On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment

NSW Chief Scientist & Engineer

May 2014

The Hon Michael Baird MP
Premier
Minister for Infrastructure
Minister for Western Sydney
Parliament House
SYDNEY NSW 2000

Dear Premier,

On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment

On 20 January 2014 the Minister for Resources and Energy wrote requesting that I build on the Initial Report on the Independent Review of Coal Seam Gas Activities in NSW to "specifically examine the cumulative impact of all activities which impact ground and surface water in the Sydney Water Catchment Special Areas".

The Minister asked that I provide my findings by May 2014 and I now submit the report to you and the Minister as requested.

After studying the Sydney Catchment and the major current and possible future activities in it, the Review examined current approaches to assessing cumulative impact and noted their limitations. This led to an investigation of whether a more quantitative approach was possible. The Review brought together acknowledged experts in a range of relevant disciplines to examine the core question of measuring cumulative impact of activities in the Catchment. Their conclusion was that there is insufficient data available at present in a coherent form to provide a deep and reliable understanding of cumulative impact in the Catchment. With more data, models can be built to provide a framework for examining predictions of cumulative impact and a mechanism for explaining measured impacts and attributing them to the most likely causes.

Accordingly, I make five recommendations in this report to address the need for better whole-of-Catchment data, risk assessment, monitoring, computational models, data visualisation tools and ongoing expert advice and analysis to assess cumulative impacts on the Catchment.

In presenting this report I wish to acknowledge the assistance of many people – in particular the experts who took the time to contribute to the understanding of this complex issue and the Review team who worked hard to develop this report.

Yours sincerely

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30 May 2014

EXECUTIVE SUMMARY

This Review was commissioned in response to the request from the Minister for Resources and Energy "to build on the Initial Report on the Independent Review of Coal Seam Gas Activities in New South Wales to specifically examine the cumulative impact of all activities which impact ground and surface water in the Sydney Catchment Special Areas" with the aim of providing "greater factual information about how the industry and other factors might influence the status of the Sydney Catchment area".

Having a thorough understanding of the cumulative impact of activities on Sydney's major water supply is important because the Catchment contains some of the best coal seams in NSW close to shipping. These seams have been mined for high-grade coal since before the Catchment was officially declared as such. The seams are also a potential source of coal seam gas. Many reports have addressed how individual activities might impact the water in the Catchment. However the State needs to ensure that the cumulation of the various activities in time and space is not having deleterious effects on Sydney's drinking water supplies.

In recent decades, companies proposing development have been required to address cumulative impact when submitting environmental impact statements as part of applications for development consent. Typically, this has involved making an intelligent assessment of whether there could be any cross impact from the proposed development on areas affected by existing developments. This is generally not a quantitative assessment. In recent years two process initiatives have led to improvements in approaching and managing for cumulative impact. The first could be best described as adaptive management. It involves understanding what is likely to be impacted, putting preventative or minimisation measures in place and then devising a way to proceed with care. While this is primarily applied to single activities, it also assists with picking up impacts that could be (unwittingly) caused by cumulative activities. The other process is the use of region-scale planning. Both processes are in widespread practice around the globe and, in this context, NSW is competent in their implementation.

The limitation with current approaches to managing for cumulative impacts is that they provide techniques for moving forward cautiously in sensitive but imperfectly characterised domains. They are unlikely to provide significant information on effects that start small and rapidly grow; nor can they provide much insight into causes of observed unexpected effects.

After studying current approaches to cumulative impact and after gaining an understanding of the Sydney Catchment and the likely impacts of individual major current and possible future activities in it, the Review investigated whether a more quantitative approach to cumulative impact was possible. It brought together acknowledged experts in a range of relevant disciplines (water provision, catchment management, water quality, mining, coal seam gas extraction, geology, geophysics, geotechnical engineering, groundwater modelling, data analytics and data management) to examine the most basic version of the question of measuring cumulative impact of activities in the Catchment on provision of drinking water. This question can be phrased as follows:
For any given new event in the Catchment (e.g. a longwall mine or a new coal seam gas well), can we predict and measure (and in turn check predictions) any changes over time on the quality and quantity of water leaving the Woronora and Metropolitan Special Areas into the upper canal, or leaving Warragamba Dam into the pipelines to Prospect Reservoir?
In other words, can we predict what is going to be the total impact of the new activity happening in parallel with existing activities in the Catchment? Can we predict the impacts at the planning stage? Do we know what to look for and when to measure impacts in particular

on the quality of drinking water entering the water filtration plants and on the quantity of water available to supply these filtration plants?

Consensus among the experts consulted was reached relatively quickly: answering these questions with quantitative precision is impossible at present given insufficient geological, geophysical and hydrogeological data available on current activities. If such data were available, they would drive data fusion models of the Catchment or allow the construction of more conventional deterministic, parametric models. If such models could be built, they would provide the framework for examining predictions of cumulative impacts and would provide a mechanism for explaining measured impacts and attributing them to the most likely causes.

The experts also recommended that useful insights could be gained by breaking the problem down into cumulative impact issues associated with i) water quality, ii) water quantity and iii) whole-of-Catchment issues.

The experts pointed out that most quality issues whether from one activity or from the cumulation of several activities can be dealt with through the combination of barrier management in the Catchment and treatment at the water treatment plants, fields in which Australia has considerable expertise. The Sydney Catchment Authority (SCA) has for some time been measuring and monitoring the water quality at various sensitive points to determine where water can be safely sourced. Specifically on the water quality matter, the Review commissioned a study by Professor Chris Fell AM to examine how challenging water quality issues resulting from the potential mixture of mining and coal seam gas activities could be handled.

Sampling and analysing water quality at sensitive points in the Catchment has a spin-off value in certain situations of providing possible signals of undesirable happenings in the Catchment (which could be caused by a single activity or by interacting activities).

The water quantity matter is more challenging. Some insight can be gained by considering the Catchment, for the purpose of study, as two systems, a surface water system which is interconnected with and overlying a deeper groundwater system under the earth. The surface water system is better understood than the underground system because it is easier to access and better instrumented and therefore able to be modelled at least in part.

The underground system is much less instrumented and much less understood. Experts assisting the Review particularly emphasised that the hydrogeology of the overburden over the coal is especially poorly understood, which poses specific problems for assessing cumulative impacts as this is the area that is most likely to be impacted by mining (both longwall mining and historical bord and pillar mining) and coal seam gas activities.

There is currently an extensive amount of data of varying quality held by several organisations (companies; governments – Commonwealth, State, local; research organisations; community groups) for a range of time periods for the Catchment. However, there is no unified data set nor are there mechanisms for bringing existing data into one well-curated repository.

Accordingly, the Review makes a series of recommendations that a range of data be collected and/or sourced from past data collections so that the construction of data fusion and deterministic, parametric models of water quantity in the Catchment can commence as a matter of urgency. This would provide the information to the SCA to manage the Catchment; to the Department of Planning to manage approvals; and to industry for submission to the planning process and for monitoring of activities – to ensure that unforeseen impacts are not occurring or, at least, are detected at an early stage.

Even without models, the provision of data will allow significant steps forward as the use of new data visualisation software for 3D display and rotation will enable experts in a range of fields to examine anomalies in the data and therefore be more likely to detect unexpected cumulative impacts.

On other environmental matters much the same issue applies: there is a need for more data – specifically to understand more comprehensively the role of sensitive ecological features of the Catchment. There is also a need to tighten the current overall management of these features.

In summary, the Review has found that we cannot yet build a complete model to understand the cumulative impacts of multiple activities in the Catchment (or even, at precise levels, impacts from single activities). However, the technologies to do so are now available and, with more data collected, it will soon be possible. The Review found that water quality issues can largely be managed through treatment works although an upgrade to infrastructure would be needed in the future to maximise this capability. On water quantity, the Review has found measuring and predicting the impact of single activities is difficult – more data from diverse sources is needed to make significant progress on this. That said, current activities should proceed while this data is gathered; the current impacts are not seeming to affect water quantity in a major way. Coal seam gas is likely to have less impact than longwall mining but, if it proceeds, increased instrumentation and monitoring should be standard practice as should special provision for the treatment of produced water from CSG production.

RECOMMENDATIONS

Recommendation 1
That Government create a whole-of-Catchment data repository.

Recommendation 2
That Government develop a whole-of-Catchment environmental monitoring system.

Recommendation 3
That Government commission computational models which can be used to assess the impacts on quantity and quality of surface water and groundwater.

Recommendation 4
That Government encourage the use of data visualisation tools for examining 3D representations of the Catchment.

Recommendation 5
That Government establish an expert group to provide ongoing advice on cumulative impacts in the Catchment.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION: THE ISSUE AND CONTEXT

On 20 January 2014 the Minister for Resources and Energy, the Hon Anthony Roberts MP, asked the Chief Scientist and Engineer to build on the work that has been undertaken as part of the Independent Review of Coal Seam Gas Activities in NSW, to look at cumulative impacts in the Sydney Catchment (the 'Catchment').

In particular, the Minister requested that the Chief Scientist and Engineer "specifically examine the cumulative impact of all activities which impact ground and surface water in the Sydney Water Catchment Special Areas. It is recognised that activities outside the Special Areas, but within the Sydney Catchment may also have significant impacts on ground and surface water." The Minister's letter is at Appendix 1.

Following the commencement of this Review, discussions within Government also raised particular concerns about activities such as mining within the Dam Safety Notification Areas, and the Chief Scientist and Engineer was requested also to examine this issue in the context of this Review.

The Minister's letter requesting this Review on Cumulative Impacts in the Catchment relayed the concern that the community had expressed regarding coal seam gas (CSG) exploration and extraction in the Special Areas of the Catchment. Concerns about extractive industries in the Catchment have a long history and have led to successive governments commissioning several reviews particularly regarding coal mining activities in the Catchment and their possible effects on the Sydney drinking water supply. This Review draws on these studies and a range of community documentation expressing concern about potential CSG production as well as coal mining in the Catchment.

1.1 THE CONTEXT: THE INDEPENDENT REVIEW OF COAL SEAM GAS ACTIVITIES IN NSW

The Chief Scientist and Engineer is undertaking a significant body of work as part of the Independent Review of Coal Seam Gas Activities in New South Wales. The initial report of that Review was released in July 2013 and highlighted *inter alia* the potential benefits of examining the cumulative impacts of activities within an area or over time, in particular in situations where there are multiple industries or developments drawing on resources such as water coincidently (CSE, 2013a).

As the Initial Report noted, "the formal study of cumulative impacts takes place within the discipline of Complex Systems, with the most comprehensive work to date occurring in safety and performance critical areas such as nuclear engineering" (CSE, 2013a). Detailed investigation of cumulative impacts requires comprehensive time-sensitive data on the area affected. With sufficient appropriate data, robust analytic and predictive models can be constructed to examine cumulative impacts.

The Initial Report made several recommendations, including that the Government commission the design and establishment of a whole-of-environment data repository for all State environment data. A data repository would, among other things, enable an increased understanding of cumulative impacts as it would enable visual examination of various processes involved and the building of the type of models referred to above.

1.2 THE CONTEXT: THE SYDNEY DRINKING WATER CATCHMENT

1.2.1 What are the Catchment and the Special Areas?

The Sydney Catchment consists of three main drainage basins, or water catchments, within the Sydney Basin, a geological province that covers about 49,000km^2, the majority of which is onshore (44,000km^2). It extends from Batemans Bay to Newcastle and is bounded on the west by the Great Dividing Range. The three separate catchments are the Central Coast, the Hawkesbury-Nepean and the Sydney Metropolitan, the latter two supplying most of greater Sydney's drinking water.

The Sydney Catchment Authority (SCA) is responsible for the management of 27 sub-catchments that drain into 11 major dams which store raw water. The SCA manages this water and its release into a range of distribution waterways including rivers, pipes and canals (GHD, 2013). Water from the Catchment is provided by SCA to Sydney Water which is responsible for managing nine water filtration plants and the water supply system that provides treated water to over four million customers.

Many of the major dams, reservoirs and canals used for drinking water supply are surrounded by 'Special Areas' established under the *Sydney Water Catchment Management Act 1998*, within which certain types of activity and access are restricted. This creates a buffer zone from human activity to reduce the risks from contamination and protect Sydney's drinking water (SCA & DP&E, 2013). The Special Areas cover approximately 3,700km^2, though the areas protected are discontinuous (SCA, 2014a). For a history of the Special Areas and developments in the Catchment see Appendix 2.

In addition to Special Areas there are also 'Controlled Areas' around water supply infrastructure, particularly the Warragamba pipelines and the Upper Canal, to which public access is prohibited. The Upper Canal is a critical piece of infrastructure which has been working since 1888 and provides between 20% and 40% of Sydney's daily water demands.

A third restricted access category is the 'Dam Safety Notification Area', which surrounds the infrastructure of dams and their storages, due to the risks that dam failure can pose to life and property. The size of a Notification Area depends on the nature of the storage, the local geology, and the potential mining operations possible (DSC, 2014b). Notification areas are established by the Dams Safety Committee (DSC) (see Appendix 3) under Section 369 of the *Mining Act 1992*.

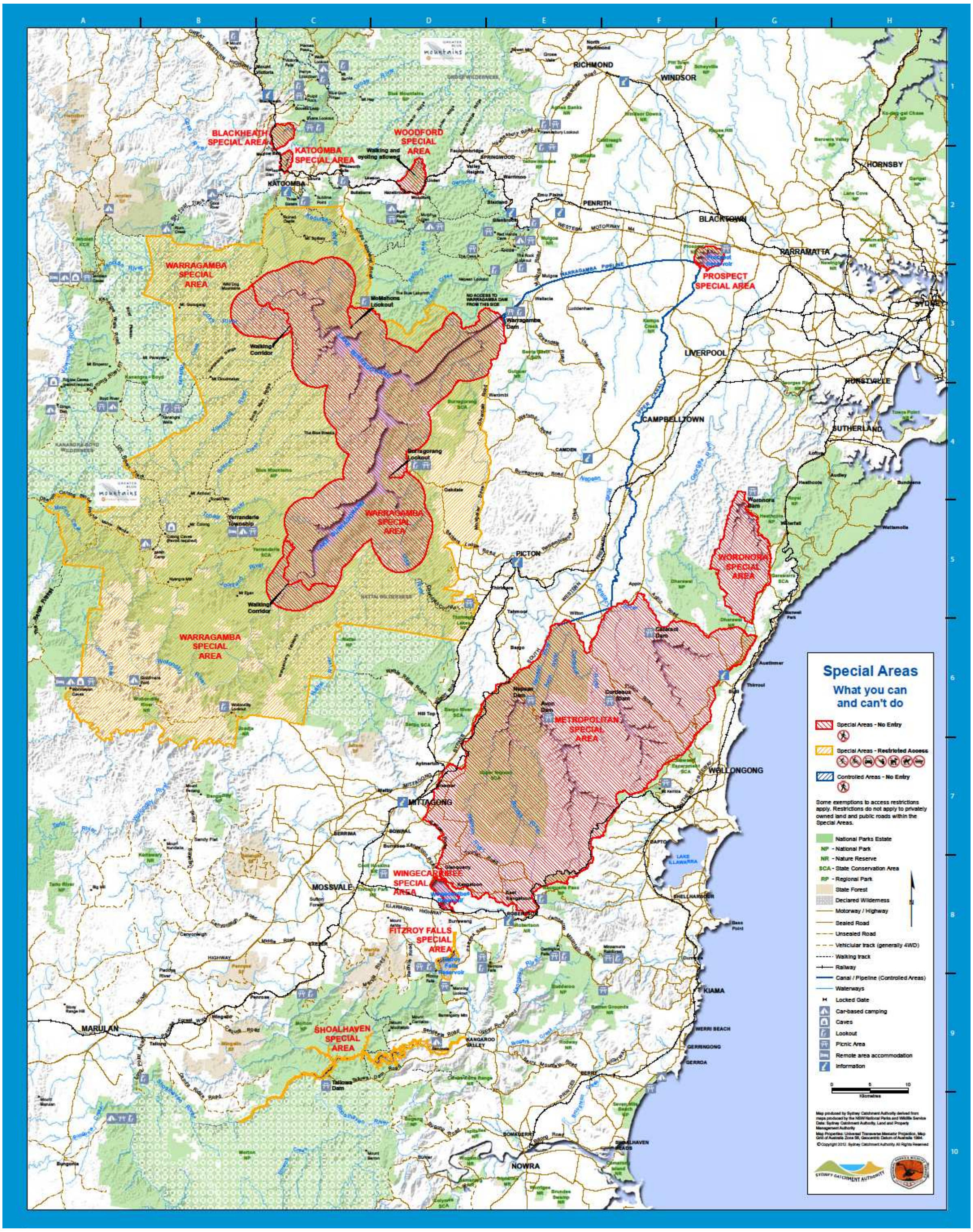

Figure 1.1: Map of Special Areas (SCA, 2012)

1.2.2 Nature of the Catchment

Biophysical characteristics

The Special Areas (see Figure 2.1) cover 365,000ha of the Catchment and are characterised by steep valleys and gorges which are incised into the underlying Hawkesbury Sandstone and drain what are otherwise essentially flat-lying plateaus which dip gently towards the west (SCA, 2013).

The Catchment contains a large range of ecosystems and habitats. The Special Areas are dominated by dry sclerophyll forest, but with significant pockets of wet sclerophyll forest, rainforests, freshwater and forested wetlands, including the upland swamps (SCA, 2013).

The swamps in this area – commonly known as 'upland swamps' – are found predominantly on the Woronora Plateau. They occur mostly on Hawkesbury Sandstone and are characterised by heath and sedge vegetation, distinguishing them from the dry sclerophyll forest that dominates the area. Coastal upland swamps are classed as an Endangered Ecological Community under the *Threatened Species Conservation Act 1995 (NSW)*.

Swamps in the Catchment act like sponges, storing surface water and in some cases accessing groundwater storage to contribute to base flow. In times of drought, they are critical in maintaining stream flow.

Geology

The Sydney Basin rests on a highly folded Palaeozoic sequence. Above this sequence are deposited marine sediments of the Talterang and then Shoalhaven groups. The Shoalhaven Group is itself overlain by the Permian Illawarra Coal Measures, which are overlain by Triassic sedimentary sequences, the Narrabeen Group and Hawkesbury Sandstone. The Narrabeen Group contains the Bald Hill Claystone, a largely continuous aquitard/aquiclude which caps the group (Bradd, Cohen, Marx, Buckman, Burkhardt, Clarke, Cook, Cullen, Daley, Gavin, Hu, Kiekebosch-Fitt, Lemcke, Lowe, Mcmahon, Mcneilage, O'Mara, Nagle, Robson, Silveri, & Stammers, 2012).

The coal seams that are typically the focus of extraction activities are the Bulli and Wongawilli coal seams, both part of the Permian Illawarra Coal Measures. The Bulli seam is about 2 to 3m in thickness while the Wongawilli seam is between 6 and 15m thick, with the economic 'working section' generally the bottom 3m of the seam (Bradd et al., 2012; Hutton, 2009). The Bulli seam represents the top of the Illawara Coal Measures and can be found at a depth of greater than 500m below Sydney, rising to the surface toward the southwest , and exposed above sea level north of Wollongong (Bradd et al., 2012). The Wongawilli seam is deeper: 35 to 90m below the Bulli seam (Hutton, 2009).

The coals in the Catchment area are considered 'gassy', having high concentrations of methane, meaning that those mines working there have had to de-gas the mines significantly prior to, and during mining operations (see Appendix 4). The Illawarra Coal Measures are also the target coal for exploitation at NSW's only commercially producing CSG operation at Camden. The coal here is dry, relative to that found in Queensland and elsewhere in NSW, meaning that the water produced during extraction is less than 5ML per year for the Camden field, in comparison to the Surat Basin of Queensland which can produce as much as 200GL per year (CSE, 2013a).

Groundwater in the Catchment occurs in what can be broadly described as two systems. The first of these is shallow unconsolidated sediments made up of soils, weathered bedrock, the swamp lands and alluvial deposits of the stream beds. These are unconfined aquifers that interact with rainfall and retain a water table at atmospheric pressure. Consolidated rocks may also contain unconfined aquifers, for example, in the Hawkesbury Sandstone near the surface, but may be confined at depth, such as the Bulgo Sandstone beneath the Bald Hill Claystone in the Narrabeen group. Water in this second, confined groundwater system can be much older, indicating a longer infiltration time (NSW Department of Planning, 2008).

Climate and weather

Weather in the Catchment varies from moderate, wet conditions along the coast, where the Woronora and Metropolitan Special Areas are located, to slightly larger temperature variations and drier conditions inland, near the Warragamba Special Areas. Average yearly temperatures range from about 14℃ to 21℃ for the eastern Special Areas with annual rainfall averaging above 1,000mm. Near Warragamba, annual average temperatures range from 3℃ to 23℃ and average rainfall tends to be c loser to 800mm per year (Bureau of Meteorology, 2013).

Bushfire risk in the Special Areas is at its greatest during prolonged dry spells. The SCA manages for bushfires by undertaking prescribed burning where appropriate, in concert with NSW National Parks and Wildlife. A response team for fire in remote areas of the Catchment is managed by these two agencies with a response time that is generally around 30 minutes and is usually successful in containing fires to a 10Ha area (GHD, 2013). However, severe fires have occurred; a significant fire in the 2001/2002 fire season affected the Warragamba and Metropolitan Special Areas.

Regional climate modelling undertaken for the area encompassing the Special Areas suggests that long term trends are likely to be toward an increase in rainfall and stream flow in the Woronora and Metropolitan Special Areas and a decrease in rainfall in the Warragamba Catchment. Across both SCA's Catchment (excluding the Blue Mountains) and Sydney's urban areas (the study area), the number of days with extreme rainfall (>40mm per day) is likely to increase by about 45%, and an increase in the frequency of prolonged dry spells (15 days or more) is also likely to occur. Very hot (>37℃) and hot (>35℃) days are to double in frequency, and evaporation is likely to increase by 10% (SCA, 2010).

The implication of this predicted climate change for water quantity is a heavier reliance on the Metropolitan dams in the water supply system coupled with a greater loss of water to evaporation and evapotranspiration (SCA, 2010). There are implications for water quality, also, as more extreme rainfall events may lead to a greater influx of pollutants to reservoirs. This may in turn increase blue-green algal blooms due to the delivery of nutrients to the reservoirs through runoff, as well as increasing the sediment load (SCA, 2010). Both of these may have the effect of significantly changing stream and lake ecology with biodiversity implications. Prolonged dry spells may lead to an increase in bushfire risk, with attendant threats to infrastructure, ecosystems and an increase in sediment load to the water bodies (SCA, 2010).

1.2.3 Management of the Catchment

A number of NSW Government agencies have responsibilities for managing Sydney's drinking water Catchment. Chief among these is the SCA, with responsibilities for the Special Areas, but key responsibilities are also held by the National Parks and Wildlife Service, the Dams Safety Committee, the NSW Office of Water, the Division of Mineral Resources and Energy in NSW Trade & Investment, the Office of Environment and Heritage and the Environmental Protection Authority. For further information on the various bodies and their role in catchment management see Appendix 3.

Proposals for development in the Special Areas are regulated under a number of different pieces of legislation. The size, scale and nature of the development determine which regulating authorities are the decision-makers for each development and which are involved in the approvals process. Various pieces of legislation apply, from the federal *Environment Protection and Biodiversity Conservation Act 1999* to state statutes and planning policies. For further information on how these work, see Appendix 5.

As developments proceed, the information and data collected by a company in order to carry out its activities are key sources of information for regulators. The information to be collected and the form in which it is to be provided to regulators are often set out in the approval conditions. Requirements for monitoring, reporting and auditing are also commonly parts of proposal approval conditions, as are remediation requirements and requirements for publication of monitoring results. Limits to impacts on certain natural and built features can be set here too, with penalties for exceedances ranging from fines to withdrawal of approval. For further information on the types of impact assessments, plans, reports and data that companies are required to collect and produce, see Appendix 5.

1.2.4 Activities in the Special Areas

Existing activities that could affect ground and surface water in the Special Areas include large-scale coal mining, as well as the presence of communities around or in the Special Areas and infrastructure such as roads, power lines and other local amenities. Many factors other than human activity also affect the ability of the drinking water catchment to supply enough water of sufficient quality: for example, climate variability, events such as droughts and bushfires, and population growth, both in the surrounding communities and in the receiving, or client, community.

There is a long history of activities occurring in or around the Special Areas. Underground coal mining predates the declaration of the Special Areas, the first of which was declared in 1880 to protect the land of the Upper Nepean Scheme (SCA, n.d.-b). The land within the Special Areas includes a small amount of land that is held or leased privately as well as the freehold land held by the SCA. CSG extraction is not currently underway in the Special Areas, though some exploration wells have been drilled.

The development of the water supply system was itself a major impact on the Special Areas. Dams flood the area behind them, restrict water flows to rivers and the construction phase involves land clearing for road works, worker camps and machinery transport. Building dams can cause induced seismicity – for example, an earthquake of magnitude 5.5 occurred in 1973 at Warragamba dam (Gibson & Sandiford, 2013). This sort of induced seismicity is relatively common when filling a dam for the first time, but is less likely to occur on subsequent fills.

Outside the Special Areas the wider Catchment includes a range of agricultural industries including sheep and cattle grazing, dairies, horse studs, piggeries and poultry production as well as intensive and perennial horticulture (olives and viticulture) (GHD, 2013). The SCA plays a part in regulating activities such as these in the wider Catchment due to their possible impact on water quality or quantity within the Special Areas.

Other activities in the Catchment include the presence of communities and the infrastructure to support these, such as roads. The town of Nattai is contained within the Warragamba Special Area. There are roads and fire trails that run through the Special Areas; mains electricity supply towers run across the Special Areas, and a freight rail line is under construction from Illawarra inland through the Special Areas.

The effect of all of these activities on water quality and quantity is closely monitored by the SCA. The SCA works with local councils and industries to ensure water pollution plans are in place and development is appropriate.

1.2.4.1 Mining

Australian coal mining began in NSW at Nobbys Head near Newcastle in the 1790s. The first mines to exploit the Illawarra Coalfields were located near Mount Keira, now within the Metropolitan Special Area. They began operations in 1848 with commercial quantities first produced in 1857.

The Metropolitan Colliery, near Helensburgh, opened in 1888. A large number of coal mines, active and inactive, are scattered through the area, including within the Special Areas. Four mines were extracting coal from under the Special Areas as at 1 January 2014 (SCA, 2014b). No major incidents have occurred connected with underground mining in the Southern Coalfields to date. However, NSW is unique in the coexistence of longwall coal mines with a drinking water catchment, with panels for these mines sometimes undercutting streams.

Mines in the area of the Sydney Catchment are predominantly underground. The two methods of underground coal mining, bord and pillar mining and the newer longwall mining technique, have both been used in this region. Both methods leave behind goafs, caverns from which the coal has been extracted, which tend to fill with collapsed rock and overburn material as the longwall progresses.

Both mining processes are described in more detail in Appendix 4.

Impacts of mining in Special Areas
Changes to geology in the Special Areas have been observed and attributed to the long history of coal mining activity in the area. With 8% of the Special Areas currently undermined, the areas exhibiting these direct impacts are a relatively small part of the protected areas (SCA, 2014b).

Understanding the relationship between the direct geological impacts and possible broader-scale and/or cumulative changes in the hydrology and ecology of the Catchment is a complex problem. The focus of this report is primarily on the cumulative impacts on water quality (Chapter 4) and water quantity (Chapter 5) in the Catchment/Special Areas and on the cumulative impacts on the Catchment as a whole.

It is helpful, in laying the context for the impact of mining activities, to understand more about the direct (rather than cumulative) physical impact of underwall mining on the land surface. A description of these direct physical impacts, namely subsidence, upsidence, far-field movements, fracturing and rockfall, is at Appendix 6.

Impacts of mining in Dam Safety Notification Areas
Concerns about mining under water storages prompted the Reynolds Inquiry in 1976. Despite the first longwall in the Catchment having been driven at Appin in 1969, and the advent of mechanised longwall mining in the late 1970s, the Reynolds Inquiry considered only the effects of bord and pillar mining. The Inquiry concluded that mining could proceed near, and even under, water storages with the condition that a minimum depth of cover of 60m was observed between the coal mine and the dam, an angle of draw of 35° was used to calculate the distance a coal mine could be from any dam wall or other infrastructure, and the size of the pillars left behind to support the overburden be calculated as 15 times the height of extraction. These recommendations were not endorsed by government, but the Dams Safety Committee was established soon after to ensure the safety of dams in NSW on a case-by-case basis, including giving input on the conduct of mining near to water storages.

Of the Dam Safety Notification Areas that overlap with or occur within the Warragamba, Woronora and Metropolitan Special Areas, 11% have so far been undermined, with a further 2% of these areas approved for mining and another 1% currently planned (SCA, 2014b). None of the mines in the Catchment currently undermine a dam wall due to the 1km exclusion zone mandated by the DSC. As described in Appendix 6, however, far-field movements resulting from mining activity have been observed to damage the Cataract Dam Wall. Mining in close proximity to Broughtons Pass Weir was also responsible for upsidence movements which resulted in noticeable cracks and leakage on the downstream face of the weir (SCA, 2001).

1.2.4.2 Coal seam gas

Apex Energy currently has two exploration wells in the region. One is at Oakdale, east of Nattai, just outside the Warragamba Special Area and the other at the Darkes Forest Mine, west of Helensburgh in the Woronora Special Area. CSG activity within Special Areas is currently on hold. Three Petroleum Exploration Licenses (PELs) are currently held over the area by Apex, but the most recent application to drill 16 boreholes to test gas extraction was denied a permit (Validakis, 2013). AGL also holds a PEL that includes much of the Metropolitan Special Area, the remaining part of the Woronora Special Area and some of the Warragamba Special Area. The Apex plan is to extract natural gas through two approaches – coal seam gas from intact coal seams and goaf gas from former mine workings.

The process of goaf gas extraction and use is described at Appendix 4.

The SCA opposed the extraction of CSG in the Special Areas, noting that while the bores themselves resemble those which have historically been permitted in the Special Areas and can be well managed, the surface impacts of CSG extraction pose too great a risk to the Special Areas and Sydney's water supply. The Planning Assessment Commission also recommended against the development, noting that this Office's CSG Review is not yet concluded and the resulting Government policy decisions not yet made (PAC, 2013).

Current titles and activities in the Sydney Catchment region
PELs cover much of the Sydney Catchment area. Apex Energy's PELs 442 and 444 are located on the eastern border of the Catchment and cover parts of the Woronora and Metropolitan Special Areas They also hold PEL 454 over part of the Warragamba Special Area. AGL holds PEL 2, which covers the rest of the Metropolitan and Woronora Special Areas, part of the Warragamba Special Area and the area between the Special Areas, extending north of Sydney. Within the area contained by this PEL AGL holds several petroleum production licenses over the Camden area, which is NSW's only CSG project formally in production. PEL 463, covering the Sydney area and the Prospect Reservoir is held by Macquarie Energy. The southern part of the Catchment is covered by PEL 469, held by Leichhardt Resources.

1.2.5 Previous studies in the Catchment

Concerns about the level of activities and their impacts in the Catchment are longstanding and have led to a number of reviews, from the Reynolds Inquiry in the 1970s to the more recent Southern Coalfields Inquiry. In addition, regular audits of the SCA and its operations are carried out under the *Sydney Water Catchment Management Act 1998*.

Inquiries and reviews on aspects related to coal mining in the Catchment include:

- 1976 report of an inquiry for the NSW Government on coal mining under stored waters of Nepean, Avon, Cordeaux, Cataract and Woronora Reservoirs, NSW (the 'Reynolds Inquiry')
- 2001 Commission of Inquiry report into the environmental effects of Dendrobium mine
- 2007 report on the impacts of longwall mining on surface and groundwater prepared for NSW Department of Environment and Climate Change
- 2008 Southern Coalfield Inquiry
- 2009 and 2010 PAC reviews of major coalmines in the area: Metropolitan and the Bulli Seam Operations Project
- 2012 Thirlmere Lakes Inquiry.

The reviews show an evolving understanding of and concern about the effects of underground mining on the Catchment and most express a need to deepen this understanding through more extensive research and modelling, including of the cumulative impacts of multiple activities.

A survey of previous reviews and their key recommendations is at Appendix 7.

1.3 THE APPROACH OF THIS REVIEW

After gaining an understanding of the role of the Catchment in the Sydney water supply and the other activities carried out in the Catchment, the Review examined how the cumulative impacts of these activities are currently assessed and managed. While there have been developments in this field over recent years, current approaches do not provide much insight into some important questions regarding cumulative impacts. Accordingly the Review brought experts together to investigate whether it was possible to do better. The advice was that, without much more data from a variety of sources, this is currently impossible. But the consolidated expert opinion did provide a way to examine the cumulative impact problems, at least in part, along several dimensions. This was then done. On the basis of this body of work, the Review formulated a set of recommendations.

1.3.1 Understanding the Catchment and the activities in it

To gain an understanding of the core problem of cumulative impacts in the Catchment, the Review:

- met with the two immediate former Chairs of the Sydney Catchment Authority (SCA) Board and with relevant staff from the SCA
- studied the various commissioned reports on various activities in the Catchment
- visited the Catchment to examine several sites that illustrate impacts from mining activities. These included Waratah Rivulet, the Upper Canal, a desiccated upland swamp in the Metropolitan Special Area and a site where the release of produced water from a coal mine during a bushfire degraded local vegetation. The team also visited (currently suspended) CSG exploration sites
- met with and sought information from representatives of a range of NSW Government departments and agencies which have responsibilities related to the Catchment and provision of drinking water for metropolitan Sydney. Departments and agencies consulted include the NSW Office of Water, the Sydney Catchment Authority, Dams Safety Committee and the Division of Resources and Energy, all in NSW Trade & Investment; the Department of Planning and Environment; and the Ministry of Health
- studied the literature on cumulative impact, particularly with regard to water catchments
- drew on a series of workshops focusing on understanding risks to water catchments across New South Wales from CSG extraction being held as part of the larger CSG Review. Attendees at these workshops were selected for their knowledge, expertise and interest in several of the issues related to coal seam gas projects and/or water catchments. Government officials, academics, industry representatives from extractive industries, peak bodies such as the Australian Petroleum Production and Exploration Association, the NSW Irrigators' Council and the NSW Farmers' Association as well as the Land and Water Commissioner and community groups all took part, providing a diverse range of backgrounds, expertise and views.

1.3.2 Community consultation

It is a general principle of the Review to meet with community representatives and hear their concerns wherever possible in order to take into account a wide variety of views and to benefit from the experience of those on the ground.

To that end, a community group concerned about development in the Catchment was consulted. Several attendees were members of community consultative committees for the mines within the Special Areas and thus have extensive experience of the areas in question. Presentations were given by the group and discussion focused on the impacts observed and recorded from mining developments in the Catchment.

1.3.3 Cumulative Impact workshops

Two workshops with experts were held. The first focused on formal characterisation of cumulative impacts of activities in the Catchment. Leading experts in water provision, catchment management, water quality, mining, coal seam gas extraction, geology, geophysics, geotechnical engineering, groundwater modelling, data analytics and data management were brought together to address this very hard question. This workshop (along with follow-up consultations with individual participating experts) provided the pivotal expert guidance for this Review.

A summary report of the workshop is attached at Appendix 8, and further discussion on the outcomes is given in Chapter 3.

A second expert workshop was held, this time with mining and subsidence engineers, and hydrogeologists to discuss in detail the (generally approved under the planning process) physical changes to the Catchment wrought by mining and extractive industry activities.

A key focus of this workshop was testing draft recommendations around modelling and monitoring. The discussion focused on what reasonable monitoring networks and reporting timeframes could be set up in order significantly to improve understanding of the cumulative impacts of extractive industries in the Catchment.

1.4 HOW THIS REPORT IS ORGANISED

Chapter 2 summarises current approaches to dealing with cumulative impacts in drinking catchments and the Sydney Water Catchment in particular. It also examines the limitations of these approaches.

Chapter 3 breaks the core problem being addressed by this Review into its simplest form; and gives the conclusions of the First Cumulative Impact Workshop on whether or not even this simple version of the problem can be answered adequately. It also describes how the Review decided to proceed following this workshop.

Chapter 4 addresses managing impacts on water quality from cumulative (and individual) activities in the Catchment.

Chapter 5 addresses impacts on water quantity from cumulative activities in the Catchment.

Chapters 6 discusses aspects of whole-of-Catchment issues.

Chapter 7 gives the Review’s conclusions and recommendations.

2 CURRENT APPROACH TO CUMULATIVE IMPACTS

2.1 INTRODUCTION

In the Initial Report of the Independent Review on Coal Seam Gas, the Review noted that increasingly intensive exploitation of the resources found in sedimentary basins is leading to competition between uses, with complicated effects on social, political and regulatory systems. Allowing the coexistence of multiple activities, including, for example, agriculture and resource developments, or extractive industries and water supply, has long term economic benefits. However, it must also be balanced with an understanding of the cumulative impacts of these activities, in order to ensure that sustainable management practices preserve basin resources for all uses and users (CSE, 2013a).

Studies of complex systems and their resilience are becoming more commonplace in environmental science. The necessity of developing a mechanism to measure, model and predict cumulative impacts, and to incorporate this data into risk management practice, has been recognised as important in a number of jurisdictions, particularly in relation to the environmental impacts from extractive industries.

“With potential for conflict over competing access regimes to sedimentary basin resources, there is a case for new approaches to the management of our sedimentary basins to help reduce adverse environmental and social impacts, reduce the potential for unintended resource depletion and/or sterilisation, and reduce economic risk arising from multiple, interacting and competing resource usage scenarios” (Rawling & Sandiford, 2013).

2.2 CUMULATIVE IMPACTS AND THE CATCHMENT

The SCA Special Areas and the Catchment are experiencing the same pressures as many sedimentary basins across Australia. However, due to the long history of coexistence in the Catchment of two major extractive uses – large-scale underground coal mining and metropolitan water supply – this is a case with special challenges.

In addition to these two uses, multiple other activities occur in the Catchment and may have impacts on the Special Areas. These include agriculture and urban development with its attendant infrastructure. As noted previously, the use of the Catchment, and the Special Areas in particular, for coal seam gas extraction is currently under consideration. To understand the cumulative impacts, or potential impacts, of all of these activities, their individual impacts must first be characterised. Table 2.1 gives a summary of these. This table is a reproduction of one given in the Chief Scientist & Engineer’s Initial Report (CSE, 2013a).

Understanding the need to determine cumulative impacts in the Catchment is not new ground. The Southern Coalfields Inquiry in 2008 discussed the need for a cumulative impact assessment for the Catchment, which was later reinforced in both the 2010 and 2013 Sydney Water Catchment Audits (GHD, 2013; NSW Department of Environment, 2010; NSW Department of Planning, 2008). Understanding cumulative impacts is difficult, however, and several different approaches to assessing and managing these are in widespread practice.

Table 2.1: Activities in sedimentary basins and potential impacts (reproduced from CSE, 2013a)

Activity	Examples of specific activities	Examples of Potential Impacts
Coal Seam Gas	• infrastructure	• groundwater depletion

	o roads o drill pads o storage areas o water storage o pipelines o processing plants • subsurface o bore drilling o gas production o water extraction o water disposal o hydraulic fracturing	• contamination (aquifer, soil) • groundwater dependent ecosystems • reducing biodiversity o introduction of invasive species along new roads o landscape and habitat fragmentation • noise • traffic • fugitive emissions and air quality • induced seismicity • health • dust
Mining	• infrastructure o roads o ventilation shafts o tailings dams and water storage o processing facilities o train lines • subsurface o explosives o digging equipment	• land clearing • subsidence • groundwater depletion • contamination (groundwater and soil) • induced seismicity • noise • traffic • dust
Agriculture	• land o land clearing o soil tilling o fertiliser and pesticide application o irrigation o monoculture • infrastructure o roads and fences o water bore o dams • introduction of production species (crops and animals)	• groundwater and surface water depletion • landscape and habitat fragmentation • reducing biodiversity o introduction of foreign plants and animals (invasive and can carry disease) o feral animals o weed species • soil structure • salinity • erosion • pollution • emissions and air quality • subsidence
Urban development	• infrastructure o buildings and houses o roads and train lines o sewerage o landfill o dams and reservoirs o drains and pipes o harbours and ports • electricity generation and usage • introduced pets • car, train and plane usage • gardens with foreign plants • land reclamation	• land clearing and habitat fragmentation • disease introduction • pollution – air, soil and water • reducing biodiversity • noise • light pollution • induced seismicity • subsidence

2.3 CURRENT TECHNIQUES

Understanding, measuring and monitoring the cumulative impact of human activities on the natural environment is a growing area of interest for regulators in particular. Most jurisdictions are now moving towards a region-based approach, attempting to understand the impacts of multiple activities in a given area and to provide overarching policies that guide planning decisions in those areas. There are two broad approaches to this: through strategic land use policies and assessments, or through building models that assess the effects of an industry on a shared resource.

Previous policies tended to require cumulative impacts to be considered in relation to individual projects only, with proponents and their approvers required to assess the cumulative impacts of each proposal, including in relation to possible future development in the region. However, a key difficulty of regulating cumulative impacts is assigning liability for impacts, particularly where the impact observed may be the result of many stressors acting on a region, caused by different parties proposing projects at different times and with various degrees of data sharing.

The use of adaptive management principles has assisted in managing cumulative impacts in an indirect fashion. This approach monitors impacts to features and thus is able to detect when impacts (from sources known and unknown) are reaching unacceptable levels and to adjust activities accordingly. As such, adaptive management is a key underpinning for the cumulative impact approaches that are starting to emerge.

2.3.1 Adaptive management of impacts

Adaptive management is an approach used by government and industry to manage impacts of an activity. Essentially this describes a management system that can ingest new data, information or technologies and change the activity as a result. It is a way of making management decisions when the system being managed is uncertain or unknown and relies on a balance between gaining more information to improve future management and achieving the best short term outcome using current knowledge (Allan & Stankey, 2009). To date, adaptive management approaches have been successful in the Catchment when used to ensure highly significant features are protected from the impacts of coal mining. Less successful are attempts to apply adaptive management approaches on larger scales.

One example of an adaptive management approach used in mining in the Special Areas is the work done to ensure the protection of the Sandy Creek waterfall. As part of the approval conditions for the Dendrobium mine, in the Metropolitan Special Area, the proponent was required to ensure that no rockfall occurred at this waterfall from its overhang; that the structural integrity of the waterfall, the overhang and its pool were maintained and that cracking within 30m of the waterfall would be of negligible environmental and hydrological consequence (BHP Billiton, n.d.).

This was achieved by establishing real time monitoring for the area around the waterfall during the extraction of Dendrobium longwalls 6, 7 and 8. An expert panel was also established to review data and provide advice on the encroachment of impacts to the waterfall as the longwalls were dug. Mining was then halted when the impacts detected were considered, by the panel, to be reaching levels that may have begun to endanger the waterfall. This approach appears to have been successful in avoiding damage to the waterfall while maximising the value of the coal extracted from the mine (BHP Billiton, 2013; Hebblewhite, 2009).

Adaptive management approaches are also used in the Catchment where mining activities may impact the dam walls or the reservoirs. The Dams Safety Committee (DSC), established by the *Dams Safety Act 1978*, has oversight of significant dams in NSW. The *Mining Act 1992* gives the DSC responsibility for advising on any mining proposals that would impact on Dam Safety Notification Areas. In addition to their involvement in the planning process, the DSC continues to provide advice during the progress of mine development and extraction, and may arrange for amendments to existing mining leases through providing advice to the Minister (DSC, 2010).

At the project level, adaptive management is realised through the use of planning and reporting processes. Proponents of significant developments in NSW are usually required to produce management plans. Common management plans for mines include a Water Management Plan, an Extraction Plan and a Public Safety Management Plan, among others. All underground mines must also produce a Subsidence Management Plan. These plans are typically produced by proponents, in consultation with relevant government agencies and community groups, and detail the monitoring, reporting and remediation steps to be taken as each action is carried out. Each plan must be individually approved and can have conditions set on its approval as well.

Within management plans, Trigger Action Response Plans, or TARPs, are defined. TARPs set particular trigger levels for impacts and outline response plans for each trigger level as well as a ‘catastrophic’ event response plan. TARPs are then reported on as part of reporting against each plan. For example, the End of Panel reports, produced against the Subsidence Management Plan, report on the impacts observed due to extraction of a particular longwall panel in the context of TARPs established by the plan.

TARPs are an implementation of adaptive management in that they create a responsive system, whereby impacts are monitored and activities must change as trigger levels are reached. In practice, however, most TARPs examined by this Review have similar responses for most impacts – continue to monitor and report the detected impact to the relevant government agencies. What changes as impact escalates tends to be the amount of monitoring done and the frequency of reporting. It is up to the regulators, in most cases, to use the information being reported to decide when activities must vary or cease.

In general, the reports made to regulatory agencies are usually in the form of summary data with analysis and assessments of what that data means in terms of impacts and activities. Sometimes reports may also contain raw data files as appendices (or electronically), and agencies could seek to request these in particular when covered by a licence. A question remains to what extent raw data provided is used, and whether regulatory staff are able to interpret or interrogate it.

This planning for, reporting, and assessment of project impacts is normally undertaken by subcontracted expert consultants that specialise in the relevant field. The quality of these can vary, and, as such, the internal organisational experience of regulators and the utilisation of peer review of the plans, models and reports is important in interrogating the information and testing the assumptions and conclusions.

Further, the seemingly subjective characterisation of impacts by the proponent in these reports has been a source of criticism (Krogh, 2012). There are also concerns that this system does not extend to recognising the link between impact and environmental consequence and thus is unable to really address cumulative impacts (Krogh, 2012).

2.3.2 Strategic land use policies

One approach to managing cumulative impacts from multiple projects and multiple industries in the same region is to introduce strategic land use policies. These are designed to manage the coexistence of activities and usually focus on planning for exploitation of a region’s resources while monitoring the impacts on a few features of concern.

An example of this in NSW is the Strategic Regional Land Use Policy (SRLUP), which was introduced in 2012 to manage potential conflicts between mining and CSG activity and agricultural and residential land use (NSW Government, n.d.). Under the policy Strategic Regional Land Use Plans are developed which identify high-quality agricultural land. Any proposals for development that would impact on this land is required to go through a ‘Gateway process’ in addition to the usual planning approvals process and, if approved, to prepare an agricultural impact management plan.

The NSW Aquifer Interference Policy, part of the SRLUP, looks at multi-industry impacts on a single resource within a region, but still requires modelling to take place at the level of the project (DPI, 2014). Proponents are required to develop groundwater monitoring and modelling plans. By introducing the Gateway process, however, the SRLUP does add a step that considers the project in relation to other land uses in the region, and thus can be considered an attempt to undertake cumulative impact assessment.

This is similar to the approach taken in Alberta, Canada, which has a substantial mining and natural gas industry. Under the *Alberta Land Stewardship Act 2009*, regional plans are developed in consultation with local communities, government and industry groups. These plans outline, for a region, specific environmental objectives, monitoring programs and trigger points and must be reviewed every 10 years. The aim is to ensure that the total impacts to specific features are considered, rather than the impacts of each individual project. The trigger points work similarly to the TARP approach outlined earlier, where specific management actions can be taken in response to identified levels of impacts.

A similar approach was taken in Australia at the federal level. The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) requires the Commonwealth Government to approve projects where they may have a significant impact on a matter of National Environmental Significance (NES, defined under the Act). Prior to the introduction of strategic assessments, it was possible for multiple projects that did not have a significant impact to be approved individually, possibly leading to an accumulated major impact. Strategic assessments take a region-based approach to understanding the impacts of development to matters of NES.

Following the amendments to the EPBC Act in 2013, water resources in relation to CSG extraction or large-scale coal mining are considered matters of NES. To assist with decision making for these developments, bioregional assessments are being undertaken. The assessments and products are yet to be released but are to be scientifically based, including conceptual modelling, technical reports, registers and maps. One of the intended bioregions is Southern Sydney, which will cover the Catchment.

2.3.3 Assessing impacts on a shared resource: A Queensland example

A second approach is to consider the impacts of multiple projects from a single industry on a shared resource, and to attempt to model and predict these impacts. This approach requires the ability to share information between projects as individual proponents will not have access to the information of other projects in the region. An example of this has been developed in Queensland. The Office of Groundwater Impact Assessment (OGIA) enables data sharing from and to petroleum tenure holders. In addition, they design, coordinate and direct an integrated, regional-based monitoring program through directing the monitoring that proponents must carry out. Using the resulting shared data, OGIA has developed a 19-layer hydrogeological model to help understand the cumulative impacts on groundwater availability from the multiple CSG developments and their overlapping impact profiles.

Under Queensland's *Water Act 2000*, the model is reviewed and updated regularly, with the first review scheduled for December 2015, three years after its first release. The model is limited to CSG impacts, but this approach could be expanded across industries. At present, the model also does not include geological structures such as faults and fractures that will affect groundwater flow pathways, but an expansion addressing this is planned (Queensland Government, 2013).

2.3.4 Closing the loop

The above are examples of policies that integrate some understanding of cumulative impacts into the planning process, and some that attempt to understand cumulative impacts in detail for a specific feature or industry. Both are methods to address the effect of small but accumulated impacts – for example, the effect of many extractions of groundwater, given a certain recharge rate, on the groundwater resource. What is missing from these approaches so far is the ability to look for and predict unexpected cumulative impacts that may result from the interactions of multiple industries or multiple impacts. In environmental science, the fear of this sort of problem leading to possible ecosystem collapse is often illustrated by looking at the classic example of Easter Island and the unsustainable use of resources that is thought to have led to the collapse of the island's ecology, resulting in catastrophic consequences for its population (see, for example, Diamond, 2005).

In the Catchment, the hypothetical situation of concern is a collapse in the ecosystem such that it can no longer provide the ecosystem services that we rely on to supply our drinking water. Is it possible that the combined impacts of longwall mining, other extractive industries and other activities could damage the environment such that a tipping point is reached? If this is possible, at what point will the ecosystem services collapse such that the Catchment is no longer able to provide us with water of sufficient quality in the quantity that we require?

The likelihood of such a tipping point causing a crisis of water availability to the consumer is low, as monitoring undertaken by the SCA will provide an early warning of such an event's approach. Once identified, a problem with water quality in the Catchment could be dealt with by upgrading the treatment available at the water filtration plants (see Chapter 4). A problem with water quantity, such as might occur if entire watercourses were to disappear underground as a result of subsidence impacts, could also be addressed: in this case through increasing the supply infrastructure (increasing the size of dam walls, for example, or building new dams). Such supply increases are already being planned by the SCA to deal with climate changes and population increases, but bringing these plans forward abruptly, to deal with a crisis, has large economic ramifications. Thus, the real issue is the cost to the Government and by extension the people of NSW of the management steps that could become necessary as a result of unexpected impacts.

However, the Review considers that the approaches currently in place to manage cumulative impacts are at present insufficient to reassure us that we are able to predict a tipping point of the kind described above, prior to the approval of any new activity in the Catchment. To do so will require a sophisticated approach to modelling, and a good and evolving understanding of the systems and processes involved based on a large amount of reliable diverse data. The chapters that follow address the main issues that will need to be considered in building this approach and the policy settings to support it.

3 THE CORE QUESTION: IF IT CAN'T BE SOLVED, WHAT CAN BE DONE?

The task of assessing the cumulative impacts of several activities occurring simultaneously in an effectively unconstrained domain is very difficult as the limitations with current approaches discussed in the previous chapter illustrate. Even in complex, constrained domains (such as nuclear power plants) the problem is hard. But it is much more difficult to assess total impacts of multiple industrial activities – possibly on top of impacts of unexpected natural disasters – on a natural resource such as a water catchment, the prime source of water for a very large city.

It is nonetheless a very important problem to solve especially as city water provision is health critical and time critical.

In approaching the problem, the first matter is to determine the significance of what could be impacted. In the case of the Sydney Water Catchment, to a first approximation, metropolitan water quality and quantity are obviously highly significant.

Ideally, to monitor for and measure cumulative impacts one would develop a robust real-time model of the Catchment. This model need not be a faithful reflection of all activities in the Catchment – a 'black box' model would suffice provided it predicts overall impacts effectively. To see if this might be possible, at least to some degree, the Review convened a workshop comprising the best available, unconflicted experts from a range of relevant disciplines to address what could be thought of as the simplest version of the core question that must be answered if we are to reliably understand cumulative impacts in the Catchment. This question is the following:

For any given new event in the Catchment (e.g. a longwall mine or a new coal seam gas well), can we predict and measure (and in turn check predictions) any changes over time on the quality and quantity of water leaving the Woronora and Metropolitan Special Areas into the upper canal, or leaving Warragamba Dam into the pipelines to Prospect Reservoir?

In other words, can we predict what is going to be the total impact of the new activity happening in parallel with existing activities in the Catchment? Can we predict the impacts at the planning stage? Do we know what to look for and when to measure impacts in particular on the quality of drinking water entering the water filtration plants and on the quantity of water available to supply these filtration plants?

Consensus among the experts consulted was reached relatively quickly: answering this question with quantitative precision is impossible at present given insufficient geological, geophysical and hydrogeological data available on current activities. Such data, if available, would be able to be examined for anomalies using 3D visualisation software as well as driving the production data fusion models of the Catchment or allowing the construction of deterministic, parametric models. If such models could be built, they would provide the framework for examining predictions of cumulative impacts and would provide a mechanism for explaining measured impacts and attributing them to the most likely causes.

However, the experts suggested that some useful insights could be gained by breaking the problem down into cumulative impact issues associated with water quality, water quantity and other matters.

Accordingly, the Review then moved to consider separately:

- how cumulative impacts on water quality might be dealt with. To flesh out the advice from the expert workshop on this matter the Review commissioned a special report from Emeritus Professor Chris Fell AM. This report is at Appendix 9
- if cumulative impacts on water quantity can be measured

- how Catchment-scale issues should be addressed.

These matters are addressed in the next three chapters.

4 DRINKING WATER QUALITY ISSUES

4.1 INTRODUCTION

The consensus of the first workshop was that any cumulative negative impacts of multiple activities being carried out in the Catchment on the quality of Sydney drinking water could be addressed through current water management practice as the water goes through multiple barriers in the Catchment and then progresses through the treatment works (the 'multi-barrier process'). In effect, this treats the Catchment as a conceptual 'black box' where the links between inputs and outputs need not be known. That is, impacts from individual activities or from the interaction of multiple activities can all be handled successfully through the multi-barrier process, provided that process includes treatment techniques designed to treat the impurities from various activities taking place in the Catchment.

To confirm the workshop's consensus, the Review commissioned a paper from a leading water treatment expert, Professor Chris Fell. This paper, entitled Water Treatment and Sydney Catchment (the 'Background Paper', Appendix 9).

In this chapter, current water treatment in the Catchment, as described in the Background Paper, is briefly summarised (Section 4.2). This is followed by a discussion of how quality monitoring can reveal changes occurring in the Catchment (Section 4.3).

4.2 WATER TREATMENT IN THE CATCHMENT: KEY ELEMENTS OF THE FELL PAPER

Professor Fell confirmed that water quality can be managed using the multi-barrier process which covers Catchment management, source water protection and treatment. Water is safe for drinking when it reaches the consumer. This does not negate the need, though, for proposals for any activities in the Catchment, including CSG operations to be accompanied by a careful appraisal of any potential threats to quality so they can be handled in the multi-barrier process.

The key elements of his paper are summarised in the sections below.

4.2.1 Management framework

The Sydney Catchment Authority (SCA) and Sydney Water have a robust management framework for their catchment protection and water treatment activities.

Managing the water from the Catchment to the consumer is the joint responsibility of the SCA and Sydney Water. The SCA manages several major dams (and other smaller pieces of infrastructure) with the main objective of providing raw water to Sydney Water for processing in water filtration plants (WFPs). Sydney Water manages nine WFPs and the water supply system that runs between the plants and the consumer's tap, with the main objective of providing treated water to over four million customers in the greater Sydney region. The largest WFP is at Prospect, which treats over 80% of Sydney's water.

For raw water in the Catchment, the SCA has identified that the major risks to water quality arise from effluent from sewage systems, stormwater ingress into reservoirs, grazing, and intensive animal facilities within the Catchment. A key part of managing these risks is measures to prevent ingress of nutrients, pollutants and pathogens. Declared Special Areas have the role of minimising the risk of human and farm animal faecal contamination, run-off of fertilisers, pesticides and the erosion and mobilisation of sediments.

The Australian Drinking Water Guidelines (ADWG) were first published by the National Health and Medical Research Council in 1999 and subsequently updated in 2011 and 2013. The ADWG provide an approach for the seamless management of water from source to consumer. The approach relies on multiple barriers, rather than relying on the effectiveness of a single barrier.

These guidelines have been adopted by the SCA and Sydney Water and provide their overarching management frameworks. SCA has a five-year (2012-2017) Water Quality Management Framework based on ADWG. Likewise, Sydney Water has a five-year (2010-2015) Drinking Water Quality Management Plan which also reflects ADWG.

4.2.2 Multi-barrier process

The multi-barrier process, covering catchment management, source water and water treatment, is used to ensure safe drinking water is delivered to consumers.

SCA and Sydney Water work together to implement the ADWG guidelines, with SCA's role being to protect the Catchment, as the first and most effective barrier to possible contaminants. The SCA undertakes some water treatment, but essentially delivers raw water to Sydney Water. Sydney Water treats the raw water and delivers it to consumers via a supply system.

For the Catchment, the water treatment consists of four steps:

- retention and settling of water in the reservoirs to allow sedimentation and some micro-organism die-off
- monitoring and modelling of storages to choose appropriate take-off levels
- plant treatment. This consists of: screening, coagulation and flocculation, sedimentation, filtration, disinfection (by chlorine and chloramine). In some facilities, membrane microfiltration is used in lieu of the flocculation and filtration steps
- maintaining disinfection levels in the distribution system.

The SCA has responsibility for the first two steps (and, in the case of the Prospect WFP, coarse screening also) and Sydney Water has responsibility for the last two.

Currently, the water treatment system has a focus on removal and deactivation of pathogenic water-borne microorganisms. The conventional processes used in the plants mean that soluble species, both inorganic and organic, are not removed. Consequently, for a plant such as that at Prospect, the levels of inorganic species and heavy metals in the treated water are similar to that in the raw water.

This is appropriate at present. Following a detailed risk assessment, the pollutants SCA decided were a priority were pathogens, nitrogen and phosphate, and suspended solids. However, as impacts accumulate within the catchments above the reservoirs over time, changes may be needed to the water treatment with additional technologies being required.

4.2.3 Monitoring network

Integral to the multi-barrier process is monitoring for water quality parameters; the SCA and Sydney Water monitor at each stage of their processes.

The SCA is focused on the possible impacts from various industries and pastoral pursuits in and around the Catchment. It monitors water quality at 100 sites, with a particular emphasis on the reservoirs and the points immediately before the WFPs. The monitoring focusses on three areas:

- routine/compliance monitoring – to ensure that the raw water meets ADWG guidelines

- targeted/investigating monitoring – to monitor hot spots (e.g. below a sewage treatment plant), after events (e.g. large rainfall) and incidents (e.g. algal bloom)
- catchment solutions monitoring – to assess controls on known source pollution loads.

The type of monitoring varies from periodic grab samples to continuous on-line instrumentation. On-line monitors near dam walls and in Sydney Water supply conduits are linked to data monitoring systems that automatically raise alerts if monitored parameters exceed pre-set values. Raw water quality data is provided to customers monthly via a website and SCA publishes a summary of all water quality data annually.

Sydney Water monitors treated water quality for pathogens (cryptosporidium and giardia) on a daily basis. Other factors are tested for less frequently but are still regularly monitored.

4.2.4 Worst case scenarios

From the perspective of providing drinking water of sufficient quality, the current management by SCA, Sydney Water and others has proven to be adequate to handle the historic and present impacts of activities in the Catchment. Based on publicly-available reports, the treated water provided to consumers has comfortably and consistently met the standards.

In the Background Paper, Professor Fell also considered whether the existing management framework as implemented in the multi-barrier process and monitoring network would be able to handle ‘worst case scenarios’. Eight scenarios were considered:

- breakthrough of dangerous pathogens from WFPs
- breakthrough of toxins from cyanobacteria
- iron and manganese too high affecting produced water quality
- pesticides in treated water
- high metals content in raw water
- high heavy metals concentration in treated water from WFP
- high organics or salt content in treated water from WFP
- significant spillage of dangerous pollutant into catchment area and progress of this pollutant to storage dam.

Professor Fell concluded “[a]part from long-term operating disturbances caused by the introduction of new industries to the Special Areas and to the catchments of streams feeding Warragamba Dam and other storage reservoirs, the current water management plans of SCA and Sydney Water would seem to cover the handling of scenarios that could lead to moderate to severe impacts.”

However, Professor Fell pointed out that a major contamination event (other than sediments and biological pathogens) might not be picked up quickly, and the authorities would need to be alerted to the notification of a potential hazard to take appropriate action. He stated: “[T]he response plan adopted by SCA/[Sydney Water] is heavily reliant on reporting of an incident and appropriate follow-up. There is timely monitoring of risks from water-borne pathogenic species, but it would be desirable to have some online monitoring for markers for pesticides and dissolved organic species on entry to SCA’s catchments and in the raw water entry to [Sydney Water]’s WFPs”.

Professor Fell suggested that “the most effective way of ensuring prompt and efficient notification of hazardous occurrences needs to be fully explored”.

4.2.5 Coal mining and water quality

Professor Fell explicitly commented on the effects of coal mining on water quality.

For coal mining, the issues relate to the consequences from subsidence on water quality. For example, surface water that infiltrates the sub-surface, due to mining induced subsidence and consequent fracturing, may re-emerge with a different chemistry due to water-rock interactions. The water may pick up iron, manganese, aluminium, sodium, calcium, barium, chloride and sulphate. Carbonates may be mobilised to give bicarbonate ions. These changes are more noticeable during low flows.

Professor Fell reports that there is currently no evidence that soluble species are increasing in the reservoirs to a level that would cause concern.

The Review concludes, based on this analysis, that from the perspective of drinking water quality, there is no reason, at this stage, for coal mining to be excluded from the Catchment.

4.2.6 Coal seam gas extraction and water quality

Professor Fell also explicitly addressed the possible effects of coal seam gas extraction on water quality in the Catchment. As there are no active CSG exploration or production activities currently occurring within the Catchment, the issue is more difficult to assess.

At present there is a moratorium on CSG activities in the Special Areas imposed by the Government. In addition, the SCA is currently opposed to CSG activities in the Special Areas as a consequence of applying the second of its Principles for Managing Coal Mining and CSG Impacts, which states that “mining and coal seam gas activities must not result in a reduction in the quality of surface and groundwater inflows to storages” (SCA, n.d.-a).

As Professor Fell has pointed out, the content of produced water from CSG extraction will vary according to the chemicals present in each coal seam, and ‘typical produced water’ from CSG operations does not exist. However, Professor Fell notes that the Camden operation, which targets the Illawarra Coal Measures, may provide a good indication of what the produced water from any potential CSG operations in the Catchment is likely to be. When compared with the Australian Drinking Water Guidelines, this water as it has emerged from that seam has unacceptably high levels of salinity, total dissolved solids, bicarbonate and barium, although the Review notes that at Camden the volumes are low (<5ML per year for the entire project). There would be substantial costs to the WFPs if soluble organics from produced water were to find their way into raw water feeding the plants. Therefore, given the risks surrounding produced water, if CSG activities are to proceed within the Catchment, any new venture should be required to treat on-site, remove the dissolved solids by reverse osmosis or ion exchange and, if necessary, remove the soluble organics by adsorption.

The storage of concentrates from treatment poses a risk to the Catchment. In Professor Fell’s words, “any proposals for coal seam gas operation in the catchment should be accompanied by a careful appraisal of any potential threats to the quality of water entering SCA dams. This would include consideration of any chemical introduced during a fraccing process”.

Produced water is often stored in surface ponds. Given the issues with produced water as highlighted by Professor Fell, the Review suggests that there is a need for guidelines on the design, construction and maintenance of these, for use in the Catchment and elsewhere in NSW. Without confidence about the integrity of these ponds, the use of such an option for produced management in the Catchment should not be allowed.

While highlighting areas which could be improved, Professor Fell also emphasised the significance of dilution in mitigating possible risks from CSG to drinking water quality in the Catchment, for example:

- comparing the volumes of produced water at the AGL CSG operation at Camden versus the throughput of the Prospect WFP, Professor Fell states “this represents a dilution factor of 10^5”

- with respect to possible spills of CSG produced water, Professor Fell states: "Whilst it would not be acceptable to routinely dispose of produced water directly to a waterway feeding Warragamba Dam as its relatively high saline and bicarbonate content would upset stream ecology, dilution and the absence of high levels of toxic substances would mean that it was safe from a health viewpoint if it were occasionally to occur during an unusually heavy rain event"
- in connection with a crisis of a gasoline tanker spilling its contents in the Warragamba catchment, Professor Fell says: "Assuming the 240kg [of benzene] entered the [reservoir] and was fully mixed…the benzene level in the [reservoir] would be 0.00012mg/L, still well below the ADWG of 0.001mg/L".

Threats to the water quality of the Catchment from CSG extraction activities may arise not only from the water extracted from coal seams, but also from chemicals that may be used to fracture the coal seam to increase the flow of CSG. These chemicals, if used, could potentially affect Catchment water quality in various ways: they could spill or leak on-site prior to their use in fracking; they could be removed from the seam as flowback water and be treated in the same ways as produced water and potentially spill once extracted; or they could remain in the coal seam and move through the groundwater system.

The use of BTEX in fracking fluids is banned in NSW (NSW Department of Trade and Investment, 2012). However, water from coal seams can contain naturally occurring BTEX. This would have to be accounted for in the suggested on-site water treatment plants.

In addition, the Review suggests that use of other chemicals in fracking fluids should be severely controlled. The Government should only allow chemicals that are known to be safe in the Catchment. Forthcoming work by NICNAS is looking at issues of chemicals associated with CSG fracking (NICNAS, 2014). If the risks to human health cannot be known with a very high degree of certainty, it may be advisable that, if CSG extraction activity is allowed, a ban on fracking within the Catchment is instituted.

4.3 WATER QUALITY PARAMETERS AS INDICATORS OF POSSIBLE STRUCTURAL CHANGES IN THE CATCHMENT

As the Background Paper makes clear, it is evident that SCA and Sydney Water are providing drinking water that meets the ADWG. The monitoring of water quality parameters serves as part of this process.

Water quality monitoring, however, has additional functions. In the first place, quality monitoring can act as a sentinel value of possible structural change due to one or more impacts in the Catchment. The detection of unexpected values in water quality parameters can indirectly point to undesirable activities, events and impacts.

This is important as, in addition to the known activities and their known associated potential impacts on water quality, there will also always be the potential for accidents or events which are difficult to predict and may also affect water quality.

An illustration of this was seen during the Review's Catchment site visit. During a bush fire in 2001 a mine released produced water from a holding pond to the surrounding environment. Whether or not this occurred as the result of a direction from the Rural Fire Service is a matter of some contention, but the release was not reported. Instead, the SCA discovered the release through its water quality monitoring downstream at Broughton Weir quite some time after the fire. The spill resulted in environmental damage still visible more than a decade on.

The other main function of water quality data in the Catchment is to assist understanding of the links between activities and consequences. This allows for stronger predictions to be made, including those of a cumulative nature.

To make good use of this concept, monitoring needs to be a whole-of-Catchment exercise.

At present, there is a particular emphasis by the SCA on monitoring the reservoirs and immediately prior to the WFPs. From the perspective of being able to tell at any given time if the water being supplied to consumers meets the guidelines, this makes sense. However, from this data, impacts of activities on water quality are only seen at the reservoir level, and it is difficult in many cases to trace back upstream to understand which activities or incidents are causing the changes seen at reservoir level. A more fine grained understanding of this is necessary in order to be able to make predictions about the effects of proposed new activities.

A number of case studies have considered water quality issues, in particular looking at Waratah Rivulet, but how these may be multiplied across the Catchment is unknown. The effects observed could simply be local. Using case studies to understand catchment-level impacts is fraught with difficulty.

To understand the impacts of activities in the Catchment, especially the cumulative impacts, monitoring is required throughout the Catchment hydrological system. This will entail monitoring programs in all the major surface water and groundwater bodies.

Water quality monitoring for this purpose has been conducted by the SCA since the mid-2000s. In contrast to water quality data for the reservoirs, which have been collected for decades, these data sets are still short, making scientifically rigorous analyses difficult. The Review commends this additional monitoring and suggests that this whole-of-Catchment understanding approach to monitoring be continued and significantly expanded.

5 QUANTITY IMPACTS

5.1 WHEN MIGHT QUANTITY ISSUES BE A PROBLEM?

While the previous chapter dealt with the means of managing most potential cumulative impacts of activities in the Catchment on water quality, this chapter focuses on potential cumulative impacts of activities on water quantity.

The focus here is on major adverse quantity events that could have a measureable significant impact on the Catchment's holding capacity and ability to supply water to the various water filtration plants for distribution. Examples include:

- a crack in a dam wall or a wall failure that could cause a considerable decrease in the availability of water to the customers of the SCA
- damage to a water course that stops it supplying surface water to a reservoir
- induced leakage of water from a storage due to an enhanced connection between the surface water and the underlying groundwater.

There are a lot of data notionally available that could be relevant to assessing these issues but they are dispersed, often one-off in nature (e.g. a single borehole drilled and then plugged) and not easily available in raw form. The technical capabilities to handle such massive amounts of diverse data have not previously been easily available.

So when one tries to investigate whether the impacts of several activities in the Catchment could combine and interact to cause a major adverse water-quantity event, the data to use in visualisation tools or to build even limited models are rarely to hand. We are at present not able to address with any degree of precision questions such as:

- What are the factors that could significantly reduce the volume of water in the system?
- How likely are these to happen?
- Can we predict these events before they occur, or can we detect them during their initiation while still at low levels?
- How can we think about the range of activities going on over the area, over time, or in terms of causal pathways?

5.2 DO WE NEED TO BE CONCERNED ABOUT THE POSSIBILITY OF LARGE-IMPACT EVENTS ARISING FROM CUMULATIVE ACTIVITIES IN THE CATCHMENT?

To date, large-impact adverse-quantity events have been avoided for the most part. This is doubtless helped in large measure by the comprehensive and cautious approach of the Dams Safety Committee. In relation to dam wall collapse and mining, the DSC has a particular remit in the regulation of mining within the Dam Safety Notification Areas and is involved in providing advice on measures to manage risks of mines to dams and reservoirs. In general the DSC does not support major mining activities within a 1km radius of the prescribed dam walls, and requires a suite of monitoring and mine management conditions for mining within the Dam Safety Notification Areas (DSC, 2010). Such requirements include vibration monitoring, drilling ahead of workings, water fingerprinting, contingency plans and monitoring management plans. Protecting the safety and integrity of dams and their storage is the major focus of the DSC (DSC, 2014a).

In its submission to the Sydney Catchment Authority 2013 Audit, the DSC stated that it works to ensure that mine owners develop a comprehensive scientific understanding of the effects of mining on stored waters and dams to ensure negligible impact to existing infrastructure (DSC, 2013). And further that "endorsement of a mine plan by the DSC is only undertaken after it has been demonstrated on sound scientific and technical grounds that the mining will have negligible impact on the dam structure and/or the water storage" (DSC, 2013).

For mining and gas activities in the Special Areas more broadly, the proponents of these activities are required at the application stage to assess the risk of their development causing impacts on features and infrastructure in Environmental Assessments, Subsidence Management Plans, and Groundwater models among other things. These are reviewed by a range of agencies. On-going observation of events occurs throughout operations, such as those anticipated in the Subsidence Management Plan, and reporting them to agencies. This reporting, as noted in Chapter 2, is largely in consolidated form and raw data is rarely requested or provided.

However, despite the good preventative measures in place, there are enough incidents that indicate that for all the extraction activities to proceed safely simultaneously in the Catchment a more sophisticated and predictive understanding of cumulative impacts on water quantity is needed. Incidents at the Blue Panel in 1982 and Thirlmere Lakes in 2011 (see breakout boxes) are relevant examples. A recent paper by Walsh et al. (2014) demonstrates an example of a management approach to avoid an expected impact on a sensitive natural waterfall feature. A monitoring regime was established to provide early indications of trouble, and extraction activities halted in time to prevent damage.

Blue Panel

Surface to mine hydraulic connection is thought to have occurred in the Catchment with the mining of the Wongawilli Seam near the Avon Reservoir in 1982 (DSC, 1989; McNally & Evans, 2007; Wilson, 1985). The proponents had requested permission to dig a bord and pillar mine under the reservoir, with the pillar extraction outside of the 35^{o} angle of draw marginal zone. Conditions of the mine were complicated by:

- an intrusive igneous sill adjacent to the work
- the presence in the area of a major fault
- dissected and rugged surface topography
- shallow overburden of 80-100 m between the coal seam and the bottom of the reservoir although these areas were some distance from the reservoir.

First workings progressed smoothly, but in December 1982 a water inflow occurred to the mine, in the Blue 3-4 panels and the Blue 2 panel associated with the igneous sill. Discharge reached 100,000L/hr causing considerable damage to the mine. The mine was closed. In examining the circumstances of the inflow, it was found that the characteristics of the water from the Blue 2 and Blue 3-4 panels were different, with Blue 3-4 remaining fairly constant, with considerable increases after periods of heavy rain, and appeared to be drawn from the surface water storage, which was confirmed with some algal sampling. The Blue 2 panel decreased inflows markedly, appeared to derive from a confined aquifer (DSC, 1989).

In investigating the event, undertaking a water balance analysis of the Avon Reservoir was considered, but a review of estimated quantities indicated that the outflow from the lake was small in relation to other factors such as evaporation, and no positive result was obtained (DSC, 1989). The outflow from the lake represented a very small proportion of the safe draft of the reservoir, averaging approximately 1.4% over three years (DSC, 1989). There was disagreement at the time as to whether the source of the water was groundwater or was directed from surface water, with the igneous dykes acting as a conduit (McNally & Evans, 2007).

Thirlmere Lakes

Thirlmere Lakes are situated in the vicinity of the Sydney Water Catchment, outside of the Special Areas. They are a set of perched lakes, within the Hawkesbury Sandstone, with a gradient toward the East, where there is a longwall mine approximately 1 km away. The Lakes have historically had a fluctuating water level, however concern was raised in the first decade of the 2000s that the lake levels did not appear to be responding to recently increased rainfall following the end of the drought.

An Inquiry was commissioned by the NSW Government in 2011 to look at the cause of the decline in lake levels. A range of possible contributing factors was put forward – including possible mining impacts on the groundwater gradient and the integrity of the aquitard layers, as well as effects of climate and weather patterns (Independent Thirlmere Lakes Inquiry Committee, 2012).

The Chief Scientist and Engineer undertook a review of the Inquiry Report (CSE, 2013b).

The Chief Scientist and Engineer concurred with the Inquiry's observation that at present there is not enough understanding of the system to be able definitively to determine the contributions of different causes to the reduced water, and that further monitoring is required, including monitoring of groundwater, surface water and precipitation. More modelling is also required, to understand the dynamics of the water in the system and its response to inflow and outflow events. Data collection is needed within the catchment of the Thirlmere lakes, and further afield in the region where the groundwater was understood to be moving and taken, and in the vicinity of the mines.

5.3 SO CAN WE DO BETTER?

The relatively recent advances in data analytics combined with a whole-of-Catchment data repository (a subset of the whole-of-State environment data repository recommended in CSE, 2013a) would allow the development of increasingly precise and robust models of Catchment activities and their impacts on issues such as water quantity as well as impacts on special features in the Catchment. Even though the models would take some time to evolve, bringing together historic data and current real-time Catchment data would be immediately useful as it could be examined in powerful 3D visualisation software or in 3D simulators such as the iCinema at the University of New South Wales Department of Mining Engineering. Such visualisation tools enable experts to conceptualise a holistic overview of different parameters they are measuring in areas of interest and to pick up anomalies that are often indicators of unforeseen cumulative events.

6 CATCHMENT-SCALE IMPACTS

6.1 INTRODUCTION

The current regulatory system for activities in the Catchment assesses and approves projects on an individual basis. As a result, the reporting of impacts is also done on a project, or even sub-project, level. These reports are the major source of information about what is taking place in the Catchment, which makes their fragmented nature problematic for attempting to build a picture of the cumulative impacts of activities.

It is important to understand the cause of effects and their magnitude, and in many cases our understanding is imperfect. In understanding cumulative impacts, however, we must also consider the Catchment as a whole system with interconnected features.

6.2 CHARACTERISING IMPORTANCE

In this context, we as a community need to make decisions about the importance of all the features within the Catchment. These decisions can be supported by scientific evidence and knowledge, for example, by understanding exactly how much the loss of a particular swamp would influence water quality and quantity, but they are also decisions that must be informed by community opinion and balanced by economic considerations.

Threatened species and communities legislation and regulation is one way in which the community assigns importance to environmental features. In NSW this is done through listings under the *Threatened Species Conservation Act 1995*. Coastal Upland Swamps, which includes swamps of the type found in the Catchment, have been listed under this Act as Endangered Ecological Communities, with longwall mining considered a Key Threatening Process. This listing has been in place since 2002, yet longwall mining has continued to impact swamps in the Catchment.

While this listing affords some protection to individual swamps, it does not assist in decisions as to how many swamps can be impacted in the region without noticeable damage to the Catchment's ecosystem as a whole.

Some attempts have been made to come to terms with this question, but none have been at a whole-of-Catchment scale. In 2008, the Southern Coalfields Inquiry (NSW Department of Planning, 2008) recommended the identification of Risk Management Zones (RMZs) to focus assessment and management of potential impacts on significant natural features. These zones would be defined surrounding significant natural features and within which an increased level of confidence in the prediction of the effect would be required (Hebblewhite, 2009).

These have been considered in subsequent PAC reviews of major development projects in the Catchment. In reviewing the Metropolitan mine expansion in 2009, the PAC differed from the Inquiry, finding it unreasonable that a "reverse onus of proof" be sought from mining companies when applying to mine near significant natural features (PAC, 2009). When later reviewing the Bulli Seam Operations project the PAC suggested 'Defined Areas' be used to recognise geographic areas within which all examples of classes of natural features would be considered of special significance and thus subject to negligible impact requirements (PAC, 2010).

The 'Defined Area' geographic concept attempts to mitigate the practice whereby proponents were avoiding recognising any significant natural features as of 'special significance' and thus subject to negligible impact requirements. However, the corollary is that for significant natural features outside of the Defined Area, the PAC considers that negative impacts should be avoided or compensated for if they are considered of special significance while others may suffer impacts as endorsed in the planning approval conditions. The PAC notes that in the case of the Bulli Seam proposal the Defined Areas suggested will fail to fully protect the SCA Special Areas (PAC, 2010).

The 2013 SCA Audit calls on various government agencies to collaborate on development of a risk assessment methodology to assess the impacts of mining, CSG and industrial developments and endorses the use of RMZs around natural features of special significance as originally suggested by the SCI (GHD, 2013). Such a method relies implicitly on determination of both the significance of features and the tolerance of adverse impacts to them.

In addition to concerns about the environment, there are features within the Catchment that may be affected by mining which have cultural significance. Some of these are culturally significant due to their aesthetic value, some are of historic value and some areas have Aboriginal heritage value. Features with significant aesthetic value, such as the Sandy Creek waterfall, or significant historic value, such as the State heritage listed Upper Canal (which is also a critical piece of water supply infrastructure), have been carefully managed when mining has been approved nearby due to their uncontested significance.

A total of 632 Aboriginal Heritage sites has been identified in the region covered by the initial Bulli Seam Operations (PAC, 2010), while the Metropolitan Coal Project identified 188 sites within its project area (PAC, 2009). However, in commenting on assessment of impacts on Aboriginal Heritage in both the Bulli Seam and Metropolitan reviews, the PAC criticised the estimation and judgment of the scale of impacts predicted for heritage sites. In the latter report the PAC noted that the assessment of Aboriginal heritage sites reinforces the finding of the Southern Coalfields Inquiry that “subsidence impacts assessments have in general focused too much on the prediction of subsidence effects and have not paid sufficient attention to subsidence impacts and consequences” (PAC, 2009).

A further problem, having identified significant features, is to determine what level of damage to these features is considered acceptable. Several reviews have noted the seeming discrepancy between the company assessments of impact severity versus the assessment by other parties (GHD, 2013; Krogh, 2012; PAC, 2010). This is a problem that can only be overcome by providing clearly agreed impact definitions at the point of approvals, and ensuring compliance. These impact definitions must be agreed upon by all parties, so that the current situation, where an impact may be considered significant by the part of the government charged with protecting the environment, and minimal, by the part of the government charged with facilitating mining, cannot continue.

This conflict can in part be addressed by providing government officials with access to as much reliable and useful information and data as possible. This should include past information such as track records of company performance or locations of previous mining; current information on issues such as the state of the environment; and also future information such as predictions and modelling of impacts – direct and indirect, singular and cumulative.

With access to such information, and in standard formats that are easily accessible, visualisable, and in a raw form that allows further analysis and comparison, government will be in a better position to undertake assessments in a whole-of-Catchment context that enable better informed decision making. In particular, the different agencies of government will have access to the same broad range of data.

6.3 A WAY FORWARD

The NSW Strategic Land Use Policy (see Chapter 2) represents a model for a possible approach to planning for the competing use of resources in a given area. That policy is concentrated on the coexistence of extractive industries such as CSG and mining with agricultural and urban land uses, with a particular focus on groundwater resources through tools such as the Aquifer Interference Policy. In planning the strategic use of the Catchment, a similar approach could be taken, though here the major competing uses of the area are large-scale coal mining, CSG and metropolitan water supply. At issue here too is the long-term preservation of a relatively pristine environment, with little surface disturbance.

Creating a detailed plan, after consulting with all users and interested parties within the Catchment, for the exploitation of its resources is a first step in resolving conflicts over resource allocation and use. Among other benefits, it should reduce conflicts between government agencies, as the detailed plan would provide policy guidance to decision-making across the whole of government.

Any such plan must be informed by an understanding of the systems involved in the Catchment. It is critical to know just how and through what pathways the activities taking place in the Catchment affect each other and affect the overall Catchment health. This knowledge will necessarily be constantly evolving, and so it is crucial that the strategic use plan for the Catchment, once developed, be adaptive in nature and able to adjust to refinements and increases in our knowledge.

Finally, it is important to recognise that many of these issues have a value dimension – that is, the features to be protected and the level of impact to be tolerated are not items that can be identified through a purely scientific enquiry. These are conversations that must be held with the community, in order for government to effectively balance the need for the economic resources of the Catchment with the ecosystem services it provides (drinking water) and the values of the land itself.

7 RECOMMENDATIONS AND CONCLUSION

7.1 RECOMMENDATIONS

The issues covered in the previous chapters led the Review to make the recommendations given below.

Recommendation 1: That Government create a whole-of-Catchment data repository

This recommendation is a subset of Recommendation 2 proposed in the Independent Review of Coal Seam Gas activities in NSW Report for a whole-of-State environment data repository (CSE, 2013).

There is currently an extensive amount of data of varying quality held by several organisations (companies; governments – Commonwealth, State, local; research organisations; community groups) for a range of time periods for the Catchment. However, there is no unified data set nor are there mechanisms for bringing existing data into one well-curated repository.

The repository should contain at least all past, present and future raw and processed data collected according to legislative and regulatory requirements associated with water management, gas extraction, mining, and environmental monitoring in the Catchment. Where possible new data should be collected by online real-time sensing. This repository would, as a minimum, have the following characteristics (as explained for the State environment data repository (CSE, 2013a)):

- have excellent curatorial systems
- be designed and managed by data professionals to highest world quality data-handling standards
- be open except for limited exceptions where the data is commercial-in-confidence and to which access is restricted to varying degrees
- be not only accessible by all under open-data conventions but also able to accept citizen data input
- be able to be searched in real time
- be spatially enabled
- hold all data electronically
- hold data of many diverse formats including text, graphics, sound, photographic, video, satellite, mapping, electronic monitoring data, etc.
- be the repository of all research results pertaining to environmental matters in the Catchment along with full details of the related experimental design and any resulting scientific publications and comments
- be the repository of historical data with appropriate metadata
- for all bodies governed by relevant legislation, generate an automatic deposit schedule, and notify the regulator and the organisation involved automatically of overdue deposits.

As for the overarching case, legislative amendments will be necessary to direct all relevant data to the data repository.

A particular issue in this case is putting in place any needed legislative mechanisms to access the raw data held by mining and CSG extraction companies for the Catchment. Generally these companies provide their reports with data summaries and only rarely raw data. Yet they hold some of the most useful data for measuring cumulative impacts available.

Another issue is that at present these companies are generally not required to leave boreholes instrumented or to monitor for more than two years past mining. This practice should change so that any drilling is used as an opportunity to collect more real-time data.

Recommendation 2: That Government develop a whole-of-Catchment environmental monitoring system

There is a need to build a comprehensive understanding of Catchment-wide monitoring requirements to maximise information for measuring impacts and, in particular, cumulative impacts and to provide adequate data to drive the construction of comprehensive Catchment models. This could be done through constructing, implementing and frequently updating a Catchment Monitoring Plan that uses the mechanism of creating the data repository to build an understanding of current data monitoring in the Catchment and inform what extra data monitoring is required. Such a monitoring plan should also draw and inform on a frequently updated Whole-of-Catchment Risk Assessment.

Recommendation 3: That Government commission computational models which can be used to assess the impacts on quantity and quality of surface water and groundwater

Robust, comprehensive, predictive models of activities in the Catchment are needed to obtain a major increase in our understanding of cumulative impacts in the Catchment. Recent significant developments in data analytics combined with the data from the proposed repository will enable the construction of both data fusion models and deterministic, parametric models. There are several research organisations that could contribute to these models and they are probably best coordinated through NICTA.

The Review notes that models are limited by the quality, type and amount of data they are built on and, in the case of deterministic, parametric models, by the assumptions used in their construction. Therefore any interpretation of model results needs to be done by experts from appropriate disciplines.

Recommendation 4: That Government encourage the use of data visualisation tools for examining 3D representations of the Catchment

As noted by Friedman (2008), the "main goal of data visualization is to communicate information clearly and effectively through graphical means." Even before computational models are constructed, examining Catchment data through 3D visualisation tools (e.g. Google Earth™ application, NICTA's 3D visualisation tool, or UNSW's Mining Engineering iCinema), can be a powerful way for various discipline experts to explore cumulative impacts. The Queensland Department of Natural Resources and Mines has been a significant pioneer in deploying visualisation tools in complex natural environments (see http://www.dnrm.qld.gov.au/mapping-data/queensland-globe/about). These tools have also been picked up recently in a range of NSW Government agencies.

Recommendation 5: That Government establish an expert group to provide ongoing advice on cumulative impacts in the Catchment

This Review has been able to highlight some significant challenges in coming to grips with cumulative impacts of multiple activities in the Catchment. However, if these activities are to continue safely in a simultaneous manner, there is a need for ongoing specialist advice to Government on the matter. A by-product of the Review is that it has demonstrated that a wealth of talent to build a more precise characterisation of cumulative impacts in the Catchment exists in NSW and in Australia more generally. Accordingly, the Review recommends that Government establish a standing expert group on Catchment cumulative impacts. Such an expert group would be an important source of advice for organisations such as the SCA; Sydney Water; the Dams Safety Committee; the Department of Planning and Environment and the PAC in particular; NSW Trade & Investment's Division of

Resources and Energy; mining and CSG extraction companies operating and seeking to operate in the Catchment; and community groups with an interest in the Catchment.

7.2 CONCLUSION

Current approaches to managing for cumulative impacts are limited, especially for complex entities such as the Catchment which involve multiple industries, uses and activities and the potential for multiple impacts. A more quantitative approach is required, but at present there is insufficient data available in a coherent form to provide a deep and reliable understanding of cumulative impacts in the Catchment. This finding is supported by experts in a range of relevant disciplines who were asked by the Review to examine the core question of measuring cumulative impact of activities in the Catchment. With more data, models can be built to provide a framework for examining predictions of cumulative impact and a mechanism for explaining measured impacts and attributing them to the most likely causes.

The Review looked in detail at two significant matters that could be cumulatively impacted, namely water quality and water quantity. It found that the current multi-barrier process for protecting water quality is sufficient, by and large, to protect water quality no matter the type of adverse impact, though special provision for produced water is desirable before CSG extraction is permitted in the Catchment. Water quantity is much harder to assess and manage. The current cautionary approach by the Dams Safety Committee and other government agencies seems to be preventing development that could cause obvious disastrous cumulative impacts, and therefore there is no reason to stop longwall mining immediately. However, there is still significant uncertainty around cumulative impacts on water quantity and the recommendations above, if implemented, should help address this matter.

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Acronyms

AEMR	Annual Environment Management Report
ADWG	Australian Drinking Water Guidelines
ALARP	As low as reasonably practicable
APPEA	Australian Petroleum Production and Exploration Association
CMAs	Cumulative Management Areas
CSE	NSW Chief Scientist & Engineer
CSG	Coal seam gas
DGR	Director-General Requirements
DRE	Division of Resources and Energy
DSC	Dams Safety Committee
DSS	Decision support systems
DTIRIS	Department of Trade and Investment, Regional Infrastructure and Services
EIS	Environmental Impact Statement
EP&A Act	*Environmental Planning and Assessment Act 1979*
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
INSAR	Interferometric synthetic aperture radar
NCRAT	Namoi Cumulative Risk Assessment Tool
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NICTA	Australia's Information Communications Technology (ICT) Research Centre of Excellence
NPWS	National Parks and Wildlife Service
NorBE	Neutral or Beneficial Effect
NOW	NSW Office of Water
OEH	Office of Environment and Heritage
OGIA	Office of Groundwater Impact Assessment
PAC	Planning Assessment Commission
POEO Act	*Protection of the Environment Operations Act 1997*
RMZ	Risk Management Zone
SCA	Sydney Catchment Authority
SCI	Southern Coalfields Inquiry
SEPPs	State Environmental Planning Policies
SRLUP	Strategic Regional Land Use Policy
SSD	State Significant Development`
SWC	Sydney Water Corporation
TARPs	Trigger Action Response Plans
WFP	Water Filtration Plant

APPENDICES

Contents

Tables

Figures

1 LETTER FROM THE MINISTER AND TERMS OF REFERENCE FOR COAL SEAM GAS REVIEW

The Hon Anthony Roberts MP
Minister for Resources and Energy
Special Minister of State

V14/477

Professor Mary O'Kane
NSW Chief Scientist and Engineer
GPO Box 5477
SYDNEY NSW 2001

20 JAN 2014

Dear Professor O'Kane Mary

As you would be aware, the NSW Government has announced a hold on all Coal Seam Gas exploration and extraction in the 'Special Areas' within Sydney's drinking water catchment. The NSW Government understands that there is community concern around Coal Seam Gas activities, and how these might affect water supplies, and we want to ensure that any future decisions are based on scientific evidence.

On behalf of the NSW Government and in recognition of the work that you have done in this area, I am requesting that you build on your *Initial Report on the Independent Review of Coal Seam Gas Activities in NSW* to specifically examine the cumulative impact of all activities which impact ground and surface water in the Sydney Water Catchment Special Areas. It is recognised that activities outside the Special Areas, but within the Sydney Catchment, may also have significant impacts on ground and surface water.

Any further work that your office conducts would help to provide greater factual information about how the industry and other factors might influence the status of the Sydney Catchment area.

If you agree to continue your review in this area, I would ask that you provide your findings to both the Premier, the Hon Barry O'Farrell MP, and myself, by May 2014.

Yours sincerely

Anthony Roberts MP
Minister for Resources and Energy
Special Minister of State

GPO Box 5341, Sydney NSW 2001
Phone: (02) 9228 5289 Fax: (02) 9228 3448 Email: office@roberts.minister.nsw.gov.au

Terms of Reference

Review of coal seam gas activities in NSW

At the request of the NSW Government, the NSW Chief Scientist and Engineer will conduct a review of coal seam gas (CSG) related activities in NSW, with a focus on the impacts of these activities on human health and the environment.

The Chief Scientist and Engineer is to:

1. undertake a comprehensive study of industry compliance involving site visits and well inspections. The Chief Scientist's work will be informed by compliance audits undertaken by regulatory officers, such as the Environment Protection Authority and other government agencies
2. identify and assess any gaps in the identification and management of risk arising from coal seam gas exploration, assessment and production, particularly as they relate to human health, the environment and water catchments
3. identify best practice in relation to the management of CSG or similar unconventional gas projects in close proximity to residential properties and urban areas and consider appropriate ways to manage the interface between residences and CSG activity
4. explain how the characteristics of the NSW coal seam gas industry compare with the industry nationally and internationally
5. inspect and monitor current drilling activities including water extraction, hydraulic fracturing and aquifer protection techniques
6. produce a series of information papers on specific elements of CSG operation and impact, to inform policy development and to assist with public understanding. Topics should include:
    - operational processes
    - NSW geology
    - water management
    - horizontal drilling
    - hydraulic fracturing (fraccing)
    - fugitive emissions
    - health impacts
    - wells and bores
    - subsidence.

The NSW Chief Scientist & Engineer will provide an initial report to the Premier and the Minister for Resources and Energy on her findings and observations by July 2013.

2 HISTORY

Figure A-2.1 illustrates some of the major events in the Sydney Catchment area. Sydney was first settled in 1788 by Europeans, who initially made use of local stream water, followed by wells at Rushcutters Bay and then the Lachlan Swamps. The Botany Swamps were also exploited as a source of water and these were relied upon until the Upper Nepean scheme began in 1869 to harness water from the Upper Nepean Catchment. This scheme was responsible for the building of Pheasants Nest Weir, Broughtons Pass Weir, the Upper Canal and Prospect Reservoir. Later expansions added the Cataract, Cordeaux and Avon dams, with the Woronora dam, to supply Sydney's southern suburbs, and the Warragamba dam completed in 1941 and 1960 respectively.

The Special Area associated with each water storage was generally declared at the beginning of the period of construction. For example, the Metropolitan Special Area was declared at the start of the Upper Nepean scheme, during the construction of the two weirs and the upper canal. Expansions and changes to the boundaries of the Special Areas have occurred over time, in response to the changing needs of Sydney's water supply.

Pre-1800

- Aboriginal occupation of area; Dharawal, Wadi Wadi and Gundungurra people estimated to go back at least 15,000 years
- 1788 First European Settlement in Sydney area

1800s

- 1848 First coal mining operation at Albert Coal Mine near Mt Keira
- 1857 Commercial quantities of coal produced at Kemira Colliery
- 1878-1991 Coal Cliff Colliery (bord and pillar) operated
- 1880 Metropolitan Special Area declared to protect Upper Nepean catchment
- 1888 Metropolitan Colliery opened at Helensburgh; Prospect Reservoir, Broughton's Pass Weir, Pheasants Nest Weir and the Upper Canal completed

1900-1950

- 1907 Construction of Cataract Dam completed
- 1908-1938 Upper, Middle and Lower Cascade Dams completed
- 1916-1993 Wongawilli Colliery in the Illawarra district
- 1924 Berrima Colliery opens
- 1926 Cordeaux Dam completed
- 1927 Avon Dam completed
- 1930-1980 Old Wollondilly Coal Mine
- 1932-1992 Nattai Bulli Coal Mine
- 1935 Completion of Nepean Dam
- 1935-1973 Wollondilly Extended Coal Mine
- 1941 Woronora Dam completed; Woronora Special Area declared
- 1942 Warragamba Special Area declared

1950-2000

- 1959-1984 Valley 1-3 Coal Mines
- 1960 Warragamba Dam opened
- 1962 Appin (Appin West) Colliery opens
- 1969 First longwall dug at Appin
- 1973 Fitzroy Falls and Wingecarribee Special Areas declared; Warragamba Dam earthquake (magnitude 5.5)
- 1974 Fitzroy Falls and Wingecarribee Reservoirs completed
- 1974-1988 Nattai North Coal Mine
- 1975-1979 Mechanised longwall mining introduced
- 1976 West Cliff longwall coal mine opens
- 1979 Tahmoor Coal Mine opens
- 1987-1989 Warragamba Dam wall strengthened and raised by 5 m as part of safety works
- 1991 Blue Mountains Special Area declared
- 1993-2005 Wongawilli Colliery consolidated with Kemira and Nebo mines to become Elouera Colliery
- 1998 Cryptospridium outbreak
- 1999 Sydney Catchment Authority became operational

2000-present

- 2001-now AGL Camden Gas Project producing CSG (144 wells, 95 of which are producing gas)
- 2002 Construction of an auxiliary spillway for the Warragamba Dam is completed
- 2005 Longwall mining commences at Dendrobium Coal Mine
- 2007-now Elouera Mine sold and re-christened NRE Wongawilli Colliery
- 2008 Prospect Special Area declared

Figure A-2.1: Timeline of events in Sydney Catchment Area

3 GOVERNMENT BODIES AND THEIR ROLE IN CATCHMENT MANAGEMENT

A number of NSW Government agencies have responsibilities for managing Sydney's drinking water Catchment. Chief among these is the SCA, with responsibilities for the Special Areas. Key responsibilities are also held by the National Parks and Wildlife Service, the Dams Safety Committee, the NSW Office of Water, the Division of Mineral Resources and Energy, the Office of Environment and Heritage and the Environmental Protection Authority.

3.1 Sydney Catchment Authority

The SCA was established and has an operating licence under the *Sydney Water Catchment Management Act 1998*. Under the Act, the SCA is responsible for the management and protection of Sydney's drinking water catchments as well as Catchment infrastructure that supplies raw water to water filtration plants. These plants, the treatment of the raw water to the standard set by the Australian Drinking Water Guidelines and the delivery of water to customers is the responsibility of water utilities, the biggest of which is Sydney Water. In total, approximately 60% of the NSW population uses water supplied by the SCA (SCA, 2011).

The SCA operates under a board of management. The chief executive officer reports to the board and to the Minister for Primary Industries. In March 2014, the Minister for Primary Industries announced that the SCA would be merged with the State Water Corporation to form Bulk Water NSW. This new body is expected to be fully in place by the end of 2015 (DPI, 2014). The State Water Corporation is the rural bulk water manager, responsible for 14 regulated rivers across NSW that supply about 6,300 customers (State Water Corporation, n.d.). The merger of SCA and the State Water Corporation is a recommendation from Stage 1 of the Bulk Water Delivery Review, which is aimed at insuring that the expertise in bulk water management is concentrated in one agency (DPI, 2014). The responsibilities of both agencies will be preserved in the new body. (As these changes are yet to flow through to rebranding and renaming of the agencies, this report uses 'Sydney Catchment Authority' throughout.)

In addition to acting as a land and infrastructure manager, the SCA also has a market role; it is responsible for managing and extracting a value from a resource by selling it to customers, the biggest of which is Sydney Water. As such, it is important for the SCA to manage any loss of water within the Catchment that may be due to other activities. The SCA has raised concerns that loss of water to mining activities may be impacting its financial bottom line; however, proving this loss has been problematic, making it difficult to claim compensation from the mining companies. The SCA is able to sell water from the Catchment directly to mining companies for use under its water sharing plan.

The SCA, as owner of the dams, is required to comply with the Australian National Committee on Large Dams Guidelines on Dam Safety Management, 2003. This is in addition to their responsibilities to the Dams Safety Committee for whom they must prepare Dam Safety Emergency Plans and Dam Surveillance Reports, reporting on the security measures in place where dam failure may put lives at risk (DSC, 2010a).

Each year the SCA publishes a Healthy Catchments Program which details the specific work and activities from the Healthy Catchments Strategy 2012-2016 to be delivered in that financial year. At the end of the year, progress is reported in the annual Catchment Management Report (SCA, 2013b). One example of an activity undertaken in the Healthy Catchment Program in 2012-13 is a project to investigate surface water - groundwater interaction and inter-catchment flow in one mining impacted catchment. Evidence was found that a small amount of water was being lost from the monitored sites; however, whether this loss was permanent or temporary, that is, whether the water lost rejoins the system at a later point, could not be determined.

Assessing and managing risk to water quantity and water quality is an essential part of the SCA's role. Two decision support systems have been built to aid the SCA in assessing risks to water quality. The first of these, the Pollution Source Assessment Tool, helps identify the significance of different pollution sources in the Catchment. It uses technical information, spatial data, modelling, expert knowledge and management practice for water quality and pollution management.

The second system, the Neutral or Beneficial Effect on Water Quality Assessment Tool, was developed by the SCA to assist local councils in assessing development applications for which they are the approval authority. This tool is built for use with development applications of low to medium complexity and allows the assessment of development site conditions and the wastewater and stormwater impacts (GHD, 2013).

In addition, the SCA has developed the Strategic Land and Water Capability Assessment Tool to assist councils in the Catchment with the review and development of Local Environmental Plans.

3.2 National Parks and Wildlife Service

In recognition of the importance of ecological integrity to water quality, the National Parks and Wildlife Service (NPWS) is a joint partner with the SCA in managing the Special Areas. National Parks constitute 65% of the Special Areas, and as such statutory responsibility for these sits with the NPWS. The Special Areas Strategic Plan of Management sets out each partner's responsibilities and guides the production of operating plans and procedures, which in turn become annual work plans (SCA, 2007).

Restrictions placed on National Parks and Special Areas differ (see Table A-3.1). A key difference is that the *National Parks and Wildlife Act 1974* forbids mining within National Parks except through an Act of Parliament. The establishment of Dharawal National Park in 2012 had the effect of halting planned longwall mining under the area as well as withdrawing approval for CSG exploration wells that were to be drilled. Dharawal borders the Metropolitan and Woronora Special Areas.

Table A-3.1: Restricted activities in Special Areas and National Parks

Special Areas (No Entry Areas)	Special Areas (Restricted Access)	National Parks
No entry	Walkers only	No lighting bushfires
No vehicles, bikes, motorboats or horses	No vehicles, bikes, motorboats or horses	No hunting of any kind
No pets	No pets	No trapping or collecting birds, birds' eggs, reptiles or other kinds of animals
No shooting	No shooting	No picking flowers or collecting plants
		No driving or riding vehicles, bikes and horses on unauthorised tracks
		No dumping rubbish or refuse
(NSW National Parks and Wildlife Service, n.d.; SCA, 2013a)		

3.3 Dams Safety Committee

The Dams Safety Committee (DSC) was established by the *Dams Safety Act 1978* with the power to inspect and monitor prescribed dams and to issue notices to ensure the safety of dams. The *Mining Act 1992* also gives the DSC responsibility for providing recommendations to the Minister on any mining proposals that would impact on Dam Safety Notification Areas.

When providing this advice to the Minister, the DSC may advise on the location and scale of the mining and the monitoring and surveillance to be undertaken. In general, the DSC notes that "substantial mining near a major dam structure is not permitted" (DSC, 2010b). The SCA board has stated publicly that it opposes any mining proposals that would impact on existing water infrastructure or that would occur within Dam Safety Notification Areas for the dams under its management (SCA, n.d.-a). Despite this, several completed, approved and planned mines are located within the Dam Safety Notification Areas in the Warragamba, Metropolitan and Woronora Special Areas.

3.4 NSW Office of Water

The NSW Office of Water (NOW) manages the SCA's access to water in the Special Areas under the *Water Management Act 2000* (SCA, n.d.-b). The SCA must comply with the Water Sharing Plan for the Greater Metropolitan Region Unregulated Rivers Water Sources 2011 and the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011, along with other users of this water including industry. The Water Supply Work and Water Use approvals also set out how the water management works are to be operated and the amount of water that the SCA must make available for environmental flows (SCA, n.d.-b). The Water Sharing Plan includes rules for protecting the environment, extractions, managing licence holders' water accounts, and water trading in the plan area (DPI, 2012a).

NOW is also responsible for a water monitoring network from which they collect and manage data. Both surface water and groundwater bore information is collected across the State. Surface water monitoring was recently upgraded following the federal *Water Act 2007* and the Modernisation and Extension of Hydrologic Monitoring Systems Program administered by the Bureau of Meteorology under that legislation. This has resulted in over 5,000 water monitoring stations across the state, giving real-time information (DPI, 2013). The quality and availability of information varies, however, and the uses to which this information can be put will be limited partly by the original purpose of its collection. For example, much of the groundwater monitoring that is currently in place was originally intended to discover useful freshwater for agricultural purposes, so its use in other applications, particularly those focused on deep groundwater or groundwater quality, is limited.

The Aquifer Interference Policy, which is part of the *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (see Chapter 2) is also managed by the NSW Office of Water.

3.5 Division of Mineral Resources and Energy

The Division of Resources and Energy (DRE) in NSW Trade & Investment administers minerals and petroleum titles under the *Petroleum (Onshore) Act 1991* and the *Mining Act 1992*. Titles include exploration licences and production leases. Some exploration activities and all production leases also need approval under the *Environmental Planning and Assessment Act 1979* (EP&A Act) for which the applicant must apply to the Department of Planning and Environment. Reporting, compliance and enforcement under the terms of the two acts administered by DRE is also part of their responsibility.

3.6 Office of Environment and Heritage

As at April 2014, the Office of Environment and Heritage (OEH) is an agency within the NSW Department of Planning and Environment. The OEH administers the *Threatened Species Conservation Act 1995* which lists several endangered species and ecological communities that are found in the Special Areas. As administrator of that Act, the OEH has a range of responsibilities, including the creation of threat abatement plans for some recognised key threatening processes and recovery plans for threatened species. These categories apply to the Special Areas; for example, the upland swamps are listed as an endangered ecological community and longwall mining is a recognised key threatening process. The OEH also has a role in the development approvals process.

3.7 Environmental Protection Authority

Activities that pollute the environment are regulated by the Environmental Protection Authority (EPA) under the *Protection of the Environment Operations Act 1997* (POEO Act). The EPA can grant pollution licences for any activities listed in Schedule 1 of the Act (those most likely to have major environmental impacts, including CSG exploration, mining and processing) and for activities likely to result in significant water pollution. The SCA has similar powers to the EPA for non-scheduled activities that take place in the Catchment area.

3.8 Catchment protection in other jurisdictions

Dudley and Stolton (2003) prepared a study for the World Bank of the protection status of water supply catchments for 105 major cities worldwide. They found that about a third of the world's largest cities rely on protected areas to maintain their water supply. Whether protected areas were declared for the purposes of water protection or not, having protected areas within a watershed was associated with better quality, and in some cases a greater quantity, of water supply.

In Victoria, Declared Water Supply Catchments can be established by Catchment Management Authorities with Ministerial approval. Special Water Supply Catchments can also be declared and Special Area Plans developed to determine land uses that may occur within the areas. Special Water Supply Catchments are designated under the *Catchment and Land Protection Act 1994 (Vic)*. Within a declared catchment, the relevant land management authority must approve any proposed developments. Melbourne's water, recognised as the best-quality drinking water in Australia, has 50% of its catchment in protected areas, in contrast to Sydney, where the Special Areas cover approximately 25% of the Catchment (Dudley & Stolton, 2003).

International approaches to water supply and protected areas vary widely. Some cities, such as Toronto, Canada, which draws its water from Lake Ontario, have no protected areas in their water catchments. Others, such as New York City, USA, manage large protected areas within their watershed. China, despite having environmental laws that would appear to protect water supply, does not manage protected areas for water supply to cities outside of Beijing, which manages some watersheds near its main reservoir but under the principle of ‘multiple use’ (Dudley & Stolton, 2003).

However, China has legislated protected areas for its drinking water catchments. Chapter 3, Article 20 of the *Law of the People’s Republic of China on Prevention and Control of Water Pollution 1984* allows governments to establish protected zones for surface sources of domestic or drinking water and prohibits any new construction projects within those zones that are not related to water supply infrastructure or protection. It also states that the protection of domestic and drinking groundwater sources should be strengthened and requires State Councils to formulate specific measures for the protection of domestic and drinking water sources (The People's Republic of China, n.d.).

4 MINING TECHNIQUES

4.1 Goaf gas extraction and use

The Apex plans for exploration and production within the Special Areas (see Chapter 1) are unusual in that part of the proposal is to extract gas from the voids or goafs left in collapsed workings by historic coal mines. Extraction of gas from these older mines is unlikely to require hydraulic fracturing as the coal seam has already been fractured by mining activity.

In modern working coal mines, removal of methane is common practice as the gas must be removed for the safety of workers to avoid explosions or asphyxiation. As such, most conventional working mines include boreholes to extract natural gas. Often, this gas is burned off or used on site for power generation to support the workings. Gas also escapes to the atmosphere both from working and completed mining operations. Once a mine has ceased working, gas will continue to collect in the goafs and escape to the atmosphere.

Removal of gas from working mines was required under the *Coal Mine Regulation Act 1982*, following a deadly explosion at the West Cliff mine in 1994. That Act has since been superseded by the *Coal Mine Health and Safety Act 2002*, which contains clauses regulating the amount of ventilation that must be provided to protect workers. Under the *Mining Act 1992*, coal mine leaseholders do not need to apply for a separate lease to extract gas, and they are not required to pay royalties to the State on the gas extracted.

Emissions of methane from the mines do come at some cost to the companies under the Federal Government's carbon price. As methane is a powerful greenhouse gas, with up to 20 times the heat-trapping efficacy of CO_2, methane emissions form a large part of a mine's overall carbon budget. Generating power and reducing methane emissions, even where the methane is converted to CO_2, can generate carbon credits, which can be used to offset the mine's emissions or sold on carbon markets (Megtec, n.d.).

The Appin, Tower and West Cliff projects all use waste coal mine gas to generate power and sell this into the grid (Global Methane Initiative, 2010). The generators for these projects are all located within the Catchment but lie outside the Special Areas. The Appin/Tower project utilises up to 230 million m^3 of gas per year, including that drained from those mines and the West Cliff mine, which is piped overland for 6.8km to reach the power plant. At West Cliff itself, a Ventilation Air Methane Project oxidises the methane to water and CO_2, using the waste heat to power the mine via steam power generation (SCA, 2012).

4.2 Bord and pillar mining

Bord and pillar mining, also called 'room and pillar' is an older method of mining coal seams. This was used from the 19th Century through to the 1960s when longwall mining became more popular. Bord and pillar mining cuts a grid of tunnels ('roads' or 'bords') through the coal seam, leaving pillars of coal remaining to support the ceiling of the cavern in the first working. The size of pillars and boards is restricted by legislation. In NSW pillars must be a minimum of one tenth the depth or 10m and bords may only be 5.5m wide except where special exemptions have been sought (University of Wollongong, 2014).

In many cases, these pillars are then extracted, during 'second workings', through a range of methods including: traditional and modern split and lift methods; traditional and modern Wongawilli method; and other methods. Partial pillar extraction involves the removal of a portion of the pillars during second working, however pillars are left behind to maintain support and decrease the extent of roof/overburden collapse into the mine void.

Even with partial pillar extraction, bord and pillar mining is less efficient than longwall mining due to the coal left behind in the supporting pillars. As a rough rule of thumb, first workings remove 10-20% of the seam area, partial pillar extraction may remove 50-60% of the area and longwall methods up to 80-90% (McNally & Evans, 2007). Old bord and pillar mines in the Special Areas occur throughout the Sydney Catchment, including under the Special Areas. Bord and pillar method mining is still used in modern longwall mines to drive the roadways and access through to and around the longwall panels.

4.3 Longwall mining

Longwall mining was introduced in the 1960s and is now the principal extraction method for underground coal mining in Australia. It involves using hydraulic supports to suspend the ceiling while the coal seam is cut out in full – as the mine moves along the coal seam, the supports are removed. This method can lead to significantly more subsidence than the bord and pillar method, due to the larger scale removal of coal. It is also more efficient than bord and pillar mining as it removes more of the coal seam. A longwall ‘panel’ is the block of the coal seam that is being mined – typically, these are up to 4km long and 400m wide and are developed in sets to exploit rich areas of coal seam and can result in movement at the surface of up to half the thickness of the coal seam removed (DSC, 2013).

The four mines currently operating in the Special Areas are the Metropolitan Colliery, Russel Vale Colliery, Wongawilli Colliery and Dendrobium Colliery. Completed mining in the area has undermined approximately 8% of the Special Areas, with a further 1% approved and another 2% planned (SCA, 2014). Coal mining covers 9% of the Catchment as a whole, suggesting that it is particularly concentrated in the Special Areas. Within the Metropolitan and Woronora Special Areas, 25% of the land area is currently undermined (GHD, 2013).

5 THE DEVELOPMENT PROCESS

Proposals for development in the Special Areas are regulated under a number of different pieces of legislation. The size, scale and nature of the development determine which regulating authorities are the decision-makers for each development and which are involved in the approvals process. Various pieces of legislation apply, from the federal *Environment Protection and Biodiversity Conservation Act 1999* to State statutes and planning policies.

As developments proceed, the information and data collected by a company in order to carry out its activities are key sources of information for regulators. The information to be collected and the form in which it is to be provided to regulators are often set out in the approval conditions. Requirements for monitoring, reporting and auditing are also commonly parts of proposal approval conditions, as are remediation requirements and requirements for publication of monitoring results. Limits to impacts on certain natural and built features can be set here too, with penalties for exceedances ranging from fines to withdrawal of approval.

5.1 Planning Legislation

5.1.1 Commonwealth legislation

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) gives the Commonwealth jurisdiction over development proposals affecting water resources related to CSG and large coal mining development. Thus the Commonwealth Environment Minister can consider and impose conditions relating to the water resource in question. EPBC Act assessment and approvals are being devolved to the States; however, any CSG-related developments must still be referred to the Commonwealth Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development. States are also required to consider the cumulative impact of development proposals in undertaking EPBC Act assessments.

5.1.2 Environmental Planning and Assessment Act 1979

The *Environmental Planning and Assessment Act 1979* (EP&A Act) governs the assessment and approval of development in NSW. It is due to be replaced in 2014 as part of an overhaul of the State's planning system. The current Act and its regulations require environmental impact assessments for 'designated developments'. These are developments that may have significant adverse impacts on the environment because of their nature, scale or location near sensitive environmental areas. For designated and State Significant Developments, an Environmental Impact Statement (EIS) must be prepared. The EIS must follow the Director-General[1] of the Department of Planning and Environment's requirements in relation to its form, content and public availability. These requirements are set by the department via consultation with relevant government agencies and the community and may differ by project (NSW Department of Planning and Environment, 2014).

5.1.3 State Environmental Planning Policies

State Environmental Planning Policies (SEPPs) are instruments created under the EP&A Act that regulate land use and development. Examples of relevant SEPPs include: *SEPP (Mining, Petroleum Production and Extractive Industries) 2007* and *SEPP (Sydney Drinking Water Catchment) 2011*. SEPPs designate the consent authority for the activities they regulate, what development is permissible with and without consent and what development

[1] The *Government Sector Employment Act 2013*, which commenced in February 2014, has changed the title of NSW Government department heads from Director-General to Secretary. However, as the planning system still refers to Director-General's Requirements, this term is retained for the purposes of this report.

is prohibited. They also describe what the consent authority must consider when determining whether to give approval to a development (usually including advice from the Director-General of Planning), and set out non-discretionary development standards.

For developments that are not designated or State Significant Developments, the Sydney Drinking Water Catchment SEPP includes a requirement that consent authorities (councils) must determine that a development will have a neutral or beneficial effect on water quality in order to approve it. This is required to be assessed according to the Guideline prepared by the SCA and using the assessment tool developed for that purpose. The SEPP also requires that all developments and activities incorporate the SCA's recommended practices and standards. Further, Water Quality Information Requirements set out what information and modelling proponents must include in their development applications.

The *Mining SEPP Amendment 2013* gave effect to measures introduced under other policies, such as the Strategic Regional Land Use Policy and the Aquifer Interference Policy through changes to the *SEPP (Mining, Petroleum Production and Extractive Industries) 2007*.

5.1.4 Strategic Regional Land Use Policy

The Strategic Regional Land Use Policy was introduced by the NSW Government in 2012 to manage potential conflicts between mining and CSG activity and agricultural and residential land use. It introduces CSG exclusion zones around residential areas and establishes a Gateway process to development proposals involving CSG or State significant mining, where they occur on biophysical strategic agricultural land or equine and viticulture critical industry clusters. The Gateway process is assessed prior to the development application and does not take into account economic benefit to the State, but considers only agricultural and water impacts (NSW Government, 2012).

The EP&A Act also includes requirements for those regulatory authorities that may issue licences under other acts, such as the *Mining Act 1992*, to take into account all matters likely to affect the environment. These agencies may then produce their own guidelines requiring environmental impact assessments, such as the DRE's *ESG2: Environmental Impact Assessment Guidelines*.

5.1.5 State Significant Developments

For State Significant Developments (SSD), which are defined by the *State and Regional Development SEPP*, assessment must be sought from the Department of Planning and Environment, and consent can be given by either senior department personnel, the Planning Assessment Commission (PAC) or the Minister for Planning. Included in SSDs are all coal mining activities, some petroleum exploration activities and all petroleum production proposals. For all development proposals from private developers, the Minister has delegated decision-making powers to either the department (for proposals with fewer than 25 objections lodged) or to the PAC.

In assessing development proposals for SSDs, the Department of Planning and Environment may seek advice from the relevant NSW Government agencies, including SCA, DSC, EPA, OEH, DRE and NOW. Once approval to a proposal has been given, these agencies are not able to refuse authorisations such as an environmental protection licence or a mining lease where they are consistent with the approval. However, aquifer interference under the *Water Act 2000* must still be separately approved by NOW (DPI, 2011).

5.2 Company information

A company submitting an application for development may be required to complete an Environmental Impact Statement (EIS) under the EP&A Act. For State Significant Developments, which includes all coal mining activities, all petroleum production activities and some petroleum exploration activities, the guidelines for the EIS are called Director-General's Requirements and must be applied for to the Department of Planning and Environment on a case-by-case basis. These outline the key issues to be addressed and the plans and documents that are to accompany the EIS. In preparing these requirements, the department consults with the relevant local councils and government departments (DPI, 2012b).

Example Director-General Requirements issued for the Apex proposal to drill exploratory CSG wells in the Catchment include the key issues of soil and water, flora and fauna, noise and vibration, greenhouse gases, Aboriginal heritage and rehabilitation. The company is asked to address all of these, and include other information such as a statement outlining its environmental management, mitigation and monitoring measures and how these will be implemented (NSW Department of Planning, 2007).

The EIS is then submitted to the department along with the Development Application. An exhibition period is observed to allow the public to comment on the DA and EIS submitted. The proponent may be asked to respond to any submissions received during this period. The decision authority, either the Department of Planning and Environment or the Planning Assessment Commission, then considers the application (DPI, 2012b).

5.2.1 Management plans

For coal mines in the Special Areas, common conditions set on approvals include the production of management plans, including a Water Management Plan, an Extraction Plan and a Public Safety Management Plan, among others. These plans are typically produced by proponents, in consultation with relevant government agencies and community groups, and detail the monitoring, reporting and remediation steps to be taken. Each plan must be individually approved by the Department of Planning and Environment, which may consult other relevant government agencies in assessing each plan.

All holders of mining leases planning to undertake underground mining must submit Subsidence Management Plans. These plans are reviewed by a committee that includes representatives from the Department of Planning and Environment, NOW, OEH, SCA and the DSC. Plans are then submitted to the DRE and must include a prediction and assessment of subsidence impacts, consultation with government agencies and the community, and proposed prevention, mitigation and rehabilitation strategies. Approvals for Subsidence Management Plans may also come with conditions (NSW Department of Trade and Investment, 2014).

5.2.2 Trigger Action Response Plans (TARPs)

Within management plans, Trigger Action Response Plans, or TARPs are defined. TARPs set particular trigger levels for impacts and outline response plans for each trigger level as well as a 'catastrophic' event response plan. TARPs are then reported on as part of reporting against each plan. For example, the End of Panel reports, produced against the Subsidence Management Plan, report on the impacts observed due to extraction of a particular longwall panel in the context of TARPs established by the plan. The seemingly subjective characterisation of impacts by the proponent in these reports has been a source of criticism (Krogh, 2012). There are also concerns that this system does not extend to recognising the link between impact and environmental consequence and thus is unable to really address cumulative impacts (Krogh, 2012).

5.2.3 Reporting

Regardless of any conditions of approval or the level of activity in a given year, all mines must also produce an Annual Environment Management Report (AEMR). The AEMR monitors progress against the approved Mining Operations Plan which details the expected progress of the mine, in concert with the process for monitoring and managing that progress towards successful rehabilitation outcomes. The Department of Planning and Environment assesses the AEMR and as part of its response may include a site visit, bringing along other relevant government agencies (NSW Department of Trade and Investment, 2013).

Monitoring programs set up under these approvals and management plans result in companies collecting significant amounts of information on environmental conditions in their area of operations. Guidelines for the preparation of a Subsidence Management Plan recommend baseline monitoring of relevant environmental values for at least one year prior to the start of mining activities (NSW Department of Mineral Resources, 2003). However, the evolving regulatory system and the duration of mining activities mean that it is difficult to make uniform statements about the nature of monitoring undertaken by each company at each separate mine or even at individual longwall panels or areas within each mine. Different approval conditions, different Subsidence Management Plans and different TARPs may apply, depending on the timing of the relevant approvals, plans and reports and the issues specific to the area of the mine.

5.2.4 Company data

Publication of company data is often required as a condition of approval. For example, the Bulli Seam Operations Project PAC approval requires the company to publish all approved strategies, plans and programs on its website as well as a comprehensive summary of the monitoring results of the project. Over time, the trend has been for government to require an increasing amount of information from companies. The information that is currently provided, however, is for the most part in the form of summary reports, which can limit its value for checking and modelling purposes.

Companies are required to provide information to the Government under existing legislation, as well as through the approvals process as discussed above. For oil and gas, the *Petroleum (Onshore) Act 1991* requires that titleholders make available to the Minister geological and other plans and information in accordance with the Director-General of Planning's directions. It also requires that samples of strata, petroleum and water be collected, labelled and preserved for reference and that any reports or scientific examinations of these also be made available. Finally, the Act allows the Minister to amend an existing title to include new or further conditions in respect of protection of the environment if the title does not contain such conditions or if the Minister considers title environmental conditions are inadequate.

After the granting of a title, the ability to add new conditions is, however, limited to the specific matters listed in the Act, namely:

- the conservation and protection of the flora, fauna, fish, fisheries and scenic attractions and the features of Aboriginal, architectural, archaeological, historical or geological interest
- the rehabilitation, levelling, regrassing, reforesting or contouring of any part of the land that may have been damaged or adversely affected by operations and the filling in and sealing of excavations and drill holes.

By contrast, the *Mining Act 1992* only requires the provision of such information as may be requested by an inspector “for the purposes of administering the Act”. This is unlikely to be interpreted broadly enough to apply to the sorts of information required for monitoring and modelling. However, the regulations require the company to submit exploration reports (including geological, geophysical reports etc.), which might include other information. The Director-General is required to keep these reports confidential for the period of the authority (i.e. permit or licence) but they can be shared with particular agencies (including SCA) and agencies administering certain other Acts.

6 DIRECT IMPACTS OF MINING

Underground mining removes large volumes of subsurface material. As a result, the overburden collapses into the void, leading to deformation of the land surface. This process is described in detail below.

6.1 Subsidence

Subsidence of the ground surface over areas that have been mined is a direct consequence of removing coal from underground. The degree of subsidence observed over longwall mines is greater than that observed over bord and pillar mines (though noting that the 'first workings' of most longwall mines, that is, the access tunnels around the longwall panels, is usually done in bord and pillar style). As the size of the longwall increases, the degree of subsidence observed also increases.

The conceptual model of subsurface caving over a longwall panel comes from Kendorski (1993), who defined five zones of effect. These start at the caved zone, where the roof strata collapses into the void. Above this is the fractured zone, where both vertical and horizontal fracturing will be common, due to collapse of the strata above the caved zone. The constrained zone overlies this, where the rate of new crack formation is significantly reduced and the magnitude of displacement will also be less. A surface zone above this may show sagging and some relatively short vertical fractures. These zones grow wider in their expression, relative to the goaf, as they get closer to the surface. The angle between the goaf edge and the edge of the surface expression of effects is known as the 'angle of draw'. This can vary between strata, but the Division of Resources and Energy recommends using a figure of 35° in the Southern Coalfields (NSW Department of Mineral Resources, 2003).

This model, while well-accepted worldwide, is a conceptual model that is subject to local variations. While it describes the zones of effect over a single longwall panel, it is almost always the case that several longwall panels are clustered together as part of a single mine, surrounded by bord and pillar access tunnels. Thus, the deformation observed above a longwall mine is much more complex, and is one reason that a study of the cumulative effects of these panels is important.

For mines with multiple longwalls, the degree of subsidence movements, the type of movement and the impact it will have on the surface topography and features depends on the width and number of panels removed, the number and stability of pillars remaining in the first workings, the thickness of the coal seam (i.e., the height of the panel removed), the geology of the area and the depth of cover. Advances in modelling subsidence have occurred over recent years with the development and utilisation of large databases of actual subsidence events where information on the predicted and actual events can be compared site by site. This information is used empirically to assist predictions for a particular mine (Kay & Waddington, 2014). Models for predicting subsidence are thought to be fairly accurate where these factors are well-known, with models tending to slightly over-predict the observed movements (NSW Department of Planning, 2008).

It is commonly thought that the majority, 90–95%, of the subsidence movement that occurs due to mining happens during the period of extraction, with an additional 5-10% occurring after the mine face passes and up to two years after extraction is completed (Reddish and Whittaker, 1989, and Al Heib, 2005, as cited in Ziegler & Middleton, 2014). However, a recent study in the Catchment appears to demonstrate that upsidence and subsidence movements continued over a period of 10-20 years post-mining, with the vertical movements continuing to occur over goafs as well as pillars, likely due to ongoing compression of the pillars. Subsidence effects did not appear to be slowing, despite the pillars having been designed for long-term stability (Ziegler & Middleton, 2014).

Although this information is a single study presented at conference proceedings, it is nevertheless of considerable interest and would be worthwhile repeating at other sites within and outside the catchment.

6.2 Upsidence

The conventional model of subsidence makes a number of assumptions, including that the surface topography is relatively flat, which is not the case in much of the Southern Coalfields, particularly within the Special Areas where steep, incised topography is the norm and unconventional subsidence occurs. The same tectonic processes that have resulted in the relief seen in these areas have also caused the horizontal stress to be up to three times greater than the vertical stress. This, interrupted by topography, results in a change in the stress regime of valley floors which can lead rock strata close to the surface to bend and buckle in an upwards direction. When mining occurs in this environment, the subsequent processes can lead to phenomena such as valley closure, where the two sides of a valley move horizontally towards a centre line, and uplift of the valley floor. The latter is often termed ‘upsidence’ (NSW Department of Planning, 2008).

In the Catchment area this process has been studied in a number of locations including Cataract Gorge, above the Appin Colliery where 460mm of valley closure was observed, along with significant relative uplift (Hebblewhite et al., 2000, as cited in NSW Department of Planning, 2008). Also in Cataract Gorge, above Tower Colliery, upsidence extending about 300m either side of the centre of the 150m wide gorge was observed, peaking at 350mm in the middle of the gorge and about 100mm at the cliff lines. Upsidence often occurs after subsidence, meaning that the upwards movement of the ground may result in the eventual ground level being lower than the pre-mining ground level. In the case of the Tower Colliery work at Cataract Gorge, however, a second longwall through the area caused a further 300mm of upsidence that left the ground level higher than it had been prior to mining (NSW Department of Planning, 2008).

6.3 Far-field movements

Far-field movements are those observed up to several kilometres from the site of mining. In the Southern Coalfields, these are generally horizontal displacements, and recorded at distances up to 1.5km away from mine workings (NSW Department of Planning, 2008). The displacement caused by these movements is generally in the direction of the mine workings or towards goafs, and the amount of movement is usually relatively minimal, between 25-60mm at a distance of 1.5km (NSW Department of Planning, 2008). An exception to the rule was found at longwall 704 of the Appin mine, which caused far-field movements where the displacement direction was away from the mine workings, with displacement measured at 29mm (GHD, 2013).

The Southern Coalfields Inquiry recognised no significant adverse impacts on any natural features from far-field movements. Concerns over far-field movement impacts tend to centre on possible impacts on infrastructure, including roads, bridges, power and water infrastructure. One such movement was recorded by Reed (1998 as cited in PAC, 2010) as affecting the Cataract Dam wall, which was moved approximately 30mm between 1988 and 1992 by mining of a longwall up to 800m away. This movement did not appear to structurally damage the dam wall, which moved en masse (PAC, 2010).

A case in Pennsylvania, USA has been recorded where a recreational dam (Ryerson Dam) was damaged by far field horizontal movements of a longwall mine panel approximately 275m away and 100m to 220m deep (Hebblewhite & Gray, 2014)

6.4 Fracturing

Subsidence movements can cause reactivation of faults, movement along joints and form new networks of fracturing and cracking, including in streambeds and through rock bars.

Fracturing that occurs with upsidence has been studied in detail at Waratah Rivulet, above Metropolitan Colliery. Surface and subsurface monitoring has recorded an extensive network of fracturing that grows with each passing longwall. As of 2008, the main fracture network was recorded as reaching depths of up to 12m with bed separation (horizontal fracturing) down to a depth of about 20m (NSW Department of Planning, 2008).

6.5 Rockfall

Cliffs affected by cracking may cause rockfalls. These have been observed in areas where the longwall passes beneath a cliff, usually within the area directly above a goaf. One exception to this was noted by the Southern Coalfields Inquiry. They recorded 5 small rockfalls that occurred outside of the direct mining area in Cataract River Gorge. The panel considered that these falls were relatively minor (less than $30m^3$ of material), were likely due to existing weaknesses, and bore a close resemblance to other falls in the area (NSW Department of Planning, 2008).

An example of steps taken to control rockfall is the work done to ensure the protection of the Sandy Creek waterfall. As part of the approval conditions for the Dendrobium mine, the proponent was required to ensure that no rockfall occurred at this waterfall from its overhang; that the structural integrity of the waterfall, the overhang and its pool were maintained and that cracking within 30m of the waterfall would be of negligible environmental and hydrological consequence. As a result, the company set up a detailed monitoring and management strategy which resulting in no significant impact to the feature.

Rockfalls can be significant in relation to erosive processes, for aesthetic, public safety and access reasons, but also in their impacts on places of Aboriginal heritage significance. Examples of such impacts were recorded during the late 1970s at a site within the Catchment called Whale Cave. In this case, the roof of the cave partially collapsed as a result of underground mining and posts were installed to prevent further collapse. A study of 52 sandstone overhang sites associated with Illawarra Coal's Southern Coalfields mines (which include Dendrobium) found that five had evidence of impact resulting from longwall mining. Most of these impacts were in the form of changed water seepage, cracking, movement along existing joints or bedding planes and block fall. No art had been disturbed and no sites had fully collapsed or been destroyed (Sefton 2000 as cited in NSW Department of Planning, 2008).

7 PREVIOUS STUDIES

7.1 Previous reviews

7.1.1 Reynolds Inquiry

The Reynolds Inquiry, which published its report in 1976, does not consider longwall mining, but only bord and pillar first workings and partial pillar extract (see Appendix 4 for a discussion of these methods). The Inquiry was asked to look at the issue of mining under water storages due to fears of possible catastrophic water loss from the reservoirs into any mines that may be built below reservoirs. The report made several recommendations for the dimension of the pillars to be left in place, the depth of cover required and the angle of draw to be considered in order to prevent significant surface cracking and to protect structures such as dam walls (Reynolds, 1976). The recommendations were not implemented in full, but the DSC and the Dams Safety Notification Areas were created soon thereafter in 1978 (McNally & Evans, 2007).

7.1.2 Commission of Inquiry

The Commission of Inquiry for Planning and Environment, a precursor to the current PAC, recommended the approval of the Dendrobium Coal Mine in its 2001 report. A number of other recommendations made in this report included that the Government produce a summary report every two years on the impacts of longwall mining beneath the Metropolitan Special Area; that the Government develop a policy position on the meaning of 'Neutral or Beneficial Effect on water quality'; and that the SCA collate information from relevant Government agencies to quantify the impact of coal mining on surface water flows in the Special Areas (Cleland & Carleton, 2001).

Several of these recommendations were enacted – the Sydney Catchment Authority developed a tool to help Councils assess Neutral or Beneficial Effect on water quality. Quantifying the impact of coal mining on surface water flows has not been an easy task, though research effort has been directed to that end.

7.1.3 Southern Coalfields Inquiry

The Southern Coalfields Inquiry (SCI) in 2008 examined the impacts of underground coal mining on natural features in the Catchment, such as watercourses, swamps, groundwater and biodiversity. The Inquiry recommended the identification of Risk Management Zones (RMZs) to focus assessment and management of potential impacts on significant natural features. RMZs were to be defined from the outside extremity of a surface feature either by a surface lateral distance of 400m to the coal seam or by a 40° angle from the vertical down to the seam. It was further recommended that all streams of third order or above, all valley infill swamps, and areas of irregular or severe topography such as major cliff lines and overhangs be considered significant natural features (NSW Department of Planning, 2008). The intention of the RMZs is not to prevent mining in these areas but to require an increased level of prediction confidence and level of proof of that confidence (Hebblewhite, 2009).

The RMZs and other recommendations of this Inquiry were not implemented by Government directly; however, Director-General's Requirements for EIS' and PAC terms of reference for reviews such as those on the Metropolitan Coal Project and the Bulli Seam Operations plan (see below) both include reference to the Southern Coalfields Inquiry and its findings. The PAC explicitly considered the recommendations of this Inquiry in both of its reviews. Several of the SCA Audits also noted the findings of the Inquiry, most notably the 2013 Audit which endorses the use of RMZs (see below).

7.1.4 PAC Review of the Metropolitan Coal Project

The subsequent PAC Review of the Metropolitan Coal Project in 2009 implemented many of the recommendations of the SCI and further recommended that future mining proposals should follow these as well. In applying the recommendations to this Review, the PAC considered that RMZs should be incorporated into a broader risk management strategy. To assist project proponents in providing adequate information to decision-makers, the PAC also laid out a step-wise implementation plan for preparation of these risk management plans. In doing so, the PAC noted that the ideal situation would be to manage for consequence, rather than impact, but considered that the difficulty in fully understanding consequences at this stage made it necessary to manage for impact (PAC, 2009).

In that same Review, the PAC differed from the SCI in considering the inquiry's position unreasonable that a "reverse onus of proof" be sought from mining companies when considering mining near natural features. The PAC held that demanding proof of no impact from mining companies was too onerous and was probably impossible for companies to provide given the lack of data for the area, as well the paucity of understanding of the links between impacts and consequence (PAC, 2009).

7.1.5 PAC Review of the Bulli Seam Operations Project

In their Review of the Bulli Seam Operations Project in 2010, the PAC implemented the RMZ approach as previously outlined, noting that their Terms of Reference required them to take into account the SCI report. However, in the same report, the PAC suggested the use of the concepts of 'Defined Areas' to recognise geographic areas within which all examples of classes of natural features would be considered of special significance and thus subject to negligible impact requirements. These classes of features included those originally listed by the SCI as well as significant Aboriginal Cultural Heritage Sites, significant Endangered Ecological Communities, and significant populations of threatened species and their habitats.

The 'Defined Area' geographic concept attempts to mitigate the practice whereby proponents were avoiding recognising any significant natural features as of 'special significance' and thus subject to negligible impact requirements. However, the corollary is that for significant natural features outside of the Defined Area, the PAC considers that negative impacts should be avoided or compensated for if they are considered of special significance while others may suffer impacts as endorsed in the planning approval conditions. The PAC notes that in the case of the Bulli Seam proposal the Defined Areas suggested will fail to fully protect the SCA Special Areas (PAC, 2010).

7.2 Audits

The *Sydney Water Catchment Management Act 1998* also requires that an externally-conducted audit be completed on Catchment health and the Catchment area no later than every three years (N.b. This period was extended from two to three years after the 2007 audit to align with State of Environment and other reporting periods). Five audits completed to date report on a range of indicators of Catchment health and make recommendations as to further work to be completed by the SCA and other government agencies to assist in management of the Catchment.

In various forms, recommendations for improved data and monitoring have been a feature of the audit reports since 2005. The 2005 report recommended that a model for the interaction of surface and groundwater systems in the Catchment be prepared (NSW Department of Environment and Conservation, 2005). The 2007 report recommends a larger suite of monitoring including for erosion and ecosystem health and notes that the 2005 modelling recommendation was not considered a priority by the agencies and had not been undertaken (NSW Department of Environment and Conservation, 2005).

In the 2010 audit, auditors recommended that the Department of Planning and Environment consider the cumulative impacts of all mining activities within the Special Areas, and renewed the call for NOW and the SCA to undertake research aimed at understanding the interactions between all ground and surface waters in the Catchment. The 2010 audit also recommended many monitoring approaches including that individual programs be integrated into a whole-of-Catchment ecosystem health program (NSW Department of Environment, 2010).

The most recent audit (2013) calls on the SCA to lead the implementation of an ecosystem health database that can report on the Catchment health indicators developed by the successive audits and integrate data from monitoring programs across the Catchment. It calls on various government agencies to collaborate on development of a risk assessment methodology to assess the impacts of mining, CSG and industrial developments and endorses the use of RMZs around natural features of special significance as originally suggested by the SCI (GHD, 2013).

7.3 SCA Literature Review: Coal seam gas impacts on water resources

The 2012 SCA literature review of CSG developments and their impacts on water resources concluded that CSG impacts would be minimal compared to the impacts of longwall mining. In particular, the SCA found that groundwater inflow rates to mines are significantly higher than the amount of produced water being extracted from the Illawarra Coal Measures at the current CSG extraction project at Camden, outside of the Catchment. Any potential hydraulic fracturing was considered to be unlikely to increase connection between shallow aquifers and coal seams due to the depth of the coal seams and the presence of claystone formations which act as aquitards. Finally, any possible settling or subsidence associated with CSG was considered to be insignificant in comparison with the amount of subsidence resulting from longwall mining (SCA, 2012)

7.4 Thirlmere Lakes Inquiry

The Thirlmere Lakes Inquiry Committee was commissioned to evaluate possible causes for the low water levels in the lakes and address community concerns that this may have been caused by nearby mining. A review of that report was undertaken by the NSW Chief Scientist & Engineer in 2013.

While the Committee's report did not find direct evidence that mining activity "breached geologic containment structures underneath the lakes", the Committee recommended, in addition to designating a Thirlmere Lakes National Park, a series of further studies, monitoring and modelling to better understand the groundwater and geological systems and the impacts from mining (Independent Thirlmere Lakes Inquiry Committee, 2012). An initial monitoring program for surface water and rainfall was implemented by OEH in 2013 in addition to the formation of a committee of scientists to research and better understand the lake system and causes of water level fluctuations.

8 WORKSHOP 1 REPORT

8.1 Introduction

This report aims to capture the discussion and outcomes of the first workshop convened and chaired by the NSW Chief Scientist and Engineer as an important component of the project on cumulative impacts commissioned by the Minister. The workshop took the approach of trying to build a methodology that could enable the prediction of cumulative impacts, with the ongoing addition of stressors.

Concerns over activities in the Special Areas centre around the protection of Sydney's drinking water, primarily, that there is enough good-quality water available to meet the demands of the 60% of the NSW population that relies on water from the areas managed by the Sydney Catchment Authority. Existing activities that affect ground and surface water in the Special Areas include large-scale coal mining, as well as the presence of communities around or in the Special Areas and infrastructure such as roads, powerlines and other local amenities. Many factors other than human activity also affect the ability of the drinking water catchment to supply enough water of sufficient quality: for example, climate variability and change, events such as droughts and bushfires, and population growth.

The question being looked at by the workshop was essentially whether, for any given new event in the catchment, one can predict and measure (and in turn check predictions) any changes over time on the quality and quantity of water leaving the Woronora and Metropolitan Special Areas into the upper canal, or leaving Warragamba Dam into the pipelines to Prospect Reservoir. The workshop was aimed at:

- understanding whether we will be able to develop a methodology for assessing cumulative impacts in the Sydney Catchment Special Areas
- thinking about whether (and how) a computer model (possibly data fusion) could be developed (piloted) that could access all the relevant data (current and historic) for this confined region.

Developing such a model or methodology for the catchments could provide a tool to allow industry and government to assess the impacts of future developments in the Sydney Catchment Special Areas, and possibly in the broader catchment. As well as being a tool for planning development and assessing the risk of new activities, this tool could also inform conditions on licences and the development of legislation.

Understanding which new activities may be permitted in the Special Areas relies on being able to predict and measure any changes over time in the quality and quantity of water present in, and leaving, the Special Areas and entering into the water supply system. In turn, this requires knowing what impacts may manifest, or have manifested, in the Special Areas as the result of certain activities. As a result, this workshop looked at known and likely impacts of the current activities, considered the possible impacts of future activities, including coal seam gas activities, and scoped the creation of a tool to allow ongoing monitoring and assessment of cumulative impacts in the Special Areas.

8.2 Methodology and approach

Published and unpublished material relevant to the Sydney Catchment Special Areas and the activities taking place within these was reviewed prior to the workshop. A site visit was also undertaken prior to the workshop.

The workshop was held on Friday, 7 February 2014 with some of Australia's leading experts in a range of relevant fields, such as geology, geotechnical engineering, groundwater engineering, petroleum engineering, environmental science, ICT and data fusion. A list of attendees is at Table 8.2. The workshop focused on understanding approaches to cumulative impact analysis and then on how and whether these approaches could be applied to the Sydney Water Catchment Special Areas.

Table A-8.1: List of Attendees to Workshop 1

Name	Affiliation	Expertise
Prof Mary O'Kane	NSW Chief Scientist and Engineer	Review leader
Prof John Carter	University of Newcastle and Advanced Geomechanics	Geotechnical engineering
Prof Hugh Durrant-Whyte	CEO National ICT Australia	Machine learning and data fusion
Prof Mike Sandiford	University of Melbourne	Sedimentary basins, seismicity, cumulative effects
Prof Damien Gore	Macquarie University	Produced water, Thirlmere Lakes
Dr Jerzy Jankowski	Sydney Catchment Authority	Hydrogeology
Prof Nasser Khalili	University of NSW	Geotechnical engineering
Dr Colin Mackie	Mackie Environmental	Groundwater
Prof Dietmar Muller	University of Sydney	Geology
Prof Val Pinzcewski	University of NSW	Petroleum engineering
Dr Alistair Reid	National ICT Australia	Data fusion and geology modelling
Prof Scott Sloan	University of Newcastle	Geotechnical engineering
Dr Chris Armstrong	Office of the NSW Chief Scientist & Engineer	CSG Review team
Dr Leah Schwartz	Office of the NSW Chief Scientist & Engineer	CSG Review team
Dr Andrew McCallum	Office of the NSW Chief Scientist & Engineer	CSG Review team
Ms Lara Litchfield	Office of the NSW Chief Scientist & Engineer	CSG Review team

8.3 Workshop discussion

The discussion at the workshop was wide ranging and informative, and very much brought home the need to collect, make available and analyse data and information on the special areas, and more widely. Key points of the workshop were:

- using data fusion approaches to comprehensively model Sydney Water Catchment Special Areas on a wide scale, to assess the cumulative impact of activities taking place in the special areas is likely to be highly complex and is probably not possible with the data currently available.
- changes to legislation, approval conditions and monitoring approaches are likely to be necessary to ensure the data needed to build such a model can be accessed and collected.
- risk based qualitative/quantitative computational models of bounded activities within the Special Areas should be developed and adopted based on current knowledge.

The workshop was divided into three sessions. In the first session, the Chief Scientist and Engineer introduced the project, including the request from government, and outlined the community concerns that prompted the study. The granting of licences for coal seam gas (CSG) exploration in the Water Catchment Special Areas has increased concerns over the cumulative impact of activities already taking place in the Catchment areas with many in the community worried that adding full-scale CSG operations to the mix may endanger Sydney's drinking water.

A background presentation was then given discussing the history of mining in the Special Areas, which have been mined for their rich coal seams since the 19th Century. Bord and pillar mining was used until around 1966/67, and thereafter longwall mining was introduced. The environmental impacts of longwall mining are significantly greater than that of bord and pillar mining and as technology has changed the size of the longwall panels has increased. At present, CSG extraction is not underway in the Special Areas, though exploration licences have been issued for several areas and exploration wells have been drilled in various locations.

The background presentation also included a slide show of the site visit undertaken earlier that week into the Special Areas to observe the effects of activities on the water catchment area. Slides were shown that demonstrated: subsidence and upsidence effects, physical damage caused to previous well pad sites (for longwall mining), degradation from a produced water release in 2001 (from a coal mine), and chemical (iron oxide) pollution of a stream.

The group discussed these effects and their provenance. They debated whether predicting such effects would be possible through modelling, including whether it would be possible to develop a model such that any Environmental Impact Statement for a proposed development proposal could be checked against the model to test for cumulative impacts.

The general consensus was that effects such as those seen in the slideshow were very difficult to predict as they were relatively small area effects, highly dependent on local geology, hydrology, hydrogeology and other factors. Understanding, for example, the degree of subsidence that might result from an action is relatively straightforward for 'conventional subsidence', but predicting the impact of that subsidence on local areas and landscape features is quite complex. Also complex are predictions for non-conventional subsidence such as valley upsidence. It was agreed that in the Catchment it is the localised effects that matter as they can be quite devastating.

Which datasets were available for the special areas and what historical data may be available to help assess impacts that have already occurred was then discussed. The problems that the Sydney Catchment Authority has accessing data from companies using the Special Areas was noted, as was the nature of the data that may be held by the companies as well as by government agencies and universities. A contrast was drawn to Alberta, Canada, where any information on public assets must be made publicly available. It was noted that there are no international examples of longwall mining operating in publicly owned drinking water catchments but there are examples of it occurring under streams and aquifers connected to privately owned wells in the Appalachians of the U.S.A.

The discussion then focused on which data would be critical to allow a risk assessment of activities and the development of models to understand the basin and the impact of activities. The possibility of requiring more information from companies as part of the regulatory environment was discussed. It was noted that the problems with many of the impacts to water quantity and quality is that they will be felt disproportionately in dry times rather than in wet times, so understanding the baseline flow during drought conditions is key to untangling which impacts are likely to be critical.

Longwall mining and CSG exploration in the Southern Coalfield target the same Permian Illawarra Coal Measures. The depth of coal seams varies across the Sydney Basin. For example, Bulli Seam depths range from surface outcrops at the Illawarra Escarpment and Burragorang Valley (Waragamba Dam) to about 800m deep in the central north (northwest of Camden).

The currently operating mines are extracting coal from the upper three seams (Bulli, Balgownie and Wongawilli) with the depth of cover in the range from approximately 140m up to 560m (located closer to the edge of basin). CSG wells at Camden (located closer to the centre of the basin) extract methane from both upper seams (Bulli, Balgownie and Wongawilli) and lower seams (Woonoona, Tongarra) at depths from 600m to greater than 800m.

The proposed CSG exploration activities in the SCA Special Areas were focused on assessment of:

- goaf gas in abandoned and sealed historical mines, at equivalent depth to mining.
- the CSG potential in the unmined areas, where the coal seams are probably still within range of the deepest longwall mine in the Southern Coalfield (Bulli Seam Operations) but generally less deep compared to the Camden Gas Project.

The depth of extraction was not thought by the attendees to be a meaningful indicator of potential surface impacts. Rather, the extent of overburden disturbance and degree of surface subsidence effects should be a better indicator of differences in potential surface impacts of CSG and longwall mining.

In general, greater concern was expressed by participants over the effects of longwall mining than over the impacts of CSG extraction. Longwall mining will invariably have greater impacts on subsurface hydrology due to creating voids by removing a large volume of rock material over a long and wide area of landscape causing collapse and subsidence of the overlying strata. By contrast, gas and groundwater extraction by CSG wells is of a relatively small magnitude.

Impacts caused by deeper activities are also likely to be seen over longer time scales, and measuring these after the licence to extract has expired can be problematic. It was agreed that, in general, to predict a certain number of years forward, one would need at least the same number of years of historical data. Caution in using models was also urged, noting that their predictive power is limited by the quality of data and the theoretical underpinning used.

When considering the possibility of losing surface water to the spaces left underground by mining operations (goafs), some experts in the room felt that the loss would be negligible compared to the loss from evapotranspiration in the catchment, which could be in the order of close to 50% of the volume of stored water.

Others questioned this argument as evapotranspiration is already factored into sustainable yield estimates for water supply catchments. They argued that it is changes over and above this that can impact on the reliability of supply and bring forward the next tranche of supply infrastructure. Over a period of hundreds of years and over large areas, even small changes in the rainfall infiltration, surface runoff and baseflow discharge to streams may result in significant changes in catchment hydrology. Larger disturbances such as broadscale cracking and its attendant hydrological changes could certainly have this sort of impact on sustainable yield.

An attempt was made to characterise what could be considered ‘catastrophic’ risks to the catchment. In doing so, the term catastrophic proved somewhat problematic – the loss of the upland swamps, for example, could be considered a significant ecological risk but so might reducing the sustainable yield of the catchment and bringing forward the next infrastructure development.

It was noted that about eight or nine of the upland swamps, which are significant ecosystems and are key to providing baseflow, are already affected in the catchment. Some thought that the monetary value of a swamp may be possible to calculate, which may help any arguments for preservation. Characterising water quantity risks in general is difficult because the effect of changes will be magnified by any increases in population that Sydney may experience.

Declines in water quality were not thought to pose a high risk, due to available water treatment techniques which can remediate most issues, but the cumulative effects may be difficult to understand. For the SCA, the reputational risk is also very high – the community is likely to consider it unacceptable for the water quality of a reservoir to be significantly affected by mining activities.

There is some evidence that affected areas can rebound, that is, that the ecosystem can improve following a contamination event without management interventions. This has been seen to some degree in the Waratah Rivulet. Understanding the rate at which this occurs may give some insight into the rate of mining that can be sustained in the area. The recovery of groundwater levels that have been drawn down, however, is particularly complex to predict, varying from years to decadal or millennial timescales.

8.4 What the workshop recommended

The workshop resulted in a series of recommendations which have formed the approach taken by the Review thereafter. For the most part, these were aimed at building a computational modelling and visualisation system that would allow government, industry and the community to have a comprehensive picture of the cumulative impacts of activities in the Catchment. There were recommendations to address concerns in the short-term, whilst this system is being established, and to build understanding of cumulative impacts in the medium term while the system is developing. The Review further developed these ideas in the course of further investigations, but the below forms the basis for the recommendations outlined in Chapter 7.

There is currently a considerable amount of data held by various organisations (company, government, research) over a range of time periods for the catchment. However, there is no unified data set, and while there are efforts to address this, such as through Geoscience Australia, there remain barriers to bringing existing data sets together. Data sets will include: water accounts (quality and quantity) from mines, geological (wire lines and seismic surveys), etc.

Data is required as inputs to models which assess impacts of activities on the catchment. The data also informs what impact trigger monitoring activities need to be in place. Finally, the gaps in the existing data sets inform the monitoring strategy.

A robust, whole-of-Catchment monitoring system would need to comprise the following elements:

- water budget – understanding where surface and ground water is going is currently a gap in knowledge for the Catchment. Water budget models need significant refining.
- water quality – risks associated with water quality tend to be more local issues, except in extreme examples such as a significant release of produced water from a mine.
- mechanical state of the basin – this can be observed using a range of technology. More problematic is how this is attributable, i.e., why and how is the basin responding and does it induce different risk scenarios for different areas?

After these are measured, the difficulty will be in understanding how to couple mechanical changes in the basin with changes in water quality or water budget in order to understand mining impacts. Furthermore, there is likely to be a significantly heterogeneous response across the basin.

Of significance for a monitoring system would be discovering the really early signals of system failure, so that these could be used to monitor operations. It will also be important to determine what spatial and/or temporal scales are relevant. At the catchment scale, a promising avenue for research is the use of satellite data. Remote sensing can be used to look at vegetation changes (which may indirectly show impacts of mining).

Any monitoring program will have to be a long-term commitment. At present, companies collect data on the basis of a snapshot or point in time. Following operations, no long term data is required to be collected on impacts from the mining activity. The previously collected data is usually not utilised. For example, after the completion of a longwall panel, the company is required to collect data for one or two years. This is insufficient. There will likely be a need to revisit legislative requirements in order to obtain long term data from companies. New rules and regulations should be looked at to enable better monitoring for at least a decade.

Building computational models is one important step, amongst others, to consider the impacts from activities within the catchment on water resources. Models allow decision makers to draw on history to inform the future. The only solid basis to guide predictive models is thus observational data and further shows the need for a whole-of-Catchment monitoring system going forward.

Within the Catchment, there has been over 100 years of mining activity, and while there has not been a major documented loss of water quantity or quality, there have been impacts such as reduced flows and changes in water quality of streams. It should be possible to draw connections between past events and the outcomes that resulted from these.

This could be done, as a first-pass assessment, by isolating each impact and correlating it with different historical activities. The Catchment could be subdivided into hydrological subregions, and links made between activities and water quantity, water quality, and subsidence, across the whole catchment. These links would be particularly reliable for the last ten years, where activities can be linked with results from increased monitoring data and remote sensing data sets such as INSAR.

Numerical models are tools which allow predictions to be made. However, the further in the future the predictions are made the less firm are the conclusions. It will therefore be necessary for any models created to be recalibrated on an ongoing basis as more data becomes available.

Data visualisation tools are useful in transforming the predictions of computational models into something easily communicated to and used by non-specialists and decision-makers. As noted by Friedman (2008) the "main goal of data visualization is to communicate information clearly and effectively through graphical means". To allow a meaningful assessment of cumulative impacts and the likely effects of proposed actions, the main data requiring visualization include: the geology of the region under consideration; parameters defining the existing and any predicted future groundwater regimes, such as ground water pressures, flow velocities and flow rates; dissolved salts; and possibly even concentration levels defining the progress of any plumes of pollution.

An AVIE 360 degree virtual environment module could be developed in parallel with visualisation tools for the web. The AVIE at UNSW is a walk-in module to simulate underground processes and longwall mines, a useful tool for the community and decision makers.

At present the risk of individual activities (e.g. a longwall coal mine) is considered on a site-by-site basis. This is natural given the heterogeneity of the environment, geology, etc. within the catchment. However, some types of risks can be monitored at the catchment scale, while other types of risk are more site-specific. It is possible to define areas where risks are more likely to be higher using information such as geological data of the area, observed past deformation activity and any other past incidents, as well as the location and management of mines.

Consideration will also need to be given to potential catastrophic risks. for example, a significant expansion of the Sydney population combined with swamps (which provide baseflow) being drained as a consequence of mining, leading to reservoirs reaching critically low levels in a severe drought.

Some present at the meeting noted that while this is a commendable objective, the practicality and value of such depends on the definition of risk and the availability of data to map it – for example, a map of subsidence contours would be very useful.

Understanding cumulative impacts from different activities across a broad area is not simple, nor is attributing the impacts that are seen to specific activities. Thus understanding cumulative impacts will take time and require several steps, many of which are outlined in the first three recommendations. In addition, and to assist with this process, government should require that any application for development in the Special Areas must refer to any existing modelling for the catchment and must refer to the risk map developed for the catchment.

In addition, any activities that are taking place in the Special Areas should be required to provide data and modelling back to government promptly.

First, there is a need to better understand potential impacts of specific activities under certain unusual conditions, such as subsidence above a longwall in an area of complex geology. Without understanding of such problems an attempt to understand cumulative processes could be limited.

9 WATER QUALITY REPORT, PROFESSOR CHRIS FELL AM

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ABN 64 096 042 563

Discussion Paper for
Office of NSW Chief Scientist and Engineer

WATER TREATMENT AND SYDNEY CATCHMENT

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30 May 2014

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EXECUTIVE SUMMARY

This paper overviews the storage and treatment processes used by the Sydney Catchment Authority and Sydney Water to provide drinking water for the 4.5 million citizens of Sydney. The Sydney Catchment Authority operates seven major dams with a total capacity of 2,500,000 megalitres in the south and west of Sydney and a network of smaller dams, reservoirs, weirs, pipelines and canals that together supply Sydney Water with 1,400 megalitres per day for treatment and reticulation to consumers. Treatment consists of coagulation, flocculation, settling and filtration, followed by disinfection, with the Prospect water filtration plant supplying 80% of Sydney's needs.

All stages of the operation are closely monitored, especially for those aspects impacting on the removal and deactivation of pathogenic water-borne microorganisms. The raw water in the dams and at entry to Sydney Water treatment facilities is also periodically examined for water characteristics which are checked against Australian Drinking Water Health Guidelines (2013). The results of these tests are made publically available.

Whilst the Sydney Catchment Authority can operate the detention and off-take from its catchments to minimise the levels of sediment and soluble iron and manganese in the raw water fed to the Sydney Water filtration plants, the steady operation of these plants is the principal determiner of the safety of the water provided to consumers. Sydney Catchment Authority, Sydney Water and NSW Health co-operate with other State authorities in handling pollution incidents which might impact adversely on dam or plant operation or water quality, with the public kept informed. The treatment plants are not currently designed to handle the removal of soluble organic species or the removal of many metals.

Regarding the quality of the water produced, the authorities are very reliant on the quality of inlet water to dams. For this reason, the Sydney Catchment Authority pays close attention to industrial and other operations, including the disposal of waste water in catchment areas. It manages Special and Controlled Areas surrounding some catchments in which pristine bushland is preserved to minimise wastes and sediments entering dams.

At the moment the treated water from Sydney Water comfortably meets Australian Drinking Water Health Guidelines. Fears have been expressed that if activities like long-wall coal mines and coal seam gas recovery proliferate within Special Areas and in catchments, surface water could become contaminated and pose a difficulty in ultimate water treatment. There is insufficient evidence at present of any soluble organic impact on water resulting from the subsidence caused by long-wall mining. As there are, as yet, no coal seam gas recovery operations in Sydney catchments, the risk of dam water contamination from CSG produced water is not known, but an analysis of typical produced waters would suggest that this is not critical because of substantial dilution, except possibly if fraccing using large quantities of chemicals is being carried out. However, there is a risk if substantial amounts of produced water concentrates are stored on site. Any new developments in catchments should be preceded by a careful investigation of their likely effect on the surface water in catchments, both in normal conditions and in extreme weather events.

TABLE OF CONTENTS

TERMS OF REFERENCE

The paper aims to examine the treatment of water sourced from the Sydney Water Catchments, in particular the Special Areas. This includes water treated at Sydney Water facilities such as those at Prospect Reservoir. The paper would discuss factors including how treatment adapts to changing water quality profile, and what monitoring is required.

a. *What approaches are used for testing, monitoring and sampling water prior to leaving the Sydney Catchment, on entering the water treatment facilities (eg Prospect Reservoir) and post treatment?*

b. *What technologies and approaches are used to treat water in the Sydney Drinking Water system? What types of substances are able to be removed from Sydney's drinking water?*

c. *How does the Sydney Drinking Water treatment system respond to changes in quantities or types of impurities in the water supplied to it from reservoirs such as the water from the Sydney Water Catchment Special Areas? How does any increase in treatment requirements impact on the cost of treatment or facility operation?*

d. *What are the potential 'worst case scenarios' related to the water treatment and management for the Sydney Water Catchment? What are the risks (i.e. likelihood and consequences) of such scenarios occurring?*

1. INTRODUCTION

The provision of safe drinking water in Australia is recognised as a major national priority and has been the subject of extensive study which has resulted in the Australian Drinking Water Guidelines (ADWG) 6 published by the National Health and Medical Research Council, first in 1996 and later modified in 2011 and in 2013[2]. At the heart of the document is a requirement for the various State bodies overseeing water to interact so as to protect public health. In the Sydney region the authorities charged with this responsibility are:

Sydney Catchment Authority Sydney Water NSW Department of Health

In NSW various other bodies are also involved, including the Environmental Protection Authority, the Department of Planning, Local Councils etc.

ADWG has established guidelines which have been adopted by the Sydney Catchment Authority (SCA) and Sydney Water (SW) in their water management processes. These are articulated in a 12-point policy summarised below:

Table 1: Framework for Management of Drinking Water Quality[2]

Element	Components
COMMITMENT TO DRINKING WATER QUALITY MANAGEMENT	
1. Commitment to drinking water quality management	Drinking water quality policy Regulatory and formal requirements Engaging stakeholders
SYSTEM ANALYSIS AND MANAGEMENT	
2. Assessment of the drinking water supply system	Water supply system analysis Assessment of water quality data Hazard identification and risk assessment
3. Preventive measures for drinking water quality management	Preventive measures and multiple barriers Critical control points
4. Operational procedures and process control	Operational procedures Operational monitoring Corrective action Equipment capability and maintenance Materials and chemicals
5. Verification of drinking water quality	Drinking water quality monitoring Consumer satisfaction Short-term evaluation of results Corrective action
SUPPORTING REQUIREMENTS	
6. Management of incidents and emergencies	Communication Incident and emergency response protocols
7. Employee awareness and training	Employee awareness and involvement Employee training
8. Community involvement and awareness	Community consultation Communication
9. Research and development	Investigative studies and research monitoring Validation of processes Design of equipment

Element	Components
10. Documentation and reporting	Management of documentation and records Reporting
REVIEW	
11. Evaluation and audit	Long-term evaluation of results Audit of drinking water quality management
12. Review and continual improvement	Review by senior executive Drinking water quality management improvement plan

The Framework envisages the development and implementation of management plans by the responsible authorities that mirrors this Framework. In broad terms it is based on application of:

ISO 9001 Quality Management
ISO 14001 Environmental Management
AS/NZS 4360 2004 Risk Management
Hazard Analysis Critical Control Point analysis

Within a given catchment it recommends multiple barriers[2]:

Traditional preventive measures are incorporated as or within a number of barriers, including:

- catchment management and source water protection;
- detention in protected reservoirs or storages;
- extraction management;
- coagulation, flocculation, sedimentation and filtration;
- disinfection;
- protection and maintenance of the distribution system

The ADWG is predicated primarily on protecting customers from the risk of water-borne disease cause by biological species. It focuses less on non-biological contaminants but does provide extensive guidelines on health and aesthetic maximum levels for a range of components in potable water. These guidelines are backed up by detailed fact sheets on each component. Levels have been decided upon by teams of experts, relying on epidemiological and toxicological data including substantial information from overseas. The 1,305 page ADWG document is available on the internet[2].

Sydney Catchment Authority

Sydney Catchment Authority (SCA) was established as a NSW Government agency in 1999. Its role is to provide raw water for further treatment by Sydney Water in water filtration plants (WFPs) to supply 4.5 million residents of the Greater Sydney, Blue Mountains and Illawarra regions. It operates a series of 7 major dams in the south and west of Sydney and a network of smaller dams, reservoirs, weirs, pipelines and canals, as shown below:

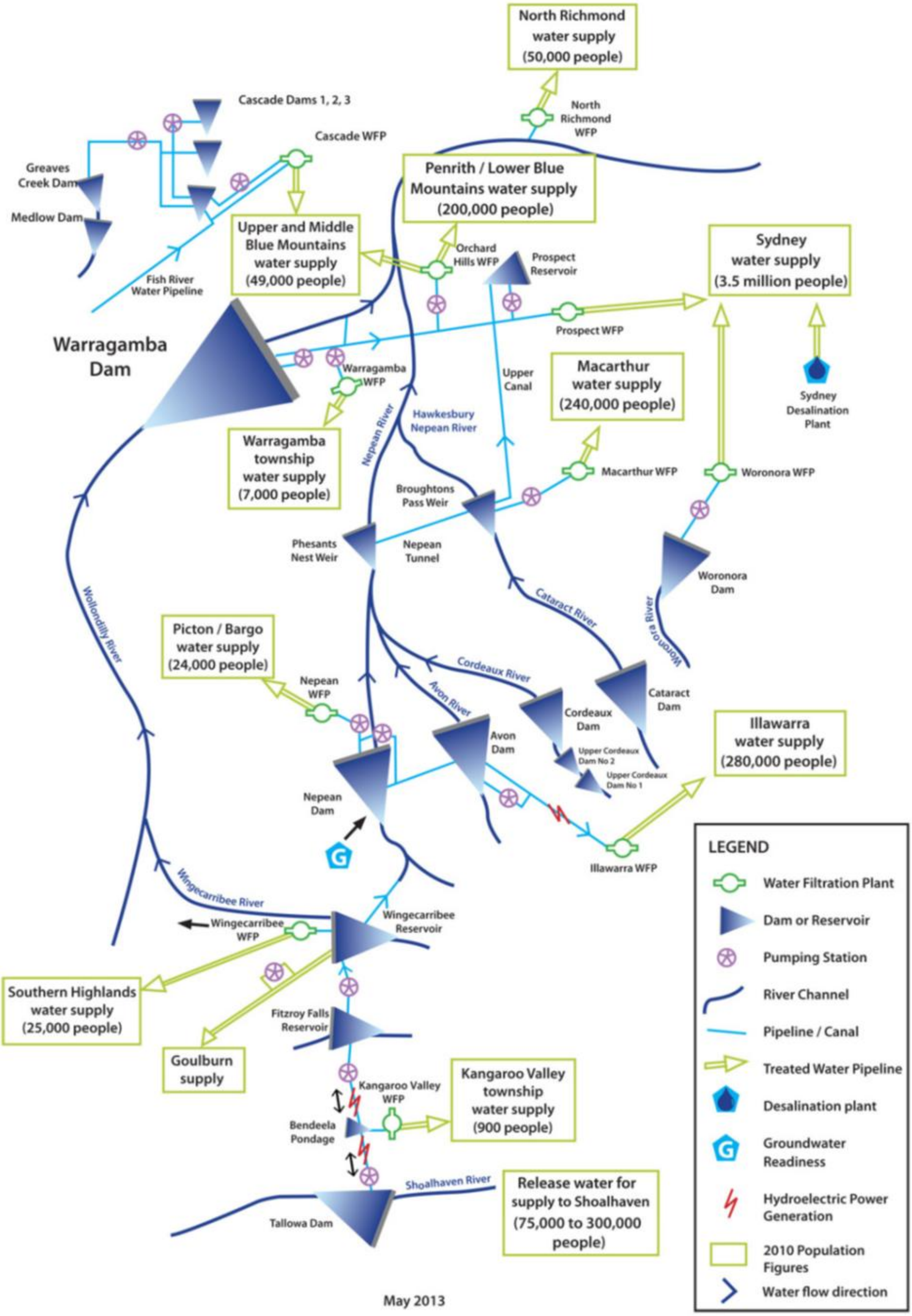

Figure 1: Greater Sydney's Water Supply System

By far the largest treatment facility supplied by SCA (77% of total) is the Prospect WFP. Associated with this WFP is the Prospect Reservoir which serves as temporary diversion facility for supply or storage in event of a system upset. Maintenance of raw water quality is considered paramount. To quote[3]:

> "Sydney Catchment Authority's Water Quality Management Framework is based on risk assessment principles including identification and assessment of potential water quality" hazards and implementation of appropriate controls."

The current SCA Water Quality Management Framework[8], which is to operate for 2012-2017 reflects the 12 elements of the ADWG and includes Enterprise Risk Management based on ISO31001.

SCA and representatives of consumers met in 2010 to conduct a detailed review of risk and decided on the following priority areas:

> Pathogens
> Nitrogen and phosphate
> Suspended solids

A later (2011) State of Science report suggested the inclusion of metals. A further review is due in 2015.

The SCA has identified the most significant factors contributing to water quality risks as[8]:

> Effluent from sewage systems
> Stormwater ingress to dams
> Grazing
> Intensive animal facilities within catchment

In accordance with ADWG, SCA manages 364,000 hectares of the Sydney Catchment as **Special Areas** (see following page), which protect water quality "by providing buffer zones of pristine bushland around dams and immediate catchment areas"[3]. Access to Special Areas is restricted. These areas are jointly managed by SCA and the NSW National Parks and Wildlife Service. They principally function by minimising the risk of human and farmed animal fecal contamination, run-off of fertilisers and pesticides and progress of sediments into reservoirs. Some underground mining activities are carried out under Special Areas.

The principal operating difficulties that have concerned SCA in recent years are the carry forward of sediments during rain events which makes chlorination less effective, the development of cyanobacteria (blue-green algae), and the presence of higher than permitted levels of water-borne pathogens. High levels of iron and manganese very occasionally manifest themselves, primarily as a result of water inversion due to seasonal changes in reservoir temperatures. SCA has a number of procedures for dealing with such occurrences, including switching feed reservoirs, withdrawing from different levels in the reservoir and chemical treatment.

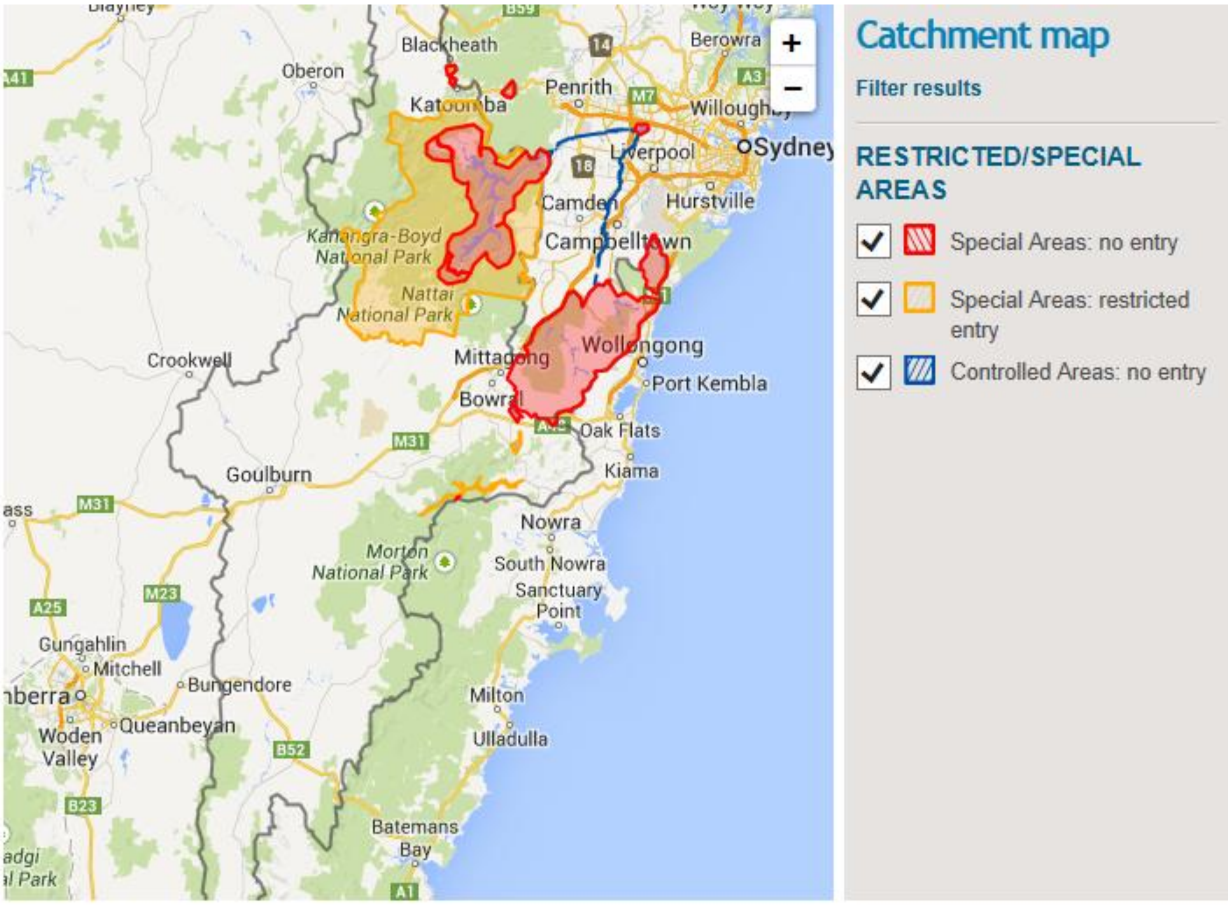

Figure 2: Catchment Areas Map

The capacities of the seven largest dams in the SCA system are[3]:

Table 2: Capacities of Major Dams

Dam	Capacity ML
Warragamba	2,027,000
Woronora	71,790
Cataract	93,640
Cordeaux	93.640
Nepean	67,730
Avon	146,700
Prospect Reservoir	33,000

Within limits, water can be transferred between dams or raw feed water for the Prospect WFP drawn from alternative dams.

Sydney Water

Sydney Water (SW) has 9 WFPs, with the principal one at Prospect. It has 251 reservoirs and supplies 1,400 ML/day to its customers. The desalination plant when operating at capacity can supply 15% of this.

It has developed a 5-year (2010-2015) Drinking Water Quality Management Plan[4], that reflects the 12 items of the ADWG and the lessons learned and reported in the 1998 Sydney Water Inquiry after a major cryptosporidium scare.

The principal WFP (Prospect) was completed in 1996 and is operated under a Public-Private Partnership by Lyonnaise Australia which holds a contract extending from 1992-2026. A new raw water pumping station at Prospect was installed in 2008-09.

Sydney Water has a Memorandum of Understanding with NSW Health[4] on drinking water quality. It follows the Water Services Association of Australia (WSAA) code for controlling materials that come into contact with water[4]. It uses a multi-barrier approach for its processing of water, recognising that a key problem is disease-causing micro-organisms from human and animal waste. This approach may be summarised:

- Detecting and settling water in storage dams to allow sedimentation and some micro-organism die-off
- Monitoring and modelling storage conditions to decide on storage take-off levels
- Treating by coagulation, flocculation and filtration
- Disinfecting with chlorine to destroy micro-organisms
- Maintaining adequate chlorine or chloramine levels throughout distribution system

The first two steps are the responsibility of the Sydney Catchment Authority. Sydney Water has indicated that it maintains the turbidity of water prior to the disinfection unit at < 0.1 Nephelometric units which is world's best practice[4]. Both chlorine and chloramine are used for disinfection, with pH control at this stage being important. Sydney Water's distribution systems ensure that there is residual chlorine in the water when it gets to consumers.

The diagram overleaf shows a typical water treatment facility similar to that operated by Lyonnaise Australia for Sydney Water. In the case of the Prospect WFP, SCA handles the initial coarse screening step, with fine screening on entry to the Prospect facility. Ferric chloride ($FeCl_3$) is the principal coagulant added together with a small quantity of polyelectrolyte. Flocculation followed by media filtration remove organic matter, sediments and some minerals such as iron and manganese. Getting the iron and manganese (both of which do not impose a health threat but can lead to unpleasant characteristics in drinking water) suitably low is in part a responsibility of SCA (by ensuring that dam water taken has been aerated) and SW (by pre-chlorination if necessary to ensure both are in a non-soluble oxidised state).

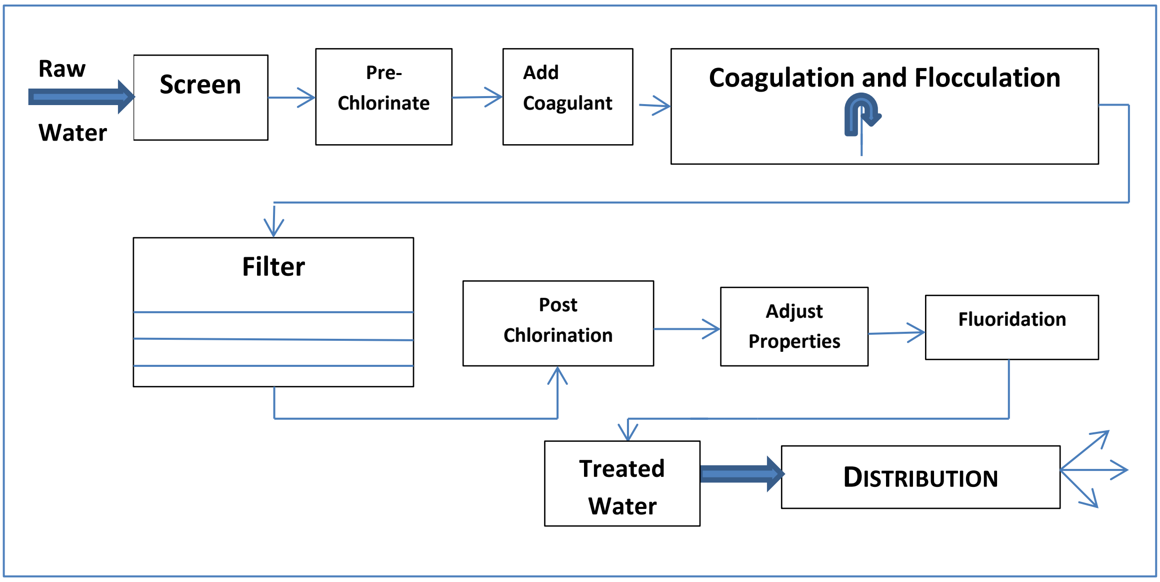

Figure 3: Water Filtration Plant

2. WHAT APPROACHES ARE USED FOR TESTING, MONITORING AND SAMPLING WATER PRIOR TO LEAVING THE SYDNEY CATCHMENT, ON ENTERING THE WATER TREATMENT FACILITIES (EG PROSPECT RESERVOIR) AND POST TREATMENT?

Under the Drinking Water Quality Management plans of both SCA and Sydney Water[4,8], extensive testing and monitoring of water is required to be carried out and the results of this testing are made publicly available. Close liaison is maintained between both bodies and NSW Health with test results being used to alert parties to possible operating problems or health or aesthetic threats likely to occur in product drinking water. Surveillance is intensified during intense rain periods or when incidents occur such as spillages in the catchment that might enter the collected water system.

Sydney Catchment Authority

SCA monitors at 100 sites for up to 600 characteristics of site water[7], with particular accent on entry points to dams and entry to water filtration plants. Monitoring ranges from continuous recording that can trigger operating alarms through to analysis of monthly grab samples in reservoirs and on-line bio-monitoring using rainbow fish. On-line water quality monitoring instruments are located near to dam walls and in supply conduits. These are connected to the Supervisory Control and Data Monitoring System which generates alarms when parameters exceed pre-set range/values. Water entering treatment plants is sampled according to the Australian and New Zealand Risk Management Standard (AS-NZS 4360.2004). Raw water quality monitoring data is supplied monthly to customers.

Most sampling and all analytical work is done by specialist contractors using ISO 9000 in NATA accredited laboratories with fortnightly reports provided to SCA and SW on water in Lake Burragorang which supplies close to 80% of Sydney's water. SCA publishes an Annual Water Quality Monitoring Report[9] which summarises results and analyses any trends for all SCA principal dams.

SCA's monitoring focuses on[7]:

- **Routine and compliance monitoring** – to ensure that raw water supplied to SCA's customers meets ADWG guidelines

- **Targeted and investigative monitoring, including:**
  Hot spot monitoring in locations such as below sewage treatment plants, sale yards or piggeries, to assess the impact of point sources of pollution on stream quality.
  Event-based monitoring in response to rainfall and other events
  Incident monitoring requiring immediate risk assessment (eg a chemical spill or algal bloom)

- **Monitoring catchment solutions to reduce pollution**
  Monitoring of known pollution sources where the SCA has funded works to control pollution loads to understand if the solution is delivering expected outcomes

The table below gives the parameters of importance to SCA in meeting ADWG[9].

Table 3: Parameters of Importance to SCA

	Specific Water Characteristic	ADWG (2011) Health Guideline
SYNTHETIC ORGANICS – RADIOLOGICAL - PESTICIDES	Amitrole	0.0009 mg/L
	Atrazine	0.02 mg/L
	Chlorpyrifos	0.01 mg/L
	2,4-D	0.03 mg/L
	2,4,5-T	0.1 mg/L
	Diazinon	0.004 mg/L
	Diquat	0.007 mg/L
	Diuron	0.02 mg/L
	Glyphosate	1.0 mg/L
	Heptachlor	0.0003 mg/L
	Hexazinone	0.4 mg/L
	Triclopyr	0.02 mg/L
	Gross alpha	0.5 Bq/L
	Gross beta	0.5 Bq/L
	Benzene	0.001 mg/L
	1,2-Dichloroethane	0.003 mg/L
	1,2-Dichloroethene	0.06 mg/L
	Hexachlorobutadiene	0.0007 mg/L
	Vinyl chloride	0.0003 mg/L
CHEMICAL/BIOLOGICAL/ORGANIC	Arsenic	0.01mg/L
	Barium	2 mg/L
	Boron	4 mg/L
	Iodide	0.5 mg/L
	Mercury	0.001 mg/L
	Molybdenum	0.05 mg/L
	Selenium	0.01 mg/L
	Silver	0.1 mg/L
	Tin	N/A
	Beryllium	0.06 mg/L
	Escherichia coli	Seek advice from NSW Health and liaise with customers if the thresholds for these analytes in Raw Water Quality Incident Response Plan are exceeded
	Enterococci	
	Clostridium perfringens	
	Cryptosporidium	
	Giardia	
	Toxin producing cyanobacteria	
	Toxicity	
	Cyanobacteria biovolume	

Those parameters shaded in yellow are characteristics that must be met in raw water supplied for treatment. Those parameters shaded in blue are characteristics for which drinking guidelines exist although they are not applicable for raw water. However, SCA endeavours to supply the best raw water possible and monitors the blue items frequently and the yellow items less frequently, providing monitoring information to the operators of the Prospect WFP.

The annual report made public by SCA[9] is extensive and covers microbiological aspects, pesticides, heavy metals and physico-chemical parameters. Information drawn from the 2012-2013 report is reproduced in reproduced tables A20 and A26 below:

Table A20 Warragamba system – water filtration plants - physico-chemical

Station Code	Statistic	Alkalinity (mgCaCO3/L)	Conductivity (mS/cm)	Dissolved Organic Carbon (mg/L)	Dissolved Oxygen (%Sat)	Dissolved Oxygen (mg/L)	pH	Temperature (Deg C)	Total Hardness (mgCaCO3/L)	Total Organic Carbon (mg/L)	True Colour at 400nm	True Colour at 420nm	Turbidity (NTU)	UV Absorbing constituents (organic)
HBR1	n	12	12	12	11	12	12	12	12	12	12	12	12	12
	Min	31	0.147	4.9	17.4	1.6	6.74	12.5	39	4.9	9	18	3.55	0.099
	Median	33	0.1715	6.05	47.8	4.85	7.14	13.5	44.5	5.95	16	35	5.01	0.184
	Max	35	0.18	6.9	76.5	7.9	7.44	16.4	50	6.8	21	43	9.3	0.207
	Above Max Guideline	0	-	-	-	-	0	0	0	-	0	-	0	-
	Below Min Guideline	0	-	-	-	-	0	0	0	-	0	-	0	-
HWA2	n	12	12	12	12	12	12	12	12	12	12	12	12	12
	Min	33	0.143	4.2	37.4	4	6.61	12.4	39	4.6	6	14	2.82	0.112
	Median	36	0.171	6	67.25	6.8	7.105	14.2	43	5.9	20	44	4.725	0.195
	Max	45	0.236	6.3	76.2	7.5	8.58	17.8	46	6.8	26	59	9.72	0.259
	Above Max Guideline	0	-	-	-	-	0	0	0	-	0	-	0	-
	Below Min Guideline	0	-	-	-	-	8	0	0	-	0	-	0	-
PWFP10	n	12	12	12	12	12	12	12	12	12	12	12	12	12
	Min	23	0.124	5	103.2	9.91	7.1	12.7	25	4.8	8	20	2.1	0.079
	Median	26.5	0.148	5.6	108.25	10.745	7.2	15	39	5.7	14	30.5	2.8	0.146
	Max	37	0.176	7.6	114.4	11.97	7.6	19	50	7.3	16	40	4.5	0.176
	Above Max Guideline	0	-	-	-	-	0	0	0	-	0	-	0	-
	Below Min Guideline	0	-	-	-	-	0	0	0	-	0	-	0	-

Table A26 Warragamba system – water filtration plants – synthetic organic compounds and radionucleids

Station Code	Statistic	1,2-Dichloroethane (ug/L)	trans-1,2-Dichloroethene (ug/L)	Benzene (ug/L)	Hexachlorobutadiene (ug/L)	Vinyl chloride (ug/L)	Gross Alpha	Gross Beta
HBR1	n	12	12	12	12	12	1	1
	Min	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Median	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Max	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Above Max Guideline	0	0	0	0	0	0	0
	Below Min Guideline	0	0	0	0	0	0	0
HWA2	n	12	12	12	12	12	1	1
	Min	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Median	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Max	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Above Max Guideline	0	0	0	0	0	0	0
	Below Min Guideline	0	0	0	0	0	0	0
PWFP10	n	12	12	12	12	12	1	1
	Min	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Median	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Max	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
	Above Max Guideline	0	0	0	0	0	0	0
	Below Min Guideline	0	0	0	0	0	0	0

SCA acts immediately on incidents where analyses exceed limits. The incidents are classified as major or minor and appropriate action taken. This may involve SCA alone in altering source water or level from which water is taken, and/or may need reporting to SW and the Department of Health. As an example of the action taken and the report provided, the activities surrounding an incident on 18 January 2013[9] are reproduced below. No similar incidents were associated with the Prospect WFP in 2012-2013.

Sub-type	Location	Details	Assess Consequences	Root cause analysis	Actions taken
Metal	Orchard Hills WFP	Sample collected at inlet of Orchard Hills WFP recorded total iron of 3.06 mg/L and total aluminium at very high concentrations. The results are at Major Incident range for iron and minor incident range for aluminium.	Sydney Water have confirmed that the plant was operating normally and has continued to operate without issue.	Unknown, potential for contamination or analysis error.	The lab was asked to repeat the analysis which confirmed the original results as accurate. These results were reported to SWC and NSW Health

Sydney Water

With the WFP operator (where relevant) Sydney Water monitors the quality of its drinking water on a continuing basis, with the frequency depending on the component involved. Results are made available in a quarterly report[11]. Inlet (raw) water analyses for the Prospect WFP are conducted by the SCA and reported on its website. SW conducts analyses of treated water on a daily basis (cryptosporidium and giardia), or at greater intervals as indicated on the Quarterly Monitoring report[11]. During the quarter in question all results other than one for cryptosporidium fell within the ADWG. By way of illustration, SW has reported “typical” results for product water from its various treatment plants[1]. That for Prospect East follows:

Table 4: Typical Results for Product Water from Prospect WFP

Parameter	Units	ADWG Health	ADWG Aesthetic	10th-90th percentile range
Physical Characteristics				
True colour	TCU or HU	na	15	<2 - 4
Turbidity	NTU	na	5	0.1 - 0.2
TDS	mg/L	na	600	100 - 136
pH	pH units	na	6.5 - 8.5	7.9 - 8.1
Conductivity	mS/m	na	na	18 - 20
Total hardness	mg $CaCO_3$ /L	na	200	48 - 62
Calcium hardness	mg $CaCO_3$ /L	na	na	29 - 40
Magnesium hardness	mg $CaCO_3$ /L	na	na	19 - 22
Alkalinity	mg $CaCO_3$/L	na	na	32 - 41
Temperature	degrees C	na	na	14 - 23
Dissolved oxygen	% saturation	Na	➢ 85%	97 - 124

…/continued

Parameter	Units	ADWG Health	ADWG Aesthetic	10^{th}-90^{th} percentile range
Disinfectants				
Free chlorine	mg/L	50.6		< 0.04 - 0.04
Monchloramine	mg/L	3	0.5	0.98 - 1.48
Disinfection by-products				
Trihalomethanes	mg/L	0.25	na	0.041 - 0.124
Inorganic chemicals				
Aluminium	mg/L	na	0.2	0.010 - 0.016
Ammonia (as NH_3)	mg/L	na	0.5	0.32 - 0.41
Arsenic	mg/L	0.01	na	< 0.001
Cadmium	mg/L	0.002	na	< 0.001
Calcium	mg/L	na	na	12.4 - 16.5
Chloride	mg/L	na	250	25.6 - 32.8
Chromium (Cr as VI)	mg/L	0.05	na	< 0.0004
Copper	mg/L	2	1	0.007 - 0.028
Cyanide	mg/L	0.08	na	< 0.005
Fluoride	mg/L	1.5	na	0.97 - 1.10
Iron	mg/L	na	0.3	0.010 - 0.021
Lead	mg/L	0.01	na	< 0.001
Nickel	mg/L	0.02	na	< 0.001
Magnesium	mg/L	na	na	4.2 - 5.5
Manganese	mg/L	0.5	0.1	< 0.001 - 0.002
Mercury	mg/L	0.001	na	< 0.0001
Nitrate (as NO_3)	mg/L	50	na	0.6 - 1.0
Nitrite (as $N0_2$)	mg/L	3	na	0.003 - 0.081
Phosphorous	mg/L	na	na	0.007 - 0.009
Potassium	mg/L	na	na	1.9 - 2.3
Reactive Silica (as SiO_2)	mg/L	na	< 80 mg/L	2.5 - 5.0
Selenium	mg/L	0.01	na	< 0.003
Silver	mg/L	0.1	na	< 0.003
Sodium	mg/L	na	180	12.7 - 15.5
Sulphate	mg/L	500	250	7.4 - 8.8
Zinc	mg/L	na	3	< 0.005
Organic compounds				
Chlorinated, polynuclear aromatic, aromatic compounds		various	various	nd
Chlorophenols		various	various	nd
Pesticides		various	various	nd

na = no published health or aesthetic value **nd** = non detectable (less than limit of detection)

3. WHAT TECHNOLOGIES AND APPROACHES ARE USED TO TREAT WATER IN THE SYDNEY DRINKING WATER SYSTEM? WHAT TYPES OF SUBSTANCES ARE ABLE TO BE REMOVED FROM SYDNEY'S DRINKING WATER?

The treatment of water in the Sydney Drinking Water System relies on a number of separate operations to remove impurities and to condition the water for human consumption:

Retention

Water from the catchment is retained in the dam for a sufficiently long time for much of the suspended matter to settle and for biopathogens to significantly de-activate. The capacity of dams in the Sydney catchment provides 4 – 5 years of supply, so residence times are significant. But water does tend to layer and it is important to ensure that the level from which water is drawn is from a layer that has had a long residence. SCA has developed monitoring techniques and skills in this direction.

A second problem arises from the lack of aeration at the lower levels of the dam. Conditions are frequently anoxic with biological action promoting the dissolution of species like iron and manganese. Ideally, water taken for the WTPs should have had residence time in the upper aerated lays where iron and manganese are oxidised to form insoluble species which settle. This problem becomes especially of consequence at the change of seasons where temperature inversions may occur, bringing water rich in soluble iron and manganese to the surface. These metals are a nuisance rather than a toxic hazard but lead to undesirable characteristics in the product water.

A further difficulty is experienced during weather events where sediments are washed into the dam and settle slowly, bringing with them unwanted biological species.

Much of the work of SCA lies in managing dam behaviour so as to present raw water to the WTPs having the best possible properties.

Screening

Prior to leaving dam site and again on entering the treatment plants, water is screened to remove macro-objects and screenable solids. Good operation of the finer screens requires regular backwashing.

Coagulation and Flocculation

In this step ferric chloride and a polyelectrolyte coagulant is added to the raw water and mixed. Both adsorb onto particles present encouraging them to coagulate into larger flocs. Good mixing is necessary in the coagulation step with more gentle mixing in the flocculation step.

Filtration

The flocculated stream is then sent under pressure to a filter where it passes through a bed comprised of crushed anthracite, sand and gravel. Remaining suspended solids are removed giving a stream of low turbidity. The filter is regenerated on a regular basis by back-washing.

Disinfection

The disinfection step may be preceded by pH adjustment, but primarily relies on the use of chlorine or chloramine to kill any micro-organisms still present. The treated product water is then reticulated to consumers. The level of chlorine dosing is such that a residual of chlorine is maintained in the water until it gets to the tap.

Alternative Processes

In newer water treatment plants membrane microfiltration (pioneered in Australia) is used to replace the flocculation and filtration steps and to deliver water needing minimum disinfection. This technology is used in two of the smaller SW WFPs.

Substances Able to be Removed

A conventional water treatment plant such as that at Prospect cannot remove most soluble species, either inorganic and organic. Some metals like iron and manganese can, if not lowered in concentration in the catchment by aeration, be oxidised by chlorine just prior to flocculation and sedimentation to give insoluble species, but the pH level that must be maintained for effective chlorination prevents other metals present from being similarly removed. Thus the level of inorganic species and heavy metals leaving a WFP plant closely mirrors that in the raw water supplied to the plant. This is also largely true for soluble organic species present though some adsorption can occur onto the surface of flocculated material.

4. HOW DOES THE SYDNEY DRINKING WATER TREATMENT SYSTEM RESPOND TO CHANGES IN QUANTITIES OR TYPES OF IMPURITIES IN THE WATER SUPPLIED TO IT FROM RESERVOIRS SUCH AS THE WATER FROM THE SYDNEY WATER CATCHMENT SPECIAL AREAS? HOW DOES ANY INCREASE IN TREATMENT REQUIREMENTS IMPACT ON THE COST OF TREATMENT OR FACILITY OPERATION?

The aim of Sydney Catchment Authority is to supply Sydney Water with a consistent quality of raw water containing expected levels of contaminants. It sees its role to take water from the catchment and to handle, as far as possible, the effects of events like heavy rain, spills and a change in use of land surrounding catchments. It aims to provide timely notice to the operators of WFPs to allow them to adjust operating conditions as appropriate to handle any expected changes to the composition of raw water. By the steps outlined previously (detention time, point of water off-take, control of algal blooms and water inversions) it can moderate the effects of many catchment disturbances.

Not surprisingly, SCA is highly focussed on the likely impact of changes in the nature of industries and pastoral pursuits in the catchment areas of its dams, and particularly in the Special Areas surrounding the dams. It closely monitors the impact of wastewater treatment plants in the catchment and the impact of run-off of fertilisers and pesticides from agricultural land.

In recent years the SCA has been particularly vocal about the likely impact of underground coal mining and the possibility of coal seam gas recovery in its catchments[13,14]. Concerns about long-wall mining relate to the possible disturbance to stream flows caused by ground subsidence after the mining operation is complete. Studies reported by SCA suggest that subsidence can cause fractures and cracks to develop in creek beds and subterranean strata, causing surface water to go underground, possibly to re-appear again in the stream some distance downstream. This water will have passed through porous mineral layers and may have picked up iron, manganese, aluminium, sodium, calcium and barium as well as chloride and sulphate. Carbonates will have been mobilised to give bicarbonate ions. In particular, downstream surface water will have iron and manganese burdens that will place particular responsibility on the SCA to hold the water in its dams under conditions that yield iron and manganese solids that will settle. The effect has been shown to be exacerbated at times of low stream flows.

With coal seam gas (CSG) recovery, the concern is that water is being removed from sub-surface aquifers and this may lead to lower surface stream flows with the removed (produced) water being highly saline and carrying troublesome dissolved organic compounds that may end up in dams and not be removed in the present SW WFPs. Current CSG plant practice is for produced water to stored in large ponds pending treatment. These ponds, if inadequately designed, may overtop during severe weather events, with the water, albeit diluted, finding its way into feeder streams for reservoirs.

The table below compares the properties of produced water from three Australian coal seam gas recovery sites with the specifications for drinking water under ADWG.

Table 5: Properties of CSD Produced Water Compared with ADWG

Parameter mg/L except for pH	ADWG mg/L Health Based	ADWG mg/L Aesthetic Based	AGL Camden[10] mg/L	Santos Narrabri PEL238[14] mg/L	Surat Basin (Tipton)[15] mg/L	ADWG Exceedences (NSW)
pH	6.5 – 8.5		7 - 8.5	8.3	7.6 – 8.9	
TDS			7,790	21,000	4,500 – 6,000	x
Fluoride	1.5		1.3	5.8	0.77 – 1.0	x
Sodium		180	3,030	6,200	1,840 – 3,461	x
Chloride		250	287	2,000	2,060	x
Magnesium			4	4.0		
Silica		80	9.6	23		
Sulfate	500	250	< 1	4	2	
Boron	4		0.06	0.87		
Potassium			10	45		
Calcium			4	7		
Manganese	0.5	0.05	0.007	0.009	0.07 – 0.10	
Iron		0.3	0.13	0.28	0.07 – 4.50	
Bicarbonate (as $CaCO_3$)			6,540	10,100	1,030	x
Strontium			3.42	1.3		
Barium	2		9.85	13	8 - 9	x
Cyanide	0.08			0.004		
Aluminium	0.2		< 0.01	0.10		
Phosphorous				0.14		
Ammonia (as N)	0.5			13		x
Nitrate (as N)	50			0.10		
Copper	2	1	< 0.001	0.022		
Zinc		3	0.005	0.023		
Arsenic	0.01		0.004	0.010		
Chromium	0.05			0.006		
Cadmium	0.002		0.001	0.0053		x
Mercury	0.001		< 0.0001	0.00071		
Molybdenum	0.05		0.007	0.00064		
Nickel	0.02		0.004	0.0013		
Antimony	0.003			0.00012		
Selenium	0.01		<0.01	0.0150		x
Uranium	0.017		< 0.001	0.0001		
Lead	0.01		< 0.001	0.0037		
Benzene	0.001					
Ethylbenzene	0.3	0.003				
Toluene	0.8	0.025				
Hydrogen sulphide		0.05				
Silver	0.1					

Note: High levels of bicarbonate ion will lead to exceedence in TDS and conductivity

For the Warragamba catchment the most appropriate comparison would be for the AGL operation at Camden as this AGL facility is in Sydney basin and its produced water could be considered representative of that of a coal seam gas recovery operation if it were to be initiated in the catchment. The produced water exceeds ADWG in several areas. The Camden operation yielded 5 ML of produced water in 2012. When compared with an annual raw water throughput of the Prospect WFP, this represents a dilution factor of 10^5. Whilst it would not be acceptable to routinely dispose of produced water directly to a waterway feeding Warragamba Dam as its relatively high saline and bicarbonate content would upset stream ecology, dilution and the absence of high levels of toxic substances would mean that it was safe from a health viewpoint if it were occasionally to occur during an unusually heavy rain event. For preference, produced water from any new venture should be treated by reverse osmosis or ion exchange to remove dissolved salts and, if necessary, by adsorption to remove any soluble organic species to meet ADWG. Currently AGL disposes of its produced water by tanker to a municipal sewage treatment plant.

Although the use of BETX chemicals in fraccing is banned in NSW, produced water may contain traces of hydrocarbons because of its contact with the coal seam. These would need to be identified and accounted for in the treatment process. Also, any fraccing chemicals used should be publicly identified and designed for, with the appropriated regulating authorities being informed. With these steps the operation of the dam and WFP should not be compromised, with any costs to remove unwanted contaminants borne by the CSG producer. If soluble organics from the production water were to find their way into the drinking water system beyond ADWG, they would need be removed by adsorption at the WFP at a substantial cost, estimated as $\$0.2/m^3$. It is far preferable to remove these chemicals at source.

The SCA has formulated a six principles policy with regard to managing mining and coal seam gas impacts on catchment infrastructure works and the Special Areas[3].

> "The principles establish the outcomes the SCA considers as essential to protect the drinking water catchments and Special/ Controlled areas, and catchment infrastructure works. The six principles currently approved, in summary, are as follows:
>
> - Quantity of water is protected – mining and coal seam gas activities must not result in a reduction in the quantity of surface and groundwater inflows to storages or a loss of water from storages or their catchments.
> - Quality of water is protected – mining and coal seam gas activities must not result in a reduction in the quality of surface and groundwater inflows to storages.
> - The integrity of SCA infrastructure must not be compromised.
> - 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.
> - The ecological integrity of the Special Areas must be maintained and protected.
> - Information provided by proponents must be detailed, thorough, scientifically robust and holistic. The potential cumulative impacts must be comprehensively addressed."

In the State planning process SCA will argue against approval being given to proposed mining and coal seam gas recovery operations being located in the Special Areas or (in the case of long-wall mining) near to major SCA infrastructure such as dams[13].

5. WHAT ARE THE POTENTIAL 'WORST CASE SCENARIOS' RELATED TO THE WATER TREATMENT AND MANAGEMENT FOR THE SYDNEY WATER CATCHMENT? WHAT ARE THE RISKS (I.E. LIKELIHOOD AND CONSEQUENCES) OF SUCH SCENARIOS OCCURRING?

Since 2008 SCA and SW have engaged in a joint analysis of hazards associated with the provision of drinking water by conducting a water quality scenario review. The first of these exercises (project 'Rainbow') explored the impact of a major diesel spill on the system. Later studies have examined other potentialities. SCA, SW, NSW Health and emergency agencies have clear incident response plans to handle potentially dangerous occurrences. At the extreme these include a 'boil water' instruction to consumers.
However, the scenarios are perhaps more focused on acute exposure rather than chronic exposure. Worst case scenarios should include those where consumers are exposed to continuing levels of contaminants likely to damage their health. Typically these involve chemical components rather than biological ones.

The following table to identifies scenarios that have potential short-term and long-term implications.

Table 6: Risk Scenarios

#	Scenario	Reason	Impact	Likelihood	Recovery
1	Breakthrough of dangerous pathogens from WFPs	Inadequate disinfection due to carry-forward of suspended solids or failure of disinfection system	Severe – 'boil water' alert issued. Risk of major health outbreak	Unlikely with present controls – every 10 years	Re-establish process control of dam off-takes and WTP
2	Breakthrough of toxins from cyanobacteria	Blue-green algae bloom in dam	Severe – consumers compromised	Moderate	Treat algal bloom in dam, restrict N & P flows into dam. Monitor continuously
3	Iron and manganese too high affecting treated water quality	Seasonal turnover in reservoir improperly controlled	Moderate - Product water stains and leaves deposits. Taste compromised.	Moderate – every 5 years	Re-establish preferred off-takes and dam residence time. Pre-chlorinate at entrance to WFP.
4	Pesticides in treated water	Agricultural run-off	Moderate – possible chronic implications for population	Low – every 5 years. Present controls tight	Dilution and time. Alternative raw water sources.
5	High metals content in raw water	Mining activity leads to leached metals, especially iron, manganese and aluminium, in dam inlet water	Moderate – Advance knowledge of developments should lead to readiness for process intervention.	Low – over long period and exacerbated by low inlet stream flows	Extra vigilance within SCA activities

#	Scenario	Reason	Impact	Likelihood	Recovery
6	High heavy metals concentration in treated water from WTP	Mining activity leads to higher concentrations in streams supplying dams	Moderate – chronic rather than acute effects	Low- Substantial dilution by surface water renders exceedance of ADWG unlikely	Alternative dam source pending remediation measures
7	High organics or salt content in treated water from WTP	Coal seam gas recovery production water overflows to streams and hence to dams.	Moderate – chronic rather than acute. Strong dilution.	Low – if proper controls are placed on such developments.	Needs to be solved at facility planning level with strong regulation on inadvertent discharge.
8	Significant spillage of dangerous pollutant into catchment area and progress of this pollutant to storage dam	Transport accident or malfunction of holding facilities for toxic treatment chemicals	Significant, depending on chemical	Moderate – One significant incident per year	Emergency activity to prevent pollutant entering stream that feeds dam. Use of barriers, recovery.

Apart from long-term operating disturbances caused by the introduction of new industries to the Special Areas and to the catchments of streams feeding Warragamba dam and other storage reservoirs, the current water management plans of SCA and SW would seem to cover the handling of scenarios that could lead to moderate to severe impacts.

As an example of a short-lived crisis that could occur, if a 30,000 gasoline tanker were to be involved in a collision and spilled its contents in a catchment there would be 240 kg of benzene released, which may be partially evaporated, or may find its way into water travelling to Warragamba dam. Assuming the 240 kg entered the dam and was fully mixed with dam water, the benzene level in dam water would be 0.00012 mg/L, still well below the ADWG of 0.001 mg/L. But the impact on the smaller dams would be proportionally higher, giving concentrations of up to 0.003 mg/L.

If the tanker contained vinyl chloride (boiling point -10^{o}C), the risk of exceeding the health guideline (0.0003 mg/L) could be higher though most of the tanker's contents would probably evaporate. Calculations such as these are trivial and do not account for a host of effects including the magnitude of dilution within the system. But they do show that Sydney's water system could be affected by an incident and the need for constant vigilance.

While it is apparent that SCA and SW have response systems in place, the monitoring of water at present occurs only periodically and, except for sediments and biological pathogens, would not detect a major contamination event in close to real time. For this the system needs to be alert to the notification of a potentially hazardous incident, allowing suitable analytical coverage to swing in to action. If there is further mining and industrial development planned for catchment areas, the most effective way of ensuring prompt and efficient notification of hazardous occurrences needs to be fully explored.

6. CONCLUSIONS

It is apparent that the Sydney Catchment Authority and Sydney Water have put together along with NSW Health and other State authorities an efficient system for ensuring the continuing supply and quality of Sydney's drinking water. The system is designed to produce water that meets the Australian Drinking Water Guidelines (2013) and in publically released annual information it has shown that the targets have been met or bettered. The system has been subject to hazard analysis as proposed in ADWG and fail-safe mechanisms put in place with multi-barrier controls. These have been tested and found to be effective on a number of occasions in recent years. Much has been learnt about operation of the system since the cryptosporidium outbreak in 1998.

At its heart the treatment system focuses on minimising the risk associated with biological pathogens. While account is taken of iron and manganese content in the product water because of the adverse non-health effects these bring to water (staining, taste), tracking of other metallic species is intermittent and control relies significantly on the quality of the inlet water to Sydney Catchment Authority's dams. This is also true for pesticides, with SCA having in place effective control measures for regulating the use of and run-off from pesticides in its catchments.

SCA can control the level of sediments and the soluble iron and manganese levels in raw water flowing to SW's WFPs by managing the water contents of the dam and the off-take level use. It can also minimise the risk posed by toxins from algal blooms by treating these blooms and/or switching to alternative water supplies.

For its part SW has relatively limited control over the removal of dissolved species, with the treatment plants primarily focussed on clarifying raw water so that it can be effectively disinfected. These treatment plants can handle changes in quantities in the water supplied, but would have to be significantly augmented by an additional treatment step if they were required to remove dissolved organic impurities, with an attendant increase in the cost of water supplied to consumers. Effective operation of SW's plants relies on advance warning of factors likely to lead to process upsets. This communication between SCA and SW is taking place.

Although the impact of underground long-wall mining in the catchment could lead to small changes in the levels of impurities in water entering SCA's dams, these changes can be coped with by SW's treatment plants as evidence to date does not suggest a sufficiently large change in soluble organic concentrations to be of concern.

Coal seam methane recovery in the catchment could pose threats to the system by way of release of salinity and bicarbonate if storage facilities for production water were to be, for example, overtopped by a severe weather event. However, the dilution that would occur within the system should mean the threat is minimal, especially as the amount of produced water associated with coal seam gas recovery in the Sydney basin is small. More of a problem would be if concentrates from the membrane treatment of production water were stored on site. For this reason any proposals for coal seam gas operation in the catchment should be accompanied by a careful appraisal of any potential threats to the quality of water entering SCA dams. This would include consideration of any chemical introduced during a fraccing process.

It is finally noted that the response plan adopted by SCA/SW is heavily reliant on reporting of an incident and appropriate follow-up. There is timely monitoring of risks from water-borne pathogenic species, but it would be desirable to have some online monitoring for markers for pesticides and dissolved organic species on entry to SCA's catchments and in the raw water entry to SW's WFPs.

ABOUT THE CONSULTANT

Emeritus Professor Chris Fell AM FTSE CPEng is a chemical engineer, listed on the National Professional Engineers Register. As an academic at the University of New South Wales he was Foundation Director of a Commonwealth Special Research Centre for Membrane and Separation Technology and Foundation Chair of the CRC for Waste Management and Pollution Control. He was co-inventor of the technology that led to the Australian membrane company Memtec Limited (see www.10innovations.unsw.edu.au). Since retirement from UNSW he has run a boutique consulting practice providing advice to government and industry and serves as a company director.

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2	http://www.nhmrc.gov.au/guidelines/publications/eh52/	Australia Drinking Water Guidelines.: National Water Quality Management Strategy	Published 2011, Updated December, 2013
3	http://www.sca.nsw.gov.au/	Welcome to the Sydney Catchment Authority	Home page for Sydney Catchment Authorities' activities
4	http://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdq1/~edisp/dd_045256.pdf	Five-year Drinking Water Quality Management Plan 2010-2015	Detailed plan as indicated
5	http://www.treasury.nsw.gov.au/ppp/nsw_projects/projects_which_have_been_awarded/water/prospect_water_treatment_plant	Prospect Water Treatment Plant	PPP from 1993-2026 for Water Treatment Plant and Prospect Supernatant Filtration Plant - Lyonnaise
6	http://www-personal.usyd.edu.au/~victor/SydneyWater.Proposal.html	Proposal for the control of microbiological contamination of Sydney water	1999 proposal of Australian Chinese Engineers Association
7	http://www.sca.nsw.gov.au/__data/assets/pdf_file/0003/36408/Water-monitoring-at-the-SCA-fact-sheet.pdf	Water monitoring at Sydney Catchment Authority	100 sites, 600 water quality characteristics measured
8	http://www.sca.nsw.gov.au/__data/assets/pdf_file/0016/36412/WQMF-2012-2017.pdf	Sydney Catchment Authority – Water Quality Management Framework 2012-2017	Detailed plan as indicated
9	http://www.sca.nsw.gov.au/__data/assets/pdf_file/0005/44591/Annual-Water-Quality-Monitoring-Report-2012-13.pdf http://www.sca.nsw.gov.au/__data/assets/pdf_file/0004/44590/Annual-Water-Quality-Monitoring-Report-2012-13-Appendices.pdf	Annual Water Quality Monitoring Report 2012-2013 Appendices	Publically available data on monitoring by SCA for 2012-2013
10	http://www.agl.com.au/~/media/AGL/About%20AGL/Documents/How%20We%20Source%20Energy/Monitoring%20Data/EPL_CamdenGasProject_Quarterly_Water_Monitoring_Report_FY13Q4.pdf	AGL Upstream Investments Pty Ltd Camden Gas Project	Reporting period: 4th quarter FY 2013
11	http://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdu1/~edisp/dd_055501.pdf	Quarterly drinking water quality report	Sydney Water 2013
12	http://www.sca.nsw.gov.au/catchment/mining/principles	Mining principles	Commentary on SCA's response to mining in catchment

13	http://www.sca.nsw.gov.au/__data/assets/pdf_file/0010/36883/9.-Prepared-by-Parsons-Brinckerhoff.pdf	Impacts of Longwall Mining on the Waratah Rivulet	Consultant report on study
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