exceedance at WRWQ9 would have resulted in a greater than negligible reduction in the quality of the water resources reaching the Woronora Reservoir.		
	Those sections of the rivulet that have experienced additional cracking up to rock bar N exhibited iron staining that has been evident across the streambed wherever surface water has flowed. Bright red staining appears to be evident in those sections across the rivulet currently under water, and brown iron staining appears to be evident in those sections across the river where the bedrock is exposed.		
	During 2011/12, gas releases in the Waratah Rivulet have been observed in Pools H, I, L and O. No adverse environmental impact observed.		
	The sliding 12 month means for dissolved aluminium, dissolved iron and dissolved manganese at site WRWQ9 exceeded the baseline mean plus one standard deviation during the review period and that because there were not similar exceedances of the same measure at the control site; water quality performance indicator was exceeded.		

Table 3-9 (cont.) Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the AEMRs for 2010-13

Mines	Water quality impact	Aquatic biota	Terrestrial biota
Xstrata - Tahmoor (LW 27) 2010 – 12*	New stormwater system has caused increased aeration of water resulting in liberated CO_2 from water and slightly elevated pH. Previous results have been within acceptable range.	The AEMR does not comment on any impact on aquatic biota due to mining activities.	No evidence of adverse impact due to mining activities.
	The 12 month moving average total manganese in Woronora Reservoir at DA01 exceeded the baseline mean plus 1 standard deviation value from the 23/6/2011 to the 1/3/2012.		
Xstrata - Baal Bone Colliery 2010 - 12	During 2010, discharge events all samples recorded were within EPL concentration limits except for iron at discharge point LDP1 in February 2010. This result was related to significant rainfall events.	The AEMR does not comment on any impact on aquatic biota due to mining activities.	No evidence of adverse impact due to mining activities.
	2011: All samples were recorded within EPL limits except for Iron levels at LD6 in April and October 2011 and at LDP1 in June 2011. The cause of elevated iron levels was unknown, weekly surface water testing at LDP1 for eight weeks was undertaken to ascertain any discernible trends. Results of this additional monitoring not presented in this report.		
	2012: all samples recorded were within EPL concentration limits during the 2012 reporting period, with the exception of total iron at LD6. There was no discernible cause for the non-compliance.		
Centennial - Clarence Colliery 2011 - 12	In 2011, an incident occurred where coal fines were identified within a manmade drainage channel connected to the south eastern most portion of the washed coal stockpile area. 3 (2 pH and 1 TSS) exceedances at LD2 during 2011 and 5 (1 TSS and 4 filterable Mn) exceedances in 2012. One discharge from LD3 during 2011 with an exceedance in TSS and 1 discharge during 2012 with exceedances in pH, TSS, Cd, filterable Mn and Zn). 1 discharge from LD4 during 2011 with a number of parameters exceeded.	The AEMR does not comment on any impact on aquatic biota due to mining activities.	No evidence of adverse impact due to mining activities.

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

Table 3-9 (cont.) Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the AEMRs for 2010-13

Mines	Water quality impact	Aquatic biota	Terrestrial biota
Centennial Coal - Angus Place Colliery 2011 - 12	2011- Discharge Points: LDP001: discharged annual average 3380 kl/day. One incident of TSS exceedance above EPL criteria. Attributed to: heavy rainfall, additional throughput of water due to mine shutdown and cleaning of fire tanks. LDP002: discharged annual average of 106 kl/day. There were no detected exceedances LDP003: Does not require volumetric measuring. Two TSS exceedances detected. Attributed to high rainfall and limited settling time in the settlement dam. Stream flow monitoring: Kangaroo Creek monitoring indicates water quality appears to be unaffected by potential mining impact 2012 Discharge Points: One TSS exceedance detected in LDP002 and LDP003 in March. Exceedances were attributed to an extreme rainfall event. LDP001, LDP002 discharge volumes were 5329 kL/day and 167 kL/day respectively. Stream monitoring: Quality of water in Kangaroo Creek and Narrow Swamp appear to be unaffected by mining extraction/subsidence.	The AEMR does not comment on any impact on aquatic biota due to mining activities.	No evidence of adverse impact due to mining activities.
Centennial Coal - Springvale Colliery 2011 - 12	2012: Discharge points: LDP001: six exceedances of pH recorded during the reporting period generally associated with the capacity of the acid dosing system to treat variable flows in the channel. LDP010: seven exceedances of total aluminium and one exceedance for oil and grease detected during the reporting period. Attributed to insufficient settling time for the coagulant used to treat clay in the water and due to inappropriate dosing by the flocculant dosing system.	The AEMR does not comment on any impact on aquatic biota due to mining activities.	No evidence of adverse impact due to mining activities.

Table 3-10 Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the end of wall reports

Mines	Completion date	Water quality impact	Aquatic biota	Terrestrial biota
BHP - West Cliff Colliery (Longwall 34)	14/09/2011	Some elevated concentrations of sulphate, iron and zinc in Leaf's Gully. Some elevated concentrations of iron and nickel, and decreased pH in Mallaty Creek. Zone of iron staining identified in Pool 40d near Rockbar 41 (ICEFT 2011). The staining is restricted to the edge of the pool and not visible downstream. No significant impact due to Longwall 34.	One small pool in Mallaty Creek (MC109) now drains more rapidly after rain due to fracturing, but monitored pools have not been impacted.	Minor cracking in the Georges River not apparently resulting in loss of surface flows. Some pools in Mallaty Creek have lost standing water. No observed impact to threatened species. Minor environmental impacts observed in relation to mining Longwall 34 has had no observed impact on terrestrial ecology.
BHP - Appin Mine (Area 7 Longwalls 701-704)	28/07/2012	Gas release was observed at a total of nine sites during the extraction of Longwall 704. Three of these sites were activated by Longwall 704. The remaining six releases were reactivations or continuation of sites identified during extraction of previous longwalls. Post LW704 only three sites remain active.	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.
BHP - Dendrobium (Area 3A Longwall 7)	23/01/2012	No evidence of adverse impact due to mining activities.	Impacts to the aquatic ecology of SC10C and WC17 (loss of aquatic habitat and potentially biota) appear transient, localised, and minor. No evidence of further downstream impacts to aquatic ecology.	Iron staining has resulted in an adverse impact to breeding pools for Littlejohn's Tree Frog though no significant impact has resulted.

Table 3-10 (cont.) Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the end of wall reports

Mines	Completion date	Water quality impact	Aquatic biota	Terrestrial biota
BHP - Dendrobium (Area 3A Longwall 8)	29/12/2012	Iron staining was observed in the Subsidence Management Plan Area but there was no ferruginous spring's observed during extraction of Longwall 8.	Concurrent impacts to the aquatic ecology of SC10C (loss of aquatic habitat and potentially biota) appear to be confined to the affected areas, and relatively minor in a local and regional contact. The same is expected to be true of impacts to aquatic ecology occurring in WC17. Some evidence of impact to aquatic ecology in Wongawilli Ck. However, this was transient and restricted to one indicator and could reflect natural variation. The potential loss of aquatic biota due to localised draining of pools in SC10C and WC17 is considered relatively minor in a local or regional context. Such biota is abundant in the local area and drainage lines only contain ephemeral habitat of limited potential aquatic ecological value.	Mining of Longwall 7 and 8 has resulted in reduced groundwater levels and increased rates of recession in Swamp 15b and Swamp 12. Dieback of Pouched Coral Fern and Button Grass has been observed in Swamp 15b. This may indicate impact to Cyperoid Heath MU44c which forms part of the threatened ecological community Coastal Upland Swamp of the Sydney Basin Bioregion. Mining of Longwall 6, 7 and 8 has resulted in fracturing of WC17 and pool water level loss. This is currently affecting 8 pools along this tributary, with 4 of these pools providing breeding habitat for Littlejohn's Tree Frog. Mining of Longwall 7 has resulted in fracturing of the creek bed in SC10C resulting in pool water level loss in Pools 7, 8 and 9, and gas release in Pool 10. Since the completion of Longwall 8, Pools 10a, 22 and 23 have recorded water levels below baseline measurements. This creek provides known breeding habitat for Littlejohn's Tree Frog.

Table 3-10 (cont.) Coal mining impacts as stated on water quality, aquatic and terrestrial biota in the end of wall reports

Mines	Completion date	Water quality impact	Aquatic biota	Terrestrial biota
Xstrata - Tahmoor (LW 26)*	15/10/2012	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.	The AEMR does not comment on any impact on terrestrial biota due to mining activities.
Xstrata - Tahmoor (LW 25)*	21/02/2011	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.	The AEMR does not comment on any impact on terrestrial biota due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 11)	13/5/2011	Bellbird Creek EC above 200 µS/cm, (not known to be subsidence induced) and Bellbird Creek pH below 4.2 and above 6 (related to a calibration error with the monitoring equipment).	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 19)	20/11/2011	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 20)	11/4/2012	Stream water quality in Bellbird Creek and the Wongawilli Creek tributaries has temporarily exceeded either the salinity and/or pH triggers, but has not been affected in the long term, with both pH and EC returning to its baseline, pre mining range.	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 15)	6/11/2012	Stream water quality in Bellbird Creek and the Wongawilli Creek tributaries has temporarily exceeded either the salinity and/or pH triggers, but has not been affected in the long term, with both pH and EC returning to its baseline, pre mining range.	No evidence of adverse impact due to mining activities.	No evidence of adverse impact due to mining activities.

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

The inquiry found that ‘changes in rainfall (natural climate change) were undoubtedly responsible for the majority of the change in lake levels in the last 30 years there may be other factors involved in the present low levels’ and that these other factors could be higher temperatures and changes in groundwater losses (NSW Chief Scientist and Engineer 2013a; b). The inquiry notes that ‘none of the models appear to discount that mining has a potential impact’ and ‘that there is not enough data to make a definitive conclusion on the cause of the reduction in lake levels’ (NSW Chief Scientist and Engineer 2013b). The inquiry found that ‘there is no direct evidence that mining has breached geologic containment structures underneath lakes, including the Bald Hill Claystone bed’; noting this was in contrast to the finding of the Pell report which postulated that this aquitard is breached (NSW Chief Scientist and Engineer 2013a; b). Importantly the inquiry found that the underlying Hawkesbury Sandstone Aquifer has been lowered, and that there is evidence to suggest mining impacts, but that this could not be separated from the impact of natural changes and other groundwater extraction (NSW Chief Scientist and Engineer 2013b). Furthermore this mining impact could not be established as being temporary or enduring.

Ultimately the inquiry found that the reduced volume of water in the lakes when compared with pre-decade conditions could not definitively be attributed to the impacts of mining. Further monitoring and modelling, along with potential remediation is proposed in order to manage this system and the active mining landuse associated with the Thirlmere Lakes Region.

Dendrobium Swamps and Sandy Creek

In contrast to the findings for Thirlmere Lakes, mine attributed damage of upland swamps is established for the BHP Billiton Dendrobium Mine. A report prepared by Krogh (2012) discusses the surface impacts of this mine, listed as 340 identified impacts for Areas 1, 2 and 3, with a particular emphasis on upland swamps. These swamps are further discussed in the Biodiversity section of this report.

The report lists mine impacts as the lowering of several aquifers, including the Hawkesbury sandstone aquifer, with limited understanding of the enduring impacts to groundwater dependant ecosystems. Impacts to Dendrobium Swamps 12 and Swamp15b, including the draining of perched aquifers is considered similar to other instances of impact and therefore a long term trend for mining in the Woronora and Metropolitan Special Areas.

Swamp 15b was visited during the Audit in September 2013. Cracking of rock within the dry creekline below the Swamp was observed along with vegetation distress in the Swamp. Vegetation changes are observed in some impacted swamps above the Dendrobium workings and can also be considered a trend. Stream impacts such as partial draining and cracking, resulting in changes to flow and water quality, including the release of iron, can also be considered a trend.

Krogh (2012) lists impacts to creeks and rivers, including the Cataract River, Waratah Rivulet, Wongawilli Creek, Native Dog Creek, Lizard Creek, Wallandoola Creek, and in this case the SC10C Creek tributing to the Sandy Creek. Figure 3-10 depicts cracking in creek SC10C which is described as having water loss.

Figure 3-10 Creek SC10C below Swamp15b

Krogh (2012) finds that there is categorisation of impacts such as 'negligible' and 'minor' without a clear definition of what constitutes these findings. There is some detail in development approvals for defining such an impact; however a uniform approach would assist the transparency and defensibility of impact findings. Krogh (2012) suggests that these impacts can be measured using factors, such as surface, perched and/or regional groundwater declines, or redirection of flows and pool draining. Characterising the fracture size, depth and extent are also suggested for clarity of impact assessment, given their potential to affect environmental systems. The completion and utilisation of the Draft Upland Swamp Environmental Assessment Guideline (DECCW 2011) could provide further clarity around the measures of impact on these systems, and ultimately result in better swamp protection, when placed into use.

Remediation for Creek SC10C and Swamp15b is yet to occur. The Development Consent for Dendrobium which incorporates Longwall 3A, describes the 'minor' impacts as being 'minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality' (DoP 2008b). The development was approved with 'minor' impact to such waterways permitted. Prior to this approval, concerns about impacts to the Creek and the Swamp were expressed by the DPI, the former Department of Environment and Climate Change (DECC), the former Department of Water and Energy (DWE) and the SCA. For the nearby Area 3B the SCA wanted a 'negligible' impact to swamps of special significance as the approved condition.

Whilst Development Conditions are set, based on the need to balance environmental and economic outcomes, better definitions of impacts could assist with determinations following harm and result in better and timely remediation outcomes.

Structures

Table 3-11 summarises a number of adverse environmental impacts that may be attributable to mining for the audit period - 2010-13. Table 3-12 summarise the impacts found in the end of panel reports.

There is no evidence that longwall mining activities are causing damage to water supply infrastructure in the vicinity of the mines assessed in the cumulative impacts tables. This finding supports the statement of the DSC in its submission to the audit that mining operations near SCA storages have resulted in 'negligible loss from the storages and no adverse impacts on the dam structures'(DSC 2013).

Cordeaux Reservoir

Through monitoring of the impacts of mining on dam structures and their associated reservoirs the DSC found that there is no observable penetration of surface water into the mine voids of the Southern Coalfields and that these mine workings are predominantly dry due to overlaying impermeable claystone layers (DSC 2013).

The DSC undertook monitoring and review regarding an increase in Dendrobium mine inflow during 2010-13. During the approvals process a loss of 1.0 ML/day was considered the maximum tolerable loss to the mine from the overlaying Cordeax Reservoir. The combined inflow for areas 1 to 3A was observed as being around 2.0 ML/day, with Area 3A spiking to >6.0 ML/day during rainfall events (DSC 2013). The source of this water was attributed to groundwater from the coal seam itself with a minor input from the Scarborough Sandstone which sits above the Wombarra Claystone and below the Cordeax Reservoir. For this study there was no evidence that water entering the mine was drawn from the Cordeax Reservoir (DSC 2013). It is evident that the Wombarra Claystone aquitard is compromised.

In contrast to this, a study by Zeigler and Middleton of the DSC (2011), on the analysis of mine water origins, using tritium and algae as indicators of the source of water entering the Dendrobium mine goafs indicated that algae, which can only be attributed to connectivity with surface water, was present in the mine in concentrations of greater than 1000 $\log_{10}$ algal cells / mL after heavy rain events (Zeigler and Middletone 2011). The conclusion of the study was that while tritium indicated a source of new water in the mine, it could not conclusively identify that source of water as being from the Cordeaux Reservoir. However, the algal signature of the water did imply surface connectivity, and therefore, requires further investigation (Zeigler and Middletone 2011). The presence of 20% modern water in some instances further implies that when inflows are beyond 5.0 ML/day, then the tolerable threshold of 1.0 ML/day was reached (Zeigler and Middletone 2011).

A further study by Coffey Geotechnics (2012) used modelling to predict both baseflow intended for the Avon and Cordeax Reservoirs that was diverted away due to the Dendrobium mine, and possible seepage of water from the Avon and Cordeaux Reservoirs away from the storage due to the mine. The seepage was modelled as a median of <0.1 ML/day meeting the tolerable loss threshold (Coffey Geotechnics 2012). The intercepted baseflow was modelled as a median of 0.61 and 0.48 ML/day for the respective reservoirs, with an additional median diversion prior to the reservoirs of 0.98 ML/day.

Stakeholder and community interest in Coal Mining

Numerous submissions discussed mining within the Catchment. Community group submissions detailed an opposition of mining within the drinking water Catchment. The following main issues represent the interest and concerns related to mining, detailed in submissions to the Audit:

- Loss of water and the resultant die back of vegetation;
- Concern of water quality impacts such as contamination with metals, e.g. iron and the associated fauna impact;
- Subsidence, cracking and disturbance of aquifers associated with longwall mining and the lack of available proven methods to remediate; and
- Permanent damage to whole systems that cannot be remediated.

Table 3-11 Coal mining impacts as stated on infrastructure in the AEMRs for 2010-13

Mines	SCA Infrastructure
BHP - Appin Mine (Area 7 Longwalls 705-710) - 2012/13	No evidence of adverse impact due to mining activities.
BHP - West Cliff Colliery (Area 5 Longwalls 34-36) - 2012/13	No evidence of adverse impact due to mining activities.
BHP - Dendrobium (Area 3B Longwall 9) - 2012/13	Not applicable
Gujarat – NRE Wongawilli Colliery - 2011/12	The AEMR does not comment on any impact on SCA infrastructure due to mining activities.
Peabody Energy - Metropolitan Mine - 2010 - 12	No evidence of adverse impact due to mining activities.
Xstrata - Tahmoor (LW 27) - 2010 – 12*	No evidence of adverse impact due to mining activities.
Xstrata - Baal Bone Colliery - 2010 - 12	2010: Ben Cullen Creek Rehabilitation project completed as part of a larger CMA project in the Upper Jews Creek area. The AEMR does not comment on any impact on SCA infrastructure due to mining activities.
Centennial Coal - Angus Place Colliery - 2011 - 12	The AEMR does not comment on any impact on SCA infrastructure due to mining activities.
Centennial Coal - Springvale Colliery - 2012	The AEMR does not comment on any impact on SCA infrastructure due to mining activities.
Centennial - Clarence Colliery - 2011 - 12	The AEMR does not comment on any impact on SCA infrastructure due to mining activities.

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

Table 3-12 Coal mining impacts as stated on infrastructure in the end of panel reports

Mines	Completion date	SCA Infrastructure
BHP - West Cliff Colliery (Longwall 34)	14/09/2011	The observed movements at the wrought iron aqueducts, after the completion of Longwall 34, were similar to or less than those predicted, with the exception of some closures that were slightly above predictions. The horizontal movements were observed to develop during times of shut down and high water flows. It is likely, therefore, that these movements were thermal movements as the water flow normally moderates the temperature of the aqueduct pipes.
BHP - Appin Mine (Area 7 Longwalls 701-704)	28/07/2012	The monitoring results indicated that small far-field horizontal movements occurred during the extraction of Longwall 704. In the latest survey, the maximum observed incremental horizontal movement was 29 mm eastwards (i.e. away from Longwall 704). It is noted, that West Cliff Longwall 35 was also being extracted during this period and, therefore, it is likely that the extraction of this longwall also contributed to the observed far-field movements along the Upper Canal and Devines Tunnels. In the latest survey, the observed incremental net subsidence at the Mallaty Creek Aqueduct was 4 mm due to the extraction of Longwall 704. It is noted, that this movement occurred at a single location, being Mark S1 in the latest survey only and, therefore, appears to be the result of a disturbed survey mark. It can also be seen from the above table, that small incremental opening movements occurred at the Ousedale Creek Aqueduct (5 mm), Ousedale Creek Bridge (3 mm) and Leafs Gully Aqueduct (3 mm). These movements have resulted in reductions in the net closures which had developed at these structures prior to the extraction of Longwall 704.
BHP - Dendrobium (Area 3A Longwall 7)	23/01/2012	Not applicable
BHP - Dendrobium (Area 3A Longwall 8)	29/12/2012	Not applicable
Xstrata - Tahmoor (LW 26)*	15/10/2012	No evidence of adverse impact due to mining activities.
Xstrata - Tahmoor (LW 25)*	21/02/2011	No evidence of adverse impact due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 11)	13/5/2011	Not applicable
Gujarat – NRE Wongawilli Colliery (Longwall 19)	20/11/2011	No evidence of adverse impact due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 20)	11/4/2012	No evidence of adverse impact due to mining activities.
Gujarat – NRE Wongawilli Colliery (Longwall 15)	6/11/2012	Not applicable

*The Tahmoor mine is located near the Catchment, but was not active within the Catchment during the audit period.

Minerals Mining

Historical Mines

The DTIRIS-DRE is responsible for public health and safety issues for declared derelict mines in NSW. The SCA had a formal arrangement with DTIRIS-DRE to rehabilitate sites that are a risk to water quality and have invested in this over the audit period. Derelict mines were identified as a risk to water quality in six drainage units in the sub-catchments of Reedy Creek, Bungonia Creek, Kowmung River, Lake Burragorang, Wingecarribee River and Mid Cox's River. The impact of derelict mines on the Catchment includes metals pollution, sediment, and acid mine drainage. Six sites were rehabilitated over the last few years including the:

- Yerranderrie Silver Mine;
- Tolwong Cooper and Tin mine;
- Mulldoon Creek and Copper mine;
- Tuglow Copper Mine;
- Black Bobs Creek Gold and Silver; and
- Oakdale Colliery which was visited as part of the audit.

Follow up monitoring has demonstrated the success of the rehabilitation works thus far with no downstream impacts of mines detected and no further rehabilitation required for sites monitored (SCA 2012j).

There is insufficient information available AEMRs to present the current impacts of mineral mining within the Catchment.

CSG

The NSW Government requested further work on the coal seam activities in water catchments to inform future policy in this area (DP&I 2013c). This further work included a review by the NSW chief Scientist and Engineer. The first part of the review is now complete. The first report provides some detail on water, geology, CSG operational processes, and health and environmental impacts. The report presents a gaps analysis and extensive stakeholder consultation.

A further stage of the review, to be delivered in 2014, will address the principles that can underpin setbacks and exclusion zones, international best practice, risk characterisation, mitigation, and the state of industry compliance. The approval of CSG development in and around the Special Areas was delayed during the audit period to await the finding of the Chief Scientist and Engineer's report.

An example of this is presented in the APEX development case study. The current findings are likely to be insufficient to assist a determination. The principal finding that 'the government commits to establishing the regime for extraction of coal seam gas' is what is required in order for decisive CSG approvals protecting water resources in the Catchment (NSW Chief Scientist and Engineer 2013b).

Further recommendations support extensive baseline studies, predictive modelling and the formalisation of engineering processes for cumulative impact assessment. The implication here is that should CSG development progress in the Catchment, there will be a method to determine the cumulative impact on which to base sound management decisions.

Stakeholder and community interest in CSG

Along with longwall mining, CSG was an important issue for submissions received from government organisations, community groups and mining organisations. The Chief Scientist and Engineer noted widespread concerns with the first major concern listed in the report as being 'contamination and depletion of groundwater resources and drinking water catchments' (NSW Chief Scientist and Engineer 2013b). The Legislative Council Inquiry on CSG in 2011 reported on the issues of community concern with a number of recommendations implemented by Government resulting in the Strategic Regional Land Use Policy reform (NSW Chief Scientist and Engineer 2013b).

There is community concern regarding the cumulative impact of undertaking CSG extractive activities where mining has already been undertaken in the Southern Coalfields, along with fracturing and the resulting product and flow back water. It is noted that proposed activities in the catchment could include extraction from wells using the fracturing method or extraction of gas from existing goafs or bores without fracturing.

The SCA has voiced concerns related to CSG on fracturing and dewatering, surface water impacts, increased groundwater connectivity with existing mine infrastructure, vegetation clearing, contaminated product and flow back water, and inadequately understood risk. This lack of risk understanding, coupled with governmental management and reform in its infancy, characterises the state of CSG science and management during the audit period.

Activity

The active Petroleum Exploration licences (PELs) are the best indication of the potential for CSG within the Catchment. Table 3-13 presents this information, along with development application status for development during the audit period.

Table 3-13 PELs in the catchment

Catchment	PEL	Licence holder	DA	Status
Upper Nepean Warragamba Wingecarribee Woronora Upper Canal	2	AGL	Approved 2011 and 2012.	Active CSG mining outside of the catchment. No catchment activity reported in the AGL submission.
Upper Nepean Woronora	442 444	Apex Energy	Mod. 1 approved 2011. Mod. 2 declined 2013.	CSG On-hold. One exploration well present. Approval being actively pursued for wells in the catchment and Special Areas.
Warragamba	454	Apex Energy	None during the audit period	No active CSG mining. Exploration well at Oakdale within the Special Areas.
Shoalhaven Wingecarribee Warragamba	469	Leichardt Resources Limited	None during the audit period	Exploration drilling proposed for the high range area to the west of Mittagong.

Case study APEX CSG

APEX Energy is an Australian Coal Seam Gas (CSG) and Coal Mine Gas (CMG) exploration company with active Petroleum Exploration licences in the Catchment. These PELs incorporate the SCA Special Areas adjacent to Lake Burragorang (PEL454) and Lake Woronora (PEL444).

In 2009, the APEX Exploration Project was approved under the Part 3A Planning provisions to drill 15 CSG exploration boreholes to a depth of 50 m below the Illawarra Coal measures to test goaf gas from abandoned mine workings and to determine the gas in unmined coal seams (DP&I 2013c). Seven of the proposed boreholes are located in the Special Areas at Darkes Forest in the Woronora and Cordeaux Catchments, with a further borehole on the boundary.

The approval was granted for a 3 year period. A modification was granted in 2011 to include an additional well. This application was referred to the interim federal Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development. None of the approved boreholes were drilled. In 2012 a modification was sought to extend the approval period 'for 3 years from the commencement of drilling the first borehole' (DP&I 2013c).

In 2012 this modification was assessed by the DP&I and referred to the Planning and Assessment Condition (PAC). Since the 2009 determination, some of the proposed exploration area had become National Park and the NSW Government had announced more stringent rules for CSG activities, including consideration of the science of coal seam gas impacts by the NSW Chief Scientist and the *Draft State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) Amendment (Coal Seam Gas Exclusion Zones) 2013 (NSW)* (Draft SEPP). The Draft SEPP prohibits CSG development on or under land within 2 km of residential zones or future residential growth areas and within critical industry clusters. Four of the proposed boreholes are located within this draft exclusion zone.

The Director General found that the two boreholes now located in the National Park should be removed from the approval, that approval should otherwise be maintained, but that an open-ended extension was unacceptable. The current project was not referred to the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development as the risk associated with drilling was deemed to be very low by the DPI.

The PAC found that 6 of the 16 boreholes were to be excluded due to the Draft SEPP and National Parks, with 8 of the remaining 10 in the Special Areas. The SCA Board were requested to comment and the following submission was issued:

'The Special Areas are highly significant and protected by legislation; nonetheless boreholes such as those proposed have been permitted in the area for a very long time, for coal mining purposes. The impact of such boreholes can be fairly well managed…the impacts of any proposed CSG extraction would have different surface disturbance impacts and would be incompatible with the SCA requirements for protection of the catchment…and that a precautionary approach should be applied.

Given the real and potential risks to the Special Areas and Sydney's water supply, SCA's strong position is that coal seam gas activities should be excluded from the Special Areas'.

The PAC further found that it would be inappropriate to approve the proposed CSG activities in the Special Areas while:

'The NSW Chief Scientist and Engineers review is underway; and

Before the Government's resulting policy conclusions are formulated' (DP&I 2013c).

The application was refused in 2013.

Public submissions raised issues of concern. The commission '*does not agree nor accept all of those views or concerns expressed*' (DP&I 2013c). The issues included:

- Uncertainties and risks associated with CSG and the reliability of the proponent;
- Appropriateness of allowing CSG in drinking water catchments and particularly the Special Areas;

- Surface and groundwater water quality and quantity impacts;
- Health, flora and fauna impacts and project legacy;
- Greenhouse gas emissions; and
- Need for the project relative to drinking water protection and other sources perceived less sensitive (DP&I 2013c).

CSG Implications

The Strategic Regional Land Use Policy, which was recently released, the establishment of the new Land and Water Commissioner and the new Gateway Assessment Process may offer an alternate avenue for the assessment of new CSG developments in the Special Areas.

3.2.5 Recommendations

To date, the SCA mining principles (SCA 2012g), have not been wholly met. New methodologies for establishing a baseline, modelling, and cumulative impacts will better address the SCA's Mining Principle 6. The acceptance of suggested development conditions in accordance with the SCA's recommendations, based on these principles, could afford better protection of the Special Areas through more pragmatic mining alongside features of significance. At present, development aligns with the principles of the DSC.

In the management of the Special Areas, the SCA shall continue to make recommendations to the DP&I, which are commensurate with their Principles for Managing Mining and CSG impacts.

Given the improvements in the understanding of impacts, the approvals process, and the results of the monitoring of impacts by a number of organisations, development in the Special Areas does protect the infrastructure, yield, and water quality of storages as far as this can be determined. Historically these, and the waterways of the Special Areas were not well protected, and the legacy of sometimes inadequate baseline data sets still results in a lack of determination of impact.

The ecological integrity of the Special Areas is not well protected with respect to the small swamps and first / second order streams that are impacted due to mining. Examples of these are detailed by Krogh (2012). Whilst it is understood that environmental and economic outcomes must be balanced, the completion of the Draft Upland Swamp Environmental Assessment Guideline (DECCW 2011; 2012) and its implementation could result in better outcomes for swamp ecosystems.

DP&I suggests that "*OEH and other affected agencies should conduct further work to establish the ecological and water services significance of upland swamps on the Woronora Plateau, and give consideration to preparing an Upland Swamp Environmental Assessment Guideline for whole-of-Government consideration and Cabinet endorsement. Work should be undeftaken to provide clear and robust rneasures of swamp significance, an assessrmrent of the extent and significance of known and potential impacts on swamps, and provide for the application of Biobanking policy or other offsets for acceptable impacts"* (DP&I 2013e).

OEH should finalise the Upland Swamp Environmental Assessment Guideline for whole of Government consideration and endorsement. The Guideline should provide clear and robust measures of swamp significance and impact.

Providing clarity around impact descriptor bands such as 'negligible' and 'minor', in relation to standard mining impacts such as water quality and quantity impacts to 1st, 2nd and 3rd order streams and above, and biological impacts due to surface alterations would assist with a direct comparison of the impacts attributed to individual mine sites and groups of panels.

In the Southern Coalfields Strategic Review, the former DoP suggest the dimensions of risk management zones should extend a lateral distance of 400 m or if greater, by a 40° projection angle from the vertical down to the coal seam (DoP 2008a) . Following this, the PAC recommended the use of 'Defined Areas' rather than applying these risk management zones to a host of features considered significant by the PAC and other stakeholders (NSW Planning and Assessment Commission 2010).

More recently the NOW has supported the use of planning principles for GDEs detailed in the Aquifer Interference Policy (NOW 2012b). This policy calls for a 40 m setback distance from GDEs with ≤10% variation in the recovered water table in the first year (NOW 2012b). The following recommendation is therefore made.

DP&I approval conditions should be set considering risk management zones around ecological features, such as streams and swamps that have 'special significance status'. Risk management should aim to achieve nil or negligible impact to 'significant' features. Where the conditions required to achieve nil or negligible impact cannot be determined then mining should be excluded by a lateral distance of 400 m on each side of the feature or, if greater, by a 40° projection angle from the vertical down to the coal seam which is proposed to be extracted, as detailed in the Strategic Review (DoP 2008a).

The impacts of mining in the Southern Coal Fields were detailed in the 2008 Southern Coal Fields Inquiry. These impacts are considered when new developments are assessed. However, the previous recommendation that a detailed consideration of the cumulative impacts of mining in the Special Areas be undertaken has not been delivered.

The SCA are undertaking research into impacts, such as those on yield. Further work is required to complete this objective. Therefore, the prior recommendation regarding a detailed consideration of cumulative impacts remains open.

DPI, SCA, OEH, NOW, DP&I and Sydney Water should collaborate to develop a risk assessment methodology to assess the impacts of mining, CSG and industrial developments on water resources in the catchment.

3.3 Sites of Pollution and Potential contamination

3.3.1 Summary

During this audit period, SCA has revised four of the 14 Pollution Source Assessment Tool (PSAT) modules which address key catchment activities or pollutants sources and have continued to undertake compliance and investigation activities within the Catchment, including the Special Areas.

Grazing accounts for approximately 36% of the land area of the Catchment and is the largest single landuse. Grazing can contribute to a number of the main pollutants of concern within the Catchment including pathogens, phosphorous, nitrogen, and suspended solids. The Sustainable Grazing Program is a joint initiative between the Department of Primary Industries (DPI), the Catchment Management Authorities, and the SCA, in order to promote best management practices for sustainable grazing within the Catchment.

During the audit period, the Sustainable Grazing program reached 2000 participants through a series of subsidised training courses, education, field days, and on-property support. In addition the SCA continued to work with a number of dairies within the Catchment to promote the effective management of dairy waste. Nineteen of the 23 dairies in the Catchment were assisted to develop Dairy Effluent Management and Operational Maintenance Plans. The water quality outcome of these programs was demonstrated to improve water quality risks to an average of 'very low' across the drainage units studied.

The EPA continued to review licence conditions and pollution improvement programs for mining activities, wastewater treatment plants, and power generation plants within the Catchment. The EPA used its regulatory tools to progressively require these licence holders to improve their environmental performance and a summary of non-compliances and inspections recorded against environmental protection licenses are outlined in this section. As a result, many wastewater treatment and collection systems, which are considered one of the most significant pollutant sources, were improved with positive implications for Catchment water quality.

Concerns were raised in the previous audit about the high concentrations of heavy metals in the Upper Coxs River and its tributaries. Since the previous audit, there were upgrades completed of the Lithgow and Wallerawang STPs and the Wallerawang Power Station in conjunction with the EPA reviewing licence conditions and initiating Pollution Reduction Programs (PRP). Springvale Colliery and Angus Place Colliery also implemented alternative strategies for the management of groundwater from their sites and to cease discharging into the tributaries of the Upper Coxs River. Modifications have been made to Environmental Protection Licences to include PRPs at identified discharge hot spots. Testing has confirmed PRP requirements are being met with ongoing improvement to be monitored.

Assessment Criteria

Criteria

1. The significant pollutant sources within the Catchment area are identified and targeted.
2. Sites and areas of pollution are enforced by regulatory authorities.
3. Licence conditions and pollution improvement programs for polluted sites are in place.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Opportunity for improvement	Sydney Water reviews their Catchment to Tap risk assessments for the Blue Mountains to ensure that dry weather sewer overflow discharges are minimised.
2	Meets Expectation	Nil
3	Meets Expectation	Nil

Prior Recommendations

Prior Recommendations	Remedial action	Status
DECCW review license limits in the Upper Coxs River sub-catchment for all licensed discharge points with a view to reducing the heavy metal and salinity concentrations and loads being discharged to the Coxs River catchment.	Since the previous audit there have been upgrades of both the Lithgow STP and the Wallerawang Power Station Blowdown Treatment Plant in conjunction with EPA licence changes and pollution reduction programs. The addition of reverse osmosis at Wallerawang has addressed a salinity issue associated with this plant. The SCA made a 2011 submission regarding the Blowdown and metals of concern that were not addressed in the new licence conditions proposed by the EPA (SCA 2011a). The improvement in water quality associated with the Lithgow STP is considered highly successful, with no problematic algal blooms in Lake Lyall since the upgrade. EPA investigations are underway regarding environmental incidents at various mines in the Upper Coxs River sub-catchment. The status of these and licence upgrades is open.	In progress

3.3.2 Background

The Catchment covers an area of 1,565,367 ha incorporating 15 LGA's and 27 sub-catchments draining into 11 major dams that supplies drinking water to approximately 4.5 million people. Given that natural systems and human activities co-exist in the catchment, a number of different land uses within the Catchment can be a source of pollutants such as pathogens, nitrogen, heavy metals phosphorous and suspended solids.

The following section outlines the main identified pollutant sources within the catchment with a particular focus on grazing activities, sewage treatment plants, mining activities, and power stations. Issues associated with soil erosion and dryland salinity are further discussed in Section 3.4.4.

3.3.3 Management and Surveillance

The EPA has regulatory authority under the *Protection of the Environment Operations Act 1997* (POEO) for licensed premises. The POEO is the key piece of environment protection legislation administered by the EPA. The EPA has responsibility for reviewing all annual returns provided by license operators, as required by each Environment Protection Licences (EPL).

The EPA, SCA, and Local Councils also have compliance and enforcement powers under the POEO in relation to environmental management and water quality and conduct targeted inspections of priority risk activities or in response to pollution incidents. Under the POEO, non-licensed premises are regulated by Local Councils.

The SCA also has similar powers to a regulatory authority in relation to compliance activities within the Special Areas under the *Sydney Water Catchment Management Act 1998* and the *Sydney Water Catchment Regulation 2008*. The SCA have powers to issue notices and new offences in relation to complying with notices, as well as enhanced penalties for offences in the Special Areas (SCA 2013a). The EPA and or Local Councils are generally responsible for leading compliance and enforcement action for areas outside of the Special Areas.

3.3.4 Findings

Pollution Source Assessment Tool

During the last audit period, the SCA developed the Pollution Source Assessment Tool (PSAT) to assess risk to water quality in order to priorities actions in the Healthy Catchments Strategy 2012-16 (SCA 2011c; 2012a; b). This GIS based tool aims to combine the best science, catchment knowledge and other data on sources, causes and pathways for pollutants. Specifically this tool aims to:

- Provide a strategic direction for the delivery of a set of new priorities for the Healthy Catchments Strategy;
- Provide strategic water quality priorities to inform programs under the Strategic Plans of Management between SCA and OEH;
- Improve SCA's contemporary knowledge of pollution source risks in the Catchment; and
- Increase SCA's confidence in the scientific methods used to assess the risk of key pollution sources and types (SCA 2013f).

The PSAT consists of 14 modules (shown in Table 3-14) that each address a key catchment activity or potential pollutant source and under each module the potential for contamination is assessed from four priority pollutants: nitrogen, phosphorous, pathogens and suspended solids.

In June 2011, SCA published the Pollution Sources Assessment Tool Results Report (SCA 2011c), which resulted in four of the 14 modules being updated to incorporate new data, changes to existing information and advances in scientific modelling. The four modules updated were: Grazing, Intensive Animal Production, Sewage Treatment Plants, and On-site Wastewater Management Systems. The outcomes from the PSAT 2011 showed the top five most significant pollution sources for all priority pollutants were:

1. Grazing;
2. Intensive Animal Production;
3. On-site wastewater management systems;
4. Sewage Collection Systems; and
5. Urban stormwater.

To identify pollutant sources within the Catchment, the SCA divided the 27 sub-catchments up in to 210 smaller areas known as drainage units. The results of PSAT 2011 then determined the count of 'high' and 'very high' risk drainage units for each module and pollutant. The following table identifies the number of 'very high' drainage units within each sub-catchment.

The analysis shows that there are a total of 26 drainage units across 13 sub-catchments that are determined to have 'very high' risk ratings for all pollutants across all modules (Table 3-15). These 'very high' risk drainage units are also shown in Figure 3-11.

Table 3-14 PSAT Modules

Module	Potential Pollution Sources
Grazing	Land grazed by all stock types including beef cattle, dairy cattle, sheep, horses, goats, and alpacas.
Horticulture and cropping	Broad-acre cropping, orchards, viticulture, potato growing, market gardens, berries, olives, nuts and cut flowers
Intensive animal production	Abattoirs (external component – processing component is considered in industry module), dairies, (cows and goats), horse studs, kennels, piggeries, poultry farms and saleyards.
Urban stormwater	All urban stormwater catchments.
Sewage treatment Plants (STPs)	Large sewage treatment plants. Small package sewage treatment plants such as those operated for tourist parks are not currently included due to lack of data.
Sewage collection systems	All sewer infrastructures, including pipes and pumping stations. Excludes sewage treatment plants and on-site wastewater management systems.
On-site wastewater management systems	All on-site systems, including pump-out systems, septics, irrigation and trench systems.
Roads	All public roads, including fire trails, tracks, sealed and unsealed rural roads, urban roads, highways, and motorways. It does not cover private farm tracks.
Industry	Includes power stations, coal processing plants, abattoirs (processing components), automotive workshops, service stations, car dealerships, fuel depots, concrete batching plants, transport depots, wool scours, landscaping supplies, and large scale food production.
Mines and quarries	Coal mines, metalliferous mines, oil shale mines and quarries. Both operational and non-operational mines are assessed.
Landfills	At present only considers municipal type landfills, rural and farm dumps excluded due to lack of data.
Forests	All areas mapped by land cover mapping as having native vegetation or pine plantation. Includes public and privately owned forested land.
Streambank erosion	Rivers
Gully erosion	Mapped drainage lines and steams

Source: (SCA 2011c)

All remaining modules of the PSAT will be next revised by 2015-16 with the SCA intending to use the next PSAT results as a basis for future management prioritisation and comparison.

Contaminated sites

The EPA's contaminated sites section was involved during the audit period in the remediation of sites within the Catchment. The Katoomba/Leura Gasworks, Goulburn Gasworks, Bowral Gasworks, and Hartley Vale Oil Shale Refinery are currently undergoing remediation to address groundwater contamination. A former service station site in Goulburn LGA was also declared on the contaminated land register.

Table 3-15 Number of 'very high' risk drainage units for all pollutants across all modules

Sub-Catchment	Very high risk drainage units
Back & Round Mountain Creeks	1
Braidwood	2
Bungonia Creek	1
Kangaroo River	6
Lower Coxs River	1
Mulwaree River	1
Nattai River	1
Reedy Creek	1
Upper Coxs River	1
Upper Nepean River	1
Upper Wollondilly River	2
Wingecarribee River	4
Wollondilly River	4
Total	**26**

Regulatory activity by the SCA

Between 2010 and 2013, SCA's compliance activities focused on mining activities, sewage treatment plants, and new developments. Table 3-16 shows the number of notices of other actions taken by the SCA in response to non-compliant activities.

Table 3-16 SCA notices or actions in response to non-compliance 2010-13

Activity	2010-11	2011-12	2012-13
Clean-up notices	2	1	1
Notices (s196/62v/62s) requiring information/ documents	16	19	17
Penalty infringement notices	0	0	0
Pollution prevention notices	1	0	1
Notice to attend and answer questions	2	0	0

A summary of the compliance activity carried out by the SCA in the Special Areas 2010-13 is outlined in Table 3-17. The SCA undertook patrols and surveillance to identify illegal activities and to support actions such as infringement notices and warning letters. No prosecutions were recorded for the audit period.

Table 3-17 Compliance activity in the Special Areas 2010-13

Activity	2010-11	2011-12	2012-13
Penalty Infringement Notices	52	43	37
Warning letters	8	15	19
Prosecution	0	0	0

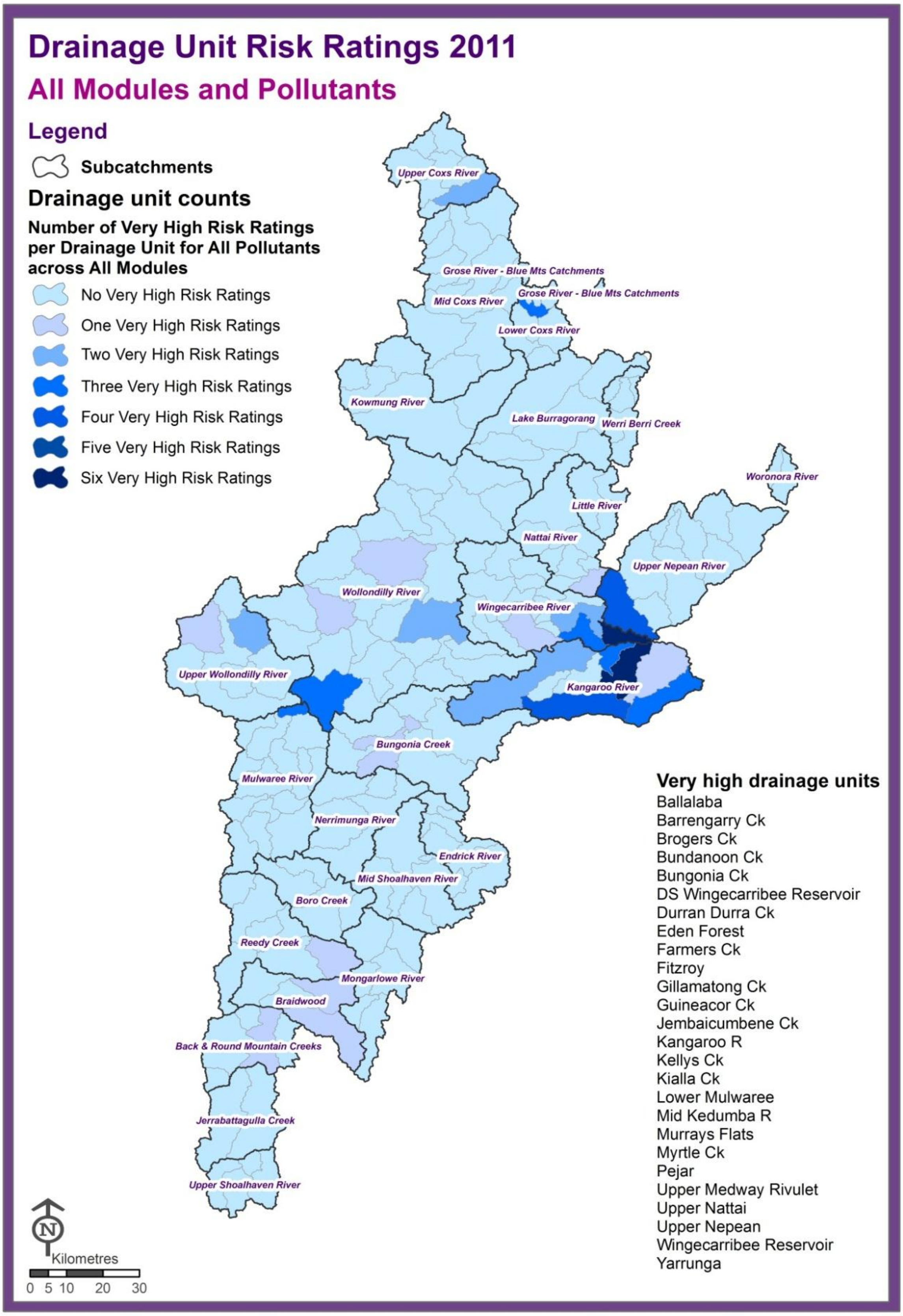


Figure 3-11 Drainage Unit Risk Ratings 2011 – all modules and pollutants

The SCA was involved in pollution incident in Jamison Creek in the Warragamba Catchment, in which prosecution is currently being sought. This case study is presented below.

Case Study - Pesticide Pollution in Jamison Creek

In July 2012, over 1000 dead freshwater crayfish were found in a two kilometre reach of Jamison Creek, a tributary of the Warragamba Catchment (BMCC 2013). A muti-agency investigation involving the Blue Mountains City Council (BMCC), the EPA, the SCA, OEH, DPI and National Parks and Wildlife (NPWS) isolated the point source impact and determined the contaminant to be Bifenthrin, a common pesticide used in the control of termites. This pesticide is toxic to aquatic organisms, including the Giant Spiny Crayfish.

The pollutant also impacted native fish, including Mountain Galaxias, and macroinvertebrates, a group of organisms frequently used as an indicator of riverine health. Through subsequent research the populations of these fauna are determined to be recovering. This recovery was aided by a swift clean-up operation involving the removal and treatment of contaminated water and sediment from the stormwater system, as the pesticide is strongly adsorbed to sediment. Groundwater flushing of the Jamison Creek after the pollution incident is credited with the recovery, along with crayfish re-population from other connected streams (BMCC 2013).

The incident demonstrates that the Catchment is subject to pollution pressures from urban point sources. However, the management of the urban environment through Council regulation and new development of stormwater assets to SCA endorsed Current Recommended Practices (CRPs), and to meet NorBE, has the capacity to lessen the impact of these incidents.

Two pest control operators were prosecuted and fined for the offence under Section 120 of the *Protection of the Environment Operations Act 1997* (prohibition of pollution of waters). The collaborative muti-agency approach and subsequent litigation indicates the capacity of the stakeholders to unify for the protection of the Catchment.

Grazing Practices

Grazing accounts for approximately 36% of the Catchment and is the largest single landuse covering 560,965 ha. All major stock types are represented, including beef and dairy cattle, sheep, horses, alpacas and goats. SCA reports that across the Catchment grazing properties range in size from lifestyle blocks and small holdings (20 ha or less) to large scale landholdings >400 ha in size. Grazing activities can contribute to a number of the main pollutants of concern within the Catchment including pathogens, phosphorous, nitrogen, and suspended solids.

The SCA has continued to work with DPI to promote best management practices for sustainable grazing within the Catchment as they recognise these practices have a direct impact on water quality and catchment health. The Sustainable Grazing Program (SGP) is a joint initiative between DPI and the SCA to offer subsidised training courses, field days and on-property support, aimed increasing sustainability and profitability for grazing enterprises (DP&I 2013a).

In order to achieve SCA's objectives around water quality and catchment health, Best Management Practices (BMPs) have been developed which are focused around 'priority drainage units'. These focus on four key areas:

- Pasture management to minimise movement of sediments, nutrients and pathogens;
- Soil management and protection;
- Livestock management and health; and
- Management of riparian areas and waterways.

Table 3-18 below outlines the activities that have been delivered under the SGP for 2010-13 with over $1 million in SCA expenditure and over 2,000 participants engaged. The SCA (2013a) conducted follow-up evaluation of the Graziers Incentives Program and found that two years after the projects' completion water quality risks are reduced to an average of 'very low.'

Table 3-18 Activities under the Sustainable Grazing Program 2010-13

Year	Participants	No. of Activities (courses, seminars, field days)	No. of individual farm visits	SCA expenditure
2010-11	608	41	35	$362,710
2011-12	828	52	78	$423,940
2012-13	570	34	54	$310,000
Total	2006	127	167	$1,096,200

Intensive animal production

The SCA estimates there are 106 intensive animal industries located within the catchment. During the current audit period, the SCA implemented strategies to minimise pollutants from dairies. The SCA worked with Dairy NSW, local dairy industry groups and key government agencies such as DPI and the CMAs to provide training and education in order to promote the effective management of dairy effluent waste. Dairy effluent waste poses a threat to water quality by transporting pathogens, nutrients and phosphorous into catchment waterways.

All the dairies located in the Catchment now have effluent management systems in place. In 2011, SCA and Dairy NSW assisted 17 dairy enterprises to prepare Dairy Effluent Management and Operational Maintenance Plans and by the end of 2012 19 out of the 23 had these plans in place. Another project was commenced during the audit period to develop site-specific effluent application plans and to de-sludge dairy effluent ponds. This project was deferred to 2014 due to inclement weather (SCA 2013a).

Mining Activities

The EPA used its regulatory authority to review annual returns and licence conditions for mining activities within the catchment during the audit period. A complete list of EPA non-compliances for coal and mineral mines for the audit period can be found in Table 3-5 and Table 3-6.

In addition, the EPA also reviewed a number of the EPLs for mining activities within the Catchment. This resulted in a number of PRPs being commenced with the aim of reducing surface water discharge impacts from mine sites. The remediation activities undertaken by coal mining enterprises with a particular focus on the Upper Coxs River and its tributaries are further outlined in the remediation section below.

Wastewater Treatment Plants and Sewer Systems

The EPA is responsible for reviewing all Annual Returns provided by licensed operators of Wastewater Treatment Plants/ Sewage Treatment Plants (STPs). A summary of non-compliances reported in annual returns of EPLs recorded against STPs are presented in Figure 5-8. During the audit period, a number of new STPs were completed under the Accelerated Sewerage Program funded by SCA, Local Councils, and NSW Office of Water. These are further discussed in Section 5.2 with some of the remediation benefits further discussed.

Sewer Overflows in the Catchment

Sewer assets have the potential to overflow during periods of high rainfall and due to chokes in the sewer system, resulting in overflow at a manhole or designed sewer overflow point. Whilst information was not available for all Councils in the catchment, presenting the information for one operator in the Warragamba, Prospect, Woodford, and Grose River catchments can provide some insight into these contamination events. Sydney Water operates water and sewer assets in the greater Sydney region and provided data for the audit period. Information on wet weather overflows was un-recorded and therefore unknown.

Incidents were recorded when a sewer choke has been observed to result in an overflow that entered a waterway. Chokes that resulted in a discharge to the ground but not a waterway were not considered an incident. There were 45 chokes in the Warragamba, 5 chokes in the Blackheath and 4 chokes in the Katoomba Special Areas during the audit period (Sydney Water 2013). There were 26 incidents reported for the Blue Mountains catchments with tributaries to the Warragamba, Cascades, Lake Medlow, Lake Greaves and Woodford catchments, 5 to the Warragamba catchment from the Wollondilly region, and 1 to the Prospect catchment.

The highest frequency of incidents was in the most urbanised Katoomba and Leura areas representing 50% of the incidents. Whilst the rate of chokes and incidents has declined over the last 10 years, indicating improved management overall, review and enhancement of the sewer system may further reduce pollution incidents in these highly connected localities. Furthermore, understanding the volume of wet weather discharge could assist in understanding the risk of these incidents, especially to the small reservoirs of the Blue Mountains.

Remediation

The previous audit had a detailed case study on the Upper Coxs River licensed discharges following concerns about high concentrations of heavy metals in the Upper Coxs River and its tributaries. The Coxs River is one of two major rivers that feed into Warragamba Dam. This section outlines a number of PRPs that have been attached to EPLs during the audit period aimed at improving water quality within the Catchment.

Pollution Reduction Programs (augmentations) of STPs

During this audit period, Lithgow City Council, Wingecarribee Shire Council, and Goulburn-Mulwaree Council completed Pollution Reduction Programs (augmentation) on identified STPs within their jurisdiction.

Lithgow City Council completed Pollution Reduction Programs (PRPs) on the Wallerawang and Lithgow STPs, both of which are in the Upper Coxs River sub-catchment. Both of these plants were updated to new treatment systems. The previous audit noted that 'nutrients were elevated downstream of Lithgow township and STP' and that an assessment of environmental impacts of the sewerage collection systems had recently been undertaken (DECCW 2010a).

These PRPs were completed during this audit period and the EPA identified:

- In regards to concentrations of pollutants for both the Lithgow and Wallerawang STP:
  - <98% reduction in Faecal Coliform concentrations discharged;
  - <95% reduction in total phosphorus (TP) concentrations discharged; and
  - ~50% reduction in total nitrogen (TN) concentrations discharged.
- In regards to calculated loads of pollutants for the Lithgow STP between 2010-2012:
  - ~25% reduction in TP load; and
  - ~ Relatively steady rate for TN load.

- In regards to calculated loads of pollutants for the Wallerawang STP between 2010-2012:
  - ~45% reduction in TP load; and
  - ~49% reduction in TN load.

The EPA and Goulburn-Mulwaree Council are working on a PRP for the Goulburn STP to identify sewage treatment methods and preliminary designs for a new STP to improve environmental performances. The Annual Returns for this plant indicated that during large storm events, the STP was periodically unable to treat effluent sufficiently. The EPA is finalising its augmentation report and Council will begin preparing detailed concept designs for an upgraded STP which will reduce nutrient loads in the Wollondilly sub-catchment.

The Mittagong Sewage Treatment System undertook a PRP to look at procedures associated with the operation and maintenance of valves located in remote or sensitive environments.

In summary, many wastewater treatment and collection systems, which are considered one of the most significant of pollutant sources, were improved with positive implications for Catchment water quality.

Wallerawang Power Station – EPL 766

During the previous audit period, local environment groups commenced proceedings against Delta Electricity (operator of the two power stations in the Upper Coxs Sub-Catchment) in the Land and Environment Court alleging elevated salts and metals in the Sub-Catchment were directly attributable to the coal mining industry and the two Delta Electricity power stations.

The EPA investigated the EPL for Wallerawang Power Station and during this audit period, a total of four non-compliances occurred, four inspections were conducted and two penalty infringement notices were issued for the discharge of low pH water from the power station.

The EPA worked with Delta Electricity to improve the quality of water discharged from Wallerawang Power Station. 'The focus has been on continual improvement with a series of PRPs, and the reliance on the results of assessments on the ecotoxicology of the discharge and aquatic health of the Upper Coxs River. The EPA has concentrated on turbidity, metals (especially copper) and salinity and the main discharge of the cooling tower water below Lake Wallace' (EPA 2013a).

To reduce salt loads and contaminants from the unit 7 cooling tower plant, Delta Electricity also completed the installation of a reverse osmosis plant. Two additional PRPs were placed on the EPL during the current audit period with the aim of further improving discharge water quality.

In the previous audit period, the EPA completed a desktop review of water monitoring data across the Upper Coxs River Sub-Catchment and finalised the variation of EPL 766 to attach a series of PRPs (U1.1 and U1.2) with a number of conditions to be met by 31 May 2010. A subsequent inspection on 4 June, 2010 by the EPA noted that they were satisfied that Delta Electricity had complied with the PRPs U1.1 and U1.2.

EPA also completed a review of the LDP4 discharge point study completed by Delta Electricity, which examined the feasibility of undertaking modification works to the drainage channel for the cooling tower discharge to facilitate the extraction of metals.

In their review, the EPA noted that with the exception of Copper, the other metals of concern (including Boron, Aluminium, Zinc, and Arsenic) will meet or very nearly meet the ANZECC 2000 95th percentile trigger values. To further reduce metals (particularly copper) in the cooling towers, the EPA varied the EPL on 23 June 2011 to allow Delta to trial the use of a corrosion inhibitor Metaflex EP.

In October 2011, Delta Electricity agreed as part of mediation with a local environment group to apply to the EPA for a licence variation to attach licence discharge concentration limits for various metals and salinity. This licence variation was applied for and will include a PRP which requires Delta Electricity to cease discharging cooling tower water to the Coxs River by 31 December 2015. SCA (2011e) wrote to Delta Electricity in December 2011 noting that they considered the four year period negotiated as part of the court settlement to achieve full treatment of blowdown water as being too long and suggested that a one and half to two year timeframe to be more sufficient.

Ultimately, the upgrading of the Lithgow and Wallerawang STPs, coupled with the addition of reverse osmosis at the Wallerawang Power Station (now owned by Energy Australia) has partly addressed saline and nutrient pollution in the Upper Coxs Sub-Catchment.

The SCA made a 2011 submission regarding the Blowdown and metals of concern that were not addressed in the new licence conditions proposed by the EPA (SCA 2011e). There is therefore still room for improvement. In comparison, the improvement in water quality associated with the Lithgow STP is considered highly successful, with no problematic algal blooms experienced in Lake Lyall since the upgrade.

EPA investigations are underway regarding environmental incidents at various mines in the Upper Coxs River sub-catchment. The status of these and licence upgrades is open.

Springvale Colliery – EPL 3607.

The EPA (2013a) submission also outlines key environmental issues related to the Springvale Colliery's discharge of groundwater from the site and poor surface water controls and groundwater seepages associated with the Centennial Coal Services washery site. A number of PRPs were commenced during the audit period which involved:

- Centennial Coal committed to researching and implementing a regional water management strategy;
- Improving surface water discharges from Springvale Colliery; and
- Undertake improvements including mechanisms to capture groundwater seepages, improved pumping arrangements between dirty water dams and the washery and upgrades to reduce the volume of water discharged from the main dam.

PRPs were also initiated at Lamberts Gully for discharges into Nuebecks Creek, a tributary of the Coxs River upstream of Lake Wallace. These PRPs have resulted in changes to water management at Lamberts Gully including redirecting water from Cooks Dam to the coal washery on site. An inspection by the EPA on 24 August 2011 revealed all the changes were completed; however, despite these changes the 2011 Annual Returns noted the concentration of metals have not reduced and they continue to investigate this with Centennial Coal (EPA 2013a).

Angus Place Colliery – EPL 467

Regulatory action was undertaken by the EPA in the form of a formal warning related to continued non-compliances with water quality limits at discharge point LDP1, as the discharge of groundwater 'typically has a higher salinity than receiving waters and has a propensity to contain colloidal clay material from the underground workings.

PRPs were implemented during the audit period for Centennial Coal to:

- Research and implement a regional water management strategy with the aim to consolidate all mine water discharged from their western coalfield premises and treating this water centrally; and
- Improve surface water discharges from its pot top.

Angus Place Colliery was also licenced to discharge groundwater into Kangaroo Creek, a tributary of the Coxs River upstream of Lake Wallace. During the audit period, the EPA modified their EPL requiring them to prepare feasibility reports to develop water treatment facilities to treat groundwater (principally salinity) which was being discharged into Kangaroo Creek.

In September 2011, the licensee put forward a proposal whereby June 2013 the mine would redirect all mine water to the Wallerawang or Mount Piper Power Stations and therefore no longer discharge to surface water except in an emergency. The EPA reports that as of 1 July, 2013, discharges through LDP1 have now ceased (EPA 2013a).

In summary, there is still work to be completed in order for the metals pollution of the Upper Coxs Sub-Catchment to be ameliorated. This can be achieved through further research and investment in works on the discharges of the Centennial Mines and the Wallerawang Power Station. This will be a collaborative effort between the EPA, the SCA, and Centennial Coal. Using PRPs was demonstrated as a partially successful strategy for addressing point sources of pollution in the Catchment.

3.3.5 Recommendations

Over the course of this audit period, the most significant pollutant sources within the Catchment areas were identified and steps undertaken to reduce pollutants. A number of sites and areas continue to be monitored and enforced by regulatory authorities; however an opportunity exists for the SCA to work with Local Councils to assemble information in relation to compliance and enforcement activities for non-licensed premises.

A particular focus of the previous audit was on the Upper Coxs River Sub-Catchment. A number of industries have undertaken steps to reduce discharges into the Catchment while implementing a number of PRPs to improve the water resources across the catchment. There is still work to be completed in order for the metals pollution of the Upper Coxs Sub-Catchment to be ameliorated; however some progress was made in improving salinity and nutrient pollution, which was demonstrated as successfully reducing algal blooms.

The SCA in partnership with Local Councils and NOW have funded the upgrade of a number of STPs through the Accelerated Sewerage Program which will benefit water quality within the Catchment. The EPA also continued to monitor sites and use their regulatory powers to enforce industries to improve their practices through new EPL conditions. Now that STPs are being addressed the following recommendation is made, based on the observation of sporadic sewer overflows in the Blue Mountains area of the Catchment.

Sydney Water reviews their Catchment to Tap risk assessments for the Blue Mountains to ensure that dry weather sewer overflow discharges are minimised.

Finally, there is an awareness of the sites and areas of potential pollution impact within the Catchment through the development of the PSAT and the implementation of a number of training and education programs which are aimed at targeting some of the most significant pollution sources. The SCA should continue to assess and monitor the effectiveness of these programs in order to best manage Catchment health.

3.4 Soil erosion

3.4.1 Summary

Gully erosion is the most prominent form of soil erosion within the Catchment, and is readily observable and measurable. For this reason the measure for this indicator is the total area of the Catchment with observed gully erosion (NOW 2009). The previous audit estimated this gully erosion using data from 1986 aerial photography (Emery 1986) and the SCA 2005 (SCA 2005). This dataset has active gully erosion in the Catchment estimated as 7.8 km^2, with more than 3 km^2 in the Upper Wollondilly and Wollondilly River sub-catchments. Whilst this data set is still in use for catchment management, the information does not acknowledge areas which have since been treated, naturally stabilised or where new (if any) eroded areas have developed.

The Gully Erosion Evaluation Trial (GEET) was undertaken to develop mapping techniques which are capable of mapping the location, extent, and severity of the existing gully erosion within the Catchment. Three drainage units; Dixons Creek, Eden Forest and Oallen Ford are currently mapped and prioritised for erosion head or fencing works and, for some gullies monitoring over time. The new mapping method provides a higher level of resolution and accuracy when compared to the existing data set.

The process is now being rolled out to an additional 45 priority areas in the SCA, HNCMA and SRCMA areas of operation. New information will be generated when the trial gully erosion methodology is deployed across the Catchment. This information will be valuable as an update on the state of erosion in the Catchment and to provide next level down prioritisation information. Future efforts will utilise light detection and ranging (LiDAR) data captured over time and soil analysis to calculate accurate gully export rates and determine if existing gullies are still active or have since become naturally stabilized.

Erosion in the Catchment is a long term issue, with many gully erosion sites pre-dating 1979. The Catchment Protection Scheme (CPS) has been in place since 1960 with the main focus on gully erosion since 1984. Through this scheme and other programs funded and facilitated by the SCA, HNCMA and SRCMA erosion works are undertaken within the Catchment, both to improve the condition of existing gully erosion and to promote land management practices that avoid new incidences of soil erosion (SRCMA 2012c).

Between 2010 and 2013 the SCA contributed $1.8 million to the Catchment Protection Scheme to undertake works in high priority drainage units. There are 21 priority drainage units located across 9 sub-catchments which are identified by the SCA as high priority areas for both gully and streambank erosion. Funding and works programs are available to all of these high risk sub-catchments and the majority of erosion works funding, and all riparian works funding were spent in priority drainage units.

In addition to estimating gully erosion, measuring and reporting the extent of streambank erosion and associated works could support a more complete understanding of the extent of erosion affecting water quality within the Catchment and would enhance an understanding of the condition of these essential riparian areas. Such evaluations could be undertaken at selected locations in the Catchment as part of the ground-truthing of the effectiveness of Catchment management activities.

Assessment Criteria

Criteria
1. The total catchment area affected by gully erosion is known.
2. Gully erosion is monitored and managed in the Special Areas.
3. SCA is involved in programs for sub-catchments where gully erosion has been identified as high priority.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil
3	Meets Expectation	Nil

Prior Recommendations

Prior Recommendations	Remedial action	Status
The SCA, HNCMA and SRCMA develop a consistent baseline map of gully erosion for the catchment	Stage 1 of the Gully Erosion Evaluation Trial has been completed with Stage 2 substantially underway with completion expected by the end of 2013. A new project is being developed to roll out the Stage 1 baseline gully erosion mapping to a further 45 priority areas.	In progress

3.4.2 Background

One of the contributing components that increases risk to water quality within a catchment is soil erosion. Apart from the actual loss of a soil profile, erosion is mainly related to the transfer of nutrients that may encourage excessive growth of algae and in-stream and riparian vegetation, which can impact river health, biodiversity, and water quality.

There are numerous types of soil erosion with the main contributors in the Sydney catchment being gully and streambank erosion. Erosion adjacent to streams in grazing areas can also assist in the transfer of pathogens and nutrients into waterways.

Erosion, due to clearing and grazing is a long term issue in the Catchment, with many gully erosion sites pre-dating 1979. The Catchment Protection Scheme (CPS) has been in place since 1960 with the main focus on gully erosion since 1984.

The CPS provides grants and incentives for land owners to treat priority and severely impacted areas through various remediation treatments and the adoption of sustainable land use practices (SCA 2011a; 2012a, c; 2013a). The SCA and DPI also manage the Sustainable Grazing Program, while SCA also manages a Grazing Incentives Program (GIP).

The ToR for this criterion is the '*estimate of the total area of the catchment with observed gully erosion*'.

3.4.3 Management and Surveillance

The SCA partners with the HNCMA and the SRCMA to deliver the Catchment Protection Scheme Gully Erosion Program. The HNCMA also manages the Improving Land Management Practices program that addresses erosion in the Catchment through remediation of sheet erosion, riparian re-vegetation, and stock management.

Further to this, the HNCMA and SRCMA have provided or subsidised Landscan and Prograze courses which in part address erosion through better management practices.

The HNCMA and SRCMA use the 1986 aerial photography (Emery 1986) and the SCA 2005 (SCA 2005) data set to identify gully head erosion. This dataset has active gully erosion in the Catchment estimated as 7.8 km^2, with more than 3 km^2 in the Upper Wollondilly and Wollondilly River sub-catchments.

The new information that will be generated when the trial gully erosion methodology is deployed across the Catchment will be valuable as an update on the state of erosion in the Catchment and to provide next level down prioritisation information which will complement the current common sense approaches currently used, such as prioritising gullies with a certain head size.

3.4.4 Findings

Erosion Management

Erosion Treated Through the Catchment Protection Scheme

In the 2010-13 audit period the SCA contributed $1.8 million to the Catchment Protection Scheme ($631,000 in 2010-11, $576,000 in 2011-12 and $671,000 in 2012-13) partly administered by the HNCMA and the SRCMA. A breakdown of the number of projects funded, and the catchment area protected, can be found in Table 3-19.

These contributions were aligned with 21 priority drainage units, located across 9 sub-catchments which have been identified by the SCA as high priority areas for both gully and streambank erosion. An agreement with the CMAs meant that up to 25% of SCA funds could be used outside of the priority catchments.

The priority sub-catchments for the 2010-13 audit period were:

- Bungonia Creek;
- Wollondilly River;
- Braidwood;
- Jerrabattagulla Creek;
- Boro Creek;
- Reedy Creek;
- Upper Wollondilly River;
- Mulwaree River; and
- Nerrimunga River.

The priority sub-catchments in the Shoalhaven catchment in which work was undertaken during 2012-13 are shown in Figure 3-12. One in three landholders reported soil erosion on their land in the Upper Shoalhaven in the last two years. There was a perception that the severity of these was low and the majority of landowners believed they had a moderate to high capacity to address these issues (SRCMA 2013b). Given this, education and CMA support should be effective in addressing moderate soil erosion in the priority sub-catchments of Shoalhaven. Whilst works were undertaken in the priority sub-catchments, undertaking funded works in priority drainage units will help address more severe erosion issues.

Table 3-19 Projects funded during the audit period 2010-13

Year	# of Projects	CMA	Area Protected (Hectares)	Priority Drainage Units (%)
2010-11	11	Hawkesbury-Nepean	4,216	98
2010-11	5	Southern Rivers	1,138	72
2011-12	9	Hawkesbury-Nepean	2,059	70
2011-12	5[1]	Southern Rivers	498	77
2012-13	10	Hawkesbury-Nepean	2,711	98
2012-13	12[2]	Southern Rivers	8,033	100

[1] 2 new projects with 3 projects carried over from the previous financial year

[2] 9 new projects (of which SCA contributions funded 8) and 3 projects carried over from the previous financial year

Erosion Management on SCA Lands

The SCA aims to implement best available sustainable practice across its land holdings. The SCA owns significant portions of Special Areas land; predominately native vegetation, as well as 23,547 ha of substantially cleared land in the Braidwood area acquired for the purpose of the now indefinitely deferred Welcome Reef Dam. Part of this land is leased back to farmers with an emphasis on management for high water quality. During the 2010-13 period, SCA spent $339,200 on erosion control activities in the Braidwood area, including:

- Erosion control programs, soil conservation plans, and identifying priority risk areas;
- Fire and management trail erosion controls;
- A Review of Environmental Factors (REF) and Environmental Management Plan for erosion control at the Tarrawarra property.

A separate project was funded by the SCA at the Fitzroy Falls Reservoir to reinforce sections which were considered susceptible to potential wave impact erosion.

Erosion Management through the HNCMA

Remediation works related to soil erosion in the HNCMA area of operation were extracted from the Land Management Database. The specific figures for 2010-13 are as follows:

- 21 sites treated with soil erosion engineering works;
- 909 ha of land treated and/or protected from soil erosion by engineering works;
- 286 ha of land treated for soil erosion through exclusion fencing;
- 166 m of stream bank stabilised with engineering works;
- 76 m of bed stabilised;
- 6 km of stream bank length of riparian vegetation enhanced/rehabilitated;
- 355 ha of riparian native vegetation protected by fencing; and
- 119 km of stream bank riparian vegetation protected.

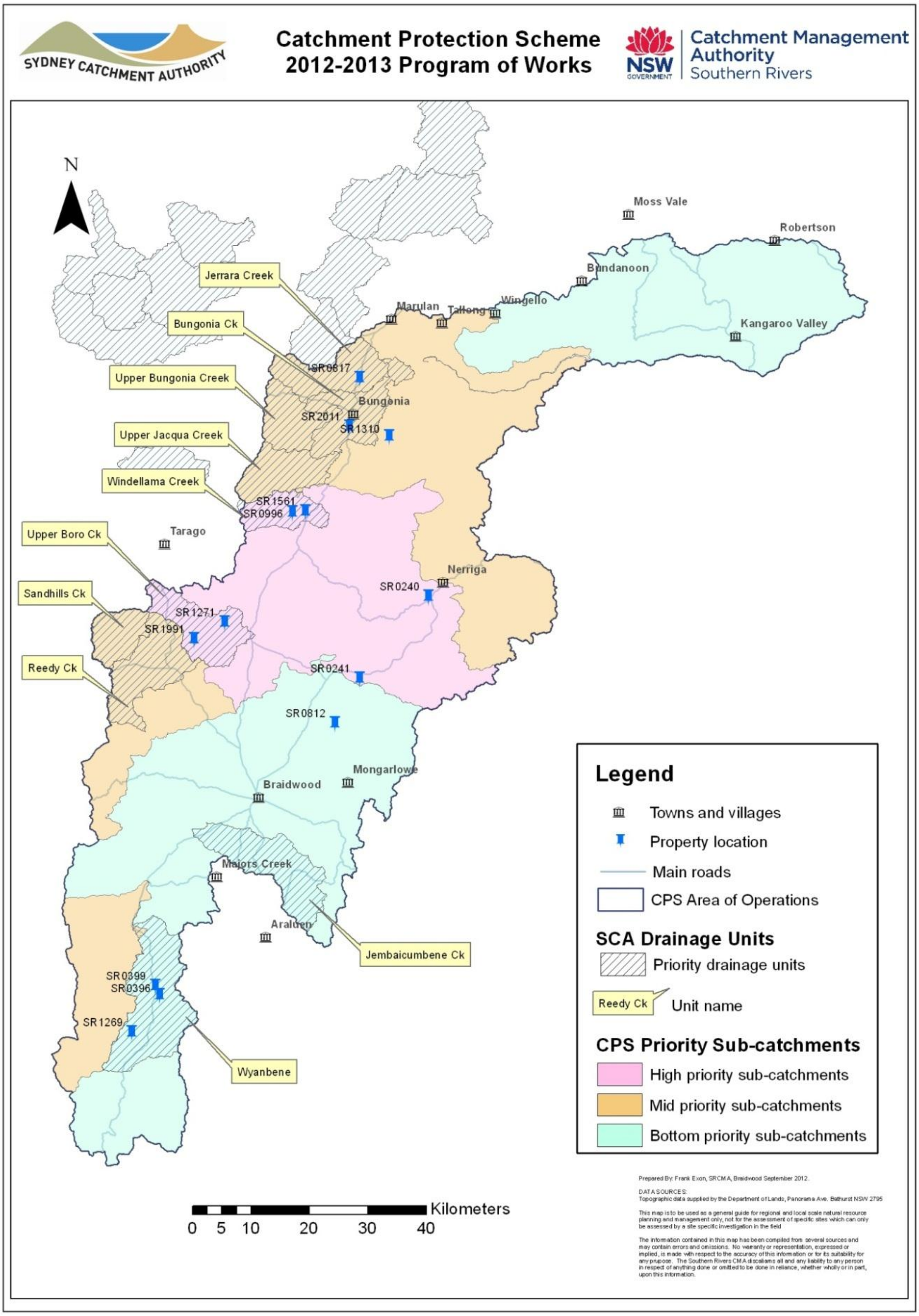


Figure 3-12 SRCMA Catchment Protection Scheme Priority areas 2012-13

The previous audit recommended that an assessment of hill slope erosion be provided in following audits. Hill slope erosion modelling is currently being undertaken by OEH, however; no details were provided in their submission for the 2013 audit.

Case Study – Arthursleigh Revisited

The Arthursleigh site is located within the Eden Forest drainage unit, one of the trial gully erosion study areas. This site has been the focus of catchment protection scheme funding, erosion treatments and rehabilitation works for many years. The progress of the works at the site was inspected during the 2013 Audit. Representative photographs are provided (see Figure 3-13; 3-14; 3-15 and 3-16).

The site had suffered severe erosion prior to 1979. Through trial gully erosion studies and in-field GPS mapping using Trimble technology it was established that gully erosion increased by up to 13 m since 1979 and only 2 m since 2008 (HNCMA 2013d).

This rate is far less than experienced prior to 1979. The dispersive podzolic / sodic soils of the Eden Forest and Dixon's Creek areas result in a high capacity for erosion and therefore prioritisation for improvement. During 2010-11 and 2012-13 there were two erosion control agreements between the HNCMA and Arthursleigh targeting a range of works on the 16,000 acre property prioritised due to its size and proximity to the Wollondilly River and Sandy Creek.

The projects included the following treatments:

- Gully control structures, flumes, diversion banks and rock ramps for gully head stabilisation;
- Sediment traps, stream bank structures and chain of ponds restoration;
- Fencing to protect vegetation and stream banks; and
- Re-vegetation of previously eroded and fenced rehabilitation sites and willow removal.

In was estimated that between these two projects that 155,000 m^3 of sediment were prevented from impacting the catchment, with a total spend of $715,000 (HNCMA 2012c,d; HNCMA 2013e). The Arthursleigh site did not have any salinity remediation work completed during the audit period. The soils are considered to have a low salinity risk (HNCMA 2013e), however minor works including ripping and re-seeding were undertaken previously.

Figure 3-13 Arthursleigh erosion control works completed in 2011

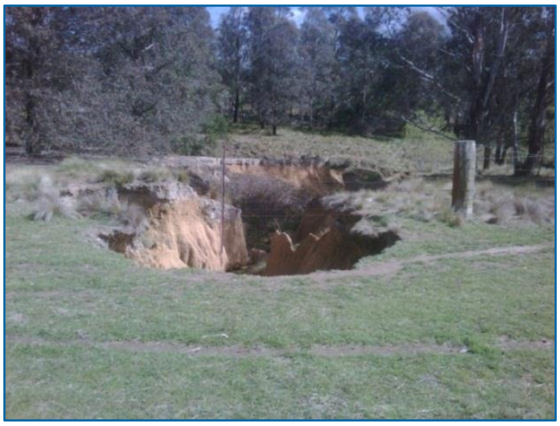


Figure 3-14 Arthursleigh erosion and fencing

(some of the 24 kms of fencing 2010-13 to assist recovery of riparian vegetation)

Figure 3-15 Arthursleigh erosion control works part completed during the audit period with wet mulch applied

Figure 3-16 Arthursleigh erosion and resulting turbidity due to dispersive soil type

Erosion in the Catchment

The Figure 3-17 presents a map of the severity of gully erosion and known sites of streambank erosion in the Shoalhaven catchment. There are approximately 400 km of minor and moderate; 160 km of severe and 110 km of extreme gulley erosion in the Shoalhaven catchment. The OEH estimates the number eroded gullies to be higher in the SRCMA area of operation at 6885 when compared to the HNCMA at 2858 (OEH 2013b).

There are more than 250 km of streambank erosion in the Shoalhaven catchment. Measuring and reporting on the extent of streambank erosion supports a better understanding of the extent of erosion affecting water quality within the Catchment. Sheet and rill erosion also impact water quality and these partnered with hill slope erosion are targeted through CMA programs.

Erosion of the streambank can indicate poor ecological integrity of the waterway, including decreased edge habitat and often poor riparian vegetation condition, which reduces the capacity of the buffer zone to attenuate other contaminants such as nutrients and pathogens.

Gully Erosion Evaluation Trial

Lengths of gully erosion, stream bank erosion and active gully erosion were presented in the previous audit, from data collected by Emery (Emery 1986) and the SCA (SCA 2005) these data sets are still being used by the CMA's, however it does not acknowledge areas which have since been treated, naturally stabilised or where new (if any) eroded areas have developed. The Gully Erosion Evaluation Trial (GEET) was initiated to develop mapping techniques which are capable of mapping the location, extent, and severity of the existing gully erosion within the SCA Catchment.

The gullies were mapped using innovative GIS approaches, which included 3D imaging with high resolution imagery and catchment size derivation utilising a hydrological model (ArcHydro). The gullies were then risk ranked using a Risk Assessment Prioritisation Tool. Stage 1 of the program was completed, successfully mapped and risk ranked for 2,887 individual gully segments which totals over 366 km across the three drainage units. The segments which were assessed as being high risk were inspected in the field to validate the mapping techniques.

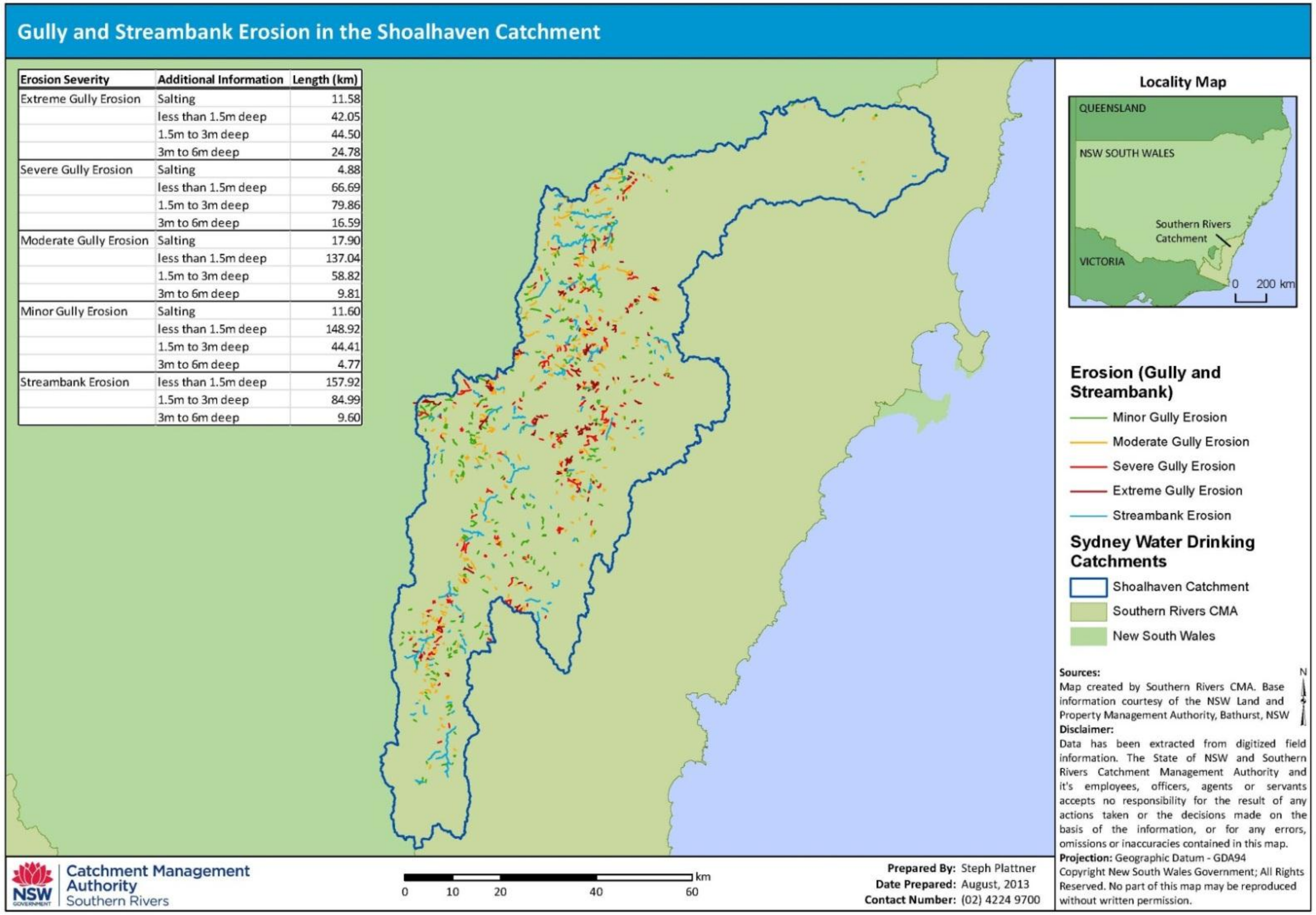


Figure 3-17 Extent of Gully Erosion in the Shoalhaven Catchment

Source: (SRCMA 2013b)

The GEET focused on three drainage units; Dixons Creek, Eden Forest and Oallen Ford. Dixon Creek was chosen due to a significant rainfall event during December 2010, Eden forest was chosen due to the long history of soil conservation treatments while Oallen Ford was is believed to be representative of severe erosion in the SRCMA area. The results of the Stage1 gully erosion mapping and risk ranking is presented in Figure 3-18 – Trial gully erosion mapping.

The outcomes from the completion of Stage 1 as outlined by the (SCA 2012i) were:

- Acquisition of 2011 ADS40 20 cm imagery over parts of the 3 trial drainage units and acquisition of planar unit to allow 3D analysis of trial areas;
- Mapping of all gullies within 3 drainage units, including presence/absence of gully treatments, stability of treatments and calculation of gully catchment areas using ArcHydro for 3 trial drainage units;
- Risk ranking of 3 trial drainage units and of individual gullies;
- Evaluation of mapping methodologies and recommendations for catchment wide mapping.

In comparison to prior gully erosion information only 24% gullies mapped in the trial drainage units were identified in the 2006 bare soil dataset, due in part to its inability to detect gullies under tree cover) where as 58% of gullies mapped in the trial drainage units were identified in the 1985 mapping information still used by the CMAs.

The outputs for the three drainage units mapped are presented in Figure 3-18. Of these, Dicksons Creek in the Upper Wollondilly is identified for the greater area of priority erosion fencing works, whereas the Oallen Ford drainage unit in the Shoalhaven catchment is prioritised for a greater area of treatments such as gully head works.

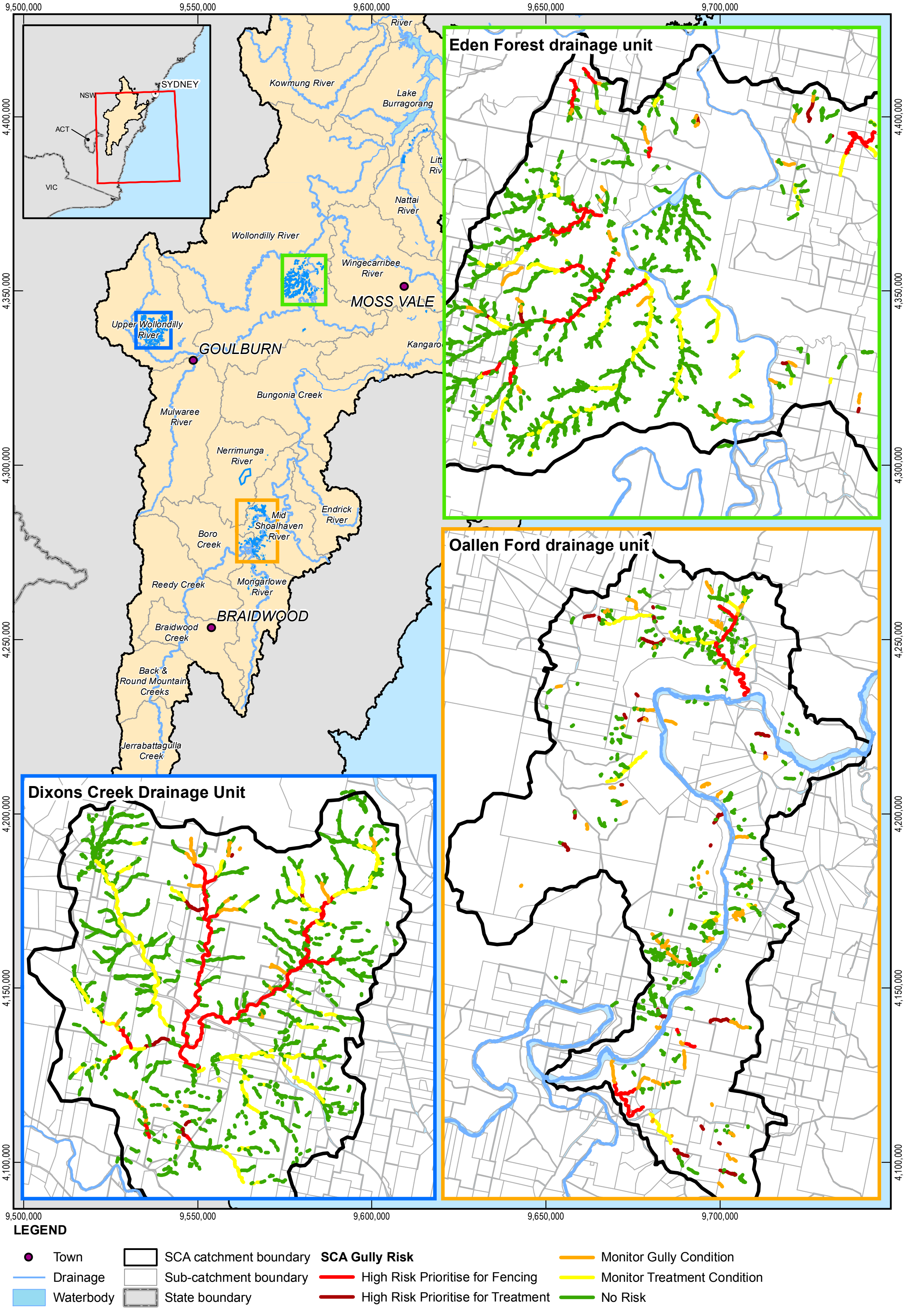
Implications

Overall, the mapping method provides a higher level of resolution and accuracy with the process now being rolled out to an additional 45 priority areas in the SCA, HNCMA and SRCMA areas of operation. Future efforts will utilise LiDAR data captured over time and soil analysis to calculate accurate gully export rates, which can then be integrated with the risk tool to produce a semi-quantitative model and to identify areas for gully erosion prioritisation.

Dryland salinity

Although not directly related to erosion, dryland salinity is a land management issue and is considered relevant in a discussion of catchment landuse. Dryland salinity has not been pursued by the SCA as a significant issue within the Catchment (SCA 2012a; b; c), although dryland salinity can result in an increase in the salinity of waterways. This is because, on-whole, the Catchment soils are not considered greatly susceptible.

Reports were completed by DPI investigating salinities within the CMAs areas of operation, with areas being given a salinity hazard ranking varying from very high to very low. The area with the highest salinity hazard ranking for the HNCMA is the Goulburn area which varies in rank from a moderate hazard to a very high hazard ranking (Winkler et al 2012), The highest risk lies to the west of Goulburn outside of the Catchment. The highest salinity hazard ranking within the SRCMA is the Braidwood area which also varies in rank from a moderate hazard to a very high hazard ranking (Jenkins et al. 2012). The remainder of the Catchment varies in rank from a very low hazard to a moderate hazard, with the exception of the Moss Vale area which is ranked as having a high salinity hazard.



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Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

Sydney Catchment Authority
Catchment Audit 2013

SCA Gully Erosion
Evaluation Trial 2012

Job Number | 2314960
Revision | 0
Date | 26 Nov 2013

Figure 3.18

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Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013), Trial gully erosion dataset (2012). Created by: KP

The SRCMA reported that less than 5% of landholders within the upper Shoalhaven catchment reported having a problem with dryland salinity on their property within the previous two years, and that a majority of landholders believe they had a moderate to high capacity to address salinity issues should they occur (SRCMA 2012b). Contradicting this, landholders within the upper Shoalhaven catchment are reported to have done something to address the issue of dryland salinity within the previous 12 months (SRCMA 2012b).

Dryland salinity information for the HNCMA was not formally available. Given some localities within the Catchment are considered high to very high hazard in 2012 studies, and that these areas are actively grazed and susceptible to landuse pressures, consideration should be given to ascertaining incidences and landholder capacity to ameliorate salinity impacts in the HNCMA areas of operation.

3.4.5 Recommendations

Currently riparian condition is assessed under the biodiversity theme. Presenting streambank erosion and associated works would enhance an understanding of the condition of these essential riparian areas.

The mapping of ‘locked-up’ riverbank, that is fenced riparian corridor, would further benefit an understanding of where this erosion could occur through grazing, or conversely where erosion could be stabilised through revegetation of remediated ‘locked-up’ areas. Consideration should be given to adding this indicator to the ‘Development of Catchment Health Indicators for Drinking Water Catchments’ following the next audit.

3.5 Populations settlement and patterns across the catchments

3.5.1 Summary

The Catchment has a population of 113,042 with seven of the total 27 sub-catchments containing over 79% of the Catchment's population. While the SCA does not have responsibility for managing the patterns of population settlement, it does play a role in ensuring that development that is approved by either local or state government agencies does not negatively impact on the water resources (both quality and quantity) of the Catchment.

There was an increase in population of 4,589 over the audit period. Five of the sub-catchments have populations of over 10,000 people with Wingecarribee River the most populated (24,190) followed by Upper Coxs River (14,493), Mulwaree River (12,287), Lower Coxs River (10,854) and Upper Wollondilly River (10,363) sub-catchments. The Nattai River (9,876) and Wollondilly River (6,975) sub-catchments also have substantial populations. The above seven sub-catchments contain the major urban centres of Moss Vale, Mittagong, Bowral, Lithgow and Goulburn. In all, twenty-one sub-catchments recorded an increase in population over the audit period with six recording a minor decrease. Population increase data indicates that growth is mostly proportional to the size of the townships, with the largest townships experiencing the most growth.

Population projections data from DP&I predict an expected increase in population from 2011 to 2031 in the six Local Government Areas (LGAs) that comprise the bulk of the Catchment area DP&I 2013b). The populations in Palerang, Wollondilly, Goulburn-Mulwaree, and Wingecarribee LGAs were projected to increase by 57.4%, 34.2%, 12.4%, and 10.9% respectively.

Analysis of this data enables the SCA and other stakeholders to observe the trends in population that have occurred in the Catchment and those that are expected in the future so that management strategies can be put in place to deal with the predicted change and minimise any future impacts on water resources within the Catchment.

Assessment Criteria

Criteria

1. There is an awareness of the trends in population and distribution for the catchments, both observed and proposed.
2. Management strategies are in place to deal with population change.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil

Prior Recommendations

There are no prior recommendations for this section.

3.5.2 Background

The majority of the land within the Catchment is comprised of 'Conservation and Natural Environments' and 'Production from Dryland Agriculture and Plantations'. These two land use classes cover approximately 90% of the Catchment with residential and farm infrastructure covering just 3.3% of the total area.

Increasing population within the Catchment will impact on infrastructure and natural resource requirements. It is necessary that population settlement and patterns be analysed to ensure that planning provisions and infrastructure proposals are in line with population growth to minimise any adverse impact on water resources in the Catchment. The following data has been assembled from Census information compiled by the ABS (ABS 2013) and the population projections assembled by DP&I (DP&I 2013b).

3.5.3 Management and Surveillance

DP&I have overall responsibility for providing strategies and policies which drive population settlements and patterns. These strategies and policies may be initiated at the LGA level through Local Councils who make decisions on local planning policies which are required to be consistent with these state-wide planning policies and strategies. To assist with planning, the SCA provided input into the regional growth strategies.

The SCA makes input into local planning decisions through their NorBE assessment tool prior to concurrence and final planning approval being received. The SCA has also provided funds to Local Councils to fast track the upgrade and/or construction of new sewage treatment plants within the Catchment.

All major developments within the Catchment are currently approved by DP&I under the SSD or SSI Assessment System. SCA provides submissions on these major developments and strategies, however ultimately the final decisions are determined by the Department.

3.5.4 Methodology

The ABS Census ‘Mesh Block Population and Dwellings 2011’ data was used to calculate the total population and population density results for the 2010-13 Audit period. The Census data was projected to GDA94 Lambert Projection for NSW prior to calculating the area of each mesh block. The data was then intersected with the SCA sub-catchment GIS layer to split population information by sub-catchment. For those mesh blocks which extended between multiple sub-catchment boundaries, the total population result of each individual mesh block was proportionally divided between each sub-catchment section based on land area. This technique assumed equal distribution of population across the mesh block. The same methodology was also applied to the ABS Census 2006 mesh block population data (MB_MSW_2006_census); however, of note some mesh block boundaries differed between datasets and therefore comparisons between 2006 and 2011 results should be considered indicative only.

3.5.5 Findings

The total population in the Catchment based on ABS 2011 Census data is 113,042 people. This data is slightly less than the population of the last audit of 115,877 which is explained by a difference in mesh block sizes between the 2006 and 2011 census data. Applying the same methodology as has been used in this audit, the total population in the Catchment in 2006 was 108,453 which results in an increase in population of 4,589 over this period.

As shown in Table 3-20, Wingecarribee River is the most populated sub-catchment with 24,190 people, followed by Upper Coxs River (14,493), Mulwaree River (12,287), Lower Coxs River (10,854) and Upper Wollondilly River (10,363) sub-catchments. Nattai River (9,876) and Wollondilly River (6,975) also have populations over 6,000.

Figure 3-20 and Figure 3-21 provide diagrammatic presentations of populations. The above seven catchments contain the major urban centres of Moss Vale, Mittagong, Bowral, Lithgow and Goulburn and many smaller towns and combined account for approximately 79% of the population within the Catchment.

Six sub-catchments recorded a minor decrease in population. Reedy Creek declined by 70 people, Woronora River (39), Little River (23), Endrick River (20), Werriberri Creek (15) and Upper Shoalhaven River (10).

The Grose River – Blue Mountains sub-catchment has the highest average population density (117.6 people/km²) followed by Lower Coxs River (44.2 people/km²), Upper Coxs River (38.02 people/km²) and Wingecarribee River (31.81 people/km²) sub-catchments.

The smallest population densities were recorded in Endrick River (0.12 people/km²), Upper Shoalhaven River (0.12 people/km²) and Kowmung River (0.14 people/km²).

Data from the two most recent Censuses were used to calculate the change in population between 2006 and 2011 for those LGAs with the majority of their land area within the Catchment. Table 3-21 shows that all six LGAs experienced net population growth over this period. The largest percentage change in population occurred in Palerang LGA which increased by 16.5% followed by Wollondilly LGA (7.2%) and Goulburn-Mulwaree LGA (5.3%). Lithgow and Upper Lachlan LGAs recorded the lowest percentage increase in population. These findings were relatively consistent with those in the previous audit, as shown in Figure 3-19 below.

DP&I (2013) have recently released its updated Preliminary 2013 Population Projections for the period 2011 to 2031. The projections show that by 2031, the populations in Palerang, Wollondilly, Goulburn-Mulwaree, and Wingecarribee LGAs will increase by 57.4%, 34.2%, 12.4%, and 10.9% respectively resulting in an additional net change of population of 27,700.

Palerang LGA is projected to have an annual increase of population of 2.3% and Wollondilly 1.5%. Due to the proximity of these LGAs to Canberra and Sydney respectively, the majority of growth in these LGAs is expected to occur outside the Catchment.

By 2031, Upper Lachlan LGA is expected to have an increase in population of 500 people, a 6.8% increase while the population of Lithgow LGA is expected to decline by 100 or -0.5%.

An increase in population has implications for the water resources in the Catchment. The analysis of these population settlements and patterns allows the SCA, government agencies and Local Councils to ensure that proper planning policies and long term sustainable growth strategies are implemented, in order to minimise any adverse impacts on the water resources.

A number of major planning proposals and strategies will impact on population settlements and patterns across the Catchment. These include the Sydney-Canberra Corridor (DP&I 2011) and the South Coast and Illawarra Regional Strategies which both contain actions related to housing and settlement.

Sewage collection systems have been identified as one of the top five most significant pollution sources within the Catchment. The SCA's *Annual Catchment Management Report 2011-12* identifies sewage treatment plants in Wollondilly River, Nattai River, Upper Coxs River, Mid Coxs River, Braidwood, and Bungonia Creek sub-catchments as posing a risk to water quality.

These sub-catchments account for approximately 40,000 people and the SCA through its Accelerated Sewage program has provided funds to assist Local Council's fast track the upgrade or construction of sewerage treatment schemes. A case study of the recently commissioned Taralga STP was discussed in Section 3.1.

The close proximity of the Catchment to Sydney and Canberra has resulted in large agricultural land holdings being subdivided for lifestyle purposes where the landholder has an off-farm income. These landholders generally engage well with the local CMAs and have an interest in environmental custodianship, but lack the capability and time to perform land management tasks compared to traditional farmers.

Table 3-20 Population and population density by sub-catchment

Sub-Catchment	2006	2011	Difference	Population Density (people/km²)
Back & Round Mountain Creeks	126	191	65	0.55
Boro Creek	155	238	83	0.68
Braidwood	1423	1522	99	4.08
Bungonia Creek	1178	1295	117	1.62
Endrick River	61	41	-20	0.12
Grose River - Blue Mountains Catchments	2387	2494	107	117.57
Jerrabattagulla Creek	65	113	48	0.32
Kangaroo River	3798	3960	162	4.59
Kowmung River	77	110	33	0.14
Lake Burragorang	1040	1142	102	1.42
Little River	1050	1027	-23	5.59
Lower Coxs River	10383	10854	471	44.22
Mid Coxs River	4219	4369	150	4.10
Mid Shoalhaven River	131	161	30	0.32
Mongarlowe River	224	303	79	0.71
Mulwaree River	11922	12287	365	15.62
Nattai River	9713	9876	163	22.20
Nerrimunga River	471	592	121	1.23
Reedy Creek	662	592	-70	1.03
Upper Coxs River	14285	14493	208	38.02
Upper Nepean River	1226	1282	56	1.44
Upper Shoalhaven River	37	27	-10	0.12
Upper Wollondilly River	9748	10363	615	14.02
Werriberri Creek	4465	4450	-15	27.05
Wingecarribee River	23022	24190	1168	31.81
Wollondilly River	6451	6975	524	2.59
Woronora River	134	95	-39	1.28
Grand Total	**108,453**	**113,042**	**4,589**	

Table 3-21 Population by LGA from ABS

LGA	2006	2011	Net Change	% Change
Wollondilly	40,344	43,259	2,915	7.2%
Wingecarribee	42,272	44,395	2,123	5.0%
Upper Lachlan Shire	7,053	7,193	140	2.0%
Palerang	12,318	14,352	2,034	16.5%
Lithgow	19,756	20,160	404	2.0%
Goulburn-Mulwaree	26,086	27,481	1,395	5.3%
Total	**147,829**	**156,840**	**9,011**	**6.1%**

Source: ABS Census Data 2006 and 2011 (ABS 2013)

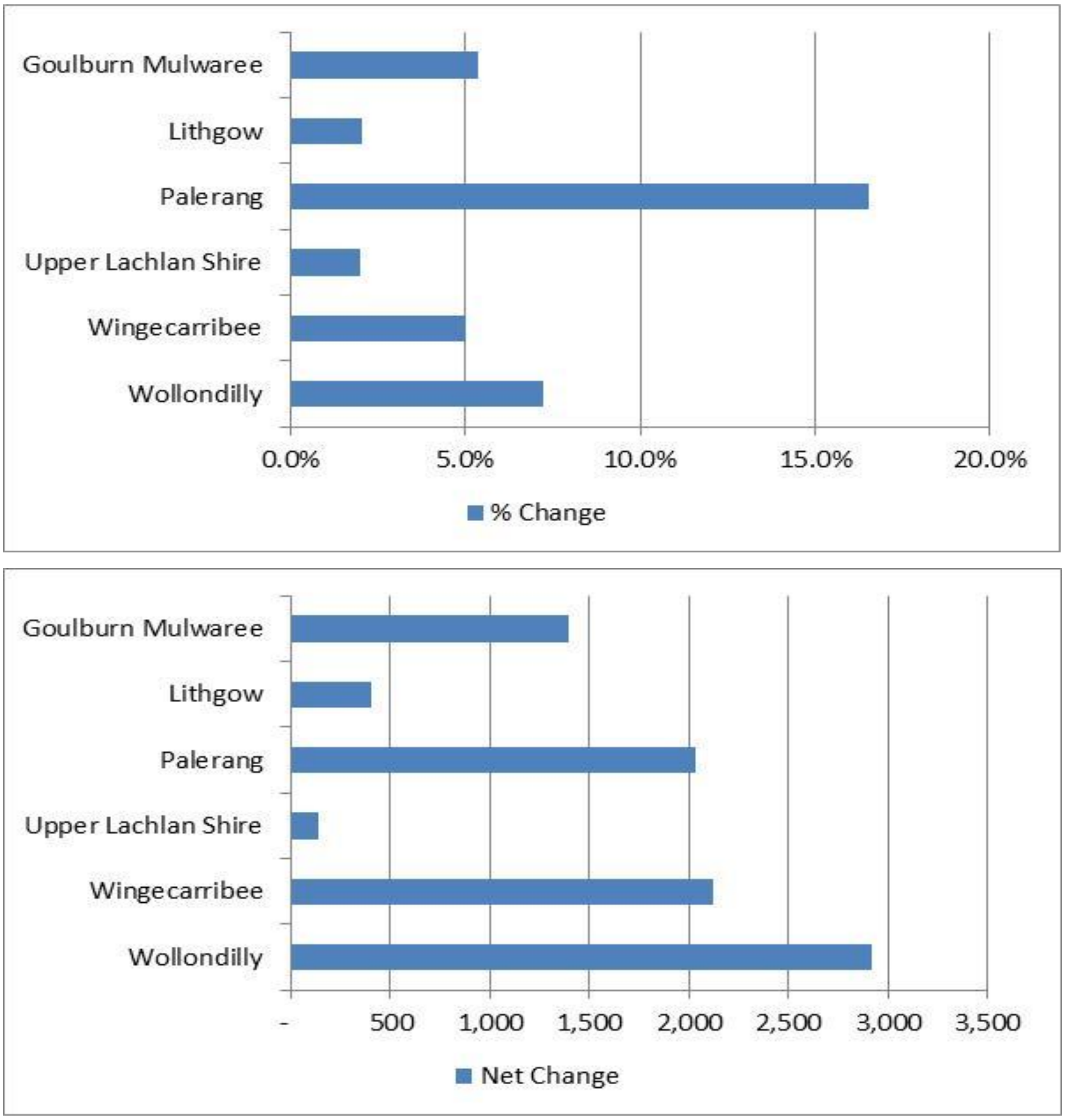


Figure 3-19 Population changes for Catchment LGAs, 2006-11

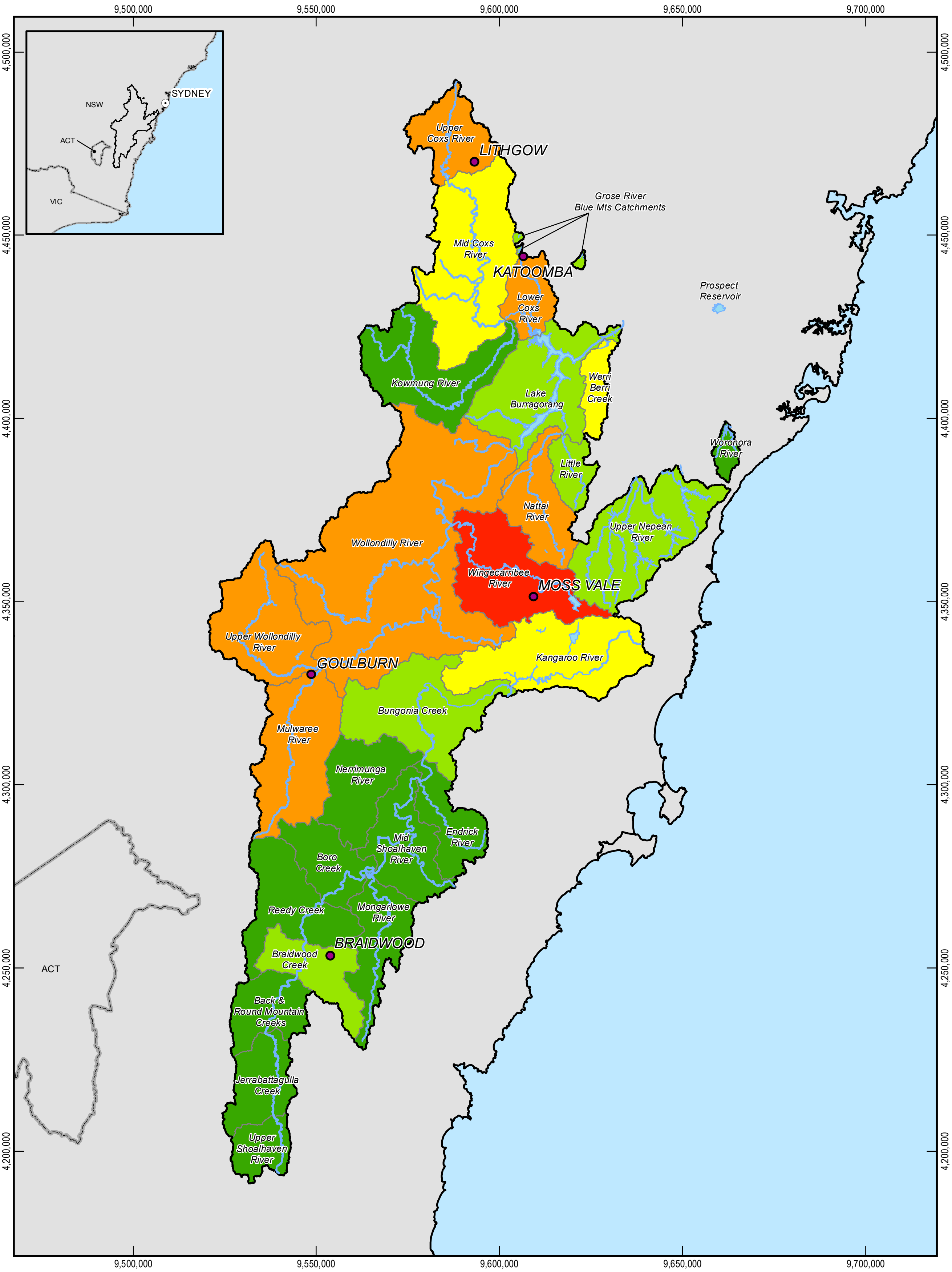
Source: ABS Census Data 2006 and 2011.

The SCA and DPI have invested resources in education programs to help train these landholders, in order to promote sustainable land management practices. The outcomes of a number of these programs and engagement with the community are further discussed in Section 3.6.

3.5.6 Recommendations

There is awareness across the relevant agencies of the trends and distribution of population within the Catchment and sub-catchments. These agencies continue to provide input advice to regional and local strategies and provide funding through various programs to manage the changing population patterns throughout the Catchment.

The Auditor is satisfied that the appropriate agencies are monitoring population change and distribution adequately and implementing appropriate catchment management strategies.



LEGEND

Town	SCA catchment boundary	**Total Population**	3301 - 6200
Drainage	Sub-catchment boundary	0 - 950	6201 - 14500
Waterbody	State boundary	951 - 3300	14501 - 24190

Paper Size A4

0 10 20 30

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Total population in the Catchment 2011

Job Number 2314960
Revision 0
Date 26 Nov 2013

Figure 3.20

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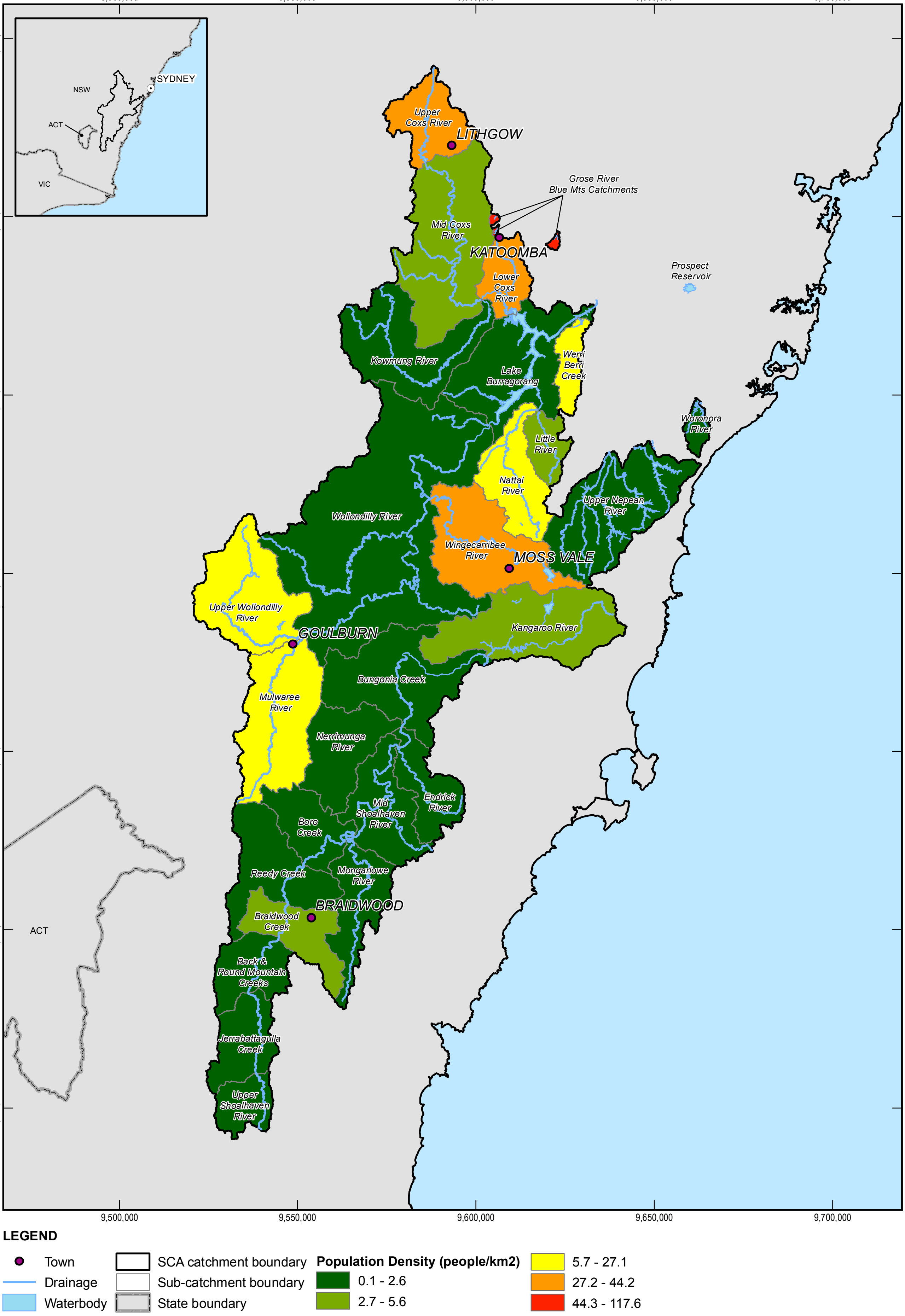
Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); ABS: Mesh block population and dwellings data (2011). Created by: KP



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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Population Density (people/km2) in the Catchment 2011

Job Number	2314960
Revision	0
Date	26 Nov 2013

Figure 3.21

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Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); ABS: Mesh block population and dwellings data (2011). Created by: KP

3.6 Community attitudes aspiration and engagement

3.6.1 Summary

There are two indicators set by the NOW to inform of community attitudes to catchment health and engagement with the community in order to facilitate catchment protection (NOW 2009). These are the number of community natural resource management (NRM) organisations within the catchment and the number of landholders engaged in improvement works. There are more than 360 community based NRM organisations that actively operate within HNCMA and the SRCMA areas of operation. Knowledge of all NRM organisation operations within the Catchment enables future engagement and programs to be targeted across suitable organisations with the capacity to deliver the best outcomes, and for initiatives to reach the broadest range of the public actively interested in catchment health.

The HNCMA and the SRCMA are the two principal organisations through which funding is directed for NRM activities and works with community-based organisations. The SCA engages with the community through these CMAs and through directly providing information, tools and engagement activities for projects and policy development. Understanding how landholders are engaging and what programs are being cooperatively delivered supports the setting of future catchment management works programs. During 2010-13 the community were engaged through workshops and knowledge sharing.

The number of landholders engaged in improvement works between 2010 and 2013 were >330 facilitated by the HNCMA and >60 facilitated by the SRCMA. The number of community groups supported in improvement works were >45 each by the HNCMA and the SRCMA. An improvement in community capacity was demonstrated through a >50% increase in volunteer hours when compared to 2008, meeting the HNCMA's target that 'by 2016, there is an increase in the catchment community's capacity to contribute to managing the catchment's natural resources'. Furthermore a higher percentage of landholders undertook action to address land management issues when compared to 2008, with the exception of addressing soil erosion and poor quality water in rivers and streams.

Given this, soil erosion and water quality could be prioritised for community engagement and capacity building programs beyond 2013. Engagement was greater than that of the previous audit period in the SRCMA area of operation as a result of the Catchment Action Plan (CAP) objective that '*communities are supported to increase their capacity to contribute to natural resource management and social wellbeing*'. Overall landholders' individual capacity was improved through knowledge sharing and capacity building programs delivered through the formal agreements between the SCA and the CMAs, with the result that the CAP objective of '*public and private land and water managers are supported to increase their capacity to manage natural resources'* was met.

Assessment Criteria

Criteria

1. Landholders' engagement in improvement works meet SCA and CMA objectives.
2. Community engagement programs are run in all sub-catchments under pollution pressure.
3. Programs relevant for water protection that are identified in the CAPS receive financial, in-kind, or in principle support.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil
3	Meets Expectation	Nil

Prior Recommendations

Prior Recommendations	Remedial action	Status
Recommendation 1: The SCA investigate ways to achieve effective Aboriginal community engagement in the audit prior to the commencement of the next Sydney Drinking Water Catchment audit.	The SCA investigated and enacted an Aboriginal Stakeholder Engagement Plan for the 2013 Catchment Audit.	Closed

3.6.2 Background

There are two indicators set by the NOW to inform of community attitudes to catchment health and engagement with the community in order to facilitate catchment protection (NOW 2009).

These are the number of community natural resource management (NRM) organisations within the catchment and the number of landholders engaged in improvement works. Understanding how landholders are engaging and what programs are being cooperatively delivered supports the setting of future catchment management works programs.

Knowledge of all NRM organisations' operation within the Catchment enables future engagement and programs to be targeted across suitable organisations with the capacity to deliver the best outcomes and for initiatives to reach the broadest range of the public actively interested in catchment health.

3.6.3 Management and Surveillance

The HNCMA and the SRCMA are the two principal organisations through which state and federal funding is directed for NRM. The function of these principal bodies is to direct NRM programs and to direct and account for NRM funding, as well as providing training and education to stakeholders and the wider community. CAPs are the primary document through which priorities and actions are set for NRM facilitated by the CMAs. The plans, which are current for the 2010-2013 audit period, were approved by the Minister for Climate Change, Environment and Water (HNCMA CAP) and the Minister for Primary Industries (SRCMA CAP).

Relevant CAP programs were supported in principle by the SCA through formal agreements with the CMAs and financial support is provided in both CMA areas of operation through the Catchment Protection Scheme (CPS) program. The executive of the SCA, HNCMA and SRCMA met as a Strategic Liaison Group every six months to liaise on strategic agreements and joint initiatives under the CAPs. In addition these agencies met quarterly as a Joint Operations Group. SCA also met quarterly with the OEH.

The Healthy Catchments Strategy 2012 details the program logic for everything that is done by SCA in the Catchment including community engagement, capacity building and works programs. Community engagement is undertaken through the provision of information and tools for key stakeholders within the Catchment as well as delivering community engagement activities for projects and policy development (SCA 2012b).

Through these activities the community is informed on water and catchment management initiatives enabling landholders and community groups to implement best management practices to achieve water protection.

The SCA also engages with Local Councils, as key stakeholders within the Catchment, on multiple levels including providing guidance information, training, and ongoing liaison through the Local Government Reference Panel which met on a quarterly basis during 2010-13.

Additional NRM groups actively involved with SCA are listed below (note that the list is not exhaustive). SCA capacity building activities are directed at these stakeholders in addition to the wider community. In some instances these groups undertake works that are part-funded by the SCA.

- Landcare and Bushcare groups;
- Indigenous groups;
- Streamwatch and Rivercare groups;
- The National Parks and Wildlife Service;
- The National Trust of NSW and Botanic Gardens groups;
- The Nature Conservation Council of NSW and environment, nature and conservation groups; and
- Rural groups and the Small Farms Network.

There are over 200 active community organisations in the SRCMA area of operation and over 160 in the HNCMA area of operation. In total the number of community NRM organisations active within the CMAs area of operations exceeds 360.

The activities of the SCA, HNCMA and SRCMA are discussed further below, noting that activities also include many of the other NRM organisations discussed above as contributors or recipients of funding.

3.6.4 Findings

Sydney Catchment Authority

The SCA works with partner agencies HNCMA, SRCMA as well as councils, community organisations and landholders to deliver programs and initiatives that foster catchment management outcomes.

Since the previous Audit period the SCA has developed materials to assist councils and developers in achieving beneficial outcomes for new development and activities in the Catchment by utilising the NorBE tool. In 2010-11 the SCA rolled out Council training in this tool and continues to provide quarterly notes on its use (SCA 2013a).

In addition the SCA developed new Current Recommended Practice (CRP) guidance materials in 2011-12 to inform of best practice for activities in the Catchment including the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) and water quality information requirements for developments to support NorBE, water sensitive design for rural residential subdivisions, water cycle management studies, horse property development and training resources to complement the CRP guidelines in wastewater system installation. Further community and stakeholder education activities during 2010-13 included:

- Workshops on erosion and sediment control;
- A school education program for 7,000 students each year;
- Hosting informative exhibitions at the Warragamba Dam Visitor Centre which is visited by approximately 100,000 individuals per year;

- Disseminating information through media stories on catchment management initiatives; and
- Hosting a science symposium in 2012 to share research knowledge.

The SCA engages with landholders and community groups to achieve education and works through programs including the Grazing Incentives Program (GIP), Riparian Management Assistance Grants, and the CPS which are jointly delivered between the SCA, HNCMA and SRCMA. The CPS aims to engage landowners to repair gully, streambed and bank erosion, improve land management and river health; and increase biodiversity across the Catchment in order to protect water supplies (HNCMA 2013a).

Through this program the SCA provides grants of up to $10,000 to community groups and landholders for capacity building and works. The SCA contributed $450,000 out of a total value of $1.4 million for projects with 23 landholders in 2010-11 and contributed $ 470,000 out of a total value of $1.2 million for 20 projects in 2011-12. These were undertaken in conjunction with the HNCMA. In conjunction with the SRCMA the SCA spent $20,000 with a total value of $142,000 for seven agreements in 2010-11 and spent $71,000 with a total value of $132,000 for eight agreements. These were achieved in priority sub-catchments and drainage units (see Figure 3-12 The CPS targeted investment and works to the highest priority sub-catchments impacted by erosion as identified by multi−attribute land degradation mapping and the SCA Pollution Source Assessment Tool (PSAT) (HNCMA 2012b).

In 2011 above average rainfall for the second year running resulted in delays in the implementation of erosion control earthworks and less than budgeted CPS funding. Overall objectives were met by the CPS which achieved significant outcomes in terms of water quality at the same time delivering both land management and biodiversity benefits (HNCMA 2012b). SCA reviews the efficacy of the CPS program through assessing the achieved outcomes and spending using a Monitoring, Evaluation, Reporting and Improvement (MERI) structure.

The HNCMA reported the following achievements for the CPS in 2012-13:

- 11 agreements with landholders that were >50% funded by SCA or other sources with 10 of these in priority catchments;
- 656 ha of land protected from soil erosion by engineered works;
- 30 sites protected through engineered works for soil erosion;
- 64 ha of land protected by exclusion fencing to treat soil erosion;
- 16 km of streambank protected from stock and 18 km of riparian native vegetation protect by fencing;
- 18 ha of native planting with 5 km of riparian vegetation planted;
- $470,000 spent in priority catchments by SCA, $160,000 spent from other funding sources in priority catchments and $260,000 spent in non-priority catchments.

In addition to the CPS the SCA supported the community and provided capacity building and training opportunities to:

- More than 2,000 graziers through the joint SCA and DPI Sustainable Grazing Program
- Landholders through the riparian management assistance program; and
- The broader community through the SCA Streamwatch water quality monitoring program (SCA 2013a).

The SCA also engaged with the community on various projects undertaken in the catchment including the Wingecarribee Dam improvement works, the Bendeela Recreation Area Masterplan process, the Cataract Tunnel remediation and the Upper Canal works.

Stakeholder engagement by other organisations

HNCMA

The HNCMA delivered the following key programs for 2010-13:

- The riparian protection and enhancement program targeting riparian condition and water quality through fencing, weed control and improving riparian vegetation;
- The CPS partnership program with SCA focusing on soil erosion;
- Native vegetation protection programs targeting remnant vegetation, pest control, restricting grazing and revegetation; and
- The improving land management practices program targeting grazing management, ground cover, soil carbon and ultimately catchment water quality.

There are 45 active Landcare groups in the HNCMA area of operation within the Catchment. These groups participated in activities including weed removal, tree planting, animal surveys and control and community education (HNCMA 2013b,c). An average of 670 hours per group per year was contributed by volunteers from the Landcare / community groups, with a total contribution of approximately 90,000 hrs. The HNCMA provided approximately $800,000 over the same period to fund the works undertaken by these groups.

Community engagement programs delivered by the HNCMA and funded by Caring for Our Country that were measured as effective include:

- The Regional Landcare Facilitator program with a dedicated staff member and capacity to fund training and awareness events and information products;
- The > $500,000 per annum Biolinks program which includes workshops; and
- Farmer Soil Microscopes group for soil health (HNCMA 2013b).

The following information summarises the investment and engagement in community works and capacity building.

<u>2010-11</u>

- The HNCMA spent $1.49 million on community programs;
- 1,524 community members were engaged in workshops and field days and six new guidance documents were produced;
- There were 266 partnerships with landholders;
- There were 64 management agreements for projects in the Warragamba catchment;
- 15 community groups were resourced to implement projects;
- 84 community groups were assisted; and
- 9 partnership projects with indigenous groups were completed (HNCMA 2011).

<u>2011-2012</u>

- The HNCMA spent $288,000 on community programs;
- A total of $2.6 million cash and in-kind contributions was contributed to Landcare projects;
- There were 70 landholder, local government and community partnerships in the Warragamba catchment and 16 capacity building events;
- There were numerous meetings and field days in the Blue Mountains catchment attracting 185 landholders;
- 26 Landcare groups were provided small grants;
- 20 community groups were assisted to obtain funding with 13 successful;

- 130 community groups were assisted;
- Insurance was covered for 79 community groups;
- 12 community members supported to attend the 2011 Landcare forum along with HNCMA representatives;
- Regional Landcare facilitator workshops attracting 395 participants; and
- Multi stakeholder community reference groups formed and consulted for the development of the new CAP (HNCMA 2012a, b).

In addition to the HNCMA funding for Landcare activities (HNCMA 2012a; b; d), the in-kind contributions by HNCMA were valued at $873,000 in 2010 and $688,000 in 2012. This is 40% less than the previous audit period. However, the number of voluntary hours by Landcare was up by more than 50%, indicating an improvement in community capacity to offset the funding deficit.

This was equivalent to an increase of $1,180,000 in voluntary contributions compared to 2008 and signifies a shift toward more sustainable community driven programs (HNCMA 2012a, b). This meets the CMA's target that '*by 2016, there is an increase in the catchment community's capacity to contribute to managing the catchment's natural resources*'. (HNCMA 2007)

SRCMA

The SRCMA undertook two noteworthy community engagement projects between 2010 -12. These were the development of Local Government Strategic Management Plans, as part of the analysis of what the community values in order to develop the new CAP, and a social benchmarking report on the state of community engagement and capacity.

The assessment gauged the landowners' awareness and attitudes and to compare this to the last audit period. The report finds that 48% of landowners believe they have the experience and knowledge and 27% believe they have the skills and training to address land and water issues (SRCMA 2012b). Of the landholders in the Southern Rivers, 23% indicated they sought recent support or advice about improving the health of their property and 11% of landholders had undertaken training. This engagement was greater than that of the previous audit period.

The three organisations most commonly contacted to assist were Landcare (34%), the SRCMA (31%) and the Local Council (31%). Of the landholders in the Southern Rivers, 15% indicated they were involved in a Landcare, natural resource management or environmental group and 22% of landholders indicated they had had contact or communication with the SRCMA. A lack of time (31%) was the most common capacity issue amongst all landholders, followed by too much red tape (25%) and the belief that the issue cannot be fixed (24%).

As a result of the community aspirations and avenues of engagement described, a higher percentage of landholders had taken action to address land management issues when compared to 2008, with the exception of addressing soil erosion and poor quality water in rivers and streams. This had declined since 2008 (SRCMA 2012a; b).

The following summarises the investment and engagement in community works and capacity building carried out in this audit period:

- 116 community groups assisted;
- Conducted 18 awareness raising events such as demonstrations, field days or study tours;
- 16 funding applications supported of which six were successful and obtained $80,000 of combined funding;
- Capacity building knowledge programs reached at least 124 individuals;

- There were 13 training events and workshops run;
- 48 community groups or land managers were supported;
- Three collaborative agreements formally implemented with stakeholders and 61 informally agreed; and
- 450 written products produced e.g. newsletters, posters or factsheets reaching over 8,000 individuals and 30 key pieces of material were developed.

The targets set in the 2013 SRCMA CAP are that '*communities are supported to increase their capacity to contribute to natural resource management and social wellbeing'* and that '*public and private land and water managers are supported to increase their capacity to manage natural resources*' (SRCMA 2013a; b). The SRCMA invested funding in the Upper Shoalhaven which broadly corresponds with the Sydney Drinking Water catchment to the value of:

- 2010-11 - $555,647;
- 2011-12 - $501,859; and
- 2012-13 - $660,242.

This, along with the number of community groups engaged, demonstrates that communities are being supported and the CAP objective met. Furthermore the number of landholders whose individual capacity was improved through knowledge, the three formal agreements with principal stakeholder groups and joint implementation of the CPS with the SCA demonstrated the second CAP objective of supporting private and public land and water managers was met.

Local Councils

Aside from the CMAs, Councils have a role to play in community awareness through programs and in linking the community to organisations that can assist with capacity building.

Examples of major Council programs were:

- The Wingecarribee Council Vegetation Conservation Program which was part funded through the HNCMA and ran from 2004 through to 2013; and
- Wingecarribee Council's assistance to 16 Bushcare groups with 2,597 hours contributed in 2010-11, 3,818 hours in 2011-12, 3,292 hours in 2012-13 with a combined value of $340,000.

Indigenous Groups

A recommendation of the 2010 audit was that '*The SCA investigates ways to achieve effective Aboriginal community engagement in the audit prior to the commencement of the next Sydney Drinking Water Catchment audit*'. As a result the SCA prepared an Indigenous Groups Engagement Plan which commenced during the audit period.

Respondents to the audit included four groups from a total of 30 groups contacted. Engagement is ongoing and face to face contact is recommended, along with earlier engagement to improve outcomes. Indigenous groups were engaged through the HNCMA and SRCMA throughout the audit period. Involvement and financial investment in indigenous programs with these CMAs and the SCA is summarised thus:

- Aboriginal Advisory Committee Meetings were supported quarterly by HNCMA in 2010-11 and $100,000 was invested in seven projects to restore areas of cultural significance and capacity building in indigenous communities (HNCMA 2011);
- In 2012 the SCA fire management program developed with HNCMA the Aboriginal Cultural Values procedures in conjunction with indigenous stakeholders (HNCMA 2012a);
- The Hawkesbury-Nepean Aboriginal NRM Forum held in 2012; and

- The SRCMA created positions for two indigenous persons to work within the SCA catchment. In addition one workshop with an aboriginal cultural element was run and a total of three aboriginal community groups were assisted (SRCMA 2013b).

The SCA drafted a broader plan to guide engagement with Indigenous communities within the Catchment during the audit period. Finalisation of the plan is contingent on the Indigenous Land Use Agreement (ILUA) with the Gundungurra people, which includes engagement responsibilities.

3.6.5 Recommendations

There are no formal recommendations for this indicator. However, the Auditor endorses continued prioritisation of soil erosion and water quality issues for community engagement and capacity building programs. The CPS appropriately targeted investment works to the highest priority sub-catchments and there were community engagement programs and landholder works in all priority sub-catchments.

There is currently a knowledge gap associated with the research around what water quality parameters are of value to landholders. Water quality is a broad goal and focusing on the specifics that are of interest to all stakeholders is more likely to result in successful engagement.

There was a prior recommendation that '*The SCA investigate ways to achieve effective Aboriginal community engagement in the audit prior to the commencement of the next Sydney Drinking Water Catchment audit*'. The SCA developed an Aboriginal Stakeholder Engagement Plan for the 2013 Catchment Audit which listed the key Indigenous stakeholders and the activities for the SCA to undertake to achieve effective engagement.

The undertaking of these activities resulted in a submission received from the Darug Custodian Aboriginal Corporation. Further efforts have resulted in limited additional submissions, indicating that the effort was only partially successful in engaging the Aboriginal community. This is primarily due to competing indigenous priorities around audit time listed as a review of the *Aboriginal Land Rights Act 1983*, NSW cultural heritage reform, and running Annual General Group Meetings among other things.

This recommendation is closed on the basis that SCA have investigated and enacted ways to achieve indigenous community engagement. This engagement strategy can be improved for future audits, based on current learning.

4. Water Availability

4.1 Surface Water Flow

4.1.1 Summary

The availability of water in the natural watercourses of the catchment and the temporal variability of its delivery are key considerations in determining the health of the watercourses in the catchment. The audit of surface water flows within the catchment was based around the following two key measures to describe surface water availability:

- Level and variability of streamflow; and
- Maximum permissible annual volume of surface water that can be extracted under water licences in each sub-catchment.

The audit process included discussions with NOW and SCA on the availability and understanding of the data. The audit concerning the level and variability of streamflow was based on data collected by the SCA from their network of river gauging stations across the catchment (no assessment of rainfall is included). The assessment of data was on 65 stream gauges across the catchment. The water access licence data were collected from NOW.

As part of the current audit (2010-2013), the stream flow gauge data were assessed for completeness and to identify the temporal trends for each of the gauges identified. The audit included consideration of the same gauges, as assessed in previous audits to identify if there have been major changes to the flow regimes in each sub-catchment. Assessment of the long-term trends in streamflow compared the flow data for the current audit period against the data captured for the complete data record of each respective gauge.

Under the assessment of surface water flows, consideration was also given to the water extraction licences within the catchment. The extraction of water from the catchment places a load on the availability of water and possibly the health of the catchment. Information on the location and permissible extraction volume was collected and collated from NOW. The assessment of extracted water considered the location of the extraction licence and the total allowable volume extracted for each sub-catchment area.

Consistent with the general increase in environmental flows released from the nominated SCA storages, the current audit period generally saw an increase in the daily flows passed through each flow monitor, compared to previous audit periods and long-term data, with some exceptions. The increased flows at most locations were despite a reduction in Raw water Transfers, carried out by the SCA. At nine locations, reduced flows less than the long term medians were recorded, and at one location, flows had declined greater than 50%. Such data suggested stress on the flows within those watercourses, or lower rainfall captured in contributing sub-catchments.

It would be beneficial for SCA to audit all gauge stations to correct basic metadata errors prior to the next audit period (for example, some inconsistences were noted during the current Audit in the spelling of or factual errors in gauge names). It would also be appropriate for the SCA and NOW to collaborate and include dam storage levels, catchment rainfall volumes and the assessment of volumes that are extracted by current water entitlements.

Assessment Criteria

The assessment criteria for the availability of surface water for this audit are shown below. These criteria were based on the key surface water availability measures.

Criteria

1. Identify flow variability and long term trends at nominated watercourse gauging stations across the Catchment.
2. Identify the maximum permissible annual volumes of surface water that can be extracted under licences in each sub-catchment.

Assessment against Criteria

Criteria	Audit finding	Recommendation
1	Meets Expectation	Nil
2	Meets Expectation	Nil

Prior recommendations

Prior Recommendations	Remedial action	Status
Recommendation 12: NOW should investigate the reasons behind the recent decline in flow in Werriberri Creek.	The Greater Metropolitan Region Water Sharing commenced in July 2011. NOW will review the Plan for effectiveness including the likely reasons for declining creek flows, if low flows persist (not complete).	Opportunity for improvement
Recommendation 13: The SCA reinstate the flow gauging station in the Little River at Fire Road W4I.	The SCA have advised that this station has been re-installed.	Closed
Recommendation 14: DECCW, SCA, I&I and NOW investigate the possibility of establishing a collaborative research program aimed at providing a better understanding of the surface water and groundwater hydrology of Thirlmere Lakes and its catchment.	In 2010, NOW conducted an assessment of possible causes and potential groundwater connectivity at Thirlmere Lakes and made a report available on its website. On 25 October 2011 the NSW Government announced an independent inquiry into water levels in Thirlmere Lakes. A committee was formed representing expertise in a broad range of environmental areas including: hydrology, geology, geomorphology, climatology, palaeogeography, freshwater ecology and mining to review scientific literature, historic information on Thirlmere Lakes and information provided by the community and completed a report in 2012. This report was reviewed and a second report completed by the NSW Chief Scientist and Engineer in February 2013 (NSW Chief Scientist and Engineer 2013a). NOW has retained strata samples from its drilling program and these are available for future research.	Closed

Prior Recommendations	Remedial action	Status
Recommendation 15: NOW should investigate the reasons behind the apparent long-term decline in flow in Reedy Creek.	The Greater Metropolitan Region Water Sharing Plan commenced in July 2011. NOW will review the Plan for effectiveness including the likely reasons for declining creek flows, if flows persist.	Opportunity for improvement
Recommendation 16: NOW should finalise the *Draft Water Sharing Plan for the Greater Metropolitan Region* as soon as practicable.	The Greater Metropolitan Region Unregulated River Water Sources Plan (NOW 2010) commenced in July 2011 and includes rules for protecting the environment; extractions, managing licence holders water accounts, and water trading in the plan area.	Closed

4.1.2 Background

The quantity of water within the streams of the Catchments and the temporal variability of its delivery are fundamental attributes determining the ecosystem health of the rivers and streams of the catchment. Therefore it has been recommended that describing the actual availability of surface water within the catchment would be the most appropriate measure of catchment health in regards to catchment hydrology (NOW 2009).

Past audits (e.g. DEC 2003, 2005; DECC 2007) considered various measurements of pressures on water availability within the catchment, in particular the maximum permissible annual volume of water that can be extracted under water access licences, and the number of farm dams that may intercept runoff before it enters catchment streams. Stakeholders considered that continuation of at least the measure of water that can be extracted was essential, to enable a description of outputs from the catchment.

4.1.3 Management and surveillance

With particular regard to surface water management in the SCA catchment, the SCA manages 16,000 km^2 of drinking water catchment to protect the raw drinking water supplies for around 4.5 million people, or 60% of the state's population.

To best protect water quality, the SCA adopts a multiple barrier approach, which includes:

- Protecting the quality of water entering the storages by monitoring and influencing activities in the catchment;
- Improving the quality of water entering the storages by protecting and managing catchment lands (Special Areas) surrounding the storages;
- Optimising management of the storages; and
- Having extensive and comprehensive water quality and quantity monitoring networks.

The SCA collects water from five catchments, with 62% of the catchment land privately owned, 28% National Park, 9% SCA freehold, and the remainder Crown land.

The SCA operates a network of river gauging stations that measure the level and variability of streamflow. For the purposes of this audit, the data for these stream gauges was provided by SCA and the data on water access licences was provided by NOW.

The SCA publishes weekly raw water storage and supply reports to provide information about how much rainfall has been recorded, how full the dams are, and how much raw water they have supplied to their customers.

4.1.4 Methodology

The availability of water in the natural watercourses of the catchment and the temporal variability of its delivery are key considerations in determining the health of the watercourses in the catchment. The audit of surface water flows within the Catchment was based around the two key measures, identified previously - to describe surface water availability.

The audit concerning the measure of the level and variability of streamflow was based on the data collected by SCA from their network of river gauging stations across the Catchment. Data were assessed from 65 stream gauges and the water access licence data was obtained from NOW.

4.1.5 Findings

Surface water flow findings

Data was provided by the SCA for a total of 65 gauges across the SCA catchment. A summary of the gauges from which data was assessed within the current audit period is presented in Table 4-1. The data was assessed for completeness of record, the availability of flow measured at each gauging station and the long-term trends across the history of the gauge to identify flow availability changes over time.

The table also provides a comparison with longer-term statistics where the column titled 'Long-term Median' presents the median for the dataset available since records commenced for each respective gauge. The column titled '2010-2013 Median' presents the median for the data record from the current audit period.

The 'Audit Median / Long term Median' column presents the ratio of the medians for the two longer-term datasets. Flow exceedance curves were prepared (Volume 2 Appendix G). Further details are provided in the sub-catchment specific sections (Volume 3 Appendix I).

Table 4-1 Summary of results from SCA's gauging stations

Station Number	Site name	Date records commenced	Long-term Median (ML/day)	2010-2013 Median (ML/day)	Audit Median / Long-term Median (ML/day)
Boro Creek Sub-catchment					
215239	Boro Creek at Marlowe	24/02/1994	3.65	2.11	0.58
Braidwood Creek Sub-catchment					
215241	Shoalhaven River at Bendoura	29/08/1994	11.89	18.89	1.59
215209	Shoalhaven River at Mountview	8/11/1973	153.20	204.54	1.34
215237	Gillamatong Creek	13/03/1994	3.11	11.74	3.78
Bungonia Creek Sub-catchment					
215014	Bungonia Creek at Bungonia	15/04/1981	0.90	0.78	0.87
215207	Shoalhaven River at Fossickers Flat	15/07/1977	364.22	495.88	1.36
Grose River Sub-catchment					
212291	Grose River at Burralow	1/11/1987	103.77	191.02	1.84
Jerrabattgulla Sub-catchment					
215008	Shoalhaven River at Kadona	18/09/1950	46.43	101.71	2.19

Table 4-1 (cont.) Summary of results from SCA's gauging stations

Station Number	Site name	Date records commenced	Long-term Median (ML/day)	2010-2013 Median (ML/day)	Audit Median / Long-term Median (ML/day)
Kangaroo River Sub-catchment					
215215	Shoalhaven River at D/S Tallowa Dam	20/07/1991	358.95	639.84	1.78
215220	Kangaroo River at Hampden Bridge	7/11/1973	167.75	201.55	1.20
215233	Yarrunga Creek at Wildes Meadow	15/11/1973	6.65	9.47	1.42
215234	Yarrunga Creek at Fitzroy Falls	2/03/1983	13.00	17.76	1.37
Kowmung River Sub-catchment					
212260	Kowmung River at Cedar Ford	1/05/1968	134.88	242.84	1.80
Lake Burragorang Sub-catchment					
2122996	Tonalli River at Fire Road W2 (Site #2)	1/07/2003	4.21	2.24	0.53
Little River Sub-catchment					
2122809	Little River at Fire Road W4I	21/08/1990	5.52	5.72	1.04
Lower Coxs River Sub-catchment					
212016	Kedumba River at Maxwells Crossing	3/06/1990	20.00	26.63	1.33
Mid Coxs River Sub-catchment					
212011	Coxs River at Lithgow	28/05/1960	32.14	17.87	0.56
212013	Megalong Creek at Narrow Neck	21/11/1968	5.50	10.11	1.84
212045	Coxs River at Island Hill	2/01/1981	49.85	93.49	1.88
212250	Coxs River at Kelpie Point	2/11/1966	169.30	220.91	1.30
2122512	Coxs River at Glenroy Bridge	1/05/1999	11.81	33.19	2.81
Mid Shoalhaven River Sub-catchment					
215004	Corang River at Hockeys	8/09/1924	25.79	35.46	1.37
215208	Shoalhaven River at Hillview	7/11/1973	301.90	340.72	1.13
215242	Corang River at Meangora	3/12/1994	21.03	34.51	1.64
Mongarlowe River Sub-catchment					
215007	Mongarlowe River at Monga	2/01/1950	16.08	34.43	2.14
215210	Mongarlowe River at Mongarlowe	8/11/1993	50.67	52.49	1.04
Mulwaree River Sub-catchment					
2122725	Mulwaree River at The Towers	7/06/1990	0.00	7.22	N/A
Nattai River Sub-catchment					
212280	Nattai River at The Causeway	7/07/1965	18.58	20.86	1.12
2122801	Nattai River at The Crags	12/07/1990	5.43	7.79	1.43
Nerrimunga River Sub-catchment					
215240	Nerrimunga Creek at Minshull Trig	3/12/1994	0.08	0.27	3.58
Reedy Creek Sub-catchment					
215002	Shoalhaven River at Warri	2/09/1914	172.54	216.75	1.26
215238	Reedy Creek at Manar	18/02/1995	5.03	17.66	3.51

Table 4-1 (cont.) Summary of results from SCA's gauging stations

Station Number	Site name	Date records commenced	Long-term Median (ML/day)	2010-2013 Median (ML/day)	Audit Median / Long-term Median (ML/day)
Upper Coxs River Sub-catchment					
212008	Coxs River at Bathurst Rd	9/02/1951	13.86	23.93	1.73
212042	Farmers Creek at Mt Walker	25/09/1980	15.95	19.15	1.20
212055	Neubecks Creek at u/s Walwang	7/12/1991	0.59	1.60	2.70
212058	Coxs River at u/s Lake Lyell	15/12/2000	20.56	34.62	1.68
212054	Coxs River at Wallerawang	18/01/1992	12.53	15.67	1.25
Upper Nepean River Sub-catchment					
212203	Nepean River at Pheasant's Nest	17/11/1983	1.74	395.05	226.82
212204	Nepean River at Avon Dam Road	24/07/1986	64.00	140.57	2.20
212209	Nepean River at McGuires Crossing	6/02/1970	37.12	53.77	1.45
212210	Avon River at Avon Weir	27/06/1969	1.87	11.34	6.05
212221	Cordeaux River at Cordeaux Weir	18/07/1990	13.82	35.91	2.60
212231	Cataract River at Jordans Crossing	9/11/1967	127.08	164.98	1.30
212233	Cataract River at Broughtons Pass Weir	16/03/1983	0.00	12.39	-
2122051	Nepean River at Nepean Dam Inflow	18/02/1990	30.63	56.84	1.86
2122052	Burke River at Nepean Dam Inflow	19/02/1990	11.18	17.24	1.54
2122111	Avon River at Summit Tank	29/03/1990	4.59	6.71	1.46
2122112	Flying Fox No3 Creek at Upper Avon	27/06/1990	0.53	0.71	1.35
2122201	Goondarrin Creek at Kemira D'Cast	3/08/1991	1.27	0.83	0.66
2122322	Loddon River at Bulli Appin Road	9/03/1990	5.56	8.13	1.46
2122341	Glenquarry Creek at Alcorns	6/04/2003	12.22	3.92	0.32
Upper Wollondilly River Sub-catchment					
212040	Kialla Creek at Pomeroy	10/06/1979	3.36	3.25	0.97
Werriberri Creek Sub-catchment					
212244	Werriberri Creek at Werombi	1/06/1988	2.87	3.12	1.09
Wingecarribee Sub-catchment					
212009	Wingecarribee River at Greenstead	26/10/1989	52.00	62.16	1.20
212031	Wingecarribee River at Bong Bong Weir	7/06/1989	23.15	23.65	1.02
212272	Wingecarribee River at Berrima	22/08/1975	30.64	38.29	1.25
212274	Caalang Creek at Maguire Crossing	27/11/1986	7.21	10.34	1.43
212275	Wingecarribee River at Sheepwash Bridge	9/10/1996	10.37	5.75	0.55
Wollondilly River Sub-catchment					
212270	Wollondilly River at Jooriland	15/12/1961	233.91	255.81	1.09
212271	Wollondilly River at Golden Valley	2/01/1974	38.79	61.71	1.59
2122711	Wollondilly River at Murray's Flat	17/08/1990	11.51	20.85	1.81
212060	Tarlo River at Willowbank	10/02/2011	13.61	13.60	1.00
Woronora River Sub-catchment					
213211	Woronora River at the Needles	12/05/1992	17.80	18.55	1.04
2132101	Woronora River Inflow	21/02/2007	2.74	4.03	1.47
2132102	Waratah Rivulet Inflow	21/02/2007	6.57	7.74	1.18

From Table 4-1, the gauging sites can be identified where the median flow during the audit period was less than 50% of the longer-term median flow. These locations are as follows:

- Glenquarry Creek at Alcorns.

From the data it is noted that the current audit (2010-2013) median flows for the majority of sites are above the long-term median. This is not the case with the following locations:

- Boro Creek at Marlowe;
- Bungonia Creek at Bungonia;
- Tonalli River at Fire Road W2 (Site #2);
- Coxs River at Lithgow;
- Goondarrin Creek at Kemira D'Cast;
- Glenquarry Creek at Alcorns;
- Kialla Creek at Pomeroy;
- Wingecarribee River at Sheepwash Bridge;
- Tarlow River at Willowbank.

Extraction licences and volumes findings

Based on water extraction licence data provided by NOW for the SCA catchment the total licenced extraction in the Catchment (as at the time of audit) is 33,576 ML/year. This is divided across 538 licences.

Table 4-2 provides a summary of the extraction licences in the Catchment. Within the current audit period the majority of licences were converted from the previous Water Act 1912 (WA) to the Water Management Act 2000 (WMA). This was undertaken in 2011.

Table 4-2 Summary of water entitlements from licensed water extractions in the Catchment (at time of audit – August/September 2013)

Catchment	Number of Licences	Total Entitlement (ML/Year)
Hawkesbury-Nepean (including Woronora)	323	23,086
Shoalhaven	215	10,490
Total	**538**	**33,576**

The largest entitlements are in the Upper Wollondilly River (6080 ML/year), Kangaroo River (6004 ML/year) and Wollondilly River (4662 ML/year) sub-catchments. This is consistent with the findings of the previous audit where the same sub-catchments held the largest total entitlements.

The lowest entitlements occur in the Upper Shoalhaven River (8 ML/year), Woronora River (17 ML/year) and Mid Shoalhaven River (66 ML/year) sub-catchments. There are no licensed water entitlements in the Boro Creek, Endrick River and Grose River sub-catchments.

If the total entitlements are divided by the total area of each respective sub-catchment then the largest entitlement by area occurs in the Upper Wollondilly River sub-catchment (8.21 ML/annum.km^2). The next highest allocations by area are in the Kangaroo River (6.93 ML/annum.km^2) and the Werriberri Creek (6.86 ML/annum.km^2) sub-catchments.

The lowest allocations by area are found in the Upper Shoalhaven River, Kowmung River and Lake Burragorang Creek sub-catchments.

As with the previous audit, these numbers do not allow for varying rainfall across the Catchment (which will affect the amount of water that can be sustainably harvested in these catchments) or for allocations for major water utilities.

The summary of the licences, total entitlements and entitlement/area for each sub-catchment is given in Table 4-3; the majority of these licences were for irrigation purposes.

Implications

The current audit period generally saw an increase in the daily flows passed through each flow monitor compared to previous audit periods and the long-term data captured. There were some exceptions with nine locations showing flows less than the long term median, and one recording more than 50% less. This would suggest that there was possibly a stress on the flows within the watercourse or lower rainfall in contributing catchments. In the case of Alcorns and Sheepwash Bridge, decrease in flows also resulted from reduced transfers from Tallowa Dam.

The general increase in daily flows was also consistent with the general increase seen in the environmental flows released from the nominated SCA storages and reduction in Raw water Transfers. Further information on these flows can be found in Section 4.2.

The audit highlighted that due to the changes imposed by the Water Act and Water Management Act between 2010 and 2013, it was not appropriate to compare this audit period with the previous audit (that is, in terms of number of licenses and allocation volumes). Therefore, the information provided in this audit was based on the assessment of the current position as at the time of audit.

Table 4-3 Total licences entitlement by sub-catchment

Sub-catchment	Area (km^2)	Number of Licences	Total Entitlement (ML/year)	Entitlement/Area (ML/annum/km^2)
Upper Wollondilly River	740.77	34	6080	8.21
Kangaroo River	865.77	128	6004	6.93
Werriberri Creek	165.08	39	1133	6.86
Wingecarribee River	762.70	71	3900	5.11
Mulwaree River	788.11	26	2348	2.98
Bungonia Creek	802.92	25	1983	2.47
Upper Nepean River	894.14	22	1682	1.88
Wollondilly River	2701.23	73	4662	1.73
Mid Coxs River	1069.76	21	1813	1.69
Braidwood	373.41	12	607	1.63
Back & Round Mountain Creeks	344.95	6	481	1.39
Upper Coxs River	382.41	12	512	1.34
Little River	184.24	2	240	1.30
Jerrabattagulla Creek	358.46	8	335	0.93
Mongarlowe River	429.46	11	388	0.90
Nattai River	446.29	13	392	0.88
Nerrimunga River	483.53	11	409	0.85
Lower Coxs River	246.27	3	110	0.45
Reedy Creek	574.86	8	209	0.36
Woronora River	74.38	1	17	0.23

Table 4-3 (cont.) Total licences entitlement by sub-catchment

Sub-catchment	Area (km^2)	Number of Licences	Total Entitlement (ML/year)	Entitlement/Area (ML/annum/km^2)
Mid Shoalhaven River	498.54	3	66	0.13
Lake Burragorang	804.49	3	105	0.13
Kowmung River	769.76	3	92	0.12
Upper Shoalhaven River	217.16	3	8	0.04
Boro Creek	352.11	0	0	0.00
Endrick River	339.45	0	0	0.00
Grose River	21.29	0	0	0.00

4.1.6 Recommendations

From consideration of the data collection and collation process, the data provided and the process to audit the surface water flows, it is recommended that flow data for the audit be collected and collated in one consolidated dataset prior to the commissioning of the audit.

The SCA should consider changing gauge recording protocols or provision of metadata and quality coding to include a data flag that differentiates between 'flow rate below the gauge's capacity to measure' vs. 'zero flow' vs. 'data not recorded for some other reason'. This would allow improved accuracy of long-term benchmarking, comparison and consideration of water balance throughout the system and reporting on the surface water flows through each watercourse.

It would be beneficial for the SCA to audit all gauge stations to correct basic metadata errors prior to the next audit period (for example, some inconsistences were noted during the current audit in the spelling of or factual errors in gauge names).

Consideration should be given to the measures and audit of surface water availability to be extended to storage levels in the dam and change over time of those storage levels.

The audit should include direct correlation between meteorological conditions relevant to the SCA catchment. This would be focussed on identification of rain gauges relevant to the nominated monitoring stations and provision of data for those gauges by the SCA.

As the area capturing rainfall contributing to each monitor can be of a significant size a consistent methodology to select the appropriate rain gauges for data review would have to be agreed with the SCA and the Bureau of Meteorology (BoM) prior to commencement (for example, one gauge representative of the sub-catchment or several gauges across the sub-catchment). This additional rain gauge data, dam storage levels and catchment rainfall volumes could be added to the integrated spatial database (see **Recommendation 1**).

The conversion of the licences from the Water Act 1912 to the Water Management Act 2000 halfway through this audit period provided mixed measures against which to assess the licences and associated volumes.

4.2 Environmental Flows

4.2.1 Summary

Healthy rivers and catchments are important for ecosystems, communities and economies that rely on them. Dams and weirs can affect the natural low flow of water in rivers and water quality and can also restrict the migration of fish through the river as well as their habitat.

Under the Water Management Licences and Approvals package held by the SCA, environmental flow releases are made from storage to particular watercourses across the catchment. These environmental flows are expected to mimic natural flow variability, downstream of the reservoirs, with the aim of supporting the maintenance of ecosystem functions. These flows are also protected from extraction by rules and extraction limits. The audit of environmental flows was based on:

- The total volume of water by type released from SCA storages; and
- Number of dams, weirs and other barriers to flow in the catchment, including the number remediated.

The SCA provided data for the assessment of the environmental flows passed through each of the assessed storage structures. This assessment of data was based on 11 storage facilities within the SCA Catchment. This data identified the total inflows and outflows of the storage including those environmental flows released. The audit of the data was based on those flows specifically identified as the environmental flows in the SCA dataset. As part of the audit, environmental flow data was assessed for completeness and to identify the trends across time for each of the storages identified.

In order to identify the long-term environmental flow trends the current audit period data was assessed against data provided for the previous audit periods. The comparison of the various audit periods allowed the identification of trends of the environmental flows released from the storages. Noting that there has been a change in environmental flows policy from 95th percentile fixed flows to variable 80/20 environmental flow releases.

Raw water transfers that are made by the SCA through natural watercourses and pipelines were examined as high flow volumes and fast flows could have significant impacts such as flooding and streambank erosion. Six main raw water transfers made by the SCA were assessed. In some instances, there were a number of different mechanisms within the transfer to convey the flows (pumped and/or gravity transfers) between the same storages.

The raw water transfers were also considered for the long-term trends. The SCA provided data for previous audit periods and this was used to assess the current audit period raw water transfers against. The comparison of the various audit periods showed that in general, a reduction over time in the volume of raw water transfers. It is noted that the raw water transfers are often used to balance water availability across the SCA catchment and between the various water supply structures. Therefore, the reduction in raw water transfers, or the need to transfer, is consistent with an increase in the environmental flows released from the various storage facilities. The reduction in raw water transfers were consistent with an increase in the environmental flows released from the various storage facilities.

The assessment of data for this indicator indicated improvement could be made with regard to the collection and management of all environmental flow data collected during the current and preceding audit periods, as well as the long term datasets. Future audits would benefit from data and information that demonstrates the links between specific activities in the Catchment that had been undertaken to maintain or alter the environmental flow regimes within each sub-catchment. The SCA, NOW and DPI collect and provide Metadata with the environmental flow data that explains how the environmental flow targets are calculated for each structure.

Assessment Criteria

Criteria

1. Identify the total volumes of environmental flow released from each of the 11 storage facilities for the audit period, and any long-term trends for each storage facility, by considering the environmental flows released during the current audit period against previous audit periods.
2. Identify the total volumes of bulk water transferred through each connection for the audit period, and any long term trends for the transfers, by considering the bulk water volumes for the audit period against previous audit periods.
3. Identify the number of dams, weirs and other barriers to flow in the Catchment including any remediation undertaken in the audit period.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil
3	Meets Expectation	Nil

Prior recommendations

No prior recommendations.

4.2.2 Background

An environmental flow can be defined as water released from a dam or weir for the health of the river downstream. Water quality is dealt with elsewhere in this audit. Under its Water Management Licences and Approvals package, the SCA is required to release environmental flows from its storages to the Hawkesbury-Nepean, Shoalhaven, and Woronora Rivers (NOW 2011a, b).

In addition to the main dams and weirs at the downstream ends of the catchment, there are also other barriers to flow within the catchment. In past audits in-stream barriers have been considered as part of the discussion of the Fish indicator. However, the impact of in-stream barriers relates more to the issues surrounding environmental flows. Two measurements therefore inform this indicator:

- Total volume of water by type released from SCA storages; and
- Number of dams, weirs and other barriers to flow in the catchment, including the number remediated.

Data for the measures above was supplied by the SCA. The data was analysed as individual inflows, outflows including environmental flows and raw water transfers. The first data set supplied covered the period of this audit from 1 July 2010 to 30 June 2013, a subsequent dataset was supplied that covered previous audit periods (July 2004 – June 2007 and July 2007 – June 2010) for analysis of the long term flow trends.

The environmental releases from the identified storage structures were made daily to mimic the natural inflow in the upper catchment. These releases provide water for the environment on the basis of environmental flow rules specified in the SCA's Water Management Licences and Approvals package, issued by NOW (NOW 2012a)

4.2.3 Management and Surveillance

The SCA has telemetry sites to measure flows in the upper catchments and these were used to estimate daily inflows to the dams and water supply weirs. The data from these telemetry sites was used to calculate daily environmental releases in accordance with the environmental flow rules in the SCA's Water Management Licences and Approvals Package.

The monitoring of these flows was also managed through the diversion weirs at Pheasants Nest (downstream of Cordeaux, Avon and Nepean Dams) and Broughtons Pass (downstream of Cataract dam). The flows were measured approximately 24 hours after being released from the dams.

The SCA has established environmental monitoring programmes, based on the stated objectives of environmental flows in the Woronora, Shoalhaven and Nepean Rivers, and involve measuring a range of environmental parameters downstream of the dams and at comparable reference sites. This work includes assessing changes to river environments as a result of environmental flows. Fish were also monitored to assess the benefits of the new fishways. Regular sampling and evaluation will provide an understanding of the effects of the new flows on river environments and determine whether any fine tuning is required.

4.2.4 Methodology

Under the Water Management Licences and Approvals package, held by the SCA, environmental flow releases were made from storages to particular watercourses across the catchment. Environmental flows are expected to mimic natural flow variability, downstream of the reservoirs, with the aim of supporting the maintenance of ecosystem functions. These flows are also protected from extraction by rules and extraction limits.

The audit of environmental flows indicator was based on the following measures:

- Total volume of water by type released from SCA storages;
- Number of dams, weirs and other barriers to flow in the catchment, including the number remediated; and
- The SCA provided data for the assessment of the environmental flows passed through 11 storage facilities within the SCA Catchment. This data identified the total inflows and outflows of the storage including those environmental flows released.

The environmental flow data were assessed for completeness and trends in flow through time for each of the storages identified. The identification of trends of the environmental flows released from the storages was identified through comparison of the current audit period against previous audit periods. In general an increase in environmental flows released was seen.

Raw water transfers made by the SCA through natural watercourses were also examined. Six main raw water transfers were identified and assessed from data provided by the SCA. These were also assessed for long-term trends.

4.2.5 Findings

SCA activities 2010 – 2013

The following activities relating specifically to environmental flows within the Catchment have been undertaken by the SCA during the current audit period:

- New variable environmental flow releases for the Upper Nepean River commenced in July 2010;
- To enable environmental flows to pass the weirs in the Nepean River, work on the weirs under the Upper Nepean Environmental Flow Works was completed in 2010-11 with new valves fitted to eight weirs on the river;
- To maintain continuous fish passage along 90 kilometres of the Nepean River 10 fishways were completed in 2010-11;
- Environmental monitoring and evaluation programs were implemented in 2013 in the Woronora, Shoalhaven and Nepean Rivers. These programs involved measuring a range of environmental parameters downstream of the dams and at comparable reference sites to assess changes in the river environments as a result of environmental flows; and
- A current NSW Government investigation project is under way to determine whether environmental releases are required from Warragamba Dam. The results from this investigation are to be incorporated in the next Metropolitan Water Plan.

Environmental flow findings

Dams and weirs affect the natural flow of water downstream of these structures. The SCA releases water from their storages to downstream rivers through environmental flows to help restore the ecological process and biodiversity of water dependant ecosystems.

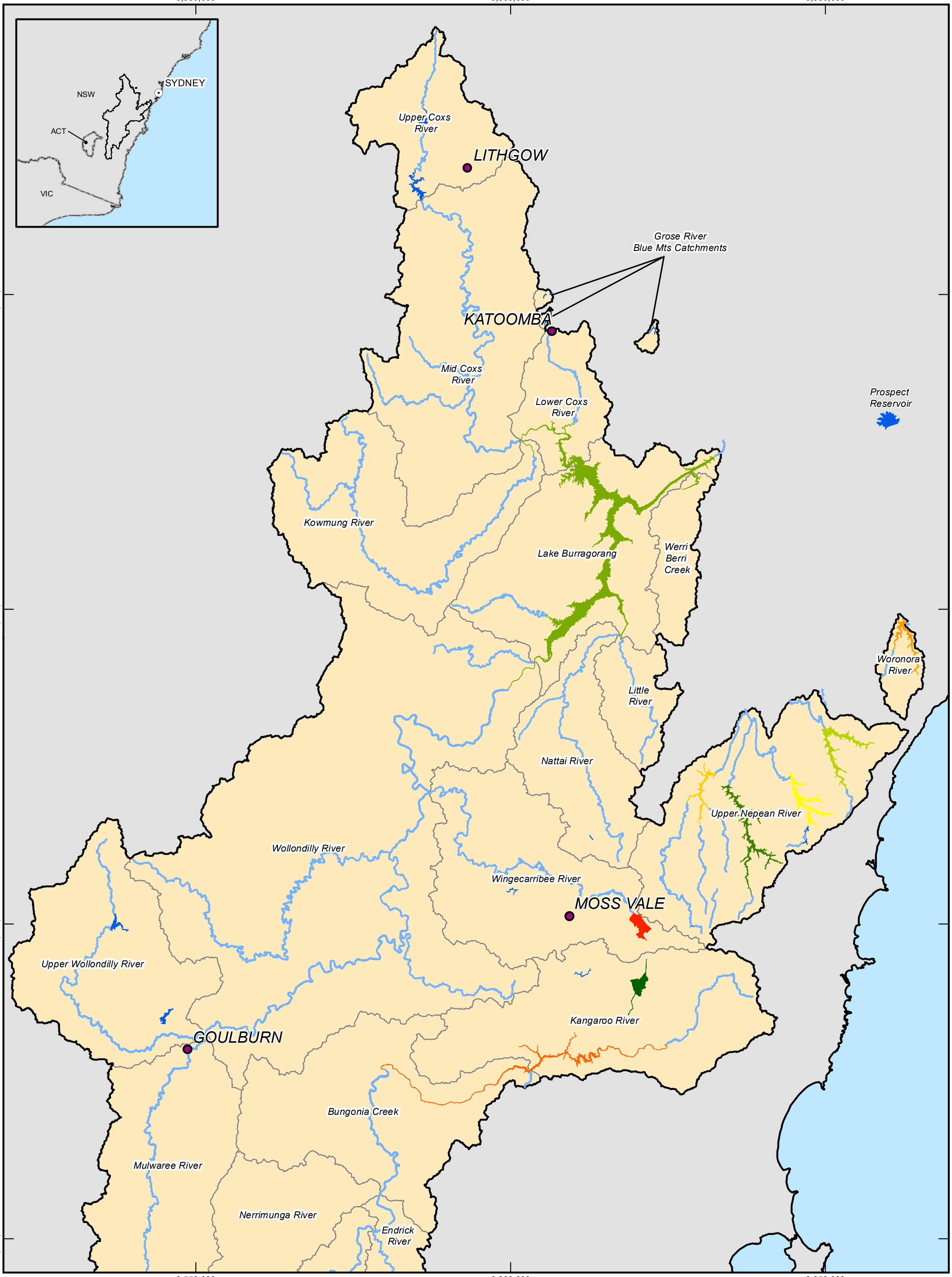
Data were provided by the SCA for the purposes of this Audit for 11 dams (Table 4-4). The data included the daily inflow and environmental flows to and from each structure. Figure 4-1 identifies the location of the storages within the Catchment and respective sub-catchments.

Table 4-4 Dams and weirs for which environmental flow data was assessed

Dam/Weir	Sub-catchment	River System
Warragamba Dam	Lake Burragorang	Warragamba System
Wingecarribee Dam	Wingecarribee River	Shoalhaven System
Tallowa Dam	Kangaroo River	Shoalhaven System
Fitzroy Falls	Kangaroo River	Shoalhaven System
Cataract Dam	Upper Nepean	Upper Nepean System
Cordeaux Dam	Upper Nepean	Upper Nepean System
Avon Dam	Upper Nepean	Upper Nepean System
Nepean Dam	Upper Nepean	Upper Nepean System
Broughton Pass Weir	Upper Nepean	Upper Nepean System
Pheasants Nest Weir	Upper Nepean	Upper Nepean System
Woronora Dam	Woronora River	Woronora System

The current environmental flow regimes are described below, based on the SCA's description of the environmental flows[1] program for each river system, and as identified by this Audit.

[1] www.sca.nsw.gov.au/dams-and-water/environmental-flows



LEGEND

Town	SCA catchment boundary	**SCA Water Storages**	Lake Avon
Drainage	Sub-catchment boundary	Other SCA Storages	Lake Burragorang
	State boundary	**Environmental Flow Storages**	Lake Cataract
		Fitzroy Falls Reservoir	Lake Cordeaux
			Lake Nepean
			Lake Woronora
			Lake Yarrunga (Tallowa Dam)
			Wingecarribee Reservoir

Paper Size A4

0 6 12 18

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

N

Sydney Catchment Authority
Catchment Audit 2013

Job Number | 2314960
Revision | 0
Date | 26 Nov 2013

SCA's Water Storages and Environmental Flows Storages

Figure 4.1

G:\23\14960\GIS\Maps\Deliverables\23_14960_509_EnviroFlows_Rev0.mxd

Level 6, 20 Smith Street Parramatta NSW 2150 Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** ptamail@ghd.com **W** www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries, water storages (2013). Created by: KP

Warragamba system

The Warragamba System is based around the Warragamba Dam located about 65 km west of Sydney in a narrow gorge on the Warragamba River. Water is collected from the catchments of the Wollondilly and Coxs River systems covering an area of 9,050 km^2 to form Lake Burragorang and Warragamba Dam. It provides about 80 per cent of the water supply for nearly four million people in the Sydney region.

The SCA releases five mega litres (ML) of water each day from Warragamba Dam to dilute discharge from the Wallacia sewage treatment plant into the Warragamba River (average 0.6 ML/day). Another 17 ML of water is released each day in winter, increasing to 25 ML in summer, for Sydney Water to extract at its North Richmond Water Filtration Plant. These releases are specified in the Water Sharing Plan (WSP) for the Greater Metropolitan Region Unregulated River Water Sources 2011.

The audit identified consistency with the SCA's description of environmental flows from July 2011. Prior to this, the daily environmental flows were 43 - 45 ML/day.

In the 2010 Metropolitan Water Plan, investigations into a new environmental flow release regime from Warragamba Dam were announced. The Department of Finance and Services is currently coordinating these investigations with substantial contributions from the SCA. A decision on environmental flows from Warragamba Dam is to be included in the next Metropolitan Water Plan.

The NOW provides comment in the document entitled *Sydney Catchment Authority Water Licences and Approvals Package, May 2012* (NOW 2012a), that identifies that the SCA is deemed to have met its requirements for passing releases through the weirs downstream of the Upper Nepean Dams if it can be demonstrated that the required releases volume is passed at Wallacia Weir. No data was obtained for this audit on flows through the eight weirs downstream of the dam, including Wallacia Weir, identified in the Licences and Approvals Package.

Shoalhaven system

The Shoalhaven Scheme is a dual-purpose water supply and hydro-electric power generation scheme. Water from Tallowa Dam, Fitzroy Falls and Wingecarribee reservoirs, is used to supply local communities and supplement other SCA storages during drought. Power generation involves regular exchange of stored waters between Lake Yarrunga, Bendeela Pondage and Fitzroy Falls Reservoir by Eraring Energy.

Water pumped from the Shoalhaven Scheme is mostly collected from the Tallowa Dam catchment area. Wingecarribee and Fitzroy Falls reservoirs have relatively small catchment areas totaling only 70 km^2. During a drought, water from the Shoalhaven can be fed into Warragamba and the Upper Nepean Dams to top-up the Sydney and Illawarra water supplies.

From Wingecarribee Reservoir water can be released into the Wingecarribee River, Wollondilly River and Lake Burragorang to feed the main Sydney supply system via Warragamba Dam. Water can also be released from Wingecarribee Reservoir via canals and pipelines, collectively known as Glenquarry Cut, into the Nepean River which flows into Nepean Dam. From there it can be transferred to Sydney via the Upper Canal or to the Illawarra region via the Nepean-Avon tunnel to Avon Dam.

As well as supplementing water supply during drought, the Shoalhaven Scheme also supplies water to local communities. Water from Fitzroy Falls Reservoir supplies Fitzroy Falls village and the National Parks and Wildlife Service Visitor Centre in Morton National Park.

Wingecarribee Reservoir supplies Bowral and Mittagong via Wingecarribee Shire Council's water filtration plant located next to the Reservoir. Kangaroo Valley Township is supplied by treated water from Shoalhaven City Council's treatment plant, which draws water from Bendeela Pondage.

Water is also released from Tallowa Dam into the Shoalhaven River to enable the Shoalhaven City Council to extract water from the river to supply Nowra.

The SCA releases water from Tallowa Dam and Wingecarribee and Fitzroy Falls Reservoirs to help improve the environmental health of the rivers downstream and sustain riparian rights. The current audit showed that environmental flows were discharged from the Tallowa Dam at an average of 388 ML/day, the Wingecarribee Dam at an average of 4 ML/day and Fitzroy Falls at an average of 18 ML/day.

At Tallowa Dam, daily variable flows under an 80/20 flow for environmental purposes began on 15 July 2009. Environmental flows and improved movement of fish up and down the river were made possible by the installation of a new high-level outlets at Tallowa Dam, a new spillway gate at the top of the dam that provides environmental flows at a similar temperature to the downstream river, and a mechanical fish lift to allow native fish to move upstream and downstream passage over the dam. The change in environmental flow regimes can be seen in Figure 4-2.

At times of low flows, all inflows to Tallowa Dam up to 371 ML/day (depending on the season) are released to the downstream river. At times of higher flows, an additional 20 percent of inflows to Tallowa Dam are released to the downstream river. SCA is also required to release town water requirements according to the Raw water Supply Protocol between SCA and Shoalhaven City Council.

At Fitzroy Falls Reservoir, environmental release levels are linked to inflow rates measured at Wildes Meadow Creek. Approximately 1.7 times the monthly inflows, as gauged at Wildes Meadow Creek, are to be released.

Upper Nepean system

The dams of the Upper Nepean collect water from the catchments of the Cataract, Cordeaux, Avon and Nepean rivers, which are tributaries of the Hawkesbury-Nepean River. These systems supply water to the Macarthur and Illawarra regions, the Wollondilly Shire, and metropolitan Sydney.

The SCA introduced daily variable flows from the Upper Nepean dams and water supply weirs for environmental purposes from 1 July 2010. Improvements to weirs along the Hawkesbury-Nepean River help the new flows make it downstream, with modified or replaced fishways to allow fish to move more freely up and down the river to breed.

At times of low flow, inflows to the Upper Nepean dams and water supply weirs are released to the downstream river. Daily variable inflows of up to 20.1 ML are released from Nepean Dam, 6.8 ML from Avon Dam, 4.5 ML from Cordeaux Dam and 14.5 ML from Cataract Dam. These releases are passed through Pheasants Nest and Broughtons Pass weirs to the downstream river. Inflows from the catchments between the dams and weirs are also released from the weirs, including up to 4.4 ML from Pheasants Nest Weir and up to 4.5 ML from Broughtons Pass Weir. At times of higher flow, an additional 20% of inflows to each dam and water supply weir are released to the downstream rivers.

The audit of the data for the environmental releases in the Upper Nepean system identified that the environmental flows released from the respective Reservoirs were well in excess of these upper limits, this may have been the result of unconstrained flows in response to rainfall. Evidence of this can be seen in Volume 3 (Appendix I).

Woronora system

Woronora Dam collects water from the catchment of the Woronora River, which drains into the dam and then into the Georges River and to Botany Bay. The dam supplies water to residents in the Sutherland Shire in Sydney's south.

The SCA introduced daily variable flows from Woronora Dam for environmental purposes from 15 July 2009. At times of low flows, all inflows up to 4.1 ML a day are released to the downstream river. At times of higher flow, an additional 20% of inflows to Woronora Dam are released to the downstream river.

The audit identified that the environmental flow data provided was consistent with the above releases over the audit period. Evidence of this can be seen in Volume 3 (Appendix I).

Blue Mountains system

The Blue Mountains System comprises three small catchment areas feeding six dams, which provide water for about 41,000 people living in the Blue Mountains region. The SCA also sources water for the Blue Mountains from the Fish River Scheme, which originates in Oberon. Aside from overflows during periods of high rainfall, there are no current environmental releases required from these dams.

Environmental Releases from SCA Storages

The current audit identified that over 1,300,000 ML of water was released from SCA dams and storages for environmental purposes for the audit period (2010 – 2013). This is illustrated in Figure 4-2 which gives an indication of the long term trends in environmental flows released from each of the storages by comparing total flows released for previous audit periods with the current period.

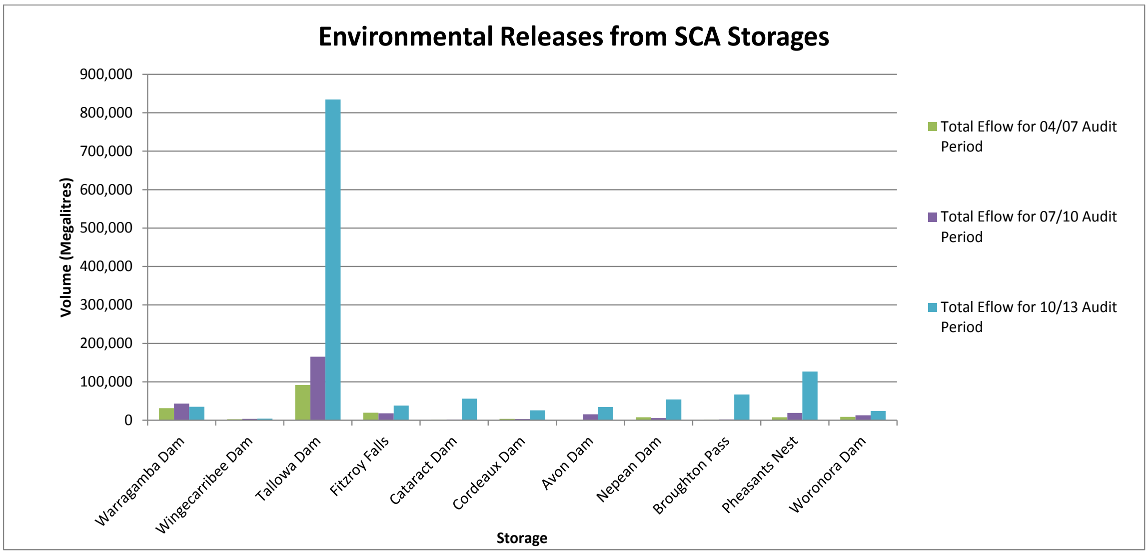


Figure 4-2 Environmental flow releases from the SCA storages for this audit period

As can be seen from Figure 4-2 with the exception of Warragamba Dam, the total volume of environmental flows released has increased between the previous audit periods, for which data was provided by SCA, and the current audit. In the 2004 – 2007 Audit, just over 176,000 ML of total environmental flow was released and this increased for 2007 – 2010 to almost 300,000 ML total environmental flow. There was a significant increase in the total volume of environmental flows released in this audit period particularly from Tallowa Dam.

Raw water transfers

The Figure 4-3 provides a summary of the volume of raw water transfers between and within the SCA systems. This figure also shows the long term trend of the total volumes transferred in previous audit periods.

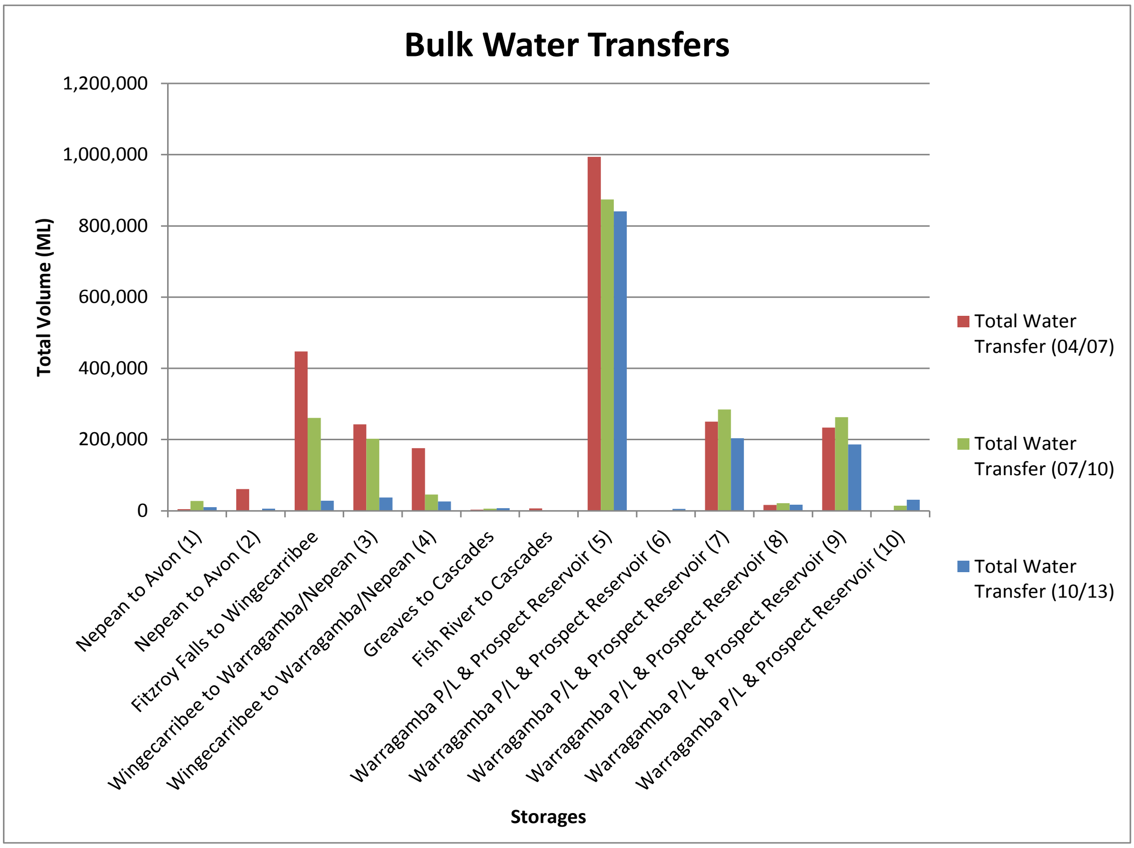


Figure 4-3 Raw water transfers for July 2010 to June 2013

NOTES:
1. Nepean Tunnel via pumping;
2: Nepean Tunnel via Gravity;
3: Wingecarribee River to Warragamba;
4: Glenquarry Cut to Nepean;
5: Warragamba Pipelines Cross Conn 3 to Supply;
6: Warragamba Pipelines Cross Conn 3 Diversion to Prospect Reservoir;
7: Upper Canal at HPR1;
8: Upper Canal Diversion to Prospect Res;
9: Upper Canal to Supply;
10: SCA Pumping from Prospect to Supply

From Figure 4-3 it can be seen that raw water transfers have generally decreased over the audit periods. During the current audit a total of just over 1,400,000 ML of raw water was transferred, this can be compared against over 2,400,000 ML in the 2004-2007 and 2,000,000 ML in the 2007 – 2010 audit periods. Further details on the long term trends of daily flow volume can be seen in Volume 3 (Appendix I) of this report.

Implications

The SCA released over 1,300,000 ML of water from its dams and storages for environmental purposes during the current audit period. The environmental benefit to the downstream ecosystems was measured in the SCA's environmental monitoring programs.

Data for these storages were provided by SCA and cover environmental flows within the following SCA sub-catchments:

- Lake Burragorang;
- Wingecarribee River;
- Kangaroo River;
- Upper Nepean; and
- Woronora River.

Data was not provided for other storages in sub-catchments within the SCA catchment and therefore could not be included in this audit.

The volume of environmental flows released has increased from past audits as has the variability of those flows with agreements now in place to provide variable release rates in some systems. The final environmental flows volume to be released from Warragamba Dam has yet to be agreed and a decision about this is scheduled to be made in 2015. The results will be incorporated in the next Metropolitan Water Plan. The final environmental flow regime for Warragamba will therefore need to be commented on in future audits, the next is due in 2016.

A total of 1,400,000 ML of water was transferred as raw water transfers around the SCA catchment. This is a decrease from previous audit periods.

To gain further appreciation of the environmental flow and raw water transfer volumes in future audits it would be prudent to extend the scope of the audit to consideration of climatic conditions. An increase in environmental flows and a decrease in raw water transfers could be directly related to the rainfall experienced within the SCA catchment.

4.2.6 Recommendations

Information was provided only on those structures that have gauges. From consideration of the data collection and collation process, the data provided and the process to audit the environmental flows, it is recommended that all environmental flow data for the current and preceding audit periods be provided at project initiation for identification of the long term trends.

The Auditor recommends that SCA, NOW and DPI provide Metadata with the environmental flow data that explains how the environmental flow targets are calculated for each structure when implementing **Recommendation 1**.

It would also be beneficial if Metadata is provided with the environmental flow data set that identifies where specific activities in the catchment have been undertaken that alter the environmental flow regimes within each sub-catchment.

For the purposes of assessing the effectiveness of passing of environmental flows downstream of Warragamba Dam, consideration should be given to reviewing the information for sites downstream of the Wallacia weir. As these locations are downstream of the Catchment this activity would require coordination from the NOW and could provide insight into the effectiveness of environmental flows strategies that are implemented within the Catchment.

4.3 Groundwater Availability

4.3.1 Summary

Extraction of groundwater for human uses, such as drinking water, agriculture, and industry can place significant stress on the environment. Groundwater extraction can modify catchment hydrology by reducing the water available for other beneficial uses such as environmental water requirements.

The 2010 Catchment Audit focused on comparing groundwater use with the key groundwater indicator: '*Extraction entitlement relative to the sustainable yield (long term average extraction limit) at a groundwater management area or water source scale...*' (NOW 2009). Based on this, the primary aim of the 2010 groundwater audit was to assess all new and existing water allocation licences against the estimated sustainable yields for each groundwater sub-catchment of the SCA catchment.

Sustainable volumetric groundwater criteria (available on a groundwater source basis) and available groundwater use data suggest that aquifers are being used sustainably within the catchment, in accordance with the WSP 2011. However, the validity of the volumetric accounting system is limited by:

- The absence of abstraction volumes from BLR bores, which are estimated;
- Groundwater data from mining developments (including quarries and CSG) is not included in the accounting system, which may account for a significant portion of the total volumetric usage.

The available groundwater elevation data across the catchment suggests that groundwater was being used sustainably in these areas and therefore, that the volumetric criteria established in the WSP 2011 were potentially suitable. It is noted that there was limited groundwater monitoring data across the catchment that can be used to assess impacts from groundwater drawdown. Identified bore sites do not appear to be strategically located to assess potential impacts from significant water users (i.e. mining, CSG, irrigation) and impacts to sensitive GDEs relative to the minimal impact criteria established in the AIP 2012.

Further investigations are required to supplement the information provided in this report to relate high usage points to groundwater users and groundwater dependent ecosystems (GDE) requirements, and to use this data to selectively expand the groundwater elevation monitoring network across the catchment. Alternatively, better data collation from identified major groundwater abstraction industries, with provision of the information to SCA (via NOW), is required to allow collation of water usage data. This may be facilitated by the enactment/regulation of the *AIP 2012*.

The change over to a new system under the WSP 2011 has resulted in different record keeping practices and management of licenses by NOW, which has prevented a reasonable comparison of the previous audit with the current audit. Further to this the separation of water access licenses from actual bore sites presents a problem for collating and interrogating water use data within a surface water catchment or groundwater source area. Better accounting of these aspects is required to improve continuity in audit results.

There was insufficient data available to assess groundwater quality changes within the catchment.

Assessment Criteria

Criteria 1. To identify new and existing water allocation licenses against the estimated sustainable yields for each groundwater sub-catchment. 2. To identify any potential threats to the adopted sustainable quality and yields during the audit period.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectations	
2	Opportunity for improvement	NOW should extend existing monitoring to include groundwater quality data as well as groundwater levels to establish a baseline for groundwater resources in the Catchment.

Prior recommendations

Prior Recommendations (2010 Audit)	Remedial action	Status
Recommendation 17: NOW and SCA to undertake research aimed at understanding the extent, connectivity and interaction between aquifers in the catchment.	The SCA completed research on groundwater – surface water interaction in the mining impacted catchments of Special Areas (report to be published by June 2014).	Closed

4.3.2 Background

Groundwater is a significant resource in most catchments, for both environmental and anthropogenic use. As well as being extracted for town supply, stock and domestic use, irrigation and industrial use, groundwater is a major contributor to surface water base flows, and for maintaining wetlands and other Groundwater Dependent Ecosystems (GDEs). Unsustainable extraction for human use can decrease the amount of groundwater available for maintaining surface aquatic ecosystems and can possibly lead to salinisation of the resource (NOW 2009).

The 2010 Audit recommended the implementation of metering of groundwater extractions and undertaking assessments of aquifer interactions as well as groundwater – surface water interactions (recommendation 2010/17). This action was undertaken; however the results will not be published until June 2014.

4.3.3 Methodology

The gazetted performance criterion for groundwater availability for this audit was *'extraction entitlement relative to the sustainable yield long term average extraction limit'* at a water source scale (NOW 2009).

The 2010 Catchment Audit focused on comparing groundwater use with the key groundwater indicator: '*Extraction entitlement relative to the sustainable yield (long term average extraction limit) at a groundwater management area or water source scale*...' (NOW 2009).

The primary aim of this analysis was to assess regional (Catchment) based increases in water use, and the total existing water use, against allocation limits and resource protection criteria, presented in the relevant Water Sharing Plan (WSP) and guidance.

These objectives for the assessment were based on the key groundwater indicator identified in the 2010 audit, and the long term average annual extraction limits (LTAAEL) stipulated in current WSPs. A second objective was to assess the validity of adopted LTAAELs in light of the wider beneficial uses of groundwater in the SCA catchment.

As part of this 2013 Audit, water supply works approvals, water use approvals and water access licences from catchment management stakeholders was requested, providing the opportunity for stakeholders to make any submissions on key groundwater related issues that have been identified over the audit period. The audit process included consultation with the SCA, NOW, EPA, DPI, and the CMAs. As part of the auditing process, the following information sources were reviewed:

- Relevant legislative frameworks, including the most up to date NSW groundwater policy and groundwater management documents. This review considered how groundwater as an indicator is reported in recent legislation and guideline documentation such as the updated groundwater sharing plans for the Sydney catchment area.
- All available groundwater supply works approvals, water use approvals, and water access licensing data.
- Available groundwater elevation monitoring data. Further to works completed in the previous report, targeted analyses of selected groundwater monitoring bores with available long term monitoring data was conducted to provide an initial assessment of whether the allocated catchment wide sustainable volumes presented in groundWSP are suitably preventing long term reduction in groundwater elevations.
- The GDE atlas was reviewed to relate GDEs, where possible, to water allocation areas and to assess potential risks to these systems.

4.3.4 Findings

Legislative review

A review of existing policies, legislation, and regulations pertaining to the Sydney catchment area was undertaken, with relevant information provided in this section.

Water Act 1912

In groundwater sources where WSP do not yet apply, an aquifer interference activity (that takes groundwater) is required to hold a groundwater licence under the *Water Act 1912*. Applications for a licence made under this Act are assessed on the same considerations as an application for a water access licence made under the *WMA 2000*. The groundwater sources within the Sydney catchment area lie within an existing Water Sharing Plan, and as such, pertain to the *WMA 2000* for water management requirements.

Water Management Act 2000

For any groundwater take activity, a water licence is required under the *WMA 2000*, with the exception of specific exemptions, or water taken under a basic landholder right. The volume of water taken from a water source as a result of an activity needs to be predicted, measured, and reported in annual returns or environmental management reports. Minimal impact considerations have been developed for impacts on groundwater sources, connected water sources, dependent ecosystems, culturally significant sites, and water users.

The *WMA 2000* works with the *EPA&A 1979* to deliver appropriate water management outcomes for significant projects.

Water Sharing Plans (WSPs) for the Sydney Catchment Area

WSPs address licensing of the take, and the use of groundwater. This is achieved by establishing rules for managing access and granting of licences and water supply work approvals. The intent of WSPs for groundwater is to manage the resource sustainably by managing groundwater quantity extractions and locations to minimise unacceptable impacts on aquifers or dependent ecosystems. These plans provide water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through the separation of land and water.

Access and licensing rules address potential interference to other users, groundwater contamination, GDEs, and culturally significant sites, protection of groundwater and surface water connectivity, and aquifer integrity. The WSPs use key terminology for sustainable water use within each groundwater source. This terminology was present in the previous audit report and is reiterated below:

- Long-term average annual extraction limits (LTAAEL): the recharge volume multiplied by a sustainability factor, which is determined through a risk assessment approach for each groundwater source. The licence holders' annual access to water is managed through LTAAELs;
- Groundwater Basic Landholder Rights (BLR): a volume of groundwater (in ML/yr) that is set aside for domestic and stock purposes;
- Total licensed groundwater entitlement (TLGE**)**: the groundwater entitlement that includes access licences (local water utilities, aquifer interference, stock and domestic access licences, and general purpose (industrial, irrigation, and recreation)). It does not include:
  - Unresolved water licence applications submitted during amnesty periods.
  - Licences that are yet to have a volume assigned to them through a volumetric conversion process.
  - Current aquifer interference activities that are yet to be assigned a volume.
- Unassigned water: The volume of water not currently allocated.

The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (NOW 2011a; b) encompasses 13 groundwater sources, nine of which lie within the catchment, as shown in Table 4-6 and listed below:

- Coxs River Fractured Rock;
- Goulburn Fractured Rock;
- Sydney Basin - Blue Mountains Sandstone;
- Sydney Basin Central;
- Sydney Basin - Coxs River Sandstone;
- Sydney Basin - Nepean Sandstone;
- Sydney Basin – North;
- Sydney Basin – Richmond Sandstone; and
- Sydney Basin – South.

Each of these groundwater sources has draft 'report cards' developed as part of the process for developing macro WSPs. Report cards contain information relating to the nature of groundwater in a source area, extraction implications, rules, regulations, and entitlements and were consulted throughout the audit process.

Once the WSP for the Greater Metropolitan Region Groundwater Sources was made a statutory document in July 2011 (i.e. during this audit period), the licensing provisions from the *Water Act 1912* were converted to *WMA 2000* 'water access licences' and 'water supply works and use' approvals. This change has the benefit of enhancing groundwater trading with the separation of water access licences from land. Bore purpose (or category) is irrelevant for trading purpose reasons under the *WMA 2000* and as such, this attribute is to some extent lost under the new management arrangement.

The WSP resulted in changed groundwater licensing management strategies throughout the State. Since July 2011, most existing licences under the *Water Act 1912* have been converted to the *WMA 2000* and in the process, received new licence approval numbers and new licence commencement dates. These legislated management changes presented an unusual setting for undertaking an audit of groundwater licensing/entitlements for the SCA. As a result of these changes, many aspects of data pertaining to groundwater availability and licensing could not be directly correlated with the previous audit period.

Licensed bore purpose data recorded under the *Water Act 1912* is purely historic and is provided only for continuity purposes under the current *WMA 2000* (pers. comms. Mr Greg Smith, Spatial Services – NOW). Under the *WMA 2000*, the bore 'purpose' attribute has been replaced with generic 'categories' for water extractions. These categories include the following:

- Local water utility –for town water purposes;
- Aquifer –for irrigation, industry, mining, recreation and general farming; and
- Aboriginal cultural and community development.

Under the *WMA 2000*, licences for basic landholder rights (BLR) such as stock and domestic purposes, do not require a licence to extract groundwater and as such, are excluded from the above bore purpose categories. The replacement of bore purpose attributes renders this aspect unfeasible in assessing against the previous audit period.

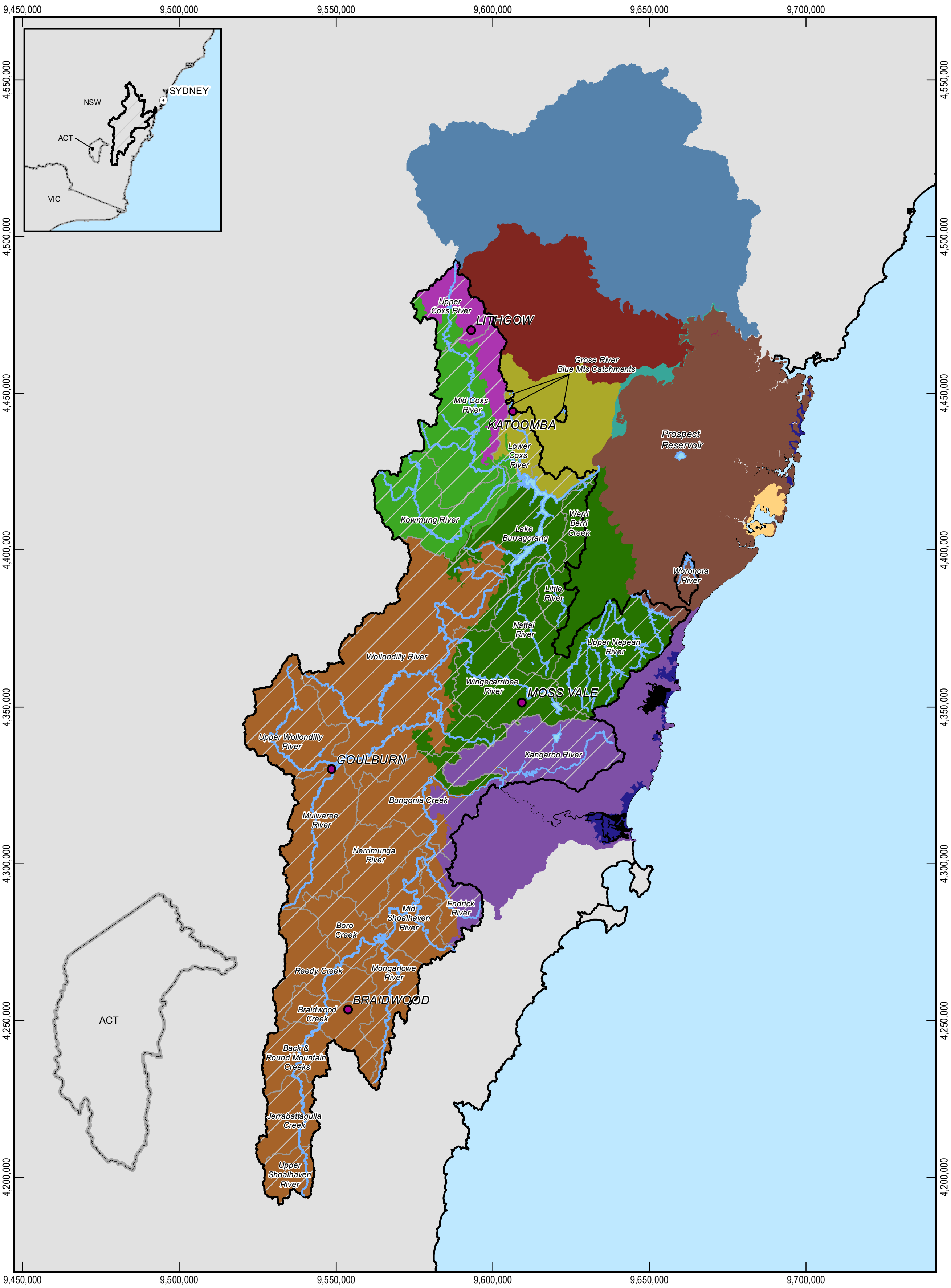
Some licences have not yet been converted from the *Water Act 1912* to the *WMA 2000*, and still retain historic attributes. In these cases, water take from these licences is still administered under the *Water Act 1912*.

NSW Aquifer Interference Policy (AIP) 2012

This policy was developed by NOW as a component of the NSW Government's Strategic Regional Land Use Policy. The policy took effect on 30 June 2011 and provides a framework under the *WMA 2000* for interference activities including water licensing and assessment processes.

Examples of aquifer interference activities include mining, coal seam gas (CSG) extraction, injection of water, and commercial, industrial, agricultural, and residential activities that intercept the water table or interfere with aquifers. The policy requires new mining and petroleum exploration activities to hold a water access licence if extraction from a groundwater source exceeds 3 ML per year.

The policy defines groundwater sources by 'highly productive' and 'less productive' categories, which are based on salinity levels, expected yield, and in the case of highly productive sources, hydrogeological setting. The policy also provides resource condition limits (including trigger levels and distance rules), based on groundwater levels, pressure and quality aspects for minimal impact considerations.



LEGEND

Town	Botany Sandbeds	Metropolitan Coastal Sands	SB - Richmond Sandstone
Drainage	Coxs River Fractured Rock	SB - Blue Mountains Sandstone	SB - South
Waterbody	Goulburn Fractured Rock	SB - Coxs River Sandstone	SB Central
SCA catchment boundary	Hawkesbury Alluvium	SB - Nepean Sandstone	Water
Sub-catchment boundary	Maroota Tertiary Sands	SB - North	

Note: SB - Sydney Basin

Page Size A4

0 10 20 30

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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SYDNEY CATCHMENT AUTHORITY

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Catchment Audit 2013

Job Number 2314960
Revision 0
Date 26 Nov 2013

Groundwater source boundaries

Figure 4.4

G:\23\14960\GIS\Maps\Deliverables\23_14960_500_GWboundaries_Rev0.mxd

Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013). Created by: KP

Mining policy

Government approval is required in NSW to develop a coal mine, including NSW development consent, a subsidence management plan (for longwall mines) and depending on the development, Commonwealth approval.

Recent amendments to the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* require significant coal mining and CSG development proposals to be referred to the Commonwealth if they are likely to significantly impact on water resources. If the proposal is likely to significantly impact water resources, Commonwealth approval is instigated through a 'controlled action'. The DP&I and the DTIRIS are responsible for assessing and approving mining and CSG activities. The final decision on specific activities usually lies with the Minister for Planning.

Water Supply Work Approvals

The Water Supply Work Approvals authorise a holder to construct and use a specified water supply work at a specified location, with limitations on trading to other properties or locations. These approvals are granted by NOW under the *WMA 2000* and can include works such as pumps, bores or spear points. Water supply works approval data was provided by NOW for use in this audit. This data was analysed to assess the number and types of entries, duplicate records, issuance dates, and correlation with previous audit findings.

Basic landholder rights approvals

Approval to construct a basic landholder rights (BLR) (i.e. domestic and stock) groundwater works is required to construct a bore, well, spear point or excavation to access groundwater for domestic and stock purpose under the basic landholder rights of the *WMA 2000*.

BLR groundwater work data was provided by NOW for use in this audit. This data was analysed to assess the number and types of entries, duplicate records, issuance dates, and correlation with previous audit findings.

Groundwater licensing

Groundwater licensing and availability (entitlement) for each groundwater source identified within the catchment is shown in Table 4-5. The WSP for the Greater Metropolitan Region Groundwater Sources identifies that the majority of these licences are for irrigation and industrial purposes.

Table 4-5 Groundwater use and licensing

Groundwater source	Groundwater Management Zones defined?	Embargoes in place?	Approximate number of existing licences (based on WSP)	Percentage of total licences in the catchment	WSP Entitlement / Unit Shares (ML/annum)
Coxs River Fractured Rock	No	No	6	1%	114
Goulburn Fractured Rock	No	No	71	11%	3,151
Sydney Basin - Blue Mountains Sandstone	No	Yes – for new commercial licences; and temporary water restrictions	13	2%	138

Table 4-5 (cont.) Groundwater use and licensing

Groundwater source	Groundwater Management Zones defined?	Embargoes in place?	Approximate number of existing licences (based on WSP)	Percentage of total licences in the catchment	WSP Entitlement / Unit Shares (ML/annum)
Sydney Basin - Coxs River Sandstone	No	No	12	2%	6,926
Sydney Basin - Nepean Sandstone	Yes; Management Zone 1 and Management Zone 2. These reflect the current embargoed and non–embargoed areas, to facilitate management of extraction.	Yes, partial; to prevent new commercial licences	285	44%	16,294
Sydney Basin – North	No	No	19	3%	557
Sydney Basin – Richmond Sandstone	No	No	50	8%	15,923
Sydney Basin – South	No	No	67	10%	2,880
Sydney Basin Central	No	No	120	19%	2,592
Total within SCA's catchment	-	-	643	-	48,575
Total within Water Sharing Plan area	-	-	786	-	62,348

Water access licences (WAL)

Water access licences (WALs) entitle licence holders to specified shares (the share component) of water available for take.

The categories identified from bore licensing data (within the WAL reports provided by NOW) for licence type do not correlate with the categories stipulated in the *WMA 2000* (i.e. local water utility, aquifer and Aboriginal purposes). A summary of the bore licensing data identified is presented in Figure 4-5 and shows that 86% of categories identified relate to unlicensed BLR bores (e.g. stock and domestic), with the remainder of licences bundled as 'water supply' purposes. The commencement date for these licences all relate to 1 July 2011, when the water management plan became a statutory document. As such, relating these licences with those issued prior to this date is not possible.

The *AIP 2012* requires access licensing for all groundwater uses. At present, it is unclear whether open cut mining operations require access licenses for dewatering activities, as this was not a requirement under the *WA 1912*.

Under the *WMP 2000* licence management arrangements, a WAL and its share components are linked to related groundwater sources and not to an approved work licence. This means that a WAL can no longer be queried against a distinct location (e.g. groundwater bore location). As a result, a comparison of groundwater bore licence quantities could not be assessed against sub catchments within the SCA catchment, as was undertaken for the 2010 audit. This information was obtained during this audit through advice from NOW.

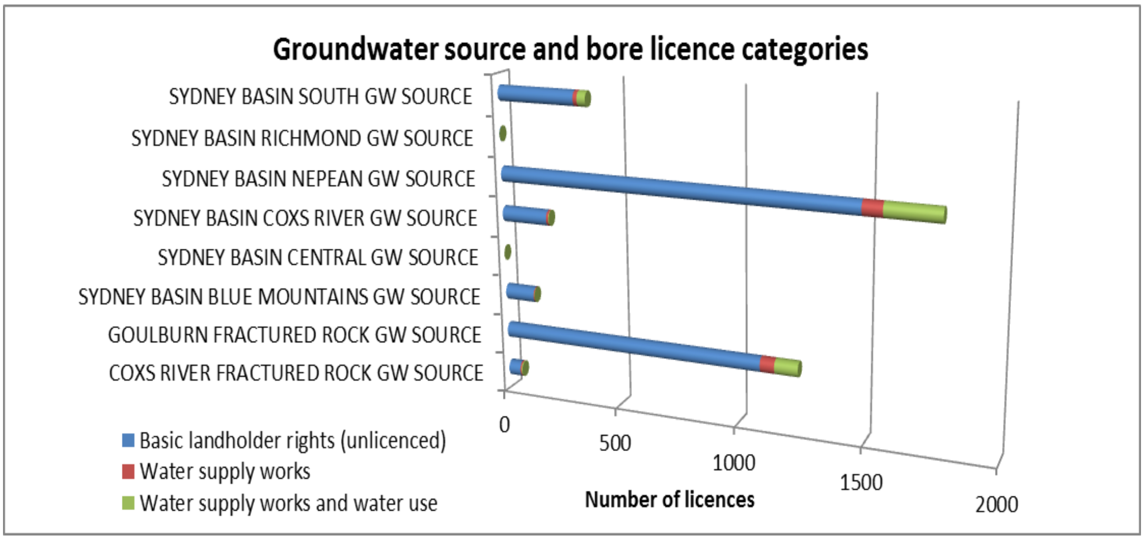


Figure 4-5Groundwater bore licence categories

Groundwater bore licences within the SCA catchment

Bore quantity and licensing statistics are provided in Table 4-6, which was based on 'CONVERTED' licence status bore data provided by NOW. Based on this groundwater licence data, a total of 3,369 bores were licensed within the SCA catchment (excluding duplicate records), with 66 bores licensed during the current audit period.

A total of 3,908 issued groundwater licences were identified within the SCA catchment (excluding duplicate records), with 122 licences issued during the current audit period. Comparatively, the 2010 audit identified 4,520 existing licences within the SCA catchment, 476 of which were issued in the 2010 audit period.

Table 4-6 Groundwater bore and licence quantities

	Historic bore record	Current audit period (July 2010 to June 2013)
Number of licensed bores in the catchment	3,413	66
Number of duplicate bore records (work_no) in the catchment	44	0
Total number of groundwater works (bores) in the catchment	**3,369**	**66**
Number of licences in the catchment	4,714	201
Number of duplicate licence records in the catchment	806	79
Total number of groundwater licences issued in the catchment	**3,908**	**122**

Based on a pre-converted licence status bore dataset, provided by NOW, a total of 3,756 bores were identified within the catchment (excluding 331 duplicate entries). Of these 90% had a 'CURRENT' status, indicating that they have been converted into the *WMA 2000*. Licensed purpose attributes indicated these bores were used for stock and domestic purposes, irrigation and for industrial purposes.

The remaining 10% of bores showed an 'ACTIVE' status, indicating that they were still managed under the *Water Act 1912*. Licensed purpose attributes indicated these bores are used for stock and domestic purposes, irrigation and for mining by Centennial Angus Place Pty. Ltd. and Springvale Coal Pty.Ltd.

Groundwater use

An appreciation of groundwater bore locations and bore purpose (use) was based on available data from the NSW PINNEENA groundwater works database (Table 4-6). As mentioned previously, legislative changes under the *WMA 2000* render bore 'purpose' information as indicative only.

Data analysed correlates with the previous audit period as well as with historic data (Table 4-6), with 85% of bores used for unlicensed stock and domestic purposes, followed by less than 8% for irrigation and 3% for industrial purposes. The majority of bores are located in the vicinity of major pastoral and agricultural townships such as Goulburn, Moss Vale, and Braidwood.

Figure 4-6 to Figure 4-13 provides bore location and use information for each groundwater source area within the catchment.

Groundwater volumetric entitlements

Table 4-7 provides a comparison of volumetric groundwater entitlements for each groundwater source. The most recent data available for this assessment was obtained from the Water Sharing Plan (Greater Metropolitan Groundwater Sources) 2011 and the draft report cards for each respective groundwater source. One minor difference in the total licensed groundwater entitlement (TLGE) was identified based on this data, namely for the Goulburn fractured rock groundwater source. This area currently shows a TLGE of 3,151 ML/annum compared with 3,149 ML/annum from the 2010 audit period (refer to red text in Table 4-7).

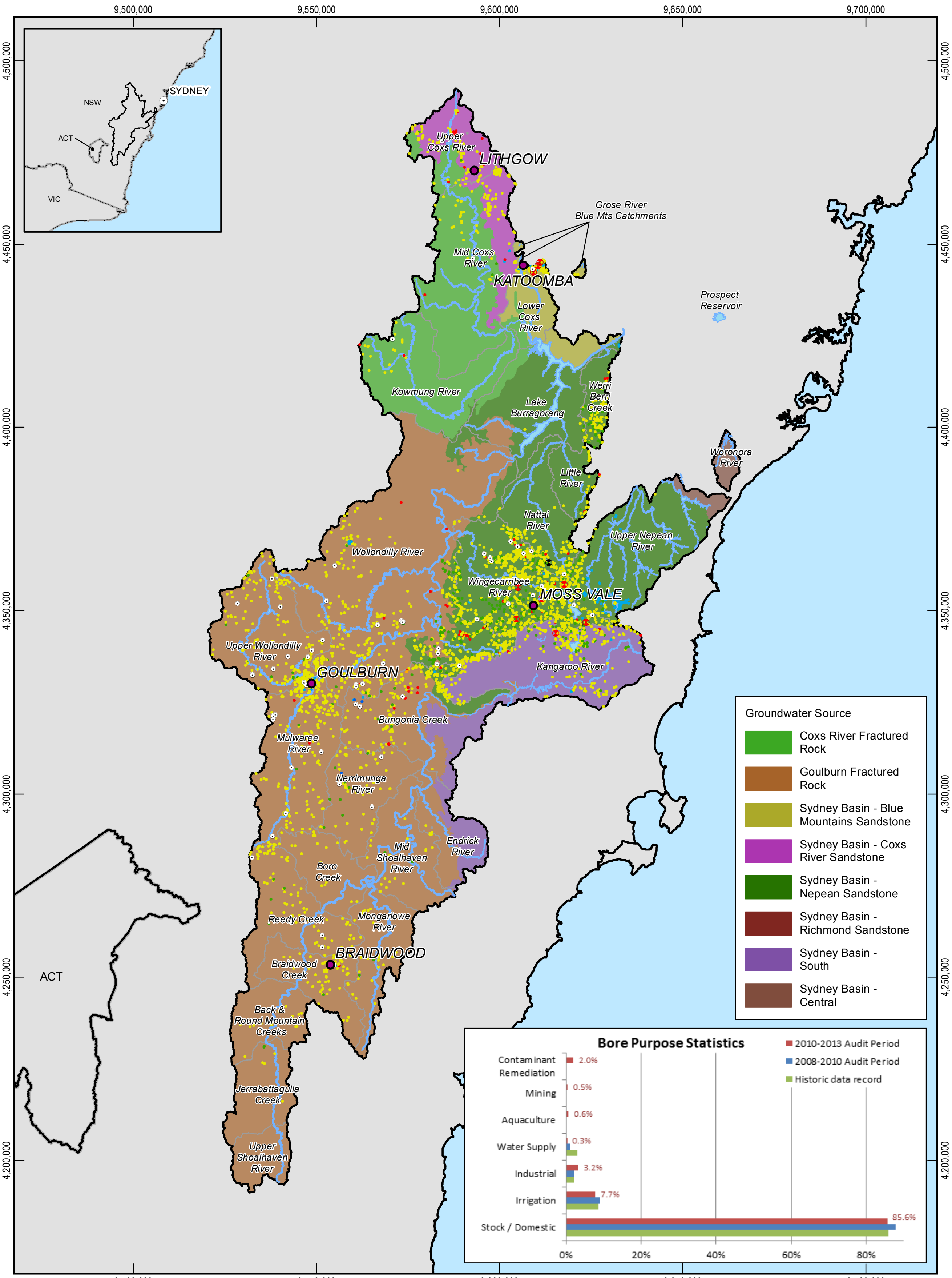
The data shows that the Sydney Basin – Richmond and the Sydney Basin – Coxs River groundwater sources have the highest percentages (75.45% and 40.48%, respectively) of their LTAAEL volume allocated with respect to licensed extractions.

Based on the criteria set in the WSP (Greater Metropolitan Groundwater Sources) 2011 in regard to volumetric extractions, the catchment is currently being used sustainably, and there is capacity for additional use in all groundwater sources within the catchment.

Since BLR uses are unlicensed and unmetered, an accurate account of the total BLR extractions cannot be made. The 'GW BLR' component shown in Table 4-7 is a volume allocated for BLR uses and not specifically the volume extracted for this purpose. From available data (water access licensing reports provided by NOW), a comparison was made of licensed water share components (actual licensed extractions) and BLR reserved volumes.

This comparison (Table 4-7) shows that potential BLR use is varied and accounts for as low as half the licensed extraction volume (Nepean Groundwater Source) and up to ten times more than is extracted for other purposes (Blue Mountains Groundwater Source).

There was insufficient data available to discriminate individual industrial (i.e. mining and CGS) extractions from other extractive groundwater uses.



LEGEND

Town	Bores installed in the 2013 audit period	**GW Licenced Purposes**	Stock / Domestic
Drainage	PINNEENA GW Bore - Confined	Aquaculture	Industrial
Waterbody	PINNEENA GW Bore - Unconfined	Water Supply	Mining
SCA catchment boundary		Irrigation	Not specified
Sub-catchment boundary		Contaminant Remediation	

Page Size A4

0 10 20 30

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
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Job Number 2314960
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Date 26 Nov 2013

Groundwater bore locations and licence purposes

Figure 4.6

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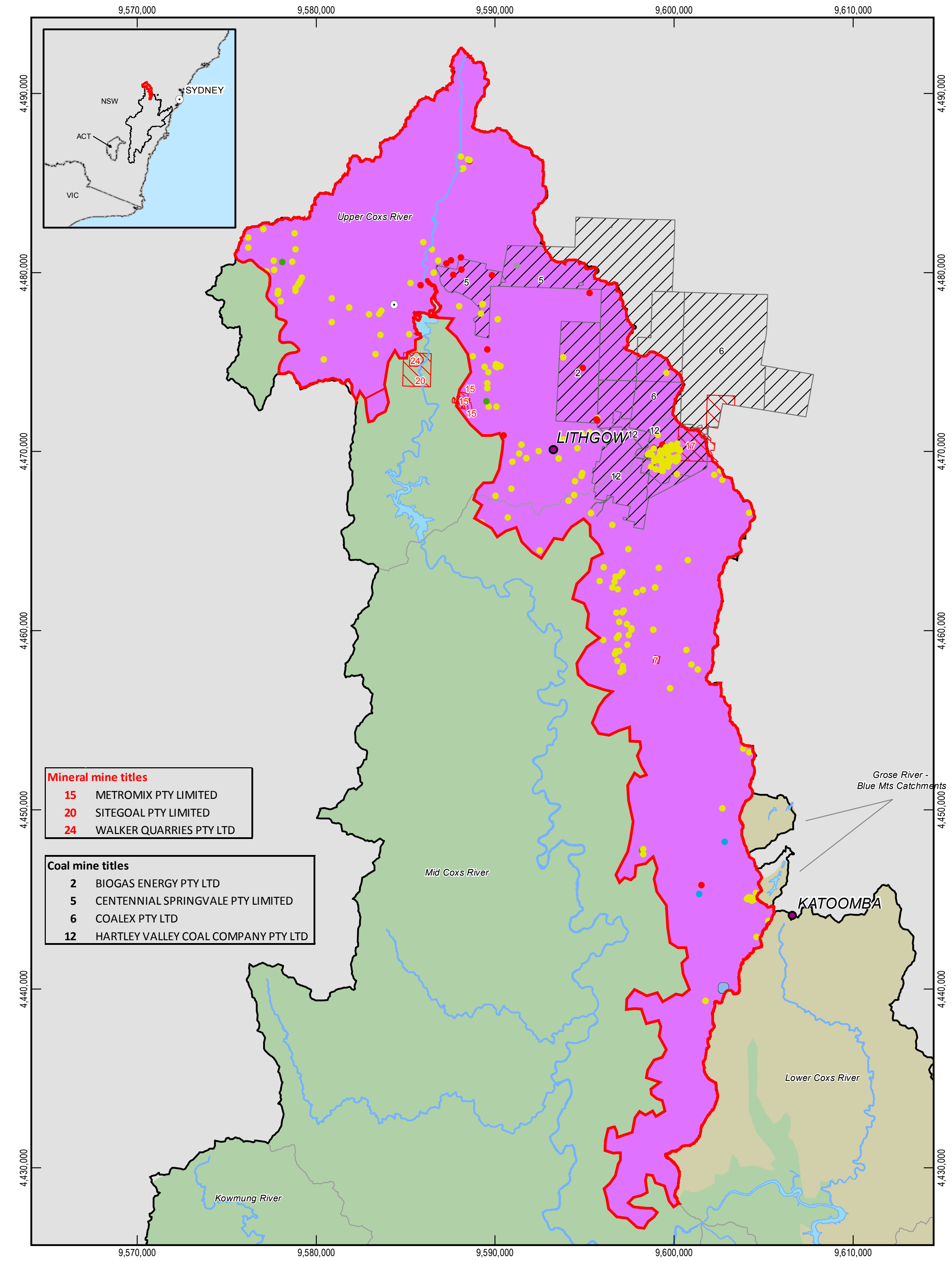
Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); NSW Office of Water: Converted Groundwater Licences (2013), Groundwater source boundaries (2011). Created by: KP



LEGEND

- Town
- Drainage
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary
- Coal mine titles
- Mineral mine titles
- Bores installed in the 2013 audit period

GDE type

- Wetland

GW Licence Purpose

- Water Supply
- Irrigation
- Stock / Domestic
- Industrial
- Mining

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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Job Number 2314960
Revision 1
Date 26 Nov 2013

Groundwater Source Bore Plan:
Sydney Basin - Coxs River Sandstone

Figure 4.7

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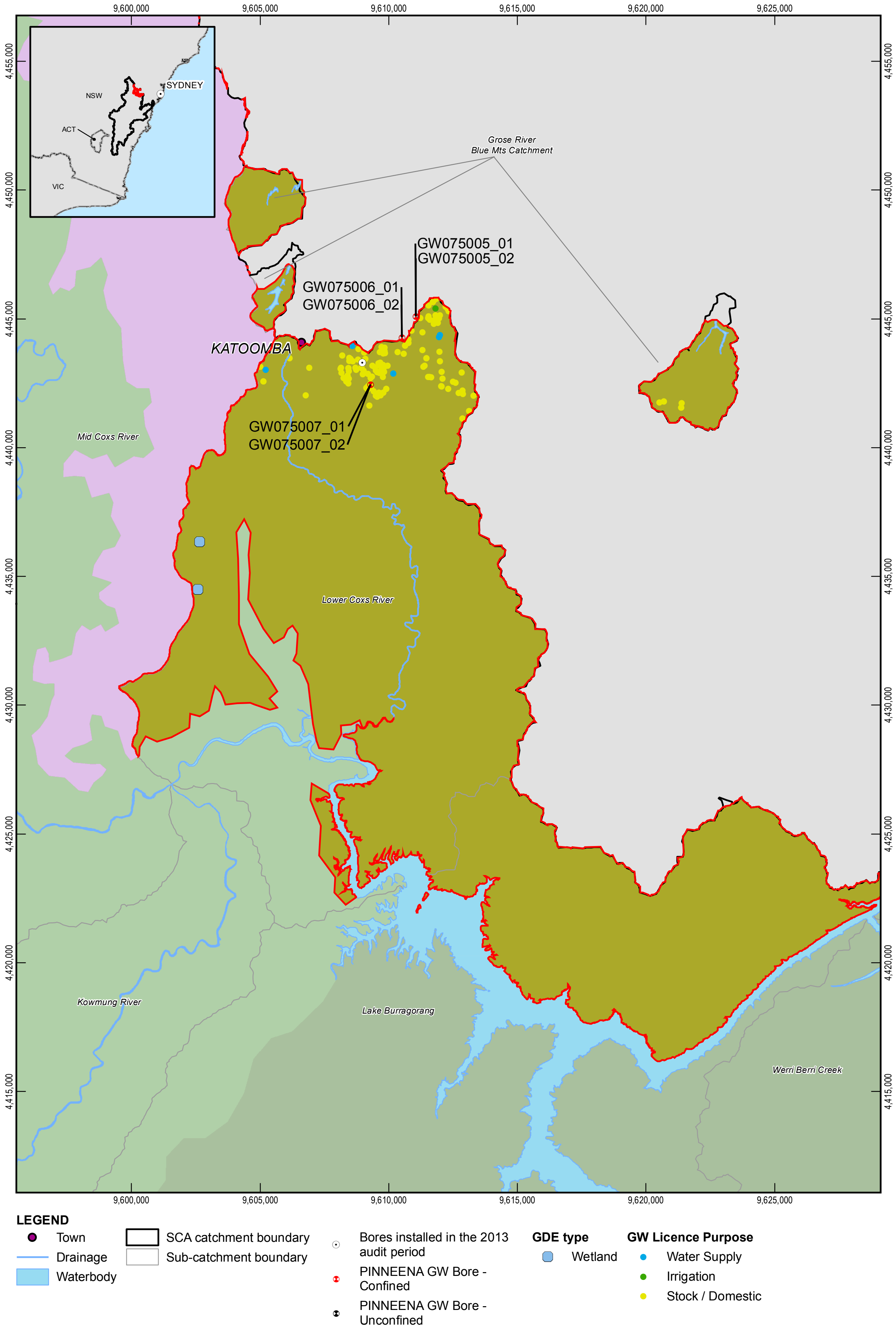
Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013) ; NSW TIRE: mining titles accessed 28/9/13; NSW Office of Water: Groundwater source boundaries (2011), Converted Groundwater Licences, GDE priority locations (2013). Created by: KP



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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

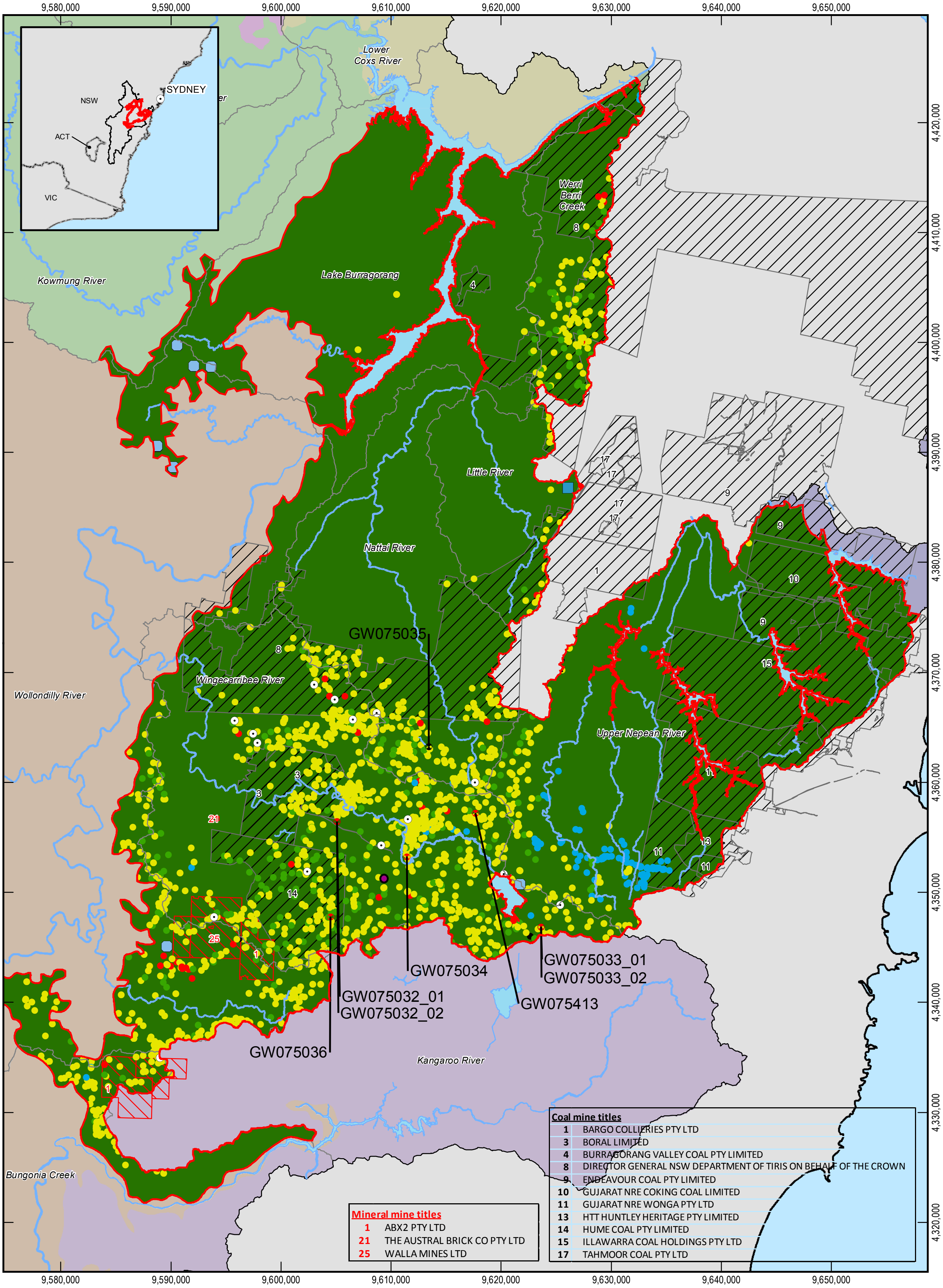
Job Number 2314960
Revision 0
Date 26 Nov 2013

Groundwater Source Bore Plan:
Sydney Basin - Blue Mountains Sandstone **Figure 4.8**

G:\23\14960\GIS\Maps\Deliverables\23_14960_503_SB_BlueMountains_Rev0.mxd

Level 6, 20 Smith Street Parramatta NSW 2150 Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** ptamail@ghd.com **W** www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); NSW Office of Water: Groundwater source boundaries (2011), GDE priority locations, Converted Groundwater Licences (2013).
Created by: KP



LEGEND

Town
Drainage
Waterbody
SCA catchment boundary
Sub-catchment boundary

Bores installed in the 2013 audit period
PINNEENA GW Bore - Confined
PINNEENA GW Bore - Unconfined

GDE type
Freshwater Lake
Karst
Wetland

GW Licence Purpose
Water Supply
Irrigation
Stock / Domestic
Industrial
Not specified

Paper Size A4
0 2 4 6 8 10
Kilometres
Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Job Number 2314960
Revision 0
Date 26 Nov 2013

Groundwater Source Bore Plan:
Sydney Basin - Nepean Sandstone

Figure 4.9

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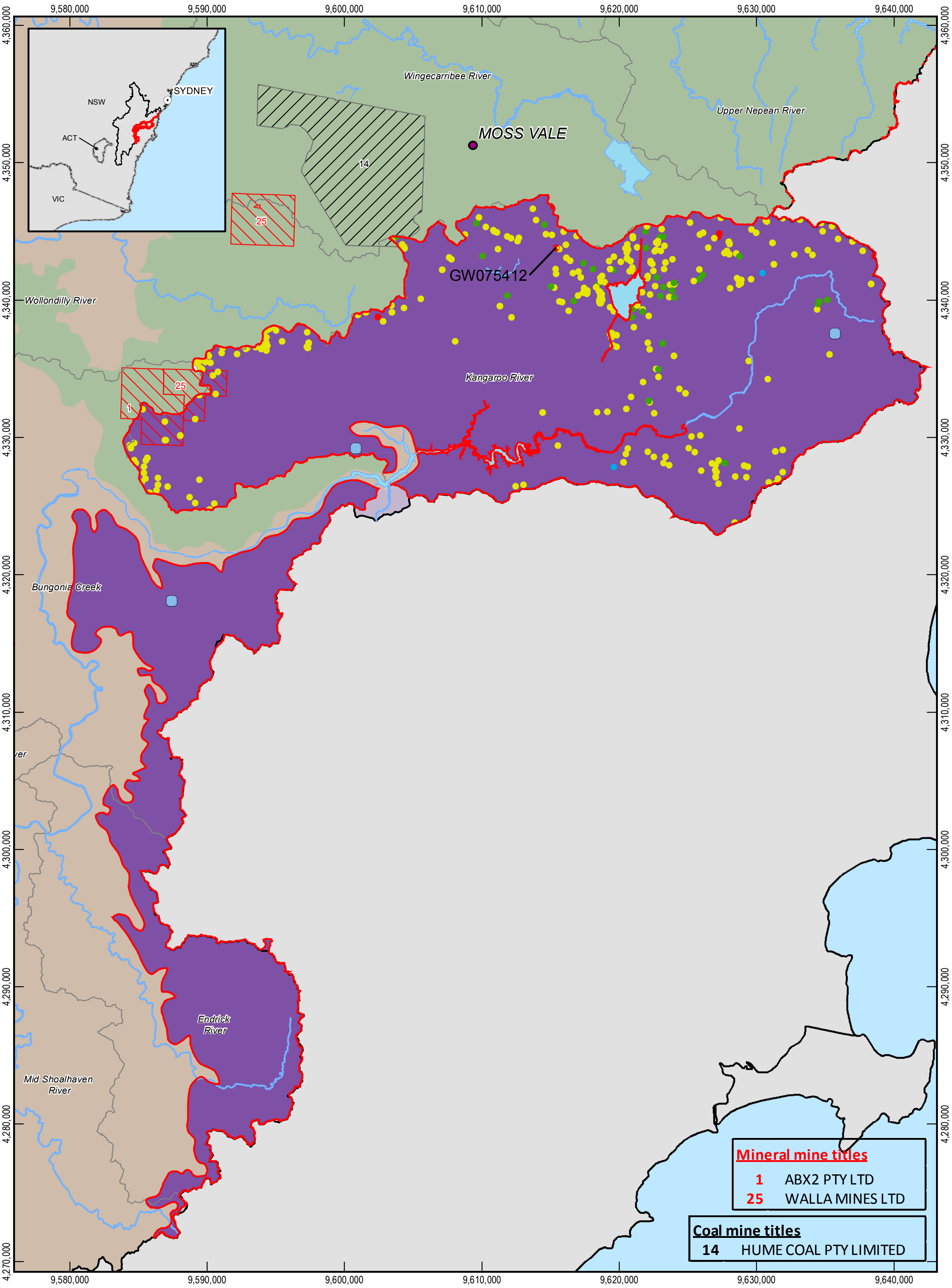
Level 6, 20 Smith Street Parramatta NSW 2150 Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** ptamail@ghd.com **W** www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); NSW Office of Water: Groundwater source boundaries (2011), GDE locations, Converted Groundwater Licences (2013); NSW TIRE: mining titles accessed 28/9/13. Created by: KP



LEGEND

Town	SCA catchment boundary	Bores installed in the 2013 audit period
Drainage	Sub-catchment boundary	PINNEENA GW Bore - Confined
Waterbody		
DIWA Listed Wetlands		

GDE type
- Wetland

GW Licence Purpose
- Water Supply
- Irrigation
- Stock / Domestic
- Industrial

Paper Size A4

0 2 4 6 8 10

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Job Number | 2314960
Revision | 0
Date | 26 Nov 2013

Groundwater Source Bore Plan:
Sydney Basin - South

Figure 4.10

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

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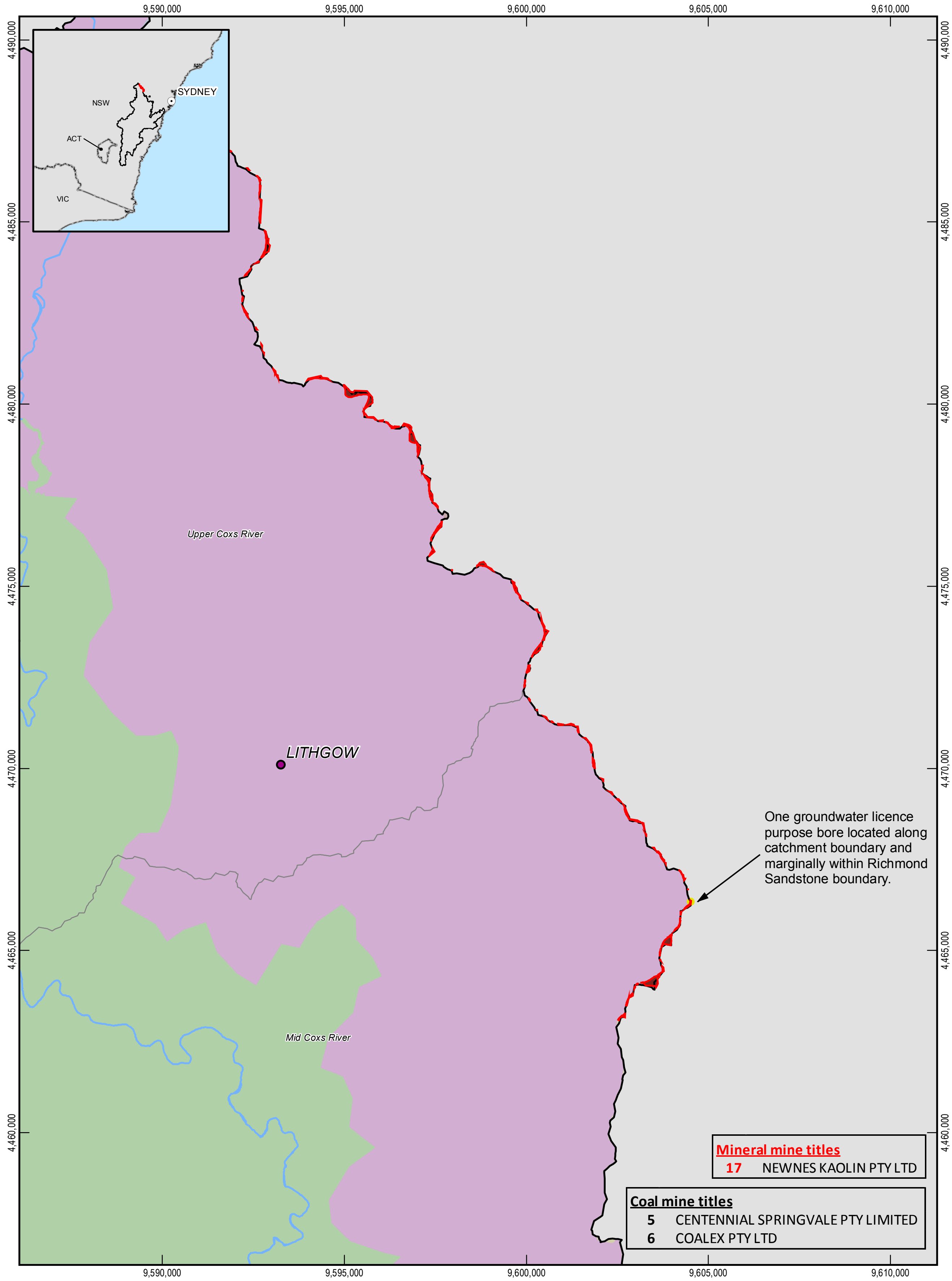

LEGEND

Town	SCA catchment boundary	**GW Licence Purpose**
Drainage	Sub-catchment boundary	Stock / Domestic

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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Date 26 Nov 2013

Groundwater Source Bore Plan:
Sydney Basin - Richmond Sandstone

Figure 4.11

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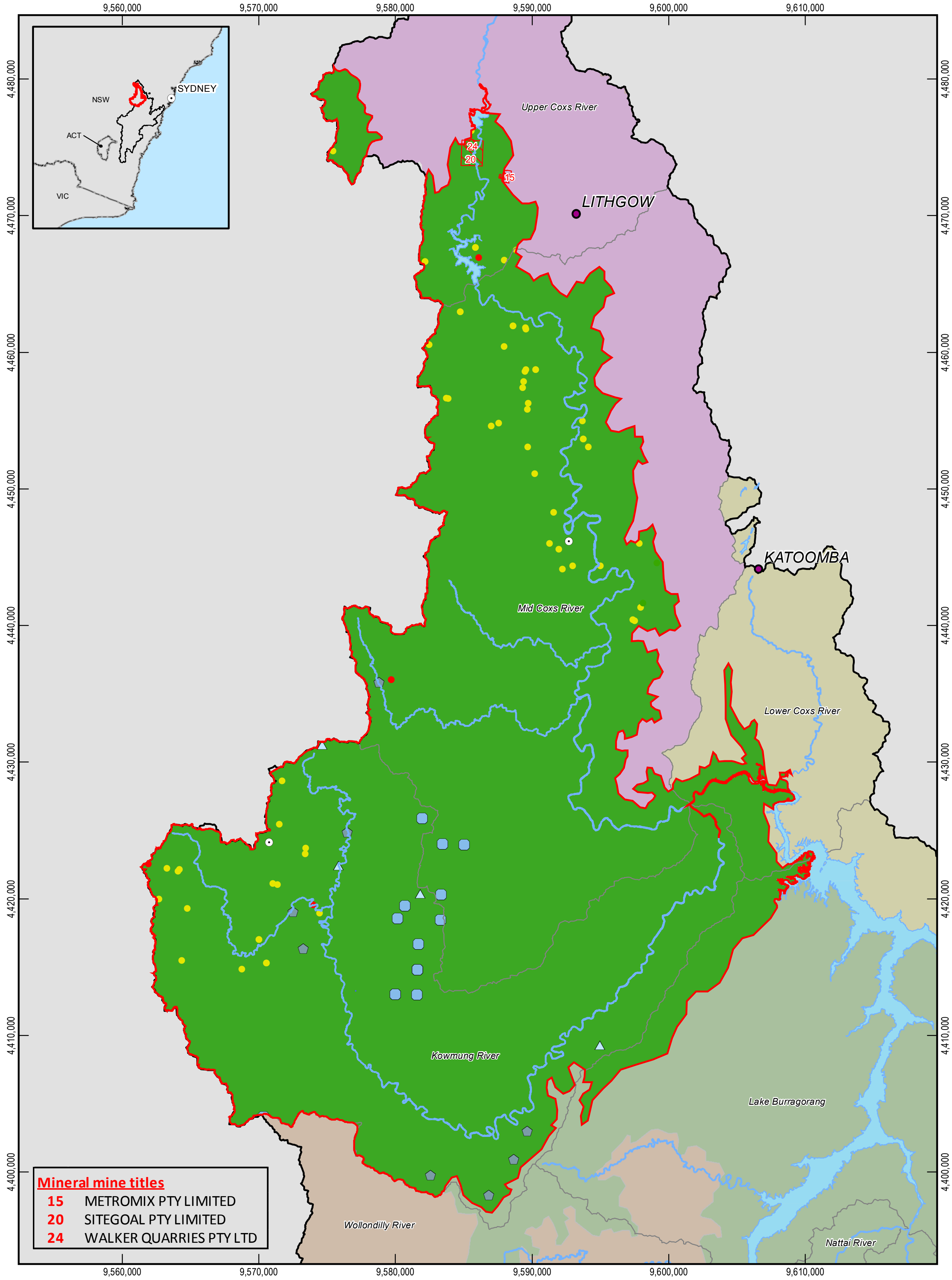
Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); NSW Office of Water: Groundwater source boundaries (2011), GDE locations, Converted Groundwater Licences (2013); NSW TIRE: mining titles accessed on 28/9/13. Created by: KP



LEGEND

- Town
- Drainage
- Waterbody
- DIWA Wetlands
- SCA catchment boundary
- Sub-catchment boundary
- Bores installed in the 2013 audit period

GDE type

- Spring
- Karst
- Wetland

GW Licence Purpose

- Irrigation
- Stock / Domestic
- Industrial

Paper Size A4

0 2.5 5 7.5 10

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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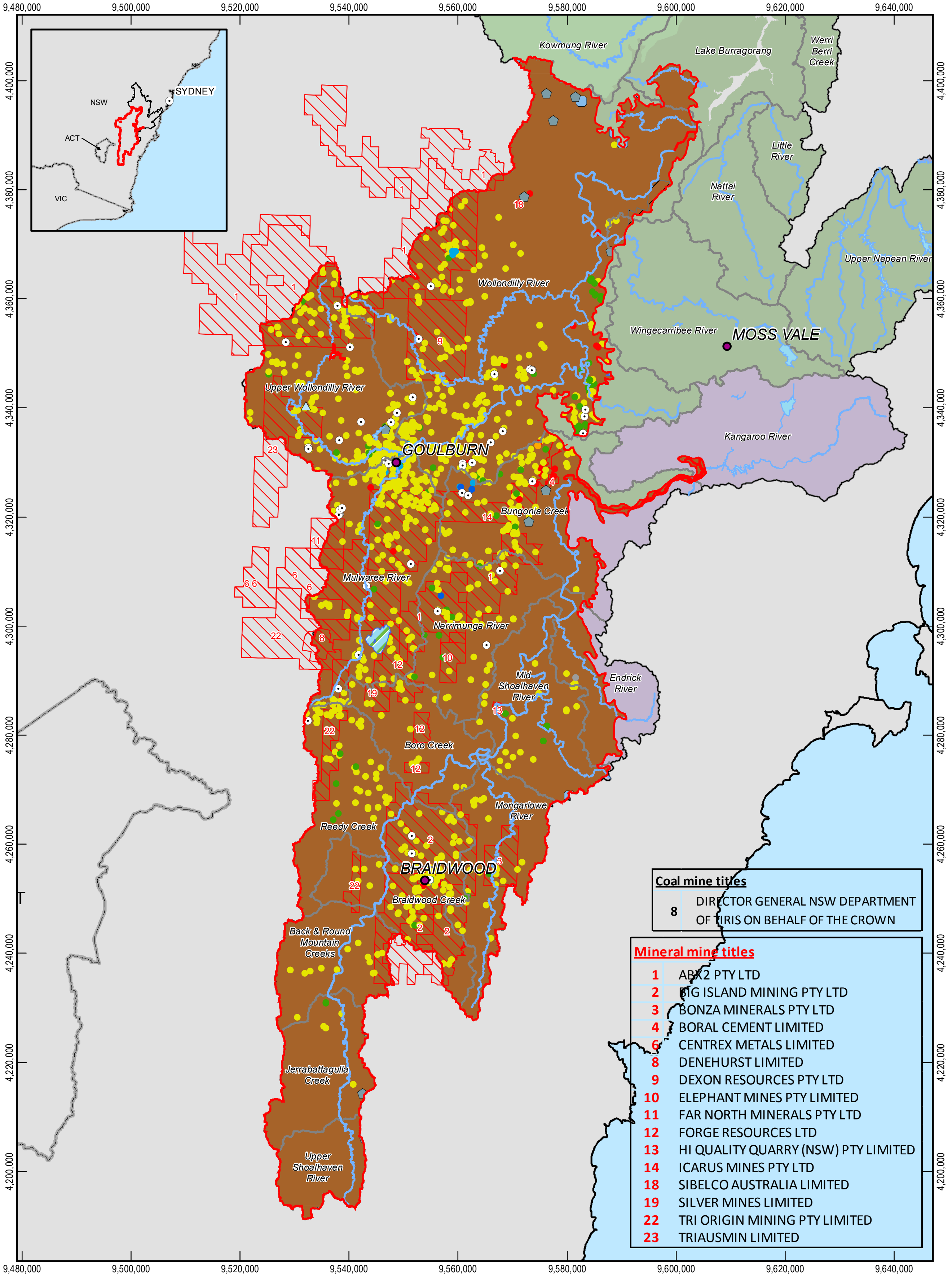
Groundwater Source Bore Plan: Coxs River Fractured Rock

Figure 4.12

G:\23\14960\GIS\Maps\Deliverables\23_14960_507_Coxs RvFR_Rev0.mxd

Level 6, 20 Smith Street Parramatta NSW 2150 Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** ptamail@ghd.com **W** www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); NSW Office of Water: Groundwater source boundaries (2011), GDE locations, Converted Groundwater Licences (2013); NSW TIRE: mining titles accesed 28/9/13. Created by: KP



LEGEND

Town	Sub-catchment boundary	**GDE type**	**GW Licence Purpose**
Drainage	Coal mine titles	Freshwater Lake	Aquaculture
Waterbody	Mineral mine titles	Spring	Water Supply
DIWA Wetlands	Bores installed in the 2013 audit period	Karst	Irrigation
SCA catchment boundary		Wetland	Contaminant Remediation
			Stock / Domestic
			Industrial
			Mining

Paper Size A4

0 4 8 12 16 20

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
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GHD

SYDNEY CATCHMENT AUTHORITY

Sydney Catchment Authority
Catchment Audit 2013

Job Number 2314960
Revision 0
Date 26 Nov 2013

Groundwater Source Bore Plan:
Goulburn Fractured Rock

Figure 4.13

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013) ; NSW Office of Water: Groundwater source boundaries (2011), GDE points, Converted Groundwater Licences (2013); NSW TIRE: mining titles accessed on 28/9/13. Created by: KP

Table 4-7 Volumetric entitlements in groundwater sources – SCA catchment

	Data from 2010 Audit (Table 5.3.1)						Data from WSP (Greater Metro. Groundwater Sources) 2011 and Draft Report Cards for these sources					
Groundwater source	**LTAAEL (ML/a)**	**TLGE (ML/a)**	**GW BLR (ML/a)**	**Unassigned (ML/a)**	**Total (ML/a)**	**TLGE / LTAAEL (%)**	**LTAAEL (ML/a)**	**TLGE (ML/a)**	**GW BLR (ML/a)**	**Unassigned (ML/a)**	**Total (ML/a)**	**WAL share component / BLR (%)**
Coxs River fractured rock	6,806	113.5	179	6,513.5	6,806	1.67	6,806	114	179	6,513.5	6,806	214
Goulburn fractured rock	53,074	3,149	3,114	46,811	53,074	5.93	53,074	3,151	3,114	46,811	53,074	70
Sydney Basin Blue Mountains	7,039	137.7	421	3,335.3	3,894	1.96	7,039	138	421	3,335.3	3,894	957
Sydney Basin Central	45,915	2,591.5	2,601	40,722.5	45,915	5.64	45,915	2,592	2,601	40,722.5	45,915	no data
Sydney Basin Coxs River	17,108	6,926	454	9,728	17,108	**40.48**	17,108	6,926	454	9,728	17,108	243
Sydney Basin Nepean	99,568	16,294	5,971	37,303	59,568	16.36	99,568	16,294	5,971	37,303	59,568	46
Sydney Basin North	19,682	557	722	18,403	19,682	2.83	19,682	557	722	18,403	19,682	no data
Sydney Basin Richmond	21,103	15,923	1,623	3,557	21,103	**75.45**	21,103	15,923	1,623	3,557	21,103	no data
Sydney Basin South	69,892	2,880	2,098	64,914	69,892	4.12	69,892	2,880	2,098	64,914	69,892	113

Bore monitoring data

Groundwater levels

Groundwater level data has been provided by NOW for this audit for 15 monitoring bores that are used to collect long-term groundwater level monitoring data through automatic data loggers. Table 4-8 provides a summary of bore summary data obtained from the NOW PINNEENA groundwater database. These bores monitor groundwater conditions at 10 locations within the Warragamba and Shoalhaven surface water catchments, namely in the Sydney Basin - Blue Mountains Sandstone (Figure 4-8), Sydney Basin - Nepean Sandstone (Figure 4-9) and the Sydney Basin – south groundwater sources (Figure 4-10).

These bores provide a very localised picture of groundwater conditions across the catchment and are not necessarily monitoring groundwater elevations near to key extractive industries and/or key GDE within the catchment.

The minimal impact considerations developed through the *Aquifer Interference Policy 2012* is acknowledged for assessing impacts on groundwater sources, connected water sources, and their dependent ecosystems, culturally significant sites and water users, but cannot be realistically assessed on a catchment-wide basis using the available data.

Groundwater bore hydrograph analysis

Groundwater level data from these 15 bores has been plotted against rainfall data[2] to develop bore hydrographs (see Volume 2 Appendix G). These have been used to assess long-term groundwater level trends, particularly in terms of the potential anthropogenic impacts to these bores from activities such as groundwater abstraction, mining, or CGS operations.

Figure 4-10 to Figure 4-13 show that these bores are generally not located in the immediate vicinity of key groundwater abstractors and as such, may be limited in assessing related impacts to groundwater levels.

Additionally, the HARTT hydrograph analysis technique (Ferdowsian 2001) was applied to separate the effect of atypical rainfall events from underlying time trends in groundwater. This technique helps to identify the lag between rainfall and the potential impact on groundwater levels and could only be applied to bores that were likely to be unconfined. The degree of confinement was inferred for each bore (Table 4-8).

Several 'nested' or grouped bore sites are discussed in this section, where subscripts 01 and 02 refer to the shallow and deep bore respectively, unless stated otherwise. The bore hydrographs and HARTT analyses show the following trends:

Blue Mountains Sandstone Groundwater Source

GW075005 – a downward pressure gradient is shown from the shallow sandstone to the deeper shale. A similar trend is shown between the shallow and deeper bore, with more pronounced variations in the shallower bore. A 6 m decline in groundwater level is shown in the deeper bore in mid-December 2008, with partial recovery in two days. The reason for this decline is unknown, but is potentially due to irrigation abstraction in the vicinity or water quality sampling of this bore.

HARTT analysis of the shallow bore at GW075005 showed that the bore was likely to be affected by rainfall fluctuations, as the analysis showed groundwater levels and accumulative average residual rainfall had a high degree of fit (R^2) of 0.92 after a 2 month delay. Statistically

[2] from the nearest climate station containing appropriate datasets for each respective bore

this result is significant and is demonstrated by the correlation of annual residual rainfall with groundwater levels (Volume 2 Appendix G).

GW075006 – a downward pressure gradient is shown from the shallow sandstone to the deeper siltstone. These bores show a similar trend, with less pronounced variations due to rainfall in the deeper bore compared with the shallow bore. Seasonal variations typically show higher groundwater levels in winter and spring.

HARTT analysis showed that variations in groundwater levels in the shallow bore are related to rainfall fluctuations, as groundwater levels and accumulative average residual rainfall had a high degree of fit within a 2 month delay. Statistically, this result is significant and correlates with annual residual rainfall and groundwater levels, as shown in the graph (Volume 2 Appendix G).

GW075007 – piezometric heads indicate a downward pressure gradient from the shallow to the deeper bore, with typically stable levels in the deeper bore. The shallow bore shows increasing levels likely in response to significant rainfall events. This trend is not shown for the period July 2001 to September 2006. The best fit delay of 46 months shows that aquifer response to rainfall is significantly time lagged. Overall, the shallow bore (GW075007_01) is affected by rainfall recharge but there are other, more dominant variables that affect groundwater levels.

Nepean Sandstone Groundwater Source

GW075032 – a downward pressure gradient from the shallow (GW075032_01) to the deeper bore (GW075032_02) is shown, with a similar trend shown for both bores. Groundwater levels show a typically declining trend from 2000 to 2007, followed by stable to marginally increasing levels until 2009, where levels again decline into 2010. Groundwater levels have increased in both bores since mid-2011, potentially in response to increased rainfall in this period.

Rainfall trends generally correlate with fluctuations in shallow groundwater levels, indicating that groundwater levels are influenced by rainfall. The degree of fit (R^2) shown in HARTT analysis indicates only a small contribution from other variables (e.g. aquifer throughflow).

GW075033 – these bores show temporal variation between upwards and downwards pressure gradients (typically upwards gradient). The deeper sandstone/shale unit shows potential declines due to abstraction elsewhere in this unit (e.g. September 2007), which are shown to a lesser extent by the shallow bore. The significant water level decline in November 2012 is probably due to groundwater abstraction. The shallow bore (GW075033_01) shows minor rainfall recharge; other variables have a greater effect on groundwater levels, based on visual observations and a small degree of fit.

GW075034 – this bore shows seasonal/cyclical variations typical of groundwater abstraction for irrigation during the drier summer months. A general increasing trend is shown since 2010.

GW075035 – this bore shows a marginally declining long-term groundwater level trend from 1998 to 2010. An increasing trend is shown from late 2010, correlating with increased rainfall and drought-break. HARTT analysis confirmed this correlation and highlighted an increasing long-term trend in accumulative residual rainfall (ARR).

GW075036 – this bore shows cyclical variations in groundwater level that correlate with lower levels during the summer months, potentially induced by regional abstraction. Water levels typically rise during winter and spring. This bore is situated on Hume Coal Pty Ltd land, amongst several stock and domestic and irrigation bores.

GW075413 – this deep bore has a limited data record, but shows stable groundwater levels from late January to April 2013, with a variable and generally increasing trend to May 2013.

Sydney Basin - South Groundwater Source

GW075412 –this bore has a limited data record, but shows marginally increasing groundwater levels from late January to March 2013, with a stable to slightly declining trend to April 2013. A distinct short term decline noted in April 2013 may be due to water quality sampling of this bore.

Targeted analyses of long term groundwater level trends at ten locations within the Sydney catchment showed that most declining groundwater level trends were attributed to rainfall trends and seasonal groundwater abstraction presumably from irrigation/farming activities.

Mining abstraction is considered unlikely to be affecting groundwater levels at these bores since key abstractors are not located in the immediate vicinity of these bores. Additionally, identified fluctuations in groundwater elevation are seasonal or short term, which indicate natural seasonal trends and/or possible, interaction with seasonal groundwater users for irrigation, stock or domestic purposes.

The sustainable allocations/entitlements presented in the groundwater sharing plan and related report cards appear to be suitably preventing long term reduction in groundwater elevations.

Groundwater dependent ecosystems (GDEs)

The Directory of Important Wetlands (DIWA) along with the high priority GDEs identified in the WSP (for the Greater Metropolitan Region Groundwater Source) 2011 and the Bureau of Meteorology GDE Atlas[3], were used to assess potential threats to identified GDEs in the catchment. Table 4-9 shows GDEs identified through these sources in terms of groundwater source and potential threats. A qualitative risk ranking has been applied based on the inferred potential threat to GDEs identified through the aforementioned sources. GDE and land use mapping (Figure 4-4 to Figure 4-13) for each groundwater source within the catchment) was used throughout this process.

A **Low** risk ranking has been applied to most groundwater sources, based on the locations of identified GDEs in relation to groundwater extraction bores and higher risk land uses such as mining and industrial.

Moderate risk was inferred within the Sydney Basin – Nepean Sandstone, Sydney Basin – Coxs River Fractured Rock and Sydney Basin – Goulburn Fractured Rock groundwater sources. These moderate risks highlight the degree of uncertainty in regards to potential threat posed by groundwater extraction and mining operations to specific GDEs.

These risks require further assessment before a more conclusive risk rating can be applied.

Mining in the catchment

The SCA catchment has had a long history of mining since the 1960s. Approximately 25% of the catchment's special areas are currently mined, with an anticipated increase to approximately 90% in the next 20 years (SCA 2013e).

The NSW DPI (2013a) identified 11 underground coal mines operating in Sydney's broader drinking water catchment, with seven in the Southern Coalfield (six of which are in the catchment Special Areas) and four in the Western Coalfield.

[3] Based on NSW Office of Water data in NSW

Table 4-8 Groundwater observation bore data

Bore ID	Zone	Easting (AMG)	Northing (AMG)	Elevation (mAHD)	Monitored geology	Groundwater source area	Screen From (m)	Screen To (m)	Bore diameter (mm)	Casing material	Drilled Depth (m)	Installation Date	Inferred degree of confinement
GW075005_01	56	255,205	6,267,941	919	Sandstone	Sydney Basin – Blue Mountains Sandstone	30	36	unknown	PVC	37	10/01/2001	Unconfined
GW075005_02	56	255,205	6,267,941	919	Shale		79.7	85.7	unknown	PVC	90	10/01/2001	Confined
GW075006_01	56	254,705	6,267,091	931	Sandstone		34	37	100	PVC	37	10/01/2001	Unconfined
GW075006_02	56	254,705	6,267,091	931	Siltstone		84	90	100	PVC	90	11/01/2001	Confined
GW075007_01	56	253,605	6,265,191	946	unknown		unknown	84	100	PVC	90	11/01/2001	Unconfined
GW075007_02	56	253,605	6,265,191	946	unknown		44	50	100	PVC	50	11/01/2001	Confined?
GW075032_01	56	254,375	6,178,962	678.23	Sandstone and Shale / Siltstone	Sydney Basin – Nepean Sandstone	24	29	80	PVC	31	21/10/1998	Unconfined
GW075032_02	56	254,375	6,178,962	678.23	Sandstone and Siltstone		73	88	80	PVC	91	21/10/1998	Confined
GW075033_01	56	273,475	6,170,521	692.96	Sandstone		30	35	80	PVC	36	24/10/1998	Unconfined
GW075033_02	56	273,475	6,170,521	692.96	Sandstone and Shale		89	99	80	PVC	101	24/10/1998	Confined
GW075034	56	260,899	6,176,190	660.01	Sandstone		90	100	100	PVC	101	29/10/1998	Confined
GW075035	56	262,322	6,186,277	648.25	Sandstone		74	89	80	PVC	91	29/10/1998	Unconfined
GW075036	56	254,286	6,170,324	660.24	Sandstone		73	84	80	PVC	100	15/11/1998	Confined
GW075413	56	266,896	6,180,461	710.69*	Sandstone		145	151	158	Steel	151	14/07/2011	Confined
GW075412	56	265,420	6,166,997	650.07*	Sandstone	Sydney Basin - south	52.4	64.4	unknown	PVC	70.4	26/06/2011	Confined

Note: Reference point of elevation data was specified as metres Australian Height Datum (AHD) from the top of the bore standpipe.

* bore elevation measured to ground surface, based on NOW advice, 30/9/13

Table 4-9 GDEs and risks

Groundwater Source	GDE type	GDE description	Inferred risk to GDE
Sydney Basin - Coxs River	Wetland	One GDE site was identified near the Lower Coxs River valley. No immediate threats identified.	Low
Sydney Basin - Blue Mountains Sandstone	Wetland	Two GDE sites were identified in the Lower Coxs River valley. No immediate threats identified	Low
Sydney Basin – Nepean Sandstone	Wetland and Freshwater Lake	One freshwater lake GDE in the vicinity of Tahmoor Coal and an industrial supply bore. One wetland GDE in the vicinity of Walla Mines Ltd. and an industrial supply bore. One wetland GDE in the vicinity of several stock and domestic bores, east of Moss Vale	Moderate
Sydney Basin – South	Wetland	Three non-threatened wetland GDEs	Low
Sydney Basin – Richmond Sandstone	N/A	GDEs not identified	N/A
Sydney Basin – Coxs River Fractured Rock	wetland, spring and karst	One karst GDE in close proximity to an industrial supply bore on the Jenolan River One karst GDE in close proximity to an industrial supply bore on the Tuglow River Several other non-threatened wetland, spring and karst GDEs identified	Moderate
Sydney Basin – Goulburn Fractured Rock	karst, freshwater lake, wetland and spring	Two wetland GDEs nearby to a stock and domestic bore, in the northern extent of the groundwater source One karst GDE in close proximity to an industrial supply bore at Sibelco Australia Ltd mining operation One karst GDE in the vicinity of several stock and domestic bores, 6 km northwest of Goulburn One spring GDE in the vicinity of several stock and domestic bores, 20 km northwest of Goulburn Two karst GDEs in the vicinity of Boral Cement Ltd and Icarus Mines Ltd operations, near Bungonia Creek, approx. 35 km east of Goulburn Several stock and domestic bores around Lake Bathurst, a freshwater lake GDE and DIWA wetland	Moderate

The primary method of coal mining in the catchment longwall mining results in land subsidence. Figure 4-4 to Figure 4-6 show identified mining operations for each respective groundwater source within the catchment. These operations include quarry sites, current mining developments and mine exploration leases. Available groundwater level data generally do not correlate spatially with known mining, CSG or industrial operations and as such, cannot be used to assess potential groundwater impacts from mining/dewatering activities.

Specific data relating to volumetric allocations and use at major mining and industrial developments was unavailable for use in this study. A review of EIS and groundwater licensing data specific to each development would enable the assessment sustainability of volumetric allocations with respect to the *WSP 2011*.

Environmental impacts of mining

Negative impacts to catchment hydrology in the Sydney catchment area have already been postulated through scientific studies. For example, mining induced fracturing of geological formations is likely to increase rainfall infiltration, potentially reducing runoff and associated baseflow discharge and resulting in stream flow reduction (Jankowski and Knights, 2010).

The Apex Gas Project is the only CSG development known to have received planning approval within Sydney's drinking water catchment (DP&I, 2013a). As part of this project, 12 exploration boreholes have been drilled within the Sydney catchment area. The NSW Chief Scientist and Engineer are currently reviewing CSG activity and regulation in NSW, with expected completion in mid-2014.

Current coal mining in the Sydney catchment area at Dendrobium Mine has identified impacts to swamps through a subsidence management plan (DP&I 2013a). A biodiversity offset strategy is required to compensate for these anticipated environmental impacts. Groundwater inflow data from this mine suggests that groundwater entering the mine workings is not from young surface water but from deep, saline aquifers that do not impact on catchment yield (BHPBIC 2013). In support of this statement is numerical modelling undertaken previously (GHD Geotechnics 2007), which identified that the proportion of rainwater infiltrating deeply into the rock mass (in Dendrobium Area 3) is around 1% to 2% of total rainfall at the ground surface. The remaining 98% of rainfall was accounted for through runoff, evapotranspiration, or infiltrating to shallow soils or shallow aquifers (rather than deeper aquifers).

GHD Geotechnics (2007) Identified hydrogeological impacts of mining at Dendrobium Mine to include the local modification of aquifer transmissivity, flow patterns and depressurisation of some stratigraphic units immediately above the longwall footprint, and up to 1.5 km from some longwall panels). This source considered hydrogeological impacts (specific to mining Area 3) to relate particularly to the stratigraphic units from the Wongawilli Seam up to and including the Bulgo Sandstone.

The presence of algae species (inherently sourced from the ground surface) has been identified in both the reservoir waters and the mine waters at Dendrobium (Ziegler and Middleton, 2011).This study suggests that a proportion of the water in the underground mine workings is sourced from the surface, probably via fractures (which must be greater than 50 µm in width to transmit algae) subsequent to significant rainfall events. It is noted that the Ziegler and Middleton (2011) study does not include the sampling and analysis of water samples for an assessment of ionic chemical signatures, which may more conclusively indicate the potential for surface water migration to the underground mine workings, by way of mining induced fractures.

Based on a method developed by Ziegler and Middleton (2011), Coffey Geotechnics (2012) assessed the calculated groundwater inflow to Dendrobium Areas 1, 2, and 3 in relation to cumulative residual rainfall. A relationship between residual rainfall (departure of weekly rainfall from the long-term average) and residual mine inflows (departure of weekly inflows from long-term trend) was identified, particularly for a seven week lag between inflow and rainfall (Coffey Geotechnics, 2012). Induced seepages were estimated through numerical modelling, for Lake Cordeaux, Lake Avon, and rivers, due to mining at the Dendrobium Mine (Coffey Geotechnics, 2012).

As discussed previously, available groundwater level data did not indicate that mining activities were affecting groundwater levels at identified monitoring bore locations.

4.3.5 Recommendations

In respect to groundwater licensing recent data outputs should be prepared in time for the audit for key indicators relating to groundwater licensing and usage (e.g. volumetric usage for BLR works). Provision of updated data will improve the auditing process by providing a means for comparison with data from the previous audit. The responsibility of this task should lie with NOW, since it is responsible for managing groundwater licensing and allocation in NSW. NOW should ensure that recently updated data on groundwater licensing and usage are prepared and available in preparation for the next audit.

An assessment of NOW's groundwater data management framework under the *WMA 2000* would be beneficial. In particular, groundwater data and geo-databases should retain key attributes to trace back licence details (e.g. WAL, volumetric entitlements, and bore purpose) to specific locations or groundwater works. This assessment will assist in future auditing and assessments of potential impacts to environmental assets (e.g. GDEs) and in the longer term, will assist NOW and other agencies in interrogating groundwater licence and allocation data. The Auditor encourages NOW to assess their data management framework in the context of the *WMA 2000*.

The impact of developments on groundwater use (e.g. formations developed, metered usage data, licence details etc.) should be collated and reviewed periodically by SCA, DPI and OEH. This data should be made available for comment and review in subsequent audits. An extensive review should be undertaken of all environmental impacts statements (EIS) associated with mining and CSG developments in the catchment prior to the next catchment audit. This review will help develop a broad understanding of predicted groundwater inflows for each major development proposed. The water accounting provisions of the *AIP 2012* will help relate potential mining and industrial abstractions to sustainable use criteria.

Collated groundwater use data from mining developments should be assessed in terms of risk to known and/or potential GDEs in the Catchment. A GDE management framework should provide rules and regulations for maintaining or improving GDE health.

A review of the current ground water monitoring network should be included as part of the proposed groundwater risk assessment. This would identify locations for additional groundwater monitoring bores in known high risk areas (e.g. high allocation/extraction zones, adjacent to dewatering activities etc.) and incorporate these bores into the monitoring network. The lack of groundwater quality data within the Catchment is a gap in the baseline of knowledge which needs to be addressed.

NOW should extend existing monitoring to include groundwater quality data as well as groundwater levels to establish a baseline for groundwater resources in the Catchment.

5. Water Quality

5.1 Ecosystem water quality

5.1.1 Summary

Ecosystem water quality is an essential theme for an audit of a Drinking Water Catchment, as it assesses the end product of the catchment management approach to water supply. Water quality in the catchment streams and rivers is a function of the inherent geological conditions and in-stream processes combined with land use, land and catchment management practices and climatic conditions, such as drought and flood.

There have been no significant changes in the quality of water in the catchment streams during the current audit period. As recorded in previous audit periods, water quality in catchment streams were largely influenced by changes in local conditions (such as land use), climatic conditions (low or high flows), geomorphology and in-stream processes.

Raw water supplied to WFPs was generally of high quality, and met the Raw water Supply Agreements (BWSAs) in terms of water quality, with only infrequent and minor, non-compliances.

Nutrient loads from point sources generally complied with the licences, with some instances of failures, mostly of TN loads released into downstream waterways, and in some cases, TP. There were however, a significant number of non-compliances related to discharge volumes (particularly, related to wet weather events) and failures in monitoring requirements.

The modelling of nutrient loads from the sub-catchments has been conducted by several stakeholders, including the SCA, using several methods. These methods have intrinsic limitations as the required data is difficult to attain and the data collection is expensive and time-consuming. A hybrid approach is recommended, to be conducted by SCA, in partnership with other key stakeholders with the capacity for modelling, such as the OEH.

Although there were occasional cyanobacterial blooms in catchment streams and storages, cyanobacteria did not pose any major threat to the water supplies during the current audit period. The SCA has achieved a high level of understanding of cyanobacterial issues within the Catchment and in the storages through its implementation of a Blue-Green Algae Management Plan; hence its preparedness to respond to future cyanobacterial risks was assessed as high.

Long-term trends (either increases or decreases, or no obvious changes) were detected for several water quality parameters in the Catchment streams and rivers, as well as in the storages. Although there were noteworthy variations amongst sub-catchments, these were expected in such a large Catchment.

Overall, the results of raw water quality during the current audit period, and the long-term trends in water quality parameters, either in catchment streams, or in storages, did not indicate unusual changes. The evidence available indicated that the raw water arising in Catchment is generally of good quality, which was regarded as a reflection of the effectiveness of relatively recent catchment management practices.

The water quality data and related information assessed in the 2013 Audit points to positive outcomes of the efforts being made by the SCA and other stakeholders to manage changing pressures in the Catchment. Efforts to further increase the level of understanding of the pressures in the Catchment, and continuing the implementation of effective catchment management practices will ensure that Sydney's Drinking Water Catchment is well managed.

Assessment Criteria

Criteria
1. Assess whether water quality parameters monitored at various catchment sites meet recreational water quality guidelines - as indicators of catchment health.
2. Determine whether raw water quality supplied for treatment complied with drinking water guidelines for health related and bulk water supply (BWSA) characteristics.
3. Assess whether long-term water quality trends are identified and effectively used to assist in catchment health improvements.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Opportunity for improvement	The SCA should refine investigation of hotspots of sporadic *Cryptosporidium* contamination to sites not proximate to STPs to determine the sources, genotypes, and potential human health risks.
3	Meets Expectation	Nil

Prior recommendations

Prior Recommendations	Remedial action	Status
Recommendation 18: The SCA undertake a targeted survey of pesticide usage and application in the catchments of Cascade Dam and Wingecarribee Reservoir.	In progress and will be addressed through updates of PSAT	Closed
Recommendation 19: The SCA continue to investigate the cause of persistent detections of *Cryptosporidium* and *Giardia* oocysts/cysts in the Catchment.	Satisfactory progress on viability of (oo)cysts downstream of STPs. Report due for completion in December 2013.	Closed

5.1.2 Background

The water quality of lotic waterways is largely influenced by land use, catchment characteristics, such as geology and vegetation structure, and in-stream processes and functioning. There are many anthropogenic influences that can alter in-stream processes and functioning, and these can often be investigated and quantified by the examination of results from water quality monitoring.

Previous audits have recorded that raw water in the Catchment is generally of good quality and meets most applicable guidelines (DECCW 2010a). However, there are significant pressures on water quality in the Catchment from point and diffuse sources of pollution. Point sources that may lead to pollution of water include discharges from STPs, and other licensed activities, such as mining. Diffuse sources include urban stormwater and rural runoff. Pollution of waterways from both point and diffuse sources is largely driven by land use, intensity of use, and catchment management practices.

Population growth in urban areas increases stormwater runoff and puts pressure on wastewater management systems, often resulting in the need for upgraded infrastructure. Population growth in rural areas can result in increased on-site sewage treatment that can add to the diffuse pollution loads - if not well managed.

Population growth and settlement patterns can also intensify land use, which can increase land clearing, runoff, and ultimately, increase the risks of adverse impacts on the quality of the raw water supply. Impacts of population growth in the Catchment were discussed in Section 3.5.

There were large areas of agricultural land in the Catchment, where much of the native vegetation has been removed. Runoff from agricultural land can carry large amounts of sediment and nutrients into rivers and creeks. The amount of material washed into waterways is increased in areas of bare soil or reduced riparian vegetation. Rural runoff can also contain pesticides, and pathogens originating from livestock waste (Ferguson et al. 2009). The condition and role of native vegetation in protecting the water supply is discussed in Section 6.2. Pollution and contamination from industrial and commercial sites in the Catchment can also impact on raw water quality.

The water quality risks to the drinking water supplies include the risks of eutrophication (nutrient enrichment) of storages, pathogens, Cyanobacterial blooms and other forms of pollution, such as from pesticides used in the catchment. Routine monitoring of catchment streams enables the assessment of catchment water quality and the identification of occurrence of any contamination in order to manage water quality hazards, within an adaptive management framework. Analyses of the annual monitoring results and the long-term trends in water quality also allow an assessment of the impacts and effectiveness of the SCA's activities, as well as those of other stakeholders, in managing the catchment, and the quality of water that drains into watercourses and storages. Understanding the nutrient loads arising from different sub-catchments allows for the modelling of water quality in storages and an assessment of catchment remediation actions.

The maintenance and/or improvements in water quality can aid in-stream processes and functioning. In terms of understanding water quality conditions and the response of ecosystems, the PSR model can be regarded under three components:

1. Influencing factors on the development of conditions (Pressure);
2. Overall eutrophic (nutrient enriched) condition within a water body (State); and
3. Future outlook for conditions within the system (Response).

Based on the above, the overall aims of the audit were to identify whether catchment scale factors and impacts were influencing the water quality of receiving waterways, what their current conditions are, and what conclusions can be drawn from the data on future trends.

5.1.3 Management and surveillance

The SCA's Water Monitoring Program covers routine, targeted, investigative, and event-based monitoring over the SCA's area of operations in the Catchment and includes the following:

- Catchments (streams and rivers);
- Storages (dams and lakes) and raw water supplies;
- Delivery systems - inlets to WFPs, transfer canals and pipelines;
- Rivers and streams downstream of water supply dams and weirs;
- Picnic area water supplies;
- Dam seepage and mining impacts; and
- Groundwater.

The program (SCA 2010b; 2011d) includes the monitoring of both water quality and quantity. This is achieved through the measurements of hydrological and meteorological parameters (to assess water quantity) and several physico-chemical and biological parameters (to assess water quality).

This Water Monitoring Program provides the basis for the SCA to assess the impacts and effectiveness of management activities, to ensure that the information collected meets regulatory compliance and operational needs. This program also provides assurance to SCA's customers, stakeholders, and regulators that the SCA has sufficient information to effectively maintain the drinking water supply catchments, and operate the raw water supply system in order to deliver high quality water to SCA's customers, and the environment, meeting regulatory specifications.

Regulatory framework

Several pieces of legislation and accompanying regulations underpin the SCA's Water Monitoring Program. These include the following (SCA 2010b):

- SCA Operating Licence, *SWCMA 1998* (Part 3);
- SCA's Water Management Licences and Approvals package and subsequent translation to Water Sharing Plan, Water Management Act (Part 4);
- Memorandum of Understanding (MoU) between NSW Health and the SCA (Clauses 6.1.6 and 6.2) *SWCMA 1998* (Part 4);
- Raw water Supply Agreements (BWSAs), *SWCMA 1998* (Part 3); and
- Water Act 2007 (Commonwealth) and water regulations.

Water quality standards

Australian Drinking Water Guidelines (ADWG)

The standard of water quality to be supplied to customers is determined by the Australian Drinking Water Guidelines (NHMRC 2011), which applies to any drinking water, irrespective of the source (e.g. municipal supplies, rainwater tanks, bores), or where it is consumed.

The ADWG are guided by the standards set by the World Health Organization (WHO 2011), which recommends integrating a risk assessment and risk management approach that covers all stages in a drinking water supply with preventive measures at all barriers from 'catchment-to-consumer'. This approach involves identifying and assessing risks to drinking water supplies, planning to minimise those risks, implementing priority actions to address the risks, and reviewing the effectiveness of actions taken to mitigate the risks. Implementing the ADWG framework involves two different types of guideline values:

- A health related guideline value, which is the concentration of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption; and
- An aesthetic guideline, which is the concentration of a water quality characteristic associated with acceptability of water to the consumer, e.g. appearance, taste, and odour.

In accordance with the SCA's Operating Licence, health related water quality characteristics are assessed against the health guideline values in the ADWG. Other physical/chemical parameters are monitored at the inflows to WFPs prior to water treatment processes, against site-specific standards, based on the treatment capabilities of each plant, and historical water quality from that catchment, as specified in the relevant Raw water Supply Agreements (BWSAs). Aesthetic guidelines under the ADWG apply for picnic area supplies.

Relevant guideline values are discussed below.

Ecosystem water quality

The benchmarks used in assessing the ecosystem water quality conditions in catchment streams are given in Table 5-1. These were derived from ANZECC (2000) Guidelines, and all except the guidelines for conductivity, Ammonium-N, Oxides of N, SRP, Aluminium and Iron are listed as such in the SCA's Water Monitoring Program (SCA 2010b).

Table 5-1 Benchmarks for catchment sites

Analyte	Units	Benchmark range
Chlorophyll-a	µg/L	< 5.0
pH	pH units	6.5 – 8.0
Conductivity	mS/cm	0.350
Dissolved Oxygen	%sat	90 - 110
Turbidity	NTU	2 – 25
Ammonium-N	mg/L	< 0.013
Oxidised-N (NOx)	mg/L	< 0.015
Total Nitrogen	mg/L	< 0.250
Soluble Reactive Phosphorus (SRP)	mg/L	< 0.015
Total Phosphorus	mg/L	< 0.020
Total Aluminium	mg/L	0.055
Total Iron	mg/L	NA

Raw water quality

Benchmarks for water storage dams and reservoirs are derived from the guidelines for freshwater lakes and reservoirs, as specified (by ANZECC 2000) for the 95-99% level of species protection.

Table 5-2 Benchmarks for storages

Analyte	Units	Benchmark range
Dissolved Oxygen	% saturation	90 – 110
pH	pH units	6.5 – 7.5
Turbidity	NTU	< 20.0
Total Manganese	mg/L	< 1.9
Total Aluminium	mg/L	< 0.055
Total Phosphorus	mg/L	< 0.01
Total Nitrogen	mg/L	< 0.35
Chlorophyll-a	µg/L	< 5

5.1.4 Methodology

Water quality data were obtained from the SCA long-term monitoring sites in the Catchment and from storages, along with information on BWSAs. The 2013 Audit examined the following 12 water quality parameters as indicators of conditions in the waterways within the Catchment:

- Algal indicators – Chlorophyll-a;
- Physico-chemical indicators – Turbidity, pH, Electrical Conductivity and Dissolved Oxygen;
- Nutrient indicators – Ammonium-N; Oxidised Nitrogen (NOx); Total Nitrogen (TN); Soluble Reactive Phosphorus (SRP); and Total Phosphorus (TP); and,
- Metal indicators – Total Aluminium and Total Iron.

The audit methodology for ecosystem and raw water quality indicators for this Audit involved analysing water quality data from the SCA, as described below:

- The water quality data were divided into a 3-year period (2010-13) to enable comparisons of the current audit period to historical data. For data values reported as less than detection limit, values of half of the detection limit were applied, as per previous audits and ANZECC (2000) guidelines. A preliminary review was carried out to determine any extreme outliers or obvious erroneous data values using box-plots. Extreme outliers were removed from the dataset if it was anticipated that they will add 'noise' to the analyses. Obvious errors in data values were rectified, where possible, or removed from further analyses.
- For each monitoring site summary statistics (i.e. means, medians, standard deviations, standard errors, ranges, and percentiles - 25th, 50th and 80th) were calculated to enable comparisons to water quality guidelines and ascertain trends over time. Data were also aggregated in successively higher spatial scales (e.g. waterways and sub-catchments), to enable conditions to be compared between waterways in different sub-catchments.
- In addition to the comparisons of the water quality to the ANZECC (2000) water quality guidelines, or BWSA Guidelines, statistical trend analyses were carried out to determine if there has been any significant increasing or decreasing trends overtime. Initially, long term trends in the data were visually examined by producing time series plots with a LOWESS line of best fit (see Section 5.4).
- Tests for significance of any trends were carried out using the software package WQ Stats Plus (Sanitas Technologies, Kansas USA). The trend analyses calculated a Seasonal Kendall statistic that was subsequently assessed for significance. The Seasonal Kendall test is a generalization of the Mann-Kendall test and accounts and corrects for natural seasonal variation in variables of interest.
- Interpretation of data and results from the analyses were made by comparing results from the current audit period to those found in previous audits. These included the 2010 audit report, indicators for the drinking water catchment (NOW 2009) and existing policies, legislation and regulations.

Ratings were applied to each indicator, with colour coding, based on the following categories:

Ratings	Descriptor
Extremely Poor	When all samples exceeded the ANZECC Guideline value for a parameter (i.e. the minimum value was greater than the ANZECC Guideline value);
Very poor	When more than 75% of samples exceeded the ANZECC Guideline value for a parameter;
Poor	When more than 50% of samples exceeded the ANZECC Guideline value for a parameter;
Fair	When more than 20% of samples exceeded the ANZECC Guideline value for a parameter
Good	When less than 20% of samples exceeded the ANZECC Guideline value for a parameter
Very good	When all samples were below the ANZECC Guideline value for a parameter (i.e. the maximum value was less than the ANZECC Guideline value)

5.1.5 Findings

A full list of routine catchment monitoring sites and storages assessed during the 2013 Audit, descriptive statistics of the analysed data, and the results from the analyses summarised below can be found in Volume 2 - Appendix H of this Report. This also provides detailed comparisons of water quality parameters, over time, for catchment sites (Appendix H - Section 8.2); storages (Appendix H - Section 8.3). Colour coding provided in the tables indicates the rating given. Box plots for individual parameters are provided to demonstrate the variability of results on the prescribed water quality parameters (see Appendix H - Sections 8.4 and 8.5).

Selected water quality indicators assessed during the current audit period are summarised below according to their greater catchment boundaries (e.g. Warragamba, Upper Nepean, Woronora, and Shoalhaven – see Table 1.1). As in the previous audit (DECCW 2010a), the 2013 Audit also placed a greater emphasis on nutrients (i.e. Ammonia (NH3-N), Nitrogen Oxides (NOx), TN, Soluble Reactive Phosphorus (SRP) and TP), electrical conductivity and Chl-a, as key indicators of eutrophication and the increasing salinisation of waterways.

All values discussed in the following sections in Table 5-3, Table 5-4 with respect of individual catchments and waterways, and in Table 5-5 and Table 5-6 for storages - are median values, based on available data for each monitored site, during the current audit period (July 2010 to June 2013). Colour coding provided in the tables indicates the rating given.

Ecosystem water quality - Findings

Catchment Sites - Chlorophyll-a (Chl-a)

Warragamba Catchment

- The highest Chl-a concentration was in the Wingecarribee River at Berrima (E332 - 28.4 µg/L; rated very poor). Relatively high Chl-a concentrations were also recorded in the Mulwaree River at Towers Weir (E457 – 8.3 µg/L), the Wollondilly River at Murrays Flat (E409 – 7.0 µg/L) and the Wollondilly River at Joorilands (E488 – 5.2 µg/L).
- In contrast, low Chl-a concentrations were recorded in the Kedumba River at Maxwells Crossing (E157 – 0.5 µg/L), Tonalli River at Fire Road W2 (E551 – 0.6 µg/L) and Little River at Fire Road W4I (E243 – 0.5 µg/L). Chl-a in the Kedumba River (E157) and Kowmung River (E130) were rated very good, with all samples below ANZECC Guideline.
- The remaining sites in the Catchment were variable with regard to Chl-a levels, and were rated from good (<20% exceeded ANZECC) to poor (>50% exceeded ANZECC).

Upper Nepean Catchment

- The highest median Chl-a concentrations were in the Nepean River at McGuires Crossing (E697 – 2.5 µg/L), Cataract River Corrimal No. 1 (E680 – 2.1 µg/L) and the Nepean River at the inflow to Lake Nepean (E601 – 1.1 µg/L). All other sites in the Upper Nepean River Catchment had Chl-a concentrations < 0.6 µg/L.
- Most sites were rated as good with less than 20% of samples exceeding the ANZECC Guideline. In the Burke River (E602), Flying Fox No. 3 Creek (E604), and Goondarin Creek (E610), all samples complied with the Guideline and these sites were rated as very good.

Woronora Catchment

- Chl-a levels in the Woronora Catchment were relatively low during the current audit (range of 1.0 to 2.0 µg/L) and the Catchment was rated as very good with all samples less than the ANZECC Guideline.

Shoalhaven Catchment

- Chl-a tended to be elevated at the Shoalhaven Catchment sites (range: 1.7 - 4.0 µg/L). The highest Chl-a concentration was in Boro Creek at Marlowe (E890 - 4.0 µg/L); and lowest at the Shoalhaven River at Mount View (E860 - 1.7 µg/L).
- Nevertheless, most sites in the Shoalhaven Catchment were rated as good with <20% of samples exceeding the ANZECC Guideline. The Boro Creek (E890) and the Shoalhaven River (E861) were rated as fair with >20% of samples exceeding the ANZECC Guideline.

Catchment Sites - Electrical Conductivity (EC)

Warragamba Catchment

Overall, with regard to EC levels, most sites in the Warragamba Catchment were rated as good (<20% of samples exceeding ANZECC), or fair (> 20% of samples exceeding ANZECC).

- The highest conductivity was in the Mulwaree River at Towers Weir (E457 – 0.871 mS/cm) and the Wollondilly River at Murrays Flat (E409 – 0.728 mS/cm).
- Relatively high conductivity was also recorded in the Wollondilly River at Golden Valley (E450) and Joorilands (E488), Werriberri Creek at Werombi (E531), Gibbergunyah Creek at the Mittagong STP and the Nattai River at The Crags (E206) with conductivities ranging from 0.333 to 0.499 mS/cm.
- Low conductivities were in the Kowmung River at Cedar Ford (E130 – 0.077 mS/cm), Kedumba River at Maxwells Crossing (E157 – 0.084 mS/cm); these sites were rated as very good with all samples less than the ANZECC Guideline.

Upper Nepean Catchment

- EC was relatively low in the Upper Nepean Catchment with the highest concentration in Sandy Creek at Fire Road 6C (E6006 – 0.243 mS/cm). This site was rated fair with more than 20% of samples exceeding ANZECC.
- All other sites in the Upper Nepean Catchment had conductivities < 0.139 mS/cm, and were rated as very good with no samples exceeding the ANZECC Guideline.

Woronora Catchment

- EC levels were also relatively low in the Woronora Catchment with the Woronora River Inflow (E677) and the Waratah River at Flatrock Crossing (E6131) both having a median conductivity of 0.180 mS/cm; these sites were rated as very good.

Shoalhaven Catchment

- EC levels were relatively consistent and low amongst sites in the Shoalhaven Catchment with concentrations ranging from 0.090 to 0.118 mS/cm. All sites in the Shoalhaven Catchment were rated as very good with all samples less than the ANZECC Guideline.

Catchment Sites - Total Nitrogen (TN)

Warragamba Catchment

- TN levels were high in the Warragamba Catchment with all samples from Gibbergunyah Creek (E203), Nattai River at the Crags (E206), Wingecarribee River (E332), Wollondilly River at Murrays Flat and Golden Valley (E409 and E450), and the Mulwaree River (E457) exceeding the ANZECC Guideline. These sites were rated as extremely poor.

- Farmers Creek (E046), the Nattai River at Smallwoods Crossing (E210) and the Wollondilly River at Joorilands (E488) were rated as very poor with >75% of samples exceeding ANZECC. The highest TN concentration was at Farmers Creek downstream of the Lithgow STP (E046 – 1.94 mg/L) followed by Gibbergunyah Creek at the Mittagong STP (E203 – 1.89 mg/L) and the Nattai River at the Crags (E206 – 1.05 mg/L).
- Relatively high concentrations of TN were also recorded from all sites on the Wollondilly River (TN ranged from 0.46 to 0.62 mg/L), the Wingecarribee River at Berrima (E332 – 0.725 mg/L) and the Mulwaree River at Towers Weir (E457 - 0.91 mg/L).
- All other sites in the Warragamba Catchment had TN concentrations < 0.350 mg/L and were rated from good to poor.

Upper Nepean Catchment

- The highest TN concentration was in the Nepean River at McGuires Crossing (E697 – 0.53 mg/L) and at the inflow to Lake Nepean (E601 – 0.475 mg/L). These sites were rated as very poor with more than 75% of samples exceeding the ANZECC Guideline.
- Relatively high TN concentrations were also recorded in Sandy Creek at Fire Road 6C (E6006 – 0.33 mg/L), Flying Fox No.3 Creek at Upper Avon (E604 – 0.26 mg/L) and the Avon River at Summit Tank (E608 – 0.25 mg/L).
- All other sites in the Upper Nepean Catchment had low TN concentrations (< 0.18 mg/L) and the ratings varied from good to poor.

Woronora Catchment

- The highest TN concentration was in the Waratah River at Flatrock Crossing (E6131 – 0.21 mg/L), followed by the Woronora River Inflow (E677 – 0.15 mg/L). Both of these sites were rated as fair for TN (> 20% of samples exceeding the ANZECC guideline).

Shoalhaven Catchment

- TN was relatively high at all sites in the Shoalhaven Catchment (range: 0.25 - 0.55 mg/L). The highest TN concentration was in the Shoalhaven River at Mount View (E860 – 0.55 mg/L) and the lowest in the Shoalhaven River at Fossickers Flat (E847 – 0.25 mg/L).
- The Kangaroo River (E706) and the Shoalhaven River (E861 and E860) were rated as very poor for TN with > 75% of samples exceeding the ANZECC Guideline.
- All other sites were rated as either fair or poor.

Catchment Sites - Total Phosphorus (TP)

Warragamba Catchment

- The highest TP concentration was in Farmers Creek downstream of the Lithgow STP (E046 – 0.08 mg/L) and Gibbergunyah Creek at the Mittagong STP (E203 – 0.078 mg/L). The TP concentration of Gibbergunyah Creek, downstream of the STP was rated as extremely poor with all samples exceeding the ANZECC Guideline.
- Relatively high TP concentrations were also recorded from the Wingecarribee River at Berrima (E332 – 0.038 mg/L), Wollondilly River at Murrays Flat (E409 – 0.034 mg/L, rated poor) and Mulwaree River at Towers Weir (E457 - 0.033 mg/L). All three sites were rated as very poor with more than 75% of samples exceeding the ANZECC Guideline.
- All other sites in the Warragamba Catchment had low TP concentrations (<0.022 mg/L), and were rated as good, fair or poor.

Upper Nepean Catchment

- Most sites in the Upper Nepean Catchment were rated as fair for low TP concentrations (range: 0.009 - 0.018 mg/L) with only >20% of samples exceeding the ANZECC Guideline. The Burke River (E602), Goondarin Creek (E610), and the Cataract River (E680) were rated as good with < 20% of samples exceeding ANZECC.

Woronora Catchment

- The TP concentrations were relatively low for both sites (E677 and E6131) in the Woronora Catchment (range: 0.01 - 0.012 mg/L). The Woronora River Site E677 was rated as good for TP with <20% of samples exceeding ANZECC, and the Waratah River (E6131) was rated as fair with > 20% recordings exceeding ANZECC.

Shoalhaven Catchment

- TP concentrations were variable and high at sites in the Shoalhaven Catchment. The highest TP concentration was in the Shoalhaven River at Mount View (E860 – 0.061 mg/L), and the lowest in the Shoalhaven River at Fossickers Flat (E847 – 0.015 mg/L).
- Overall, most sites in the Shoalhaven Catchment were rated as very poor for TP concentrations with >75% of samples exceeding the ANZECC Guideline. The exception was for the Shoalhaven River at Fossickers Flat, rated as fair with much less number of samples exceeding ANZECC.

Overall, the above results from SCA's catchment monitoring sites indicated that nutrients continue to be elevated above ANZECC Guidelines in several catchments and sub-catchments. The variability in the data on different water quality parameters largely reflect local conditions, and is shown in the box plots (see Section 8.4 in Volume 2 - Appendix 8.4).

The immediate impacts of STP releases on downstream environments were also evident with the results at Farmers Creek - downstream of Lithgow STP (Site E046) and Gibbergunyah Creek - downstream of Mittagong STP (Site E203).

Storage Sites – Chlorophyll-a (Chl-a)

Warragamba Catchment

- Chl-a level were variable in the storages of the Warragamba Catchment. The highest Chl-a concentration was recorded at the Wingecarribee Lake outlet (DWI1 – 11.7 µg/L). This site was rated very poor with >75% of samples exceeding the ANZECC Guideline.
- Sites associated with Lake Burragorang also had relatively high Chl-a (range: 2.5 - 7.4 µg/L). In particular, Chl-a levels were consistently high in the Kedumba Arm of Lake Burragorang (DWA19), which received a very poor rating.

Blue Mountains Catchment

- Chl-a levels were low in the Blue Mountains storages, which were rated as good for all sites with <20% of samples exceeding the ANZECC Guideline. The highest median Chl-a concentration was in Lake Top Cascade (DTC1 – 2.9 µg/L), followed by Lake Cascade No. 2 (DLC1 – 2.5 µg/L) and Greaves Creek (DGC1 – 2.2 µg/L).

Upper Nepean Catchment

- Low Chl-a characterised the Upper Nepean storages with all sites ranging from 2.3 to 4.1 µg/L, and most sites, rated good. The highest Chl-a concentration was in Lake Cordeaux (DCO1 – 4.1 µg/L, rated fair (with >20% samples above ANZECC), and the lowest in Lake Avon (DAV1 – 2.3 µg/L).

Woronora Catchment

- Low Chl-a concentrations also characterised Lake Woronora (median Chl-a 0.8 µg/L at the Lake Woronora dam wall, DWO1), which was rated as good with <20% of samples exceeding the ANZECC Guideline.

Shoalhaven Catchment

- Much lower Chl-a concentrations were recorded from Lake Yarrunga sites DTA 1, DTA3, DTA5 and DTA8 with median values ranging from 2.5 to 5.0 µg/L, these sites were rated as fair with >20% of samples exceeding the ANZECC Guideline. There was one exception - Site DTA3, Lake Yarrunga at the Kangaroo and Yarrunga junction, where Chl-a levels were rated as poor with >50% of samples exceeding ANZECC.

Storage Sites - Electrical Conductivity (EC)

Warragamba Catchment

- EC levels were low in the storages of the Warragamba Catchment (and rated very good with all results below ANZECC Guidelines). The median EC ranged from 0.076 mS/cm at the Lake Wingecarribee Outlet (DWI1) to 0.194 mS/cm in Lake Burragorang at the Wollondilly Arm (DWA39).

Blue Mountains Catchment

- Similarly, EC levels were relatively low in the Blue Mountains storages (and rated very good) with the lowest conductivity at Greaves Creek near the offtake (DGC1 – 0.018 mS/cm) and the highest at Cascade No. 2 (DLC1 – 0.071 mS/cm).

Upper Nepean Catchment

- Low EC levels characterised the Upper Nepean storages, which were rated as very good with all samples below the ANZECC Guideline. The highest EC level was in Lake Cordeaux (DCO1 - 0.10 mS/cm). All other Upper Nepean storages had EC <0.10 mS/cm.

Woronora Catchment

- Lake Woronora (DWO1) also recorded a low EC level (median EC 0.108 mS/cm). All results were below the ANZECC Guideline and the storage was rated as very good.

Shoalhaven Catchment

- Low EC levels were evident in Lake Yarrunga as well, and all sites were rated as very good with all samples below the ANZECC Guideline (range from 0.078 to 0.102 mS/cm).

Storage Sites - Total Nitrogen (TN)

Warragamba Catchment

- TN concentrations in the storages of the Warragamba Catchment were generally high. The sites were mostly rated as either fair (>20% of samples exceeding ANZECC Guideline) or poor (>50% exceeding ANZECC).
- Three Lake Burragorang sites (DWA21, DWA27, and DWA39) were rated as very poor with more than 75% of samples exceeding ANZECC. The highest TN concentration was in the Wollondilly Arm (DWA39 – 0.58 mg/L). Sites DWA27 and DWA311 – also located on the Wollondilly Arm – had high TN concentrations ranging from 0.41 to 0.44 mg/L.
- The minimum TN concentration recorded in the Warragamba Catchment was 0.31 mg/L at the Wingecarribee Dam Outlet (DWI1).

Table 5-3 Chlorophyll-a and select physico-chemical parameters measured at catchment sites

Site	Site name	Sub-catchment	Water Quality Parameter				
			Chl-a (mg/L)	pH	EC (mS/cm)	DO (% Sat)	Turbidity (NTU)
E046	Farmers Creek d/s Lithgow STP	Upper Cox	3.2 (N=59)	7.4 (N=56)	0.210 (N=56)	94.1 (N=56)	4.7 (N=56)
E083	Coxs River at Kelpie Point	Mid Coxs	2.0 (N=36)	7.5 (N=36)	0.163 (N=36)	98.9 (N=36)	3.6 (N=36)
E157	Kedumba River at Maxwells Crossing	Lower Coxs	0.5 (N=36)	7.2 (N=36)	0.084 (N=36)	95.7 (N=36)	2.4 (N=33)
E130	Kowmung River at Cedar Ford	Kowmung	1.1 (N=36)	7.4 (N=36)	0.077 (N=36)	97.5 (N=36)	3.1 (N=33)
E550	Tonalli River at Fire Road W1B	Lake Burragorang	NA	6.8 (N=45)	0.110 (N=45)	96.8 (N=44)	15.4 (N=44)
E551	Tonalli River at Fire Road W2	Lake Burragorang	0.6 (N=26)	7.0 (N=129)	0.240 (N=129)	92.2 (N=98)	2.2 (N=127)
E552	Tonalli River at Cemetery	Lake Burragorang	NA	6.8 (N=45)	0.108 (N=45)	96.8 (N=44)	15.4 (N=44)
E531	Werriberri Creek at Werombi	Werriberri	1.9 (N=36)	7.1 (N=36)	0.389 (N=36)	83.3 (N=36)	4.4 (N=34)
E243	Little River at Fireroad W4I	Little	0.5 (N=36)	6.8 (N=36)	0.134 (N=36)	93.1 (N=36)	1.8 (N=33)
E203	Gibbergunyah Creek at Mittagong STP	Nattai	3.1 (N=36)	7.5 (N=36)	0.390 (N=36)	87.7 (N=36)	4.4 (N=33)
E206	Nattai River at The Crags	Nattai	2.3 (N=36)	7.7 (N=36)	0.333 (N=36)	97.4 (N=36)	1.8 (N=34)
E210	Nattai River at Smallwoods Crossing	Nattai	2.3 (N=36)	7.2 (N=36)	0.289 (N=36)	89.1 (N=36)	7.0 (N=33)
E332	Wingecarribee River at Berrima	Wingecarribee	28.4 (N=36)	7.5 (N=36)	0.201 (N=36)	90.1 (N=36)	13.1 (N=34)
E409	Wollondilly River at Murrays Flat	Wollondilly	7.0 (N=36)	7.5 (N=36)	0.728 (N=36)	83.5 (N=36)	3.0 (N=34)
E450	Wollondilly River at Golden Valley	Wollondilly	2.8 (N=36)	7.9 (N=36)	0.499 (N=36)	92.3 (N=36)	2.4 (N=34)
E457	Mulwaree River at Towers Weir	Mulwaree	8.3 (N=36)	7.8 (N=36)	0.871 (N=36)	82.7 (N=36)	3.3 (N=34)
E488	Wollondilly River at Joorilands	Wollondilly	5.2 (N=36)	7.8 (N=36)	0.360 (N=36)	98.8 (N=36)	10.1 (N=34)
E601	Nepean River at Inflow to Lake Nepean	Upper Nepean	1.1 (N=36)	7.4 (N=36)	0.107 (N=36)	103.3 (N=36)	2.6 (N=36)
E602	Burke River at Inflow to Lake Nepean	Upper Nepean	0.4 (N=36)	6.7 (N=36)	0.077 (N=36)	103.7 (N=36)	1.5 (N=36)
E697	Nepean River at McGuires Crossing	Upper Nepean	2.5 (N=36)	7.3 (N=36)	0.096 (N=36)	99.4 (N=36)	4.4 (N=36)
E6006	Sandy Creek at Fire Road 6C	Upper Nepean	0.6 (N=26)	7.0 (N=129)	0.243 (N=129)	92.2 (N=98)	2.2 (N=127)
E604	Flying Fox No.3 Creek at Upper Avon	Upper Nepean	0.4 (N=80)	7.1 (N=74)	0.139 (N=74)	99.0 (N=74)	0.5 (N=74)
E608	Avon River at Summit Tank	Upper Nepean	0.4 (N=154)	7.0 (N=153)	0.130 (N=175)	96.9 (N=153)	0.5 (N=175)

Table 5-3 (cont.) Chlorophyll-a and select physico-chemical parameters measured at catchment sites

Site	Site name	Sub-catchment	Water Quality Parameter				
			Chl-a (mg/L)	pH	EC (mS/cm)	DO (% Sat)	Turbidity (NTU)
E609	Cordeaux River Crossing at Cordeaux No.1	Upper Nepean	0.4 (N=40)	7.0 (N=37)	0.139 (N=37)	98.3 (N=37)	1.8 (N=37)
E610	Goondarin Creek at Vent Shaft	Upper Nepean	0.3 (N=76)	7.0 (N=81)	0.094 (N=81)	98.5 (N=81)	0.5 (N=81)
E680	Cataract River Corrimal No. 1	Upper Nepean	2.1 (N=78)	7.1 (N=74)	0.101 (N=74)	98.2 (N=74)	0.5 (N=74)
E677	Woronora River Inflow	Woronora	0.1 (N=43)	6.0 (N=63)	0.180 (N=60)	100.1 (N=63)	1.0 (N=62)
E6131	Waratah River at Flatrock Crossing	Woronora	0.3 (N=40)	7.3 (N=36)	0.180 (N=36)	99.0 (N=36)	2.0 (N=36)
E706	Kangaroo River at Hampden Bridge	Kangaroo River	2.5 (N=80)	7.2 (N=97)	0.097 (N=93)	105.0 (N=96)	4.5 (N=97)
E847	Shoalhaven River at Fossickers Flat	Bungonia	2.1 (N=41)	7.5 (N=43)	0.104 (N=39)	102.8 (N=43)	3.2 (N=43)
E890	Boro Creek at Marlowe	Boro Creek	4.0 (N=43)	6.5 (N=41)	0.118 (N=38)	64.8 (N=41)	5.5 (N=41)
E861	Shoalhaven River at Hillview	Mid Shoalhaven	3.8 (N=39)	7.5 (N=52)	0.113 (N=49)	101.9 (N=52)	4.7 (N=52)
E822	Mongarlowe River at Mongarlowe	Mongarlowe	NA	NA	NA	NA	NA
E891	Gillamatong Creek at Braidwood	Braidwood Creek	NA	NA	NA	NA	NA
E860	Shoalhaven River at Mount View	Braidwood Creek	1.7 (N=42)	7.5 (N=64)	0.090 (N=61)	100.3 (N=64)	4.6 (N=64)

Table 5-4 Nutrients - Ammonia-N, NOx, TN, SRP and TP measured at catchment sites

Site	Site name	Sub-catchment	Water Quality Parameter				
			NH_3 (mg/L)	NOx (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
E046	Farmers Creek d/s Lithgow STP	Upper Cox	0.020 (N=59)	1.11 (N=59)	1.94 (N=59)	0.04 (N=59)	0.080 (N=59)
E083	Coxs River at Kelpie Point	Mid Coxs	0.002 (N=36)	0.012 (N=36)	0.200 (N=36)	0.006 (N=36)	0.014 (N=36)
E157	Kedumba River at Maxwells Crossing	Lower Coxs	0.002 (N=36)	0.217 (N=36)	0.300 (N=36)	0.004 (N=36)	0.009 (N=36)
E130	Kowmung River at Cedar Ford	Kowmung	0.002 (N=36)	0.049 (N=36)	0.160 (N=36)	0.006 (N=36)	0.014 (N=36)
E550	Tonalli River at Fire Road W1B	Lake Burragorang	NA	NA	0.270 (N=46)	NA	0.015 (N=46)
E551	Tonalli River at Fire Road W2	Lake Burragorang	0.002 (N=26)	0.048 (N=26)	0.330 (N=161)	0.004 (N=26)	0.014 (N=161)
E552	Tonalli River at Cemetery	Lake Burragorang	NA	NA	0.265 (N=46)	NA	0.015 (N=46)
E531	Werriberri Creek at Werombi	Werriberri	0.007 (N=37)	0.062 (N=37)	0.250 (N=37)	0.004 (N=37)	0.012 (N=37)
E243	Little River at Fireroad W4I	Little	0.002 (N=36)	0.005 (N=36)	0.065 (N=36)	0.004 (N=36)	0.009 (N=36)
E203	Gibbergunyah Creek at Mittagong STP	Nattai	0.037 (N=36)	1.315 (N=36)	1.890 (N=36)	0.015 (N=36)	0.078 (N=36)
E206	Nattai River at The Crags	Nattai	0.002 (N=36)	0.788 (N=36)	1.050 (N=36)	0.010 (N=36)	0.022 (N=36)
E210	Nattai River at Smallwoods Crossing	Nattai	0.011 (N=36)	0.084 (N=36)	0.350 (N=36)	0.004 (N=36)	0.011 (N=36)
E332	Wingecarribee River at Berrima	Wingecarribee	0.011 (N=36)	0.106 (N=36)	0.725 (N=36)	0.003 (N=36)	0.038 (N=36)
E409	Wollondilly River at Murrays Flat	Wollondilly	0.002 (N=35)	0.008 (N=35)	0.620 (N=35)	0.010 (N=35)	0.034 (N=35)
E450	Wollondilly River at Golden Valley	Wollondilly	0.002 (N=35)	0.005 (N=35)	0.500 (N=35)	0.003 (N=35)	0.014 (N=35)
E488	Wollondilly River at Joorilands	Wollondilly	0.002 (N=36)	0.008 (N=36)	0.460 (N=36)	0.004 (N=36)	0.016 (N=36)
E457	Mulwaree River at Towers Weir	Mulwaree	0.013 (N=35)	0.005 (N=35)	0.910 (N=35)	0.009 (N=35)	0.033 (N=35)
E601	Nepean River at Inflow to Lake Nepean	Upper Nepean	0.002 (N=36)	0.308 (N=36)	0.475 (N=36)	0.004 (N=36)	0.012 (N=36)
E602	Burke River at Inflow to Lake Nepean	Upper Nepean	0.002 (N=36)	0.004 (N=36)	0.075 (N=36)	0.003 (N=36)	0.010 (N=36)
E697	Nepean River at McGuires Crossing	Upper Nepean	0.006 (N=36)	0.381 (N=36)	0.530 (N=36)	0.005 (N=36)	0.018 (N=36)
E6006	Sandy Creek at Fire Road 6C	Upper Nepean	0.002 (N=26)	0.048 (N=26)	0.330 (N=161)	0.004 (N=26)	0.014 (N=161)
E604	Flying Fox No.3 Creek at Upper Avon	Upper Nepean	0.002 (N=77)	0.138 (N=77)	0.260 (N=171)	0.004 (N=77)	0.015 (N=171)
E608	Avon River at Summit Tank	Upper Nepean	0.002 (N=170)	0.146 (N=170)	0.250 (N=278)	0.002 (N=170)	0.009 (N=278)

Table 5-4 (cont.) Nutrients - Ammonia-N, NOx, TN, SRP, and TP measured at catchment sites

Site	Site name	Sub-catchment	Water Quality Parameter				
			NH_3 (mg/L)	NOx (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
E609	Cordeaux River Crossing at Cordeaux No.1	Upper Nepean	0.002 (N=40)	0.087 (N=40)	0.180 (N=71)	0.004 (N=40)	0.014 (N=71)
E610	Goondarin Creek at Vent Shaft	Upper Nepean	0.002 (N=76)	0.003 (N=76)	0.130 (N=187)	0.003 (N=76)	0.009 (N=187)
E680	Cataract River Corrimal No. 1	Upper Nepean	0.008 (N=78)	0.019 (N=78)	0.150 (N=251)	0.003 (N=78)	0.012 (N=251)
E677	Woronora River Inflow	Woronora	0.002 (N=43)	0.002 (N=43)	0.150 (N=180)	0.002 (N=43)	0.010 (N=180)
E6131	Waratah River at Flatrock Crossing	Woronora	0.002 (N=40)	0.009 (N=40)	0.210 (N=195)	0.003 (N=40)	0.012 (N=195)
E706	Kangaroo River at Hampden Bridge	Kangaroo River	0.016 (N=87)	0.167 (N=87)	0.420 (N=193)	0.009 (N=82)	0.035 (N=193)
E847	Shoalhaven River at Fossickers Flat	Bungonia	0.002 (N=41)	0.022 (N=41)	0.250 (N=44)	0.006 (N=41)	0.015 (N=44)
E890	Boro Creek at Marlowe	Boro Creek	0.002 (N=43)	0.007 (N=43)	0.300 (N=43)	0.006 (N=43)	0.030 (N=43)
E861	Shoalhaven River at Hillview	Mid Shoalhaven	0.002 (N=39)	0.008 (N=39)	0.415 (N=106)	0.006 (N=39)	0.038 (N=106)
E822	Mongarlowe River at Mongarlowe	Mongarlowe	NA	NA	NA	NA	NA
E891	Gillamatong Creek at Braidwood	Braidwood Creek	NA	NA	NA	NA	NA
E860	Shoalhaven River at Mount View	Braidwood Creek	0.002 (N=42)	0.005 (N=42)	0.550 (N=144)	0.010 (N=42)	0.061 (N=144)

Blue Mountains Catchment

- In the Blue Mountains storages TN concentrations were low at all sites. The range was 0.13 mg/L at Greaves Creek (DGC1) to 0.16 mg/L at Cascade No. 2 (DLC1). At both sites, all samples were below the ANZECC Guideline and they were rated as very good. At Lake Top Cascade (DTC1), the TN concentrations were rated as good with <20% of samples exceeding ANZECC.

Upper Nepean Catchment

- The highest TN concentration in the Upper Nepean Catchment was at Lake Nepean (DNE2 - 0.38 mg/L). TN concentrations in >50% of samples exceeded ANZECC, which resulted in a poor rating.
- TN was elevated in Lake Cordeaux (DCO1 – 0.24 mg/L). Only a small number (<20%) of samples exceeded ANZECC in Lake Cataract (DCA1) and Lake Cordeaux (DCO1), which received a rating as good.
- All samples collected from sites associated with Lake Avon (DAV1 and DAV7) were below the ANZECC Guideline these sites were rated as very good for TN.

Woronora Catchment

- The median TN concentration at Lake Woronora (DWO1) was 0.2 mg/L. The storage was rated as good with <20% of samples exceeding ANZECC for TN concentrations.

Shoalhaven Catchment

- TN levels were relatively high at all sites in the storages of the Shoalhaven Catchment. The levels ranged from 0.31 mg/L at Lake Fitzroy Falls (DFF6) to 0.43 mg/L at Lake Yarrunga at the Shoalhaven River (DTA5).
- The TN concentrations at all storage sites in the Shoalhaven Catchment were rated as either fair (>20% of samples exceeding the ANZECC Guideline) or poor (>50% of samples exceeding ANZECC). One exception was at Lake Fitzroy Falls (DFF6), which received a rating of good (TN levels in <20% of samples exceeding ANZECC).

Storage Sites - Total Phosphorus (TP)

Warragamba Catchment

- In the storages of the Warragamba Catchment, TP concentrations were somewhat elevated, at most sites. The highest TP level was at the Lake Wingecarribee Outlet (DWI1 – 0.02 mg/L), rated as poor with >75% of samples exceeding ANZECC.
- In addition, despite relatively low median values, three sites on Lake Burragorang (DWA19, DWA21 and DWA39) received poor to very poor ratings with >50% or >75% samples recording TP levels above the ANZECC Guideline.
- All other sites had median TP concentrations ranging from 0.007 to 0.018 mg/L and most sites were rated as fair with >20% of samples exceeding the ANZECC Guideline.

Blue Mountains Catchment

- In the Blue Mountains Catchment TP concentrations ranged from 0.006 mg/L at Lake Top Cascade (DTC1) and Cascade No. 2 (DLC1) to 0.008 mg/L at Greaves Creek (DGC1).
- TP concentrations at Lake Top Cascade (DTC1) were rated as good with <20% of samples exceeding the ANZECC Guideline. TP levels at Cascade No. 2 (DLC1) and Greaves Creek (DGC1) were rated as fair with >20% of samples exceeding ANZECC.

Upper Nepean Catchment

- In the Upper Nepean storages, TP concentrations for all sites were low and ranged from 0.002 to 0.011 mg/L. At most sites TP was rated as either fair (>20% of samples exceeding ANZECC Guideline) or good (<20% of samples exceeding ANZECC), although Lake Nepean (DNE2) was rated as poor with >50% results exceeding ANZECC.

Woronora Catchment

- The median TP concentration at Lake Woronora (DWO1) was 0.006 mg/L. The storage was rated as good with <20% of samples exceeding ANZECC for TP concentrations.

Shoalhaven Catchment

- TP levels were relatively high at all sites in the storages of the Shoalhaven Catchment. The highest TP concentration was at the Kangaroo Valley WFP (DBP1 – 0.031 mg/L) and in Lake Yarrunga at the Kangaroo River (DTA8 – 0.031 mg/L). The lowest concentration was at Lake Fitzroy Falls (DFF6 – 0.013 mg/L).
- The Lake Fitzroy Falls site (DFF6) was rated as poor with >50% of samples exceeding the ANZECC Guideline. Three of the Lake Yarrunga sites (DTA3, DTA1 and DTA5) were rated as very poor with >75% of samples exceeding ANZECC.
- Importantly, TP levels at the Kangaroo Valley WFP (DBP1) and Lake Yarrunga on the Kangaroo River (DTA8) were rated as extremely poor with all samples exceeding the ANZECC Guideline.

Overall, the above results indicated that nutrients continue to be elevated well above ANZECC Guidelines in the storages of several catchments and sub-catchments.

The variability of the dataset is indicated in the box plots (see Volume 2 Appendix H Section 8.4), and the trends of elevated nutrients in the storages is further discussed in Section 5.4. Elevated nutrient levels will continue to pose a threat of increased eutrophication in the storages, manifested by increased algal productivity.

Implications - Ecosystem water quality

The Auditor notes that generalisations on the ecosystem water quality that have been made above, based on available monitoring data and the limited number of long-term monitoring sites may not necessarily provide an accurate description of the state of water quality in all rivers and streams within a sub-catchment.

As evident from the results, water quality is quite variable across the Catchment, and these reflect variability in geology, land-use, and a variety of in-stream processes, which occur in waterways. As discussed in Section 3 of this Report, the geomorphology of the Catchment has also been significantly modified in many areas by structures, such as dams and weirs, and by streambank and gully erosion. A number of areas in the Catchment continue to be somewhat poor in water quality, when assessed against ANZECC (2000) Guidelines for ecosystem protection.

In assessing the data and information provided by multiple stakeholders, the Auditor notes the significant progress that has been made by the SCA, other government agencies, industry and community groups, including HNCMA, SRCMA, OEH, DPI, EPA and Local Councils to improve catchment conditions through various management interventions. These have been assessed and recorded in other sections of this Report.

Sub-catchments that require continuing management interventions to improve water quality at sub-catchments sites include; the Warragamba Catchment, the Upper Nepean Catchment and the Shoalhaven Catchment.

Table 5-5 Chlorophyll-a and select physico-chemical parameters measured at storage sites

Site	Site name	Sub-catchment	Water Quality Parameter				
			Chl-a (mg/L)	pH	EC (mS/cm)	DO (% Sat)	Turbidity (NTU)
DWA15	Lake Burragorang at Coxs River Arm 4 km u/s Butchers Creek	Lower Coxs	4.7 (N=130)	7.4 (N=1154)	0.146 (N=1154)	81.2 (N=1154)	3.4 (N=1154)
DWA19	Lake Burragorang at Kedumba River Arm	Lower Coxs	7.4 (N=35)	7.2 (N=122)	0.152 (N=122)	68.1 (N=122)	4.2 (N=122)
DWA21	Lake Burragorang at Coxs Arm 37 km u/s Dam	Lower Coxs	6.9 (N=35)	7.3 (N=129)	0.157 (N=129)	69.0 (N=129)	3.0 (N=129)
DWA12	Lake Burragorang at 9 km u/s Coxs River	Burragorang	2.9 (N=390)	7.3 (N=3549)	0.161 (N=3549)	63.4 (N=3549)	3.3 (N=3348)
DWA2	Lake Burragorang at 500 m u/s Dam Wall	Burragorang	2.5 (N=447)	7.2 (N=12430)	0.163 (N=12434)	58.5 (N=12325)	4.3 (N=12259)
DWA27	Lake Burragorang at Wollondilly Arm 23 km u/s Dam	Burragorang	2.8 (N=390)	7.3 (N=4082)	0.173 (N=4082)	61.1 (N=4082)	4.2 (N=3965)
DWA311	Lake Burragorang at Wollondilly Arm 300 m u/s Nattai River	Burragorang	4.7 (N=139)	7.5 (N=1151)	0.179 (N=1151)	76.3 (N=1151)	4.4 (N=1151)
DWA39	Lake Burragorang at Wollondilly Arm 40 km u/s Dam	Burragorang	5.2 (N=43)	7.4 (N=140)	0.194 (N=140)	73.2 (N=140)	4.6 (N=140)
DWA9	Lake Burragorang at 14 km u/s Dam Wall	Burragorang	2.6 (N=448)	7.3 (N=7739)	0.164 (N=7732)	64.8 (N=7734)	4.2 (N=7512)
DWI1	Wingecarribee Lake at Outlet	Wingecarribee	11.7 (N=18)	7.3 (N=412)	0.076 (N=412)	95.5 (N=412)	7.3 (N=412)
DLC1	Cascade No.2	Grose	2.3 (N=62)	7.4 (N=224)	0.072 (N=224)	87.4 (N=224)	1.5 (N=223)
DTC1	Lake Top Cascade at 100 m u/s Dam Wall	Grose	2.9 (N=175)	7.2 (N=609)	0.040 (N=609)	86.4 (N=609)	1.0 (N=607)
DGC1	Greaves Creek near Offtake	Grose	2.1 (N=135)	5.9 (N=313)	0.018 (N=159)	84.5 (N=313)	2.6 (N=313)
DCA1	Lake Cataract at Dam Wall	Upper Nepean	3.0 (N=139)	5.9 (N=313)	0.022 (N=313)	84.5 (N=313)	2.6 (N=313)
DCO1	Lake Cordeaux at Dam Wall	Upper Nepean	4.1 (N=142)	6.7 (N=1424)	0.100 (N=1424)	68.1 (N=1424)	0.5 (N=1423)
DAV1	Lake Avon at Dam Wall	Upper Nepean	2.3 (N=142)	6.6 (N=1902)	0.079 (N=1902)	82.3 (N=1902)	0.5 (N=1902)
DAV7	Lake Avon at Upper Avon Valve Chamber	Upper Nepean	3.1 (N=197)	6.8 (N=607)	0.080 (N=607)	90.8 (N=607)	0.5 (N=607)
DNE2	Lake Nepean at 300 m u/s Dam Wall	Upper Nepean	2.6 (N=134)	6.8 (N=1598)	0.092 (N=1598)	91.6 (N=1598)	0.5 (N=1598)
DBP1	Kangaroo Valley WFP Raw Water	Kangaroo	14.6 (N=60)	7.2 (N=55)	0.094 (N=55)	96.7 (N=55)	5.1 (N=55)
DFF6	Lake Fitzroy Falls at Dam Wall	Kangaroo	13.2 (N=117)	7.5 (N=269)	0.078 (N=269)	99.8 (N=269)	4.2 (N=269)
DTA3	Lake Yarrunga at Kangaroo and Yarrunga Jn.	Kangaroo	5.4 (N=41)	6.6 (N=520)	0.092 (N=520)	60.1 (N=520)	3.4 (N=520)
DTA8	Lake Yarrunga at Kangaroo River at Bendeela PS	Kangaroo	5.0 (N=183)	6.9 (N=277)	0.099 (N=277)	94.8 (N=277)	5.5 (N=277)
DTA1	Lake Yarrunga at 100 m from Dam Wall	Bungonia	2.9 (N=125)	6.7 (N=872)	0.097 (N=872)	66.0 (N=872)	4.5 (N=872)
DTA5	Lake Yarrunga at Shoalhaven River	Bungonia	2.5 (N=137)	7.0 (N=539)	0.102 (N=539)	78.7 (N=539)	5.3 (N=539)
RPR1	Lake Prospect at Midlake	Prospect	3.0 (N=203)	7.8 (N=704)	0.244 (N=704)	99.5 (N=704)	0.5 (N=704)
RPR6	Prospect Lake at raw water pumping station	Prospect	3.2 (N=115)	7.9 (N=199)	0.250 (N=199)	102.3 (N=199)	0.5 (N=199)
DWO1	Lake Woronora at Dam Wall	Woronora	0.8 (N=174)	6.4 (N=1638)	0.108 (N=1681)	86.0 (N=1681)	0.5 (N=1681)

Table 5-6 Nutrients - Ammonia-N, NOx, Total Nitrogen, SRP and TP measured at storage sites

Site	Site name	Sub-catchment	Water Quality Parameter				
			NH_3 (mg/L)	NOx (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
DWA19	Lake Burragorang at Kedumba River arm	Lower Coxs	0.010 (N=26)	0.080 (N=26)	0.390 (N=26)	0.003 (N=26)	0.014 (N=26)
DWA21	Lake Burragorang at Coxs Arm 37 km u/s Dam	Lower Coxs	0.010 (N=26)	0.086 (N=26)	0.380 (N=26)	0.004 (N=26)	0.015 (N=26)
DWA15	Lake Burragorang at Coxs River Arm 4 km u/s Butchers Creek	Lower Coxs	0.002 (N=130)	0.052 (N=130)	0.320 (N=130)	0.002 (N=130)	0.009 (N=130)
DWA12	Lake Burragorang at 9 km u/s Coxs River	Burragorang	0.002 (N=501)	0.150 (N=501)	0.390 (N=502)	0.003 (N=501)	0.010 (N=502)
DWA2	Lake Burragorang at 500 m u/s Dam Wall	Burragorang	0.002 (N=654)	0.160 (N=654)	0.380 (N=653)	0.002 (N=654)	0.007 (N=654)
DWA27	Lake Burragorang at Wollondilly Arm 23 km u/s Dam	Burragorang	0.002 (N=522)	0.176 (N=522)	0.440 (N=522)	0.003 (N=522)	0.010 (N=522)
DWA311	Lake Burragorang at Wollondilly Arm 300 m u/s Nattai River	Burragorang	0.002 (N=135)	0.101 (N=135)	0.410 (N=135)	0.002 (N=135)	0.008 (N=135)
DWA39	Lake Burragorang at Wollondilly Arm 40 km u/s Dam	Burragorang	0.011 (N=34)	0.171 (N=34)	0.580 (N=34)	0.004 (N=34)	0.018 (N=34)
DWA9	Lake Burragorang at 14 km u/s Dam Wall	Burragorang	0.002 (N=673)	0.174 (N=673)	0.420 (N=673)	0.003 (N=673)	0.009 (N=673)
DWI1	Wingecarribee Lake at Outlet	Wingecarribee	0.002 (N=119)	0.005 (N=119)	0.310 (N=119)	0.001 (N=119)	0.020 (N=119)
DLC1	Cascade No.2	Grose	0.006 (N=55)	0.042 (N=55)	0.160 (N=51)	0.002 (N=55)	0.006 (N=55)
DTC1	Lake Top Cascade at 100 m u/s Dam Wall	Grose	0.002 (N=148)	0.011 (N=148)	0.140 (N=148)	0.002 (N=148)	0.006 (N=148)
DGC1	Greaves Creek near Offtake	Grose	0.002 (N=82)	0.012 (N=82)	0.130 (N=82)	0.003 (N=82)	0.009 (N=82)
DCA1	Lake Cataract at Dam Wall	Upper Nepean	0.045 (N=189)	0.011 (N=189)	0.190 (N=189)	0.001 (N=189)	0.006 (N=189)
DCO1	Lake Cordeaux at Dam Wall	Upper Nepean	0.031 (N=196)	0.033 (N=196)	0.240 (N=196)	0.002 (N=196)	0.009 (N=196)
DAV1	Lake Avon at Dam Wall	Upper Nepean	0.006 (N=224)	0.030 (N=224)	0.160 (N=224)	0.002 (N=224)	0.002 (N=224)
DAV7	Lake Avon at Upper Avon Valve Chamber	Upper Nepean	0.002 (N=209)	0.012 (N=209)	0.160 (N=209)	0.001 (N=209)	0.006 (N=209)
DNE2	Lake Nepean at 300 m u/s Dam Wall	Upper Nepean	0.008 (N=233)	0.199 (N=233)	0.380 (N=233)	0.003 (N=233)	0.011 (N=233)
DBP1	Kangaroo Valley WFP Raw Water	Kangaroo	0.002 (N=3)	0.001 (N=3)	0.320 (N=3)	0.002 (N=3)	0.031 (N=3)
DFF6	Lake Fitzroy Falls at Dam Wall	Kangaroo	0.002 (N=94)	0.004 (N=94)	0.310 (N=94)	0.001 (N=94)	0.013 (N=94)
DTA3	Lake Yarrunga at Kangaroo and Yarrunga Jn.	Kangaroo	0.027 (N=53)	0.126 (N=53)	0.370 (N=53)	0.004 (N=53)	0.018 (N=53)
DTA8	Lake Yarrunga at Kangaroo River at Bendeela PS	Kangaroo	0.021 (N=113)	0.150 (N=113)	0.370 (N=113)	0.006 (N=113)	0.031 (N=113)
DTA1	Lake Yarrunga at 100 m from Dam Wall	Bungonia	0.020 (N=134)	0.109 (N=134)	0.400 (N=134)	0.006 (N=134)	0.025 (N=134)
DTA5	Lake Yarrunga at Shoalhaven River	Bungonia	0.034 (N=130)	0.049 (N=130)	0.430 (N=130)	0.006 (N=130)	0.030 (N=130)
DWO1	Lake Woronora at Dam Wall	Woronora	0.016 (N=284)	0.069 (N=284)	0.200 (N=284)	0.002 (N=284)	0.006 (N=284)
RPR1	Lake Prospect at Midlake	Prospect	0.002 (N=153)	0.008 (N=153)	0.210 (N=153)	0.001 (N=153)	0.002 (N=153)
RPR6	Prospect Lake at raw water pumping station	Prospect	0.002 (N=64)	0.007 (N=64)	0.205 (N=64)	0.001 (N=64)	0.002 (N=64)

TN concentrations continue to be generally high in these catchments, and TP levels were also of concern in the Warragamba and Shoalhaven Catchments. The high TN and TP concentrations in the Warragamba Catchment were associated with STPs on Farmers Creek and Gibbergunyah Creek and may be indicative of high TN being delivered from the STPs and/or the upper catchment.

Chl-a levels (which are directly related to algal productivity) were of most concern in the Warragamba Catchment in the Wingecarribee River. These were associated with the relatively high nutrient concentrations in this river. Electrical conductivity was generally at acceptable levels throughout all catchments, although high EC levels were recorded from the Wingecarribee River in the Warragamba Catchment.

With regard to storage water quality, the catchments that were identified as having water quality issues were the Warragamba Catchment and the Shoalhaven Catchment. In particular, high TN and TP concentrations were recorded from Lake Burragorang in the Warragamba Catchment and Lake Yarrunga and Lake Fitzroy Falls in the Shoalhaven Catchment. These persistently high nutrients concentrations probably contribute to the high Chl-a concentrations in these storages.

As noted in the previous audit (DECCW 2010a), relative to the size of the Catchment, there were only a few sites with long-term water quality monitoring data, and some sub-catchments in the Shoalhaven River catchment have no current long-term water quality monitoring sites. This is the case for the sub-catchments of; Grose River, Upper Wollondilly River, Nerrimunga River, Endrick River, Reedy Creek, Mongarlowe River, Back and Round Mountain Creek and Jerrabattgulla Creek. Examination of the data and information provided by the SCA and other stakeholders, during the current audit, also indicated that the number of monitored sites may not adequately cover the variations in water quality at those sub-catchment sites.

However, the Auditor notes that the SCA's Water Monitoring Program (SCA 2010b), discussed in Section 5.1.1, is presently under review and encourages the SCA and other stakeholders (HNCMA and SRCMA, in particular) to collaborate in maintaining the existing monitoring sites. It may also be possible to support dedicated, local community groups, interacting directly with the CMAs, to establish and monitor key water quality parameters, at key sites; collect and retain compatible water quality data that can add value and achieve a greater coverage of the watercourses that show the highest variability.

Raw water quality - Findings

Raw water supplied for treatment is monitored by the SCA within the delivery system, and at inlets to WFPs prior to the water treatment process (SCA 2009b). This is to ensure that both the quantity and quality meet agreed criteria. The raw water supplied for treatment is required to conform to site-specific standards specified in BWSAs. These standards have been derived based on treatment capabilities of the WFPs. For these parameters and other specific water quality characteristics, raw water is not required to meet drinking water guideline standards, provided that the water can be treated to meet ADWG.

There are a number of WFPs in the Sydney drinking water system operated by Sydney Water Corporation and Local Councils. WFPs are also an important part of the multiple barrier approach to improve drinking water quality (NHMRC 2011).

The level of contaminants in raw water supplied to 10 of the WFPs is monitored by SCA to optimise the raw water quality supplied and to minimise treatment costs. Raw water in storages is not required to meet drinking water quality standards. However, the most cost effective provision of good drinking water is a balance between ensuring good quality raw water and the application of water treatment technologies at WFPs.

The relevant raw water quality standards for individual WFPs are given in Table 5-7.

Raw water supplied by the SCA to WFP operators is expected to meet site-specific raw water quality requirements for each WFP. The requirements for the Prospect, Warragamba, Orchard Hills, Macarthur, Nepean, Illawarra, Woronora, and Cascade WFPs are detailed in the SCA's BWSAs with Sydney Water Corporation. In addition, the SCA has BWSAs with the Wingecarribee Shire Council (Wingecarribee WFP) and the Shoalhaven City Council (Kangaroo Valley WFP).

The Audit examined the level of exeedances of the specified raw water quality parameters with the BWSA requirements. As shown in Table 5-8, the level of meeting the requirements was determined to be very high, which is important in the production of high quality drinking water, and for the effective operation of WFPs with minimal operating costs incurred.

As in the previous audit period (DECCW 2010a), during 2010-13, most WFPs received fairly high quality water, as specified in the BWSAs, with the exceedances largely limited to water hardness, alkalinity, pH and temperature.

The Cascade WFP recorded lower temperatures on 10 instances, attributed to colder water temperatures in winter months and the Illawara WFP recorded higher levels of alkalinity and pH in raw water on five and 14 instances, respectively, over the past three years.

Raw water received at the Nepean WFP also showed some minor exceedances (i.e. alkalinity and hardness on two occasions; and pH, on three occasions). Despite these, the raw water supplied for water treatment, largely met the requirements of the specific BWSAs, which is an overall reflection of good quality water arising in the Catchment.

The Aerial Standard Unit (ASU) of algae, inhabiting raw water supplies, indicates the potential for filter blockages, and this measure is derived from cell counts and the average size of each algal species present. Given that there were no exceedances of this parameter at any of the raw water supplies, the risks of filter blockages would have been minimal during the audit period.

Heavy Metals, Pesticides, and Synthetic Organic Compounds (SOC) in raw water

The SCA tests for a range of heavy metals, pesticides, and other compounds in raw waters at the inflow to the WFPs (SCA 2010b). In 2009, SCA reported on a screening level risk assessment of pesticides and SOCs in the Catchment (SCA 2009b; 2013a).

Evaluation of monitoring data had shown that although some pesticides were occasionally detected, none of the pesticides or SOCs exceeded the ADWG (NHMRC 2008) *Health Values* during the period January 2000 to June 2008.

The overall risk assessment concluded that of the pesticides assessed, all were a low risk, with the exception of the foliar-herbicide Triclopyr, which was assessed as a medium level risk of occurring at slightly elevated levels in the raw water supply. The majority of SOCs were rated as having a low overall risk. Five were classified as medium risk: benzene, 1,2- dichloroethane, 1,2 dichloroethene, hexachlorobutadiene, and vinyl chloride (DECCW 2010a).

During the previous audit period, none of the pesticide or SOC levels exceeded the ADWG (NHMRC 2011). However, very low-level detections of a second herbicide - Hexazinone - were made several times in raw water at the inflow to Cascade WFP, and Triclopyr was also detected infrequently, at very low levels, in raw water at the inflow to Wingecarribee WFP.

Table 5-7 Site specific standards for raw water supplied for treatment [1]

Parameter (Units)	Prospect	Orchard Hills	Warragamba	Macarthur WFP Value of Parameter Based on Demand Range (ML/d)				Illawarra WFP	Woronora WFP	Nepean WFP	Cascade WFP	Kangaroo Valley	Wingecarribee
				185- <265	125- <185	80- <125	<80						
Turbidity NTU^	40	40	40	10	25	50	60	10	10	150	15	20	40
True Colour CU^	60	60	60	40	40	40	40	50	70	60	60	70	70
Iron mg/L^	3.50	3.50	3.50	0.6	0.8	1.1	1.3	1.1	1.0	5.0	3.0	1.1	1.1
Manganese mg/L^	1.40	1.40	1.40	0.2	0.25	0.3	0.35	0.4	0.1	1.5	0.3	NA	NA
Aluminium mg/L^	2.60	2.60	2.60	0.4	0.5	0.75	0.95	1.4	0.4	1.0	0.2	NA	NA
Hardness mg/L as CaCO3	25.0 – 70.0	25.0 - 70.0	25.0 - 70.0	6.0 – 30.0	6.0 – 32.2	6.0 – 32.2	6.0 – 32.2	0 – 30.0	2.0 – 30.0	2.0 – 35.0	0 – 40.0	0 – 36.5	0 - 36.5
Alkalinity mg/L as CaCO3	15 – 60	15 - 60	15 - 60	0 - 15.0				0 – 10.0	0 – 15.0	0.5 – 25.0	0 – 30.0	0 - 29	0 - 35
pH units	6.3 – 7.9	6.3 - 7.9	6.3 - 7.9	5.7 – 7.7				6.2 – 7.2	5.1 – 7.5	4.8 – 7.7	6.0 – 7.9	6.5 – 8.5	6.5 – 8.5
Temp °C	10.0 – 25.0	10.0 - 25.0	10.0 - 25.0	8.0 - 25.0				10.0 – 25.0	10.0 – 25.0	10.0 – 25.0	10.0 – 25.0	NA	NA
Algae (ASU)	2000	1000*	2000	**see note				5000	5000	2000	2000	5000	5000

[1] Source: SCA 2010; ^ only upper limits are shown for these analytes

* Maximum for Prospect WFP is 1000 ASU, except if turbidity is greater than 10 NTU or true colour is greater than 30 CU, then the maximum algae criterion will be 500 ASU.

** Algal limits for Macarthur WFP (average of 3 samples): 500 ASU small individual cells (<10 µm) of filamentous or colonial species or 100 ASU large cells (>10 µm) of branching or gelatinous species.

Table 5-8 Exceedances of BWSA (2010-13) levels at each WFP during the current audit period

Site Code	Station	Sampl	Tur	Tru	Iron	Man	Alu	Tot	Alk	pH (	Tem	Are	Dis
HCSR	Cascade WFP	36	0	0	0	0	0	0	0	0	10	0	N/A
IWFP	Illawarra WFP	36	0	0	0	0	0	0	5	14	0	0	N/A
HMAC	Macarthur WFP	36	0	0	0	0	0	0	0	0	0	0	N/A
HNED	Nepean WFP	36	0	0	0	0	0	2	2	3	0	0	N/A
HBR1	Orchard Hills WFP	36	0	0	0	0	0	0	0	1	0	0	N/A
PWFP10	Prospect WFP	36	0	0	0	0	0	1	0	0	0	0	N/A
HWA2	Warragamba WFP	36	0	0	0	0	0	0	0	0	0	0	N/A
HWO1A	Woronora WFP	35	0	0	0	0	0	0	0	0	0	0	N/A
HWI1	Wingecarribee WFP	40	7	0	0	NA	NA	0	0	1	NA	0	3*
HKV1	Kangaroo Valley WFP	Variable**	1	0	0	NA	NA	0	1	19	NA	0	29*

* In the absence of a site-specific dissolved oxygen standard for Wingecarribee and Kangaroo Valley WFPs, a DO level of 8.5 mg/L (equivalent to about 90% O_2 saturated water) was used. The incidences, therefore, indicate instances when raw water supplied for treatment may have had less DO than ideal.

** At Kangaroo Valley WFP, the above results are from water quality parameters that had been more frequently monitored (i.e. Number of samples - Turbidity: 88; pH: 99; DO: 99; others: 37). The greater level of monitoring does reflect high variability in raw water quality that had been anticipated by the WFP.

With the information provided by the SCA for the current audit (SCA 2011c; 2012b; c; SCA 2013a; d), the following observations can be made[4]:

- In the Warragamba System (Orchard Hills, Warragamba and Prospect WFPs) and In the Upper Nepean System (Macarthur, Nepean and Illawarra WFPs), all samples showed 100% compliance with ADWG (NHMRC 2011) with regard to levels of heavy metals, pesticides and SOCs.
- Metals, pesticides, and SOCs were rarely detected, if at all. Similarly, none of the samples taken from the Woronora WFP, or Cascade WFP (Blue Mountains system) recorded any heavy metals, pesticides, or SOCs above the ADWG (NHMRC 2011) Guidelines.
- In the Shoalhaven System, sampling at the inlets of the Kangaroo Valley WFP and Wingecarribee WFP also showed 100% compliance with ADWG (NHMRC 2011) Guidelines with regard to heavy metals, pesticides, and SOCs. However, in 2011-12, the foliar herbicide Triclopyr was detected at very low levels in about 46% of samples (i.e. 6 out of 13 samples), confirming a trend that had been recorded in the previous audit.

Pathogens - Cryptosporidium and Giardia

The ADWG (NHMRC 2011) provide the authoritative reference for the assessment of drinking water quality. They do not contain guideline values for the protozoan parasites *Cryptosporidium* or *Giardia*, either in raw or treated drinking water. However, ADWG recommends a multi-barrier approach to minimising risks of both *Cryptosporidium* oocysts and *Giardia* cysts entering the water supply. Investigative testing is encouraged in response to events that could increase the risk of contamination (e.g. heavy rainfall). The SCA implements additional monitoring during high risk events.

Cryptosporidium and *Giardia* monitoring in the catchments is undertaken to provide an early warning function to enable optimal configuration of the raw water supply system in the event of high levels of *Cryptosporidium* and/or *Giardia* detections within the storages. Catchment monitoring also contributes to the understanding of sources and estimates of concentrations which can then improve the robustness of risk assessments.

The SCA responds to detections of *Cryptosporidium* and *Giardia* in raw water supply in accordance with the Raw Water Quality Incident Response Plan developed in consultation with NSW Health and wholesale customers.

The SCA Response Plan identifies four event levels:

- Alert Level: 1 – 10 oocysts (IFA /10 L Adjusted for Recovery)
- Minor Incident: >10 – 100 oocysts (IFA /10 L Adjusted for Recovery)
- Major Incident: 101 – 1000 oocysts (IFA /10 L Adjusted for Recovery)
- Emergency: >1000 oocysts (IFA /10 L Adjusted for Recovery).

The current audit examined the incidence of immunofluorescent assay (IFA) presumptive positive *Cryptosporidium* oocysts and *Giardia* cysts sampled in the catchment and in the storages.

[4] Data or information on heavy metals, pesticides and SOCs for 2012-13 period was unavailable to the Auditor at the time of the Audit

Findings

The results of monitoring in the catchments for *Cryptosporidium* oocysts and *Giardia* cysts are summarised in Table 5-9 and Table 5-10, respectively. Similar results for the storages are summarised in Table 5-11 for *Cryptosporidium* oocysts and Table 5-12 for *Giardia* cysts.

Results were defined as follows;

- Low: <100 oocysts (IFA /100 L Adjusted for Recovery);
- Medium: > 100 – <1000 oocysts (IFA /100 L Adjusted for Recovery); and
- High: > 1000 oocysts (IFA /100 L Adjusted for Recovery).

During this audit period, the majority of catchment samples reported low concentrations of *Cryptosporidium* oocysts (>85%) and *Giardia* cysts (>75%). The most frequent detections of both *Cryptosporidium* oocysts and *Giardia* cysts occurred in Gibbergunyah Creek downstream of the discharge of Braemar STP (E203).

At this site 41% of samples tested contained either medium or high concentrations of *Cryptosporidium* and 88% of samples contained medium to high concentrations of *Giardia* cysts. These results were not surprising given the relatively constant source of protozoan pathogens from the STP discharge and were consistent with previous audits (DECCW 2010a).

The previous audit case study investigation of Gibbergunyah Creek site E203 cited evidence from both an SCA study (SCA 2013c) and a University of NSW (2010) study that indicated it was likely that a very high proportion of these oocysts, if not all, were non-viable as a result of the UV disinfection process at Braemar STP.

Table 5-9 *Cryptosporidium* results for Catchment samples collected from July 2010 - June 2013

Site Code	Site Description	No. Samples tested	*Cryptosporidium* oocysts*/100 L		
			Low	Medium	High
E046	Farmers Creek d/s of Lithgow STP	1	1	0	0
E083	Coxs River at Kelpie Point	48	47	1	0
E130	Kowmung River at Cedar Ford	56	55	1	0
E157	Kedumba River at Maxwells Crossing	46	44	2	0
E203	Gibbergunyah Creek at Braemar STP	120	70	40	10
E206	Nattai River at Crags	2	2	0	0
E210	Nattai River at Smallwoods Crossing	42	42	0	0
E243	Little River at Fire Rd W41	42	42	0	0
E332	Wingecarribee River at Berrima Weir	3	2	1	0
E488	Wollondilly River at Jooriland	69	63	5	1
E531	Werriberri Creek at Werombi	186	181	5	0
E706	Kangaroo River at Hampden Bridge	34	21	12	1
	Total	**649**	**570**	**67**	**12**
	Total (%)		**87.8**	**10.4**	**1.8**

* Recovery adjusted count

Table 5-10 *Giardia* results for Catchment samples collected from July 2010 - June 2013

Site Code	Site Description	No. Samples tested	*Giardia* cysts*/100 L		
			Low	Medium	High
E046	Farmers Creek d/s of Lithgow STP	1	1	0	0
E083	Coxs River at Kelpie Point	48	48	0	0
E130	Kowmung River at Cedar Ford	56	48	8	0
E157	Kedumba River at Maxwells Crossing	46	44	2	0
E203	Gibbergunyah Creek at Braemar STP	121	14	52	55
E206	Nattai River at Crags	2	2	0	0
E210	Nattai River at Smallwoods Crossing	42	42	0	0
E243	Little River at Fire Rd W41	42	42	0	0
E332	Wingecarribee River at Berrima Weir	3	0	3	0
E488	Wollondilly River at Jooriland	69	56	12	1
E531	Werriberri Creek at Werombi	186	182	4	0
E706	Kangaroo River at Hampden Bridge	34	13	18	3
	Total	**650**	**492**	**99**	**59**
	Total (%)		**75.7**	**15.3**	**9.0**

* Recovery adjusted count

The site E706, Kangaroo River at Hampden Bridge also showed consistent detections of medium or high abundance of *Cryptosporidium* oocysts and *Giardia* cysts (38% and 61% of samples respectively). Figure 5-1 shows the concentrations of both *Cryptosporidium* oocysts and *Giardia* cysts detected at this site since 2005. It is likely that the high counts are indicative of sporadic sewage contamination from on-site systems. The auditor understands that this area of the catchment is currently being converted to a centralised sewage treatment plant which is under construction. Continued water quality monitoring at E706 will facilitate assessment of the effectiveness of the centralised sewage treatment program to remediate faecal contamination at this location.

Wollondilly River at Jooriland (E488) also had medium and high abundance of *Cryptosporidium* oocysts (8% of samples) and *Giardia* cysts (19% of samples) see Figure 5-2. This site is located within the Special Areas and the likely sources of protozoan pathogens are diffuse inputs from wild animal sources. Periodic evaluation of *Cryptosporidium* genotypes at this location would enable this hypothesis to be assessed and provide confidence in the source attribution as well as informing risk analysis related to human infectious potential of the isolates.

Site E531, Werriberri Creek at Werombi (Figure 5-3) also had occasional samples that showed medium abundances of *Cryptosporidium* and *Giardia* (oo)cysts, the previous audit noted that the Werriberri Creek site warranted further investigation and this site is monitored weekly for protozoan pathogens by the SCA (SCA 2010b). The importance of water quality at this site is due to its proximity to the main off-takes for Warragamba dam.

The peak concentrations in Werriberri Creek in this audit period occurred on 18/4/12, 23/2/13 and 28/6/13 which all coincided with rainfall events in the preceding 72 hours. This suggests that although the majority of the adjacent urban areas were sewered in the last ten years, not all residences may have connected to the system and there may be either sewer overflows or remaining on-site systems, which are contributing faecal contamination to Werriberri Creek in response to wet weather events.

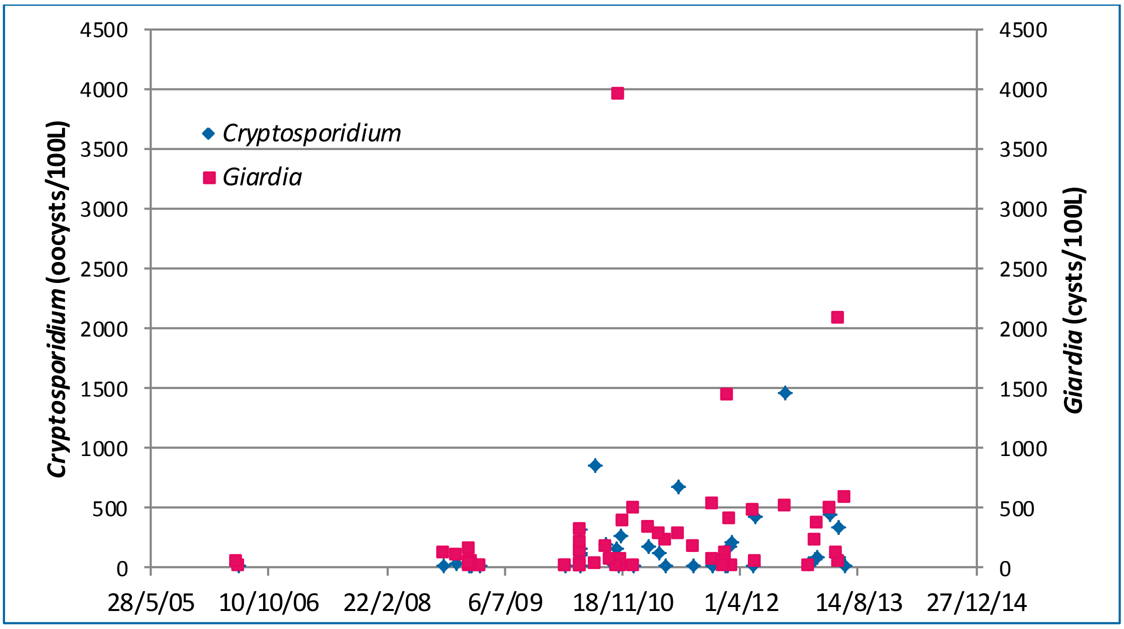

Figure 5-1 ***Cryptosporidium*** **and** ***Giardia*** **(oo)cyst results for E706 Kangaroo River at Hampden Bridge since 2005**

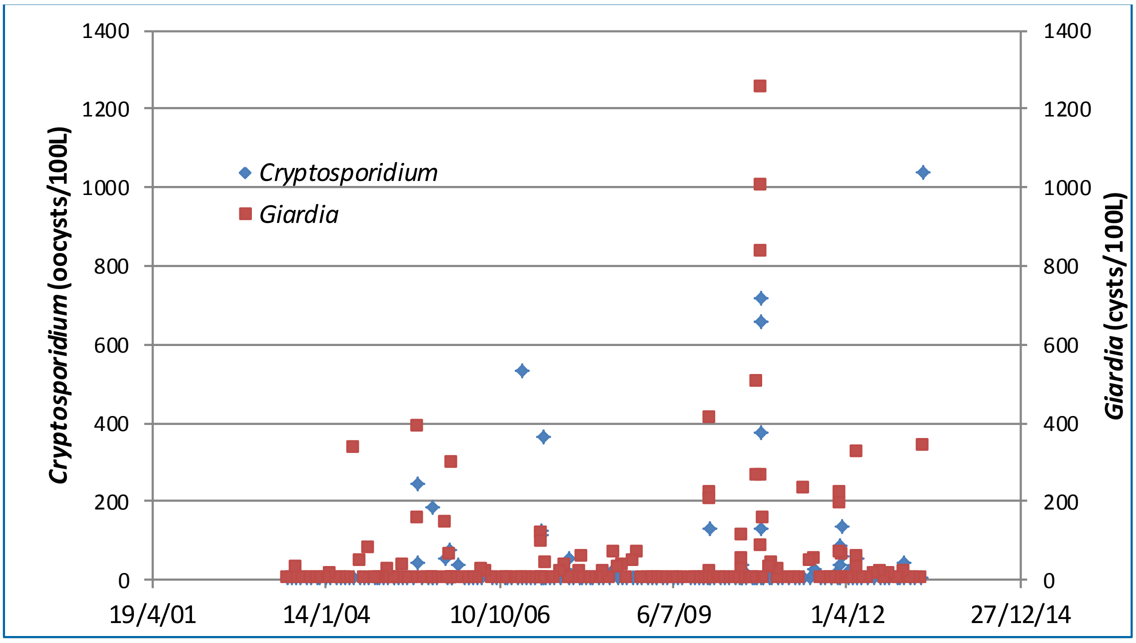

Figure 5-2 ***Cryptosporidium*** **and** ***Giardia*** **(oo)cyst results for E488 Wollondilly River at Jooriland from 2001**

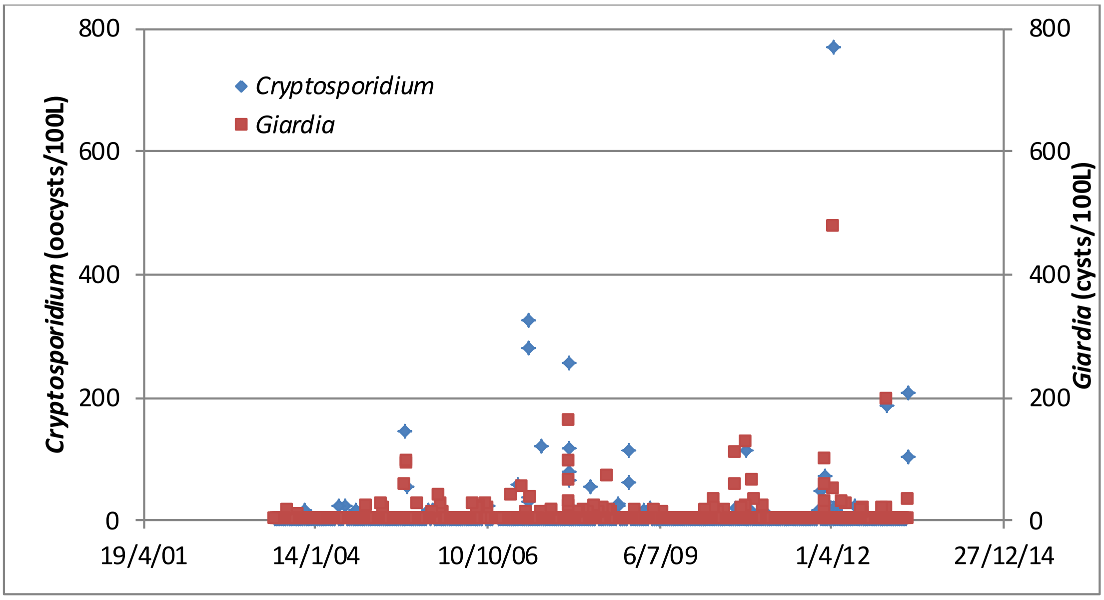

Figure 5-3 ***Cryptosporidium*** **and** ***Giardia*** **(oo)cyst results for E531 Werriberri Creek at Werombi since 2001**

Table 5-11 summarises the results of monitoring for *Cryptosporidium* oocysts and *Giardia* cysts in the storages. The sampling program is heavily weighted towards the major storages and intakes of Lake Burragorang (DWA2), Lake Prospect (RPR1 and RPR6), and Wingecarribee reservoir (DWI1) and all samples tested from these sites reported low abundance of both *Cryptosporidium* and *Giardia* (oo)cysts throughout the audit period.

Table 5-11 ***Cryptosporidium*** **results for Storages samples collected from July 2010 - June 2013**

Site Code	Site Description	N	*Cryptosporidium* oocysts*/100 L		
			Low	Medium	High
DAV7	Lake Avon at Upper Avon valve house	3	3	0	0
DCA1	Cataract Lake 30 m u/s of dam wall	3	3	0	0
DCO1	Cordeaux Lake 30 m u/s of dam wall	1	1	0	0
DNE2	Lake Nepean 200 m u/s of dam wall	2	2	0	0
DWA12	Lake Burragorang Coxs arm 24 km u/s of dam wall	3	3	0	0
DWA15	Lake Burragorang Coxs arm 4 km u/s Butchers Creek	1	1	0	0
DWA2	Lake Burragorang	997	997	0	0
DWA27	Lake Burragorang Wollondilly arm 23 km u/s of dam wall	17	16	1	0
DWA311	Lake Burragorang Wollondilly arm 300 m u/s of Nattai River	1	0	1	0
DWA9	Lake Burragorang 14 km u/s of dam wall	17	17	0	0
DWI1	Wingecarribee Reservoir	160	160	0	0
DWO1	Woronora Lake 50 m u/s of dam wall	1	1	0	0
RPR1	Lake Prospect at midlake	315	315	0	0
RPR6	Lake Prospect at inlet to RWPS	312	312	0	0
	Total	**1833**	**1831**	**2**	**0**
	Total (%)		**99.9**	**0.1**	**0**

N - Number of samples tested; * Recovery adjusted count

Table 5-12 *Giardia* results for Storages samples collected from July 2010 - June 2013

Site Code	Site Description	N	*Giardia* cysts*/100 L		
			Low	Medium	High
DAV7	Lake Avon at Upper Avon valve house	3	3	0	0
DCA1	Cataract Lake 30 m u/s of dam wall	3	3	0	0
DC01	Cordeaux Lake 30 m u/s of dam wall	1	1	0	0
DNE2	Lake Nepean 200 m u/s of dam wall	2	2	0	0
DWA12	Lake Burragorang Coxs arm 24 km u/s of dam wall	3	3	0	0
DWA15	Lake Burragorang Coxs arm 4 km u/s Butchers Creek	1	1	0	0
DWA2	Lake Burragorang	997	997	0	0
DWA27	Lake Burragorang Wollondilly arm 23 km u/s of dam wall	17	16	1	0
DWA311	Lake Burragorang Wollondilly arm 300 m u/s of Nattai River	1	0	1	0
DWA9	Lake Burragorang 14 km u/s of dam wall	17	17	0	0
DWI1	Wingecarribee Reservoir	160	160	0	0
DWO1	Woronora Lake 50 m u/s of dam wall	1	1	0	0
RPR1	Lake Prospect at midlake	315	315	0	0
RPR6	Lake Prospect at inlet to RWPS	312	312	0	0
	Total	**1833**	**1831**	**2**	**0**
	Total (%)		**99.9**	**0.1**	**0**

N - Number of samples tested; * Recovery adjusted count

The SCA have continued to investigate sources of protozoan pathogens in the catchment and their transport and mobilisation in surface water runoff. Scientific studies are currently underway to investigate the potential viability and infectivity of *Cryptosporidium* oocysts at all major STPs in the catchment including; Bowral, Moss Vale, Bundanoon, Berrima, Braemar (Mittagong), Goulburn, Braidwood, Lithgow and Wallerawang.

Although the final report is not yet available, preliminary findings indicate a 'median overall 1.8 log reduction of *Cryptosporidium* oocyst counts was achieved by STPs across the catchment. UV disinfection provided very little additional physical removal of the oocysts, but was critical in terms of *Cryptosporidium* infectivity (see Figure 5-4).

The treatment processes prior to UV disinfection on the other hand were found to have little impact on the infectivity of the oocysts. However, the median reduction in infectivity by UV systems was >~1 log. While effluent commonly still contained *Cryptosporidium*, not a single oocyst tested for any sample was found to be infective' (SCA 2013c).

The evaluation of viability and infectivity downstream of Braemar STP will involve additional monitoring from December 2012 until December 2013, and has included nine samples analysed thus far. The preliminary report states that although 'there are some limitations in fully quantifying the log reduction of infective *Cryptosporidium* at STPs in the catchment, mainly because of low starting concentrations and complete removal of infectivity by the UV treatment.

The results indicate that the treatment processes are producing an effluent that has no infective *Cryptosporidium*. It is therefore highly likely that the historical *Cryptosporidium* detections at Gibbergunyah Creek are those of non-infectious oocysts' (SCA 2013c).

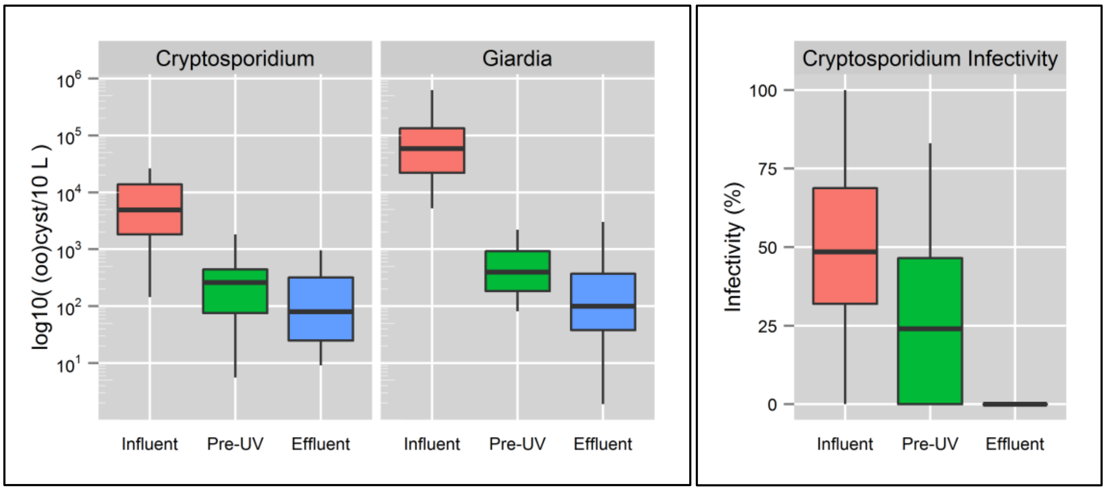

Figure 5-4 Boxplots showing distribution of *Cryptosporidium* and *Giardia* concentrations and *Cryptosporidium* infectivity measured at different points of the treatment train of all major STPs in the catchment

5.1.6 Recommendations

Water Quality and Trend Assessments

During the analyses, the SCA supplied multiple Excel spread sheets with water quality data. However, due to different versions, the spread sheets had different date formats. As such, when data was aggregated into one spread sheet, the dates were changed by a four year period.

The Auditor recommends that all water quality data for future audits should be collected, verified, and collated in one consolidated dataset by the SCA, prior to the commissioning of an audit. This would decrease potential data handling errors, eliminate potential errors regarding date formats, and enable a future Auditor to focus more on what the data reveal.

Using the approach from the previous audit, all water quality data for storages were used to calculate summary statistics (e.g. medians, percentiles, etc). However, Chl-a analyses were carried out using 0-6 m data only. Future audits should separate water quality data for all parameters into surface samples (e.g. 0-6 m) and depth samples (>6 m). This would reduce analytical errors that may arise from widely disparate data that are the result of natural differences in water storages that can occur due to stratification.

For example, anoxic conditions at 50 m (i.e. <10% oxygen) and aerated conditions in surface waters (i.e. >90% oxygen) lead to large disparities in the water quality data. If these two sets of data are not separated, median values – which are important for comparisons to previous audits – may become close to zero. Such a result would be inaccurate, as it would indicate poor oxygen conditions in the overall storage.

Future audits would also benefit from the SCA providing a comprehensive list of all water quality monitoring sites, site codes and locations, and corresponding catchments and sub-catchments in which they are located. As expected, there was variation amongst water quality indicators at sites and sub-catchments. Increasing trends of nutrient levels and Chl-a in the Warragamba, Upper Shoalhaven and Shoalhaven Catchments highlight the need to continue targeted management of these areas.

Pathogens - Cryptosporidium and Giardia

Microbial water quality at the storages was consistently high with regard to pathogen loads. Some catchment sites showed sporadic contamination with pathogen protozoa. However, the risk associated with consistent detection of *Cryptosporidium* and *Giardia* (oo)cysts at E203 and other sites downstream of STPs can be regarded as mitigated, if as expected, the current study of viability and infectivity confirms that the (oo)cysts have been inactivated by the ultraviolet disinfection treatment processes at the major STPs.

Sporadic contamination at catchment sites not proximate to STPs, and hence, likely to be arising from diffuse sources primarily faecal contamination from animals (for example E488 and possibly E531) require continued investigation to confirm sources, and identify genotypes, and thus, the potential human infectivity of the protozoa detected.

The SCA should refine investigation of hotspots of sporadic *Cryptosporidium* contamination to sites not proximate to STPs to determine the sources, genotypes, and potential human health risks.

5.2 Nutrient Loads

5.2.1 Summary

Both point source and diffuse source nutrient loads have been considered in the Catchment health audits. Point sources are direct releases of treated effluent into waterways from STPs, and other wastewater treatment systems in the Catchment, and any unmitigated effluent discharges from rural industries.

Diffuse and indirect sources of nutrients in waterways could arise from consequences of complex interactions and natural inputs from inherent geological features and soil types. In addition, human-induced, diffuse sources of nutrients in the Catchment were largely associated with run-off from agriculture - both grazing lands and cultivated lands, irrigation, and urban developments and run-off from areas of soil erosion, including gully and streambank erosion.

The measure used to inform the nutrient loads indicator for this Audit was the level of compliance of sites of point source nutrient input with EPLs and/or PRPs during the audit period. The level of compliance of EPLs was determined to be somewhat variable, but not significantly different from previous audit periods. Overall, most non-compliances were related to nutrient loads, pH and volumes discharged (particularly under wet conditions) and monitoring requirements.

It is evident that the annual loads of N and P released by individual STPs have declined over the past eight or so years. This is regarded as a highly positive outcome. Nevertheless, some STPs (Goulburn, Braemar, and Lithgow) still discharge relatively high loads, intermittently, which may cause at least short-term impacts on immediate downstream environments.

Based on the available data and information, the current audit found that all of the STPs in the Catchment have made significant improvements to STP performances, and these are likely to contribute progressively to better catchment health. Stricter enforcement of EPL conditions by the regulators - the EPA and SCA - may also contribute further to improved performances, and thereby, mitigate any adverse impacts of non-compliances on the Catchment's waterways.

While point source loads are reasonably easy to measure, input from diffuse sources are much more difficult to determine empirically, requiring detailed monitoring of both flow and nutrient concentrations at a wide range of locations around the Catchment, over time. As a result, past audits have used modelling to estimate nutrient loads from diffuse areas using assumed export rates by area for various types of land use, and the total area of that land use per sub-catchment. The models can also be calibrated to flow and water quality data.

None of the previous modelling efforts have been adequately ground-truthed with sub-catchment water quality or flow data, even for relatively small drainage units. The 2013 Audit finds the required approach yet to be agreed upon by multiple stakeholders, and the available data for modelling, generally inadequate.

In the Auditor's view, the SCA's existing PSAT modules are a useful mechanism to identify and prioritise drainage areas for a variety of water pollutants. Further improvements to the PSAT modules are in progress, and these would enhance the SCA's capacity to identify areas, which are sources of diffuse nutrient pollution.

The Auditor recommends the use of a Bayesian network model approach to complement the PSAT tool, and incorporate disparate information and data so that management scenarios can be easily evaluated in the context of a triple bottom line framework.

Assessment Criteria

Criteria
1. Determine the level of compliance of sites of point source nutrient input with EPLs and/or Pollution Reduction Programs during the audit period. 2. Assess the status of nutrient loads arising from STPs within the Catchment.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Opportunity for improvement	The SCA use the existing data (including PSAT) to develop a predictive tool to evaluate catchment management scenarios for the reduction of diffuse sources of nutrient pollution.

Prior recommendations

Prior Recommendations	Remedial action	Status
Recommendation 20: The operators and regulators of sewage treatment systems in the Catchment should continue efforts to reduce nutrient loads.	Accelerated sewerage upgrade scheme has reduced nutrient loads from individual sewage treatment systems across the catchment.	Closed
Recommendation 21: Estimates of nutrient loads from diffuse sources should be included in future audits in order to understand the full context of nutrient loading in the Catchment.	Several nutrient modelling investigations have been performed with variable results. A methodology needs to be developed to prioritise management actions to address diffuse nutrient pollution in the catchment (see above Recommendation).	Opportunity for improvement

5.2.2 Background

Nutrient loads in the waterways of the Catchment arise as a result of direct inputs from point sources (such as from STPs), and from indirect sources, which are consequences of complex interactions and natural inputs from inherent geological features and soil types, diffuse sources, such as run-off from agriculture.

The main human-induced sources of nutrients in waterways are those that are associated with the point-source discharges, urban run-off, soil erosion, including streambank erosion, run-off from grazing and cultivated lands, including irrigation and any unmitigated effluent discharges from rural industries.

Nutrient enrichment, or eutrophication, of waterways and storages, generally leads to increased productivity, manifested as enhanced growth opportunities for phytoplankton and other algae, as well as aquatic macrophytes. Excessive algal and plant growth can result in a reduction in water quality and the health of aquatic ecosystems, because it can lead to increased organic material, increased biological oxygen demand, and reductions in dissolved oxygen concentrations in the water column. If oxygen levels in the water are low, aquatic life becomes stressed, if anoxic conditions prevail, particularly at the bottom of water bodies, this leads to mobilisation of P, metals and other chemicals, as well as noxious gases from sediments. Such changes in water quality can have considerable adverse impacts on the other aquatic flora and fauna, which inhabit aquatic ecosystems.

Nutrient load is a measure of the quantity of various nutrients, usually N and P that has entered a water body over a particular unit of time, and has been an indicator used in past audits (DEC 2003, 2005; DECC 2007, DECCW 2010a).

Both diffuse source and point source nutrient loads have been considered in these audits. While point source loads are reasonably easy to measure, input from diffuse sources are much more difficult to determine empirically, requiring detailed monitoring of both flow and nutrient concentrations at a wide range of locations around the catchment over time.

As a result, past audits have used modelling to estimate nutrient loads from diffuse areas using assumed export rates per hectare for various types of land use, and the total area of that land use per sub-catchment. The models can also be calibrated to flow and water quality data.

The measure used to inform these nutrient load indicators for this audit was:

- Level of compliance of sites of point source nutrient input with Environment Protection Licences and/or Pollution Reduction Programs during the audit period.

Additional considerations in the Audit were:

- Estimates and ranking of diffuse pollution loads arising from each sub-catchment using the CERAT modelling framework constructed during the last audit (DECCW 2010a); and
- Evaluation of previous nutrient modelling studies for the Sydney Drinking Water Catchment and assessment of potential methodologies to prioritise future catchment actions to reduce nutrient loads.

However, given that the diffuse nutrient loads from these sub-catchments have been modelled previously (Previous audit - DECCW 2010a), further modelling is unlikely to provide much new additional information, unless land use or climatic conditions change markedly. The Auditor agrees with this view held by both OEH and the SCA. Based on the land use analysis, previously discussed under the Land Use Indicator (Section 3.1), significant land use changes have not occurred in the Catchment (see further discussions below).

It should also be noted that the use of assumptions not reflective of local conditions or management practices, will only reflect major land use changes and not the critical changes in management practices, which are the primary focus of catchment interventions.

5.2.3 Management and Surveillance

There are 11 Council operated STPs within the SCA catchment which are licensed by the EPA under the *Protection of the Environment Operations Act* 1997 (POEO Act). These are: Berrima, Bowral, Braemar (Mittagong), Braidwood, Bundanoon, Goulburn, Lithgow, Moss Vale, Kangaroo Valley, Robertson and Wallerawang.

The Goulburn STP uses an effluent irrigation system for disposal of the treated wastewater. However, the other ten STPs directly discharge the treated effluent into waterways of the Catchment, under load-based Environment Protection Licenses (EPLs). There are also two very small unlicensed STPs within the catchment (Taralga and Marulan), the Marulan STP utilises an effluent irrigation system rather than direct discharge.

In addition to the STPs, there are four Sewerage Treatment Systems (STSs) that discharge treated effluent outside the Catchment areas. However, these sewerage reticulation systems can potentially overflow within the Catchment areas. These STSs are: Blackheath, The Oaks/Oakdale (part of West Camden STS), Warragamba (Wallacia STS) and Winmalee. Information and data on these systems were not available for the Audit.

5.2.4 Methodology

Broadly, water quality and quantity data were sourced from SCA, OEH, relevant CMAs and LGAs, NOW and DPI for the 27 sub-catchments. Information on land use, soils, climate and land management practices were sourced as GIS data, where these were available. Evaluation of the land use layers supplied by SCA indicated that the proportion of land use changes in the catchment since the last audit were negligible (<0.2%).

In the current Audit, the Auditor examined the EPL conditions imposed, as well as the data available and penalty notices issued to individual STPs, through the NSW EPA's web site; http://www.epa.nsw.gov.au/prpoeoapp/.

The major conditions imposed to regulate the STPs are related to load and volume-based limits on treated effluent volume discharged, N and P loads and other parameters, including pH of the discharge, and amounts of Total Suspended Solids (TSS); Biological Oxygen Demand (BOD); Oil and Grease, Faecal Coliforms, and sludge volume that can be discharged.

The monitoring requirements and reporting frequencies under dry or wet weather conditions, and under exceptional circumstances, are also clearly stated in the EPLs. Complete datasets on effluent quality from six of these plants were available, and were analysed to determine their contribution to the total nutrient load[5]. It is important to note that some of the STPs use effluent for irrigation, or other reuse, and as such, will not be a direct discharge to waterways (e.g. Goulburn STP is typically irrigated for grazing and nutrients may exit the catchment via a different pathway other than direct discharge into a waterway).

Other point source data for industrial processes or decentralised systems (100 or more equivalent person sewage systems) in the Catchment were not available for inclusion in the calculations. This means that the loads calculated for point sources were under-estimates.

5.2.5 Findings

Point Source Compliance

Point sources of nutrients, mainly from STP discharges and other industrial discharges, have the potential to cause significant adverse impacts of water quality and ecosystem health, because they are commonly continuous sources of nutrients, rather than intermittent inputs associated with heavy rainfall events.

Temporal changes in the N and P loads released from the licensed STPs are presented in Figure 5-5 and Figure 5-6. As evident in Figure 5-5, the discharge loads of N from individual STPs has been variable, and loads from at least the Lithgow and Braemar STPs have actually increased in 2011-12, compared to previous years. On the other hand, P loads that were discharged by all of the STPs have steadily decreased over time (Figure 5-6). These were largely attributable to on-going upgrades to the STPs, and to more effective biological treatments.

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[5] Data and information on the Braidwood STP (EPL 1733) operated by Palerang Council; Jenolan Caves STP (EPL 1962) operated by the Jenolan Caves Trust; and Wallerawang STP (EPL 598) operated by Lithgow Council were not available in time for inclusion in the current Audit.

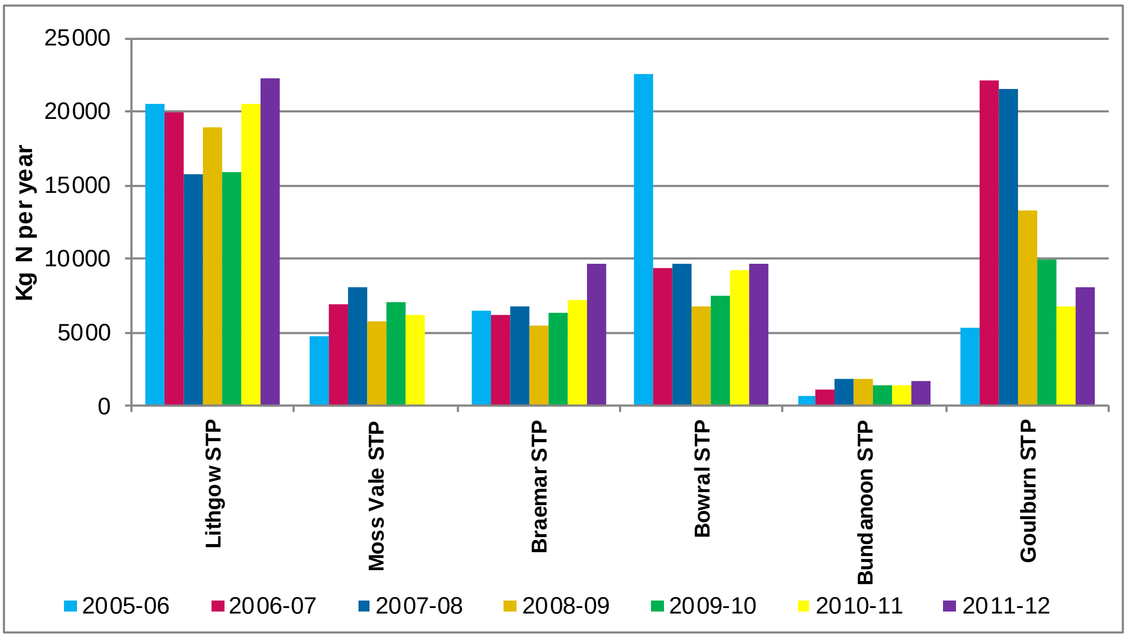


Figure 5-5 Nitrogen Loads (Kg/year) discharged from STPs during 2005-12

Data for 2011-12 were not available for Moss Vale STP; Data for 2012-13 were not available for all STPs.

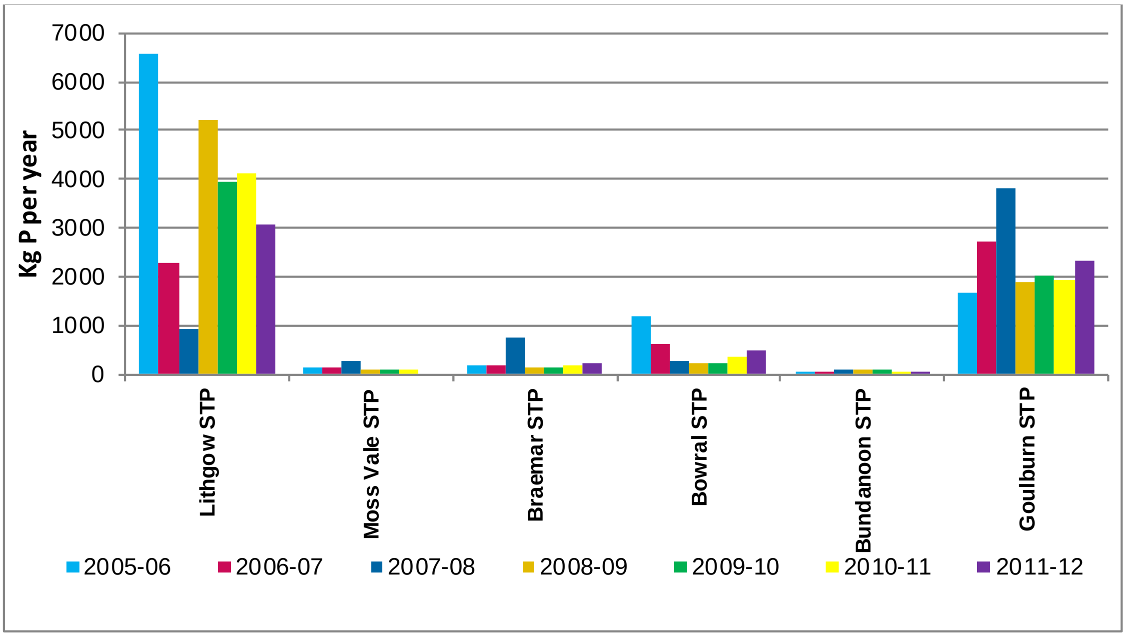
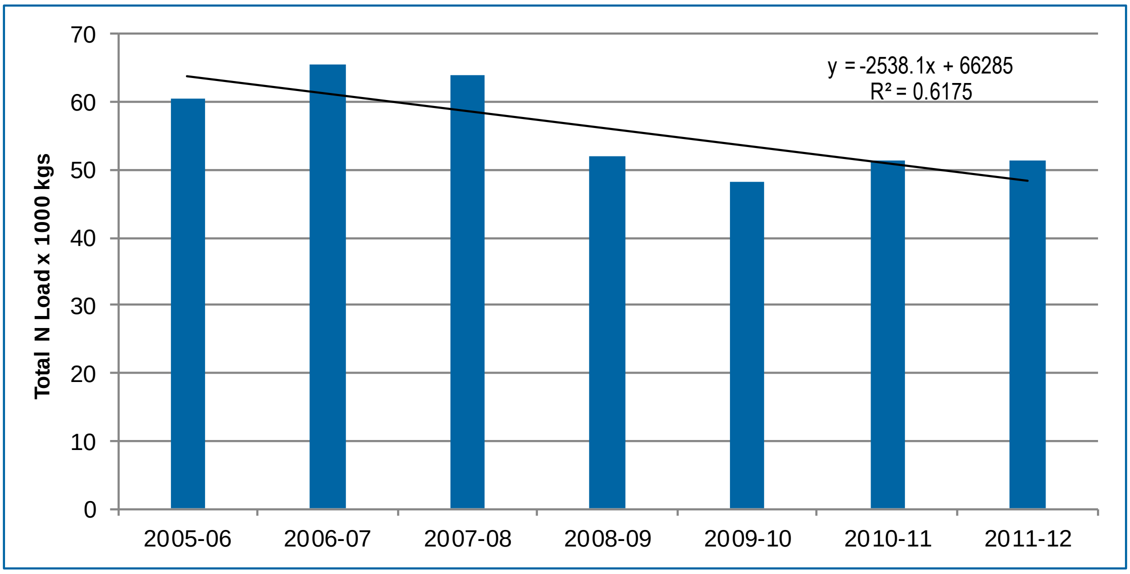


Figure 5-6 Phosphorus Loads (Kg/year) discharged from STPs during 2005-12

Data for 2011-12 were not available for Moss Vale STP; Data for 2012-13 were not available for all STPs.

Overall, there has been decreasing trends of discharge loads, which was evident with regard to both nutrients (Figure 5-7). This was assessed as a very positive trend despite the variability of individual STPs. As in the previous audit period, STPs in the Wollondilly and Upper Coxs sub-catchments have discharged the largest N and P loads into the Catchment.



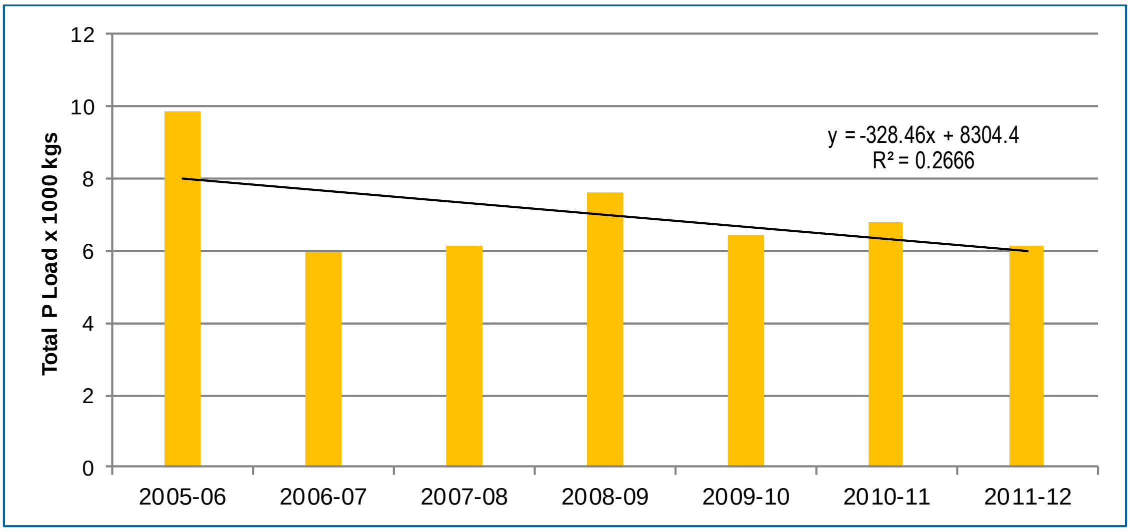


Figure 5-7 Total Loads of N and P released from seven STPs during 2005-12

In addressing the Nutrient Loads Indicator, it is necessary to consider the level of compliance with the current EPLs, which target pollution reduction in the Catchment through load-based limits. Data for 2012-13 were not available for the current Audit.

Figure 5-8 summarises the levels of compliance of individual STPs and the types of non-compliances on the above measures. Table 5-13 provides brief details on the nature of these non-compliances. The data indicated that although the overall number of breaches has declined over time, there were still many instances of non-compliances, related to excessive loads of N and P being released into the receiving water.

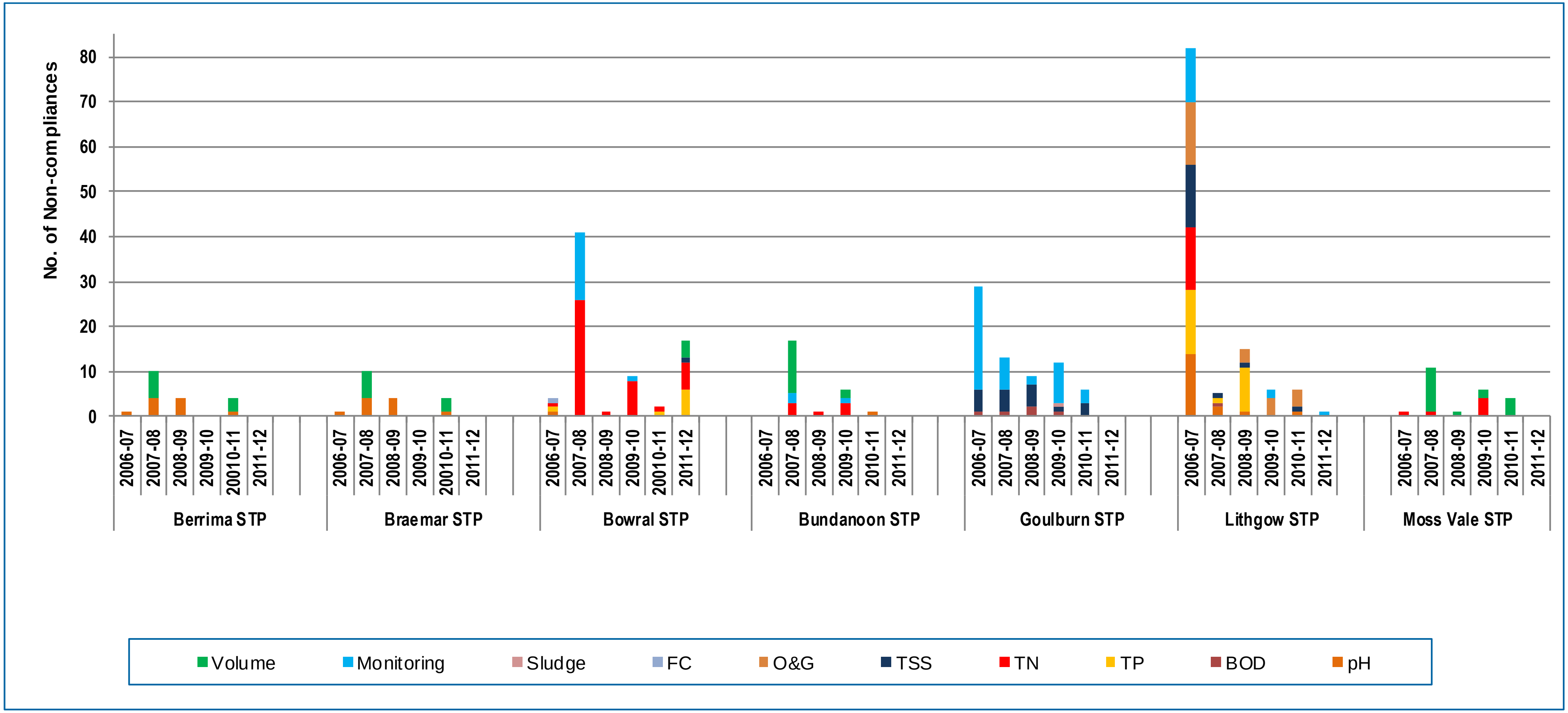


Figure 5-8 Number and type of non-compliances recorded against individual STPs in the Catchment during 2006 to 2012

Table 5-13 Summary of EPL non-compliances recorded against STPs during 2006-12

STP and EPL	Total Non-compliances (2006-12)	Observations
Berrima STP EPL 3575	19	Of 19 non-compliances, 10 were related to pH being outside EPL limits, and 9 exceedances of discharge volumes, in wet weather
Braemar STP EPL 10362	30	Most of the non-compliances were related to pH (11), TN loads (14), and TP loads exceeding EPL limits, and some monitoring and reporting failures (2).
Bowral STP EPL 1749	74	Most non-compliances were related to TN loads (43), less frequently TP loads (8), and increased volumes discharged (4), there were also rare instances of pH (1), TSS (1) Oil & Grease (1) and many instances of failures of monitoring (16).
Bundanoon STP EPL 3436	25	Most non-compliances were related to discharge volumes exceeding limits (14) and elevated TN loads (7), pH (1) and monitoring failures (3).
Goulburn STP EPL 1742)	69	Most non-compliance were related to BOD (5) and TSS (19) exceedances and many instances of failures related to monitoring (44).
Lithgow STP EPL 236	115	The largest numbers of non-compliances were related to the following exceedances; TP (25), FC (25), pH (18), TSS (17), and TN (14), there was one BOD exceedance and 15 failures in monitoring as well.
Moss Vale STP EPL 1731	23	Most non-compliances were related to discharge volume exceedances in wet weather (17) and some exceedances of TN Loads (6)

The Auditor is of the view that reductions in the release of nutrient loads have been achieved by individual STPs due to upgrades that have occurred during the past 8-10 years. The previous audit report (DECCW 2010a) recorded various upgrades of existing STPs and associated sewerage transfer and utilisation works. Upgrades to the Jenolan Caves STP, Wallerawang STP, and Lithgow STP were completed during the current audit period and the respective EPLs have been modified to reflect these improvements.

During the current audit period, many of the major STPs in the Catchment have continued their programs of upgrades and system improvements, which would be of benefit to the health of the Catchment’s waterways; these include the new STPs at Robertson and Kangaroo Valley.

Diffuse Nutrient Sources and Loads

The 2010 catchment audit (DECCW 2010a) recommended that future audits include estimates of nutrient loads from diffuse sources of pollution to assist in determining the contribution of all sources of nutrients (both point and diffused sources) within individual sub-catchments. These estimations could then be used to determine the effectiveness of current and future catchment management actions with regards to nutrient reduction within those sub-catchments.

However, this Auditor is of the view that the nutrient modelling activity is not aligned to the purpose of a Catchment Audit, which is to review information that has been collected and to examine actions that have occurred within the audit timeframe of the past three years. Hence, in this audit, the information currently available was evaluated, with a view to proposing a methodology that will enable the lead agencies to progress the issue of diffuse nutrient load prioritisation, prior to the next audit.

The previous studies that have examined nutrient generation and associated risks to the catchments include:

- Nutrient modelling of the catchment using a CERAT Model using stream flows, event mean concentrations (EMC) and land use as part of the 2010 audit by the Department of Environment Climate Change and Water (DECCW 2010a);
- The Pollution Source Assessment Tool (PSAT) developed by SCA, which attributes loads of nutrients to sub-catchments, based on their land-use attributes;
- Modelling sediment and nutrient budgets in the Lake Burragorang catchment (Rustomji 2007);
- Synthesis Report – The Sources of Sediment in the Lake Burragorang Catchment (Caitcheon 2007); and
- Development of a Distributed Rainfall-Runoff Model for the Nattai catchment (report to the SCA by Jacobsen et al. 2012).

In addition to the above studies, relating to the Sydney Drinking Water Catchment area, a report for the Department of Sustainability Victoria by Vanderkruk (2010) evaluated the capabilities of currently available nutrient models to estimate loads and predict in-stream transport of nutrients through surface water catchments. The evaluation included ten models commonly used to predict nutrient loads for surface water catchments and included both simple models (with minimum input data requirements) and complex models.

They concluded that WaterCAST and HSPF (Hydrologic Simulation Program Fortran) were the best candidate models for modelling TP, while INCA-N (Integrated Nitrogen in Catchments model) was the most suitable model for predicting in-stream nitrogen. INCA-N is a simple kinetic model for both nitrate and ammonia and does not require a biological component. WaterCAST was chosen as the most suitable model for TP, because it has low input data requirements, no algal parameters, and is the most recently developed model that has been adapted for Australian conditions (Vanderkruk et al. 2010).

The previous audit used the catchment models contained in OEH's Coastal Eutrophication Risk Assessment Tool (CERAT; **http://www.ozcoasts.gov.au/nrm_rpt/cerat/index.jsp**) to estimate nutrient loads from diffuse sources (Littleboy et al. 2009). The catchment models were based on the export coefficient approach, based on modelled export rates per hectare for various types of land uses. The specific methods are described below, with some descriptions quoted directly from the methods described in CERAT.

'*CERAT is a tool for assessing the risks of eutrophication to New South Wales estuaries, as a result of catchment development. It is a coupled series of catchment and estuary models, which can be used to predict catchment loads and consequent impacts on the water quality and ecological condition of the estuary*'.

In applying the model, DECCW (2010a) classified the land use layers for the Catchment into eight different land use categories, as follows:

- Intensive cultivation;
- Grazing;
- Conservation and scrub;
- Cropping;
- Tree horticulture;
- Irrigated pasture;

- Cleared land; and
- Urban.

'*The Catchment Model is based on an export coefficient modelling approach that has been applied widely for natural resource management in the United States and Europe (including the United Kingdom), due to its transparency and simplicity (e.g. Johnes 1996; Worral and Burt 1999; Lepisto 2001). For these reasons, the approach is being increasingly applied to predict nutrient and sediment runoff from Australian catchments (for example see the review by Drewry 2006). The Catchment is simply divided into different land use types and the area of each land use type is multiplied by an export coefficient or generation rate for that particular land use type. The export coefficient is the rate at which nutrients and sediments from each land use type is exported to the river or stream. The total export of nutrients and sediments from the catchment is the sum of the export for each land use type in the catchment:*

$$L = \sum_{i=1}^{n} Ei\ (Ai)$$

Where

L = total export of nutrients or sediments from a sub-catchment

i = land use type

E = export coefficient (kg/km^2 /y)

A = area of land use type (km^2)

In CERAT, an export coefficient model was developed for each sub-catchment in the catchment. The export coefficients were expressed as kilograms of Total Nitrogen (TN), Total Phosphorus (TP), or Total Suspended Solids (TSS) per km^2 of the sub-catchment per year (kg/km^2/y). The export coefficients were derived by multiplying modelled surface flow data with measured nutrient and sediment concentration data from the published scientific literature and from past OEH monitoring projects. Over 4000 export coefficients were generated for CERAT, reflecting unique combinations of climate, land use and soil types along the NSW coast'.

Importantly, the information included Sydney Drinking Water Catchment data on estimated nutrient export coefficients collected by AWT (2003). As there has been negligible change in land use types, and as soil type is considered static, the only parameters that could be updated to refine the predicted nutrient loads relate to changes in climate (e.g. rainfall, evapotranspiration). However, to update the climate information is beyond the scope of this current audit. OEH have advised that they are looking into statistical methods for updating the current catchment models CERAT. This project has the potential to encompass the Sydney Drinking Water Catchment area, and this information, will become available when the project is complete (Jocelyn Dela Cruz, *pers. comm.*).

The CSIRO study by Rustomji (2007) utilised the ANNEX (Annual Network Nutrient Export) model to predict the average annual loads of phosphorus and nitrogen in each link in a river network in a similar way to SEDNET, with which it is run in conjunction (see Young et al. 2001).

The main inputs used to calculate nutrient loads were those associated with sediments from hillslope erosion, gully erosion, river bank erosion, dissolved loads in runoff water and point source inputs from the five main STPs. As with SEDNET the model then routes the nutrient loads through the river network, estimating the losses from floodplain and reservoir deposition and in-stream de-nitrification.

It is important to note that the dissolved nutrient concentrations for various land uses were derived from a study carried out in the Goulburn-Broken catchment in Victoria and may not accurately represent dissolved nutrient generation rates in the Sydney catchment (Rustomji 2007). Also, the nutrient content of surface soils was estimated across the catchment using the national scale TN and TP maps produced by Henderson et al. (2001) at an approximate resolution of 1.1 km^2. The extent of ground-truthing for this data within the Sydney Catchment area is unknown, and needs to be regarded as a limitation.

The aim of the study by Jacobsen et al. (2012) was to develop a distributed numerical model that can provide flow forecasting capabilities for both short and long term flows, as well as a water quality assessment tool for the Nattai River. The basis of the project utilised the existing SCA MIKE Floodwatch forecasting system and MIKE SHE catchment model. The model used a grid cell size of 200 m and a maximum time step of 2 hours. Water quality parameters examined included TN, TP and TSS.

The in-stream modelling approach included dilution, based on discharges, plus a first-order decay function. The first-order decay function was calibrated to account for observed differences between upstream and downstream monitoring stations that could not be described by adjusting the load from the entire catchment. The loads were based on the observed average load from the point source at Braemar (Mittagong) STP and diffuse pollutant export rates derived from the literature (using 2.0 kg N/ha/y and 0.2 kg P/ha/y for agricultural and cleared land and 1.0 kg N/ha/y and 0.07 kg P/ha/y for forest and natural vegetation areas.

In calculating the water quality loads with the MIKE model, the model was adjusted to better fit the observed water quality concentration data. In the estimate of TN loads, this involved reducing the predicted load from cleared/agricultural areas to 20% of the predicted load and assuming that there were zero loads during periods of low to normal discharge in the river branch. Similarly TP export loads for cleared/agricultural areas were reduced to 15% of the predicted load with low flow again being assigned zero phosphorus load (Jacobsen et al. 2012).

The authors noted that '*these model calibrations were significant, but probably realistic for a drought period*' (Jacobsen et al. 2012). They also indicated that the reduction in loads applied for TP could *'be justified because particulate transport and wash off of phosphorus is very important and during dry conditions these processes are very limited'* (Jacobsen et al. 2012).

The authors concluded that although the model generally simulates both the TN and TP levels, 'in some low flow periods, the measured TN variation was not reproduced by the model' likewise the 'TP was not reproduced by the model in events that were poorly reproduced by the hydrodynamic flow model'.

The Table 5-14 and Table 5-15 show a comparison of outputs from the three different modelling approaches. The results show that for most sub-catchments the TN loads estimated by the CERAT model were approximately an order of magnitude lower than those estimated by the CSIRO model with the exception of the Mulwaree River, Upper Coxs River, and Wingecarribee River sub-catchments. These three sub-catchments were predicted by the CERAT model to have higher TN loads than predicted by the ANNEX model. The MIKE model outputs for Nattai River sub-catchment predict an annual TN load of 57 tonnes, or 11 tonnes if the reduced (calibrated) model is used. Both of these predicted TN loads were closer to the CERAT predicted load than the CSIRO predicted load for Nattai River sub-catchment.

As a further comparison, we used the available water quality data (median nutrient concentration for the 3 year audit period) multiplied by the recorded annual flow volume for sites located at the downstream nodes of selected sub-catchments, to estimate the annual loads transported.

Based on the water quality results and flow at E210 the annual TN flux for this audit period ranged from 5 to 22 tonnes (see column 4 of Table 5-14) suggesting that both the CSIRO and CERAT models are overestimating TN loads in this sub-catchment, although the latter to a much lesser extent than the former. The calibration of the MIKE model using Nattai water quality data has enabled this model to provide an estimated TN load that is closer to the loads predicted by the water quality data for this audit period.

Comparison of predicted loads for other catchments shows that in 5 out of 8 sub-catchments (see Table 5-14), the CERAT model is giving the closest estimate of TN load compared to the estimated load calculated from the observed water quality/flow data. The exceptions were the Mulwaree, Wingecarribee and Nattai River catchments.

Table 5-14 Comparison of Total Nitrogen Loads (tonnes/year) by sub-catchment for the Warragamba Catchment

Sub-catchment	CERAT Tonnes/yr (DECCW 2010)*	CSIRO Tonnes/yr (Rustomji, 2007)*#	MIKE model Tonnes/yr (Jacobsen *et al.* 2012)*^	Estimated load Tonnes/yr (3 audit years)
Kowmung River	39	320	-	29, 39, 19
Lake Burragorang	39	347	-	
Little River	9	116	-	0, 0.1, 1.6
Lower Coxs River	30	107	-	
Mid Coxs River	92	488	-	35, 66, 37
Mulwaree River	82	43	-	19, 49, 13
Nattai River	32	199	57 (11)^	5, 18, 22
Werriberri Creek	19	66	-	1.2, 4, 4
Upper Coxs River	57	46	-	
Upper Wollondilly River	49	61	-	
Wingecarribee River	219	176	-	47, 121, 59
Wollondilly River	291	665	-	158, 360, 165
Total for Warragamba	**958**	**2632**	**-**	

* All values were rounded to the nearest kg

The net loads per sub-catchment were calculated from Table 11 in (Rustomji, 2007), rounded to the nearest kg.

^ Annual estimated load from Table 9 in (Jacobsen *et al.* 2012), number in brackets is 20% of the total annual load used in the comparison to observed TN concentrations.

Table 5-15 shows the estimated TP loads, similar, to the TN predictions the CERAT estimations are all considerably lower than those from the CSIRO investigation with the exception of the Mulwaree River, Upper Coxs River and Wingecarribee River sub-catchments. The similar pattern of results suggests that it is related to a systematic difference in these catchments between the two models, most probably the soil type.

Similar to the TN predictions, the un-calibrated MIKE model estimates were between the CERAT and CSIRO predicted loads with the calibrated estimates (in brackets) being quite similar to the CERAT model estimates. The estimated TP flux from the water quality and flow observations at E210 ranged from 0.2 to 0.7 tonnes per year which are similar to the calibrated MIKE model predictions. These similarities are to be expected since the MIKE model was calibrated using water quality data from E210. Similar to the TN estimates, the TP estimates predicted by the CERAT model were closer to the loads predicted from the observed water quality/flow data (see column 4 Table 5-15) than the estimates from the CSIRO model. In all but one instance, the observed loads were lower than the loads predicted by the models (CERAT model estimate for year 2 of this audit period for Kowmung River).

Table 5-15 Comparison of Total Phosphorus Loads (tonnes/year) by sub-catchment for the Warragamba Catchment

Sub-catchment	CERAT Tonnes/yr (DECCW 2010)*	CSIRO Tonnes/yr (Rustomji, 2007)*#	MIKE Tonnes/yr (Jacobsen *et al*. 2012)*^	Estimated load Tonnes/yr (3 audit years)
Kowmung River	3.2	40.9	-	2.5, 3.4, 1.7
Lake Burragorang	2.6	49.2	-	
Little River	0.7	5.1	-	0, 0, 0.2
Lower Coxs River	2.7	16.2	-	
Mid Coxs River	8.2	67.0	-	2.4, 4.6, 2.6,
Mulwaree River	9.8	5.1	-	0.7, 1.8, 0.5
Nattai River	2.4	10.7	7.2 (1.1)	0.2, 0.6, 0.7
Werriberri Creek	1.6	7.5	-	0.1, 0.2, 0.2
Upper Coxs River	8.3	1.3	-	
Upper Wollondilly River	6.0	9.9	-	
Wingecarribee River	17.0	15.3	-	2.4, 6.3, 3
Wollondilly River	34.2	109.9	-	5.5, 12.5, 5.8
Total for Warragamba	**96.7**	**338**	**-**	**-**

* All values were rounded to one decimal point

The net loads per sub-catchment were calculated from Table 11 in (Rustomji, 2007), rounded to one decimal point.

^ Annual estimated load from Table 9 in (Jacobsen *et al*. 2012), number in brackets is 15% of the total annual load used in the comparison to observed TP concentrations.

The use of export coefficients not reflective of local conditions or management practices will only reflect broad-scale nutrient loads, and not the critical changes in management practices, which are the primary focus of catchment interventions. This is a limitation that applies to the modelling estimates from the CSIRO study and which may explain why the predicted nutrient loads are much higher than the predictions from the CERAT model.

One disadvantage of the CERAT export coefficient modelling approach is that it does not consider delivery ratios of the nutrient and sediments. Delivery ratios are the fractions of nutrients and sediments entering the river or stream (from the catchment) that eventually make it to the downstream node. The delivery ratio is dependent on the ambient flow conditions. For example, low flow conditions typically equate to very low delivery ratios due to in-stream attenuation processes and this may explain why the CERAT predictions are higher than either the observed loads for the last 3 years and also the MIKE model predictions.

Proposed methodology for integrating modelling approaches

Without carrying out a ground-truthing analysis, it is difficult to determine which of the current modelling approaches would most accurately reflect the actual conditions in the sub-catchments. However, one approach that may be useful and that would have the advantage of utilising all of the existing information to date would be to construct a Bayesian network model.

A Bayesian framework is able to accommodate different types of data, and allocate weightings, based on the estimated uncertainties within the datasets. The advantage of this approach is that it utilises all the previous existing work and places it in the context of the potential value of that work (Pollino et al. 2007; Bromley et al. 2003). Bayesian network models have been used in NRM and more specifically water resource management, to understand complex systems with related environmental, economic, social and political issues (Cain, 2001; Hart et al. 2009).

For example, they have been used to understand fauna population viability related to land or water management, for the management of a catchment wide demand on water, to review proposed actions for the remediation of groundwater contamination, and to evaluate the fauna impacts of choosing alternate water supply options (Bromley et al. 2003). It is the ability to represent these uncertain complex ecosystems and management issues that has made Bayesian networks increasingly popular (Uusitalo 2007).

Bayesian network models are also relatively simple to develop and utilise (Hart 2009). They can be used to integrate information from other model sources, such as hydrological flow, biophysical factors, such as water or habitat quality, or characteristics, and ecological responses, such as faunal species abundance and diversity (Hart et al. 2009).

Among other attributes, they can combine qualitative and quantitative information, and serve as repositories of information. While there are some drawbacks to using Bayesian network models for NRM, they are overall considered a useful tool for environmental assessment and decision-making. A further benefit of using Bayesian networks is that through sensitivity analysis some components of a system will be shown to have little influence on the final decision or outcome, and can therefore be excluded from the network (and hence, monitoring programs). This could simplify the modelling process.

A distinct advantage of Bayesian networks for NRM is that nodes / variables and causal relationships are based on whatever data is available at the time (Bromley et al. 2003). This may be monitoring data, output from a model; or, in the absence of data, can be based on expert opinion (Bromley et al. 2003). This enables the modelling to be undertaken even when there is a known knowledge gap or lack of data or evidence. Expert opinion can be used as a credible inclusion and the network can be updated as hard data becomes available. This is particularly important to natural resource managers who need to understand the effect of management options on ecosystems, often in the absence of specific data, and who cannot halt activities while monitoring or experimental data is slowly obtained (Marcot et al. 2001).

The active involvement of stakeholders in the modelling process is considered essential for successful NRM, since without community involvement poor decisions are likely to be made (Bromley et al. 2003). Stakeholders are important to consider in NRM since their relationship with, and opinions relating to a resource both informs and directs management and outcomes. Therefore it is important to elicit stakeholder opinion and represent causal relationships leading to the outcome in any Bayesian network for NRM (Cain 2001).

The use of elicitation workshops can also serve as consultation and facilitate active involvement in the decision and modelling process. Through workshop elicitation conflict resolution is more likely to be achieved, the decision making process becomes more transparent to the stakeholders, and the final decision is more likely to be accepted due to a sense of ownership of the result (Bromley et al. 2003). By this method, reaching a decision, such as solving a water scarcity problem, through workshop elicitation, offering alternate schemes as solutions, and by indicating the cost the community will pay if it facilitates this decision, allows the community to 'buy in' to the process and become actively involved in the decision process (WSAA 2006).

This elicited stakeholder opinion can be entered into a Bayesian network through the informing of probability tables, during or after elicitation in a workshop. Where it is known that stakeholders have the power to direct outcomes, the strength of that influence can be incorporated into a model from the outset. Either way, the complex myriad of relationships that inform the management of a natural resource are expressed as probabilistic dependencies informed and quantified by a set of conditional probability tables (Bromley et al. 2003).

Bayesian networks are also useful where uncertainties in management are not able to be further informed or resolved in a timely manner by the collection of more data (Hart et al. 2009). Such is the case when the immediate management of an endangered species or habitat is required and a decision cannot wait for further information or certainty (Hart 2009). They are particularly useful to facilitate the integration of different knowledge domains including expert elicited knowledge, modelling results and monitoring data from hydrology, economy, ecology and social domains (Henriksen 2007). This is particularly relevant to complex natural resources issues.

Sensitivity analysis is used to measure the sensitivity of the changes in probabilities of query nodes / variables dependant on a change in parameters and inputs (Pollino et al. 2007). In this way it is frequently used to measure the effect of one variable on another (Wooldridge 2003).

Using sensitivity analysis can lead to a better understanding of the modelled system and support the development of management strategies and further information gathering. Given that new data can be entered into a Bayesian model as it becomes available, management strategies or mitigating measures embedded in the Bayesian model can be tested based on this information. Data obtained through further research can be used in case-based evaluation to test how well a model's predictions match actual outcomes (Wooldridge 2003). This can further inform the refining or changing of NRM strategies.

Even when an outcome is known, retrospective sensitivity modelling can be used to characterise how effective individual variables, such as management strategies, were in facilitating the outcome. Where an outcome is unknown, or further learning is yet to be undertaken, case-based evaluation can be undertaken by partitioning data and using a large portion for model population. Model evaluation or verification can be undertaken using the small remaining portion.

The ability for Bayesian Networks to deal with continuous data is limited. As such, data generally needs to be discretised (Uusitalo 2007). In environmental research, data and parameters often have continuous values (Uusitalo 2007). Discretisation relies on the modeller and may not fully represent the original distribution of the data set. Statistical power may be compromised (Uusitalo 2007). This is therefore considered a significant disadvantage when using Bayesian networks for NRM. Also, large Bayesian network models can become difficult to manage unless carefully designed and managed (Wooldridge 2003).

While Bayesian networks are a valuable tool for testing hypothesis on environmental problems, they can be limited (Wooldridge 2003). Certainly one of the traps in modelling on elicited expert opinion alone is that the model may somehow give false credibility to the judgement statement. The elicitation of multiple expert opinions and the population and verification of the model with scientific data will add to its rigor and mitigate this problem.

5.2.6 Recommendations

Similar to previous audits the 2013 Audit finds the performance of STPs in the Catchment to be variable. However, it is evident from the data and information assessed, that all of the STPs have improved their performances, and their contribution to pollution of downstream waterways has steadily declined during the past 8-10 years.

Given that pollution reduction and wastewater re-use programs at STPs have great potential to reduce the amount of pollution and nutrients reaching waterways in the Catchment, the 2013 Audit makes the observation that stricter enforcement of EPL conditions by the regulator - the EPA - may contribute further to improved performances, and thereby, mitigate any adverse impacts of non-compliances on the Catchment's waterways.

Calculation of nutrient loads for individual sub-catchments, and then, for the entire Catchment, is a significant undertaking, and it is the Auditor's view that such an exercise should not be carried out unless there is a specific need or use for such information.

The approach of estimating nutrient loads for the entire catchment using default export coefficients for various land use types; even when these coefficients have been locally derived is unlikely to produce results that match individual field observations or estimated flux using the available water quality and flow data. Hence, the generated results can be misleading if used for the purpose of prioritising the need for catchment management and interventions. In the Auditors' view, the more important objective is for a tool that is able to accurately rank the relative nutrient loads, particularly from diffuse sources, so that management objectives for catchment management can be prioritised and more targeted.

The SCA's existing PSAT tool is adequately identifying priority drainage areas for a range of water quality pollutants including nutrients. Further improvements to the PSAT modules, intended by SCA, would further enhance its ability to identify areas which are sources of diffuse nutrient pollution.

The Auditor suggests the use of a Bayesian network model to complement the PSAT and incorporate both quantitative and qualitative data, so that management scenarios can be easily evaluated in the context of a triple bottom line framework. A Bayesian network model could incorporate information from all previous studies in a hybrid that enables information to be weighted and evaluated. Other approaches could also be investigated.

The SCA use the existing data (including PSAT) to develop a predictive tool to evaluate catchment management scenarios for the reduction of diffuse sources of nutrient pollution.

The use of intensive ground-truthing of model input data in selected sub-catchments by obtaining 'event-based' wet weather monitoring information via the use of auto-samplers could also supplement this methodology and inform the development of a scenario analysis tool.

5.3 Cyanobacterial blooms

5.3.1 Summary

Cyanobacterial blooms intermittently occurred in catchment streams and the water storages, as during previous audit periods. These occurrences are likely to be dependent largely on climatic factors (i.e. drought, and low flows) and other 'in-stream' conditions, including nutrient levels.

The composition of phytoplankton in waterways changes, often in response to local conditions, which include nutrient levels and other factors (i.e. temperature, sunlight or shade, etc.). Under some conditions, such as stagnation, calm conditions, and unusually high temperatures, combined with elevated nutrient levels, cyanobacteria may dominate over other phytoplankton in the water column.

The recommended indicator for the current audit with regard to cyanobacteria was compliance with the NHMRC (2008) recreational water quality guidelines for Cyanobacteria in freshwater.

The water quality data and information provided for the Audit indicated that although instances of high levels of cyanobacteria were recorded during the audit period, these instances were not unusual, nor did they pose a great risk to waterways and storages. There were no significant bloom events during the audit period, unlike in the previous audit period, when a large bloom of *Microcystis aeruginosa* occurred in Warragamba Dam in 2007.

Based on the data and information provided, the 2013 Audit finds that the SCA has made significant progress in obtaining a better, scientific understanding of conditions that lead to bloom formations, in both catchment streams and storages. This has significantly increased the SCA's preparedness of management to respond to blooms.

Overall, the Auditor finds the scientific, evidence-based approach taken by the SCA during the past few years, and the progress made, as highly significant. This increased understanding should assist future management of the waterways and storages in the Catchment, and for more effective and targeted use of resources for both on-going monitoring and management of cyanobacterial issues. The Auditor encourages the SCA to continue the approach taken, so that the stakeholders can respond more effectively to any future cyanobacterial events.

It would also be prudent to give more publicity to the increased knowledge gained, so that other stakeholders and land managers could benefit from the knowledge. It would also give the SCA's customers and the general public an increased level of confidence in the capacity of catchment managers to respond adequately to cyanobacterial problems, or other catchment issues, if and when significant problems occur.

Assessment Criteria

Criteria

1. Incidence of Cyanobacterial blooms
2. SCA has an understanding of the risks of mixing, and other factors that contribute to Cyanobacterial blooms.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil

Prior recommendations

Prior Audit Recommendations	Remedial action	Status
Recommendation 22: The SCA should continue to investigate the risk of mixing of cyanobacteria between water bodies in the Shoalhaven system during periods of low flow.	None required; continue to maintain understanding	Closed
Recommendation 23: The SCA should investigate trends and long-term patterns in the community composition of cyanobacteria and phytoplankton in the dams and reservoirs.	None required; continue to maintain understanding	Closed
Recommendation 24: The SCA should look closely at including monitoring sites in sub-catchments that currently have no long-term water quality or flow gauging sites.	The SCA is currently undertaking a review of its Water Monitoring Program	Opportunity for improvement

5.3.2 Background

Cyanobacterial blooms may have water quality and environmental impacts, particularly when they occur in reservoirs and slow-moving or ponded sections of rivers. This is because a number of common Cyanobacterial species found in freshwater within the Catchment, including *Anabaena circinalis*, and *Microcystis aeruginosa*, can produce potent toxins that can pose a threat to water users unless the water is appropriately treated. Some Cyanobacteria also impart tastes and odours, which require removal during water treatment. Other Cyanobacteria have been implicated in causing skin irritations.

Apart from known toxin-producing species, there are also many other non-toxic and potentially harmless Cyanobacteria, which occur naturally in catchment rivers and watercourses. Many factors promote the growth of Cyanobacteria, and these include temperature, stagnant conditions and elevated levels of nutrients, particularly N and P.

A large number of Cyanobacterial species can obtain nitrogen from the atmospheric N_2 using a special enzyme (Nitrogenase), associated with special cells, called heterocysts. These species in particular, and all Cyanobacteria, in general, respond positively to elevated phosphorus levels in water by increased growth and reproduction. Proliferation and abundance of Cyanobacteria in waterbodies and watercourses in the catchment are often the clearest indication that the water may be somewhat elevated in nutrient status, both N and P.

In the context of catchment health, recreational guidelines are used rather than drinking water guidelines to assess Cyanobacterial bloom occurrence within the sub-catchments. Therefore, the recommended indicator is:

- Compliance with the NHMRC (2008) recreational water quality guidelines for Cyanobacteria in freshwater.

5.3.3 Management and Surveillance

As stated in Section 5.1.3, the SCA's Water Monitoring Program covers routine, targeted, investigative, and event-based monitoring over the SCA's area of operations in the Catchment, and monitoring for cyanobacteria is included in the program.

This monitoring covers catchment sites (streams and rivers), storages (dams and lakes) and raw water supplies, as well as delivery systems - inlets to WFPs, transfer canals and pipelines, and picnic area water supplies.

Sampling for algae and cyanobacteria occurs concurrently with routine catchment and storage monitoring. Catchment sites are sampled at the surface and reservoir sites are sampled, down to a depth of 6 m to provide a 'composite' sample.

In storages with a history of cyanobacterial blooms, seasonal monitoring occurs, between October and May. These sites are monitored by the SCA at an increasing frequency (weekly) during the summer, so that emerging algal events can be detected early. Routine algal monitoring is also undertaken at WFPs.

The NHMRC (2008) *Guidelines for Managing Risks in Recreational Water* state that fresh recreational water bodies should not contain:

- 10 µg/L total microcystins; or >50 000 cells/mL toxic *Microcystis aeruginosa*; or bio-volume equivalent of >4.0 mm^3/L for the combined total of all Cyanobacteria where a known toxin producer is dominant in the total bio-volume, or
- 10.0 mm^3/L for total bio-volume of all Cyanobacterial material where known toxins are not present, or
- Cyanobacterial scums consistently present.

The recommended method for interpreting and applying the guideline is via a risk-based approach and designates three alert levels for management response:

- **Green alert**: ≥ 500 < 5000 cells/mL *M. aeruginosa* or bio-volume equivalent of ≥0.04 < 0.4 mm^3/L for combined total of all Cyanobacteria; A green alert indicates that managers should continue routine sampling for Cyanobacteria;

- **Amber alert**: ≥ 5000 < 50000 cells/mL *M. aeruginosa* or bio-volume equivalent of ≥0.4 < 4 mm^3/L toxic cyanobacteria, or bio-volume equivalent ≥ 0.4 to < 10 mm^3/L all Cyanobacteria where known toxins are not present; An amber alert requires investigation of the potential causes of the Cyanobacterial abundance, as well as increased sampling effort, be undertaken to enable an accurate assessment of risks to recreational users

- **Red alert**: ≥10.0 µg/L total microcystins, or ≥50,000 cells/mL *M. aeruginosa* or bio-volume equivalent of ≥4.0 mm^3/L toxic cyanobacteria, or bio-volume equivalent >10.0 mm^3/L all cyanobacteria where known toxins are not present. Red alerts require relevant authorities issue warnings that the water body is unsuitable for primary contact.

The National Health & Medical Research Council's Australian Drinking Water Guidelines, ADWG (NHMRC 2008) provide the following guidelines for management responses for cyanobacteria in storages:

- 500 cells/mL of toxic cyanobacteria - increase monitoring;
- 2000 cells/mL of toxic cyanobacteria - consider need for toxicity testing (seek expert advice; and
- 6500 cells/mL of toxic cyanobacteria - seek advice from health authorities.

These have been adopted by the SCA in its Water Monitoring Program (SCA 2010b).

5.3.4 Methodology

In line with the previous audit report, cyanobacterial data were analysed in following two ways to assess the state of cyanobacterial blooms in the catchment:

1. Incidences of green, amber and red alerts since the previous audit (quantified as the number of weeks under alert) in different waterbodies;
2. Cyanobacterial cell counts, bio-volumes and microcystin concentrations in water samples collected as part of the Water Monitoring Program conducted by the SCA.

In addition to the compliance reporting, statistical trend analyses were also carried out to determine if there has been any significant increasing or decreasing trends in Cyanobacterial assemblages, over time, at key sites.

5.3.5 Findings

Incidences of significant blooms

NSW Office of Water (NOW) has no Cyanobacterial sampling sites within the Sydney Drinking Water Catchment. However, NOW receives notification of Cyanobacterial results, and issue State-wide alert levels, based on the recreational alert levels for Cyanobacteria.

Figure 5-9, Figure 5-10 and Figure 5-11 summarise the data provided by the Metropolitan & South Coast Regional Algal Coordinating Committee for bloom alerts in the Catchment for the period of the current Audit. Note: Colour coding corresponds with the green, amber and red alert levels specified for Cyanobacteria in the NHMRC (2008) recreational guidelines

The following observations highlights of the results:

- **Red alerts**: Cyanobacterial blooms at various sites monitored were sufficiently large to warrant the issuing of 38 red alerts (weeks under alert) by the Committee in 2010-11; this figure declined to 12 in 2011-12. There were no red alerts in 2012-13.
- **Amber alerts**: Cyanobacterial abundance was relatively high in many waterbodies, which resulted in the issuing of 46 weeks under amber alerts in 2010-11. This number increased to 65 weeks in 2011-12, but declined to 16 weeks in 2012-13.
- **Green alert**: Moderate levels of Cyanobacteria persisted in waterbodies through the warm months of 2010-11, which resulted in a total of 65 weeks under green alerts. This number increased to 98 weeks in 2011-12, but declined to 76 weeks in 2012-13.

The largest number of blooms occurred downstream of the Lithgow STP in Farmers Creek (Figure 5-9 and Figure 5-10), a pattern that has continued for many years. No information was available for the Farmers Creek site downstream of Lithgow STP for 2012-13, and the Regional Algal Co-ordination Committee (RACC) recorded that there were ‘no samples’ for this period.

A relatively high number of red, amber and green alerts were issued for Lake Wallace and Lake Lyell in 2010-11. However, Cyanobacterial blooms at these sites, and at other locations declined in 2011-12, and in 2012-13.

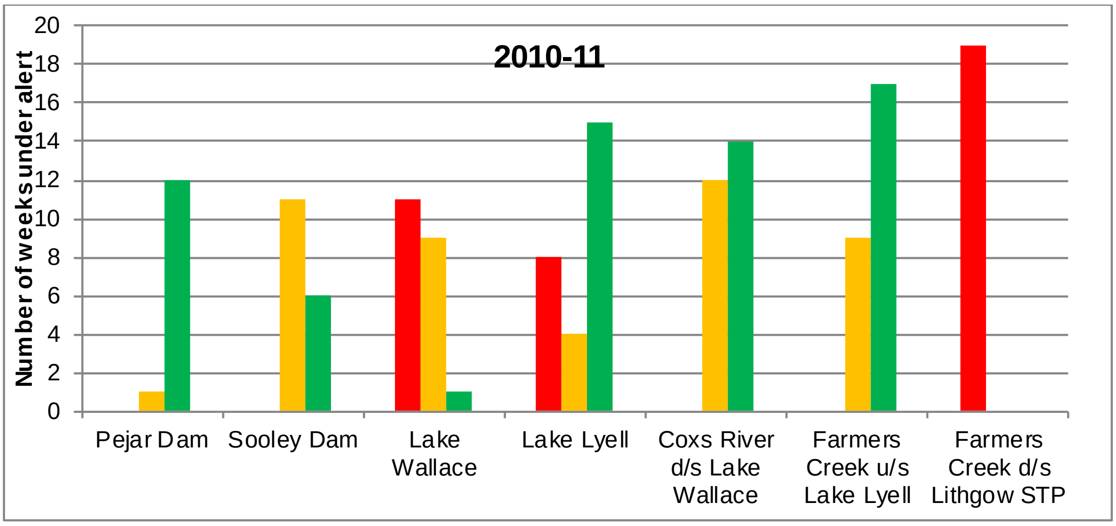


Figure 5-9 Cyanobacterial bloom alerts (Red, Amber, Green) in the Catchment, 2010-11

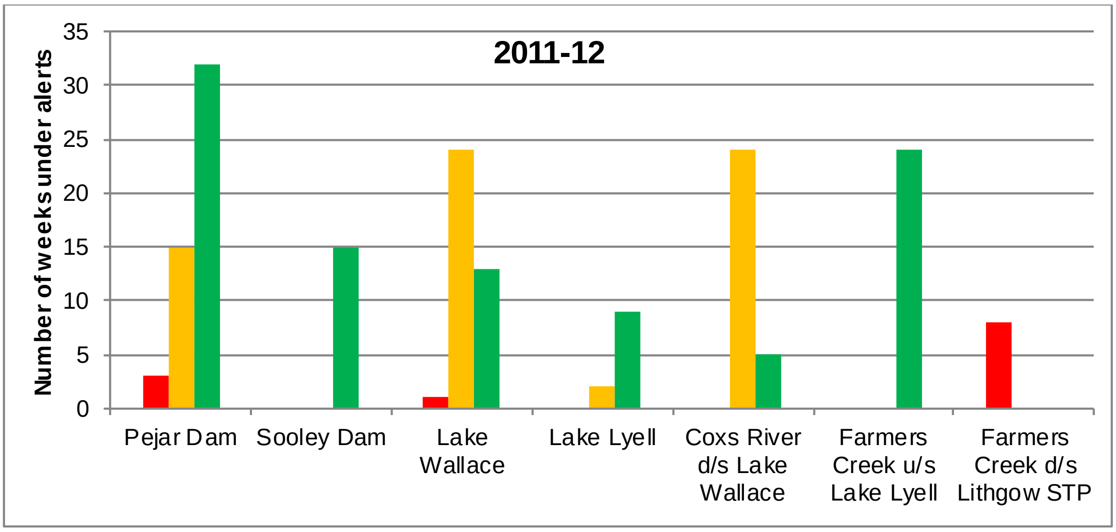


Figure 5-10 Cyanobacterial bloom alerts (Red, Amber, Green) in the Catchment, 2011-12

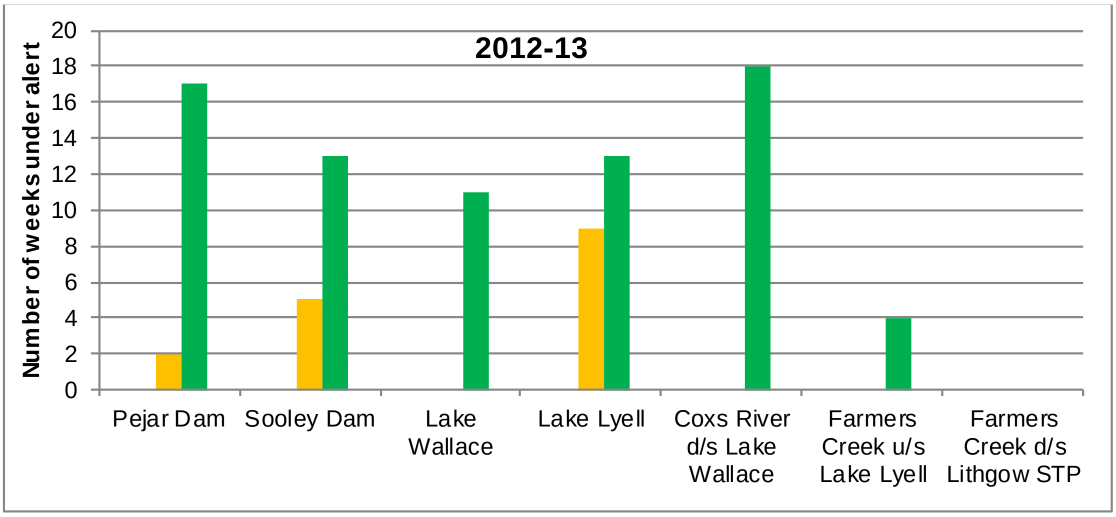


Figure 5-11 Cyanobacterial bloom alerts (Red, Amber, Green) in the Catchment, 2012-13

The data for the current audit period could be compared with those presented in the previous audit (DECCW 2010a), as shown in Figure 5-12. In general, the incidences of significant blooms in the Catchment (i.e. total numbers of weeks under which waterbodies in the Catchment were under any kind of cyanobacterial alert), increased in 2011-12 and then declined in 2012-13.

The period 2010 to 2013 was after the drought of earlier years. Higher rainfall and probably higher flows are likely to have reduced Cyanobacterial presence in catchment streams compared to during the drought years (Dr. Lee Bowling, *pers. comm*., Aug 2013).

The Auditor agrees with this view. However, the predisposition of many sites in the Catchment to cyanobacterial blooms, evident in the results, is a clear indication of relatively poor water quality conditions, contributed to by human activities, discussed in previous Sections.

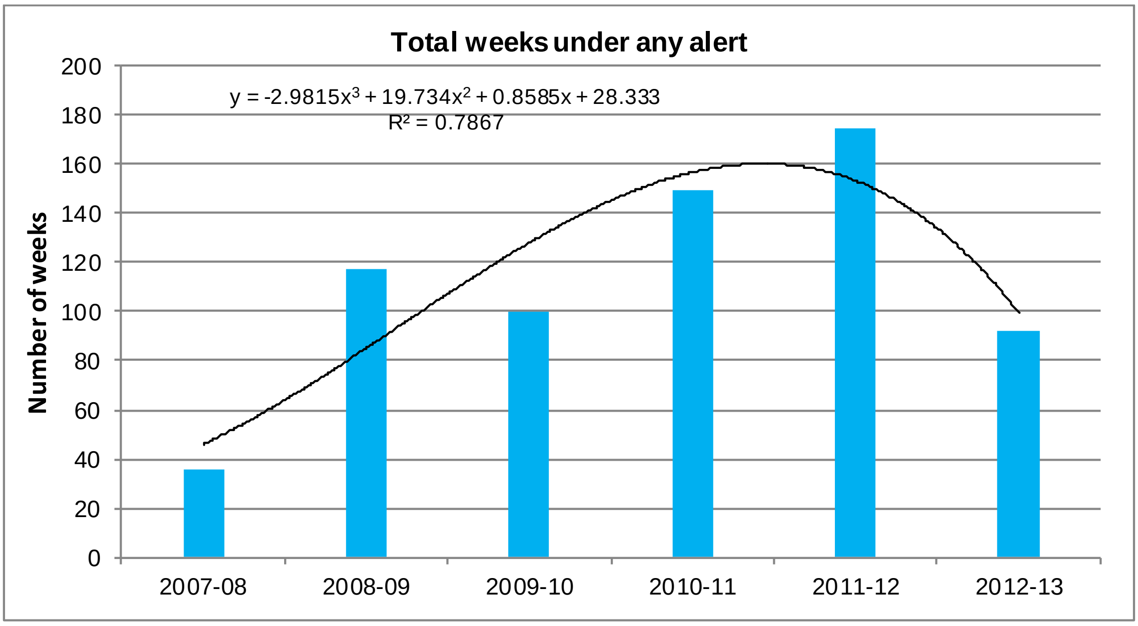


Figure 5-12 Trend in Cyanobacterial alerts (total number of weeks under algal alerts)

Catchment sites

Table 5-16 provides summary statistics of total and toxic cyanobacterial detected in samples collected from various catchment sites. The Table presents median and maximum values encountered during the current audit period (2010/11; 2011/12 and 2012/13).

The colour coding corresponds with the green, amber and red alert levels specified for cyanobacteria in the NHMRC (2008) recreational guidelines. The data for the audit period (2011-13) indicated that there were several instances when the maximum values of potentially toxic cyanobacteria reached >0.04 mm^3/L (coloured in green), >0.4 mm^3/L (coloured amber), and >4.0 mm^3/L (coloured red).

Figure 5-13 and Figure 5-14 present the cyanobacterial counts data for the catchment sites as box plots. The plots are on logarithmic scale, and these indicate the high variability of the results, median values of the data sets, 25^{th} and 75^{th} percentiles and outliers. The reference lines corresponding to either 500 cells/mL; 5000 cells/mL; or 50,000 cells/mL of total cyanobacteria are also presented for comparisons.

The following observations can be made of the prevalence of cyanobacterial blooms from the results of the monitoring of catchment sites (Table 5-16):

- The worst affected site in the Catchment with regard to cyanobacterial abundance was Site E046 Farmers Creek d/s of Lithgow STP where median reached amber level and maximum recorded was at red alert level;
- In some instances, both median levels and maximum levels of cyanobacterial counts and bio-volumes reached amber alert levels at E332 (Wingecarribee River at Berrima Weir) and E409 (Wollondilly River at Murray's Flat) sites;
- There were also instances when both median and maximum values of total cyanobacteria reached green alert levels at E243 (Little River at Fire Road W41); E601 (Nepean River at Nepean Dam inflow); and E847 (Shoalhaven River at Fossickers Flat) sites.

In addition, maximum values of cyanobacterial counts recorded during the audit period reached green alert levels at several other sites (see Table 5-16), indicating a pre-disposition for blooms at those sites. However, in general, the prevalence of toxic cyanobacteria was low at most sites.

Table 5-16 Cell counts, bio-volumes of total and toxic cyanobacteria and alert codes in samples from catchment sites, 2010-13

Sub-catchment	Site		Total Cyano-bacteria (cells/mL)	Total Cyano-bacteria Bio-volume (mm^3/L)	Toxic Cyano-bacteria (cells/mL)	Toxic Cyano-bacteria Bio-volume (mm^3/L)
Upper Cox River	E046 - Farmers Creek d/s Lithgow STP	N	10	10	10	10
		Median	16345	0.4365	16181.5	0.4365
		Maximum	662600	17.88	662300	17.88
Lower Cox River	E083 - Coxs River at Kelpie Point	N	5	5	5	5
		Median	159	0.001	0	0
		Maximum	554	0.013	14	0
Nattai River	E203 - Gibbergunyah Greek at Welby (d/s Mittagong STP)	N	11	11	11	11
		Median	494	0.004	0	0
		Maximum	10280	0.091	211	0.017
Nattai River	E206 - Nattai River at the Crags	N	4	4	4	4
		Median	351.5	0	0	0
		Maximum	500	0.003	0	0
Nattai River	E210 - Nattai Rive at Causeway (at Smallwoods Crossing)	N	8	8	8	8
		Median	20	0	0	0
		Maximum	8250	0.045	0	0
Little River	E243 - Little River at Fire Road W41	N	1	1	1	1
		Median	18930	0.098	0	0
		Maximum	18930	0.098	0	0
Wingecarribee River	E332 - Wingecarribee River at Berrima Weir	N	35	35	35	35
		Median	16160	0.056	390	0.013
		Maximum	87720	1.37	11020	1.19
Wollondilly River	E409 - Wollondilly River at Murray's Flat	N	27	27	27	27
		Median	115	0.003	0	0
		Maximum	20680	3.032	20020	3.032
Wollondilly River	E450 - Wollondilly River at Golden Valley	N	7	7	7	7
		Median	23	0	0	0
		Maximum	3530	0.043	530	0.034

Table 5-16 (cont.) Cell counts, bio-volumes of total and toxic cyanobacteria and alert codes in samples from catchment sites, 2010-13

Sub-catchment	Site		Total Cyano-bacteria (cells/mL)	Total Cyano-bacteria Bio-volume (mm^3/L)	Toxic Cyano-bacteria (cells/mL)	Toxic Cyano-bacteria Bio-volume (mm^3/L)
Mulwaree River	E457 - Mulwaree River at Towers Weir	N	25	25	25	25
		Median	613	0.015	28	0.001
		Maximum	72370	28.79	68850	28.77
Wollondilly River	E488 - Wollondilly River at Jooriland	N	18	18	18	18
		Median	1033.5	0.007	0	0
		Maximum	66630	0.143	1660	0.044
Werriberri Creek	E531 - Werriberri Creek at Werombi	N	3	3	3	3
		Median	0	0	0	0
		Maximum	0	0	0	0
Werriberri Creek	E551 - Tonalli River at Fire Road W2	N	1	1	1	1
		Median	416	0.006	0	0
		Maximum	416	0.006	0	0
Upper Nepean	E608 -Goondarrin Creek at Kemira 'D' Cast	N	2	2	2	2
		Median	133	0.0075	0	0
		Maximum	266	0.015	0	0
Upper Nepean	E680 - Cordeaux River at Dam No.1	N	6	6	6	6
		Median	852.5	0.0005	0	0
		Maximum	3670	0.009	0	0
Upper Nepean	E601 - Nepean River at Nepean Dam inflow	N	2	2	2	2
		Median	30495	0.0505	142	0.0055
		Maximum	54390	0.084	142	0.006
Upper Nepean	E602 - Burke River at Nepean Dam inflow	N	1	1	1	1
		Median	0	0	0	0
		Maximum	0	0	0	0
Upper Nepean	E697 - Nepean River at McGuires Crossing	N	7	7	7	7
		Median	5310	0.016	46.5	0.003
		Maximum	85490	0.104	246	0.008
Kangaroo River	E706 - Kangaroo River at Hampdon Bridge	N	8	8	8	8
		Median	29	0	0	0
		Maximum	24180	0.072	0	0
Mongarlowe River	E822 - Mongarlowe River at Mongarlowe	N	1	1	1	1
		Median	1220	0.01	0	0
		Maximum	1220	0.01	0	0
Bungonia Creek	E847 - Shoalhaven River at Fossickers Flats	Count	2	2	2	2
		Median	23460	0.069	0	0
		Max	46280	0.124	0	0
Braidwood	E860 - Shoalhaven River at Mountview	N	1	1	1	1
		Median	324	0	0	0
		Maximum	324	0	0	0
Braidwood	E861 - Shoalhaven River at Hillview	N	9	9	9	9
		Median	262	0	0	0
		Maximum	15180	0.026	202	0.008
Braidwood Creek	E890 - Gillamatong Creek at Braidwood	Count	11	11	11	11
		Median	281	0.001	0	0
		Max	5790	0.05	165	0.022

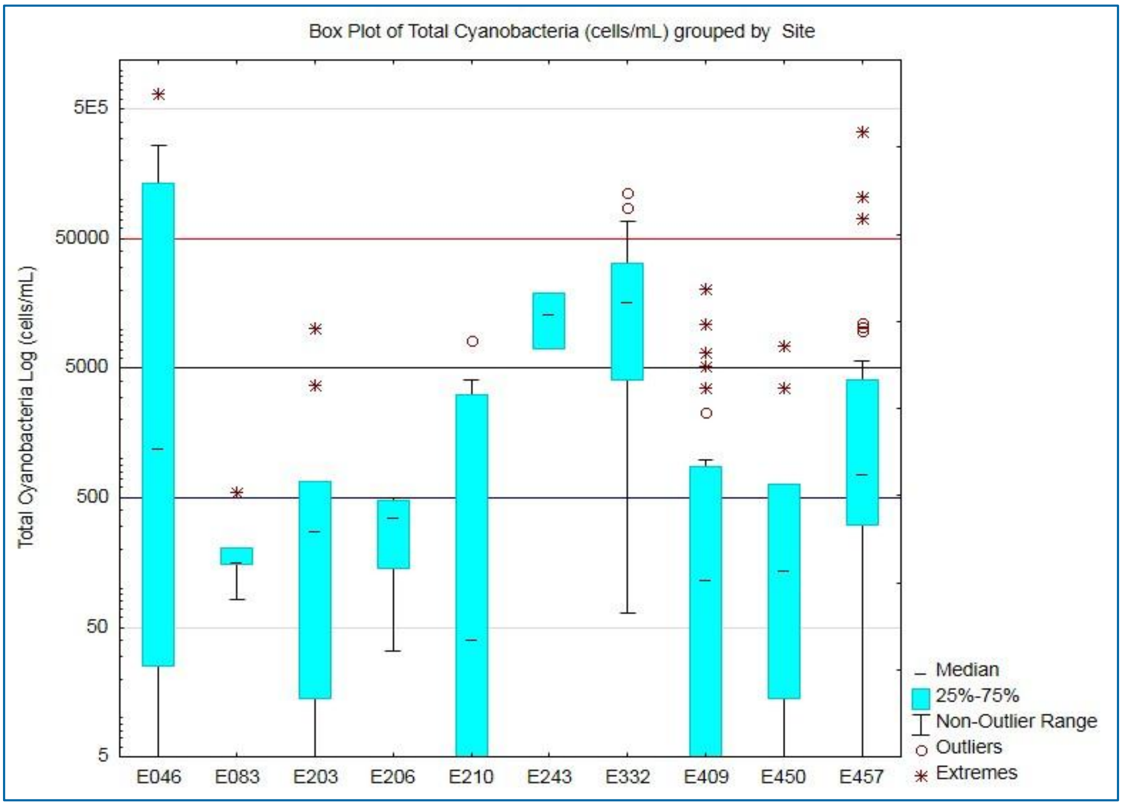


Figure 5-13 Box plot of total cyanobacterial counts (Log) at various sites monitored in the Warragamba catchment

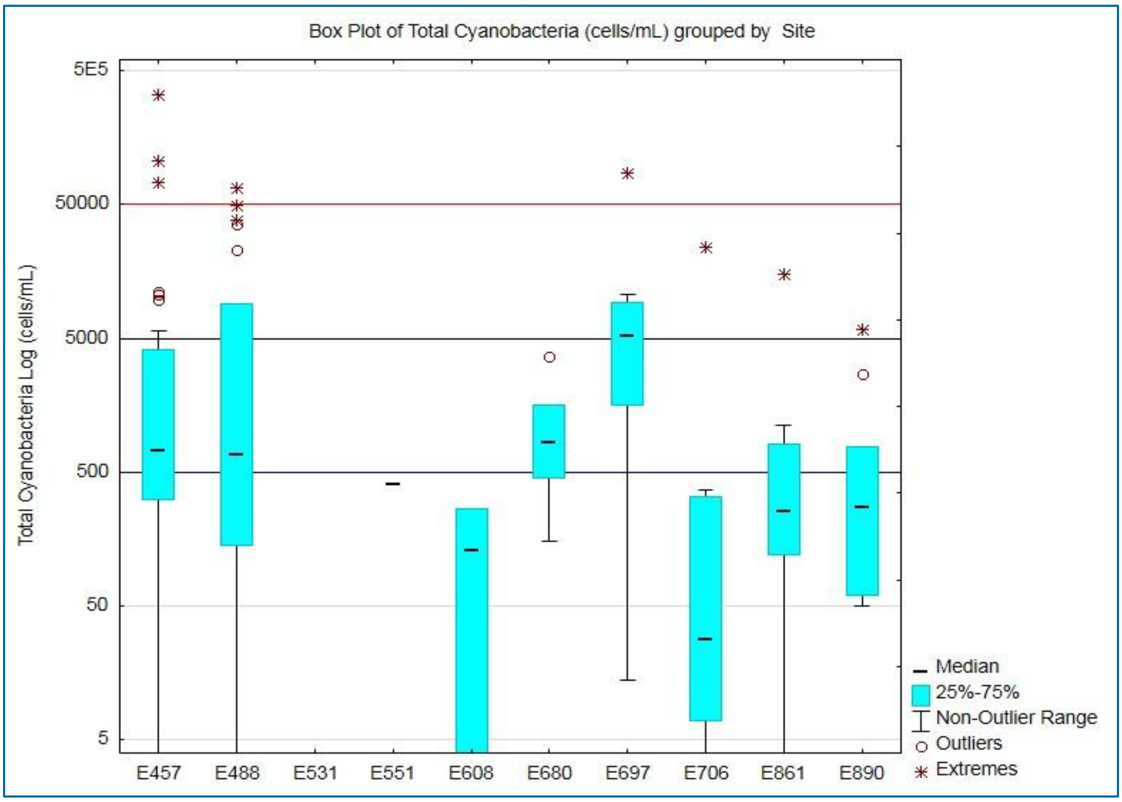


Figure 5-14 Box plot of total cyanobacterial counts (Log) at various sites monitored in the Shoalhaven catchment

The Auditor notes that there is no value in directly comparing the current results with the prevalence of cyanobacteria at catchment sites during the previous audit period, because the abundance of these organisms at any site can be highly variable, and is determined by several local conditions (i.e. low flows; nutrient levels; temperature).

However, the incidences and occasional presence of toxic cyanobacteria in the Catchment's waterways indicate the need for continuing with the targeted water quality monitoring of catchment streams, as carried out by the SCA's Water Monitoring Program.

Storage sites

Table 5-17 provides summary statistics (medians and maximum values) of total and toxic cyanobacterial detected in samples collected from various lakes and reservoirs during the current audit period (2010/11, 2011/12 and 2012/13). The following observations can be made of the prevalence of cyanobacterial blooms from the results of the monitoring of storages:

- None of the sites monitored recorded toxic cyanobacteria above 6500 cells/mL;
- Several sites recorded maximum counts of toxic cyanobacteria above 2000 cells/mL, although the median values were much lower;
- The worst affected site in the Catchment with regard to cyanobacterial abundance was Site E046 Farmers Creek d/s of Lithgow STP where median reached amber level and maximum recorded was at red alert level;
- Both median levels and maximum levels of cyanobacterial counts and bio-volumes reached amber alert levels at E332 (Wingecarribee River at Berrima Weir) and E409 (Wollondilly River at Murray's Flat) sites;
- Both median and maximum values of total cyanobacterial counts reached green alert levels at E243 (Little River at Fire Road W41), E601 (Nepean River at Nepean Dam inflow) and E847 (Shoalhaven River at Fossickers Flat) sites.

Table 5-17 Cell counts and bio-volumes of total and toxic cyanobacteria in samples collected by SCA from water storages, 2010-13

Sub-catchment	Site	Parameter	Total Cyano-bacteria (cells/mL)	Total Cyano-bacteria Bio-volume (mm^3/L)	Toxic Cyano-bacteria (cells/mL)	Toxic Cyano-bacteria Bio-volume (mm^3/L)
Grose River	DLC1 - Lower Cascade Dam	N	78	78	78	78
		Median	247	0	0	0
		Maximum	51,170	0.035	14	0
	DTC1 - Top Cascade Dam	N	149	149	149	149
		Median	2260	0.003	0	0
		Maximum	54,080	0.049	44	0.004
	DGC1 - Greaves Creek	N	132	132	132	132
		Median	2265	0.003	0	0
		Maximum	22,240	0.055	489	0.051
Woronora River	DWO1 - Lake Woronora at Dam Wall	N	35	35	35	35
		Median	716	0	0	0
		Maximum	9690	0.001	0	0

Table 5-17 (cont'd) Cell counts, bio-volumes of total and toxic cyanobacteria and alert codes in samples collected by SCA from water storages, 2010-13

Sub-catchment	Site	Parameter	Total Cyano-bacteria (cells/mL)	Total Cyano-bacteria Bio-volume (mm^3/L)	Toxic Cyano-bacteria (cells/mL)	Toxic Cyano-bacteria Bio-volume (mm^3/L)
Upper Nepean	DNE2 - Lake Nepean at 300 m u/s Dam Wall	N	30	30	30	30
		Median	3275	0.003	7	0
		Maximum	185,800	0.176	3640	0.176
	DCO1 - Lake Cordeaux at Dam Wall	N	17	17	17	17
		Median	6040	0.013	0	0
		Maximum	108,400	0.068	58	0
	DC A1 - Lake Cataract at Dam Wall	N	6	6	6	6
		Median	3805	0.003	0	0
		Maximum	14420	0.006	0	0
	DAV7 - Lake Avon at Upper Avon Valve Chamber	N	36	36	36	36
		Median	8590	0.004	0	0
		Maximum	95,620	0.05	62	0
Prospect	RPR1 - Lake Prospect at Midlake	N	124	124	124	124
		Median	41,295	0.021	0	0
		Maximum	721,500	0.309	922	0.064
Lake Burragorang	DWA27 - Lake Burragorang at Wollondilly Arm 23 km u/s Dam Wall	N	21	21	21	21
		Median	10,020	0.014	241	0.006
		Max	370,200	0.303	3960	0.077
	DWA21 - Lake Burragorang at Coxs Arm 37 km u/s Dam Wall	N	8	8	8	8
		Median	5540	0.0065	141	0.002
		Maximum	160500	0.075	296	0.006
	DWA12 - Lake Burragorang at 9 km u/s Coxs River	N	13	13	13	13
		Median	10720	0.026	403	0.006
		Maximum	252200	0.204	994	0.161
	DWA9 - Lake Burragorang at 14 km u/s Dam Wall	N	11	11	11	11
		Median	32,870	0.022	36	0
		Maximum	264,400	0.202	728	0.018
	DWA2 - Lake Burragorang at 500 m u/s Dam Wall	N	78	78	78	78
		Median	2800	0.0045	38.5	0
		Maximum	114,400	0.095	5680	0.085
Wingecarribee River	DWI1 - Wingecarribee Lake at Outlet	N	152	152	152	152
		Median	29970	0	553.5	0.012
		Maximum	166500	0.893	5460	0.82
Kangaroo River	DBP1 - Kangaroo River WFP Raw Water	N	122	122	122	122
		Median	15,280	0.025	104	0.001
		Maximum	2,459,000	1.169	2810	0.118

Progress on 2010 Audit Recommendations relating to Cyanobacteria management

According to the information provided, SCA has made significant progress in the assessment of Cyanobacterial risks to the water supplies, since the previous audit. In so doing, SCA has strongly complied with two of the recommendations from the 2010 Audit, as discussed below. In addition, SCA has undertaken a comprehensive risk assessment of Cyanobacterial risks, which has led to characterising the water supply reservoirs, based on the risks.

Cyanobacterial Management Strategies

The Cyanobacteria Management Strategy 2012-2015 (SCA 2012d; e; f) outlines the actions that will be undertaken over the next four years to maintain the SCA's preparedness and response capability for Cyanobacteria incidents and the longer term actions to increase understanding and knowledge about Cyanobacteria within the water storages.

The SCA has also undertaken a risk assessment for each SCA reservoir, using a multiple criteria approach, consistent with the SCA's Enterprise Risk Management Framework. This risk assessment included the scientifically quantified work of the Cyanobacteria Risk Profile (SCA 2010c; 2012 e; f). The results of this Cyanobacteria risk assessment were:

- Severe risk rating — **0 reservoirs**
- Major risk rating — **0 reservoirs**
- Moderate risk rating — **4 reservoirs** (Wingecarribee, Yarrunga (Kangaroo), Bendeela and Warragamba (gorge)
- Low risk rating — **12 reservoirs (**Fitzroy Falls, Warragamba (Junctions), Warragamba (Coxs) Warragamba (Wollondilly), Cordeaux, Cataract, Yarrunga (Shoalhaven), Woronora, Nepean, Prospect, Cascades, and Avon.

The highest risk group (Group A) has a high probability of potentially toxin producing cyanobacteria events (70-90% of years) and is **eutrophic** (Carlson Index between 50 and 60). The yearly trajectories of trophic status since 2000 for the reservoirs within this group indicated a strongly positive trend (i.e. worsening trophic condition).

The second group (Group B) is composed of the Warragamba Reservoir zones, where potentially toxin producing Cyanobacterial events occur in 40-60% of years; and the storage is **mesotrophic** (Carlson Index between 40 and 50). The trophic trajectories of the Junction and Gorge areas of Warragamba Reservoir appeared to be stronger than the corresponding trajectories of the Wollondilly and Coxs Arms.

The third group (Group C) is composed of mesotrophic reservoirs, which develop potentially toxic cyanobacterial blooms only infrequently (<10% of years). All storages in this group showed a low trophic trajectory, with the exception of Yarrunga - Shoalhaven Arm, which showed a trajectory similar to Group A Reservoirs.

The last group (Group D) remained as a group of **oligotrophic** reservoirs (Carlson index up to 40) with a very low risk of a potentially toxic cyanobacterial bloom event occurring.

Following the risk characterisation, the SCA has identified actions which are expected to reduce the risks associated with Cyanobacteria in its reservoirs and raw water supplies. Actions are listed by reservoir groupings, or where actions will benefit the management and development of knowledge across all reservoirs, they are listed as generic actions. There are various actions within the strategy that are ranked as a high priority and indicative timeframes and the work areas, which will lead actions.

5.3.6 Recommendations

Overall, the Auditor finds the scientific, evidence-based approach taken by the SCA during the past few years, and the progress made, as highly significant. This increased understanding (SCA 2007b; 2012d; e; f) should assist future management of the waterways and storages in the Catchment, and for more effective and targeted use of resources for both on-going monitoring and management of cyanobacterial issues.

The Auditor encourages the SCA to continue the approach taken, so that the stakeholders and the community can respond more effectively to any future cyanobacterial events.

It would also be prudent to share information on the above achievements, particularly the risk-based approach and knowledge gained, through publications in the scientific literature. If the knowledge gained is communicated more widely across other stakeholders, it would be to the benefit of other land managers and NRM groups.

The Auditor's view is that it would also give the SCA's customers and the general public an increased level of confidence in the capacity of catchment managers to respond adequately to cyanobacterial problems, or other catchment issues, if and when significant problems occur.

5.4 Water quality trend assessments

5.4.1 Summary

Assessment of water quality trends was undertaken as part of the current audit, using long-term water quality datasets provided by the SCA. Two statistical techniques were used: (1) Time series plots, with locally weighted regression scatterplot smoothing (LOWESS) to determine a regression line of best fit; and (2) Seasonal Kendall trend analyses - to determine if statistically significant temporal trends exist in the in the datasets.

Significant long-term trends were detected for several water quality parameters at various catchment sites and storages. The magnitude of the detected increasing or decreasing, long-term trends was quantified. This allows further considerations of the causes - whether the trends are due to natural variation, or due to other factors, such as hydrological variations, or land use.

Taking an adaptive management approach, this information could be used to characterise those sites, and also possibly measure whether management actions are effective in causing any desired changes (i.e. decreases in nutrients).

The Auditor encourages the findings of long-term trend analyses - either improvement, or deterioration of water quality parameters - to be related to the long-term management actions of all stakeholders. Investigation into other factors, such as hydrological variations or climatic factors, which affect long-term data, is beyond the scope of the current audit.

The SCA and other stakeholders, such as OEH, are encouraged to collaboratively undertake more comprehensive trend analyses in the future, taking into account the influence of other major factors, including climate, hydrology and land use.

Assessment Criteria

Criteria

1. Determine and quantify the magnitude of any significant long-term trend for water quality parameters.
2. Assess the directions of change (increasing or decreasing) for water quality parameters that have a significant long-term trend.
3. Determine if natural variation is responsible for any long-term trends in water quality.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Meets Expectation	Nil
2	Meets Expectation	Nil
3	Opportunity for improvement	The SCA undertake targeted projects to ground-truth the effectiveness of Catchment improvement activities at a drainage unit scale to verify the prioritisation of on-ground works via PSAT and use this information as feedback to the Land Management Database.

Prior recommendations

Prior Recommendations	Remedial action	Status
Recommendation 24: The SCA should look very closely at including monitoring sites in sub-catchments that currently have no long-term water quality or flow gauging sites.	The SCA Water Monitoring Program 2010-2015 has identified additional water quality and gauging sites which are currently being installed.	closed
Recommendation 25: The SCA collate all recent work undertaken on water quality trend assessments and provide a unifying summary of trends in water quality across the Catchment.	Trend analysis is undertaken as required under the Operating Licence and is included in the SCA's Annual Water Quality Monitoring Report every two years. This Audit has also conducted trend analyses of water quality datasets	closed
Recommendation 26: The SCA in cooperation with other state and local government agencies explore ways to integrate individual monitoring programs into a broader ecosystem health monitoring program for the entire Catchment.	State and Local Government organisations have specific objectives and data requirements for their ecosystem monitoring programs, limiting the capacity to integrate individual monitoring to broader programs. However, the SCA works with agencies to share data and integrate monitoring programs where appropriate.	Opportunity for improvement
Recommendation 27: The SCA in cooperation with other state and local government agencies investigate ways of integrating their respective ecosystem health databases so that a common comprehensive database on ecosystem health indicators is developed for the Catchment.	The SCA maintains a comprehensive suite of spatial data and satellite imagery which is used for vegetation condition mapping, and other ecosystem health denotations which it can make available to other agencies. Currently, there is no integrated ecosystem health database across state and local government, however, there have been a number of initiatives to improve ecosystem datasets and make them accessible for relevant agencies. The OEH managed LMDB is being used by the SCA, CMAs, DPI and Crown Lands to capture data on on-ground works from catchment intervention programs including: habitat protection and restoration; weed control and stock exclusion zones.	Opportunity for improvement
Recommendation 28: The SCA ensure these combined databases are readily available to be used in future catchment audits and/or other programs relying on assessments of catchment health.	The SCA maintains a comprehensive suite of spatial data and satellite imagery, which can be readily displayed and analysed for catchment audits and other purposes. The LMDB also captures information about the SCA's on-ground works in the catchment which can be accessed for use in future catchment audits and/or other programs relying on assessments of catchment health.	Opportunity for improvement

5.4.2 Background

The ToR indicated that this Audit include 'long term trend analyses. In order to undertake a meaningful trend assessment, there needs to be long-term data on the indicator of interest, as well as data on the major co-variates that influence or explain an indicator's state.

During the audit, the Auditor assessed the availability of data and information to achieve this task. As pointed out by DECCW (2010a), some catchment indicators are insufficiently developed to enable a trend assessment (e.g. riparian condition; or wetland condition), while others have not been consistently measured over a timescale long enough or frequent enough to provide a reliable identification of trend (e.g. fish data).

The Auditor recognises that the data collected up until the present time on catchment health indicators represent a significant historical and ongoing investment. The data are also a valuable resource, in terms of identifying long-term trends indicated by that indicator. However, undertaking a trend assessment of various indicators across the large Drinking Water Catchment is a challenging and time-consuming process, particularly in light of the effects of short and long term climatic cycles. As a result, only a relatively simplified assessment of trends of water quality could be made in the timeframe available for the current audit.

5.4.3 Management and Surveillance

As discussed in Section 5.1.3, the SCA has a strong Water Monitoring Program that has generated long-term data for many catchment sites and storages. As pointed out by the previous auditor (DECCW 2010a), this monitoring has resulted in generating some of the best long-term series of water data in NSW (and Australia). The long-term data sets represent a significant, historical and on-going investment, and a very valuable resource, in terms of long-term information on water quality and quantity, particularly in the Hawkesbury-Nepean River and Shoalhaven River Catchments.

However, in the previous audit, DECCW (2010a), the Auditor, expressed the concern that a reduction in the sampling effort (such as reduction of monitored sites; numbers of samples; and numbers of analytes measured) may not be desirable from the point of view of maintaining the long-term data and knowledge.

The view expressed was that the expenditure on maintaining the monitoring program without significant reductions may be more than compensated for by the increased understanding on the quality and quantity of water flowing through the Catchment, and the opportunity that would be afforded to more effectively target catchment management intervention

Long-term datasets were provided by the SCA for various catchment sites and storages that have been subject to monitoring over a long period. The Auditor is aware that the SCA undertakes long term trend anaysis every 2-years as part of its water quality monitoring report.

5.4.4 Methodology

The water quality trend assessments, using long-term datasets provided by the SCA were carried out for the current audit using the following two statistical techniques:

1. Time series plots, with Locally Weighted Scatterplot Smoothing (LOWESS) technique - to determine a line of best fit; and
2. Seasonal Kendall trend analyses to determine if statistically significant temporal trends in the data exist.

The LOWESS analyses were carried out using StatSoft Inc. (2012) and the Seasonal Kendall analyses used WQStatPlus (2010). Each of these techniques is discussed briefly below.

LOWESS smoothing

In statistical analyses, ordinary least squares (OLS) or linear least squares are often employed to estimate unknown parameters in a linear regression model.

However, a linear model may be inappropriate to describe relationships between two parameters because a scatterplot suggests obvious non-linearity, it is known theoretically that some other model should apply, or there is no preconceived model to fit the data (Quinn and Keough 2002).

In such situations a smoothing method is required for fitting a line of best fit to describe the relationship between X and Y that is not restricted to a specific model structure. As discussed by Quinn and Keough (2002), the logic of LOWESS smoothing is as follows:

- Each observation is substituted by a predicted value (target value) from a regression model through a subset of surrounding observations;
- Surrounding observations are initially weighted depending on how far they are from the target value (i.e. LOWESS smoothing);
- The surrounding observations are those within a window that covers a range of observations along the X-axis;
- The size of the window is determined by a smoothing parameter and successive windows overlap so that the resulting line is smooth; and
- Target values in each window are not affected by observations in other windows so smoothing techniques are robust to extreme observations.

Seasonal Kendall trend analysis

To investigate long term temporal changes or trends in water quality, a simple linear model may be applied to examine the rate of change over time. However, there are many occasions where seasonal variation is a major source of changes in a parameter. In such cases, this seasonal variation must be removed or compensated for in order to better discern changes in the parameter of interest over time (Helsel and Hirsch 2002).

The Seasonal Kendall trend analysis is an extension of the Sen's Slope/Mann-Kendall analyses that removes seasonal cycles. Initially, individual slope estimates for each season are calculated with all seasonal slopes subsequently ranked.

The median slope is then used as the seasonal slope estimator and the Mann-Kendall test is similarly run on the segregated seasonal data (see Helsel and Hirsch 2002; Quinn and Keough 2002). Outputs from the Seasonal Kendall trend analyses include a test for significance (at 80%, 90% and 95% confidence levels) and an estimation of the slope, which indicates the quantitative changes in the target parameter per year.

Limitations

The time constraints of the Audit limited the capacity to account for hydrologic condition (e.g. discharge at catchment sites) in the analysis. It is acknowledged that water quality at any location or at any given time is influenced by flows in the streams, and other factors, such as climate. Hence, a simple linear model may not be the best for the analysis. The Auditor acknowledges that had flows and other factors been included, the trends of changes in water quality parameters over time may not actually be linear (e.g. it could be a step function, polynomial, or other more complex model).

5.4.5 Findings

Volume 2 Appendix H Section 8.6 provides the detailed results of the LOWESS and Seasonal Kendall Trend analyses, conducted on the long-term data of the 12 selected water quality parameters. Results for catchment sites are provided Section 8.6.1; and for storages - in Section 8.6.2. The overall findings of these analyses are also discussed below.

It should be noted that the LOWESS analyses are predominately aimed at presenting a visual representation of temporal trends in the water quality parameters.

The Seasonal Kendall trend analyses, applied in this Audit, are a statistical test to determine:

1. Whether there is a significant trend in the dataset; and
2. The magnitude of the trend per year (either positive/increasing or negative/decreasing).

It should also be noted that although the Seasonal Kendall trend analyses removed the influence of natural seasonal variation, they did not compensate for differences in flow or other seasonal influences. As suggested by the previous audit (DECC 2010a), changes and/or trends in water quality need to consider variation in flows; however, this aspect was regarded as beyond the scope of the 2013 Audit. Consequently, investigations of water quality trends in this Audit were primarily aimed at long-term changes, rather than shorter term changes, associated with hydrological variations, or other seasonal influences.

A summary of changes in the water quality parameters assessed in the catchment streams, creeks, rivers and storages can be found in the various sub-catchment summaries in Volume 3 Appendix I of this Report. The following sections provide the highlights of analyses with regard to the important long-term data water quality parameters that have been monitored.

River monitoring sites

As could be expected for a large Catchment, long-term trends in water quality were variable across the Catchments and within sub-catchments (Table 5-18). The trends are summarised in Table 5-19 with reference to increasing, decreasing, or variable trends in each sub-catchment, based on the results of the long-term monitoring sites. Individual parameter summaries are as follows:

Chlorophyll-a

The trends in Chl-a were variable across all catchments and sub-catchments. The major long-term, decreasing trends were in the Warragamba Catchment, where concentrations were found to be decreasing by 0.81 µg/L per year in the Mulwaree River, 0.47 µg/L per year in Farmers Creek, 0.13 µg/L per year in the Tonalli River, and up to 0.27 µg/L per year in the Wollondilly River. Furthermore, in the Upper Nepean Catchment, in the Nepean River, Chl-a was found to be decreasing by 0.29 µg/L per year. In contrast, increasing Chl-a trends were detected in the Warragamba Catchment in the Wingecarribee River (0.55 µg/L per year) and Wollondilly River (0.52 µg/L per year), and in the Shoalhaven Catchment in Boro Creek (0.35 µg/L per year).

Electrical Conductivity

Long-term trends in EC were also variable across catchments and sub-catchments. Overall, there were no major changes in EC in any of the catchments with only minor increases or decreases or no long-term trends detected. The exceptions to this were in the Warragamba Catchment where EC was found to be decreasing in Farmers Creek and Gibbergunyah Creek by 0.027 and 0.017 mS/cm per year, respectively.

EC trends were also detected to be decreasing in the Waratah River in the Woronora Catchment (0.013 mS/cm per year) and the Gillamatong River in the Shoalhaven Catchment (0.023 mS/cm per year). The only location where EC displayed a major long-term increasing trend was in the Mulwaree River with EC increasing by 0.066 mS/cm per year.

Total Nitrogen

Overall TN concentrations were generally decreasing or remaining stable in the Warragamba and Woronora Catchments. More variable trends were identified in the Upper Nepean and Shoalhaven Catchments. The major changes in TN were in Farmers Creek and Gibbergunyah Creek in the Warragamba Catchment, where concentrations were detected to be decreasing by 0.122 and 0.298 mg/L per year respectively.

The most notable increasing TN trends were in the Shoalhaven Catchment at Gillamatong Creek and in the Upper Nepean Catchment at the Nepean River, where concentrations were detected to be increasing by 0.016 and 0.014 mg/L per year respectively.

Total Phosphorus

TP concentrations were generally stable (any changes < 0.003 mg/L per year) or increasing in all catchments. However, long-term decreases were detected for TP in Farmers Creek and the Wollondilly River in the Warragamba Catchment with concentrations, found to be decreasing by 0.017 and 0.007 mg/L per year, respectively.

Storage monitoring sites

For storages, large amounts of data were available, reflecting intensive monitoring, over a long period. The results of the long-term trend analysis of water quality data from the storages are given in (Table 5-18). The trends are summarised in Table 5-19 with reference to increasing, decreasing, or variable trends in each storage based on the results of the long-term data.

The following observations can be highlighted from the analyses:

- For storage monitoring sites, Chl-a levels were variable across all catchments and within sub-catchments, although there were some noteworthy long-term trends. The largest increasing trend in Chl-a was in the Shoalhaven Catchment and Lake Burragorang at the Kangaroo River, where concentrations were detected to be increasing by 1.48 µg/L/year.
- No long-term trends in EC were detected for the storages of the Woronora Catchment, and there were only minor changes in the Blue Mountains, Upper Nepean and Shoalhaven Catchments. In the Warragamba Catchment, there were no clear trends in EC, or only minor decreases. The exceptions in the Warragamba Catchment were increases of 0.014 and 0.017 mS/cm per year in the Coxs River Arm and the Kedumba Arm of Lake Burragorang, respectively.
- Generally decreasing trends in TN were detected in the Blue Mountains, Upper Nepean and Woronora Catchments. Variable trends were detected in the Warragamba Catchment with concentrations increasing by 0.100 mg/L per year in the Coxs River Arm of Lake Burragorang 4 km upstream of Butchers Creek.
- There were no clear trends in the Warragamba Catchment for the Kedumba Arm of Lake Burragorang or 37 km upstream of Lake Burragorang on the Coxs River Arm. Variable trends in TN were also detected in the Shoalhaven Catchment with decreases of up to 0.010 mg/L/year in Lake Yarrunga (DTA3), and Lake Fitzroy Falls. However, there were no changes in Lake Yarrunga at DTA8.
- There was evidence of long term increasing TP trends in all storages, except the Upper Nepean, where TP concentrations displayed either minor decreases (< 0.001 mg/L per year) or remained stable. The major increasing trends were detected in the Shoalhaven storages. Particularly, at Lake Yarrunga, where concentrations were detected to be increasing by 0.007 mg/L/year and in the Warragamba Catchment with increases of 0.005 mg/L/year, 9 km upstream of Lake Burragorang.

Table 5-18 Catchment Sites – Results from Seasonal Kendall Trend Analyses for the indicator water quality parameters

Note: Values represent the slope of the trend line, based on all available data. The percentage values in subscript are the level of statistical significance that a trend was associated with the data. NS = No significant trend. Colour coding: Red indicates an increasing trend; Yellow no trend; and Blue a decreasing trend.

	Chl à (µg/L)	Turbidity (NTU)	pH (units)	EC (µS/cm)	DO (% Saturation)	TN (mg/L)	NH_3 (mg/L)	NOx (mg/L)	TP (mg/L)	SRP (mg/L)	Al (mg/L)	Fe (mg/L)
E046	-0.47 $_{95\%}$	0.2 $_{90\%}$	0.0 $_{95\%}$	-0.027 $_{95\%}$	1.2 $_{95\%}$	-0.122 $_{95\%}$	NS	-0.173 $_{95\%}$	-0.017$_{\%}$	-0.032 $_{95\%}$	0.008 $_{95\%}$	NS
E083	0.09 $_{95\%}$	NS	NS	0.002 $_{95\%}$	NS	0.004 $_{95\%}$	-0.001 $_{95\%}$	NS	0.000 $_{95\%}$	0.000 $_{95\%}$	0.003 $_{95\%}$	0.011 $_{95\%}$
E157	NS	-0.1 $_{90\%}$	NS	0.001 $_{95\%}$	0.4 $_{95\%}$	-0.011 $_{95\%}$	-0.001 $_{95\%}$	0.005 $_{90\%}$	-0.001 $_{95\%}$	NS	0.001 $_{80\%}$	0.019 $_{95\%}$
E130	0.05 $_{95\%}$	0.0 $_{90\%}$	0.0 $_{95\%}$	NS	NS	NS	-0.001 $_{95\%}$	0.001 $_{95\%}$	0.000 $_{95\%}$	0.000 $_{90\%}$	0.002 $_{95\%}$	0.010 $_{95\%}$
E550	NA	0.0 $_{80\%}$	0.0 $_{95\%}$	-0.007 $_{95\%}$	2.0 $_{90\%}$	NS	-0.001 $_{95\%}$	-0.001 $_{95\%}$	NS	0.000 $_{95\%}$	NS	NS
E551	-0.13 $_{80\%}$	NS	0.1 $_{95\%}$	-0.007 $_{80\%}$	1.4 $_{95\%}$	NS	-0.001 $_{95\%}$	0.003 $_{95\%}$	0.001 $_{95\%}$	0.000 $_{80\%}$	0.000 $_{90\%}$	0.016 $_{95\%}$
E552	NA	NS	0.1 $_{95\%}$	NS	3.2 $_{95\%}$	-0.006 $_{95\%}$	-0.002 $_{95\%}$	0.003 $_{95\%}$	NS	0.000 $_{95\%}$	0.000 $_{95\%}$	NS
E531	0.08 $_{95\%}$	-0.1 $_{95\%}$	-0.0 $_{95\%}$	NS	0.4 $_{95\%}$	NS	-0.001 $_{95\%}$	NS	0.000 $_{95\%}$	NS	0.002 $_{95\%}$	0.018 $_{95\%}$
E243	-0.02 $_{90\%}$	0.0 $_{95\%}$	0.0 $_{95\%}$	-0.001 $_{95\%}$	0.4 $_{80\%}$	-0.011 $_{95\%}$	-0.002 $_{95\%}$	-0.003 $_{95\%}$	NS	NS	0.000 $_{90\%}$	NS
E203	0.12 $_{90\%}$	0.4 $_{90\%}$	0.0 $_{95\%}$	-0.017 $_{95\%}$	1.1 $_{95\%}$	-0.298 $_{95\%}$	-0.009 $_{95\%}$	-0.205 $_{95\%}$	-0.003 $_{80\%}$	-0.001 $_{95\%}$	NS	0.016 $_{80\%}$
E206	NS	-0.1 $_{95\%}$	0.0 $_{95\%}$	NS	0.7 $_{95\%}$	-0.022 $_{95\%}$	-0.001 $_{95\%}$	-0.033 $_{95\%}$	0.002 $_{95\%}$	-0.001 $_{95\%}$	0.021 $_{95\%}$	0.064 $_{95\%}$
E210	0.06 $_{95\%}$	0.1 $_{90\%}$	0.0 $_{90\%}$	0.006 $_{95\%}$	-0.3 $_{95\%}$	NS	-0.001 $_{95\%}$	NS	0.000 $_{95\%}$	NS	0.001 $_{80\%}$	0.041 $_{95\%}$
E601	0.02 $_{95\%}$	-0.3 $_{95\%}$	NS	NS	0.9 $_{95\%}$	-0.011 $_{95\%}$	NS	NS	NS	NS	NS	NS
E602	0.01 $_{95\%}$	0.0 $_{80\%}$	0.0 $_{95\%}$	-0.001 $_{95\%}$	1.0 $_{95\%}$	-0.002 $_{90\%}$	-0.001 $_{95\%}$	0.000 $_{95\%}$	0.000 $_{95\%}$	0.000 $_{90\%}$	0.004 $_{95\%}$	0.010 $_{95\%}$
E697	-0.29 $_{95\%}$	NS	0.0 $_{95\%}$	NS	1.0 $_{95\%}$	0.014 $_{95\%}$	-0.001 $_{95\%}$	0.030 $_{95\%}$	0.000 $_{80\%}$	0.000 $_{80\%}$	0.009 $_{95\%}$	0.033 $_{95\%}$
E6006	NS	-0.1 $_{95\%}$	NS	-0.003 $_{95\%}$	1.0 $_{95\%}$	-0.006 $_{95\%}$	-0.001 $_{95\%}$	-0.001 $_{95\%}$	0.001 $_{95\%}$	NS	0.009 $_{95\%}$	0.017 $_{90\%}$
E604	0.00 $_{90\%}$	-0.1 $_{95\%}$	0.0 $_{95\%}$	0.002 $_{95\%}$	2.5 $_{95\%}$	NS	-0.001 $_{95\%}$	-0.004 $_{80\%}$	NS	0.000 $_{95\%}$	NS	0.000 $_{95\%}$
E608	0.02 $_{95\%}$	-0.3 $_{95\%}$	0.0 $_{80\%}$	-0.005 $_{95\%}$	2.6 $_{95\%}$	NS	-0.001 $_{95\%}$	NS	0.001 $_{95\%}$	0.000 $_{95\%}$	0.007 $_{95\%}$	0.020 $_{95\%}$
E609	NS	-0.2 $_{95\%}$	0.0 $_{95\%}$	-0.003 $_{95\%}$	2.6 $_{95\%}$	NS	-0.001 $_{80\%}$	NS	0.002 $_{95\%}$	0.000 $_{95\%}$	0.014 $_{95\%}$	0.032 $_{90\%}$
E610	NS	-0.2 $_{95\%}$	0.0 $_{90\%}$	-0.003 $_{95\%}$	2.2 $_{95\%}$	-0.005 $_{80\%}$	-0.001 $_{95\%}$	-0.000 $_{95\%}$	0.000 $_{80\%}$	0.000 $_{95\%}$	0.012 $_{95\%}$	NS

Table 5-18 (cont.) Catchment Sites – Results from Seasonal Kendall Trend Analyses for the indicator water quality parameters

Note: Values represent the slope of the trend line, based on all available data. The percentage values in subscript are the level of statistical significance that a trend was associated with the data. NS = No significant trend. Colour coding: Red indicates an increasing trend; Yellow no trend; and Blue a decreasing trend.

	Chl à (µg/L)	Turbidity (NTU)	pH (units)	EC (µS/cm)	DO (% Saturation)	TN (mg/L)	NH_3 (mg/L)	NOx (mg/L)	TP (mg/L)	SRP (mg/L)	Al (mg/L)	Fe (mg/L)
E680	0.10 $_{80\%}$	-0.1 $_{80\%}$	0.0 $_{90\%}$	-0.001 $_{95\%}$	1.9 $_{95\%}$	-0.008 $_{95\%}$	NS	NS	0.001 $_{95\%}$	0.000 $_{95\%}$	0.010 $_{95\%}$	0.085 $_{95\%}$
E409	-0.27 $_{90\%}$	-0.2 $_{95\%}$	0.0 $_{95\%}$	NS	NS	-0.019 $_{95\%}$	-0.001 $_{95\%}$	-0.001 $_{95\%}$	-0.007 $_{95\%}$	-0.007 $_{95\%}$	0.003 $_{95\%}$	0.028 $_{95\%}$
E450	-0.22 $_{95\%}$	NS	NS	-0.021 $_{95\%}$	NS	NS	-0.001 $_{95\%}$	0.000 $_{80\%}$	0.001 $_{80\%}$	0.000 $_{95\%}$	0.008 $_{95\%}$	0.040 $_{95\%}$
E488	0.52 $_{95\%}$	0.5 $_{95\%}$	0.0 $_{95\%}$	-0.009 $_{95\%}$	NS	NS	-0.001 $_{95\%}$	-0.001 $_{95\%}$	0.001 $_{95\%}$	0.000 $_{95\%}$	0.014 $_{95\%}$	0.026 $_{95\%}$
E457	-0.81 $_{95\%}$	-0.4 $_{95\%}$	NS	0.066 $_{95\%}$	NS	-0.046 $_{95\%}$	NS	-0.004 $_{95\%}$	-0.003 $_{90\%}$	NS	-0.015 $_{95\%}$	NS
E332	0.55 $_{95\%}$	-0.3 $_{80\%}$	NS	0.002 $_{95\%}$	0.4 $_{95\%}$	-0.021 $_{95\%}$	-0.003 $_{95\%}$	-0.014 $_{95\%}$	NS	-0.001 $_{95\%}$	0.016 $_{95\%}$	0.023 $_{95\%}$
E677	0.00 $_{80\%}$	-0.1 $_{90\%}$	-0.1 $_{90\%}$	-0.005 $_{95\%}$	1.3 $_{95\%}$	NS	-0.001 $_{95\%}$	-0.001 $_{95\%}$	0.000 $_{90\%}$	0.000 $_{95\%}$	0.013 $_{95\%}$	0.029 $_{95\%}$
E6131	0.00 $_{95\%}$	NS	NS	-0.013 $_{95\%}$	2.0 $_{95\%}$	NS	-0.001 $_{95\%}$	NS	0.001 $_{95\%}$	0.000 $_{95\%}$	0.032 $_{95\%}$	0.102 $_{95\%}$
G0515	0.04 $_{95\%}$	0.0 $_{80\%}$	-0.1 $_{95\%}$	NS	NS	NS	NS	NS	0.000 $_{95\%}$	NS	-0.003 $_{95\%}$	NS
E706	0.10 $_{95\%}$	-0.1 $_{95\%}$	0.0 $_{95\%}$	0.001 $_{95\%}$	0.7 $_{95\%}$	NS	NS	0.010 $_{95\%}$	0.001 $_{95\%}$	NS	NS	0.017 $_{95\%}$
E847	0.13 $_{95\%}$	-0.2 $_{90\%}$	0.0 $_{90\%}$	NS	0.4 $_{95\%}$	-0.004 $_{90\%}$	-0.001 $_{95\%}$	-0.001 $_{90\%}$	NS	0.000 $_{95\%}$	NS	0.017 $_{95\%}$
E890	0.35 $_{95\%}$	0.3 $_{95\%}$	NS	0.004 $_{95\%}$	-0.9 $_{95\%}$	0.007 $_{90\%}$	-0.001 $_{95\%}$	NS	0.003 $_{95\%}$	0.000 $_{95\%}$	NS	0.063 $_{95\%}$
E851	0.18 $_{95\%}$	-0.4 $_{95\%}$	0.0 $_{95\%}$	0.002 $_{95\%}$	0.2 $_{90\%}$	-0.005 $_{95\%}$	NS	NS	-0.001 $_{95\%}$	-0.001 $_{90\%}$	-0.021 $_{95\%}$	-0.034 $_{95\%}$
E861	NS	-0.4 $_{95\%}$	0.0 $_{80\%}$	-0.002 $_{95\%}$	0.6 $_{95\%}$	NS	-0.001 $_{95\%}$	0.000 $_{80\%}$	0.001 $_{95\%}$	NS	NS	0.055 $_{95\%}$
E822	NS	-0.1 $_{95\%}$	0.0 $_{95\%}$	0.000 $_{95\%}$	0.7 $_{95\%}$	NS	-0.000 $_{95\%}$	NS	0.001 $_{95\%}$	NS	0.003 $_{95\%}$	0.020 $_{95\%}$
E891	NS	0.5 $_{95\%}$	0.0 $_{80\%}$	-0.023 $_{95\%}$	1.8 $_{95\%}$	0.016 $_{95\%}$	0.000 $_{95\%}$	NS	0.003 $_{95\%}$	0.000 $_{80\%}$	0.000 $_{95\%}$	0.073 $_{95\%}$
E860	-0.07 $_{95\%}$	-0.4 $_{95\%}$	0.0 $_{95\%}$	-0.003 $_{95\%}$	0.9 $_{95\%}$	-0.006 $_{80\%}$	-0.001 $_{95\%}$	NS	0.002 $_{95\%}$	NS	0.007 $_{95\%}$	0.056 $_{95\%}$

Table 5-19 Summary of long-term trends detected at catchment sites

Parameter	Increasing Trends (concentration/year)	Decreasing Trends (concentration/year)	Stable or variable trends (concentration/year)
Chl-a	• Mid Coxs River - 0.09 µg/L/year • Kowmung River - 0.05 µg/L/year • Werriberri Creek - 0.8 µg/L/year • Wingecarribee River - 0.6 µg/L/year • Boro Creek - 0.4 µg/L/year • Woronora River, Kangaroo River and Bugonia Creek - each 0.1 µg/L/year.	• Upper Coxs River 0.47 µg/L/year • Mulwaree River 0.8 µg/L/year • Little River 0.2 µg/L/year	• No long-term trends detected in: Lower Coxs River, Mid Shoalhaven River, Mongarlowe River and Reedy Creek sub-catchments • In Warragamba Catchment – Chl-a increasing at E203 and E210 by 0.12 and 0.06 0.02 µg/L/year, respectively; but no trend at E206 • Upper Nepean River sub-catchment – Chl-a generally increasing by up to 0.10 µg/L/year or remaining stable. Exceptions were - E697 with concentrations decreasing by 0.29 µg/L/year • Braidwood River sub-catchment – Chl-a decreasing at E860 by 0.1 µg/L/year; and no change at E891 • No long-term trend for Lake Burragorang sub-catchment at E550 and E552; but concentrations decreasing by 0.13 µg/L/year at E551 • Wollondilly River sub-catchment – Chl-a decreasing at E409 and E450 by up to 0.27 µg/L/year, but increasing by 0.52 µg/L/year at E450
EC	• Mid Coxs River - 0.002 mS/cm/year • Lower Coxs River - 0.001 mS/cm/year • Mulwaree River - 0.066 mS/cm/year • Wingecarribee River - 0.002 mS/cm/year • Boro Creek -0.004 mS/cm/year	• Upper Coxs River - 0.027 mS/cm/year • Little River - 0.027 mS/cm/year • Woronora River - 0.027 mS/cm/year • Braidwood Creek - 0.023 mS/cm/year	• No significant long-term EC trends in Kowmung River, Lake Werriberri and Bugonia Creek sub-catchments. • Variable long-term trends for EC in : Lake Burragorang sub-catchment – EC decreasing by 0.007 mS/cm/year at E550; and E551; but no trend at E552 • Nattai River sub-catchment - EC decreasing at E203 by 0.017 mS/cm/year, and increasing at E210 by 0.006 mS/cm/year. No trend at E206. • Upper Nepean River sub-catchment - EC either increasing or decreasing but by no more than 0.005 mS/cm per year or remaining stable. • Wollondilly sub-catchment – EC decreasing by 0.021 and 0.009 mS/cm per year at E450 and E488 respectively. No trend at E409.

Table 5-19 (cont.) Summary of long-term trends detected at catchment sites

Parameter	Increasing Trends (concentration/year)	Decreasing Trends (concentration/year)	Stable or variable trends (concentration/year)
TN	• Mid Coxs River - 0.004 mg/L/year • Boro Creek - 0.007 mg/L/year	• Upper Coxs River - 0.122 mg/L/year • Lower Coxs River - 0.011 mg/L/year • Little River - 0.011 mg/L/year • Mulwaree River -0.046 mg/L/year • Wingecarribee River - 0.021 mg/L/year • Bungonia Creek - 0.004 mg/L/year	• No significant long-term TN trends detected in: Kowmung River, Lake Werriberri, Woronora River, Kangaroo River, Mid Shoalhaven River, Mongarlowe River, and Reedy Creek sub-catchments. • Variable long-term trends for TN : • Lake Burragorang sub-catchment – no trend at E550 or E551 but TN decreasing by 0.006 mg/L per year at E552. • Nattai River sub-catchment - TN decreasing at E203 and E206 by 0.298 and 0.022 mg/L per year respectively but no trend at E210 • Upper Nepean River sub-catchment - TN generally decreasing by up to 0.011 mg/L per year or remaining stable. Exception was at E697 with TN increasing by 0.014 mg/L per year • Wollondilly sub-catchment –no trends at E450 and E488 but decreasing by 0.019 mg/L per year at E409 • Braidwood Creek sub-catchment – TN increasing by 0.016 mg/L per year at E891 and decreasing by 0.006 mg/L per year at E860
TP	• Mid Coxs River, Kowmung River, Lake Werriberri, Woronora River, Kangaroo River, Mid Shoalhaven, Mongarlowe River and Reedy Creek - TP increasing by no more than 0.001 mg/L/year • Boro Creek - TP increasing by 0.003 mg/L/year • Braidwood Creek - up to 0.003 mg/L/year	• Upper Coxs River sub-catchment - TP decreasing by 0.030 mg/L/year • Lower Coxs River sub-catchment - TP decreasing by 0.001 mg/L/year • Mulwaree River sub-catchment - TP decreasing by 0.003 mg/L/year	• No clear trends detected in: Little River, Wingecarribee and Bugonia Creek sub-catchments. • Upper Nepean River sub-catchment - TP decreasing by up to 0.002 mg/L/year, or remaining stable • Lake Burragorang sub-catchment – TP generally stable, but minor increases of 0.001 mg/L/year at E551 • Nattai River sub-catchment - TP decreasing at E203 by 0.003 mg/L/year, and increasing at E206 and E210 by about 0.002 mg/L per year • Wollondilly sub-catchment - TP decreasing at E409 by 0.007 mg/L/year, and increasing at E450 and E488 by 0.001 mg/L/year

Table 5-20 Storage Sites – Results from Seasonal Kendall Trend Analyses for the indicator water quality parameters

Note: Values represent the slope of the trend line, based on all available data. The percentage values in subscript are the level of statistical significance that a trend was associated with the data. NS = No significant trend. Colour coding: Red indicates an increasing trend; Yellow no trend; and Blue a decreasing trend.

	Chl-a (µg/L)	Turbidity (NTU)	pH (units)	EC (µS/cm)	DO (% Saturation)	TN (mg/L)	NH_3 (mg/L)	NOx (mg/L)	TP (mg/L)	SRP (mg/L)	Al (mg/L)	Fe (mg/L)
DAV1	-0.09 95%	-0.1 95%	-0.0 95%	0.001 95%	-1.7 95%	-0.006 95%	0.004 95%	NS	NS	NS	NS	NS
DAV7	NS	NS	-0.2 95%	-0.003 95%	NS	-0.006 95%	NS	NS	NS	0.000 80%	NS	NS
DBP1	NS	NS	-0.3 80%	NS	-5.8 90%	NA	NA	NA	NA	NA	NA	NA
DCA1	-0.10 95%	-0.1 95%	-0.0 95%	0.001 95%	-0.5 80%	-0.003 95%	0.041 95%	NS	0.000 95%	0.000 95%	0.006 90%	0.011 95%
DCO1	-0.15 95%	-0.1 95%	NS	0.002 95%	-0.5 80%	-0.002 90%	NS	NS	NS	NS	NS	NS
DGC1	-0.05 80%	NS	NS	-0.001 95%	-0.9 95%	-0.005 95%	0.005 95%	0.006 80%	0.000 95%	NS	NS	NS
DLC1	0.05 90%	-0.0 95%	0.1 95%	0.001 95%	-0.6 95%	-0.008 95%	0.005 95%	NS	NS	NS	NS	-0.002 95%
DNE2	NS	-0.1 95%	0.0 95%	0.001 95%	0.7 95%	-0.003 95%	NS	0.030 95%	0.000 90%	NS	0.005 80%	-0.004 80%
DTA1	NS	4.1 95%	NS	0.004 80%	-5.2 80%	0.041 90%	0.009 80%	NS	0.007 95%	NS	0.067 95%	0.299 95%
DTA3	NS	-0.3 95%	0.0 95%	0.001 95%	NS	-0.010 95%	NS	0.076 80%	-0.001 95%	NS	NS	-0.023 95%
DTC1	NS	-0.1 95%	0.0 95%	-0.002 95%	-0.7 95%	-0.019 95%	0.002 95%	0.009 95%	0.000 95%	NS	0.005 95%	0.003 95%
DTA5	-0.59 80%	1.8 95%	-0.1 80%	0.005 80%	-4.7 NS	NS	0.015 90%	-0.013 80%	NS	NS	NS	0.197 95%
DTA8	1.48 95%	NS	NS	NS	NS	NS	-0.004 80%	NS	NS	NS	NS	NS
DWA12	NS	NS	-0.2 95%	0.008 95%	-16.8 95%	0.094 95%	0.001 95%	0.048 95%	0.005 95%	0.001 95%	0.010 95%	0.080 95%
DFF6	0.56 95%	0.2 95%	0.0 95%	0.002 95%	NS	-0.009 95%	0.000 95%	-0.004 90%	NS	NS	NS	0.014 95%
DWA15	NS	0.4 80%	-0.2 95%	0.014 95%	-18.2 95%	0.100 95%	0.003 95%	0.022 95%	0.004 95%	0.000 80%	NS	0.067 95%
DWA19	NS	NS	NS	0.017 80%	NS	NS	NS	NS	NS	NS	NS	NS
DWA21	NS	NS	NS	NS	NS	NS	0.010 80%	NS	NS	NS	NS	NS
DWA2	0.07 95%	0.2 95%	-0.0 95%	-0.001 95%	-2.4 95%	0.002 95%	NS	0.054 95%	0.000 95%	0.001 95%	NS	0.005 95%
DWA27	NS	0.3 80%	-0.2 95%	0.006 95%	-15.5 95%	0.094 95%	NS	0.058 95%	0.004 95%	0.001 95%	0.020 95%	0.089 95%

Table 5-20 (cont.) Storage Sites – Results from Seasonal Kendall Trend Analyses for the indicator water quality parameters

Note: Values represent the slope of the trend line, based on all available data. The percentage values in subscript are the level of statistical significance that a trend was associated with the data. NS = No significant trend. Colour coding: Red indicates an increasing trend; Yellow no trend; and Blue a decreasing trend.

	Chl-a (µg/L)	Turbidity (NTU)	pH (units)	EC (µS/cm)	DO (% Saturation)	TN (mg/L)	NH_3 (mg/L)	NOx (mg/L)	TP (mg/L)	SRP (mg/L)	Al (mg/L)	Fe (mg/L)
DWA311	NS	NS	-0.2 $_{95\%}$	0.004 $_{95\%}$	-14.2 $_{95\%}$	0.111 $_{95\%}$	0.001 $_{80\%}$	0.046 $_{95\%}$	0.004 $_{95\%}$	0.001 $_{90\%}$	0.022 $_{90\%}$	0.139 $_{95\%}$
DWA39	NS	NS	NS	NS	NS	NS	0.017 $_{90\%}$	NS	NS	NS	NS	NS
DWA9	NS	NS	-0.2 $_{95\%}$	0.006 $_{95\%}$	-15.5 $_{95\%}$	0.087 $_{95\%}$	-0.001 $_{95\%}$	0.053 $_{95\%}$	0.002 $_{95\%}$	0.001 $_{95\%}$	NS	0.046 $_{95\%}$
DWI1	0.29 $_{95\%}$	0.1 $_{95\%}$	0.1 $_{95\%}$	NS	NS	-0.015 $_{95\%}$	-0.001 $_{95\%}$	-0.004 $_{80\%}$	0.000 $_{95\%}$	NS	0.016 $_{95\%}$	0.018 $_{95\%}$
DWO1	NS	-0.0 $_{95\%}$	0.0 $_{95\%}$	0.002 $_{95\%}$	NS	-0.001 $_{90\%}$	0.008 $_{95\%}$	-0.026 $_{95\%}$	0.000 $_{95\%}$	NS	0.008 $_{90\%}$	0.010 $_{95\%}$
RPR1	0.08 $_{95\%}$	-0.1 $_{95\%}$	0.0 $_{95\%}$	0.006 $_{95\%}$	NS	-0.007 $_{95\%}$	0.001 $_{95\%}$	NS	0.000 $_{95\%}$	0.000 $_{80\%}$	0.001 $_{90\%}$	-0.001 $_{95\%}$
RPR6	1.85 $_{95\%}$	0.3 $_{95\%}$	-0.1 $_{90\%}$	-0.016 $_{95\%}$	-5.4 $_{95\%}$	NS	NS	NS	0.000 $_{90\%}$	NS	0.012 $_{95\%}$	0.025 $_{95\%}$

Table 5-21 Summary of long-term trends detected at storages

Parameter	Increasing Trends (concentration/year)	Decreasing Trends (concentration/year)	Stable or variable trends (concentration/year)
Chl-a	• Wingecarribee River sub-catchment – Chl-a increasing by 0.29 µg/L/year	-	• No significant long-term Chl-a trends were detected in Lower Coxs River and Woronora River sub-catchments • Variable long-term trends for Chl-a: – Lake Burragorang sub-catchment – no trend in Chl-a at, DWA9, DWA12, DWA27, DWA311 and DWA39. Chl-a increasing by 0.07 µg/L/year at DWA2. – Grose River sub-catchment – No trend at DTC1. Chl-a increasing by 0.05 µg/L/year at DLC1, but decreasing by 0.05 µg/L/year at DGC1. – Upper Nepean River sub-catchment – Chl-a generally decreasing by up to 0.15 µg/L/year, but remaining stable at DAV7 and DNE2. – Kangaroo River sub-catchment – Chl-a increasing by 1.48 and 0.56 µg/L/year at DTA8 and DFF6, respectively. No trend at other sites. – Bugonia Creek sub-catchment – Chl-a decreasing at DTA5 by 0.59 µg/L/year and no change at DTA1
EC	• Bugonia Creek sub-catchment – EC increases by up to 0.005 mS/cm/year	-	• No significant long-term EC trends detected in: Wingecarribee River and Woronora River sub-catchments • Variable long-term trends for EC detected in: – Lower Coxs River sub-catchment – no trend at DWA21; but EC increasing by 0.014 and 0.017 mS/cm/year at DWA15 and DWA19, respectively. – Lake Burragorang sub-catchment – EC increasing by 0.004 to 0.008 mS/cm/year at DWA12, DWA27 and DWA311. EC decreasing by 0.001 mS/cm/year at DWA2. No trend at DWA39. – Grose River sub-catchment - EC increasing by 0.001 mS/cm/year at DLC1. EC decreasing by 0.001 and 0.002 mS/cm/year at DGC1 and DTC1, respectively. – Upper Nepean River sub-catchment - EC increasing by up to 0.002 mS/cm/year at all sites except at DAV7 where EC decreasing by 0.003 mS/cm/year. – Kangaroo River sub-catchment – EC increasing by up to 0.002 mS/cm/year at DTA3; and DFF6, but remaining stable at other sites.

Table 5-21 Summary of long-term trends detected at storages

Parameter	Increasing Trends (concentration/year)	Decreasing Trends (concentration/year)	Stable or variable trends (concentration/year)
TN	• Lower Coxs River sub-catchment – no trend at DWA19 or DWA21, but TN increasing by 0.100 mg/L/year at DWA15 • Lake Burragorang sub-catchment – TN increasing by 0.002 to 0.111 mg/L/year at all sites, but no trend at DWA39. • Kangaroo River sub-catchment – TN decreasing by up to 0.010 mg/L per year at DTA3 and DFF6, but no trend at DTA8 • Bugonia Creek sub-catchment - TN increasing at DTA1 by 0.041 mg/L/year, but no trend at DTA5.	• Wingecarribee River sub-catchment - decreasing by 0.015 mg/L/year • Grose River sub-catchment – TN decreasing by 0.005 to 0.019 mg/L/year • Upper Nepean River sub-catchment – TN decreasing by up to 0.006 mg/L/year • Woronora River sub-catchment – TN decreasing by 0.015 mg/L/year	
TP	• Wingecarribee River sub-catchment – TP increasing by <0.001 mg/L/year • Woronora River sub-catchment – TN increasing by <0.001 mg/L/year.	•	• Lower Coxs River sub-catchment – no trend at DWA19 or DWA21 but TP increasing by 0.004 mg/L per year at DWA15. • Lake Burragorang sub-catchment – TP increasing by <0.001 to 0.005 mg/L per year at all sites but no trend at DWA39. • Grose River sub-catchment – TP increasing by <0.001 at DGC1 and DTC1. No trend at DLC1. • Upper Nepean River sub-catchment - TP decreasing by <0.001 mg/L per year or remaining stable. • Kangaroo River sub-catchment - TP decreasing by 0.001 at DTA3 but remaining stable at other sites. • Bugonia Creek sub-catchment – TP increasing by 0.007 mg/L per year at DTA1 but stable at DTA5.

5.4.1 Recommendations

Long-term data analysis detected significant long-term trends for some water quality parameters at specific sites, both at the catchment monitoring sites and storages. Stable (no real change) or non-significant trends (marginal increases or decreases) were also detected. This analysis provides an opportunity to consider the magnitude and direction of water quality changes in various water quality parameters and the possible reasons for those changes, on a sub-catchment basis.

Although relatively simple, the increasing or decreasing trends, demonstrated by the analyses, with statistical significance, should be useful to obtain a better understanding of how the sub-catchments are changing with regard to water quality.

Taking an adaptive management approach, this information could be used to characterise those sites, and also possibly used to measure whether management actions have been effective in causing any desired changes (i.e. future decreases in nutrients). The Auditor encourages the findings of long-term trend analyses - either improvement, or deterioration of water quality parameters - to be related to the long-term management actions of all stakeholders.

Investigations into other causal factors, such as hydrological variations, climatic factors, which affect long-term water quality data of any site, were beyond the scope of the current audit. The SCA and other stakeholders, such as OEH, are encouraged to collaboratively undertake more comprehensive trend analyses in the future, taking into account the influence of other major factors, including climate, hydrology, and land use.

The Auditor is also of the view that this type of trend analyses may provide further inputs into, or complement the findings of SCA's PSAT analyses and provide a mechanism to evaluate the effectiveness of on-ground works documented in the Land Management Database (LMDB).

Using the outputs of the trend analysis would act as a "feedback loop" and facilitate the prioritisation of future on-ground works towards management interventions and Current Recommended Practices (CRPs) that have demonstrated ability to improve water quality.

There is significant value to the SCA and other stakeholders in maintaining and/or increasing the number of long-term water quality monitoring sites as analysis of data from these sites provides a robust scientific method for the evaluation of the effectiveness of management interventions.

The SCA undertake targeted projects to ground-truth the effectiveness of Catchment improvement activities at a drainage unit scale to verify the prioritisation of on-ground works via PSAT and use this information as feedback to the Land Management Database.

6. Biodiversity and Habitats

6.1 Pressures in the Catchment

Healthy and intact natural ecosystems play a crucial role in maintaining water quality as they provide processes that help purify water, and mitigate the effects of drought and flood. Native vegetation provides essential habitat for plant and animal species, and is an integral component of healthy, functioning ecosystems. Healthy riverine ecosystems, comprising rivers and their riparian zones, floodplains and wetlands, are vital for the maintenance of aquatic and terrestrial biodiversity. Healthy rivers are also critical to provide the ecosystem services necessary to maintain good water quality and supply.

The SCA Special Areas are tracts of largely native vegetation in good condition around water storages. The Special Areas are particularly important as part of the multiple barrier approach to protecting water quality. These areas act as a buffer for nutrients and other pollutants and are an effective barrier under low and moderate flow conditions when water can take several years to travel between the outer catchment and the dam wall. However, under periods of high flow, the barrier effect breaks down, and the capacity of the ecosystem in the remainder of the Catchment becomes critically important (SCA 2012b; c). This capacity is strongly dependent on the integrity and health of the ecosystems across the entire Catchment.

Ecosystem health is affected by a number of natural and human induced pressures. Natural pressures which impact on ecosystem health include fire, flood and drought. The primary human induced pressures on ecosystem health in the Catchment are population growth, water demand, and current and intensifying land use. These pressures can directly disturb or destroy ecosystems, as well as indirectly affect ecosystem processes through impacts on water quality and changes to flow regimes.

Clearing of native vegetation and riparian zones can affect land condition, biodiversity and runoff volumes which ultimately impact upon water quality and aquatic ecosystem processes. Clearing of native vegetation is listed as a key threatening process under the *Threatened Species Conservation Act (TSCA) 1995*. Riparian vegetation is particularly crucial for water quality and aquatic ecosystem processes, and also provides habitat for terrestrial fauna. Managing native vegetation clearing, particularly in riparian areas and the rehabilitation of degraded areas, is therefore important to maintaining ecosystem health.

The presence of exotic fauna is also a pressure on ecosystem health in the Catchment, with exotic species causing physical damage to soil and vegetation, and preying on native species and disrupting natural ecosystem processes. Exotic plant species (weeds) can also affect aquatic and terrestrial ecosystem processes.

A regime of regular bushfires is a natural and often vital component of the Australian environment. However, modified fire regimes of either very frequent or occasional but extremely intensive fires, can have detrimental effects on ecosystem health, especially in the short-term. Fire management actions can mitigate the post-fire impacts, for example by preventing sediment and particulates from entering the waterways and affecting water quality.

The resilience of natural ecosystems is the capacity of an ecosystem to respond to a disturbance by resisting damage and recovering quickly. In general, healthy ecosystems are more resilient than disturbed ecosystems. Factors that affect the resilience of river ecosystems include river geomorphology, riparian vegetation, natural flow regimes, water quality, and exotic species.

6.2 Native vegetation

6.2.1 Summary

The largest percentage cover of native vegetation is in the Little River, Lower Coxs River, and Endrick River sub-catchments, with greater than 90 % cover. The majority of the Catchment is cleared (37.6 %) and the sub-catchments with the least percentage cover of native vegetation were: Upper Wollondilly River (16.3 % cover) and Mulwaree River (28.8 % cover). The dominant native vegetation type in the Catchment is dry sclerophyll forest and the largest area is in the Wollondilly River sub-catchment.

There is significant investment by SCA, OEH, DPI, CMAs, and Local Councils in protecting and rehabilitating native vegetation in the Catchment. The CMAs carry out a number of on-ground works in the Catchment to rehabilitate and protect native vegetation, including native vegetation protection under conservation agreements. The total area infested by weeds in the Catchment is unknown, and is difficult to estimate. However, the SCA and CMAs currently treat large areas of weeds in the Catchment each year.

The Vegetation Condition Index (VCI) is currently under review by SCA and any improvement in the extent and condition of native vegetation in the Catchment during the current audit period is difficult to determine.

All of the existing programs and on-ground works to rehabilitate degraded areas and re-establish native vegetation are likely to contribute to an improvement in the condition of native vegetation and provide improved protection of water quality.

Assessment Criteria

Criteria

1. The diversity and health of native vegetation in the Catchment is monitored.
2. Protect and rehabilitate areas of native vegetation and native terrestrial habitat.
3. Control weeds in the Catchment according to the requirements of the *Noxious Weeds Act 1993* and the *Rural Lands Protection Act 1998.*

Assessment against Criteria

Criteria	Audit finding	Recommendation
1 & 3	Opportunity for improvement	OEH and CMAs should investigate the potential to update the extent and condition of native and riparian vegetation in the Catchment for the next audit period.
2	Meets Expectation	Nil
2	Meets Expectation	Nil

Prior recommendations

Prior Recommendations	Action	Status
Recommendation 7: DECCW, in collaboration with SCA, develop a consistent, uniform, and integrated vegetation dataset that covers the entire Catchment.	Office of Environment and Heritage (OEH) has prepared a State-wide Land Cover and Trees Study dataset (SLATS), which is a consistent woody and non-woody vegetation dataset that covers the entire Catchment. A broad vegetation type dataset based on a National Parks and Wildlife Service (NPWS) classification for the Catchment has been created.	Closed

6.2.2 Background

Native vegetation in the Catchment is important for maintaining the health of individual species of flora and fauna, ecosystem process and genetic diversity. Native vegetation in good condition provides a richness of plant species and variability in vegetation structure which supports a diversity of fauna species and key habitats such as hollows, fallen logs, and bush rocks.

Native vegetation in NSW has been extensively cleared for urban, industrial, and agricultural land uses. Clearing of native vegetation has a number of impacts, including displacing native animals and plants, a reduction in biodiversity and habitat fragmentation.

The degradation or clearing of native vegetation can impact on critical ecosystem services such as the improvement of water quality, nutrient recycling and the provision of resources such as food and fibre. Impacts on native vegetation can also induce soil salinity and acidity, soil erosion, loss of nutrients, changes to flow regimes, and climate change.

The clearing of native vegetation has been identified as the process representing the greatest single threat to biodiversity in NSW (Coutts-Smith & Downey 2006). Land clearing is listed as a key threatening process under both the NSW *Threatened Species Conservation Act 1995 (TSCA 1995*) and the Commonwealth's *Environment Protection & Biodiversity Conservation Act 1999 - EPBC Act)* (Australian Government 1999).

Weeds pose the second greatest threat to biodiversity after land clearing and habitat loss in New South Wales (NSW DPI and OEH 2011). Weeds threaten biodiversity both directly by competing with native species and indirectly through their impacts on ecosystem structure and function. The Biodiversity priorities for widespread weeds project identified and prioritised widespread weeds impacting on biological assets and sites for weed control within each CMA region in NSW (DPI 2008; 2009; DPI and OEH 2011). Weeds of significance in the Catchment include:

- Lantana (*Lantana camara*);
- Serrated Tussock (*Nasella trichotoma*);
- Blackberry (*Rubus fruiticosus* aggregate);
- African Lovegrass (*Eragrostis curvula*);
- Scotch Broom (*Cystis scoparius*);
- Gorse (*Ulex europaeus*);
- Willows (*Salix* spp.);
- Madeira Vine (*Anredera cordifolia*); and
- Saint John's Wort (*Hypericum perforatum*).

There are also a number of weeds that were classed as emerging in the Catchment including:

- Fireweed (*Senecio madagascariensis*);
- Chilean needle grass (*Nasella neesiana*);
- Asparagus Fern (*Asparagus aethiopicus*); and
- Water Hyacinth (*Eichhornia crassipes*).

6.2.3 Management and Surveillance

The *Native Vegetation Act (NV Act) 2003* is the key legislation, which regulates the clearing of native vegetation in NSW. The Act aims to prevent broad-scale land clearing unless it maintains or improves environmental values.

The Act regulates the clearing of native vegetation in most of NSW, except on land in urban areas and land excluded for major development, and in national parks, conservation areas, state forests, and reserves.

The NSW Government is currently reviewing the *Native Vegetation Regulation* 2005 and various other provisions under the *NV Act 2003*, including the Environmental Outcomes Assessment Methodology (EOAM) and *Private Native Forestry Code of Practice*. Drafts of the proposed *Native Vegetation Regulation*, EOAM, and *Private Native Forestry* Code were released for public consultation in May 2012.

The new Regulation is currently being drafted, and it is proposed that consultation will place on the design of key elements of the new Regulation including draft self-assessable codes for lower impact clearing activities and a revised EOAM. It is anticipated that the new Regulation will be in place by the beginning of 2014 to coincide with the commencement of Local Land Services.

Currently, clearing on private property is only permitted if environmental values are improved or are maintained, this is implemented through a framework of voluntary agreements called Property Vegetation Plans (PVPs). A range of measures to improve landscape management, enhance the condition of native vegetation, and maintain biodiversity are also implemented through PVPs. PVPs are based on outcomes under four criteria in the EOAM. These are: biodiversity, soil health, water quality, and soil salinity. The CMAs play a pivotal role in establishing PVPs with private landholders.

NSW 2021: A plan to make NSW number one (NSW Government, 2011b) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Protect and conserve land, biodiversity and native vegetation'. This target is to be achieved through the following strategies:

- 'Identify and seek to acquire land of high conservation and strategic conservation value for permanent conservation measures'; and
- 'Establish voluntary arrangements with landowners over the next decade to bring an average 20,000 hectares per year of private land under conservation management and an average 300,000 hectares per year of private land being improved for sustainable management'.

Under Goal 22 of NSW 2021 – 'Protect our natural environment', the plan also contains a target to manage weeds and pests. Weed management is important to achieve the objectives under this indicator. The NSW legislation relating to weed species management is the *Noxious Weeds Act 1993*, *Rural Lands Protection Act 1998,* and *TSC Act 1995*.

The current NSW Government response to invasive species is set out in the *NSW Invasive Species Plan 2008–2015* (DPI 2008). The Plan provides a framework for the coordinated and cooperative management of invasive species aiming to prevent new incursions, contain existing populations, and adaptively manage already widespread species. The *NSW New Weed Incursion Plan 2009–2015* (DPI 2009) was developed to address the NSW Invasive Species Plan goals to exclude and to eradicate or contain new weed species. The incursion plan:

- Coordinates weed surveillance in NSW;
- Identifies new weeds and weed incursions;
- Provides for risk assessments of species;
- Facilitates the implementation of effective barriers to prevent weed establishment; and
- Specifies ways in which responses to weed incursions are coordinated, implemented, monitored, and reported.

The Southern Rivers Regional Weed Management Strategy 2011-2015 (SRCMA and Southern Councils Group 2011) provides strategic direction for the management of weeds and a coordinated weed management regime for the Southern Rivers region.

The development of this Strategy was initiated by Southern Rivers CMA and supported by local government, NSW Department of Primary Industry (DPI) and Southern Tablelands South Coast Noxious Plants Committee. The strategy identifies weed management issues and sets clear achievable objectives, underpinned by strategic actions. It provides a framework for decision making in the region to:

- Identify weed issues and recommend actions for achievable outcomes;
- Identify regional priorities for investment, ensuring they are consistent with NSW and national priorities;
- Provides consistency across local weed strategies and plans;
- Provides opportunities for partnerships that encourage co-ordinated weed management;
- Improve weed management through use of best management practices; and
- Improve weed management through increased education, training, discussion, and exchange of information and initiatives.

The BMCC released an updated weed management strategy in 2010 (BMCC 2010a). The weed management strategy describes local weed issues and relates national and state government and regional targets to local weed management. The strategy adopts three targets:

1. Reduce impacts of existing weeds;
2. Prevent establishment of new weed species; and
3. Enhance Council and community capacity to solve weed problems.

6.2.4 Methodology

The 2013 Audit focused on the extent of native and type of native vegetation in the Catchment; as well as activities to enhanced, protected or rehabilitated areas of native vegetation in the Catchment. This audit examined the areas in the Catchment with respect of the following:

- Cleared of native vegetation;
- Native vegetation revegetated and rehabilitated; and
- Weeds removed.

6.2.5 Findings

The vegetation formations for NSW version 3.0 was used to categorise and map the native vegetation in the Catchment (Figure 6-2). The eight vegetation formations occurring in the Catchment are described below based on Keith (2004).

Dry sclerophyll forests

The shrub/grass sub-formation of dry sclerophyll forests is dominated by Eucalypts sometimes exceeding 30 m in height, and has a shrubby understorey with conspicuous components of grasses in the ground layer. The shrubs may include a mixture of sclerophyllous and non-sclerophyllous species from the Asteraceae, Dilleniaceae, Euphorbiaceae, Fabaceae, and Myrtaceae families (Figure 6-1).

The shrub/grass dry sclerophyll forests form a transition between the grassy woodlands and the shrubby sub-formation of dry sclerophyll forest: the stature and composition of their tree stratum, the relative proportion of shrubs and grasses in the understorey, and the soils on which they occur, are all intermediate between these two other forms.

The forests are widespread on the coast, escarpment, and tablelands, extending to the western slopes. They span a wide range of altitude and rainfall and occupy soils of moderately low fertility.

Figure 6-1 Dry Sclerophyll forest in the Upper Nepean River sub-catchment (September 2013)

The shrubby dry sclerophyll forests differ from the shrub/grass sub-formation in having a lower tree canopy (usually <20-25 m) and greater abundance and diversity of sclerophyll shrubs in their understorey, particularly in the Proteaceae, Myrtaceae, Fabaceae and Ericaceae families.

They also generally lack a substantial tussock grass component in their ground layer, although tussock grasses maintain a presence in lower rainfall climates. Instead, the ground layer includes a sparser cover of sclerophyll sedges and rushes and scattered herbs. The two sub-formations share similar distributions from the coast to the western slopes, but the shrubby dry sclerophyll forests occur on more depauperate sandy loams and sands.

Wet sclerophyll forests

Tall forests dominated by straight-trunked Eucalypts (especially blue gums and ashes), with a prominent understorey or sub-canopy of soft-leaved shrubs and/or tree ferns. The ground layer is dominated by ferns, forbs, and occasional grasses. The open tree canopy is commonly 30 – 50 m tall, occasionally exceeding 70 m. The combination of hard-leaved 'sclerophyllous' tree canopy and soft-leaved 'mesophyllous' sub-canopy or shrub stratum understorey plants sets the shrubby wet sclerophyll forests apart from other structural forms of vegetation.

In New South Wales, the shrubby wet sclerophyll forests are limited to the coastal ranges and eastern side of the escarpment wherever moderately fertile soils occur in areas of high rainfall, although outliers do occur on western extensions of the Great Dividing Range.

Grassy wet sclerophyll forests resemble the shrubby sub-formation, but have a less developed stratum of mesophyllous small trees and shrubs, which allows greater abundance of grasses in the ground layer.

Dominant Eucalypts often exceed 40 m in height, but on average, the tree canopy is not as tall as may be attained in shrubby wet sclerophyll forests and a more diverse range of species may be present (including blue gums, grey gums, ashes, mahoganies, bloodwoods and ironbarks). The grassy wet sclerophyll forests occur throughout the coast and escarpment and may extend to slightly drier sites, including the edge of the tableland, than shrubby wet sclerophyll forests.

Rainforests

Rainforests are largely comprised of broad-leaved mesomorphic trees, with vines, ferns, and palms. They include a broad range of tree species, but generally lack Eucalypts except where these are emergent from a canopy of other trees. All forms of rainforest are characterised by a closed and continuous tree canopy composed of relatively soft, horizontally-held leaves.

They range from subtropical forests with palms, tall complex tree canopies up to 40 m tall, epiphytic ferns and mosses, to dry vine thickets, which may be no more than 4 m tall and contain some sclerophyllous plants. Rainforests also include temperate and littoral communities.

Grassy Woodlands

Grassy woodlands are dominated by well-spaced Eucalypts (mostly boxes and red gums) with a conspicuous and diverse ground cover of grasses and herbs and a typically sparse layer of shrubs. Trees may exceed 30 m in height. Perennial tussock grasses form the structural matrix of the ground layer, while perennial herbs occupy the inter-tussock spaces, supplemented by various ephemeral grasses and herbs, which emerge after sufficient rain.

Grasslands

The uniting features of grasslands include dominance by large perennial tussock grasses, a lack of woody plants, the presence of broad-leaved herbs in the inter-tussock spaces, and their ecological association with fertile, heavy clay soils on flat topography in regions with low to moderate rainfall. In drier climates, they may have a significant ephemeral component amongst perennial grass tussocks.

Heathlands

Heathlands are sclerophyll shrublands, which are mostly treeless, but may include Mallee Eucalypts or scattered emergent Eucalypts or Banksia trees. The shrub canopy may be closed or open and typically has small leaves. The ground layer includes sclerophyll sedges and rushes and occasional herbs. Heathlands are scattered along the coast and escarpment on rocky or sandy soils.

Forested Wetlands

Forested wetlands are dominated by sclerophyllous trees (Eucalypts, Paperbarks, or She-oaks) 5-40 m tall, with an understorey of hydrophytic shrubs, sedges, ferns, and herbs. Both the tree canopy and the understorey are often relatively dense, although this varies depending on the water regime. Forested wetlands include a diverse range of communities associated with riparian corridors and floodplains throughout New South Wales.

Freshwater Wetlands

Freshwater wetlands include a diverse range of essentially treeless communities dominated by shrubs, sedges, or herbs that are capable of tolerating prolonged periods of inundation or waterlogging. Inundation may be essentially permanent (in perennial wetlands) or punctuated by periods of dryness that may extend for months to decades (in ephemeral wetlands).

As a consequence of this diversity of water regimes, as well as variation in catchment characteristics, freshwater wetlands encompass a range of structural forms including dense graminoid heathlands, open shrublands, sedgelands, and aquatic herb fields. Submerged, floating, emergent, and amphibious plant growth forms are represented.

Cover of native vegetation in the Catchment

A significant portion of the Catchment is cleared (37.6 %) and the sub-catchments with the least percentage cover of native vegetation are the Upper Wollondilly River (16.3 % cover) and Mulwaree River (28.8 % cover). The largest percentage cover of native vegetation is in the Little River, Lower Coxs River and Endrick River sub-catchments (Figure 6-2), with >90 % cover.

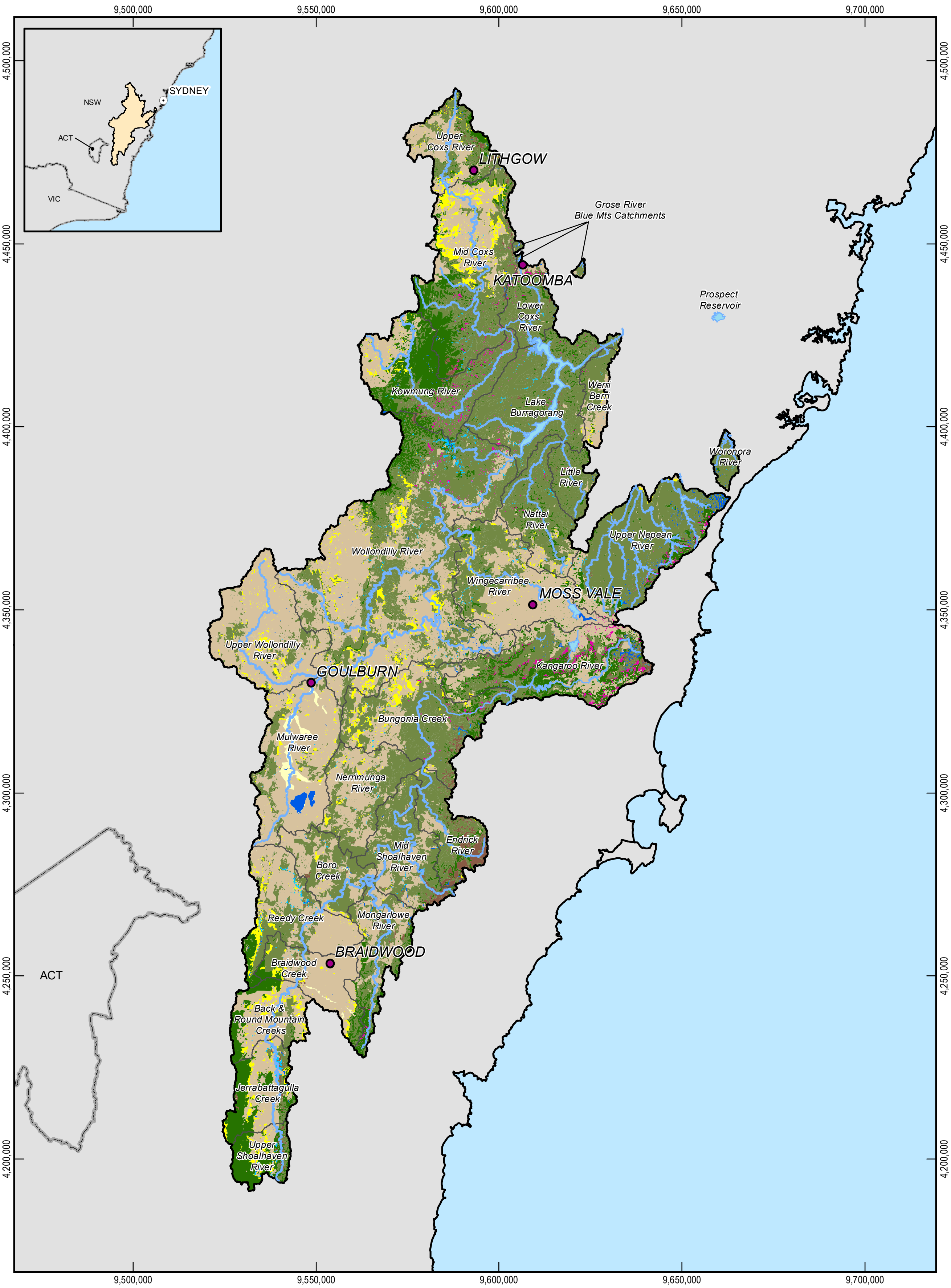
The dominant native vegetation type in the Catchment is dry sclerophyll forest and the largest area is in the Wollondilly River sub-catchment. Just over 10 % of the Catchment is covered with wet sclerophyll forest and the largest area is in the Kangaroo River and Kowmung River sub-catchments (Figure 6-3). Less than 2 % of the Catchment is covered by forested and freshwater wetland vegetation, with the greatest area in the Wollondilly River and Upper Nepean River sub-catchments. Wetlands are further discussed in Section 6.5.

There are a small percentage of grasslands (0.5 %), rainforest (0.8 %), heathlands (1.4 %), and grassy woodlands (3.7 %) in the Catchment. The largest area of grasslands is in the Mulwaree River sub-catchment, rainforest in the Kangaroo River sub-catchment, heathlands in the Endrick River and grassy woodlands in the Wollondilly River sub-catchment (Figure 6-3).

The Tablelands Snow Gum, Black Sallee, Candlebark, and Ribbon Gum Grassy Woodland in the South Eastern Highlands, Sydney Basin, South East Corner, and NSW South Western Slopes Bioregions community was declared as an endangered ecological community (EEC) in 2012 by the NSW Scientific Committee. Tablelands Snow Gum, Black Sallee, Candlebark, and Ribbon Gum Grassy Woodland EEC fall within the structural formation of Grassy Woodlands.

The Tablelands Snow Gum, Black Sallee, Candlebark and Ribbon Gum Grassy Woodland EEC typically forms an open-forest, woodland or open woodland that transitions into grassland at low tree cover. The canopy is dominated by *Eucalyptus pauciflora* (Snow Gum), *E. rubida* (Candlebark), *E. stellulata* (Back Sallee) and *E. viminalis* (Ribbon Gum), either as single species or in combinations. Other more localized *Eucalyptus* species may also occur within this community such as *E. aggregata* and *E. parvula*. A shrub layer may be present and sub-shrubs are often a component of the ground stratum; characteristic species include *Hymenanthera dentata* and *Melichrus urceolatus*. The ground layer is dominated by grasses and other herbaceous species including *Themeda australis*, *Poa* spp., *Austrostipa* spp., *Austrodanthonia* spp., *Leptorhynchos squamatus*, *Chrysocephalum apiculatum,* and *Asperula conferta*.

SCA developed a Vegetation Condition Index (VCI) to map vegetation in the catchments. It uses satellite images to calculate the relative health of vegetation communities and changes over time. The VCI is used to identify changes in native vegetation. A negative deviation from the average condition (as measured over a five year period) suggests some sort of vegetation disturbance. SCA reported that the condition of woody vegetation in the Catchment was generally improved since January 2009, with the percentage within and above average higher for most sub-catchments (SCA 2012c). Currently the VCI is under review by SCA.



LEGEND

- Town
- Drainage
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary

Vegetation Formation Name

- Forested wetlands
- Freshwater wetlands
- Cleared
- Grasslands
- Grassy woodlands
- Heathlands
- Dry sclerophyll forests
- Wet sclerophyll forests
- Rainforests

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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
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N

Sydney Catchment Authority
Catchment Audit 2013

Broad vegetation types in the Catchment

Job Number	2314960
Revision	0
Date	26 Nov 2013

Figure 6.2

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); OEH: Vegetation Formations (2010); SCA: boundaries (2013). Created by: KP

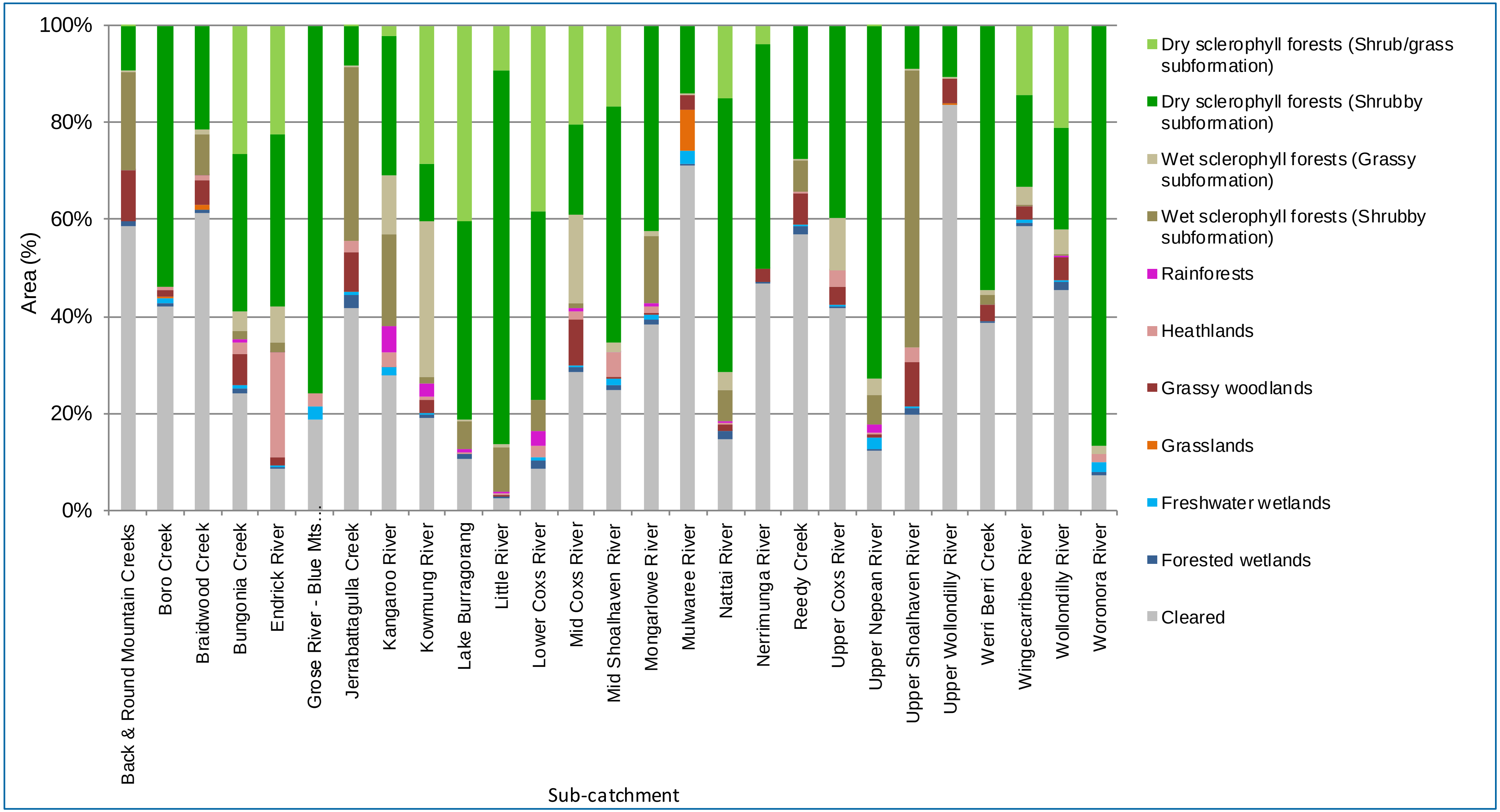


Figure 6-3 Percentage of vegetation types in each sub-catchment

Source: OEH 2011

Activities in the catchment

Activities in the catchment to protect and rehabilitate native vegetation and control weeds in the Catchment are carried out by SCA in special areas and the HNCMA and SRCMA in other areas of the Catchment. The Mount Murray Pine plantation in the Metropolitan Special Area was removed in 2005 and the area left to naturally rehabilitate (Figure 6-4).

Figure 6-4 Mount Murray Pine plantation (September 2013)

The main priorities on SCA land within Special Areas have been the removal of blackberry, serrated tussock, willows, and privet. A summary of SCA's weed control activities in special areas in 2010-2011 and 2011-2012 is presented in Table 6-1.

Also targeted are aquatic weeds (e.g. Water Hyacinth) that can be a significant risk to water quality and water supply infrastructure. Water Hyacinth is an emerging aquatic weed in the Kangaroo River and Lake Yarrunga. In May and June 2011, it was removed from 10 km of the foreshore. The SCA has a continuing maintenance program of control in the Kangaroo River arm which has prevented its dominance of the waterway. In 2010-2011, SCA identified and eradicated two invading pasture grass species (Johnson Grass and Coolatai Grass).

CMAs play a central role in delivering programs to protect, maintain, or improve native vegetation. The CMAs are responsible for developing CAPs which provide priorities, actions, and targets for natural resource management at a regional level. The HNCMA provides support to Landcare groups through CMA staff, funding, and training.

On ground activities in the Catchment that have been carried out by the CMAs to achieve CAP targets related to native vegetation are listed in Table 6-2 and Table 6-3. There was an increase in the area of native habitat rehabilitated and the number of landholders involved in landscape-scale conservation agreements carried out by HNCMA in the Catchment during the audit period (Table 6-2). The majority of the works were located in the Wingecarribee River, Wollondilly River, Upper Wollondilly River, Mulwaree River, Kangaroo River, Jerrabattgutta Creek, Nerrimunga Creek, Back and Round Mountain Creeks sub-catchments.

Table 6-1 Summary of weed control activities in special areas

Special Area	Weed target	Area treated/ removed (ha)	Weed target	Area treated/ removed (ha)	Population Trend (Estimated)	Weed target	Area treated/ removed (ha)	Population Trend (Estimated)
Blue Mountains			Environmental weeds	500	Declining	Serrated tussock	N/A	Low with isolated spots
Braidwood	Blackberry	92.5	Blackberry	20	Declining	Blackberry, Broom, Paterson's Curse, Scotch Thistle, Serrated Tussock, St. John's Wort	5 Braidwood properties	Steady
	Serrated Tussock	3860						
Metropolitan and Woronora	Blackberry	11.2	Blackberry	420		Blackberry, Boneseed, Castor Oil Plant, Cherry Laurel, Coolatai Grass, Cotton bush, Crofton Weed, Gorse, Horehound, Ivy, Lantana, Pampas Grass, Pine species, Queensland Silver Wattle, Saffron Thistle, Scotch Thistle, Serrated Tussock, St. John's Wort, *Tradescantia*., Turkey Rhubarb, Whiskey Grass, Wild Olive	340	Weeds are at low density and considered to be at maintenance levels
	St John's Wort, Privet, Crofton Weed and others	30	Pampas grass	250	Declining			
			Other environmental weeds	1,240	Declining			
Prospect Nature Reserve						African Olive, Blackberry, Boneseed, Crofton Weed, *Juncus acutus*, Lantana, Moth Vine, Prickly Pear, Privet, Silky Oak	213	

Table 6-1 (cont.) Summary of weed control activities in special areas

Special Area	Weed target	Area treated/ removed (ha)	Weed target	Area treated/ removed (ha)	Population Trend (Estimated)	Weed target	Area treated/ removed (ha)	Population Trend (Estimated)
Shoalhaven	Blackberry	2600	Blackberry	1	Declining	Blackberry, Cape Ivy, Elephant Ears, Fireweed, Hemlock, Khaki weed, Lantana, Mistflower, Privet, Scotch Thistle, Water Hyacinth, Wild Tobacco, Willows	30	Generally declining although Wild Tobacco is increasing
	Privet	2000	Water Hyacinth	10 km removed	Declining			
	Water Hyacinth	1 plant removed	Environmental weeds	1765				
Warragamba	Blackberry	35 km	Blackberry	524	Declining	African Olive, Berberis, Blackberry, Blue periwinkle, Broom, Castor Oil Plant, Deutzia, Honeysuckle, Ivy, Lantana.	1,606	Generally declining
	Serrated Tussock	502	Environmental weeds	8,584	Declining			
	Lantana	38						
	Moth Vine	65						
	Tree of Heaven	6						
	Prickly Pear	500						
	Bridal Creeper	>1						

Source: SCA 2010a, 2011a and 2012a

Table 6-2 Native vegetation protection and rehabilitation projects undertaken by the HNCMA

	2010-11	2011-12	2012-13
Native habitat conserved and rehabilitated (ha)	1108	922	1417
Threatened vegetation communities protected (ha)	442	484	402
Weeds controlled in priority native habitat (ha)	693	1271	703
Landholders involved in cross-property conservation agreements	12	20	11
Landholders involved in landscape-scale conservation agreements	15	83	98

Source: HNCMA 2013a; b; c

Table 6-3 Native vegetation protection and rehabilitation projects completed or funded by the SRCMA

	2009-10	2010-11	2011-12	2012-13
Voluntary management contracts - not tied to title	11	18	25	16
Area (ha) of voluntary management contracts - not tied to title	77.81	721.87	726.32	266.81
Terrestrial native vegetation protected by fencing (ha)	0.55	204.50	242.04	176.78
Terrestrial native vegetation enhanced/rehabilitated (ha)	0.55	194.94	237.69	100.68
Terrestrial native species planted (ha)		18.14	9.05	22.61
Total area (ha) protected by fencing specifically for significant flora and fauna		44.33	1.18	48.79
Pest plant control measures implemented (ha)	57.15	216.17	0.80	0.24
Area (ha) of this pest plant control measures that represent initial treatment		165.74		0.24

Source: SRCMA 2013

A new project was established in 2011 which aims to establish a bushland corridor between Morton National Park and the Blue Mountains World Heritage Area called the Southern Highlands Biolink project. The project is a partnership between HNCMA, Greening Australia and the Office of Environment and Heritage and funded by the Australian Government's Caring for Our Country initiative.

The Southern Highlands Biolink project aims to protect where possible, a range of local vegetation from paddock trees, riparian corridors, rocky outcrops and remnant woodlands and initially focused on working with landholders in a corridor which extends from Morton National Park at Wingello, through areas such as Paddy's River, Canyonleigh, Belanglo, Medway, Joadja, to the Nattai National Park north of High Range.

The Wingecarribee Shire Council has an Environment Strategy 2010-2015 with an objective to ensure that all on-the-ground environmental projects are prioritised with clear and measurable outcomes - especially those projects associated with Wingecarribee Our Future Environment Levy program. The Wingecarribee Shire Council Environmental Levy, with addition funds from grants, funded a number of environmental enhancement projects, achieving the following:

- Over 280 ha of bushland regenerated;
- 202.5 ha of native vegetation improved by weed management;
- Community nursery established to grow plants required for revegetation;
- Over 44,000 native plants established on degraded land; and
- 58 properties (comprising 378 ha of private land) have joined the 'Land for Wildlife' program since 2009.

The Wingecarribee Shire Council has also recently released (February 2013) the brochure 'Environmental Weeds in the Southern Highlands'. This new brochure profiles the 15 worst environmental weeds in the Southern Highlands, and also provides a comprehensive list of recommended alternative native and exotic plants.

The Palerang Shire Council made a number of property inspections and issued notices requiring weed control to be undertaken in the current audit period. Most of the property inspections focussed on new and emerging weed threats in accordance with the NSW management plan (DPI 2008). Of significant concern was the increasing discovery of isolated Fireweed plants, a relatively new weed in the Palerang area with significant potential to invade. Crown Lands, together with reserve managers, also implement weed control programs within the Catchment.

The SCA and CMAs have programs, which fund a number of on-ground works to protect and rehabilitate native vegetation. The exact extent and location of native vegetation works carried out by the SCA, CMAs, Local Councils and community groups (landcare and bushcare) in the Catchment is difficult to determine. All of these programs and on-ground works are likely to contribute to an improvement in the condition of native vegetation and provide improved protection of water quality.

6.2.6 Recommendations

No new native vegetation condition information was available for the 2013 Audit. Updated native vegetation condition information is required to determine any change in condition and identify emerging issues affecting the condition of native vegetation in the Catchment.

The 2010 Audit (DECCW 2010a) recommended that data on ecosystem health indicators, including native vegetation condition, should be integrated to provide a more comprehensive understanding of stream and catchment health and enable a more focussed and better prioritised management response to catchment condition. This recommendation is reiterated in this audit.

A number of programs targeting weeds are conducted in the Catchment. The current extent of weeds in the Catchment is required to determine priority areas for investment, emerging weeds infestations and improvements in ecosystem health.

OEH and CMAs should investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period.

Previous audits (2005 and 2007) have recommended that a spatial information system be established to track and record information on all on-ground works being undertaken, or funded by government, for the purposes of water quality and ecosystem health management in the Catchment. This suggestion is reiterated (see **Recommendation 1**).

All on-ground works being undertaken in the Catchment to revegetate and rehabilitate native vegetation and control weeds should be integrated and a spatial database of location, type and area of works created and maintained. The LMDB Framework collaboration between OEH and CMAs contains information regarding on-ground works such as weed control, erosion control and riparian management. The LMDB captures extensive project based information, including projects such as the CPS.

The OEH in cooperation with other state and local government agencies should continue to update and progress the current LMDB to track and record information on all native vegetation on-ground works being undertaken or funded by government for the purposes of water quality and ecosystem health management in the Catchment.

6.3 Riparian vegetation

6.3.1 Summary

There is significant investment by SCA, CMAs and Local Councils in protecting and rehabilitating riparian vegetation in the Catchment. CMAs carry out a number of on-ground works in the Catchment to protect and rehabilitate riparian vegetation, including limiting stock access and removing weeds from riparian zones. CMAs currently treated large areas of weeds in the riparian zone each year; however, the total area of weeds in the riparian zone within the Catchment is unknown. All of these programs and on-ground works in the riparian zones are likely to contribute to an improvement in the health of riparian zones and provide improved protection of water quality.

The 2006 Riparian Connectivity Index (RCI) and a Riparian Vegetation Index (RVI) are out dated and any improvement in the extent and condition of riparian vegetation in the Catchment during the audit period is difficult to determine.

Assessment Criteria

Criteria

1. The extent of riparian lands is known.
2. The type and condition of riparian vegetation is understood.
3. Action is taken by appropriate stakeholders to protect and rehabilitate degraded areas of riparian vegetation.

Assessment against Criteria

Criteria	Audit finding	Recommendation
1	Opportunity for improvement	OEH and CMAs should investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period.
2	Meets Expectation	Nil
3	Meets Expectation	Nil

Prior recommendations

Prior Recommendations	Action	Status
No prior recommendations	N/A	N/A

6.3.2 Background

Plants growing alongside rivers and creeks are termed *riparian vegetation*. Riparian vegetation is critical to the health and viability of streams. Streams with well-developed riparian vegetation generally have a higher biological productivity than those without trees along their banks (Fairfull 2013).

The riparian zone (Figure 6-5) can provide nutrients, shading, temperature control, stream bank stability, minimising erosion, and habitat for a range of species. The riparian zone can also provide a buffer which partially filters out pollutants, such as soil, pesticides, and fertilisers, being carried towards the waterway (Fairfull 2013).

Riparian zone degradation resulting from the alteration of natural water flow regimes of rivers, streams, floodplains and wetlands has been listed as key threatening processes in NSW under the *TSC Act 1995* (DECC 2008).

'Degradation of native riparian vegetation along NSW water courses' has also been listed as a 'key threatening process' under the *Fisheries Management Act (FM Act) 1994*, in recognition of its role in the decline of several threatened species of fish. Protection of riparian vegetation along streams has been identified as a primary action to reduce threats to fish in NSW (Morris et al. 2001).

Figure 6-5 Riparian vegetation along Sandy Creek, a tributary of Cordeaux Dam (September 2013)

The primary pressures on riparian vegetation are removal of riparian vegetation, introduced plant species, such as Willows, and stock access. Willows are listed as a Weed of National Significance, and are regarded as one of Australia's most serious riparian and wetland weeds (Holland Clift and Davies 2007). The impact of Willows includes:

- Increased erosion and flooding;
- Reduced quality and flow of water;
- Reduced availability of water;
- Less habitat available for fish, birds, frogs, insects, mammals and reptiles;
- Obstructing access to streams for fishing and aquatic activities; and
- Damage to nearby infrastructure.

Stock access to the riparian zone is of particular importance as grazing adjacent to watercourses can lead to a reduction in vegetation, promote stream bank erosion and can contribute to deterioration of water quality (e.g. sediment, nutrients, pathogens etc).

The degradation of riparian vegetation can impact upon waterways and native aquatic flora and fauna in a number of ways, including:

- Increased nutrient and sediment runoff;
- Erosion due to altered channel structure; and
- Loss of food and habitat for aquatic and terrestrial fauna.

The SCA estimated there are approximately 110,000 km of river length with associated riparian land in the Catchment (SCA 2009a; c). In 2003, it was estimated that there was 81,125 ha of riparian zone in the Catchment of which native vegetation covered 54,787 ha (67.5%) and 23,806 ha was pasture (DEC 2003). The SCA also estimated that 38,753 km (35% of stream length) of watercourses in the Catchment were currently being, or had the potential to be, accessed by stock.

Riparian vegetation is important in maintaining the health of aquatic ecosystems in the Catchment. There are a number of historical land management practices that have influenced riparian vegetation in the Catchment.

6.3.3 Management and Surveillance

Riparian vegetation is protected under several pieces of NSW legislation, including the following:

- *Fisheries Management Act 1994* (FM Act 1994) identifies the 'degradation of native riparian vegetation along NSW water courses' as a key threatening process. The FM Act provides for the maintenance and establishment of riparian buffer zones along waterways. The removal of freshwater aquatic vegetation or work that involves the removal of any other material from water land that disturbs, moves or harms freshwater aquatic vegetation is considered 'dredging' under the FM Act.
- *Native Vegetation Act 2003* (NV Act 2003) provides for the protection of living native riparian vegetation. Development consent or a property vegetation plan may be required to clear riparian native vegetation under the NV Act.
- *Native Vegetation Conservation Act 1997 (NV Act 1997)* applies to the clearing of living and dead exotic trees and dead native trees on State protected land, which generally includes the bed and banks of named rivers and creeks in NSW.
- *Environment Planning & Assessment Act 1979 (EPA&A 1979)* provides for the protection of living native vegetation within urban areas and certain local government authorities specifically exempt from the application of the NV Act.
- *Threatened Species Conservation Act 1995 (TSCA 1995)* establishes mechanisms for the management and protection of listed threatened species of native flora and fauna.
- *National Parks and Wildlife Act 1974* protects native flora and fauna in NSW and establishes mechanisms for its protection.
- *WMA 2000 requires a* 'controlled activity approval' to carry out activities in, on or under waterfront land, which includes the bed and a distance of 40 m from any river, lake or estuary.

6.3.4 Methodology

The 2013 Audit focused on the extent of riparian vegetation enhanced, protected or rehabilitated, as well as the activities to exclude or minimise livestock access to riparian area in gullies, streams and creeks in the Catchment.

This audit examined the areas in the Catchment with respect of the following:

- Riparian land protected, revegetated and rehabilitated;
- Riparian weeds removed; and
- Controlled livestock access to riparian areas.

6.3.5 Findings

In 2006, two indices - a Riparian Connectivity Index (RCI) and a Riparian Vegetation Index (RVI) - were developed by SCA to determine the connectivity of riparian vegetation and the proportion of standing vegetation in riparian zones in the Catchment. The RVI, however, does not discriminate between native and exotic species. Based on the RVI, riparian zones in the Mulwaree River, Upper Wollondilly River, Braidwood Creek and Reedy Creek sub-catchments were identified as having little or no standing vegetation cover along the riparian zone.

The RVI is currently used to prioritise assessment of sites for the Riparian Management and Assistance Program (RMAP). The SCA has identified 6,000 km of streams and gullies in grazing areas as high priorities within the Kangaroo River, Bungonia Creek, Wollondilly River, Wingecarribee River, Upper Nepean River, Mid Coxs River and Werriberri Creek sub-catchments (SCA 2012a; b; c).

Recently, the NSW Office of Water conducted an assessment of native and invasive riparian vegetation. The NSW River Condition Index (RCI) assessment includes the bio-forecaster for riparian vegetation (NSW Office of Water 2010)[6]. The extents of riparian vegetation within 30-metre riparian buffer zones around water courses with high stream orders (orders three and above) were determined. The methodology included the use of the most recent SPOT 5 and ADS 40 imagery, and field validation, to test remote sensing techniques to differentiate between native woody/non-woody and non-native/invasive vegetation.

Outputs from this project include the Riparian Vegetation Extent (RVE) dataset, which includes 'woody' and 'non-woody' vegetation classes. The secondary product is the Hybrid Riparian Native Vegetation Extent (HRNVE) dataset, which consists of 10 different vegetation classes. The HRNVE was derived from interim foliage projective cover and includes 'native non-woody', 'native woody', 'non-native non-woody', 'non-native woody' and other classes.

The results for the Hawkesbury- Nepean and Southern Rivers CMAs are provided in Table 6-4 and Table 6-5.

Table 6-4 Extent of classes of riparian vegetation in Hawkesbury-Nepean and Southern Rivers CMA areas derived from the NSW Office of Water RVE dataset

CMA	Riparian (ha)	Woody (ha)	Woody (%)	Non-woody (ha)	Non-woody (%)	Others (ha)	Others (%)
Hawkesbury – Nepean	100101.8	75791.6	75.7	18124.2	18.1	6186.0	6.2
Southern Rivers	136323.4	93660.8	68.7	38136.7	28.0	4525.9	3.3

Source: NSW Office of Water 2010

[6] NSW Office of Water (2010). *Riparian Vegetation Extent for Environmental Monitoring, Evaluation and Reporting. Project report*. ISBN 978 1 74263 020 5

Table 6-5 Extents of riparian, native vegetation in the Hawkesbury-Nepean and Southern Rivers CMA areas, derived from the NSW Office of Water HRNVE dataset

Class	Hawkesbury-Nepean		Southern Rivers	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Non-woody—(most likely) native	10572.7	10.6	21795.1	16.0
Non-woody—(most likely) non-native	629.6	0.6	1305.4	1.0
Non-woody—(likely) native	6249.1	6.2	13921.7	10.2
Non-woody—(likely) non-native	408.6	0.4	773.1	0.6
Non-woody—(K&S) native	57526.5	57.4	5.9	0.0
Woody—(most likely) native	132.9	0.1	65889.9	48.3
Woody—(most likely) non-native	5984.1	6.0	559.9	0.4
Woody—(likely) native	14283.8	14.3	2350.1	1.7
Woody—(likely) non-native	77.5	0.1	26436.3	19.4
Woody—(K&S) native	70.1	0.1	220.5	0.2
Other	4241.8	4.2	3075.6	2.3

Source: NSW Office of Water 2010, note: 'K&S' refers to the Keith and Simpson native vegetation extent data.

Activities in the catchment

There are a number of ongoing activities in the Catchment by the SCA, Hawkesbury Nepean CMA and Southern Rivers CMA to protect and rehabilitate riparian vegetation, which have continued during the current audit period.

The SCA's RMAP aims to increase the use of water quality best management practices on rural land in the Catchment. Reducing stock access to waterways reduces faecal contamination, nutrients, pathogens and sediment in the water supply.

The RMAP helps landholders protect water quality and riparian health by controlling grazing, and managing vegetation and erosion in gullies and waterways of priority catchments. The program focuses on minimising or excluding uncontrolled stock access to riparian areas in gullies, streams and creeks, the control of erosion sites and revegetating riparian areas.

Since 2006, grants have helped graziers fence and manage 127 km of riparian land, provide alternative watering points for stock, treat and control erosion, and establish native vegetation (SCA 2012a; b; c). These activities contribute to developing the infrastructure to manage stock grazing without damaging stream banks and water quality. The majority of the works funded by SCA in the riparian lands during the current audit period have been in the Kangaroo River, Bungonia Creek, Upper Nepean River, and Braidwood Creek sub-catchments (Table 6-6).

Table 6-6 SCA RMAP activities in the Catchment during the audit period (2010–13)

Sub-catchment	Creek protected (km)	Fencing (km)	Piping (km)	Troughs	Tank	Farm dam	Pump	Stock access point
Braidwood Creek	1.1	2.3	0.2	3				
Bungonia Creek	4.1	7.3			1			
Kangaroo River	27.4	40.2	5.4	62	3	1		35
Nattai River	0.67	0.67						
Upper Nepean River	1.3	2.3						
Wollondilly River	2.3	3.1	1.1	7	3		1	1
Total	**36.9**	**55.9**	**6.7**	**72**	**7**	**1**	**1**	**36**

Stock access to Wallaby Creek was observed during the 2003 Audit Catchment inspections (Figure 6-6). During the 2013 Audit, the same location was visited and inspected. Since the 2003 Audit, the SCA has purchased the property, fenced the creek, so that the cattle can no longer access Wallaby Creek, and provided an alternate water pointing (Figure 6-7).

Figure 6-6 Stock access to Wallaby Creek (August 2003)

An evaluation of the RMAP was undertaken in 2010 and a number of changes to the RMAP including a cap on the dollar value of every metre of riparian length protected and the increase in the duration of landholder agreements to 10 years were made.

A riparian Grants Evaluation and Monitoring (GEM) tool has also been developed by SCA to assess the water quality risk of various riparian conditions, such as stock access, groundcover and streambank stability. Every RMAP project site is assessed using the riparian GEM tool prior to the start of works, and again two years after works are completed.

The HNCMA has also carried out a number of projects in the Catchment to enhance and rehabilitate riparian lands and protect riparian land from stock (Table 6-7). There was an overall decrease in the area of works undertaken to enhance and rehabilitate riparian lands by the HNCMA during the Audit period.

A summary of SCA's Willow removal in special areas in 2010-2011 and 2011-2012 is presented in Table 6-8. Willow removal in the Wingecarribee swamp is detailed in Section 6.5.5.

Figure 6-7 Wallaby Creek fencing and water point observed in September 2013

Table 6-7 Summary of HNCMA riparian projects, 2010-13

	2010/11	2011/12	2012/13
Riparian land enhanced, protected and rehabilitated (ha)	423	182	406
Stream Habitat established (km)	107	67	134
Length (km) of streambank protected from stock	151	5	17
Area (ha) of riparian native vegetation protected by fencing enhanced and rehabilitated	140	8	18
Streambank length (km) of riparian vegetation protected, enhanced and rehabilitated	25	3	10
Area (ha) planted to riparian native species	115	26	16
Stream bank length (km) of riparian vegetation planted	40	12	6

Source: HNCMA 2013a

Table 6-8 Summary of SCA willow removal in special areas in 2010-11 and 2011-12

	2009-10		2010-11			2011-12		
Special Area	Weed control target	Area treated/ removed (ha)	Weed control target	Area treated/ removed (ha)	Population Trend (Estimate)	Weed control target	Area treated/ removed (ha)	Population Trend (Estimate)
Shoalhaven			Willows	0.007		Several weeds including Willows	30	Generally declining
Warragamba	Willow	520	Willows	500	Declining			

Source: SCA 2010a; c; d; 2011a; 2012a; b

The BMCC is undertaking stream restoration works in the following priority areas within the Catchment (BMCC 2010a):

- Popes Glen Reserve, Blackheath;
- Harold Hodgson Reserve, North Katoomba;
- Yosemite Creek, North Katoomba;
- Echo Point, Katoomba;
- Katoomba Park, Katoomba;
- Vale Street Wetlands, Katoomba;
- Leura Park, Leura;
- Wentworth Falls Lake, Wentworth Falls;
- Central Park, Wentworth Falls; and
- Jamison Creek, Wentworth Falls.

The Wingecarribee Shire Council is responsible for managing over 130 km of waterways in the Catchment. In 2011-2012, Wingecarribee Shire council obtained grants from the HNCMA to conduct riparian works including weed control and bush regeneration works at (Wingecarribee Shire Council 2012):

- Berrima River Bend Reserve;
- Iron Mines Creek;
- Stingray Swamp; and
- Mittagong Creek upstream tributary.

The Wingecarribee Shire Council's bush regeneration team also supports the Shire's Landcare and Bushcare volunteers who work at riparian sites including Jordan's Crossing, Wingecarribee River at Berrima, Mittagong and Gibbergunyah Creeks. Work at these sites focuses on the removal of noxious and environmental weeds, revegetation and regeneration of native bush all of which contributes to improving the water quality of these waterways. The Council's Environmental Levy, with addition funds from grants, has funded 14.5 km of river/ creek vegetation improvements.

The Mittagong Creek Riparian Management Plan was developed by the Wingecarribee Shire Council in 2012 (Australian Wetlands Consulting (2012), setting the direction for future works within this riparian corridor to be supported by the Environment Levy. The major threats to the Mittagong Creek are weed encroachment, sedimentation and bank erosion. Other issues include urban encroachment, limited riparian buffer vegetation and with some potential threat from land use such as grazing (cattle access to banks) and industrial zone activities.

The key objectives of the Mittagong Creek Riparian Management Plan are to:

- Provide bed and bank stability;
- Protect water quality;
- Maintain viability of riparian vegetation;
- Integration with floodplain processes;
- Manage edge effects at riparian/ urban interface;
- Protect natural values within the creek;
- Provide adequate access;

- Vegetation to reflect public open space usage;
- Does not promote pest vegetation/ fauna; and
- Provide continuity and connectivity.

Wingecarribee Shire Council also has a program that funds conservation activities on private land. This program aims to protect endangered vegetation communities and riparian corridors and complements programs run by the HNCMA (Wingecarribee Council 2012).

Lithgow City Council completed weed reduction and other improvements along Farmers Creek in 2011-2012 (Lithgow City Council 2012). The Lithgow and Districts Landcare group is also working to rehabilitate and re-establish native vegetation in the Lithgow riparian urban landscape focusing on Lake Pillans Wetland, Farmers Creek & associated tributaries.

The SCA and CMAs have strong programs, which fund a number of on-ground works to protect and rehabilitate riparian zones. The exact extent and location of all riparian works carried out by the SCA, CMAs, Local Councils and community groups (landcare and bushcare) in the Catchment is difficult to determine.

However, the Auditor is of the view that all of these programs and on-ground works in the riparian zones are likely to contribute to an improvement in the health of riparian zones and provide improved protection of water quality.

6.3.6 Recommendations

In the future, Catchment Action Plans and the SCA's RMAP should include updated native riparian vegetation cover as an input into the rehabilitation of rivers and streams. The NSW Office of Water has developed mapping and assessment tools to assist with this process and the incorporation of the RVE and HRNVE data into Catchment Action Plans and SCA's RMAP is recommended.

Previous audits (2005, 2007 and 2010) have recommended that integrating ecosystem water quality, macroinvertebrate, fish and riparian vegetation condition monitoring programs be developed for the Catchment. The Auditor agrees that such a program should be developed and would have significant benefits with regard to knowledge and information sharing, availability and consistency.

The CMAs, SCA and OEH should investigate the potential for integrating riparian condition monitoring into a broader catchment-wide ecosystem monitoring program.

A number of programs targeting weeds in the riparian zone are conducted in the Catchment. The current extent of the riparian zone covered in weeds in the Catchment is required to determine priority areas for investment, emerging weed infestations, and improvements in ecosystem health. The use of HRNVE data should be investigated to determine whether it is an appropriate m measure of the extent of the riparian zone covered in weeds in the Catchment.

OEH and CMAs should investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period.

The 2010 audit recommended that data on ecosystem health indicators, including riparian vegetation condition, should be integrated to provide a more comprehensive understanding of stream and catchment health and enable a more focussed and better prioritised management response to catchment condition. This recommendation is reiterated in this audit (see **Recommendation 1**).

Previous audits (2005 and 2007) have also recommended that a spatial information system be used to track and record information on all on-ground works being undertaken or funded by government for the purposes of water quality and ecosystem health management in the Catchment.

The SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (Recommendation 1) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection.

The LMDB Framework collaboration between OEH and CMAs contains information regarding on-ground works such as weed control, erosion control and riparian management. The LMDB captures extensive project based information, including projects such as the CPS. The OEH in cooperation with other state and local government agencies should continue to update and progress the current LMDB to track and record information on all riparian zone on-ground works being undertaken or funded by government for the purposes of water quality and ecosystem health management in the Catchment.

6.4 Physical Form

6.4.1 Summary

The Riverstyles spatial layer used in the 2010 Audit report was updated in 2012. The current layer provides a finer scale of coverage of waterways and has increased the total length of stream assessed. The percentage of stream reaches within the Catchment in either good condition or in a protected area is 57 %, whilst 39 % of the Catchment is in moderate or poor condition.

The sub-catchments which have the highest percentage of stream length in good condition are Endrick River, Bungonia Creek, Kangaroo River and Upper Shoalhaven River. The sub-catchments which have the highest percentage of stream length in moderate and poor condition are the Upper Wollondilly River, Mulwaree River, Boro Creek, Braidwood Creek and Back and Round Mountain Creeks.

Based on the recovery potential assessment of streams within the Catchment, the sub-catchments with a high percentage of conservation reaches were Endrick River (94 %), Bungonia Creek (69 %) and Kangaroo River (69 %). Preventing the degradation of these areas through immediate protection strategies will have environmental, social, and economic benefits long into the future. Reaches which have moderate to low recovery potential have reduced likelihood for a natural recovery and exhibit continued signs of on-going instability. The sub-catchments with a high percentage of moderate and low recovery potential reaches were the Mulwaree River (86 %), Upper Wollondilly River (81 %) and Reedy Creek (68 %).

Assessment Criteria

Criteria	
1.	The geomorphic river condition is known and assessed.

Assessment against Criteria

Criteria	Audit finding	Recommendation
1	Meets Expectation	Nil

Prior recommendations

Prior Recommendations	Action	Status
No prior recommendations	N/A	N/A

6.4.2 Background

Physical form describes the geomorphic complexity of a river and may be used as a measure of the recovery potential of degraded rivers (NOW 2009). A system for assessing physical form is provided by the Riverstyles® framework. Riverstyles is a geomorphic approach for examining river character, behaviour, condition and recovery potential (Brierley and Fryirs 2005).

Riverstyles captures data at the river reach scale and provides a more detailed analysis of geomorphic condition.

There are a number of stages in implementing the Riverstyles framework:

1. Baseline survey of river character and behaviour;
2. Assessment of the geomorphic condition of each reach in the catchment;
3. Prediction(s) of likely future changes in geomorphic condition and geomorphic recovery potential;
4. Setting realistic target conditions for river rehabilitation.

Stage One of the Riverstyles framework provides a baseline survey of river character and behaviour. The Riverstyle is determined by the river/stream character and behaviour and is typically characterised by a distinctive set of attributes (e.g. topography, geology, climate, hydrology, vegetation cover), and analysed in terms of channel geometry, planform and geometric units that make up a river reach such as floodplains, levees, pools and riffles.

Stage Two of the Riverstyles framework assesses river condition throughout a catchment. Near intact condition is characterised by reaches with numerous geomorphic units and an extensive riparian corridor, whereas the degraded condition is characterised by reaches that have homogenous sand sheets that infill pools and smother channel beds, and a non-existent riparian corridor.

The geomorphic condition has been classified as *reserve, good, moderate, poor and none* based on Outhet and Cook (2004). The reserve category indicates stream length in the HNCMA which is protected in national park. A small length of waterways was assessed as having no condition (none), this applied to urban waterways and major water storages where waterway form has been completely altered or obscured by inundation.

Good condition (e.g. natural and intact) – must contain all of the following characteristics:

- River character and behavior is similar to the pre-development state presenting a high potential for ecological diversity;
- Minimal alteration to catchment controls such as sediment supply and the hydrological regime allowing fast recovery from natural disturbance;
- Relatively intact and effective vegetation coverage dominated by native species, giving resistance to natural disturbance and accelerated erosion.

Moderate condition (e.g. noticeably impacted by human disturbances) – contains one or more of the following characteristics:

- Localised degradation of river character and behavior, typically marked by modified patterns of geomorphic units;
- Patchy effective vegetation coverage allowing some localised accelerated erosion.

Poor condition (e.g. degraded) – contains one or more of the following characteristics:

- Abnormal or accelerated geomorphic instability (reaches are prone to accelerated and/or inappropriate patterns or rates of planform change and/or bank and bed erosion);
- Excessively high volumes of sediment inputs which blanket the bed, reducing flow diversity;
- Absent or geomorphologically ineffective coverage by vegetation (allowing most locations to have accelerated rates of erosion).

Stage Three of the Riverstyles framework examines the future trajectory of change a reach is likely to take and the potential for that reach to recover along that trajectory. Recovery potential is a measure of a stream reach's capacity to return to good condition or to a realistic rehabilitated condition, given the limiting controls of the reach.

These controls are based on the physics of hydraulics and the ability of vegetation and sediment to facilitate geomorphic evolution (Outhet and Cook 2004). Recovery potential has been classified as conservation, strategic, very high recovery, high recovery, moderate and low recovery potential.

Conservation – Preventing the degradation of these areas through protecting them now will have environmental, social and economic benefits in the future.

Strategic – Investing in these reaches will protect, build-on and connect streamlines in good condition.

Very High Recovery Potential – The rate of success for works in these areas should be high because they are typically connected to reaches/areas in good condition such that the balance of flow and sediment transfers are generally within a natural range.

High Recovery Potential – Generally, through reducing the impacts of land management practices on these reaches, the rate of degradation can be slowed or stopped such that the future costs of rehabilitation will be significantly reduced.

Moderate and Low Recovery Potential – These reaches have minimal natural recovery potential and exhibit continued signs of on-going instability. Typically, expensive and risky invasive intervention is required for these reaches to recover. Often, the most effective strategy is to wait until these reaches regain some sort of balance before physical intervention actions are implemented.

6.4.3 Management and Surveillance

The updated River Styles data and the River Condition Index (RCI) have been used by the NOW and the HNCMA. The HNCMA used the RCI information as a key component of the water theme spatial prioritisation in the 2013 CAP.

6.4.4 Methodology

The 2013 Audit focused on the type and condition of stream lengths in the Catchment. This Audit examined:

- The Riverstyles in the Catchment;
- The stream condition in the Catchment;
- The recovery potential of streams in the Catchment; and
- Stream stabilisation projects.

6.4.5 Findings

The Riverstyles spatial layer used in the 2010 Audit report was updated in 2012. The current layer provides a finer scale of coverage of waterways and has increased the total length of stream assessed. There are 22 different Riverstyles represented in the Catchment:

- Bedrock controlled, fine grained;
- Bedrock controlled, gravel;

- Bedrock controlled, sand;
- Chain of ponds;
- Channelised fill;
- Floodplain pockets, gravel;
- Floodplain pockets, sand;
- Gorge;
- Headwater;
- HNCMA Reserve;
- Low sinuosity, fine grained;
- Low sinuosity, gravel;
- Low sinuosity, sand;
- Meandering, fine grained;
- Planform controlled, low sinuosity, fine grained;
- Planform controlled, low sinuosity, gravel;
- Planform controlled, low sinuosity, sand;
- Terrace Gorge;
- Urban Stream - Highly Modified;
- Valley fill, fine grained;
- Valley fill, sand; and
- Water storage - dam or weir pool.

The majority of the stream length in the Catchment is categorised by Gorge and Valley fill (fine grained) (Figure 6-8). The Gorge style is primarily in the Wollondilly River, Mid Coxs River, Kangaroo River and Bungonia Creek sub-catchments and the valley fill (fine grained) is within the Wollondilly River sub-catchment. The greatest diversity of styles is in the Wollondilly River (19), Mid Coxs River (18), Reedy Creek (17), Upper Wollondilly River (17) and Boro Creek (16) sub-catchments.

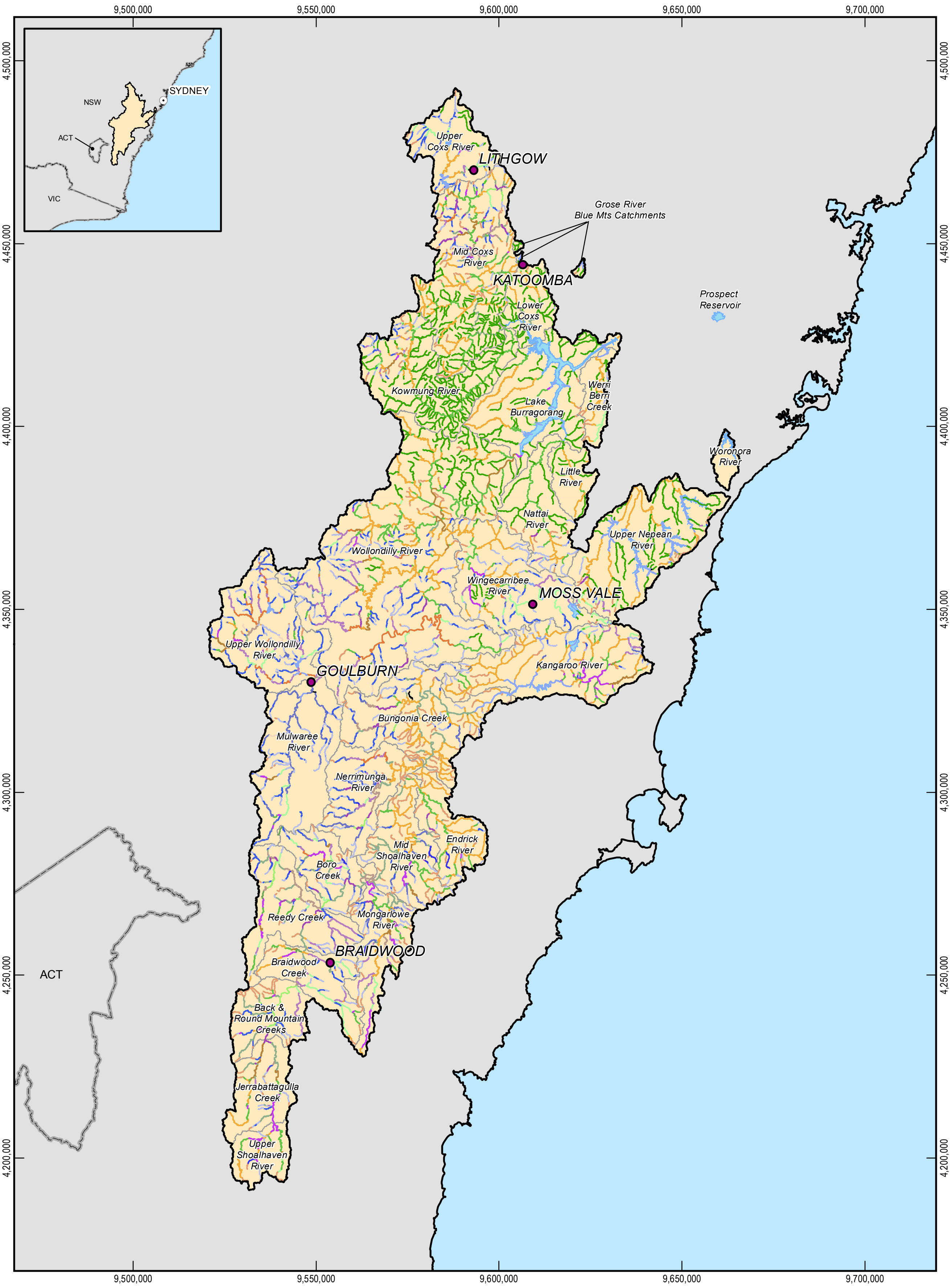
The Chain of Ponds style is classed as a fragile river styles and represents 3 % of the Riverstyles in the Catchment. The majority of Chain of Ponds is found in the Mulwaree River and Nerrimunga River sub-catchments.

The percentage of the Catchment in good condition or in a protected area is 57 %, whilst 39 % of the Catchment is in moderate or poor condition (Figure 6-9). The sub-catchments which have the highest percentage of stream length in good condition are Endrick River, Bungonia Creek, Kangaroo River and Upper Shoalhaven River.

The sub-catchments which are predicted to have a high percentage in the good condition due to the majority of the stream network in protected areas are the Little River, Lower Coxs River, Lake Burragorang, Kowmung River and Nattai River.

The sub-catchments which have the highest percentage of stream length in moderate and poor condition are the Upper Wollondilly River, Mulwaree River, Boro Creek, Braidwood Creek and Back and Round Mountain Creeks (Figure 6-9 and Figure 6-10).

Stream length that has been determined to be in a moderate or degraded condition have also rated as moderate to low recovery potential (Figure 6-11). Conversely, stream lengths considered to be in good condition have been identified as areas that should be conserved.



LEGEND

- Town
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary

RiverStyles

- Headwater
- Gorge
- Terrace Gorge
- Bedrock controlled, fine grained
- Bedrock controlled, gravel
- Bedrock controlled, sand
- Floodplain pockets, gravel
- Floodplain pockets, sand
- HNCMA Reserve
- Low sinuosity, fine grained
- Low sinuosity, gravel
- Low sinuosity, sand
- Meandering, fine grained
- Planform controlled, low sinuosity, fine grained
- Planform controlled, low sinuosity, gravel
- Planform controlled, low sinuosity, sand
- Channelised fill
- Valley fill, fine grained
- Valley fill, sand
- Chain of ponds
- Water storage - dam or weir pool
- Tidal
- Urban Stream - Highly Modified

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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
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RiverStyles in the Catchment

Figure 6.8

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Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); GHD: RiverStyles (2013). Created by: KP

The sub-catchments with a high percentage of conservation reaches are Endrick River (94 %), Bungonia Creek (69 %) and Kangaroo River (69 %).

Preventing the degradation of these areas through immediate protection strategies will have environmental, social, and economic benefits long into the future. Reaches which have moderate to low recovery potential have reduced likelihood for a natural recovery and exhibit continued signs of on-going instability.

The sub-catchments with a high percentage of moderate and low recovery potential reaches were the Mulwaree River (86 %), Upper Wollondilly River (81 %) and Reedy Creek (68 %).

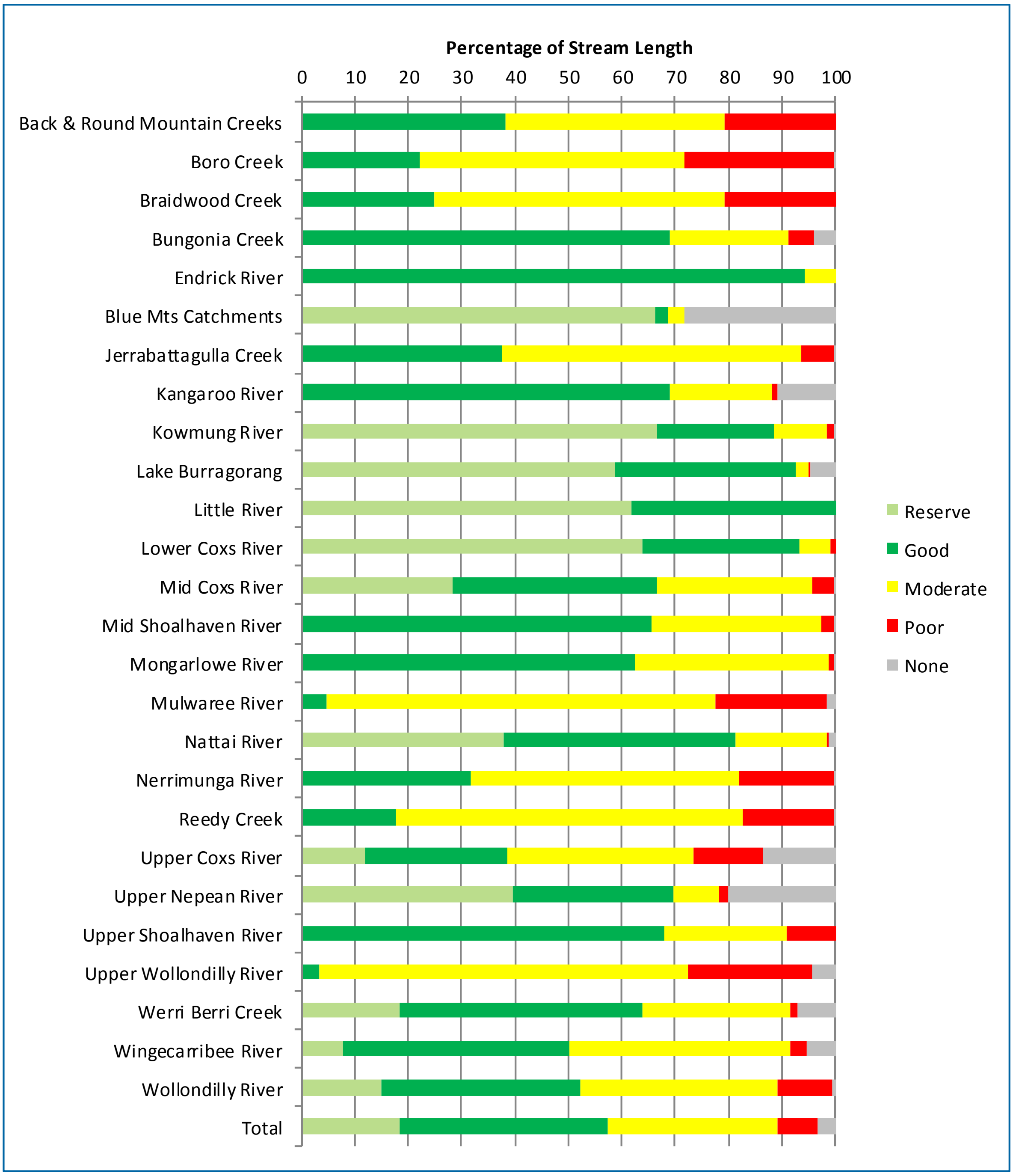
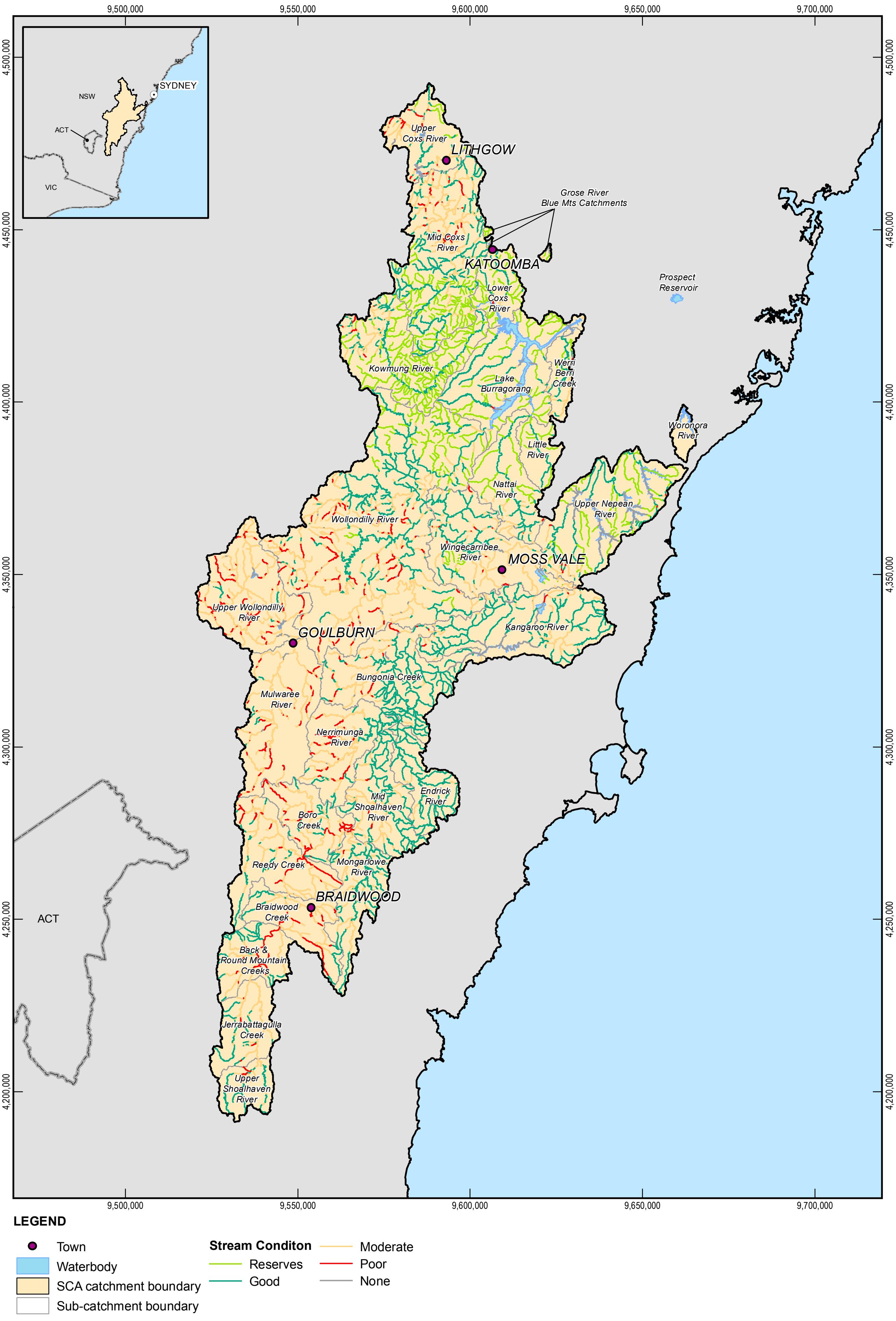


Figure 6-9 Stream length condition as a percentage in each sub-catchment

Source: GHD 2013



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Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
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Sydney Catchment Authority
Catchment Audit 2013

Condition of river reaches
in the Catchment

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Figure 6.10

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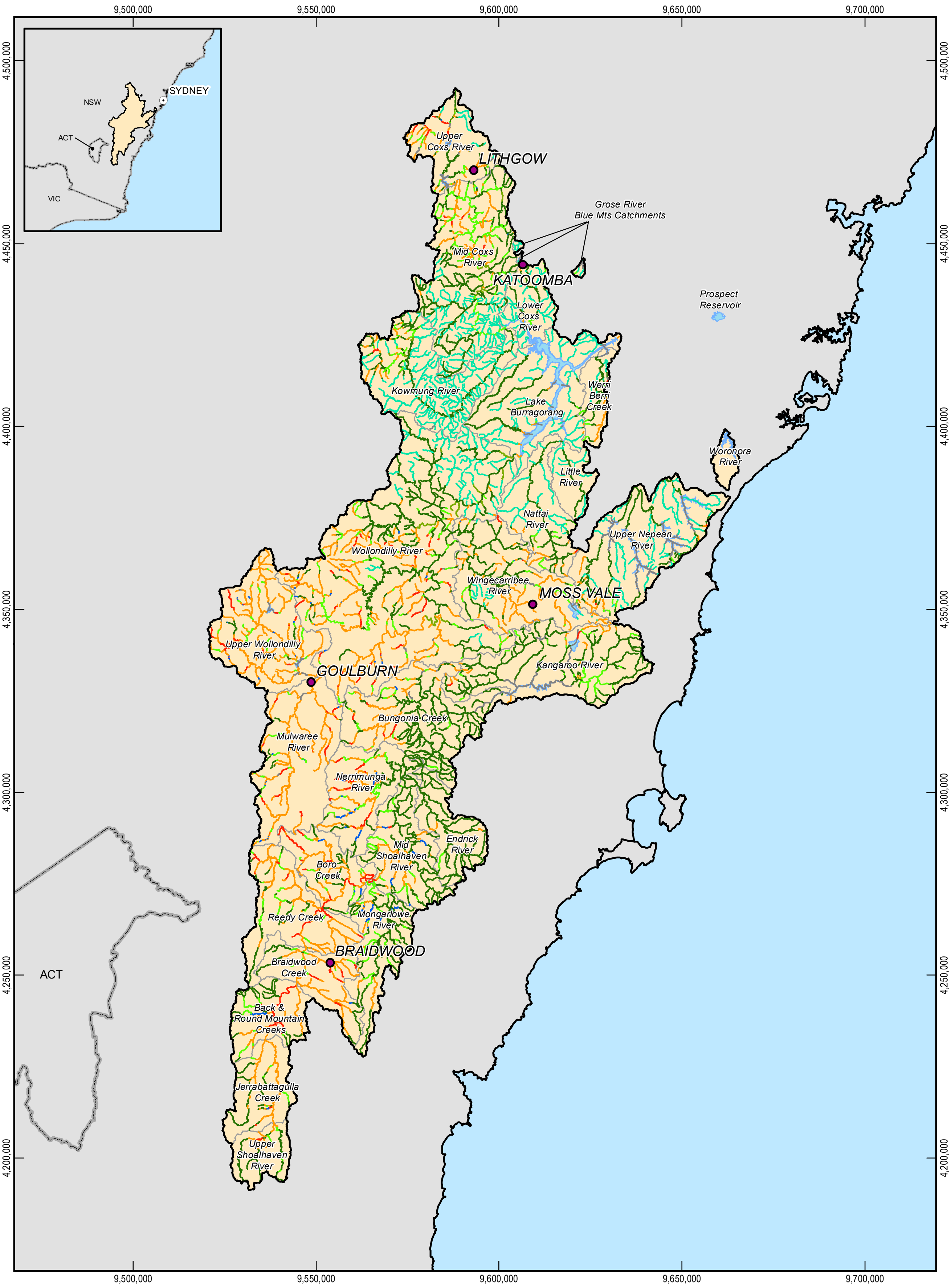

LEGEND

Town	**Recovery Potential**	Conservation	Moderate recovery potential
Waterbody	Reserves	Rapid recovery potential	Low recovery potential
SCA catchment boundary	Strategic	High recovery potential	None
Sub-catchment boundary			

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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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GHD

SYDNEY CATCHMENT AUTHORITY

Sydney Catchment Authority
Catchment Audit 2013

Recovery potential of river reaches in the Catchment

Job Number 2314960
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Date 26 Nov 2013

Figure 6.11

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Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries (2013); GHD: RiverStyles (2013). Created by: KP

Activities in the catchment

Bank erosion in Glen Quarry Creek 100 m downstream of the Glen Quarry Cut was observed during the 2003 Audit Catchment inspections. During the 2013 Audit Catchment inspections the same location was visited (Figure 6-12). Since the 2003 Audit the SCA has carried out bank stabilisation works on the left bank.

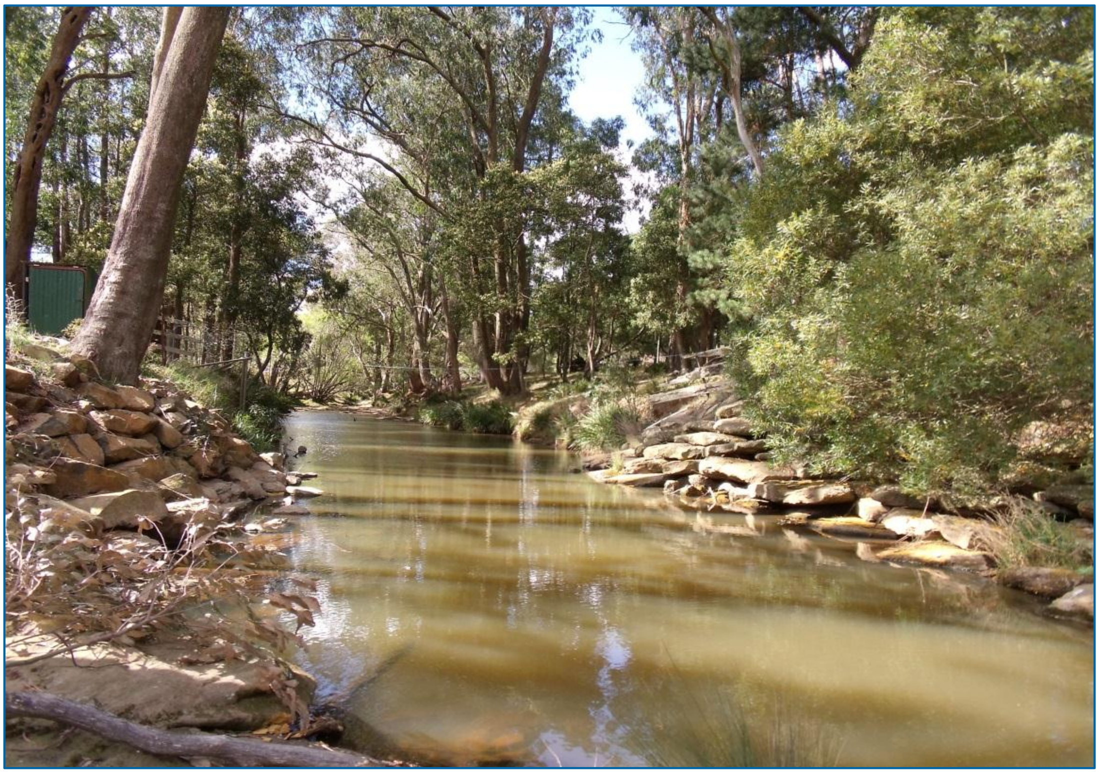


Figure 6-12 Glen Quarry Creek bank stabilisation works (September 2013)

The HNCMA has carried out a number of projects in the Catchment during the audit period to stabilise stream bank and beds, and these are listed in Table 6-9. There was an overall decrease in the area of works undertaken to stabilise stream bed and banks by the HNCMA during the Audit period.

Table 6-9 Area of stream bank and bed stabilisation by HNCMA in the Catchment

	2010-11	2011-12	2012-13
Length (m) of stream bank stabilised with engineering works	151	35	39
Number of stream bank stabilisation works	144	72	30
Length (m) of bed stabilised	64	16	20
Number of stream bed stabilisation sites	143	69	30

Source: HNCMA

The DPI – Fisheries funded bank erosion control works on the Mongarlowe River at the 'River Lea' property under the Fish Habitat Action Grants Program. The works were undertaken by the Friends of Mongarlowe River community group between February 2011 and February 2012.

6.4.6 Recommendations

The protection of river reaches in good geomorphic condition, or with high, rapid or conservation recovery potential for protection is an affective and cost saving way to improve overall catchment health and utility for water supply purposes.

In Rapid Recovery and High Recovery reaches low cost rehabilitation works, such as fencing, revegetation, land use change and weed management that maximise improvements to river condition and work with natural river processes should be promoted.

In Moderate/Low Recovery reaches will not improve in condition without significant, costly intervention. Incised and/or expanded stream channels should be managed to maintain their current geomorphic form. Realistic management goals to address ongoing instabilities should only be implemented once degrading influences have been removed.

On ground activities to address geomorphically degrading processes and minimise or prevent degradation occurring in adjacent river reaches should include arresting degradation occurring as a result of incision, channel widening, sediment slug release and transport downstream or other geomorphic processes. Further streambank and bed stabilisation works within the Catchment should be focused on:

- Protecting identified conservation and strategic reaches through the removal of threatening processes and the implementation of appropriate rehabilitation and preventative actions.
- Protecting and enhancing good and moderate condition reaches of rare or low representation and fragile river styles such as the Chain of Ponds.

6.5 Wetlands

6.5.1 Summary

The wetland types with the largest area in the Catchment are permanent lakes and rivers/streams. The largest area of permanent lakes is within the Lake Burragorang and Upper Nepean River sub-catchments, these sub-catchments contain the water supply reservoirs.

The Wollondilly River sub-catchment contains the largest areas of permanent and seasonal rivers and streams and marshes, as well as the largest area of farm dams. The Upper Wollondilly River sub-catchment also has a large proportion of farm dams and the Mid Shoalhaven River sub-catchment also has a large proportion of seasonal marshes.

The Upper Nepean and Kangaroo Rivers sub-catchments contain the largest areas of shrub dominated wetlands and the Bungonia Creek catchment contains the largest area of freshwater springs in the Catchment. The Mulwaree River sub-catchment contains the largest area of seasonal lakes; this includes the listed important wetland - Lake Bathurst.

Extensive swamp restoration works have been completed within the Wingecarribee Swamp and upland Swamps, including the Temperate Highland Peat Swamps on Sandstone EEC in the Catchment. There are, however, continued impacts to upland swamps from longwall mining in the Metropolitan and Woronora Special Areas.

Assessment Criteria

Criteria

1. Wetlands in the Catchment are recognised and their condition documented, to assist in their protection where required.

Assessment against Criteria

Criteria	Audit finding	Recommendation
1	Opportunity for improvement	OEH, SCA, CMAs and other relevant agencies collaborate to develop and apply a standardised procedure for assessing the extent and condition of wetlands in the Catchment.

Prior recommendations

Prior Recommendations	Action	Status
Recommendation 3: Where significant streams and wetlands in the Catchment are impacted by longwall mining there should be a requirement that these impacts are remediated at the expense of the mining company.	Mine plans are prepared to avoid the potential for significant impact on important surface features, including significant streams and wetlands (swamps). The preference is to avoid any impacts on significant streams and swamps and prevent the need for any remediation to be required. This is a major focus of the Subsidence Management Plan approval process. These approvals typically include conditions requiring 'negligible impacts' on important surface features, including significant streams and swamps. Should significant impacts on streams and swamps occur, the mining company will be required to remediate these impacts to ensure compliance with DA conditions, mining lease conditions, and Subsidence Management Plan approval conditions. Remediation is required to be funded fully by the mining company. The Department of Trade and Investment can direct a mining company to undertake remediation works if required and holds a security deposit to cover the full cost of the associated remediation works.	In progress

Recommendation 9: Lithgow City Council and Centennial Coal should ensure that water transfers from the Clarence Water Transfer Scheme are piped around, rather than flow through, Farmers Creek Swamp.	Clarence Colliery has a Water Management Plan (MP-2041) approved by the Director-General of the Department of Planning and Infrastructure on 25 June 2012. Water can be transferred from the Clarence Colliery Main Header Tank to the Lithgow Council Tank and then into the Farmers Creek catchment for use by Lithgow Council in the water supply catchment. Once water is transferred to the Lithgow Council Tank it is no longer the responsibility of Clarence Colliery. The Water Management Plan identifies that approximately 4 ML/day of process water is transferred from the Main Header Tank to the Lithgow Council tank. A major upgrade to the system was progressed by Lithgow City Council which involved a water pipeline being diverted around Farmers Creek Swamp.	Opportunity for improvement
Recommendation 10: DECCW finalise its *Draft Upland Swamp Environmental Assessment Guidelines* in order to achieve consistency in the application of risk assessment methodology for swamps over areas of longwall mining in the Catchment.	The Draft Upland Swamp Environmental Assessment Guideline has been prepared. The main elements of the guideline are: - How to determine whether swamps are of special significance. - Undertaking a pre-mining risk assessment, and modifying the mining plan if impacts to significant swamps are predicted. - How to determine whether mining is causing negative environmental outcomes. - If negative environmental outcomes are detected, modifying mining operations under an adaptive management framework to avoid further damage.	Opportunity for improvement
Recommendation 11: DECCW and the SCA should finalise their classifications of wetlands to produce a complete and consistent coverage of wetlands in the Catchment.	A consistent classified wetland dataset for Sydney's drinking water catchments has been completed. A draft report *Wetlands in Sydney's Drinking Water Catchments* states that 3.1% (47,505 ha) of the catchments are permanent or periodically inundated by water and considered wetlands. Wetlands were classified using the RAMSAR Classification System for Wetland Types. The RAMSAR Classification System uses a broad framework to allow rapid identification of sites. The system is based on the form and relationships rather than intrinsic content or wetland processes. A number of other NRM agencies have chosen the RAMSAR classification system, including the Queensland Department of Environment and Resource Management, NSW Office of Environment and Heritage, and the Australian Department of Sustainability.	Closed

6.5.2 Background

Wetlands are important ecosystems as they provide essential ecosystem services and add to catchment health. Wetlands can provide:

- Sinks for sediments, nutrients and other pollutants mobilised from the catchment;
- Habitats and food for a variety of fauna and flora;
- Connectivity for biodiversity; and
- Store runoff during periods of heavy rainfall and thus providing a measure of flood mitigation.

Wetlands in the Catchment are particularly vulnerable to changes to surface and subsurface drainage from localised disturbances including invasion of exotic species, road and drain construction and underground mining. Direct impacts to wetlands occur from clearing for development and/or cropping and may result in a loss of biodiversity and irreparable damage to wetland ecosystems. Indirect impacts to wetland habitats can be caused by surrounding land uses, pests and weeds. Increased nutrient and sediment loads are particular threats to aquatic vegetation in wetlands (CSIRO 2006). Subsidence and cracking of watercourses and upland swamps resulting from longwall mining can also impact of water quality and the wetland aquatic ecosystems.

Grazing by livestock and pest species, such as pigs, within wetlands can also impact on the diversity, distribution, and health of wetland plants. Impacts include compaction of soils, increased nutrient inputs, and the introduction of weed species, trampling of native plants, digging and ringbarking of mature trees.

Introduced plants, which can change wetland structure and function, are favoured by disturbances such as altered flow regimes, clearing or draining of wetlands, and increased nutrient loads. Significant weed species in NSW wetlands include water hyacinth, which can rapidly clog waterways when conditions are favourable for recruitment and spread. Introduced aquatic species, such as European carp and mosquito fish, can also affect the water quality and native fish populations within wetlands.

The Catchment includes several nationally significant wetlands, which are listed in the *Directory of Important Wetlands in Australia* (DIWA) (Environment Australia 2001) and wetlands that are listed under the *EPBC Act 1999*. Listed DIWA's in the Catchment are:

- Wingecarribee Swamp – Wingecarribee River sub-catchment (NSW093);
- Long, Hanging Rock, Mundego and Stingray Swamps (Paddys River Swamps) – Wollondilly River sub-catchment (NSW082);
- Boyd Plateau Bogs – Kowmung River sub-catchment (NSW074);
- Budderoo National Park Heath Swamp – Kangaroo River sub-catchment (NSW075);
- Lake Bathurst – Mulwaree River sub-catchment (NSW066).

Temperate Highland Peat Swamps on Sandstone (DSEWPaC 2010g) is listed as an EEC under both state and federal legislation. These swamps are represented in the Catchment and include:

- Swamps on the Newnes Plateau (some of which occur in the headwater tributaries of the Coxs River);
- Butlers Swamp (upper reaches of the Nepean River sub-catchment);
- Gallahers Swamp (upper reaches of Avon River, Upper Nepean sub-catchment);
- Jumping Rock Swamp (Paddys River catchment, Wollondilly River sub-catchment);
- North Pole Swamp (upper reaches of Dudewaugh Creek, Upper Nepean sub-catchment);
- Rock Arch Swamp (upper reaches of Avon River, Upper Nepean sub-catchment);
- Stockyard Swamp (upper reaches of Dudewaugh Creek, Upper Nepean sub-catchment); and
- Wildes Meadow Swamp (upper reaches of Wildes Meadow Creek, Kangaroo River sub-catchment).

Since many wetlands in NSW are under increasing pressure from human activity and climatic changes, it is increasingly important to protect those that remain (DECCW 2010a). The recommended measure for reporting on wetlands is size, type, location and condition of wetlands (NOW 2009).

6.5.3 Management and Surveillance

The object of the *Water Management Act 2000* (WMA 2000) is the sustainable and integrated management of the state's water for the benefit of both present and future generations. The *Water Management Act 2000* is based on the concept of ecologically sustainable development. Specifically, in relation to wetlands, the Act recognises that the fundamental health of our rivers and groundwater systems and associated wetlands, floodplains, estuaries has to be protected.

Section 5 of the *Water Management Act 2000*, outlines the water management principles of the Act and states that generally:

a. Water sources, floodplains and dependent ecosystems (including groundwater and wetlands) should be protected and restored and, where possible, land should not be degraded, and
b. Habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and (in the case of habitats) restored, and
c. The water quality of all water sources should be protected and, wherever possible, enhanced, and
d. The cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised, and
e. The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirements.

Goal 22 of the NSW 2021: A plan to make NSW number one (NSW Government 2011b) 'Protect our natural environment' contains the following target: *'Improve the environmental health of wetlands and catchments through actively managing water for the environment by 2021'*.

The NSW Wetlands Policy (DECCW 2010c) updates the 1996 NSW Wetlands Management Policy to reflect developments in natural resource management and planning that affect wetlands. It promotes the sustainable conservation, management and wise use of wetlands in NSW and the need for all stakeholders to work together to protect wetland ecosystems and their catchments.

As a result of the rarity and importance (both for ecological (swamps provide habitat for freshwater species and communities, some of which are endemic) and hydrological values), certain upland swamps are protected under legislation. In 2005, the Scientific Committee (formed under the *TSCA 1995*) listed the 'Alteration of habitat following subsidence due to longwall mining' as a key threatening process to upland swamps.

Following an independent inquiry, the Planning Assessment Commission (in its own reviews of mine projects and proposals) noted that 'a problem is that there is no long term robust scientific information showing before and after mining outcomes for swamps and, as yet, there is not accepted approach to obtaining it' (NSW Planning Assessment Commission 2010 p. 86). In response to these statutory provisions, knowledge gaps and recommendations, the DECCW drafted the *Upland Swamp Environmental Assessment Guidelines* (the Guidelines).

These Guidelines assist the underground mining industry and the NSW Government in improving environmental assessment approaches and understanding subsidence impacts on upland swamps in the southern and western coalfields (DECCW 2012). The Guidelines form a component of environmental assessment and the statutory regulations under a number of NSW Government agencies approvals process, and are required for development of the Coordinator

General's conditions for referred projects. Underground mining proponents are also obligated to adhere to the Guidelines, particularly for enforcement and auditing.

The Guidelines advocate proper assessment and effective management to avoid impacts, particularly to upland swamps classed as 'highly significant natural features' (NSW Department of Planning, 2008) or being of 'special significance status' (NSW Planning Assessment Commission 2009; NSW Planning Assessment Commission 2010). Avoidance is preferable, as remediation is generally ineffective.

The Guidelines also stipulate methodologies for the application of adaptive management, appropriate monitoring, evidence based evaluations (on baseline data), BioBanking assessments, appropriate classification of upland wetlands (including identification of values), flexible contingency plans, appropriate risk assessment, proponent commitment to remediation (where applicable) and performance measures.

6.5.4 Methodology

This audit provides information on the location and type of wetlands present in the Catchment and the management activities that have been undertaken to improve the condition of wetlands in the Catchment during the current audit period. Limited information is available on the current condition of wetlands in the Catchment, where information is available it is presented.

6.5.5 Findings

The wetlands within the Catchment have been classified to produce a complete and consistent coverage for the Catchment (Figure 6-13). There are a large number of wetland types in the Catchment, ranging from rivers/streams, lakes, springs, marshes and man-made structures, including farm dams.

The wetland types with the largest area in the Catchment are permanent lakes and rivers/streams. The largest area of permanent lakes is within the Lake Burragorang and Upper Nepean River sub-catchments, these sub-catchments contain the water supply reservoirs (Table 6-10).

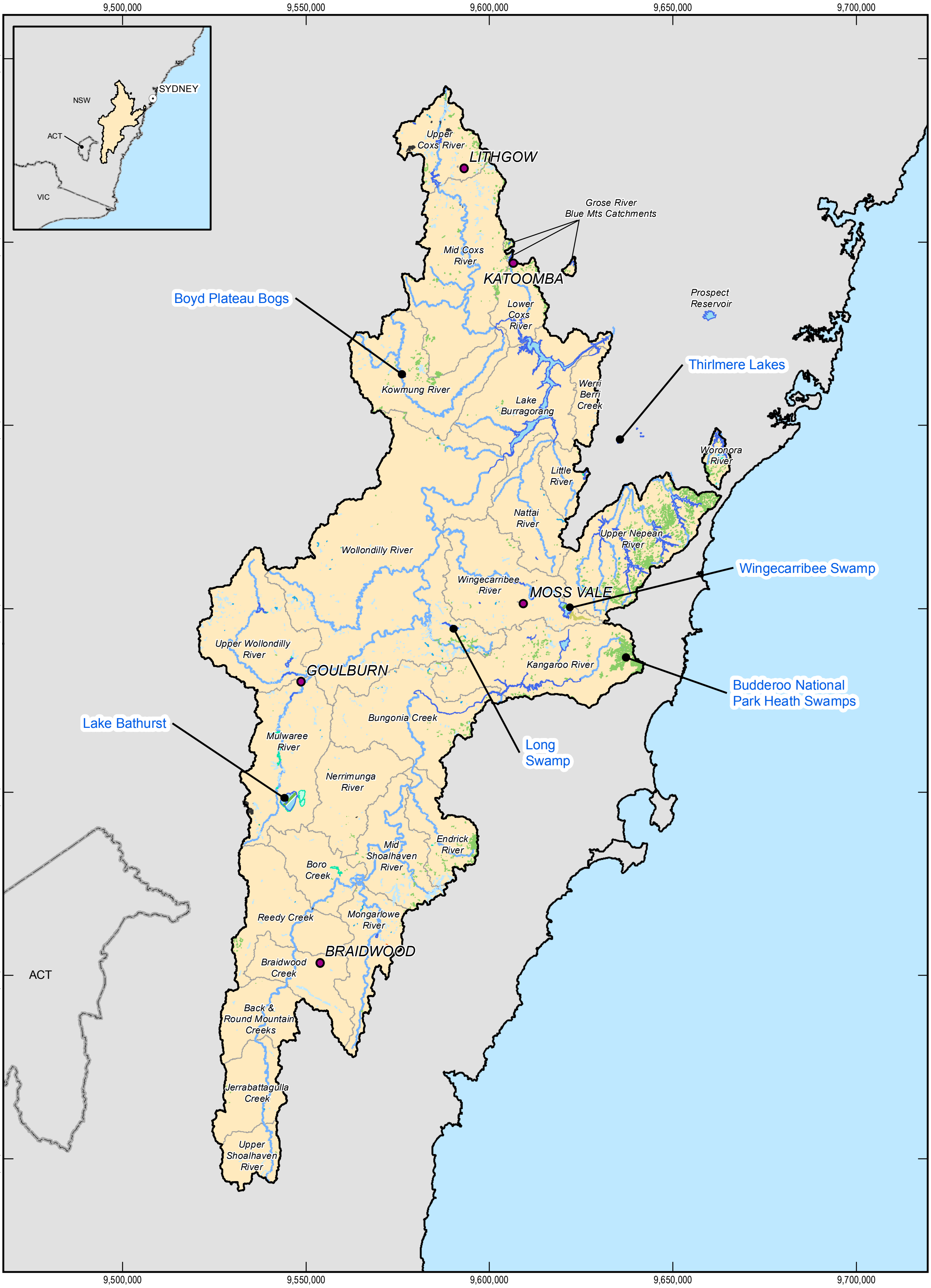
The Wollondilly River sub-catchment contains the largest areas of permanent and seasonal rivers and streams and marshes, as well as the largest area of farm dams. The Upper Wollondilly River sub-catchment also has a large proportion of farm dams and the Mid Shoalhaven River sub-catchment also has a large proportion of seasonal marshes (Table 6-10).

The Upper Nepean and Kangaroo Rivers sub-catchments contain the largest areas of shrub dominated wetlands and the Bungonia Creek catchment contains the largest area of freshwater springs in the Catchment. The Mulwaree River sub-catchment contains the largest area of seasonal lakes; this includes the area of the Lake Bathurst important wetland. Greater than 200 ha of the Upper Coxs and Mulwaree River sub-catchments have been classified as mining pools or gravel pits (Table 6-10).

A description of the DIWA and other important wetlands in the Catchment is provided below.

Wingecarribee Swamp

Wingecarribee Swamp is an outstanding montane peatland located ~15 km east of Bowral. At 344 ha, the wetland is the largest peatland in NSW and is considered an outstanding representation of peatland ecosystems in Australia (DSEWPAC, 2010a). The wetland is characterised by a fibrous and humic peat which plays an important role in maintaining water quality within the Wingecarribee Reservoir (DSEWPAC 2010a). Wingecarribee Swamp is classified as a Peatlands; forest, shrub or open bogs. A conceptual model of an upland bog is provided in Figure 6-14.



LEGEND

- Town
- Drainage
- DIWA listed wetland
- SCA catchment boundary
- Sub-catchment boundary

Wetland Type

- Freshwater springs
- Non-forested peatlands
- Shrub-dominated wetlands
- Permanent marshes
- Seasonal marshes
- Permanent lakes
- Seasonal lakes
- Aquaculture
- Wastewater treatment areas
- Excavations mining pools/gravel pits

Page Size A4

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Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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Sydney Catchment Authority
Catchment Audit 2013

Job Number | 2314960
Revision | 0
Date | 26 Nov 2013

Location of important wetlands and wetland types in the Catchment

Figure 6.13

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Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries, wetland types (2013); Dept of the Environment: DIWA listed wetlands (2013). Created by: KP

Table 6-10 Area (ha) of wetland type in each sub-catchment

				Marshes		Lakes		Rivers/streams		Man-made			
Sub-catchment	Freshwater spring	Non-forested peatlands	Shrub dominated wetlands	Permanent marshes	Seasonal marshes	Permanent lakes	Seasonal lakes	Permanent rivers/stream	Seasonal rivers/stream	Farms dams	Wastewater treatment areas	Aquaculture	Mining pools/gravel pits
Back and Round Mountain Creeks			0.22	0.18	6.68			167.21	184.77	86.19			
Boro Creek			3.42	1.16	19.06		105.33	200.16	188.67	115.26			1.60
Braidwood Creek					208.08			178.05	99.27	126.23	1.31		
Bungonia Creek	2.68		78.04	14.28	98.07	256.45	8.26	333.90	391.61	299.63	2.71		
Endrick River	0.09		617.07		153.88		2.34	249.46	124.79	13.71			
Grose River			69.40		6.52	45.24		10.99	7.83	0.05			
Jerrabattagulla Creek			2.47	1.57	4.90			200.98	73.85	50.98			
Kangaroo River			1,843.76	3.42	85.14	1,081.43		451.84	152.63	310.66			
Kowmung River			238.17	0.29	148.30	6.68		659.19	403.83	40.04			
Lake Burragorang			10.51	4.35	0.91	6,595.57	0.79	291.44	283.74	27.47			
Little River			0.63		0.67	40.51	6.67	118.03	69.45	13.06			
Lower Coxs River			186.07	1.68	32.88	598.47		160.80	118.42	15.71			
Mid Coxs River			394.81	0.80	245.14	0.52		866.16	647.99	184.70	0.07		0.35
Mid Shoalhaven River			53.08		408.49		1.44	392.16	236.65	64.73			
Mongarlowe River			6.11	15.51	100.86	23.98	2.00	482.19	110.91	79.41		6.20	
Mulwaree River	0.50		0.11	12.19	282.04	33.66	2,058.07	223.28	248.58	483.16	0.65		204.09
Nattai River			2.22	11.99	0.03	5.21		335.22	128.71	127.69	1.97		
Nerrimunga Creek	0.31		3.02		13.43			305.47	73.78	295.77			1.93
Reedy Creek			33.30	0.46	49.97			276.75	173.34	225.59			1.92
Upper Coxs River			188.01	10.93	217.40	388.34	15.96	152.42	113.67	143.88	8.59		261.31
Upper Nepean River			3,800.00	10.51	25.70	2,830.73		656.47	146.80	99.00			

Table 6-10 (cont.) Area (ha) of wetland type in each sub-catchment

				Marshes		Lakes		Rivers/streams		Man-made			
Sub-catchment	**Freshwater spring**	**Non-forested peatlands**	**Shrub dominated wetlands**	**Permanent marshes**	**Seasonal marshes**	**Permanent lakes**	**Seasonal lakes**	**Permanent rivers/stream**	**Seasonal rivers/stream**	**Farms dams**	**Wastewater treatment areas**	**Aquaculture**	**Mining pools/gravel pits**
Upper Shoalhaven River			0.68		19.31			192.05	3.14	12.22			
Upper Wollondilly River			0.39	11.13	162.31	314.14	33.29	523.62	173.28	597.04	1.65		
Werriberri Creek					5.90	83.12		147.77		250.92			
Wingecarribee River	0.69	481.42	17.37	5.31	134.06	654.66	5.57	411.98	270.42	747.10	5.89		0.67
Wollondilly River	1.15		168.93	81.41	472.26	26.94	0.68	1,818.81	1,067.04	1,131.85	23.45		
Woronora River			194.39	4.05	214.38	360.18	40.18	33.35		2.41			
Total	**5.43**	**481.42**	**7,912.19**	**191.23**	**3,116.37**	**13,345.83**	**2,280.56**	**9,839.75**	**5,493.16**	**5,544.47**	**46.29**	**6.20**	**471.87**

Source: OEH 2011. The highlighted cells indicate the largest area for that wetland type.

The wetland includes two endangered ecological communities (montane peatlands and swamps and southern highlands shale woodlands), and seven threatened species. Threatened flora species include the Wingecarribee leek orchid (*Prasophyllum uroglossum*), which is endemic to the site (SCA and DEC 2007; DSEWPAC 2010a) and the Wingecarribee Gentian (*Gentiana wingecarribiensis*). The hydrological characteristics of the wetland were artificially altered in the 1970s with the construction of the Wingecarribee Reservoir. Additional land uses within the wetland include peat mining and grazing. The ecological integrity of Wingecarribee Swamp has recently declined due to a collapse of the peat, which has resulted in 5 million cubic metres of sediment and peat being deposited within Wingecarribee Reservoir (DSEWPAC 2010a).

Wingecarribee Swamp continues to be a priority for wetland management activities in the Catchment. The management of Wingecarribee Swamp is guided by the Wingecarribee Swamp and Special Area Plan of Management (WSSAPoM) (SCA 2007c).

Long, Hanging Rock, Mundego and Stingray Swamps (Paddys River Swamps)

The Paddys River Swamps comprise four swamps (Long, Hanging Rock, Mundego and Stingray Swamps) in tributaries of the Paddys River system (DSEWPAC 2010d). These Swamps are classified as a Peatland; forest, shrub or open bog. A conceptual model of upland bogs is provided in Figure 6-14. These swamps provide an important ecological service for the Paddys River (and broader Wollondilly River) catchment in that the sediment and vegetation maintain and regulate water flow and also water quality.

Long Swamp is particularly unusual to Australia in that it is a peat-accumulating wetland with several plant communities (DSEWPAC 2010d). The vegetation the Paddys River Swamps is characterised by herb layer (predominantly sedges) and a shrub layer.

A number of threatened flora species are recorded from the Paddys River Swamps, including (but not limited to):

- Dwarf Phyllota (*Phyllota humifusa*) (listed as vulnerable under the EPBC Act and *TSCA 1995* (NSW));
- Dwarf Kerrawang (*Rulingia prostrata*) (listed as endangered under the EPBC Act and *TSCA 1995* (NSW));
- *Gentiana wingecarribiensis* (listed as endangered under the EPBC Act and critically endangered under the *TSCA 1995* (NSW));
- Cord rush (*Baloskion longipes*) (listed as vulnerable under the EPBC Act and *TSCA1995* (NSW)) (DSEWPAC 2010d).

The Swamps support a diverse assemblage of native fauna, including nineteen marsupials, two monotremes, thirteen reptiles and at least 90 bird species (DSEWPAC 2010d). Several of the species are considered threatened under the EPBC Act and/or *TSCA 1995* (NSW). Such examples include the:

- Broad-headed snake (*Hoplocephalus bungaroides*) (listed as vulnerable under the EPBC Act and endangered under the *TSCA 1995* (NSW);
- Brush-tailed rock wallaby (*Petrogale penicillata*) (listed as vulnerable under the EPBC Act and endangered under the *TSCA 1995* (NSW));
- Green and golden bell frog (*Litoria aurea*) (listed as vulnerable under the EPBC Act and endangered under the *TSCA 1995* (NSW)) (DSEWPAC 2010d).

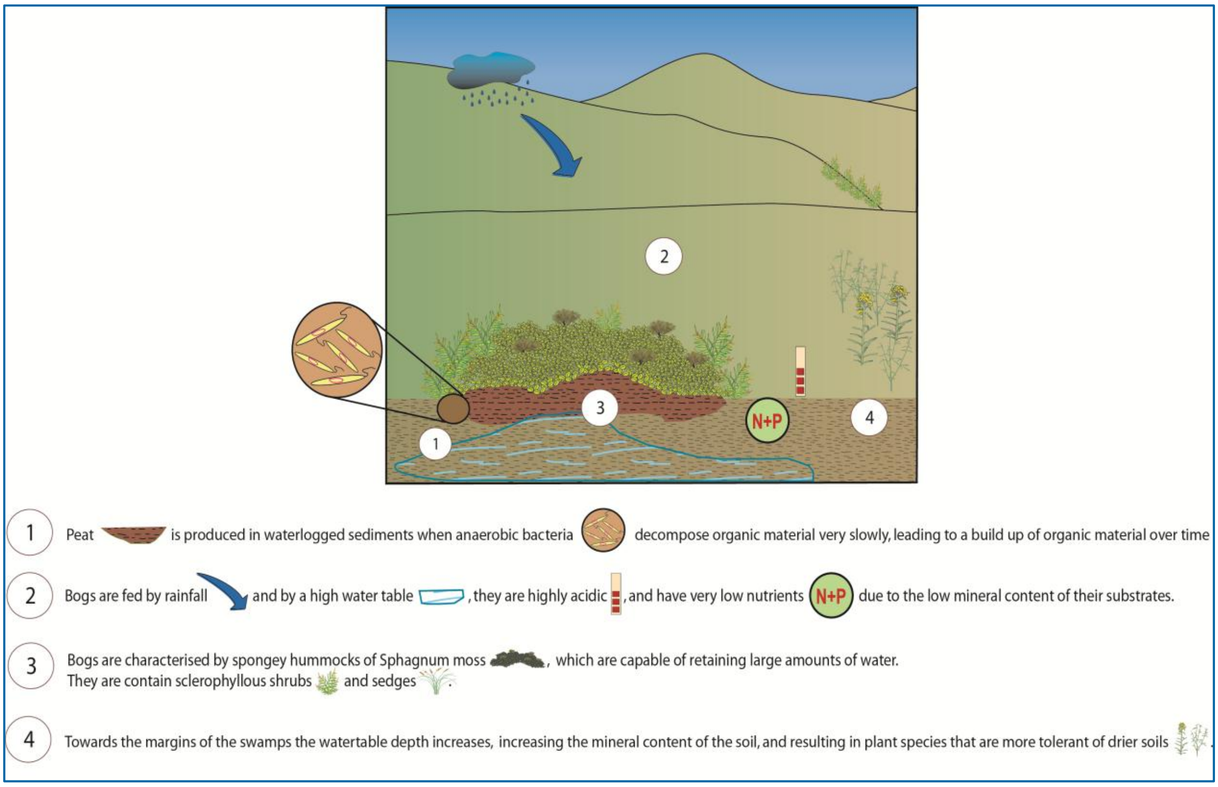


Figure 6-14 Conceptual model of an upland bog

Source: Adapted from Clauset al. 2011

The major threatening process to the Paddys River Swamps was historical peat mining (DSEWPAC 2010d). A 1 km stretch of Long Swamp is currently planned for further peat extraction. Land clearing for agricultural purposes has resulted in the establishment of grazing pastures and forestry. A large part of adjoining land has been cleared for the establishment of pine forests. Associated road infrastructure and burning regimes have impacted some swamps in these State Forests (Stricker and Wall 1994).

The southern section of Stingray Swamp is also impacted by high nutrient discharge from a nearby sewage treatment works (DSEWPAC 2010d). The Swamps currently provide habitat for eels; however, the owner of Long Swamp is considering introducing fish into the system which could impact ecological balances (DSEWPAC 2010d).

A management plan was prepared in 2008 for the Paddys River Wetlands for the Hawkesbury Nepean Catchment Management Authority (WetlandCare Australia 2008b; c). The aim of the plan was to identify the risks and threats to Paddys River Wetlands, provide options for managing those threats and identify management objectives for on-ground outcomes.

This Wetland Management Plan established management objectives to improve the biological and physical health of the wetland, while maintaining community and cultural significance.

Boyd Plateau Bogs

The Boyd Plateau Bogs are an upland bog and fen of some 142 ha (DSEWPAC 2010e). These Swamps are classified as a Peatland; forest, shrub or open bog. A conceptual model of upland bogs and fens is provided in Figure 6-15.

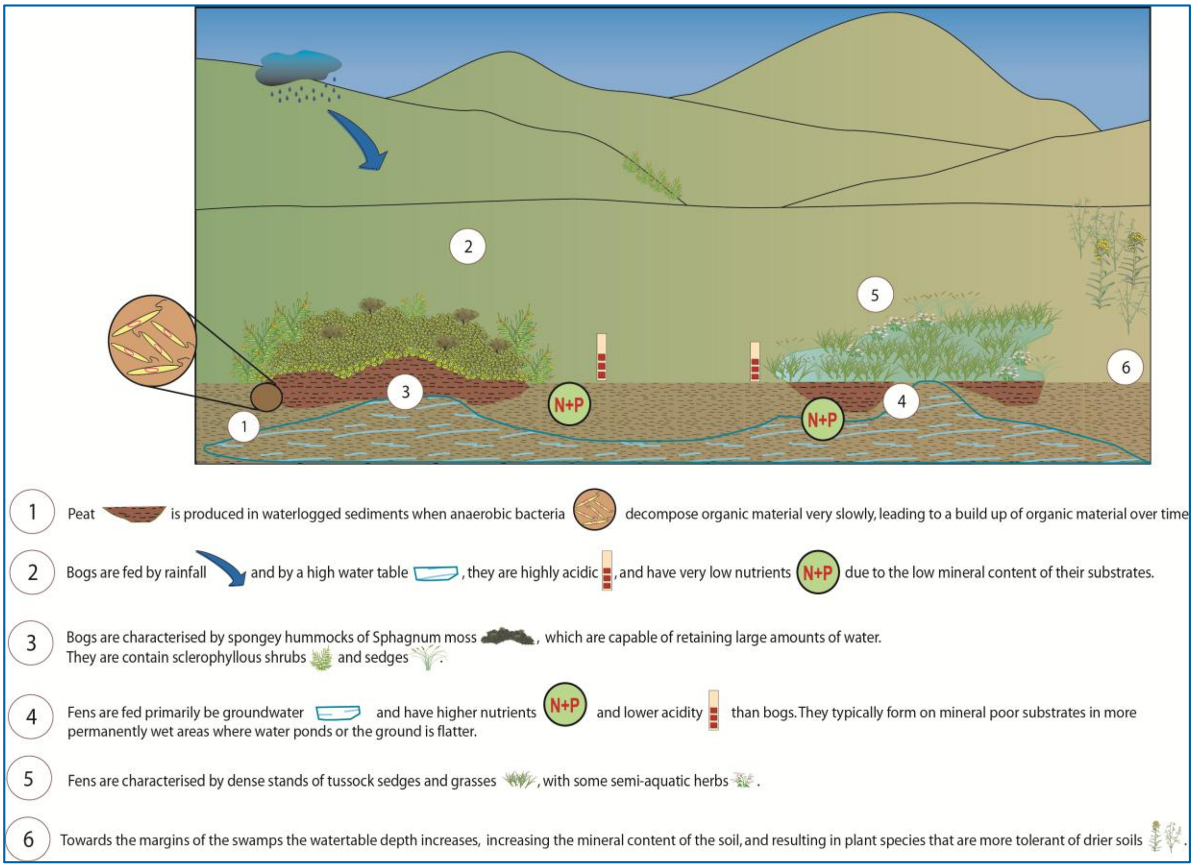


Figure 6-15 Conceptual model of upland bogs and fens

Source: Adapted from Claus et al. 2011

A diverse ecological community is supported by the Boyd Plateau Bogs (DSEWPAC 2010e). These include the following:

- Deane's boronia (*Boronia deanei*) - listed as vulnerable under the EPBC Act and *TSCA 1995* (NSW);
- Cord rush (*Baloskion longipes*) - listed as vulnerable under the EPBC Act and *TSCA 1995* (NSW);
- Waxy bluebell (*Wahlenbergia ceracea*) - a locally disjunct population (Stricker & Wall, 1994; Kodela et al. 1996);
- Paddy's river box (*Eucalyptus macarthurii*) - listed as vulnerable under the *TSCA 1995* (NSW);
- Powerful owl (*Ninox strenua*) - listed as vulnerable under the *TSCA1995* (NSW);
- Squirrel glider (*Petaurus norfolcensis*) - listed as vulnerable in NSW, with some endangered populations under the *TSCA1995* (NSW);
- Blue Mountains water skink (*Eulamprus leuraensis*) - listed as endangered under the EPBC Act and *TSCA 1995* (NSW).

The vegetation of the Boyd Plateau Bogs is characterised by sedges interspersed by shrubs and dense thicket (DSEWPAC 2010e). Flora common to the Boyd Plateau Bogs include *Grevillea acanthifolia*, *Gymnoschoenus sphaerocephalus* (button grass), *Tetrarrhena turfosa*, *Baeckea linifolia*, *Hakea teretifolia* (dagger hakea), *Lepidosperma limicola* (blade grass), *Xyris ustulata* and *Empodisma minus* (Keith and Benson 1988; LeBreton 1996).

The main threatening processes for the Boyd Plateau Bogs are historical clearing, grazing and feral animals (DSEWPAC 2010e). The Boyd Plateau Bogs are managed by the NSW National Parks and Wildlife Service under the Plan of Management prepared for the Kanangra-Boyd National Park (NPWS 2001).

Budderoo National Park Heath Swamp

Barren Grounds Nature Reserve and Budderoo National Park is located approximately 15 km southwest of Robertson (NSW) and covers an area of some 1150 ha (DSEWPAC 2010f). The Budderoo National Park heath swamp is an extensive complex at the headwaters of the Kangaroo River, and is one of only four large areas of heath on the southern coast (DSEWPAC, 2010f). This heath swamp provides important hydrological functions in the landscape as a discharge point of groundwater (DSEWPAC 2010f). Budderoo National Park heath swamp provides habitat for significant populations of a number of species (including endemic species) (NPWS 2013). A conceptual model of a heath swamp is provided in Figure 6-16.

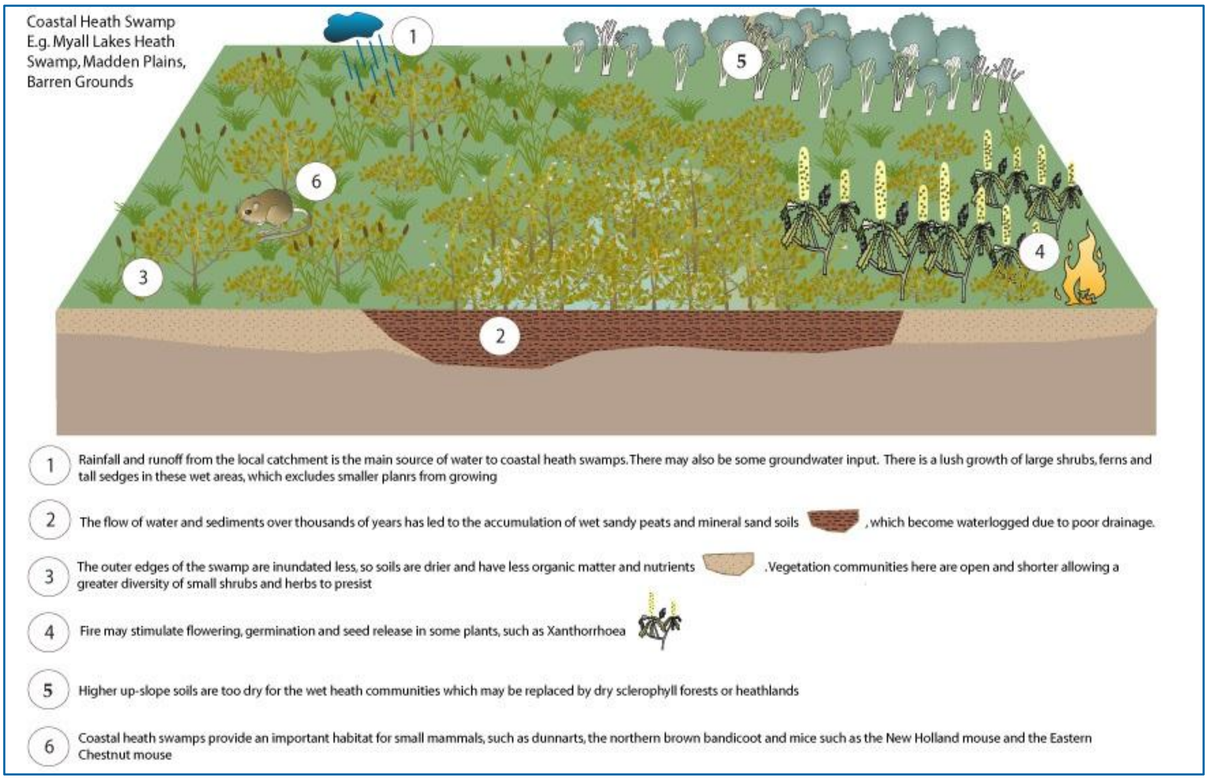


Figure 6-16 Conceptual model of a heath swamp

Source: Adapted from Clauset al. 2011

Numerous threatened species are known to occur within the Budderoo National Park Heath Swamp, including:

- Eastern bristlebird (*Dasyornis brachypterus*) - listed as endangered under the EPBC Act and *TSCA 1995* (NSW);
- Giant burrowing frog (*Heleioporus australiacus*) - listed as vulnerable under the EPBC Act and *TSCA 1995* (NSW);
- Red-crowned toadlet (*Pseudophryne australis*) - listed as vulnerable under the *TSCA 1995* (NSW);

- Swift parrot (*Lathamus discolor*) - listed as endangered under the EPBC Act and *TSCA 1995* (NSW);
- Tiger quoll (*Dasyurus maculatus*) - listed as vulnerable under the *TSCA 1995* (NSW)).

Migratory species listed under the EPBC Act have also been recorded from the area (DSEWPAC 2010f).

Current land use is limited to some farming; although most of the area is included in the Barren Grounds Nature Reserve and Budderoo National Park (DSEWPAC 2010f). Fire is currently considered the greatest threat to the heath swamp. The area is currently managed by the NSW National Parks and Wildlife Service under the guidance of the Budderoo National Park, Macquarie Pass National Park, Barren Grounds Nature Reserve and Robertson Nature Reserve Plan of Management (NPWS 1998).

Lake Bathurst and the Morass Wetlands

Lake Bathurst and the associated Morass Wetlands cover an area of approximately 1350 hectares within the HNCMA (Abell 1995). These inland wetlands are listed in the DIWA as temporary freshwater/floodplain lakes. A conceptual model of a freshwater lake is provided in Figure 6-17. Lake Bathurst provides habitat for waterbirds, and is considered to be particularly important for its value as a refuge during times of drought (WetlandCare Australia, 2008).

The wetland complex is large and heavily vegetated, and provides breeding habitat for at least 64 species of birds (including JAMBA and CAMBA listed species) when surface water levels are sufficient (WetlandCare Australia 2008a). A number of vulnerable species (listed under the *TSCA 1995*) have been recorded from Lake Bathurst, including the blue-billed duck (*Oxyura australis*) and freckled duck (*Stictonetta naevosa*) (NPWS 2013).

The major threatening processes to Lake Bathurst and the Morass Wetlands include soil salinity, loss of native vegetation, erosion, poor grazing practices and introduced species (DSEWPAC 2010b). There are a number of pest species threatening the habitat values of Lake Bathurst and its wetlands. Weeds, particularly blackberry (*Rubus fruticosus* agg.), serrated tussock (*Nassella trichotoma*), and Bathurst burr (*Xanthium spinosum*), are competing with native plants and becoming widespread, despite management efforts (WetlandCare Australia 2008a). Rabbits (*Oryctolagus cuniculus*) are also competing with native fauna for resources; however, they also alter the composition and structure of vegetation, and more broadly, the landscape (NSW Scientific Committee 2002).

The lake and wetlands is managed under WetlandCare Australia's *Lake Bathurst and The Morass Wetland Management Plan*, and measures to protect and/or enhance the area are coordinated by the HNCMA.

Thirlmere Lakes

The Thirlmere Lakes are a series of five ancient, hydrologically connected lakes, believed to be approximately 15 million years old (Independent Thirlmere Lakes Inquiry Committee 2012). These lakes are located within Blue Gum Creek, approximately 100 km southwest of Sydney. Thirlmere National Park abuts Nattai National Park to the west, and is at the edge of the Warragamba hydrological catchment draining via the Little River and Nattai River to Warragamba Dam.

The five lakes (Lakes Nerrigorang, Baraba, Couridjah, Werriberri and Gandangarra) are shallow, mostly perennial waterbodies perched above alluvial unconsolidated sediments (Russell *et al.* 2010). The broader catchment has low rates of sedimentation, and so the Lake's surface waters are clear and the process of infilling slow (Atkinson 2000). Rainfall and groundwater supply surface water for the Thirlmere Lakes (Independent Thirlmere Lakes Inquiry Committee 2012).

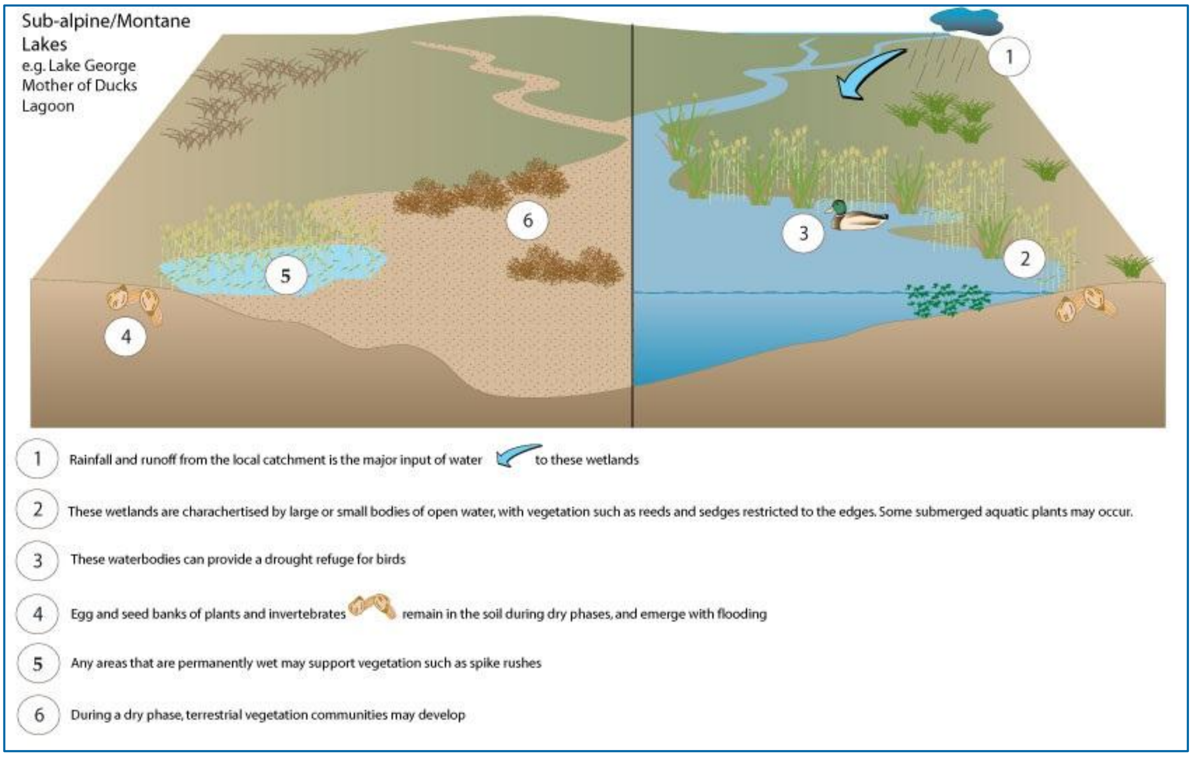


Figure 6-17 Conceptual model of a freshwater lake

Source: Adapted from Claus et al. 2011

In the past, the Lakes were popular with water-skiers; as a result, a number of changes were made to improve access to the water (with the establishment of roads, and the removal of riparian vegetation (Atkinson 2000)) and to increase the area of 'ski-able' water (by creating channels to link the lakes). Land use within the Thirlmere Lakes catchment is at present limited to small-scale farms and orchards (DSEWPAC 2010c).

Currently, the Thirlmere Lakes are listed in the DIWA, protected under the Thirlmere Lakes National Park, and are included in the Greater Blue Mountains World Heritage Area (DSEWPAC 2010c). Subsequently, this area is only available for low impact uses (*e.g.* walking, swimming).

Water resources for the Thirlmere Lakes are managed by the Sydney Basin Nepean Porous Rock Groundwater Management Unit and the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (Russell *et al.* 2010).

The management of the Greater Blue Mountains World Heritage Area is also delivered through a Strategic Plan (NSW National Parks and Wildlife Service 2009). The specific management of the Thirlmere Lakes National Park is delivered through the New Plan of Management (NSW National Parks and Wildlife Service 1997).

The water level of the already shallow lakes has declined in recent years. While it was suspected that longwall coal mining had altered groundwater conditions (through bedrock fracturing or subsidence), an investigation by Russell *et al.* (2010) and the Independent Thirlmere Lakes Inquiry Committee (2012) showed that prevailing climatic conditions are most likely responsible for the changed water levels. Historical evidence suggests that the Thirlmere Lakes undergo relatively frequent, rapid changes in water levels (Independent Thirlmere Lakes Inquiry Committee 2012).

The ecological values of the Thirlmere Lakes are poorly understood (Independent Thirlmere Lakes Inquiry Committee 2012). In general, the lentic environment of the lakes contains a number of macrophyte species, particularly floating lilies. The margins of the lakes are typically characterised by sedges and paperbark (*Melaleuca linariifolia*).

The region also provide habitat for a number of threatened or ecologically significant species. For example, locally significant river peppermint (*Eucalyptus elata*) and endangered dwarf Kerrawang (*Rulingia prostrata*) (listed under both the EPBC Act and *TSCA 1995* (NSW)) are found at the Thirlmere Lakes (DSEWPAC 2010c). Additionally, Australasian bittern (*Botaurus poiciloptilus*) (listed as endangered (under both the EPBC Act and *TSCA 1995* (NSW)) and Latham's snipe (*Gallinago hardwickii*) (listed as marine and migratory (Bonn, CAMBA, JAMBA and ROKAMBA) under the EPBC Act) have both been observed (Independent Thirlmere Lakes Inquiry Committee 2012).

A freshwater sponge (*Radiospongilla sceptroides*) is endemic to the Warragamba catchment and Thirlmere Lakes (DSEWPAC 2010c).

Blue Mountains Swamps

Blue Mountains Swamps are a biologically diverse plant community that occurs nowhere else in the world. Blue Mountains swamps often occur on steep valley sides and form due to the unique geology of the upper and mid Blue Mountains. Rainwater penetrates the soil and then starts to seep through the permeable Narrabeen sandstone layers. Where the impermeable sandstone layers outcrop on the valley sides the groundwater trickles out providing the constant moisture required to maintain swamp vegetation. Over millennia the peaty swamp soils develop from the decay of the swamp vegetation and starts extending down the slope. The Blue Mountain swamps are also referred to as hanging swamps. A conceptual model of a hanging swamp is provided in Figure 6-18.

There are less than 3,000 ha of Blue Mountains Swamp in existence and they comprise many small areas. The vegetation in these swamps range from low buttongrass clumps to large shrubs such as Hakea and Grevillea species. The swamps provide essential habitat to several Threatened Species, such as the Blue Mountains Water Skink (*Eulamprus leuraensis*) and the Giant Dragonfly (*Petalura gigantea*). Threatened flora species such as *Epacris hamiltonii* and *Microstrobos fitzgeraldii* rely on the continued seepage from hanging swamps for survival.

As the urban footprint expands to the edges of the Newnes plateau, the swamps are coming under increasing pressure. The predominant threats to Blue Mountains Swamps are:

- Sediment deposition, tunnelling and channelisation from stormwater discharges;
- Nutrient enrichment;
- Weed invasion;
- Clearing for urban development;
- Mowing;
- Grazing;
- Water extraction (bores, tapping natural springs and building dams);
- Fire (both 'wild' and hazard reduction).

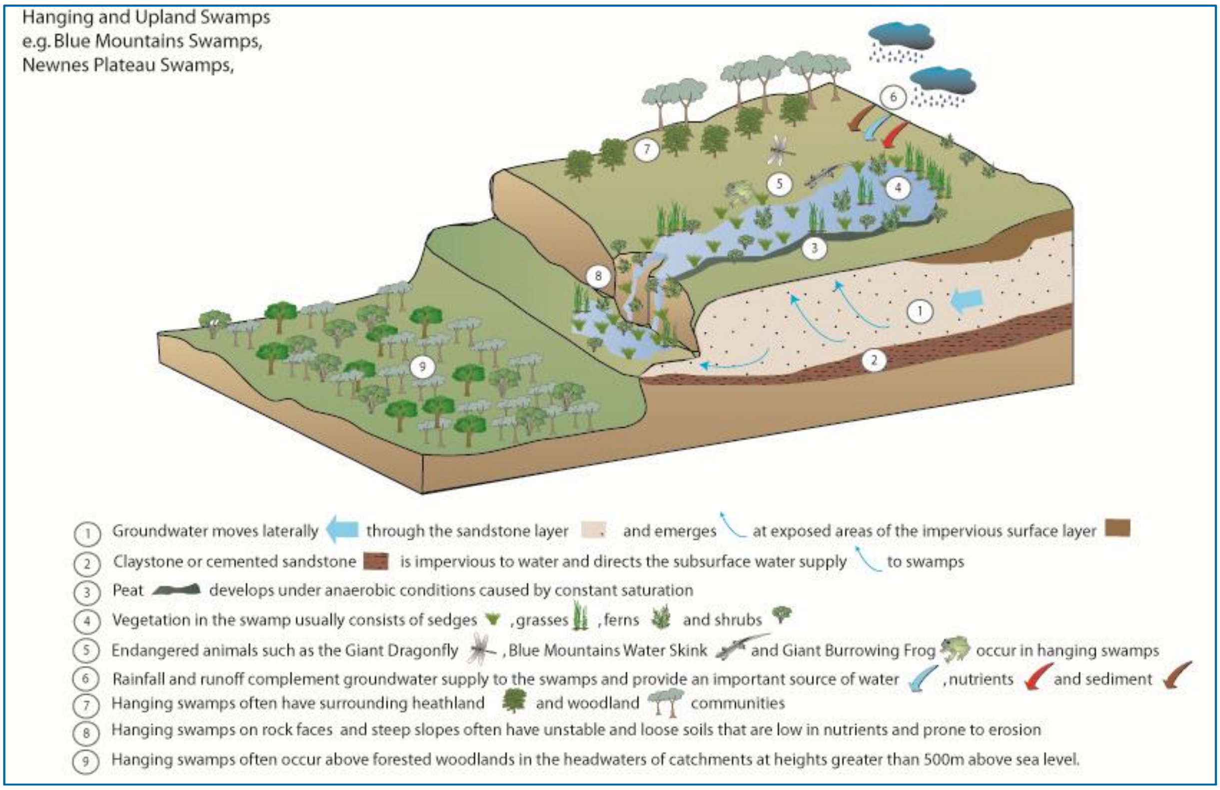


Figure 6-18 Conceptual model of a hanging swamp

Source: Adapted from Claus et al. 2011

Activities in the catchment

Wingecarribee Swamp

During the Audit period, the SCA has undertaken research into the ecological condition of the vegetation communities on the Wingecarribee Swamp and their association with groundwater as well as seasonal flora surveys at Wingecarribee Swamp to inform pest and weed control programs (SCA 2007c; 2012a). The SCA also carries out routine willow and blackberry control on Wingecarribee Swamp and along Wingecarribee River foreshore. In 2010-2011 17.6 ha of willow and blackberry were treated, in 2011-2012 52 ha were treated and 100 ha were removed (SCA 2010a; b; c; d; SCA 2011a and SCA 2012a; b; c).

Upland Swamps

Blue Mountains City Council's Upland Swamp Rehabilitation Program was commenced in 2006 after Blue Mountains Swamps were listed as part of the Temperate Highland Peat Swamps on Sandstone endangered ecological community (EEC). In August 2008, Blue Mountains City Council and Lithgow City Councils formed a partnership to deliver the 'Save our Swamps' (SOS) project to restore Temperate Highland Peat Swamps on Sandstone.

The SOS project has delivered a three part program that includes

- Education and community awareness raising
- Community and agency capacity building
- An on-ground program of Temperate Highland Peat Swamps on Sandstone EEC (THPSS) swamp rehabilitation across both LGAs.

In 2009 the SOS project received a $400,000 federal 'Caring for our Country' grant to expand the program to incorporate Wingecarribee Shire Council and Gosford City Council. The partnership of the four councils resulted in the SOS model being rolled out over 95% of the extent of the THPSS EEC.

The innovative integrated and landscape scale approach to the management of THPSS has resulted in the SOS project receiving four awards including:

- National Governments Local Government Award for Innovation in Natural Resource Management 2010
- United Nations World Environment Day Award for Excellence in Overall Environmental Management 2011 (Special Commendation)
- NSW Sustainable Cities award for Biodiversity Conservation 2010
- National Keep Australia Beautiful (Tidy Town award) for Biodiversity Conservation 2011

The SOS has led to over 30 hectares of Blue Mountains Swamp undergoing bush regeneration, treated over 600 metres of channelised swamp with soft engineering rehydration structures and planted 11,825 endemic swamp plants.

During 2010–2011, the SCA and BMCC carried out works to restore and protect seven wetlands listed as THPSS EEC. The project aimed to improve soil stability, water quality, protect 10 nationally threatened plant species and two threatened animal species (SCA 2011). SCA also funded the BMCC on behalf of the Garguree Swampcare in 2011–2012 to expand the Garguree Swampcare project area of the THPSS EEC (SCA 2012a; b; c).

Lithgow City Council also has a SOS Swampcare community engagement program for all Newnes Plateau Shrub Swamp related programs. It includes Swampcare's educational and on ground activities, the Swampwatch program and the Blue Mountains Water Skink and Giant Dragonfly Monitoring Program.

A new practical guide for 'Soft engineering solutions for swamp remediation' has been published by BMCC with the assistance of Lithgow City Council and Wingecarribee Shire Council. This publication comprehensively covers soft engineering swamp rehabilitation applications, techniques and materials. It also covers background information on swamp geomorphology, threats and impacts to Temperate Highland Peat Swamps on Sandstone swamps.

Other wetlands

Wingecarribee Shire Council has a Wetland Management Strategy (2003) which was prepared with the aim to develop various wetland management strategies for the protection of natural wetlands within the Shire, particularly those identified as having high conservation values. A total of 346 wetlands have been identified in the shire, of which 30% are classified as upland wetlands, 37% as riverine wetlands, and 33% as drainage / seepage channel wetlands (Wingecarribee Shire Council 2011). During 2010 – 2011 regeneration works were undertaken on 4 publicly owned wetlands (Paddys River swamp, Stingray Swamp, Currabunda wetland and Garland Rd reserve), and 1 wetland on private property has been conserved.

The HNCMA has carried out a number of projects in the Catchment to protect, enhance, and rehabilitate wetlands during the current audit period; these are listed in Table 6-11. There was a decrease in the area of works undertaken to protected, enhanced, and rehabilitated wetlands by the HNCMA during the Audit period.

Table 6-11 Area of wetland protected, enhanced and rehabilitated by the HNCMA in the Catchment

	2010/11	2011/12	2012/13
Wetlands protected, enhanced and rehabilitated (hectares)	113	33	16

The HNCMA and the Goulburn Mulwaree Shire Council have been working together to restore the Goulburn wetlands. Goulburn-Mulwaree Council purchased the ruins of Goulburn's May Streetbrick pits in 2003 and recently (2010) made their rehabilitation a top priority. The site was abandoned in the 1950s and covers 13.5 hectares of weed-infested floodplain.

The project aimed to transform the neglected area by restoring and protecting its historical and natural heritage. The floodplain is to be rehabilitated and enhanced to create an active riparian zone, with gross pollutant traps, rock mattresses and earthworks that harvest and biologically treats stormwater. The site will be replanted with indigenous vegetation and weeds will be controlled and removed (HNCMA 2011).

The Wentworth Falls Lake feeds Jamison Creek, which continues over Wentworth Falls and on to join the Kedumba River, Lake Burragorang and ultimately Warragamba Dam. The Wentworth Falls Lake was created by the damming of Jamison Creek to supply water for the steam railway. Much of the Lake is surrounded by sensitive Blue Mountains swamp. The Lake is home to a range of native and domestic waterfowl, native fish such as Gudgeons, and water bugs including freshwater crayfish, freshwater shrimp and dragonfly nymphs.

BMCC has a number of projects aimed at improving the health of the lake and the surrounding Blue Mountains Swamps (BMCC 2004; BMCC 2010b). A number of stormwater quality improvement devices have been placed around the Lake to reduce the amount of litter, sediment and organic material entering the water body. The Living Catchments project is working to reduce sediment and stormwater inputs from Council and private land in the Wentworth Falls Lake catchment.

Extensive swamp restoration works have also been conducted in the Blue Mountains swamps surrounding the lake, to treat erosion and weed invasion caused by stormwater impacts. BMCC also maintains ongoing community involvement and education to help improve practices in the catchment and stop the source of the pollution. This includes holding Living Catchment workshops and supporting volunteer groups such as Streamwatch and Bushcare.

To better understand the potential impacts of CSG extraction and coal mining activities on environmental assets in the Sydney Metropolitan, Southern Rivers and Hawkesbury-Nepean CMAs commissioned the University of Wollongong in 2012 to assess potential impacts on water, land and biodiversity (University of Wollongong 2012). This assessment involved the collation and extrapolation of existing data to generate a preliminary assessment of potential impacts associated with coal seam gas extraction and coal mining activities.

Coal lithology was used as the principle factor in determining potential impacts to the region and associated risks. Environmental assets less than 500 m above coal seams with a high fracture density were classed as being potentially at risk from coal mining. Environmental assets greater than 500 m above coal seams with a high fracture density were classed as being potentially at risk from coal seam gas extraction.

The potential impacts on water environmental assets varied with the mining method, the proximity of the asset to mining, the groundwater extraction regime and the connectivity of aquifers. Groundwater environmental assets in the shallow Hawkesbury-Nepean alluvial aquifer associated with the main river systems of the Hawkesbury-Nepean catchment and the deeper Hawkesbury Sandstone aquifer that lies above the Southern Coalfields were found to be most vulnerable to current of future coal operations.

High potential impacts to groundwater were found to be possible for much of the Hawkesbury-Nepean catchment, Sydney Metropolitan catchment and northern parts of the Southern Rivers catchment, as these aquifers are highly valuable for domestic and agricultural uses. The assessment also detected medium to high hazards for surface water assets within the Hawkesbury-Nepean catchment and Sydney Metropolitan catchment, including at the Nepean, Avon, Cordeaux, Cataract and Woronora dams and Wingecarribee Reservoir.

Through the process of the assessment, a number of recommendations were developed to address knowledge and data gaps, and improve the understanding of impacts on environmental assets. These recommendations included the following:

- Collating and developing a collection of agreed standardised baseline monitoring data, particularly for groundwater resources from aquifer systems in vertical profiles;
- Comprehensive research and modelling of potential fracture networks in aquifers;
- Developing a cumulative risk assessment framework to determine the long-term environmental effects of coal seam gas exploration and extraction;
- Developing an environmental asset sensitivity analysis; and
- Developing an integrated GIS and environmental database system that can be used to characterise risk and potential impacts

Longwall mining impacts

A number of factors influence the vulnerability of upland swamps to impact from longwall mining. The swamp geomorphology and hydrology particularly determines the retention of water within the swamp itself, but also the direction of flow. Consequently, these determining factors ultimately influence the persistence and resilience of the upland swamp to change. Upland swamps are particularly important for the function of catchment wide hydrological cycling, as they are a provider of long-term flows during dry phases, and maintain water quality by trapping metals, compounds and suspended particles (Keith et al. 2006). The specific threats to upland swamps as a direct result of longwall mining include:

- Cracking of baserock;
- Increased drainage;
- Change in the water table level;
- Creation of nick points;
- Change in surface topography (and subsequent hydrology);
- Flushing and erosion of sediment (leading to changes in water quality and impacts to flora and fauna) (DoP 2008a).

The extent and condition of upland swamps in the Metropolitan and Woronora Special Areas are under threat from longwall mining. Previous studies have found that the fracturing of the relatively impervious base of the swamps and alteration to drainage patterns associated with underground coal mining can lead to degradation in these swamps (Krogh 2004; 2007; DP&I Assessment Commission 2009; DECCW 2009b). A number of creeks (including the Waratah Riverlet and Wongawilly Creek) and swamps in the Special Areas have already been impacted, and it is possible that further swamps may be impacted by current (or future) mining operations.

SCA commissioned a project 'Impact of longwall mining on subsidence, flow and water quality in the Waratah Rivulet' in 2010. The aim of the project was to provide the SCA with a better understand of the impacts of mining, and apply this knowledge to other catchments to minimise the impact of mining on water resources and the environment.

The project found that the subsidence caused cracking in bedrock and streambeds and loss of surface water into underground routes. This changed the chemical composition of water in affected creek channels including increased total dissolved solids, iron and manganese leading to precipitation of metal-oxides and hydroxides. These water quality changes are caused by the release of metals from rock as surface water flow is diverted through subsurface routes. Metals are mobilised and carried to storages, potentially affecting storage water quality.

BHP Billiton began mining operations at the Dendrobium Underground Mine in 2001. The mine is situated in close proximity to the storages of Cordeaux Dam and Avon Dam within the Metropolitan Special Area. Mining to date at Dendrobium has been conducted progressively in four separate blocks of longwalls, referred to as Area 1, Area 2, Area 3A and Area 3B. Longwall extraction in Area 1 began in 2005 and started in Area 3B early in 2013.

The mine workings are between 150 and 320 m below the ground surface. It was concluded in a study by the Dam Safety Committee that negligible losses from the storages and no adverse impacts on the dam structures has been caused by the Dendrobium mine (DSC 2013).

An impact assessment for Area 3 was conducted in 2007. The assessment predicted that the risk of surface cracking was likely and flow diversion possible at a number of swamps within Area 3 (Cardno Forbes Rigby 2007).

An assessment of the impacts and monitoring of the upland swamps on the Dendrobium Mine and wider Woronora Plateau was conducted by Krogh (2012). A number of impacts associated with the longwall mining have been identified and were generally considered to be ‘minor’ by industry. Consequently, Krogh’s (2012) Assessment showed that these ‘minor’ impacts caused by the Dendrobium Mine are actually quite severe in nature, and are resulting in significant alteration of the environment. For example, a ‘minor’ impact in Dendrobium Area 3 consisted of rock fractures of up to 300 mm in width, a depth of 4 m and length of 30 m.

The Assessment also highlighted the inadequate sensitivity of the Mine’s trigger-action-response plan (TARP), particularly in instances where impacts are not considered substantial enough (*i.e.* classed as ‘minor’) to set the TARP into action.

Within the Dendrobium Mine, a number of groundwater impacts have been observed in regards to groundwater levels, perched aquifers and upland swamp EECs. Deep aquifers are being impacted above the longwall panels, with drawdown of up to 50 m being recorded, yet the true/ultimate consequence of these impacts is poorly understood. The upland swamps and groundwater aquifers of the Woronora Plateau are important providers of surface water to riverine systems (Young 1982). In turn, this water sustains the species and communities within these riverine systems, particularly during periods of drought or low flow. Where the supply of surface water is altered, these species and communities (groundwater dependent ecosystems, riverine ecosystems and human users) become vulnerable to potential impacts.

An increasing number of riverine ecosystems (*e.g.* Cataract River, Georges River, Waratah Rivulet, Wongawilli Creek, Native Dog Creek, Lizard Creek, Wallandoola Creek) on the Woronora Plateau have been impacted by longwall mining (Krogh 2012).

Dendrobium Area 3A is particularly affected, where widespread iron-staining is common, much of the surface water has completely disappeared, or surface water levels have declined. These hydrological changes are of particular concern as most of the streams within this area are habitat for threatened species.

For the upland swamps, the existing monitoring program has identified impacts, with groundwater monitoring outcomes showing that perched aquifers and sandstone aquifers are being lost to a reduced water table.

Where the base of the swamp has been fractured, the perched aquifer is no longer contained and drains through the fracture. This process has resulted in the desiccation of upland swamps, and changes to swamp vegetation composition.

Overall, the Assessment found that the monitoring results of the Dendrobium Mine have not triggered the adaptive management response required for remediation of the significant impacts, particularly to upland swamp EECs. The overall findings of the Assessment highlight the importance of understanding impacts for future development, both within the Dendrobium Mine and within the broader area.

Since the Krogh 2012 report was finalised, longwall mining was completed in Panel 8 within Area 3A (Figure 6-19). The End of Panel 8 Report was published in April 2013. The findings from the monitoring conducted during longwall mining of Panel 8 found that the water level in Wongawilli Creek (WC17) dropped below the baseline period, rock fracturing in a tributary of Banksia Creek (SC10C) was observed covering an area of 8 x 5 metres, and the water level in the pools within SC10C had dropped below the baseline period (BHPB. 2013). Impacts on the shallow groundwater levels associated with Swamp 12 and Swamp 15b were also observed (Ecoengineers 2013).

Vegetation and frogs were also monitored during longwall mining of Panel 8. Following mining of Longwall 8 pools within WC17 and SC10C exhibited low water levels and some become dry during low flow conditions (Biosis 2013). The loss in pooled water levels resulted in impacts to breeding habitat for Littlejohn's Tree Frog, which is listed as vulnerable under the NSW *TSCA 1995* and EPBC Act.

At Swamp 12 and 15b the rate of recession of groundwater increased following the mining of Longwall 8. Dieback of pouched coral fern (*Gliechenia dicarpa*) was also observed (Biosis 2013) at Swamp 15b.

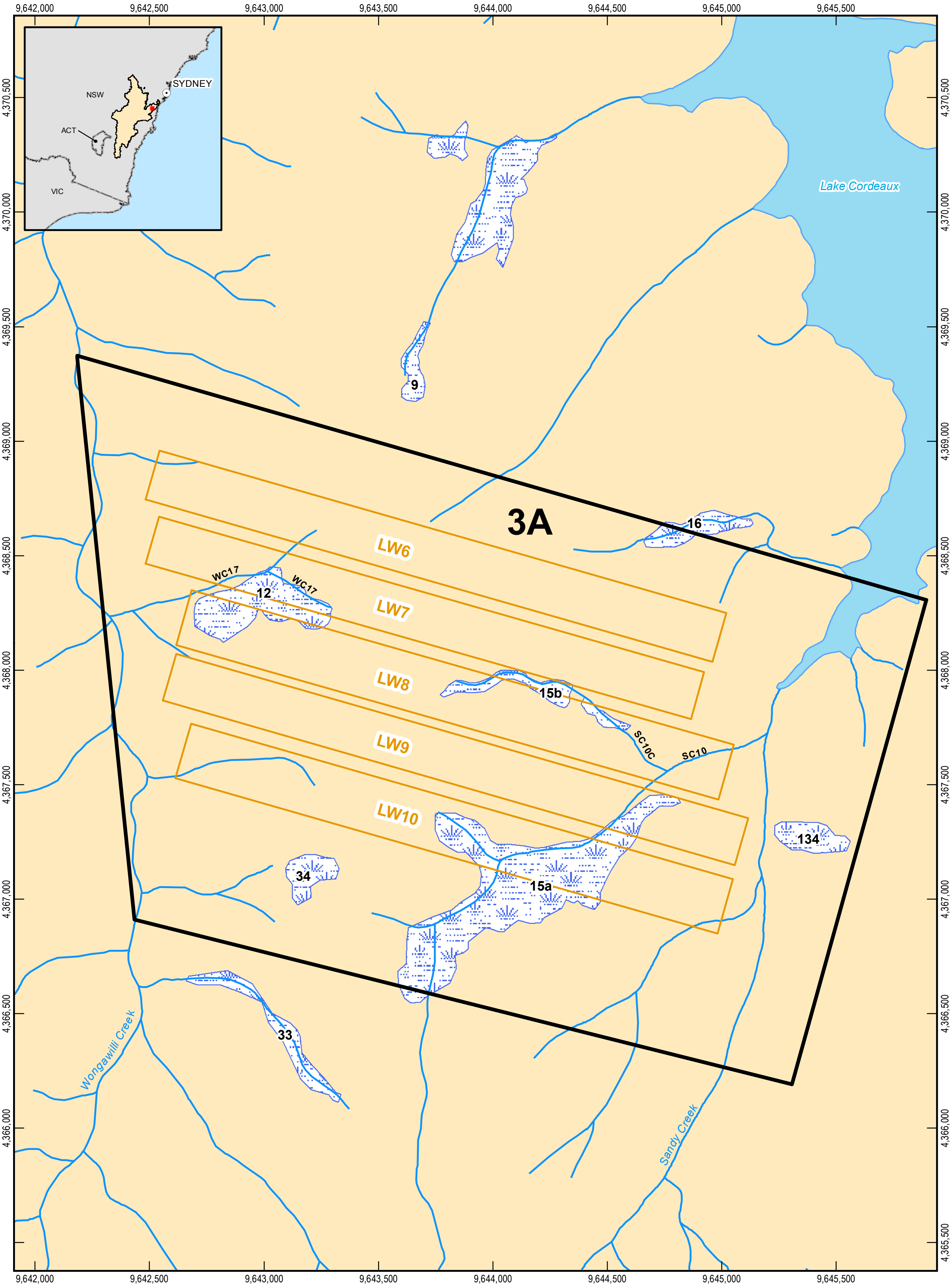
During the 2013 Catchment Inspection, the Metropolitan Special Area was visited, including parts the Dendrobium Area 3A. Rock fracturing and dry pools in a tributary of Banksia Creek (SC10C) (Figure 6-20) and drying of swamp 15b and dieback of pouched coral fern (*Gliechenia dicarpa*) and Banksia species (Figure 6-21) was observed.

Extensive swamp restoration works have been completed within the Wingecarribee Swamp and upland Swamps, including the Temperate Highland Peat Swamps on Sandstone EEC in the Catchment (DSEWPaC 2010g). There are, however, continued impacts from longwall mining to upland swamps in the Metropolitan and Woronora Special Areas. There are 13 upland swamp EECs within Area 3B. Twelve of these EECs were predicted to undergo impacts associated with subsidence and upsidence (Krogh 2012).

Approval was granted in February 2013 that permits extraction of 5 longwalls from Area 3B. The approval was based on recognition that there will be impacts on several upland swamps, which could not be avoided.

Environmental impacts have been observed on swamps from the first of these 5 longwalls (Longwall 9). It is likely that impacts will remain after any remediation actions and for this reason the approved Subsidence Management Plan (SMP) requires substantial biodiversity offsets to compensate for the anticipated impacts to uplant swamps.

The draft mine plan for the next mining domain must be submitted for approval prior to undertaking any longwall gate road development. This will prevent a mine layout being developed without prior approval from the DP&I.



LEGEND

●	Town		SCA catchment boundary		BHPBilliton Illawarra Coal Proposed Area 3 Footprint
—	Drainage		Sub-catchment boundary		Mine layout - SMP Area 3A
	Waterbody		State boundary		Shrub-dominated wetlands

Paper Size A4

0 100 200 300 400 500

Metres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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SYDNEY CATCHMENT AUTHORITY

Sydney Catchment Authority
Catchment Audit 2013

Job Number | 2314960
Revision | 0
Date | 28 Nov 2013

Dendrobium Mine Area 3A

Figure 6.19

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** ptamail@ghd.com **W** www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries, wetland types (2013); GHD: digitised BHPBilliton Illawarra Coal boundaries from Cardno Forbes Rigby 2007 report (2013). Created by: KP

Figure 6-20 Rock fracturing in SC10C (September 2013)

Figure 6-21 Dieback in pouched coral fern (*Gliechenia dicarpa*) and Banksia within Swamp 15b (September 2013)

6.5.6 Recommendations

As identified in the 2010 Audit, long-term data on the condition of wetland types in the Catchment are rare and often restricted to individual swamps (e.g. Wingecarribee Swamp). Wetland mapping in the Catchment has not been undertaken at a frequency which adequately enables an assessment of change in wetland extent or condition. In addition, there is no standardised procedure currently available for documenting wetland condition in the Catchment.

OEH, SCA, CMAs and other relevant agencies collaborate to develop and apply a standardised procedure for assessing the extent and condition of wetlands in the Catchment.

There are continued impacts from longwall mining to upland swamps in the Metropolitan and Woronora Special Areas. The waterfall at Sandy Creek was protected from impacts from longwall mining at longwall 6 and 7 within Area 3A by stopping the longwalls 700 m from Sandy Creek (SCA 2013g). Similar protection should be applied on a case by case basis to protect upland swamps and watercourses within the Special Areas.

6.6 Fish

6.6.1 Summary

The number of native fish species collected in the Catchment has increased, with 16 native fish species collected during the 2005 – 2007 fish surveys, 14 native fish species in 2007-2010 and 24 native fish species in 2010-2013.

The sub-catchments with the greatest diversity of fish species are Bungonia Creek, Kangaroo River, Upper Nepean River and the Wollondilly River. Low species diversity (3 species or less) was found in seven sub-catchments, including Endrick River, Kowmung River, Mid Shoalhaven River, Mulwaree River, Reedy Creek, Wingecarribee River and Woronora River.

During the current audit period, 97 Macquarie perch, listed as endangered under the *FMA 1994*, were recorded from the Little River, Mongarlowe River and Upper Nepean River sub-catchments. The majority of the high and medium priority barriers to fish passage in the Catchment are located in the Wollondilly River, Kangaroo River, Mid and Upper Coxs River sub-catchments.

Works have been undertaken to improve fish passage in the Catchment. However, there are a large number of medium to high priority barriers to fish passage which were identified in 2006 which may currently be affecting the passage of fish in the Catchment.

Assessment Criteria

Criteria

1. Identify and document the number of native fish species in the catchment;
2. Identify the proportion of introduced fish species in the Catchment;
3. Describe obstacles to fish passage, habitat, and connectivity.

Assessment against Criteria

Criteria	Audit finding	Recommendation
1 & 2	Meets Expectation	Nil
3	Opportunity for improvement	The SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (Recommendation 1) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection.

Prior recommendations

Prior Recommendations	Remedial action	Status
No prior recommendations	N/A	N/A

6.6.2 Background

Fish are an important component of most aquatic ecosystems. Fish are seen as useful indicators of riverine health as they interact at many trophic levels and are sensitive to human disturbance (Harris 1995). The *Policy and guidelines for fish habitat conservation and management* (Fairfull 2013) identify the main causes of decline in freshwater fishes include:

- Habitat degradation due to various forms of water pollution, catchment development and land use-related activities;

- Changes to water flow regimes;
- Barriers to fish passage;
- Introduction of alien fish species; and
- Historical overfishing.

Fish habitat includes the water column, the substrate and other features submerged by water which are used by fish to shelter, access food, to breed and which provide territorial markers for migration. Aquatic habitats can be described by referring to:

- Natural materials that comprise the habitat (e.g. rocks, gravel, sand and mud);
- Type of vegetation present (e.g. macrophytes and snags);
- Shape and nature of the habitat (e.g. pools and riffles); and
- Overall ecosystem (e.g. wetlands, floodplains and streams).

Native fish in the Catchment are affected by habitat modification, exotic species, pollution, modification of river flows and physical barriers. Dams, weirs, and other in-stream works in the Catchment act as significant barriers to fish passage. These prevent the upstream and downstream passage of migratory native fish. Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands is listed as a key threatening process under the *Threatened Species Conservation Act 1995*.

The obstruction of fish passage can negatively impact on native fish by:

- Restricting the migration of spawning fish;
- Reducing the dispersal of juvenile fish to new habitat areas;
- Limiting the passage of fish between feeding grounds
- Increasing the susceptibility of fish accumulating below barriers to predation and disease;
- Fragmenting fish communities and reducing gene flow within fish populations;
- Creating unsuitable living or breeding conditions;
- Altering the hydrology and water quality of waterways both upstream and downstream of in-stream structures; and
- Changing species diversity due to local extinctions of some species and altering the abundance of remaining populations.

Water released from dams is often colder than downstream flow, especially if the dam has a bottom valve off-take. Cold water pollution can affect fish growth and survival and can potentially limit the distribution of fish within rivers to warmer areas (NSW Fisheries, 2003).

Snags are important fish habitat and refer to large woody debris from trees and shrubs, including whole fallen trees, broken branches and exposed roots that have fallen or washed into a waterway and are now wholly or partially submerged by water. Snags tend to accumulate in freshwater areas and provide habitat components for fish within streams by (Fairfull, 2013):

- Providing flow refuges for fish (i.e. places to rest out of the main current flow);
- Providing cover for fish (i.e. sites to hide from predators, interact with competitors, or avoid direct sunlight);
- Providing ‘markers’ to designate territorial boundaries for species that move or migrate within the river system;
- Providing breeding sites for species which lay adhesive eggs onto hard substrates;

- Providing substrate for algal, biofilm, fungal, bacterial, benthic plants, macroinvertebrates and vertebrate communities to colonise;
- Providing organic enrichment by capturing detritus and contributing to secondary production as the debris degrades;
- Stabilising sediments and armouring the stream bed and banks, thereby preventing stream erosion, and providing structure in alluvial systems; and
- Increasing the physical habitat complexity of the stream.

In accordance with the *FMA 1994*, the definition of 'fish' includes not only fin fish, but also crustaceans, molluscs, worms, insects and other invertebrates that spend all or part of their life cycle in aquatic habitats.

6.6.3 Management and Surveillance

NSW DPI administers the *FMA 1994* and associated Regulations (FM Regulations). Permits under the FM Act are required for the following activities:

- Boat ramps and boat sheds (i.e. reclamation);
- Bridges, culverts, causeways (both piped and un-piped) or other road-crossings of waterways (temporary or permanent) which require placing material on the bed of the waterway (i.e. reclamation) and/or which may obstruct the free passage of fish;
- Dams, weirs, floodgates, or levee banks across waterways (i.e. obstruction of fish passage);
- Channelisation, relocation or realignment of waterways;
- Installation of pipelines across a waterway (involving dredging or reclamation);
- Installation of stormwater outlets (involving reclamation of the bed or bank of a waterway);
- Stream bed or bank stabilisation works (involving dredging or reclamation to halt erosion);

A licence under the *FMA 1994* is also required to harm threatened species or damage their habitat and to take fish by any specified method and timeframe from any specified waters for research purposes.

The updated *Policy and guidelines for fish habitat conservation and management* (Fairfull, 2013) outlines the policies and guidelines aimed at maintaining and enhancing fish habitat for the benefit of native fish species, in freshwater, marine, and estuarine environments.

This document aims to help developers, consultants and government and non-government organisations to ensure compliance with legislation, as they relate to fish habitat conservation and management. It is also a valuable tool to improve awareness and understanding of the importance of fish habitats and how impacts can be mitigated, managed or offset.

The NSW DPI undertakes fish monitoring for the State-wide Monitoring, Evaluation and Reporting program. Fish monitoring programs are also underway to assess the effectiveness of various fishways and the fish 'lift' at Tallowa Dam.

6.6.4 Methodology

This Audit examined:

- The total number of native species in the Catchment;
- The total number of introduced species in the Catchment; and
- Projects to improve fish passage and fish habitat.

The recommended measurement for the fish indicator was the numbers and proportions of native fish and exotic species present within each sampled water body (NOW 2009). The total number of native species is often used and is a measure of the general health of aquatic ecosystems because it has been shown that the number of native species declines with increasing environmental stress.

The presence of exotic (introduced) species also reflects the general condition of the aquatic ecosystem and may represent both a symptom and a cause of declines in stream health and disturbance (Harris 1995).

6.6.5 Findings

A list of 24 native fish species that were expected in the Sydney Drinking Water Catchment was determined from NSW Fisheries and the Australian Museum records pre 1930s in the 2003 Sydney Drinking Water Catchment Audit Report (DEC 2003).

The number of native fish species collected in the Catchment has increased. During the 2005 – 2007 fish surveys, 16 native species were collected, 14 fish species in 2007-2010 and 24 native species in 2010-2013 (Table 6-12). Not all native species collected were expected to occur and some species have been translocated including the silver perch and Murray cod.

There was also an increase in the number of sites sampled in the Catchment. Forty nine sites were sampled in 2005-2007 in 15 sub-catchments, 67 sites in 2007-2010 in 16 sub-catchments and 79 sites in 2010-2013 in 18 sub-catchments. During the 2010 – 2013 fish surveys a number of invertebrates were also collected in the Catchment including:

- Fitzroy Falls spiny crayfish (*Euastacus dharawalus*) collected in the Kangaroo River catchment;
- Giant spiny crayfish (*Euastacus spinifer*) collected in the Wingecarribee River catchment;
- Hairy crayfish (*Euastacus hirsutus*) collected in the Kangaroo River catchment;
- Sydney crayfish (*Euastacus australasiensis*) collected in the Kowmung River catchment;
- Southern lobster (*Euastacus yanga*) collected in the Kangaroo River and Upper Shoalhaven River catchments;
- Yabby (*Cherax destructor*) collected in the Kangaroo River, Reedy Creek, Mid Coxs River, Upper Wollondilly River, Mid Shoalhaven River, Upper Nepean River, Mongarlowe River and Wollondilly River catchments.

The sub-catchments with the greatest diversity of fish species (species richness) were Bungonia Creek, Kangaroo River, Upper Nepean River and the Wollondilly River (Table 6-12). Low species diversity (3 species or less) was found in seven sub-catchments. The number of native fish species collected in the Bungonia Creek sub-catchment increased from 11 in 2007-2010 to 21 in 2010-2013.

The majority of this increase was in native species, with 9 new native species collected in the 2010–2013 audit period. Conversely, the species richness in the Lake Burragorang sub-catchment decreased from 13 to 5 fish species between the 2007-2010 audit and 2010-2013 audit periods. This decrease was due to a reduction in native fish species collected in 2010-2013. There was also a reduction in species richness in the Wollondilly River sub-catchment, with a reduction from 10 to 6 species collected between the 2007-2010 and 2010-2013 audit periods (Table 6-13).

Table 6-12 Fish species expected to occur and collected between June 2005 and June 2013 in the Catchment

Family	Common name	Species	Status	Expected to occur	2005-2007	2007-2010	2010-2013
Anguillidae	Short-finned eel	*Anguilla australis*	Native	x	x	x	x
	Long-finned eel	*Anguilla reinhardtii*	Native	x	x	x	x
	Silver perch	*Bidyanus bidyanus*	Native*		x		x
Clupeidae	Freshwater herring	*Potamalosa richmondia*	Native	x			x
Galaxiidae	Climbing galaxias	*Galaxias brevipinnis*	Native	x	x		x
	Common jollytail	*Galaxias maculatus*	Native	x			x
	Mountain galaxias	*Galaxias olidus*	Native	x	x	x	x
Eleotridae	Striped gudgeon	*Gobiomorphus australis*	Native	x	x	x	x
	Cox's gudgeon	*Gobiomorphus coxii*	Native	x	x	x	x
	Empire gudgeon	*Hypseleotris compressa*	Native	x			x
	Firetail gudgeon	*Hypseleotris galii*	Native	x		x	x
	Western carp-gudgeon	*Hypseleotris klunzingeri*	Native		x	x	x
	Unidentified carp-gudgeon	*Hypseleotris spp*	Native		x		x
	Flat-headed gudgeon	*Philypnodon grandiceps*	Native	x	x	x	x
	Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Native	x	x	x	x
Mordaciidae	shortheaded lamprey	*Mordacia mordax*	Native	x			
Mugilidae	Sea mullet	*Mugil cephalus*	Native	x			x
	Freshwater mullet	*Trachystoma petardi*	Native	x			x
Percichthyidae	Macquarie perch	*Macquaria australasica*	Native	x	x	x	x
	Estuary perch	*Macquaria colonorum*	Native	x			
	Australian bass	*Percalates novemaculeata*	Native	x	x	x	x

Table 6-12 (cont.) Fish species expected to occur and collected between June 2005 and June 2013 in the Catchment

Family	Common name	Species	Status	Expected to occur	2005-2007	2007-2010	2010-2013
	Trout cod	*Maccullochella macquariensis*	Native				x
	Murray cod	*Maccullochella peelii*	Native*		x		
	Trout cod - Murray cod hybrid	*Maccullochella hybrid*					x
Petromyzontidae	Lamprey	*Mordacia praecox*	Native			x	
Plotosidae	Freshwater catfish	*Tandanus tandanus*	Native		x	x	x
Pseudomugilidae	southern blue eye	*Pseudomugil signifer*	Native	x			
Retropinnidae	Australian smelt	*Retropinna semoni*	Native	x	x	x	x
	Australian grayling	*Prototroctes maraena*	Native	x			
Tetrarogidae	Bullrout	*Notesthes robusta*	Native	x			x
Cyprinidae	Goldfish	*Carassius auratus*	Introduced		x	x	x
	Common carp	*Cyprinus carpio*	Introduced		x	x	x
Poeciliidae	Eastern gambusia	*Gambusia holbrooki*	Introduced		x	x	x
Cobitidae	Oriental weatherloach	*Misgurnus anguillicaudatus*	Introduced		x	x	x
Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	Introduced		x	x	x
	Brown trout	*Salmo trutta*	Introduced		x	x	x
Percidae	Redfin perch	*Perca fluviatilis*	Introduced		x	x	

Source: DEC 2003, DECCW 2010a, DP&I 2013a

Table 6-13 Number of native and introduced fish species collected in the Catchment between June 2005 and June 2013

	June 2005 - June 2007				July 2007 - June 2010				July 2010 - June 2013			
Sub-catchment	Sites sampled	Native	Introduced	Species richness	Sites sampled	Native	Introduced	Species richness	Sites sampled	Native	Introduced	Species richness
Boro Creek					2	0	3	3				
Bungonia Creek	4	7	2	9	5	8	3	11	7	17	4	21
Endrick River					1	3	0	3	1	2	0	2
Kangaroo River	5	7	2	9	8	7	3	10	24	9	2	11
Kowmung River					3	0	3	3	3	1	1	2
Lake Burragorang	4	7	1	8	3	10	3	13	1	3	2	5
Little River	1	1	0	1	4	4	2	6	4	6	2	8
Lower Coxs River	2	5	2	7	1	4	1	5				
Mid Coxs River	2	1	2	3	4	2	3	5	4	2	3	5
Mid Shoalhaven River	1	2	0	2					1	2	1	3
Mongarlowe River	3	5	0	5	1	4	3	7	2	5	3	8
Mulwaree River	1	0	2	2	1	2	1	3	1	0	2	2
Nattai River	2	3	1	4								
Reedy Creek									1	2	0	2
Upper Coxs River									7	3	4	7
Upper Nepean River	12	12	1	13	17	11	2	13	16	13	2	15
Upper Shoalhaven River					1	1	1	2	1	2	2	4
Upper Wollondilly River	3	2	2	4					2	3	3	6
Werri Berri Creek	1	2	2	4								
Wingecarribee River	2	2	0	2	3	2	3	5	1	2	1	3
Wollondilly River	6	6	5	11	11	6	4	10	2	4	2	6
Woronora River					2	2	1	3	1	1	0	1

Source: DEC 2003, DECCW 2010a, DP&I 2013a

During the current audit period 97 Macquarie perch, listed as endangered under the FM Act, were recorded from the Little River, Mongarlowe River and Upper Nepean River sub-catchments.

As identified in the 2010 Audit, fish monitoring programs throughout the Catchment are relatively rare and obtaining adequate long term fish data to undertake an assessment of trend is therefore very difficult.

In July 2012, a water pollution incident in Jamison Creek, Wentworth Falls resulted in hundreds of dead and dying crayfish. An interagency investigation into the cause of the deaths was immediately launched by BMCC, EPA, OEH and the DPI.

Testing of crayfish carcasses, water and sediment samples and aquatic macroinvertebrates sampling was carried out to determine the cause and source of the crayfish deaths. A pesticide, Bifenthrin, was detected in the crayfish tissues. Jamison Creek was thought to have recovered from the pollution event and in April 2013, giant spiny crayfish, mountain galaxias and Australian smelt were found in Jamison Creek.

The site of the suspected 'release' of Bifenthrin is directly connected to the creek by concrete stormwater infrastructure. The BMCC has identified the Wilson Park stormwater outlet as a priority for end-of-pipe treatment such as a bioretention system.

Activities in the catchment

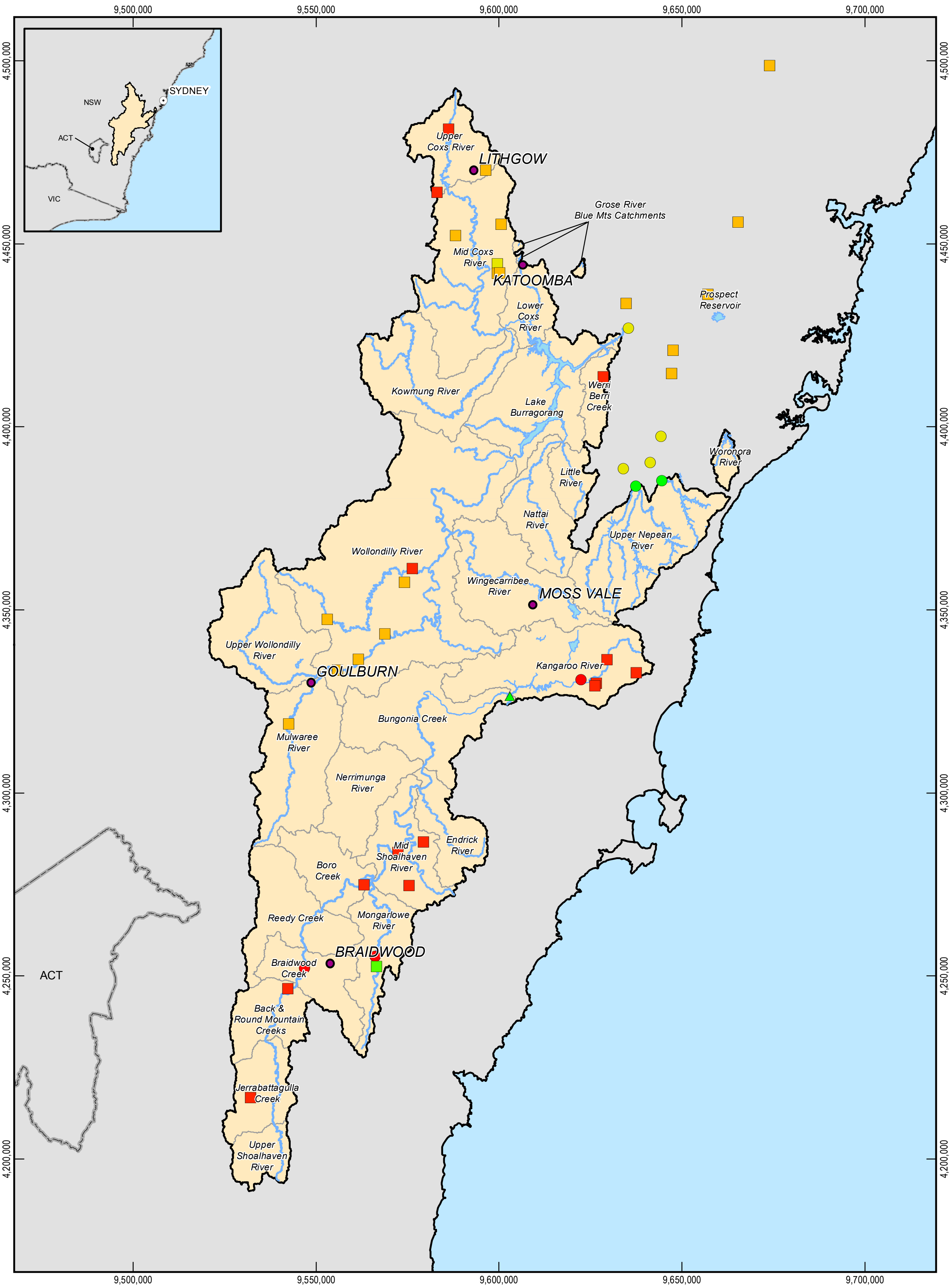
The proliferation of dams, weirs and regulators throughout NSW has had a significant effect on the abundance and diversity of native fish populations (Fairfull 2013). As a result, the restoration of fish passage at dams and weirs throughout NSW waters is a key aspect of NSW DPI's commitment to improving aquatic ecology and biodiversity. The restoration of fish passage throughout NSW waters is a key aspect of NSW DPI's commitment to improving aquatic ecology and biodiversity.

In 2006, the DPI undertook several state-wide projects to identify barriers to fish passage (Figure 6-22). These studies identified 28 barriers to fish passage classified as medium to high priority sites for remedial action in the Catchment. The majority of the high and medium priority barriers to fish passage in the Catchment are located in the Wollondilly River, Kangaroo River, Mid and Upper Coxs River sub-catchments.

There were a number of programs in NSW to improve fish passage including the *Bringing Back the Fish Project* which concluded in 2009 and the *Fish Superhighways Program* which includes the installation of fishways and the removal of weirs.

To date, remedial works on nine barriers to fish passage, including five that were identified as high or medium priority sites, have been conducted in the Catchment. During the 2007 audit period, a fishway was built on Black Bob's Creek (a medium priority site work), which was undertaken in conjunction with other works to stabilise banks and improve in-stream habitat. In 2009, fish passage was improved at Tallowa Dam with the SCA constructing a fish 'lift' at to allow fish to move upstream and downstream of the dam structure. During the previous audit period a fish-friendly crossing was constructed on the Mongarlowe River at Northangera Road (Burke's Crossing) as part of the *Bringing back the fish* program. This resulted in improved fish access, including the threatened Macquarie Perch, to 43 km of upstream habitat.

Thirteen weirs were built on the Hawkesbury–Nepean River over the last 100 years. During the current audit period, new fishways were installed at 10 weirs along the Nepean River. These 10 weirs included five listed as a high priority sites for remedial action, including Wallacia, Brownlow Hill, Menangle (Figure 6-23), Maldon and Douglas Park weirs.



LEGEND

- Town
- Drainage
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary

Fish Barriers
Type, Priority, Improvement

- Dam, Nil, Yes
- Road crossing, Nil, Yes
- Road crossing, Medium, Yes
- Road crossing, Medium, No
- Road crossing, High, No
- Weir, Nil, Yes
- Weir, High,Yes
- Weir, High, No

Page Size A4

0 10 20 30
Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

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SYDNEY CATCHMENT AUTHORITY

Sydney Catchment Authority
Catchment Audit 2013

Job Number 2314960
Revision 0
Date 26 Nov 2013

High and medium priority barriers to fish passage

Figure 6.22

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries, fish barriers (2013). Created by: KP

Figure 6-23 Weir and fishway at Menangle on the Nepean River

Source: SCA 2012, photo by Bob Hughes

These new fishways allow fish to pass during a wider range of flows and help smaller native fish to migrate along the river. In particular, the Pheasants Nest Weir fishway facilitates the movements of the threatened native fish species, Macquarie perch.

In 2011 SCA and DPI – Fisheries entered into a 3 year joint arrangement to sample fish to identify changes in populations from new environmental flows and fish passage works in the Nepean and Shoalhaven Rivers (SCA 2012b). To date, the surveys confirm that the new fishways are being used by fish as small as 25-30 mm in length (for example Australian smelt and Cox's gudgeons) as well as by larger fish including Australian bass and Freshwater mullet (60 mm to 400 mm long) and Long-finned eels up to 1200 mm in length. The results of fish sampling have found that the new fishways are effective in improving fish passage.

The DPI Fish Habitat Action Grants provides funding for rehabilitating fish habitats in freshwater and saltwater areas throughout NSW. Habitat rehabilitation projects can include:

- Removal or modification of barriers to fish passage;
- Rehabilitation of riparian lands (river banks, wetlands, mangrove forests, saltmarsh);
- Re-snagging waterways with timber structure;
- Removal of exotic vegetation from waterways;
- Bank stabilisation works; and
- Re-instatement of natural flow regimes.

In 2010-2011, the Friends of the Mongarlowe River group were provided a Fish Habitat Action grant to rehabilitate a severely eroded bank in the Mongarlowe River, including the installation of engineered log jams (10) and the revegetation of the riparian zone (0.45 km). These works aimed to reduce a significant source of sediment and improve habitat for fish in the Mongarlowe River.

Dams in the Catchment that are estimated to cause moderate cold water pollution effects are Tallowa, Cataract, Warragamba, Cordeaux and Fitzroy Falls (NSW Cold Water Pollution Interagency Group 2012).

The NSW Government has developed the NSW Cold Water Pollution Strategy (NOW 2011) which endorsed the principle of requiring dam operators to match the temperature of releases from individual dams as closely as possible to the natural temperature regime having regard to the associated costs and benefits.

The number of native fish species collected in the Catchment has increased, with 24 native fish species collected during the current audit period. The sub-catchments with the greatest diversity of fish species (species richness) are Bungonia Creek, Kangaroo River, Upper Nepean River and the Wollondilly River. Low species diversity (3 species or less) was found in seven sub-catchments.

Works have been undertaken to improve fish passage in the Catchment, however, there are a large number of medium to high priority barriers to fish passage which were identified in 2006 which may currently be affecting the passage of fish in the Catchment. A review of the barriers to fish passage in the Catchment should be undertaken.

6.6.6 Recommendations

Previous audits (2005, 2007 and 2010) have recommended that an integrating ecosystem water quality, macroinvertebrate, fish and riparian vegetation condition monitoring program be developed for the Catchment.

The 2010 Audit identified that the integration of fish monitoring data with other indicators, such as water quality, macroinvertebrates and riparian zone monitoring, would be beneficial and would help provide a more comprehensive and integrated assessment of Catchment *health* across a wider range of catchment health indicators.

A fish monitoring program that is integrated over the entire Catchment, using the same methods and amount of sampling effort per site, would provide more information about the numbers of species and composition of native/introduced species at each site. The 2010 Audit recommended that data on ecosystem health indicators, including fish, should be integrated to provide a more comprehensive understanding of stream and catchment health and enable a more focussed and better prioritised management response to catchment condition (see **Recommendation 1**). The OEH, SCA and DPI fisheries and local government agencies should also continue to update and progress the current LMDB to track and record information on all fish passage and fish habitat improvement on-ground works being undertaken or funded by government for the purposes of water quality and ecosystem health management in the Catchment.

Previous audits (2005 and 2007) have recommended that a spatial information system be used to track and record information on all on-ground works being undertaken or funded by government for the purposes of water quality and ecosystem health management in the Catchment

The SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (Recommendation 1) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection.

6.7 Macroinvertebrates

6.7.1 Summary

Of all biological communities used to assess ecosystem health, aquatic macroinvertebrate assemblages are most widely used, as they are abundant and diverse, sensitive to changes in water quality, flow regime and habitat conditions. Macroinvertebrate communities also allow detection of impacts sometime after the impact has occurred. The use of macroinvertebrate assemblages in the assessment of river health is a nationally accepted and applied methodology (i.e. AUSRIVAS - Australian River Assessment System).

Overall, the 2013 Audit found a decrease in the condition of macroinvertebrates in the Catchment sites monitored during the current audit period. There has been a decrease in the percentage of samples rated as more biologically diverse than reference (Band X) and reference condition (Band A) and an increase in samples rated as significantly (Band B) or severely impaired (Band C) during the current audit period.

Assessment Criteria

Criteria

1. The condition of macroinvertebrate assemblages in the Catchment is monitored.

Assessment against Criteria

Criteria	Audit finding	Recommendations
1	Opportunity for improvement	The SCA and OEH should investigate the causes of the decline in the condition of macroinvertebrates at core sites in the Catchment.

Prior recommendations

Prior Recommendation	Action	Status
Recommendation 6: The SCA continue to undertake follow-up monitoring at macroinvertebrate monitoring locations that have scored an AusRivAs rating of *significantly impaired, severely impaired* or *extremely impaired* where there is no obvious driver for an impacted rating.	The SCA continued conducting its Macroinvertebrate Monitoring Program (MMP) spring sampling at all core sites in 2010, 2011 and 2012 including those which have recorded lower AUSRIVAS and/or SIGNAL ratings in previous years. A review of the MMP in 2012 concluded that the program in its present form does not produce a wholly reliable assessment of sub-catchment health, as its results primarily reflect the ecological condition of individual sites. The review recommended that the program be changed from its present form and the SCA is considering various options to improve the program.	Opportunity for improvement

6.7.2 Background

The measurement of aquatic macroinvertebrate community structure and abundance is a widely used technique to determine aquatic ecosystem health. Macroinvertebrates are typically visible with the naked eye and exist in a variety of habitats in streams, lakes, and wetlands. Of all biological communities used to assess ecosystem health, macroinvertebrate assemblages are most widely used, as they are abundant and diverse, sensitive to changes in water quality, flow regime and habitat conditions and they allow detection of impacts sometime after the impact has occurred (Qld DNRM 2001).

Aquatic macroinvertebrates are usually abundant and diverse at any given site, when water quality is good, but they are sensitive to deteriorating water quality and habitat condition, and to changes in flow regimes. AUSRIVAS (Australian River Assessment System) is a nationally accepted and applied methodology for the assessment of river health. It utilises the Rapid Bio-assessment (RBA) method for sampling and assessment of aquatic macroinvertebrates and AUSRIVAS applies computer models to determine the ratio of observed and expected macroinvertebrate taxa at a site.

The AUSRIVAS system generates river health assessments by predicting the macroinvertebrates that would be present (expected) and compares this with the macroinvertebrates collected (observed) to create an index of health. The lower the observed/expected value, the more impaired the macroinvertebrate assemblage.

The model applied is determined by the physical and chemical properties of the site, the time of collection (spring or autumn), the habitat (edge or riffle) and the macroinvertebrate families collected. The model output O/E ratio scores are placed into bands that provide an indication of environmental health of the assessed site.

The AUSRIVAS models predominantly applied to samples collected in the Catchment are the NSW spring edge and riffle models and the AUSRIVAS bands applicable to these models are provided in Table 6-14.

Table 6-14 AUSRIVAS bands for NSW Spring, edge and riffle habitats

Band Label	Edge O/E Bandwidth Upper Limit	Riffle O/E Bandwidth Upper Limit	Band Name	Comments
Band X	Infinity	Infinity	More biologically diverse than reference sites	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
Band A	1.16	1.18	Reference condition	Most/all of the expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity.
Band B	0.83	0.8	Significantly impaired	Fewer families than expected. Potential impact either on water quality or habitat quality or both, resulting in loss of taxa.
Band C	0.51	0.43	Severely impaired	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial impacts on water quality and/or habitat quality.
Band D	0.19	0.06	Extremely impaired	Few of the expected families remain. Extremely poor water quality and/or habitat quality. Highly degraded.
OEM	N/A	N/A	Outside Experience of the Model	This site is outside the experience of the model (Chi^2<0.001)

6.7.3 Management and Surveillance

A number of agencies collected macroinvertebrate data within the Catchment including:

- SCA - which is required by its Operating Licence to report annually on macroinvertebrate assemblages in the Catchment (SCA 2013b);
- OEH – which is responsible for the macroinvertebrate component of the Monitoring, Evaluate and Reporting (MER) program for NSW rivers and streams; and
- Delta Electricity – which collect annual macroinvertebrates sampling in spring and autumn as required under their water management licence[7].

The BMCC also conducted an Aquatic Monitoring and Action Program (AMAP), which delivered an annual report on the waterways' health in the BMCC area. The program used aquatic macroinvertebrates as biological indicators of water quality and ecosystem health, giving the Council a regular picture of the quality of waterways. The building up of a bank of data, over time, allows the Council to observe trends, predict and respond to issues in the catchment.

6.7.4 Methodology

The macroinvertebrates living in rivers and streams can provide a good indication of pollution and disturbance. This audit examined the trend in condition of macroinvertebrate assemblages in the Catchment.

6.7.5 Findings

The results for the current audit period suggest that the majority of sites were 'significantly impaired' (Figure 6-24). Within the current audit period there was an improvement in the health of the Catchment in 2011, with more sites rated as reference condition and less sites significantly or severely impaired than in 2010. However, in 2012 there was a decrease in sites rated as reference condition and an increase in sites rated as significantly impaired.

The 2010 Audit report stated that almost half (48.9 %) of the sites sampled were found to be in similar to reference (Band A) or richer than reference (Band X) condition and that the macroinvertebrate health throughout the Catchment is generally good (DECCW 2010a).

During the current audit period a decrease (16 %) in the condition of macroinvertebrates in the Catchment was found, with 32.8 % of the sites sampled were found to be in similar to reference (Band A) or richer than reference (Band X) condition (Figure 6-24).

Based on data from 2001 to 2009, the Upper Coxs River sub-catchment had the highest percentage of sites (52.7%) in the severely impaired (Band C) or extremely impaired (Band D) condition (DECCW 2010). The Mid Shoalhaven River (89.5 %), Mongarlowe River (86.7%) and Kangaroo River (84.2%) sub-catchment had the highest percentage of sites in the similar to reference (Band A) or richer than reference (Band X) condition.

During the current audit period, the Endrick River (66.7 %), Mid Shoalhaven River (55.6 %) and Mongarlowe River (50 %) had the highest percentage of samples in the severely impaired (Band C) or extremely impaired (Band D) condition (Table 6-16).

[7] Information on the sites monitored by Delta Electricity was not provided for the current audit

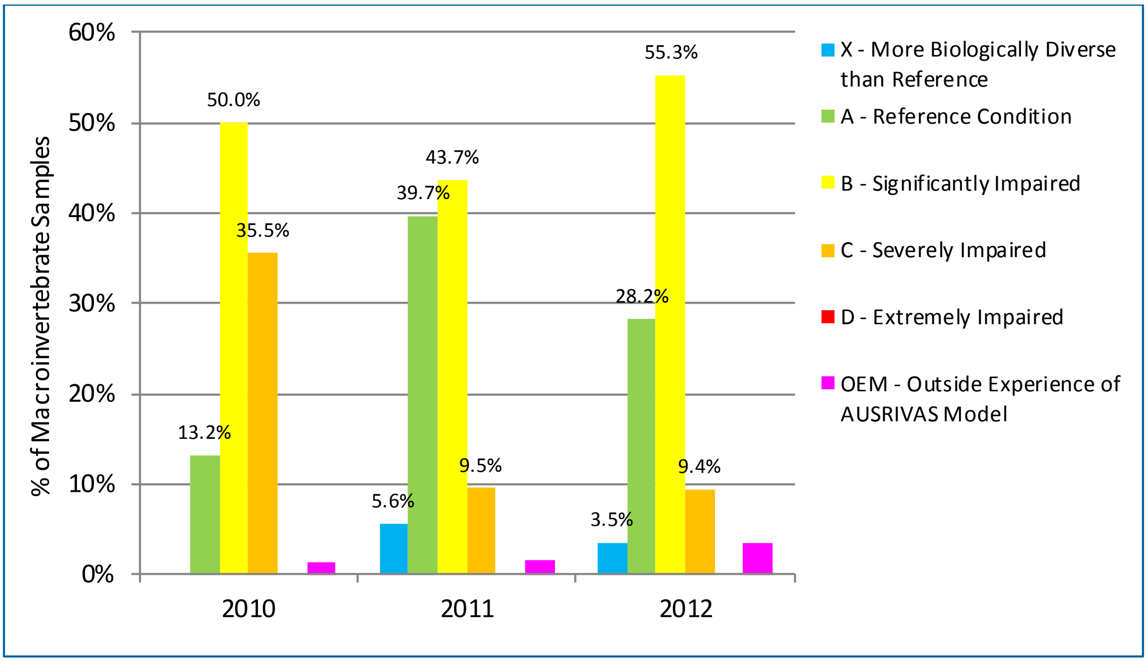


Figure 6-24 AUSRIVAS results for macroinvertebrate samples collected across the Catchment in 2010, 2011 and 2012

The Kowmung River (71.4 %), Lake Burragorang (62.5 %) and Upper Nepean River (62.5 %) sub-catchments had the highest percentage of samples in the similar to reference (Band A) or richer than reference (Band X) condition (Table 6-15).

A number of core sites in the Catchment have been sampled since 2001. The core sites showed a similar decrease in macroinvertebrate health during the current audit period within most sub-catchments, except in the Braidwood Creek, Kowmung River and Mid Coxs River sub-catchments (Figure 6-25).

- Overall, there was a decrease in the percentage of samples at core sites, which were rated as more biologically diverse than the reference (Band X); and similar to reference condition (Band A).
- In addition, there was an increase in core sites, which were rated as significantly impaired (Band B) or severely impaired (Band C) during the current audit period (Figure 6-25 and Table 6-16).
- As shown in Table 6-16, there was also a reduction in macroinvertebrate health during 2010, with only 12 % of samples rated as reference condition (Band A) and 31 % rated as severely impaired (Band C).

The reasons for the reduction in the condition of macroinvertebrate assemblages at core sites in the Catchment were unknown, and should be investigated to determine if causal drivers for the *impaired* rating can be found, and to confirm the impacted state at the sites.

Activities in the catchment

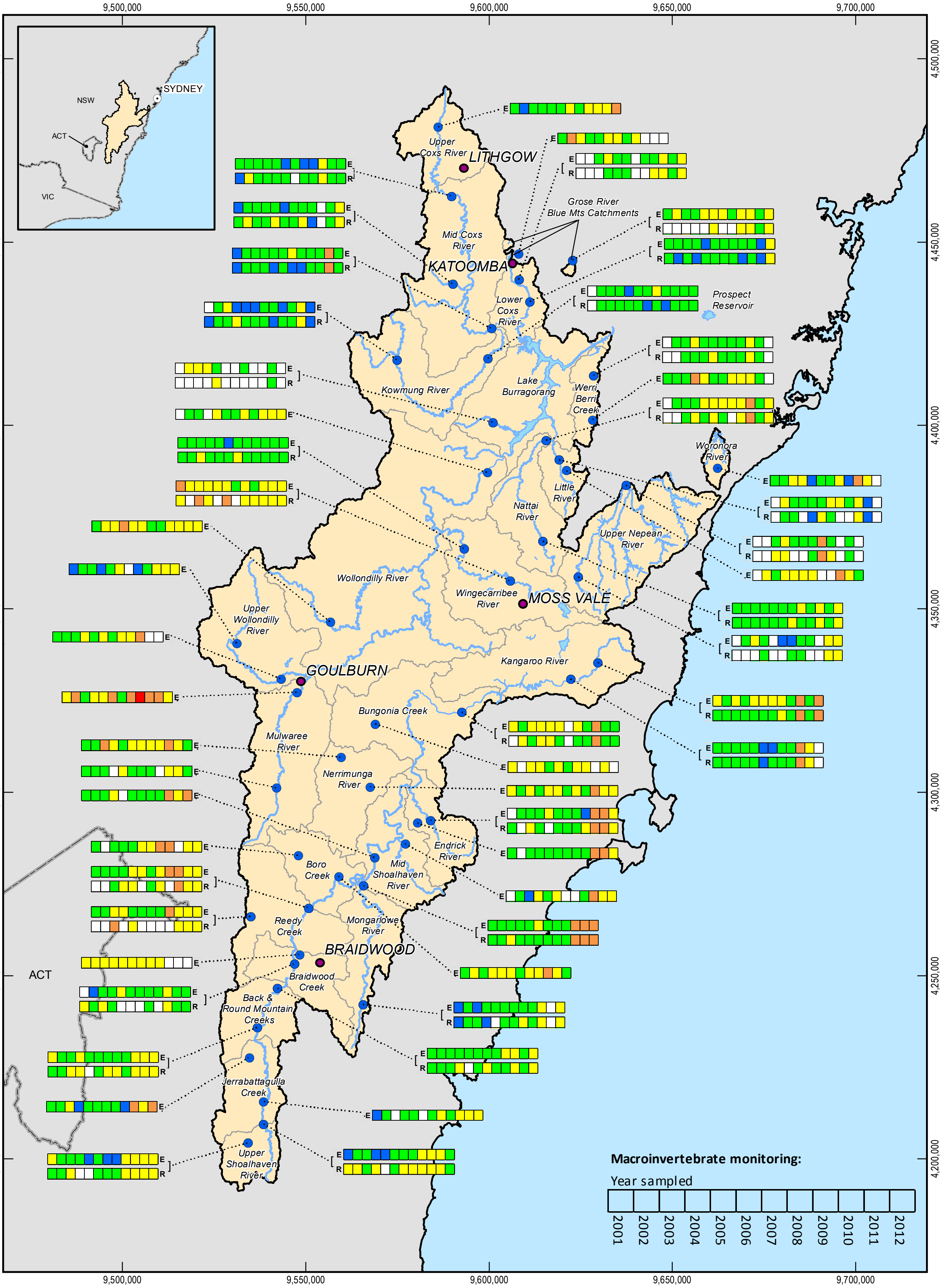
A review of the Macroinvertebrate Monitoring Program in 2012 concluded that the program in its present form does not produce a wholly reliable assessment of sub-catchment health, as its results primarily reflect the ecological condition of individual sites. The review recommended that the program be changed from its present form and the SCA is considering various options to improve the program.

Table 6-15 Sub-catchment summaries of macroinvertebrate AUSRIVAS rankings for 2010-12

Sub-catchment	Number of sites	X (%)	A (%)	B (%)	C (%)	D (%)	OEM (%)
Back and Round Creeks	2	0	16.7	83.3	0	0	0
Boro Creek	2	0	20	60	20	0	0
Braidwood Creek	2	0	57.1	42.9	0	0	0
Bungonia River	2	0	44.4	11.1	22.2	0	22.2
Endrick River	2	0	0	33.3	66.7	0	0
Grose River	7	11.1	22.2	55.6	11.1	0	0
Jerrabattgulla Creek	2	0	0	66.7	33.3	0	0
Kangaroo River	2	0	16.7	16.7	50	0	16.7
Kowmung River	4	14.3	57.1	28.6	0	0	0
Lake Burragorang	5	0	62.5	37.5	0	0	0
Little River	3	25.0	12.5	50	12.5	0	0
Lower Coxs River	3	14.3	28.6	57.1	0	0	0
Mid Coxs River	7	0	59.1	31.8	9.1	0	0
Mid Shoalhaven River	2	0	0	44.4	55.6	0	0
Mongarlowe River	2	0	0	33.3	50	0	16.7
Mulwaree River	3	0	14.3	57.1	28.6	0	0
Nattai River	4	0	35.7	50	14.3	0	0
Nerrimunga Creek	2	0	16.7	50	33.3	0	0
Reedy Creek	3	0	0	84.6	15.4	0	0
Upper Coxs River	7	0	20	50	30	0	0
Upper Nepean River	7	12.5	50	37.5	0	0	0
Upper Shoalhaven River	3	0	28.6	71.4	0	0	0
Upper Wollondilly River	3	0	20	60	20	0	0
Werriberri Creek	5	0	60	30	10	0	0
Wingecarribee River	2	0	50	50	0	0	0
Wollondilly River	13	0	16.7	77.8	5.6	0	0
Woronora River	4	16.7	16.7	50	16.7	0	0
Total	**103**	**3.5**	**29.3**	**48.8**	**16.4**	**0**	**2.1**
Total for sites sampled pre-2010	**456**	**5.0**	**43.9**	**37.5**	**11.2**	**0.7**	**1.8**

Table 6-16 Percentage of samples in macroinvertebrate AUSRIVAS rating bands at core sites between 2001 and 2012

Band Label	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Band X	12.0	3.6	2.4	7.2	9.6	8.4	6.0	6.0	9.6	0	4.8	2.4
Band A	42.2	60.2	61.4	49.4	47.0	50.6	57.8	49.4	47.0	12.0	37.3	21.7
Band B	13.3	14.5	26.5	32.5	26.5	27.7	19.3	30.1	26.5	42.2	42.2	47.0
Band C	1.2	2.4	3.6	2.4	0	2.4	0	4.8	3.6	31.3	9.6	9.6
Band D	0	0	0	0	0	0	0	0	1.2	0	0	0



LEGEND

Town	SCA catchment boundary	Sampling point
Drainage	Sub-catchment boundary	E Edge habitat
Waterbody	State boundary	R Riffle habitat

Ausrivas Health Rating

- Richer than reference
- Similar to reference
- Significantly impaired
- Severely impaired
- Extremely impaired
- No data

Paper Size A4

0 10 20 30 40 50

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

N

GHD

SYDNEY CATCHMENT AUTHORITY

Sydney Catchment Authority
Catchment Audit 2013

Job Number	2314960
Revision	0
Date	26 Nov 2013

Macroinvertebrate Ausrivas health rating in the Catchment 2001 - 2012

Figure 6.25

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries, Ausrivas results (2013). Created by: KP

The macroinvertebrate data collected by the BMCC was used to determine the impacts of a pesticide (Bifenthrin) contamination event (July 2012) in Jamison Creek and the subsequent recovery. The results showed that the macroinvertebrate composition of Jamison Creek had recovered 6 months (November 2012) after the pesticide contamination event (Table 6-17).

Table 6-17 Number of families in each macroinvertebrate group before and after the pesticide contamination at Jamison Creek, July 2012

Macroinvertebrate group	March 2012	July 2012	August 2012	September 2012	November 2012	March 2013	July 2013
Crayfish	1				1		
Caddisfly	2		1		3	1	2
Stonefly	2			1	1	1	1
Mayfly					1	1	1
Damselfly				1		1	1
Dragonfly	3	1		1		1	2
Diptera (fly larvae)	3	2	3	1	3	4	3
Beetle	3			2	4	1	1
Water bug	1				1	2	1
Giant water bug						1	
Water mite				1		1	1
Segmented worm				1	1		
Flatworm					1		
Snail (exotic)					1		1
Total	16	3	4	8	17	14	14

6.7.6 Recommendation

The reduction in the condition of macroinvertebrates assemblages at core sites in the Catchment is unknown and should be investigated to determine if causal drivers for the *impaired* rating can be found and to confirm the impacted state at the sites.

The SCA and OEH should investigate the causes of the decline in the condition of macroinvertebrates at core sites in the Catchment.

Previous audits (2005, 2007 and 2010) have recommended that an integrating ecosystem water quality, macroinvertebrate, fish and riparian vegetation condition monitoring program be developed for the Catchment. SCA and OEH could investigate the potential for integrating macroinvertebrate monitoring into a broader catchment-wide ecosystem monitoring program (see **Recommendation 1**).

The 2010 audit recommended that data on ecosystem health indicators, including macroinvertebrate data, should be integrated to provide a more comprehensive understanding of stream and catchment health and enable a more focussed and better prioritised management response to catchment condition (see **Recommendation 14**).

6.8 Fire

6.8.1 Summary

Fire management to manage the risks and impacts of bushfires is being implemented across the Catchment, in accordance with Bushfire Risk Management Plans, prepared as required by Section 52 of the *Rural Fires Act 1997*. A key focus of these plans is the protection of human life and property within the Catchment. Bushfire mitigation activities, including prescribed burning, are also undertaken to mitigate the risk of potentially high-consequence bushfires adversely impacting water catchment and other environmental values. These are undertaken by the SCA, and by the NSW National Parks and Wildlife Service (NPWS), principally, on public land.

A significant increase in the scale of the annual prescribed burning program was achieved in 2012/13 (16,451 ha in 2012/13), which is more than an 8-fold increase on the previous year, and nearly 2.5 times more than the highest year from the previous reporting period (i.e. 6,765 ha in 2008/09).

Since the last major fire events of the 2000-2003 drought period, a relatively small proportion of the Catchment (less than 10 %) has been burnt (either by bushfire or prescribed fire) resulting in widespread fuel accumulation to high levels across more than 90 % of native vegetation areas within the Catchment. Without either major bushfires or substantial increases in prescribed burning programs these fuel will rise to Very High levels over the next 5 years.

On private lands within the catchment the NSW Rural Fire Service (RFS) and NSW Fire and Rescue (NSWF&R) also undertake prescribed burning in areas of native vegetation, although this is at a smaller scale than burning of public land, and focussed mainly on areas adjacent to settlements to reduce fire risk to local communities.

An active program of bushfire suppression is carried out, with initial response capacity provided by the SCA, NPWS and the RFS/NSWF&R on public and private land respectively, and coordinated inter-agency fire response efforts made when required. This serves to limit the extent and impacts of bushfires within the Catchment.

Data for fires within the Catchment are included in the RFS managed Bushfire Risk Information Management System. However, there appears still to be fire management data integrity issues as burnt area summaries in SCA Annual Reports have inconsistencies with fire history data provided to the Auditor.

Assessment Criteria

Criteria

1. Fire management regimes are in place to manage risks and impacts of bushfires in the Catchment.

Assessment against Criteria

Criteria	Audit finding	Recommendation
1	Meets Expectation	Nil

Prior recommendations

Prior Recommendations	Action	Status
Recommendation 8: The Rural Fire Service (RFS), in cooperation with SCA and OEH, integrate their spatial datasets across all sub-catchments so that a single, consistent estimate for the area burnt by hazard reduction burns and bushfires can be reported.	The SCA supply RFS with spatial extent for wildfires on an annual basis for collation into a state-wide dataset. The SCA also submits hazard reduction burn plans to RFS via the Bush Fire Reporting Information Management Systems. The RFS has an annual process of reviewing data that it receives from SCA and OEH however it is not clear if ground truthing of actual burn areas versus declared burns occurs.	Opportunity for Improvement

6.8.2 Background

Fire has been present on the Australian continent for millions of years and is a key factor in plant and animal population dynamics in most NSW ecological communities. Many Australian animals and plants have evolved, not only to survive, but also to benefit from the effects of fire.

Many of the vegetation communities in NSW require recurrent fires to maintain their distribution in the landscape, their species diversity, and their health and vigour. Different vegetation communities require different fire regimes (different combinations of fire frequency, intensity, season and patchiness).

Flora species can be eliminated from a vegetation community if the fire regime shifts to one they cannot tolerate, and other species may become established or significantly increase their abundance where the fire regime shifts in their favour. A high frequency of fire (beyond tolerable frequency thresholds for a species/community) can result in the disruption of life cycle processes in plants and animals and loss of vegetation structure and composition and is listed as a key threatening process under the *TSCA 1995*.

Patterns of urban and rural settlement, vegetation clearance, changes to land use and fire ignition patterns, cessation of traditional Aboriginal burning practices and statutory requirements to suppress bushfires have altered fire regimes and resulted in ecological impacts across a variety of landscapes.

Bushfires can have devastating effects on catchment health. Large, high intensity bushfires can cause widespread mortality of native vegetation and fauna, substantially altering fauna populations and habitat condition, and resulting in loss and damage to agricultural enterprises and infrastructure.

Areas burnt by bushfires, particularly high-intensity fires, are prone to accelerated soil erosion, resulting in enhanced sediment and nutrient export to the surface water bodies downstream. Removal of vegetation by fire also reduces the ability of catchment areas to retain rainfall and can lead to altered hydrological conditions in streams until the vegetation becomes re-established (NOW 2009).

Fire regimes in the Catchment are highly variable. In some locations, particularly in areas with a history of careless or illegal ignition by people in summer, there can be adverse, high frequency and high intensity fire regimes. In other areas, where lightning is the principal cause of fire, fires can be successfully extinguished (preventing their spread) over long time periods (decades), and the risks reduced to have a low frequency regime. However, when successful suppression is not possible, due to high accumulated fuel loads and severe fire weather; such areas may also be subject to large scale fires and highly adverse consequences.

During high-consequence fire events (such as occurred extensively in the northern part of the Catchment in 2001), fire can become established in peat, posing a significant threat to the upland swamps in the Catchment which play an important hydrological function to regulate water quality (Keith et al. 2006).

Bushfires can also have many impacts on the quality of water generated in drinking water catchments. The magnitude of the effects depends on the extent of the fire, its intensity, the rate of vegetation regeneration, soil properties, topography, geology, and rainfall patterns after the fire (Krogh et al. 2008). If the vegetation in the catchment is extensively removed by a fire and heavy rain occurs soon afterwards, there can be serious degradation of water quality. Increased water runoff after a fire will include suspended soil and ash particles and can cause increased sediment and turbidity in streams, wetlands and dams (Krogh et al. 2008).

In addition, forest fires can change the pattern of water use by the forest, leading to changes in streamflow. It is common to find streamflows increasing in the period immediately after the fire and decreasing in the subsequent periods of rapid vegetation regrowth (8 to 50 years after the fires) (Krogh et al. 2008).

Fires can remove the buffering capacity of vegetated riparian zones and they can have complex impacts on species composition and biodiversity in post-fire habitats, including the potential for localised species extinctions (Krogh et al., 2008). Fires can also produce conditions that favour the establishment of noxious weeds and invasive species, which can compete with and threaten the existence of important native species.

The incidence of fire varies greatly each year with the number of fires closely linked to prevailing weather patterns. The main factors determining the severity and extent of a bushfire are (NSW Government 2012):

- Weather conditions, including wind speed, temperature and relative humidity;
- Dryness of the fuel, the type of fuel and the fuel load;
- Physical structure of vegetation and the terrain in which the fire is burning; and
- Effectiveness of fire management actions.

The ecological effects of fires depend on:

- Intensity of a fire;
- Season of the burn;
- Previous fire history of an area; and
- Sensitivity of ecosystems affected.

A clear understanding of the spatial extent of land burnt by fire is important in identifying the potential impacts of bushfires on flora and fauna, catchment health, erosion and water quality.

6.8.3 Methodology

This audit examined the area and extent of land burnt by bushfire and hazard reduction burns and the management activities that have been undertaken to minimise the impacts of fire on water quality and catchment health in the Catchment.

6.8.4 Findings

Fire occurrence during the audit period

The audit period (2010 – 2013) was dominated by extended period of well-above average rainfall as depicted in Figure 6-26 below. This was particularly the case in 2010 and 2011 up to autumn of 2012.

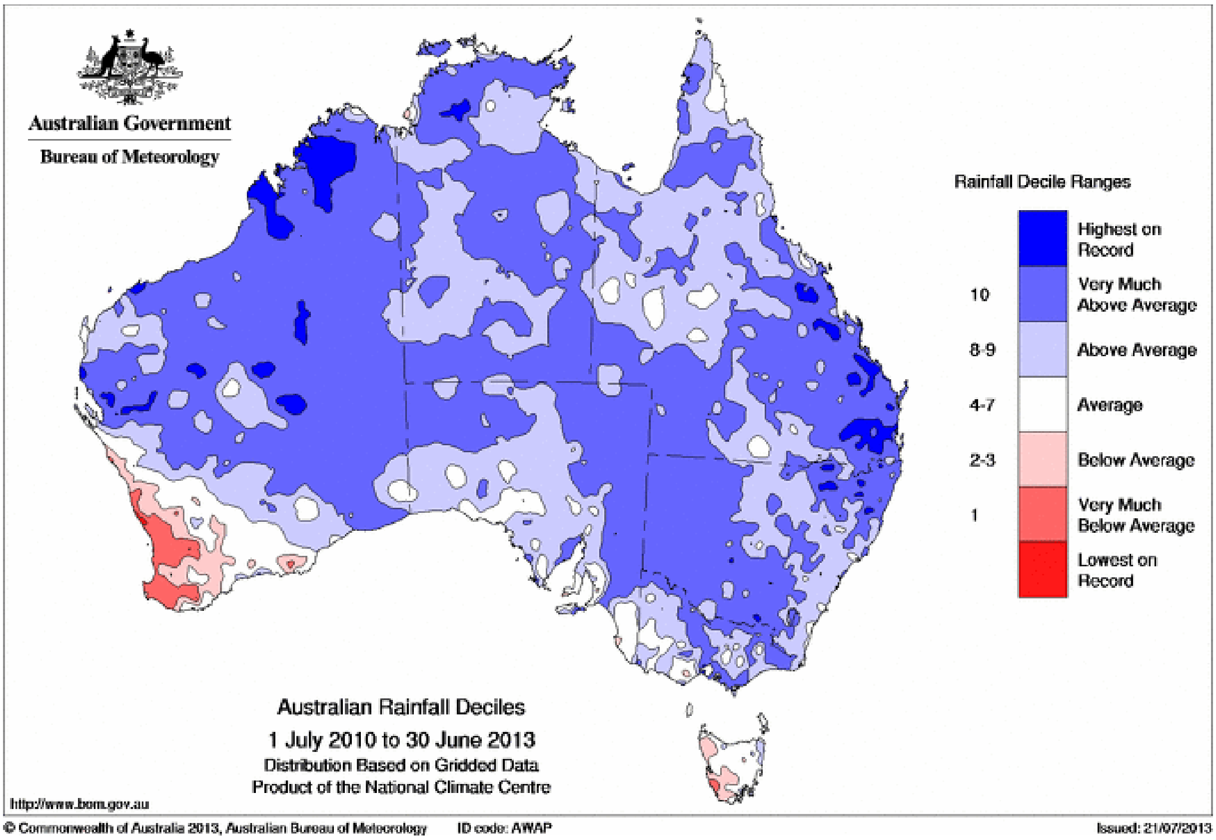


Figure 6-26 Rainfall deciles 1 JUL 2010 – 30 JUN 2013

Source: Bureau of Meteorology (BoM 2013)

Area burnt by bushfires in the 2010/11 and 2011/12 bushfire seasons was therefore significantly lower than average. Rainfall patterns then retreated from wetter than average conditions becoming drier than average through winter and spring months leading up to the summer fire season period of 2012/13. While the 2012/13 fire season was the warmest on record in south-eastern Australia, days with strong north-westerly winds during the summer were fewer than have occurred in high-consequence bushfire seasons in recent decades. Area burnt by bushfires in the 2012/13 fire season was generally close to average in the catchment area.

The area of the Catchment burnt by bushfires during the audit period is presented in Table 6-18. As a percentage of the total SCA Catchment Area (1,565,377 ha), the annual totals for bushfire-burnt areas amount to:

- 2010/11 0.135% of the catchment;
- 2011/12 0.00006% of the catchment; and
- 2012/13 0.12% of the catchment.

Table 6-18 Area burnt by bushfires during the audit period

Sub-catchment	2010–11[1]	2011–12[2]	2012–13[2]
Bungonia Creek			105.5
Kangaroo River	454		14.5
Kowmung River	249		
Lake Burragorang	369		3.5
Little River	616		0.1
Lower Coxs River		34.5	538.5
Mid Coxs River	130		29
Mid Shoalhaven River			2.5
Nattai River	56		4.5
Upper Coxs River	4		
Upper Nepean River	226		1097
Upper Shoalhaven River			1
Werri Berri Creek		63	
Wollondilly River	10		57
Woronora River			21
Annual Total	**2,114**	**97.5**	**1,874.1**

1 There was no bushfire data from OEH for the 2010/11 year therefore GHD used Data from SCA for 2010/11 (all burnt area assumed to be bushfire)

2 OEH fire history data used for 2011/12 and 2012/13

The area of the Catchment burnt by prescribed burning during the audit period is presented in Table 6-19. As a percentage of the total SCA Catchment Area, the annual totals for prescribed burn-treated areas amounts to:

- 2010/11 0.17% of the catchment;
- 2011/12 0.12% of the catchment;
- 2012/13 1.05% of the catchment.

The above analysis is in respect to the whole SCA Catchment. The Auditor notes that not all the catchment is treatable with prescribed fire. For example, a significant proportion of the catchment is private land tenure, and the SCA and NPWS are not responsible for applying fire management works on these lands.

There are also ranges of vegetation types in which low intensity prescribed burning are not normally practiced. Analysis of the proportion of the catchment treated by prescribed burning should be limited to only that proportion of the Catchment which supports vegetation types in which low intensity prescribed burning can be practiced.

Assuming these vegetation types are limited to Dry Sclerophyll Forests (grassy and shrubby sub-formations), Grassy Woodlands, Grasslands (native), and Wet Sclerophyll Forests (grassy sub-formation), and that analysis is limited only to the ‘Conservation and Natural Environments’ land use category then the total treatable area is 654,805 ha. As a proportion of this area, prescribed burn-treated areas amount to:

- 2010/11 0.42% of the prescribed burn-treatable catchment vegetation;
- 2011/12 0.29% of the prescribed burn-treatable catchment vegetation;
- 2012/13 2.51% of the prescribed burn-treatable catchment vegetation.

Table 6-19 Area treated with prescribed burning during the audit period[1]

Sub-catchment	2010–11	2011–12	2012–13
Bungonia Creek		5.5	1963
Grose River-Blue Mountains		3.5	58.5
Kangaroo River	381	481	1655
Kowmung River			4235.5
Lake Burragorang		6.5	
Little River	454.5		
Lower Coxs River		837	31.5
Mid Coxs River			6322.5
Mongarlowe River			216.5
Nattai River	1500.5		201.5
Nerrimunga River			577.5
Upper Nepean River	401.5	81.5	367.5
Werri Berri Creek		459	
Wingecarribee River			780
Wollondilly River			42
Woronora River			0.1
Annual Total	**2737.5**	**1874**	**16451.1**

[1] OEH prescribed burn history data used for all three years

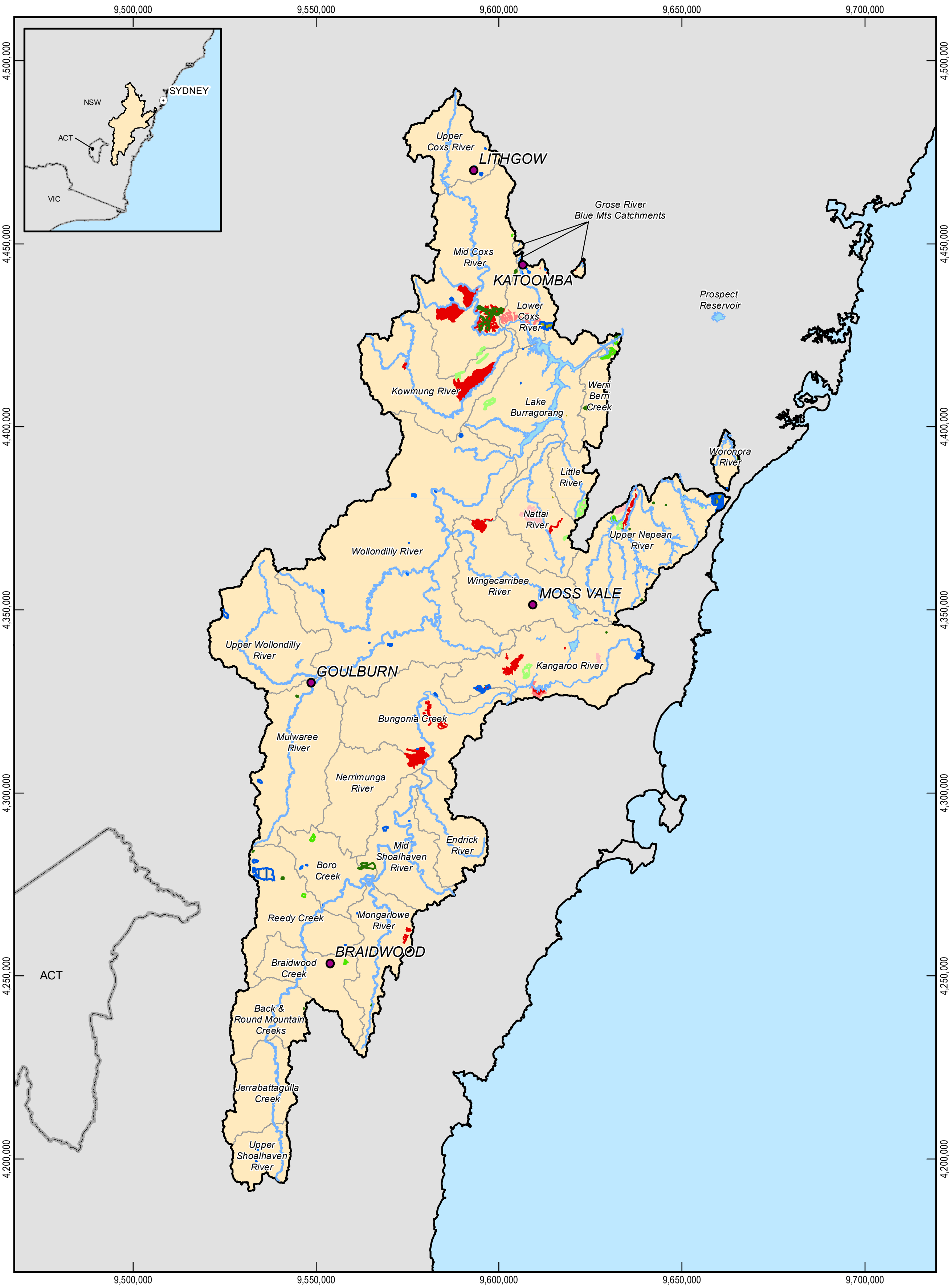
A significant increase in the scale of the annual prescribed burning program was achieved in 2012/13 (16,451 ha in 2012/13), which is more than an 8-fold increase on the previous year, and nearly 2.5 times more than the highest year from the previous reporting period (i.e. 6,765 ha in 2008/09).

Aggregated area burnt analysis 2007/08 to 2012/13

Cumulatively, over the six year period from 2007/08 to 2012/13, a total of 37,492 ha have been treated with prescribed fire (an annualised average of 6,249 ha per annum). Cumulatively, over the six year period from 2007/08 to 2012/13, a total of 46,362 ha have been burnt by bushfires (an annualised average of 1,060 ha per annum). The area burnt within the catchment is shown in Figure 6-27.

The total fire load (combination of prescribed fire and bushfire) over the past six years amounts to 43,854 ha. As a proportion of the total catchment area this is 2.8 % of the catchment in six years (annualised this is 0.47% per annum). As a proportion of the 'Conservation and Natural Environments' land use category component of the catchment this is 6.7 % over a six year period (annualised this is 1.1% per annum). This is a low proportion of the native vegetation in the catchment being burnt each year.

The Auditor notes in the 2001/02 fire season the catchment areas experienced large, widespread bushfires in the northern part of the catchment, which burnt at high-severity across very substantial areas. Further fires occurred in the Catchment in the 2002/03 season; however this were largely at the fringes of the catchment. Since 2003, relatively small areas have burnt within the Catchment. The general result is that with a very low extent of Catchment area burnt since 2003, a very high proportion of the native vegetation within the Catchment (exceeding 90 %) is carrying vegetation/fuels in the 10+ years' time-since-last-fire class (typically carrying an Overall Fuel Hazard Rating in the 'High' range). In the absence of major bushfire events or further significant expansions of the prescribed burning program, fuels across these areas will accumulate to Very High levels within the next 5 years.



LEGEND

- Town
- Drainage
- Waterbody
- SCA catchment boundary
- Sub-catchment boundary

SCA and RFS Fire History

- 2010-11 Wildfire
- 2011-12 Wildfire
- 2012-13 Wildfire

SCA Fire History

- 2010-11 HRB
- 2011-12 HRB
- 2012-13 HRB

OEH Fire History

- 2011-12 Wildfire
- 2012-13 Wildfire

- 2010-11 Prescribed Burn
- 2011-12 Prescribed Burn
- 2012-13 Prescribed Burn

Page Size A4

0 10 20 30

Kilometres

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 NSW lambert

N

Sydney Catchment Authority
Catchment Audit 2013

Bushfires and prescribed burns during 2010/11 to 2012/13 period

Job Number	2314960
Revision	0
Date	26 Nov 2013

Figure 6.27

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Level 6, 20 Smith Street Parramatta NSW 2150 Australia T 61 2 8898 8800 F 61 2 8898 8810 E ptamail@ghd.com W www.ghd.com

Data source: © Commonwealth of Australia (Geoscience Australia): 250K Topo Data (2007); SCA: boundaries, fire history (2013); RFS: fire history (2013); OEH: fire history (2013). Created by: KP

Whilst this will be within tolerable fire regime thresholds, the disproportionately large area in this time-since-fire class serves to increase the risk of large scale fire occurrence. This is a strategic management issue for consideration in considering more quantitative fire management objectives. The Auditor is aware that SCA are currently in the process of initiating a strategic review of SCA's role and strategies for fire management.

Activities in the catchment

There were a number of activities in the Catchment related to bushfire management including community engagement and arson prevention. The Hotspots Fire Project involves state agencies and non-government organisations and provides landholders and land managers with the skills and knowledge they need to protect life and property while protecting and maintaining biodiversity. The project promotes the understanding that well-informed and prepared communities complement the roles of land managers and fire agencies.

Bushfire Management Committees (BFMC) are responsible for establishing Bush Fire Risk Management Plans. In the Catchment, the SCA, Rural Fire Service (RFS), NPWS, neighbouring landholders and Local Councils actively participate within the BFMC. As a landowner and manager, the SCA, under the Rural Fires Act 1997 is required to take all practical steps to prevent and minimise the spread of bushfires on, or from, SCA land. The SCA has first response strategies, annual hazard reduction burning and slashing programs for the Special Areas. A Catchment Remote Area Fire Team (CRAFT) program between SCA and NPWS to deploy seasonal fire fighters, including helicopter air support for initial wildfire response is in place for the Special Areas.

The SCA aims to respond to 80% of fires in Special Areas within 30 minutes of detection, containing them to less than 10 ha. The CRAFT seasonal team attended four fires during 2010/2011, three of those in the Warragamba Special Area and one in the Metropolitan Special Area (SCA 2011a). All but one fire were attended within 30 minutes of detection, with the other responded to within one hour. The average response time was 37 minutes and all fires were contained to less than 10 ha. In 2011/2012 the average response time was 30 minutes for all fires and two of the four fires were contained to less than 10 ha. The two fires that exceeded the 10 ha threshold burnt 29 and 150 ha (SCA 2012a).

Hazard reduction burns were undertaken in 2010-11, reducing the fire hazard for 2,533 ha of National Parks estate within the Metropolitan and Warragamba Special Areas. The SCA uses monitoring and evaluation to determine the impact of severe wildfires on catchment waterways and to determine the water quality impacts of fire fuel retardants.

The Wingecarribee Shire Council is a member of the Wingecarribee BFMC and is working closely with the RFS and Fire and Rescue NSW to develop a strategic approach to fire management across the Wingecarribee Shire.

The Wingecarribee Shire Council has developed a number of fire mitigation activities including:

- Bush Fire Management Plans for Mt Gibraltar, Gibbergunyah and Mt Alexandra Reserves;
- Inspecting bush fire hazard complaints relating to Council managed land with the RFS and Implementing Asset Protection Zones;
- An ongoing program of fuel reduction works on Council managed land to provide greater protection for vulnerable residences, Strategic Fire Advantage Zones, Ecological burns and Asset Protection Zones;
- Pre and Post hazard Reduction Weed Control and fire trail maintenance;
- Bush fire risk management assessment for Mt Gibraltar & Mt Alexandra Reserves;
- Community education.

Gundary Travelling Stock Reserve

Fire has been used to manage the Natural temperate grasslands EEC at Gundary Travelling Stock Reserve, near Goulburn. The Gundary Travelling Stock Reserve contains one of the best Natural Temperate Grassland sites in the Southern Tablelands. The site also hosts two threatened species: the endangered Button Wrinklewort and the vulnerable Striped Legless Lizard. The grassland hosts a variety of flora species including the dominant grasses (Kangaroo Grass, Brush-tailed Speargrass and a variety of wallaby grasses) as well as a huge variety of wildflowers, including orchids, peas, daisies and lilies.

Many of the sensitive grassland species have been retained at Gundary due to a lack of grazing pressure. However, at some sites a layer of dead thatch may build up and threaten the diversity of the site. In the total absence of grazing or other biomass control, ultimately even the dominant grasses can lose vigour and die, leaving sites vulnerable to weed invasion. Because of the size of Gundary Reserve, it has not been possible to apply a large enough amount of stock for short enough periods of time to remove biomass without the stock affecting the more sensitive species on site. It is for these reasons that the Tablelands Livestock Health and Pest Authority has been applying fire as a management tool at Gundary.

The fire management of Gundary has been occurring for a number of years now, with one hectare burns applied by the local Rural Fire Service brigade. Inspection of the burn sites in the following spring after each of the winter burns reveals vigorous growth of wildflowers that are freed from the competition of the Kangaroo Grass.

The SCA has provided funding to the Clifftop Landcare Group to provide post fire weed and sediment control on private properties adjoining Council and NPWS Reserve (SCA 2012a).

Fire management regimes to manage risk and impact of bushfires are being implemented across the Catchment through the Bushfire Management Committees. Data of fires within the Catchment are included in the RFS managed Bushfire Risk Information Management System.

6.8.5 Recommendations

RFS undertakes an annual process of integrating fire history data into a single, quality controlled and validated dataset distinguishing between bushfire and prescribed burns. As part of this process the annual review should include ground truthing a portion of the data to ensure that declared burns match actual burn areas.

The Auditor is aware that SCA undertakes on-going review of its fire management program, giving due consideration to the accumulating fuel profile across the Catchment. This information is used to establish fire management objectives and priorities, which should continue.

7. Conclusions and Recommendations

7.1 Review of the 2010 Recommendations

The 2010 Audit (DECCW 2010a) made a number of recommendations, which were largely aimed at improving the 'knowledge-base' of catchment information, and how data and information could be linked with the assessment of catchment health.

Detailed submissions were received and a summary of the responses is given in Volume 2 Appendix C and D (SCA 2013a; 2013g).

7.2 Conclusions of the 2013 Audit

This section highlights the key findings and outcomes of the 2013 Audit, based on the data and information provided by various stakeholders.

7.2.1 General comments

In conducting the Audit with the gazetted performance indicators, the following observations and suggestions are made to enhance future Catchment Audit outcomes.

Several criteria could be improved by updating the analysis techniques applied to the data. This can be illustrated with the following examples:

- The Macroinvertebrate Indicator is currently limited to AUSRIVAS, although the same data can be used to generate a SIGNAL2 score. SIGNAL-2 scores were reported annually by both the SCA and OEH with macroinvertebrate data. Other relevant indicators for reporting would be macroinvertebrate 'richness' and Ephemeroptera-Plecoptera-Trichoptera (EPT) Taxa, which can also be generated by the same data.
- In the reporting on the Surface Water Availability Indicator, it would be valuable to include the changes in storage levels in the Catchment's dams, and change over time of those storage levels. Given the importance of climatic changes on the Catchment's water resources, it would also be meaningful to assess the impacts of climatic conditions (i.e. rainfall) under the Surface Water Availability Indicator and report on the direct correlations between meteorological conditions in the Catchment and water resources, both in catchment streams and rivers, and storages.

Given that the audit is a legislative requirement, the SCA and other agencies should be well prepared to provide the Auditor with relevant and accurate data and information for the audit, before the Catchment Audit commences.

Anticipating delays in collating information from multiple stakeholders, it is necessary to call for the required data from various data custodians, well in advance. Obtaining data and information in a timely manner is crucial to an effective assessment that fulfils the legislative requirements of the audit. Therefore, the SCA needs to commence the Audit process at least six months prior to the 30 November Ministerial deadline, to ensure that sufficient time is available to advertise calling for submissions, and to collate data and information from other Government Departments.

A common theme of previous audits that also emerged in the 2013 Audit is the disparate ways in which data on the Catchment Health Indicators are maintained and updated. Coordination and leveraging of monitoring programs to maximise the range of biodiversity indicators collected at sites would enable Catchment Health outcomes to be evaluated more holistically and ensure that this information is available for the next audit.

The SCA lead the implementation of an integrated ecosystem health database to collate and maintain information for the catchment with support from OEH and other government agencies. The spatial database should contain all data and metadata required for the assessment of the gazetted Catchment health indicators (**Recommendation 1).**

7.2.2 Specific comments on Indicators

The following sections provide a synthesis of the most significant findings of the 2013 Audit under each of the 18 Indicators.

Land use and Human Settlements

Land use: Measuring any changes in land use patterns within the Drinking Water Catchment is important, because significant changes could have impacts on the Catchment's water resources (both quantity and quality). Of the 1.6 million ha of the Catchment, >50% areas is classed as conservation and natural environments. In this category, the SCA manages approximately 93,000 ha (about 5.8%) of Special Areas land in the more sensitive areas, to protect water quality. Minor changes in land use (about 0.2%) occurred during the audit period, this being a small decrease in the Production from Dryland Agriculture and Plantations category, and a slight increase in the Water category. The increase in the water category reflected an increased number of farm dams. There was a minor, overall decrease in the Intensive Uses category, within this category, an increase of 71 ha occurred in the Mining classification.

The Audit found that the SCA, Local Councils and other stakeholders have implemented various, and quite effective measures (such as NorBE assessments for all development applications) to manage land use across the Catchment.

Mining Impacts: Mining in the Catchment is perhaps the most significant issue identified by this audit, and by previous audits, requiring management to reduce impacts on water resources. The 2013 Audit documents various impacts that have occurred. These impacts were largely related to geological impacts (such as fracturing, subsidence and cracking, as a result of longwall mining), which may affect surface water flows and quality, and groundwater levels. There were also examples of mining reported where a detrimental impact to water quality and quantity was not observed.

The 2013 Audit found that negative impacts of longwall mining on aquatic or terrestrial biota were not well documented. However, the reviews of data and information from previous studies and reports indicated that ecological communities, such as upland swamps, were impacted by longwall mining. Limited site inspections, conducted during the current Audit, confirmed these findings.

The Auditor endorses the approach taken by stakeholders to collaboratively set the guiding principles for approving mining applications and for developing guidelines to mitigate those mining impacts. To effectively manage the potential impacts of mining in the Catchment, particularly in the Special Areas, the SCA shall continue to recommend approval conditions for mining within the Special Areas which are consistent with their Principles for Managing Mining and CSG impacts (**Recommendation 2**).

Sensitive, upland swamps in some sub-catchments, affected by longwall mining, have begun to show deterioration in condition, particularly of native vegetation and surface water availability. Hence, the precautionary principle should apply in these areas until more data are collected and clear management guidelines are implemented. The Audit recommends OEH should finalise the Upland Swamp Environmental Assessment Guideline for whole of Government consideration and endorsement. The Guideline should provide clear and robust measures of swamp significance and impact (**Recommendation 3**).

As a precautionary approach the Audit recommends that approval conditions be set considering risk management zones around ecological features, such as streams and swamps that have 'special significance status'. Risk management should aim to achieve nil or negligible impact to 'significant' features. Where the conditions required to achieve nil or negligible impact cannot be determined then mining should be excluded by a lateral distance of 400 m on each side of the feature or, if greater, by a 40° projection angle from the vertical down to the coal seam which is proposed to be extracted, as detailed in the Strategic Review (DoP 2008a). (**Recommendation 4**).

Proper assessment of mining impacts, particularly, long-term and cumulative impacts, is crucial for the future management of the Drinking Water Catchment, to safeguard water resources. In this regard, the Auditor commends the work already done by the SCA, Dam Safety Committee (DSC), OEH, NOW and other stakeholders. However, these organisations need to finalise clear management guidelines for all mining activities covering all Catchment areas, including Special Areas. This will ensure that they can be implemented by the relevant agencies and facilitate clear understanding around the definition of the severity of impacts and the requirements for baseline, on-going and post-mining monitoring and rehabilitation.

The Auditor recommends that SCA in consultation with OEH, DPI, DP&I, NOW and Sydney Water assess the potential cumulative impacts of all mining activities within the designated Special Areas (**Recommendation 4**). In addition to this activity the DPI, SCA, OEH, NOW, DP&I and Sydney Water should collaborate to develop a risk assessment methodology to assess the impacts of mining, CSG and industrial developments on water resources in the Catchment (**Recommendation 5**).

Sites of Pollution and potential contamination: The SCA, in partnership with Local Councils and NOW, have funded the upgrade of a number of STPs through the Accelerated Sewerage Program. The EPA continues to monitor sites across the Catchment, and enforce conditions to mitigate pollution and improve catchment protection practices through EPLs. However, an opportunity exists for SCA to work with Local Councils to assemble information in relation to compliance and enforcement activities for non-licensed premises. There is also an opportunity for Sydney Water to their Catchment to Tap risk assessments for the Blue Mountains to ensure that dry weather sewer overflow discharges are minimised (**Recommendation 6**).

Many industries have undertaken positive steps to reduce discharges into waterways, implementing pollution reduction programs. These are likely to further improve water quality in the Catchment's streams and rivers. The SCA has also significantly improved its awareness of sites and areas of potential pollution impacts within the Catchment through the development of the PSAT. The SCA has implemented a number of on-ground works programs, as well as training and education programs, aimed at targeting the most significant pollution sources.

Soil erosion: Erosion in the catchments is a long term issue, with many gully erosion sites pre-dating 1979. The extent of soil erosion was difficult to assess without updated data. With funding and facilitation by the SCA, HNCMA and SRCMA, erosion mitigation works continue to be undertaken in the high-risk sub-catchments and drainage units under the Catchment Protection Scheme (CPS) and other programs. These programs were progressing well, and their success will improve the condition of existing erosion sites. The Auditor supports the efforts of stakeholders to actively promote good land management practices across the Catchment. These will reduce future occurrences of soil erosion.

The mapping of 'locked-up' riverbank (i.e. fenced riparian corridor) would inform where stream-bank erosion is significant in the Catchment, and where such erosion could be stabilised through revegetation of remediated 'locked-up' areas. There would be value in OEH and other stakeholders mapping the extent of streambank riparian vegetation and evaluating the extent and impact of 'locked-up' riverbanks in selected drainage units within the Catchment to assess the effectiveness of catchment improvement activities.

Population settlement and patterns: The Catchment's population of 113,042 increased only by 4.1% during the audit period, and these increases were largely in the sub-catchments, which contain the major urban centres (i.e. Moss Vale, Mittagong, Bowral, Lithgow and Goulburn). The critical aspect in this regard is to ensure that developments that are approved by either the Local Government or State Government agencies do not impact on the water resources of the Catchment. The 2013 Audit found that the SCA and other stakeholders have developed effective management tools (i.e. NorBE assessment) to address on-going population settlements, and these are being stringently implemented.

Community attitudes and aspirations: Community engagement and participation in managing natural resources in the Drinking Water Catchment is regarded as crucial to sustainable management of the Catchment. The Audit found increasing efforts being made by the appropriate agencies to engage with and support Landcare and other groups, including indigenous groups. The Auditor endorses continued prioritisation of soil erosion and water quality issues for community engagement and capacity building programs.

Water availability

Surface Water: Consistent with the general increase in environmental flows released from the nominated SCA storages, the current audit period generally saw an increase in the daily flows passed through each flow monitor, compared to previous audit periods and long-term data, with some exceptions. The increased flows at most locations were despite a reduction in Raw water Transfers, carried out by the SCA. At nine locations, reduced flows less than the long term medians were recorded, and at one location, flows had declined greater than 50%. Such data suggested stress on the flows within those watercourses, or lower rainfall captured in contributing sub-catchments.

It would be beneficial for SCA to audit all gauge stations to correct basic metadata errors prior to the next audit period (for example, some inconsistences were noted during the current Audit in the spelling of or factual errors in gauge names). It would also be beneficial if all the necessary data for the Catchment including dam storage levels, catchment rainfall volumes and the assessment of volumes that are extracted by current water entitlements be integrated into the one spatial database prior to future audits (see **Recommendation 1**).

Environmental flows: The current audit period saw a reduction in raw water transfers, which balance water availability across the Catchment and between the various water supply structures. However, these reductions were consistent with an increase in the environmental flows released from the various storage facilities under the new 80/20 flows policy. Future audits would benefit from data and information that demonstrates the links between specific activities in the Catchment that had been undertaken to maintain or alter the environmental flow regimes within each sub-catchment.

The assessment of the effectiveness of environmental flows would also benefit from the construction of a central database for the collation of Catchment data and supporting metadata including the locations of barriers to environmental flows, such as the weirs downstream of dams (**Recommendation 1**).

Groundwater: Extraction of groundwater for drinking water, agriculture and industry can place significant stress on the resource. Unless well managed, groundwater extraction can significantly modify catchment hydrology by reducing the water available for other beneficial uses, such as environmental water requirements. Targeted analyses of long term groundwater level trends at ten locations within the Sydney Drinking Water Catchment showed that most declining groundwater level trends could be attributed to rainfall trends and seasonal groundwater abstraction, presumably from irrigation/farming activities, and not to mining abstraction.

Additionally, fluctuations in groundwater levels are seasonal, or short term, which indicate natural seasonal trends, and/or possible, interactions with seasonal groundwater users for irrigation, stock or domestic purposes. The sustainable allocations/entitlements presented in the groundwater sharing plans and related report cards appear to be suitably preventing long term reduction in groundwater elevations.

There was insufficient data available to assess groundwater quality changes within the Catchment. Hence, NOW should extend existing monitoring to include groundwater quality data as well as groundwater levels to establish a baseline for groundwater resources in the Catchment (**Recommendation 7**).

Water quality

Ecosystem water quality: The 2013 Audit found that water quality at catchment sites and storages was variable, as in previous audit periods, but had not deteriorated in any significant way. Water quality parameters, including nutrients (N and P), either occasionally, or regularly, exceeded benchmarks at various sites (primarily those with significant agricultural or urban development). Water quality in waterways or storages, located in sub-catchments with more natural characteristics, including vegetation cover (e.g. Woronora River, Cordeaux River, Nepean River) was noticeably better than catchments with human development (e.g. Wollondilly River, Wingecarribee River, Shoalhaven River), which highlights the important function of Special Areas in protecting water quality.

Protozoan pathogens - *Cryptosporidium* and *Giardia* (oo)cysts were detected infrequently at low concentrations at some catchment sites. Occasionally, elevated concentrations of pathogens were found at a few Catchment sites. The Audit recommends the SCA should refine investigation of hotspots of sporadic *Cryptosporidium* contamination to sites not proximate to STPs to determine the sources, genotypes and potential human health risks (**Recommendation 8**).

Nutrient Loads: Nutrient enrichment (eutrophication) of waterways could result from both point source and diffuse source nutrient loads. The level of compliance of sites of point source nutrient inputs with their respective Environment Protection Licences (EPLs) was somewhat variable, but not significantly different from previous audit periods. Overall, most non-compliances were related to nutrient loads, pH and volumes discharged (particularly, under wet conditions) and monitoring requirements.

All of the STPs in the Catchment have made significant improvements to STP performances, and these will contribute to better catchment health, over time. Stricter enforcement of EPL conditions by the regulators - the EPA and SCA - may contribute further to improved performances, and mitigate adverse impacts of nutrients on the Catchment's waterways.

The data and information, available to the SCA or OEH are not yet adequate to characterise diffuse sources of pollution across the Catchment. None of the previous modelling efforts have been adequately ground-truthed with sub-catchment water quality or flow data, even for relatively small drainage units. The required approach to modelling is also yet to be agreed upon by multiple stakeholders. The SCA's existing PSAT tool is a very useful tool that assists in the identification of priority drainage areas. Further improvements to the PSAT modules are in progress, and these would further enhance the SCA's capacity to identify priority areas, which are sources of diffuse nutrient pollution. The Auditor recommends the SCA use the existing data (including PSAT) to develop a predictive tool to evaluate catchment management scenarios for the reduction of diffuse sources of nutrient pollution (**Recommendation 9**).

Cyanobacterial blooms: Water quality at catchment sites, as well as in storages varied with regard to phytoplankton (and cyanobacterial) growth. However, the quality of water in the storages was generally good during the audit period and posed no threat to drinking water supplies in terms of cyanobacterial blooms, or to recreational users or ecological communities, according to ANZECC benchmarks.

The SCA has made significant progress with regard to understanding the risks to water quality in the catchment streams and storages, posed by cyanobacteria. The Auditor commends the SCA for investing well in cyanobacterial research during the past few years, and for initiating pre-emptive planning to manage those risks, if and when cyanobacterial blooms do occur at a future date.

Long-term trend analyses: Long-term water quality datasets from monitored sites are extremely valuable for the on-going management of the Catchment. The examination of the SCA's long-term water quality data from catchment sites and storages using statistical techniques, indicated that several important parameters (such as Chl-a, EC, TN and TP) showed significant, increasing or decreasing trends in the sub-catchments. For instance, TN concentrations were detected to be decreasing by 0.22 mg/L in Farmers Creek and by 0.298 mg/L in Gibbergunyah Creek in the Warragamba Catchment. In contrast, the most notable increasing TN trends were in the Gillamatong Creek (Shoalhaven Catchment) and in the Nepean River (Upper Nepean Catchment), where concentrations were detected to be increasing by 0.016 and 0.014 mg/L/year, respectively.

Rather than undertaking another long-term trend analysis or Catchment wide water quality modelling exercise the Auditor recommends the SCA undertake targeted projects to ground-truth the effectiveness of Catchment improvement activities at a drainage unit scale to verify the prioritisation of on-ground works via PSAT and use this information as feedback to the Land Management Database (**Recommendation 10**).

Biodiversity and Habitats

Native vegetation: No new native vegetation condition information was available for the 2013 Audit, which constrained the assessment of any changes over time in native vegetation cover and condition. Lack of updated information also limited the capacity of the Auditor to identify emerging issues affecting native vegetation in the Catchment. Information on the extents of weeds, or levels of weed infestations, was also not readily available on a sub-catchment basis. The Audit makes a recommendation for OEH and CMAs to investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period (**Recommendation 11**).

The 2013 Audit found that a large portion of the Catchment is cleared (37.6 %) and several sub-catchments have poor native vegetation cover (i.e. Upper Wollondilly River - 16.3 %; and Mulwaree River - 28.8 % cover). In contrast, each of the Little River, Lower Coxs River and Endrick River sub-catchments recorded greater than 90% cover of native vegetation. The Audit documented many programs in sub-catchments, implemented by various stakeholders, which continue to reduce the pressure of weeds and improve the condition of native vegetation.

All catchment management stakeholders would benefit from further efforts to integrate all ecosystem health indicators, including native vegetation condition, into a more comprehensive understanding of stream and catchment health. This would enable a more focussed and better prioritised management response to catchment conditions.

Riparian vegetation: Previous audits had used the Riparian Connectivity Index (RCI) and a Riparian Vegetation Index (RVI) to assess changes over time. However, the 2013 Audit found that these indices have not been updated by stakeholders, which constrained the assessment of the extent and condition of riparian vegetation in the Catchment during the audit period (see **Recommendation 11**).

Despite the limitation on riparian data, the assessment of information revealed a high level of investment by the SCA, CMAs and Local Councils in protecting and rehabilitating riparian vegetation in the Catchment. These programs include native vegetation protection under conservation agreements, limiting stock access, and removing weeds from riparian zones, contributing to improved health of riparian zones and protection of water quality.

Physical form: The Riverstyles spatial layer, updated in 2012, provided a finer scale of coverage of waterways in the Catchment. The assessment found that 57% of stream reaches within the Catchment to be in either good condition, or in a protected area; these were mainly in Endrick River, Bungonia Creek, Kangaroo River and Upper Shoalhaven River sub-catchments. However, 39 % of reaches (mainly in the Upper Wollondilly River, Mulwaree River, Boro Creek, Braidwood Creek and Back and Round Mountain Creek sub-catchments) were in moderate or poor condition. The assessment of the recovery potential of streams within the Catchment to categories of reaches with high, moderate or low potential, has allowed stakeholders to prioritise future works, and plan according to the specific needs of reaches (i.e. either immediate protection strategies, or phased rehabilitation.

Wetlands: Wetland mapping in the Catchment has not occurred at a frequency which enables changes in wetland extent or condition to be assessed. Furthermore, there is presently no standardised procedure for assessing the condition of wetlands. The Auditor recommends the OEH, SCA, CMAs and other relevant agencies collaborate to develop and apply a standardised procedure for assessing the extent and condition of wetlands in the Catchment (**Recommendation 12)**.

Long-term data and information on the condition of wetland types in the Catchment were only available for individual swamps (e.g. Wingecarribee Swamp). Positive catchment protection outcomes include swamp restoration works at several major wetlands in the Catchment, which have been completed, or are in progress. There are, however, continued impacts from longwall mining to upland swamps, particularly in the Metropolitan and Woronora Special Areas.

Fish: There was an increase in native fish species collected from the Catchment's waterways during 2010-13 compared with previous fish surveys. The greatest diversity of fish species were found in the sub-catchments of Bungonia Creek, Kangaroo River, Upper Nepean River and the Wollondilly River. Waterways in many other sub-catchments remained low in species diversity, and despite continuing works to improve fish passages, significant barriers to fish movements still remained, particularly in the Wollondilly River, Kangaroo River, Mid and Upper Coxs River sub-catchments. A positive outcome was the collection of 97 Macquarie Perch, listed as endangered under the *FMA 1994*, from the Little River, Mongarlowe River and Upper Nepean River sub-catchments during 2010-13.

The Auditor suggests the LMDB, a collaboration between OEH, SCA and the CMAs, could be used by the DPI (Fisheries) to track and record information on all fish passage and fish habitat improvement on-ground works being undertaken or funded by government. To facilitate a more holistic interpretation of biodiversity criteria across the Catchment the Auditor recommends the SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (**Recommendation 1**) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection (**Recommendation 13**).

Macroinvertebrates: The Audit found a decrease in the condition of macroinvertebrates at a significant number of sites in the Catchment during the current Audit period. The decline was most notable in the southern part of Catchment, including Bungonia Creek, Upper and Mid Shoalhaven River, Kangaroo River, Endrick River, Mongarlowe River. The reasons for this decline are not known, and require further investigations. The sensitivity of macroinvertebrate communities to 'in-stream' conditions, particularly flows, hydraulic features, and water quality variables (especially those arising from agriculture), are well-known and hence there are several possible causes for the noted decline. The Auditor recommends the SCA and OEH investigate the causes of the decline in the condition of macroinvertebrates at core sites in the Catchment (**Recommendation 14**).

Fire: Since the last major fire events of the 2000-03 drought, <10% of the Catchment has been burnt, either by bushfire or prescribed fire. This has resulted in widespread fuel accumulation to high levels across more than 90% of native vegetation areas in the Catchment. Without either major bushfires, or substantial increases in prescribed burning programs, these fuel loads are likely to increase to very high levels in future years. However, as a positive development, in 2012/13, an eight-fold increase in prescribed burning over the previous year was achieved.

7.3 Recommendations of the 2013 Audit

The justifications for recommendations on each of the Catchment Indicators were provided in each section. Given below are the final recommendations from this 2013 Audit.

7.3.1 Audit methodology

Recommendation 1:

The SCA lead the implementation of an integrated ecosystem health database to collate and maintain information for the catchment with support from OEH and other government agencies. The spatial database should contain all data and metadata required for the assessment of the gazetted Catchment health indicators.

7.3.2 Land Use and Human Settlements

Recommendation 2:

The SCA shall continue to recommend approval conditions for mining within the Special Areas which are consistent with their Principles for Managing Mining and CSG impacts.

Recommendation 3:

OEH should finalise the Upland Swamp Environmental Assessment Guideline for whole of Government consideration and endorsement. The Guideline should provide clear and robust measures of swamp significance and impact.

Recommendation 4:

DP&I approval conditions should be set considering risk management zones around ecological features, such as streams and swamps that have 'special significance status'. Risk management should aim to achieve nil or negligible impact to 'significant' features. Where the conditions required to achieve nil or negligible impact cannot be determined then mining should be excluded by a lateral distance of 400 m on each side of the feature or, if greater, by a 40° projection angle from the vertical down to the coal seam which is proposed to be extracted, as detailed in the Strategic Review (DoP 2008a).

Recommendation 5:

DPI, SCA, OEH, NOW, DP&I and Sydney Water should collaborate to develop a risk assessment methodology to assess the impacts of mining, CSG and industrial developments on water resources in the catchment.

Recommendation 6:

Sydney Water reviews their Catchment to Tap risk assessments for the Blue Mountains to ensure that dry weather sewer overflow discharges are minimised.

7.3.3 Water Availability

Recommendation 7:

NOW should extend existing monitoring to include groundwater quality data as well as groundwater levels to establish a baseline for groundwater resources in the Catchment.

7.3.4 Water Quality

Recommendation 8:

The SCA should refine investigation of hotspots of sporadic *Cryptosporidium* contamination to sites not proximate to STPs to determine the sources, genotypes, and potential human health risks.

Recommendation 9

The SCA use the existing data (including PSAT) to develop a predictive tool to evaluate catchment management scenarios for the reduction of diffuse sources of nutrient pollution.

Recommendation 10:

The SCA undertake targeted projects to ground-truth the effectiveness of Catchment improvement activities at a drainage unit scale to verify the prioritisation of on-ground works via PSAT and use this information as feedback to the Land Management Database.

7.3.5 Biodiversity and Habitats

Recommendation 11:

OEH and CMAs should investigate the potential to update the data on the extent and condition of native and riparian vegetation in the Catchment for the next audit period.

Recommendation 12:

OEH, SCA, CMAs and other relevant agencies collaborate to develop and apply a standardised procedure for assessing the extent and condition of wetlands in the Catchment.

Recommendation 13

The SCA and other government agencies ensure that all monitoring program sites are incorporated into a spatial database (**Recommendation 1**) to enable agencies to coordinate and leverage programs across the Catchment to promote systematic data collection.

Recommendation 14

The SCA and OEH should investigate the causes of the decline in the condition of macroinvertebrates at core sites in the Catchment.

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GHD

133 Castlereagh St Sydney NSW 2000
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T: +61 2 9239 7100   F: +61 2 9239 7199   E: sydmail@ghd.com.au

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Rev No.	Authors	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
1	N. Chandrasena D. Baker M. Presswell S. Claus C. Ferguson			C. Ferguson		27/11/2013

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