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Discussion Paper for
Office of NSW Chief Scientist and Engineer

WATER TREATMENT AND SYDNEY CATCHMENT

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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.

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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:

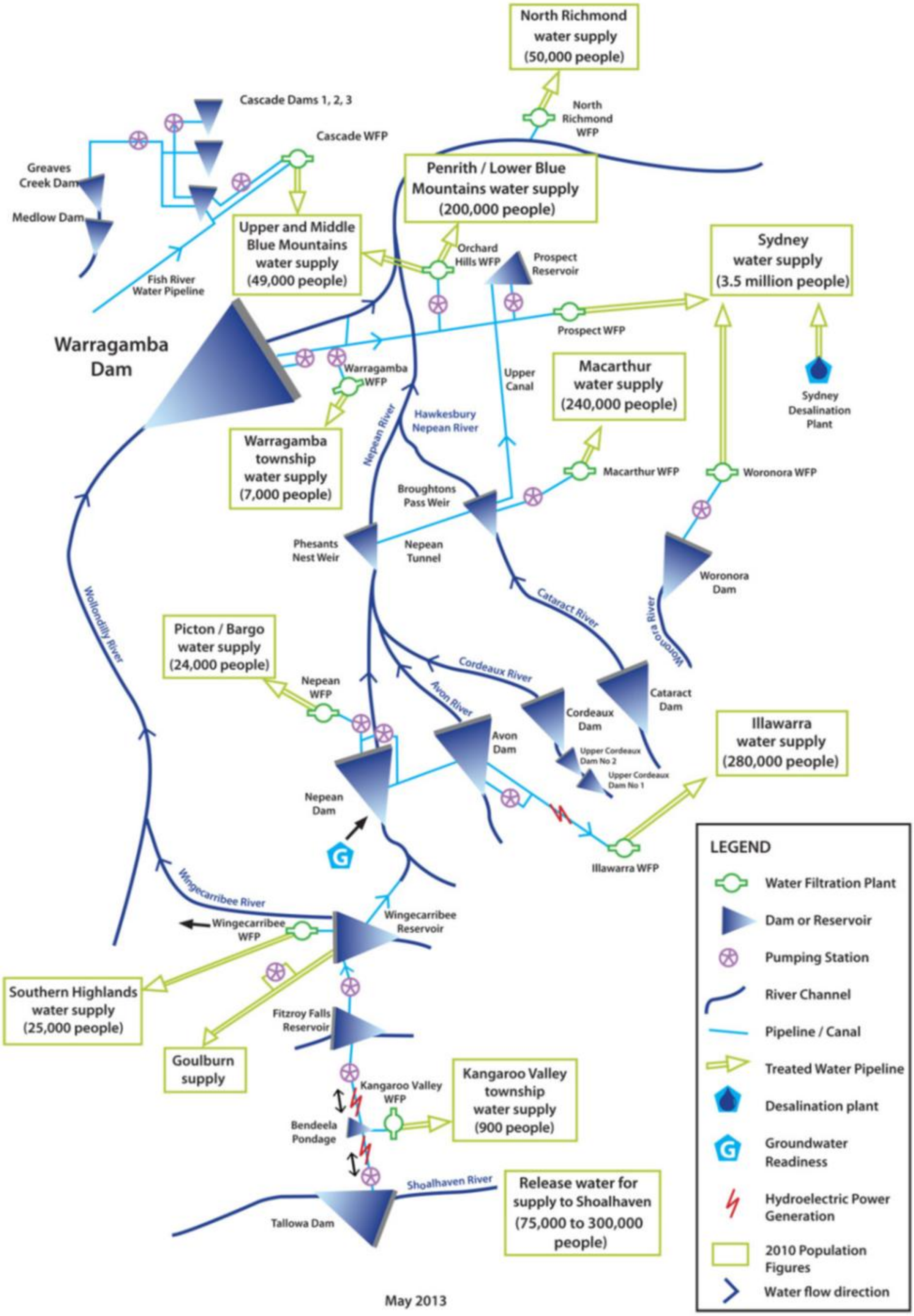

Figure 1: Greater Sydney's Water Supply System

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.

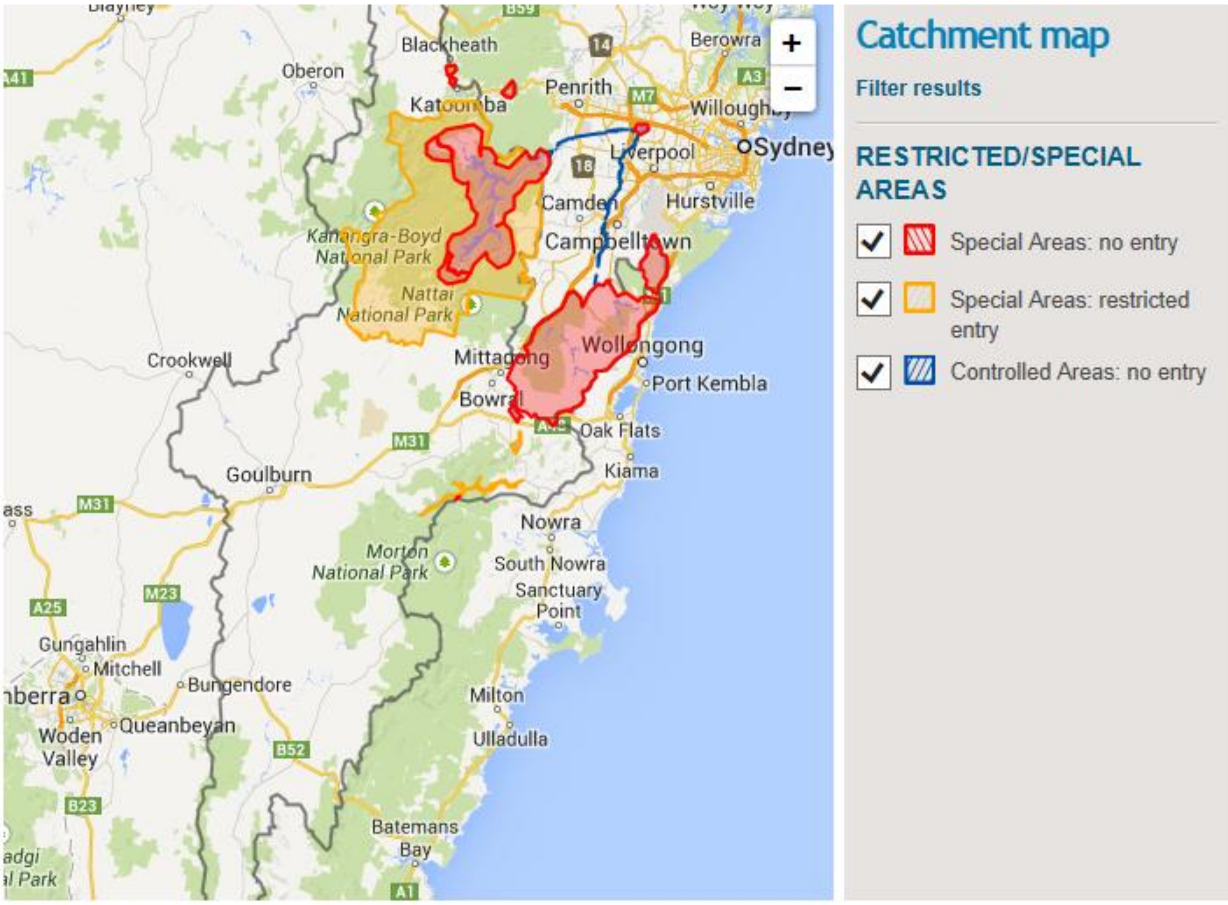

Figure 2: Catchment Areas Map

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).

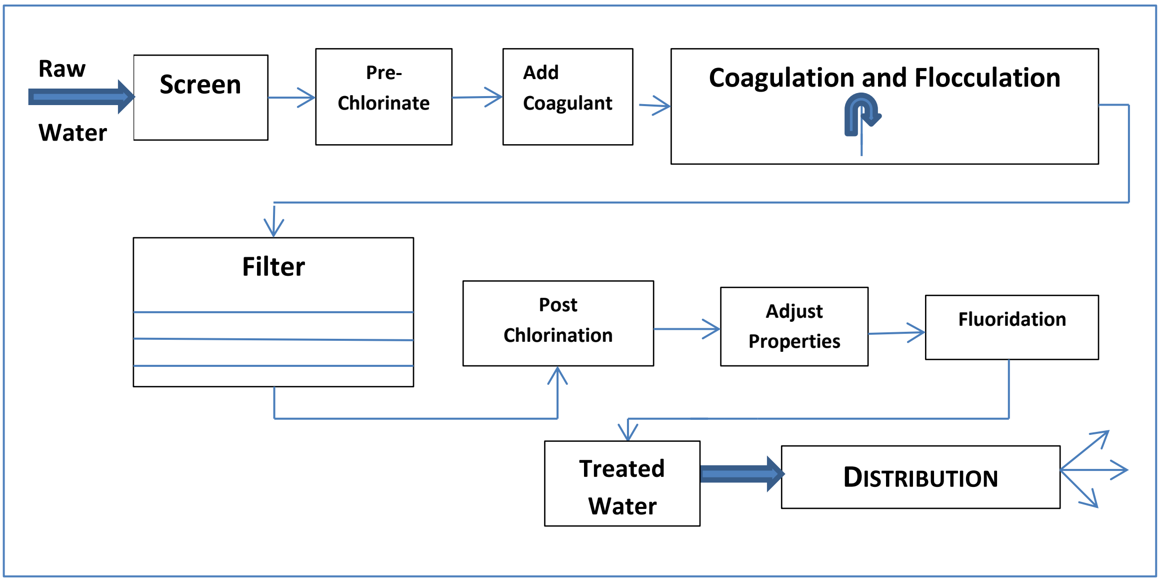

Figure 3: Water Filtration Plant

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	10^{th}-90^{th} 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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