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Risk Assessment for Drinking Water Sources

Research Report 78

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Risk Assessment for Drinking Water Sources

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FOREWORD

Research Report Title: Risk Assessment for Drinking Water Supplies

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The invaluable and insightful inputs from the major project contributors to this project are acknowledged, as follows:

CRC for Water Quality and Treatment Centre Members:
- Bruce Whitehill, Sydney Catchment Authority (Project Leader)
- Dr Daniel Deere, Sydney Catchment Authority and CRCWQT (Catchments Program Leader)
- Rachael Miller (Project Officer)
- Dr Mark O'Donohue, South East Queensland Water
- Dr Melita Stevens, Melbourne Water
- Peter Engler, WA Water Corporation
- Clairly Lance, Water Corporation
- Karla Billington, SA Water
- Declan Page, NT Power and Water
- Bob Ford, Central Highlands Water

Non Members:
- Peter Newland, SA EPA Watershed Protection Office
- Prof Barry Hart, CRC Freshwater Ecology
- Pat Feehan, Goulburn Murray Water
- Mike Grace, eWater CRC

CRC for Water Quality and Treatment Project No. 2.1.0.2 – Catchment Risk Management: A Tool to Structure source Water Protection

EXECUTIVE SUMMARY

This Research Report describes work undertaken through a Cooperative Research Centre for Water Quality and Treatment (CRCWQT) project, which was led by Mr Bruce Whitehill of the Sydney Catchment Authority. Project contributors included representatives from the Cooperative Research Centre for Freshwater Ecology, eWater CRC, South East Queensland Water, SA Water, Melbourne Water, Northern Territory Power and Water, SA EPA Watershed Protection Office, NT Power and Water, Goulburn-Murray Water, Central Highlands Water and WA Water Corporation. These contributors to the project covered the range of approaches being used by water utilities across Australia and included varying scales of water management organisation, types of water supply system management and catchment land uses and activities.

Water management organisations have long recognised the importance of a multiple barrier, risk management approach to protecting drinking water quality from contaminants (Deere *et al.*, 2008). The Australian Drinking Water Guidelines (2004) (ADWG) indicate that the most important barrier in water quality protection is the effective protection of the source or catchment. Effective source protection can mitigate significant cost and reliance on fallible downstream barriers such as water treatment and disinfection (Ford, 2008). Effective risk mitigation in the source can theoretically have significant cost-savings by offsetting more expensive downstream water treatment barriers.

The most important tool in determining where to implement preventative barriers within the source is through the application of a source water risk assessment. Source water risk assessments involve assessing the risks presented to drinking water quality that arise in that particular source recharge area, with the results determining the appropriate risk management actions and their prioritisation (Deere *et al.*, 2008).

The water industry uses several different risk assessment methods as part of implementing the Framework for Management of Drinking Water Quality (Framework) given in Chapters 2 and 3 of the ADWG. The Framework outlines a quality management approach to ensure water quality is protected from catchment to tap. Examples of related management approaches in use by contributing water utilities were Hazard Analysis and Critical Control Points (HACCP), AS/NZS 4360:2004 Risk Management and Water Safety Plans (described in the WHO Guidelines for Drinking-water Quality 2006). Each approach has its strengths but they are most readily applicable to engineered rather than environmental systems. There can be some difficulties in accommodating the characteristics of the unique natural ecosystem that is the water source when applying these types of risk assessment approaches. Other ecosystem-based methods, e.g. Ecological Risk Assessment (ERA), can accommodate these issues but can require complex data inputs that are often incomplete or not available to water utilities.

This paper provides examples of ways to implement the Framework in drinking water supply sources and discusses the use of a number of risk assessment techniques in use by water suppliers. A step-by-step catchment risk assessment methodology was proposed as an interpretation of the Framework. The interpretation was undertaken to set the management of drinking water source risks and water supply operational needs within the context of broader source water management environmental objectives.

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1.1 Background

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This paper provides examples of ways to implement the Framework in drinking water supply sources and discusses the use of a number of risk assessment techniques in use by water suppliers. A catchment risk assessment methodology was proposed as an interpretation of the Framework. The interpretation was undertaken to set the management of drinking water source risks and water supply operational needs within the context of broader source water management environmental objectives.

1.2 Scope

For the purposes of this paper a catchment is defined as:

> *'The area of land which intercepts rainfall and contributes the collected water to surface water (streams, rivers, wetlands) or groundwater, with the reservoir wall or abstraction bore representing the downstream end of the catchment.'*

Although desalination of ocean areas presents new sources for water utilities and regulators to manage and protect, these types of sources were not considered explicitly in the development of this manual. However, it is noted that the methods outlined in this document could also apply to ocean areas, although some interpretation by the practitioner is required to ensure application. This would include for instance the definition of a protection area for the ocean source.

This document explicitly addresses Elements 2 to 3 of the Framework in relation to catchments as well as implicitly addressing components of the remaining elements.

1.3 Project tasks

The following tasks were undertaken during the project:

1. A literature review on the topic and an operational review of present catchment risk management programs being developed in Australia and overseas;
2. Review related water quality management programs including the Framework, and establish a project relationship between this and other relevant research programs;
3. Identify the key components required for a catchment risk management program, establish their relationship in a structured framework and provide clearly defined terminology;
4. Examine the information requirements to effectively identify hazards and assess risks to raw water quality in catchment areas;
5. Examine existing risk assessment approaches for applicability to catchment risk management including ecological and human health risk assessment including: Hazard Analysis and Critical Control Points (HACCP), AS/NZS 4360:2004 Risk Management, ADWG Framework and Pressure-State-Response;
6. Examine the role of contaminant budgeting, water quality modelling applications and cause/effect relationships in the risk assessment process;
7. Recommend appropriate risk assessment methodologies for use in catchment scenarios and describe their use with examples; and
8. Examine the resource and information implications for organisations of various sizes and for catchments varying in size, landscape and information coverage.

1.4 Project contributors

The major project contributors to this project were as follows:

CRC for Water Quality and Treatment Centre Members:

- Bruce Whitehill, Sydney Catchment Authority (Project Leader)
- Dr Daniel Deere, Sydney Catchment Authority and CRCWQT (Catchments Program Leader)
- Rachael Miller (Project Officer)
- Dr Mark O'Donohue, South East Queensland Water
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- Peter Newland, SA EPA Watershed Protection Office
- Prof Barry Hart, CRC Freshwater Ecology
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- Mike Grace, eWater CRC

2 BENEFITS OF RISK MANAGEMENT PROCESSES

Like other management activities, risk management helps an organisation meet its objectives through the allocation of resources to undertake planning, make decisions and carry out productive activities (Shortreed *et al.*, 2003). Risk management focuses on uncertainties that an organisation faces such as:

- Uncertainties in the probability of occurrence of events;
- Uncertainties in the value to the organisation of consequences of events; and
- Other uncertainties that fall outside the normally expected range of variation.

In general, risks facing the water industry in catchments tend to have a low probability of occurrence, but have a high consequence that can cause major disruption or problems for the organisation and the community as a whole.

Risk management programs generally cover five main components:

- Context – What is at risk and why?
- Risk identification – What and where are the risks?
- Risk analysis – What is known about them?
- Risk evaluation – How important are they?
- Risk treatment – What should be done about them?

Risk assessment and management planning became an area of heightened interest for the Australian water sector following incidents within Australia and internationally. For instance, in late 1998, water quality incidents affected both Sydney and Adelaide. In Sydney, the incident arose due to suspected *Cryptosporidium* contamination and resulted in a boil water notice for millions of customers. The resultant costs of the incident were significant but fortunately there was no increased community illness. In the same year, detections of *Giardia* and *Cryptosporidium* were found in Adelaide reservoirs. In this incident, the *Giardia* detection led to the closure of the Hope Valley Water Filtration Plant and Reservoir on two occasions. In addition to microbial contamination, pesticide detection in five Adelaide reservoirs led to the introduction of activated carbon dosing at the Barossa Water Filtration Plant at an annual cost of $1 m (Billington pers. comm., 2003), although there were not health impacts.

Internationally, numerous microbial and chemical contamination incidents have occurred over the last few decades. Some of these are documented in Hrudey and Hrudey (2004), where one of the key findings was that a significant portion of the drinking water quality incidents had the origin of the contamination tracked to the source water.

Risk assessment and management in water supply is linked with the demonstration of due diligence. Due diligence can mean the prevention of reasonably foreseeable harm. It may also have a practical definition of showing compliance with statutory obligations. Due diligence can be applied in both preventative and reactive operations:

- To mitigate water contamination; and
- To manage contamination to mitigate any further harms.

Australian courts only recognise due diligence as a defence where it is expressly provided for by statute (as it is in the Trade Practices Act and the proposed food safety legislation). Where due diligence is available as a statutory defence, the legislature has often left it to the courts to determine what is actually meant by the term 'due diligence'. Direction on the principal factors to be considered in environmental due diligence, has been given by a Canadian court[1]. The establishment of a defence of due diligence on behalf of the company's directors was based on the following:

- Established or facilitated establishment of a pollution prevention system;
- Ensured that employees complied with relevant laws and industry practices and reported any non-compliance to the board;

[1] *R v Bata Industries Ltd* (1992) 7 CELR (NS) 245

- In being responsible for reviewing environmental compliance reports, placed unreasonable reliance on those reports;
- Were prompt in addressing environmental concerns which had been raised;
- Were aware of the standards of the industry (dealing with similar environmental pollutants or risks); and
- Personally reacted when they became aware of a system failure.

Intrinsic to demonstrating due diligence in the water industry, therefore, is:

- An assessment of the foreseeable risks to the consumer from source to delivery point;
- An appropriate system for managing those risks (in the appropriate regulatory and statutory context);
- Evidence of a culture of compliance (that the system is being adhered to);
- A rolling revision process to actively seek out and incorporate new knowledge; and
- Appropriate contingency planning.

Generally, these key requirements can be addressed by an Environmental Management System (EMS) accommodating a key component of risk assessment. Adherence to an EMS can assist in establishing a defence of due diligence (Bates and Lipman, 1998). However currently only the ACT, South Australian and Tasmanian legislation explicitly recognises the role for EMS in relation to due diligence.

As this manual has been designed to guide catchment risk assessments and actions to improve water quality in the catchment, storages and raw water delivery infrastructure, it is a preventative complement to incident response plans. The risk management approach outlined in this manual has been developed to allow compatibility with existing “downstream” treated water quality management processes, allowing outcomes of the catchment risk management to flow into the downstream water safety plan. This will result in mutual reinforcement of the actions of both mechanisms.

Within water utilities, the catchment risk management process is usually part of a larger program that encapsulates corporate risk and drinking water quality management. Some organisations use fully integrated management systems, linking all components of business risk (including catchment based) to a corporate risk plan. As such the guidance provided in this manual recommends how to ensure proper consideration of catchment risks in a water quality management plan.

3 RISK ASSESSMENT AND RISK MANAGEMENT CONCEPTS

3.1 Risk Terminology

One of the key issues associated with risk assessment is the interpretation of differing terminology used across organisations and risk methodologies. To remedy this, it was deemed appropriate to establish some standard terminology for this project, based on Framework. Definitions associated with this document are outlined below, in Table 1.

Table 1 Terminology in catchment management.

catchment:	area of land that collects rainfall and contributes to surface water (streams, rivers, wetlands) or to groundwater.
critical control point:	a point, step or procedure at which control can be applied and which is essential to prevent or eliminate a hazard or reduce it to an acceptable level (adapted from Codex Alimentarius).
critical limit:	a prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability (adapted from Codex Alimentarius).
dose–response:	the quantitative relationship between the dose of an agent and an effect caused by the agent.
exposure:	contact of a chemical, physical or biological agent with the outer boundary of an organism (e.g. through inhalation, ingestion or dermal contact).
hazard:	a biological, chemical, physical or radiological agent that has the potential to cause harm.
hazard analysis critical control point (HACCP) system:	a systematic methodology to control safety hazards in a process by applying a two-part technique: first, an analysis that identifies hazards and their severity and likelihood of occurrence; and second, identification of critical control points and their monitoring criteria to establish controls that will reduce, prevent, or eliminate the identified hazards.
hazard control:	the application or implementation of preventive measures that can be used to control identified hazards.
hazard identification:	the process of recognising that a hazard exists and defining its characteristics (AS/NZS 3931:1998).
hazardous event:	an incident or situation that can lead to the presence of a hazard (what can happen and how).
preventive measure:	any planned action, activity or process that is used to prevent hazards from occurring or reduce them to acceptable levels.
raw water:	water in its natural state, prior to any treatment; or the water entering the first treatment process of a water treatment plant.
residual risk:	the risk remaining after consideration of existing preventive measures.
risk:	the likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm.
risk assessment:	the overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 4360:1999).
risk management:	the systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
sanitary survey:	a review of the water sources, facilities, equipment, operation and maintenance of a public water system to evaluate its adequacy for producing and distributing safe drinking water.

3.2 Uncertainty of Information Used in Risk Assessments

In risk assessments it is imperative to recognise the level of certainty or confidence you have in the information you are using in the risk assessment (Sullivan, 1998). It is important to recognise that results of risk assessments are highly uncertain as a consequence of the significant gaps in our knowledge and understanding. Sullivan (1998) outlines that the most significant shortcomings are:

- Difficulties in estimating the likelihood of occurrence of low probability events;
- Limited understanding of the sources of pollution, in particular those sources which contain a range of pollutant hazards;
- Limited understanding of the transport and fate mechanisms which determine the concentrations and duration of pollutants in the environment;
- Difficulties in characterising ecosystem responses to pollutants and other stressors; and
- Limited data on the synergistic effects of chemicals.

There is also the potential for risk assessments to be biased or affected by external factors such as public concerns and health protection as well as economic and political interests (Sullivan and Hunt, 1999). Guidance on the "level of certainty" that we have on a piece of information can be expressed in the form of Certainty Guidelines and thus allow this to be recognised in the risk assessment. These guidelines should be based on the drinking water supply or catchment manager's knowledge of the hazards or hazardous event and barrier or control measure effectiveness. It is suggested that four levels ranging from low, moderate, high, very high could be allocated. A low level of certainty is suggested as it reflects the reality of poor understanding of source characteristics, risks or water quality issues that can be common in catchment management. The use of certainty guidelines can then provide further emphasis to drive local and operational research and monitoring into areas of low or moderate certainty.

Mitigation actions addressing a key hazard or hazardous event as a result of a risk assessment will be based on the recognition of this level.

There is much value in including certainty or confidence guidelines, particularly for confidence in decision-making for financial allocations. Hart *et al.* (2001) suggests that management would react to, and treat results differently, if they knew the level of certainty associated with a specific risk. To this end, Hart *et al.* (2001) suggested that the final risk assessment outcomes should include a summary of the assumptions used, the scientific (and other) uncertainties, and the strengths and weaknesses of the analysis.

3.3 The Range of Risk Assessment Methods

There are a number of different risk assessment methods available, some of which are detailed in Appendix 1. However, generically there are two distinct risk assessment approaches being used by water utilities and research organisations. One approach uses quantitative risk assessment (QRA) (whether human health or ecological) and is born out of the use exposure and reference dose data. This includes the selection of assessment and measurement endpoints and the comparison of endpoint water quality measurements or distributions to a guideline value. Current research in this approach is focused on the comparison of multiple contaminants and how to compare these, and the use of stochastic models to understand the origins of risk. A second approach is qualitative and involves the use of expert groups assessing water quality issues, either as contaminants, pollution sources or hazard events, and prioritising these issues from this assessment. Methodologies used include the AS/NZS 4360:2004 Risk Management and the HACCP system.

Differing risk assessment methods based on these generic approaches and case examples are outlined in more detail below in this section. Methods vary over different components such as driving compliance frameworks, input information, base categorisation (hazard or hazardous event based) and if they are qualitative or quantitative in assessment. Generically however, there are five main types of risk assessment methods as identified by Deere and Davison (2005):

Qualitative Risk Assessment Methods

1. Conceptual descriptions of the cause and effect relationships that lead to risks arising from a particular activity or scenario (e.g. Vigneswaran and Deere 2003). These are not quantitative but provide a demonstration of the potential for cause and effect, to rule risks in or out, and are particularly valuable as educative and illustrative tools. This approach was used in the original food HACCP risk assessments, pre 1996, and by Gold Coast Water in its catchment to tap HACCP risk assessment;
2. Qualitative, subjective risk ranking models (e.g. Deere *et al.,* 2001). These models are used to rank scenarios, events or options in terms of risk or impact rather than to provide estimates of actuals. They include the Drinking Water Quality Management Framework approach, the AS/NZS 4360:1999 methodology and the more recent approaches to HACCP such as used by the Melbourne water utilities (Mullenger *et al.,* 2002, Hellier, 2003);
3. Semi-quantitative objective risk ranking models (e.g. Deere *et al.,* 2001). As for the above bullet point, such models are applied to ranking events, options or scenarios but these use objective data such as occurrence frequencies or receptor population sizes. This approach was used by Sydney Water in its 1999 catchment to tap risk assessment;

Quantitative Risk Assessment Methods (QRA)

4. Point-estimate quantitative risk assessment models (e.g. Deere *et al.,* 1998). These models do not represent uncertainty and variability well, although they are very useful in screening level assessments for single hazards and endpoints; and
5. Probabilistic quantitative models employing randomised frequency distributions to represent one or more elements. These models provide a useful representation of the uncertainty and variability in estimates and have been evaluated previously by the CRC for Water Quality and Treatment under project 1.1.1 (Deere 1998, Nadebaum *et al.*, 2000a, b).

The two generic approaches are not necessarily un-related, but are not often used together. This may be due to the separate evolutions of the approaches, from toxicological/microbiological and from manufacturing and quality systems. The two however have intersected in the management of water resources. There is a need for the quantitative approach to be able to assess multiple contaminants, prioritise these and link to the development of management (treatment) options. The qualitative approach suffers from a lack of use of actual water quality data and focus on an endpoint, unrecognised uncertainties and the potential for biased results from the “expert team” (Burgman, 2001). Risk assessment methods can be informed by, and are perfectly consistent with the approach of pollutant budgeting. This has recently been expanded to cover pathogens and organic carbon (Ferguson *et al.,* 2002). This report provides an evaluation of the following risk assessment techniques outlined Table 2.

Table 2 Risk assessment methodologies assessed in this report

Risk assessment methodology reviewed	**Type of method**
Australian Standard/New Zealand Standard 4360, 2004 (AS/NZS 4360:2004) – Risk Management;	Qualitative, subjective risk ranking model
Hazard Analysis and Critical Control Points (HACCP);	Conceptual descriptions of the cause and effect relationships
World Health Organisation: Water Safety Plan (WSP);	Qualitative, subjective risk ranking model
The Australian Drinking Water Guidelines – Drinking Water Quality Management Framework (Framework); and	Qualitative, subjective risk ranking model
Ecological Risk Assessment (ERA).	Point estimate quantitative

The risk assessment method used by the Ministry of Health in New Zealand method was also reviewed as a benchmark of well-recognised global approaches.

Case studies of the above approaches are detailed in Appendix 2 and cover the following water utilities, and are summarised in Tables 4 and 5:

- Sydney Catchment Authority (SCA);
- WA Water Corporation (WC);
- Melbourne Water Corporation (MW);
- New Zealand Ministry of Health (NZ MoH); and
- South East Queensland Water Corporation (SEQW).

These methods were selected for assessment in this report as they represented a good coverage of different source risk management approaches being used by Australian water utilities of varying scales; types of water supply system management; and land use and activity-based risks in the catchment area of the source. In this report, an assessment of each approach is made through comparison with the risk framework of Australian Standard AS4360. Strengths, weaknesses and gaps are identified and discussed.

It is understood that depending on the type of system operation, some risk assessment methods may be more suitable than others. In some states of Australia, the operation of the full water supply system is broken up into different organisations, covering such sections as raw water delivery, treatment plant operation and the distribution system (see Table 3). Methods used for each component of such a system require potentially different inputs and assessing factors but should be highly reliable and follow the "catchment to tap" approach recommended by the ADWG. In addition, limitations for some approaches are caused by a lack of available data as utilities have varying complexity of water quality monitoring programs based on their organisational responsibilities for water supply delivery.

Table 3 Management boundaries for several major water supply utilities in Australia.

<table>
<tr><th rowspan="2">Component of the water supply system</th><th colspan="5">State or City of Australia</th></tr>
<tr><th>Melbourne</th><th>Sydney</th><th>Brisbane</th><th>WA</th><th>SA</th></tr>
<tr><td>Catchment</td><td rowspan="2">Melbourne Water</td><td>Sydney Catchment Authority</td><td rowspan="2">Seqwater</td><td rowspan="5">WA Water Corporation</td><td rowspan="5">SA Water Corporation</td></tr>
<tr><td>Treatment</td><td rowspan="4">Sydney Water</td></tr>
<tr><td>Distribution</td><td rowspan="3">Yarra Valley Water, South East Water, City West Water</td><td>Linkwater</td></tr>
<tr><td>Retail</td><td rowspan="2">Local councils</td></tr>
<tr><td>Customer</td></tr>
</table>

Table 4 Review of approaches in selected Australian and overseas organisations.
(Strengths are highlighted in grey. Weaknesses and gaps are identified and discussed).

AS/NZS 4360:1999 Element	Factor	ADWG Framework	Sydney Catchment Authority (AS 4360)	South East Queensland Water (HACCP)	WA Water Corporation (ADWG Framework)	New Zealand Public Health Risk Management Plan (WHO Water Safety Plans)	Melbourne Water Corporation (HACCP)
Risk Identification							
	Initial screening by water quality data	✓ - Element 2 – Assessment of the water supply system	✓	✓	✓	X	X
Identification of hazardous events	Hazard or event based	Hazard	Pollution sources	Hazard	✓ - Land use activity, hazardous event and then hazard	✓ - Hazardous event as first screen of issue then hazard of most concern in that event	✓ - Process or activity, hazard type, hazardous event
Identification of causes and scenarios		✓ - Element 2 – Water supply system analysis	✓	✓ – incoming materials	✓	✓	✓
Tools and techniques for identifying risks		✓ - Water quality data and land uses and activities	✓ - Water quality and catchment health evaluation parameters	✓ - Water quality data and land uses and activities	✓ - Water quality data and land uses and activities	✓ - Flow diagram of the supply, *Guide* information, Identification early of barriers to contamination	✓ - HACCP team (multi-disciplinary), describe product and intended use, Flow diagram of process operation as basis for hazard analysis
	Flexibility for inputs based on spatial information	unknown	X	unknown	✓ – element in likelihood determination that requires quantity and distance inputs	unknown	X
Risk analysis							
Determine existing controls	Control measures included for upstream and downstream	✓ - Upstream and downstream	X- Upstream	✓ - Upstream and downstream (treatment plant only)	X- Upstream	✓ - Upstream and downstream	✓ - Upstream and downstream
Determine consequence and likelihood	Likelihood and consequence subjectivity	✓	✓ – evaluation parameters	✓ - Probability - Likelihood, Consequence and Exposure - Duration	✓	unknown	✓ – scoring involved to allow for weighting
Risk assessment	Qualitative or quantitative	X - Qualitative	✓- Semi-quantitative	✓ - Semi-quantitative	✓ - Qualitative with outcomes that are semi-quantitative	X - Qualitative	ü✓ - Qualitative with some scoring
	CCPs	✓	X – controls at pollution sources	✓	✓	X	✓
	Residual risk (after controls are taken into account)	✓	X	X	✓	X	✓

Table 4 Continued

AS/NZS 4360:1999 Element	Factor	ADWG Framework	Sydney Catchment Authority (AS 4360)	South East Queensland Water (HACCP)	WA Water Corporation (ADWG Framework)	New Zealand Public Health Risk Management Plan (WHO Water Safety Plans)	Melbourne Water Corporation (HACCP)
Risk evaluation							
	Verification by water quality data or auditing of actions	✓ - Element 5 – Verification of drinking water quality	✓– actions audited annually	✓ – Risk Calculator	✓ (part of Source Protection Operations Manual)	X	✓ - verification schedule
	Scientific and technical validation - objective evidence that the stated control processes will indeed keep hazards under control	✓	✓	unknown	✓ (part of Source Protection Operations Manual)	✓	✓ - validation schedule

(Note: ✓ = meets requirements and X = does not meet requirements)

Table 5 Other factors that outline method strengths and weaknesses.

Factor	ADWG Framework	Sydney Catchment Authority (AS 4360)	South East Queensland Water (HACCP)	WA Water Corporation (ADWG Framework)	New Zealand Public Health Risk Management Plan (WHO Water Safety Plans)	Melbourne Water Corporation (HACCP)
Alignment with ADWG 2004 DWQMF	Not applicable	X- Partially but not completely	✓	✓	X - Partially but not completely	✓
Emphasis on catchment as a key component in water quality management	✓	✓	✓	✓	X - Partially but not completely	✓
Establishment of water quality targets (through linkage to downstream treatment)	X	✓	✓	✓	X	X
Full reliance on water quality data (regardless of limitations)	✓	✓	X	X	X	X
Facilitates an increased understanding of catchment of source water	✓	✓	✓	✓	X	X
Includes multi-stakeholder approach	✓	✓	✓	✓	✓	✓
Linkage to public health reporting	X	X	X	✓	✓	✓
General internal reporting	✓ Risk Management Action Plans	✓ - Risk Management Action Plans	✓ – HACCP plan	✓	✓ - Improvement schedule, contingency plans, performance assessment	✓
Demonstrates due diligence and justifies decision-making	✓	✓	✓ – part of an overall EMS	✓	✓	✓
Uncertainty/certainty measure	X	X	X	X	X	X
Covers full water supply system	X	X	X	X - Just catchment area of source water It is linked to downstream processes	✓	✓
Approach aligned with downstream water supply system	X	X	✓	✓	✓	✓ – Suitable for full supply system
Aligned with freshwater ecology values and ERA process (thus applicable for holistic system assessment)	✓	✓	✓`	X	X	X
Suitable for use for small supplies	✓	✓	✓	✓	✓	✓
Industry acceptance and good for reputation	unknown	unknown	✓ - EMS certified	unknown	unknown	✓ -Certification

(Note: ✓ = meets requirements and X = does not meet requirements)

4 EXAMPLE APPROACH FOR SOURCE WATER RISK ASSESSMENT

4.1 Introduction

In general, catchment-based risks facing the water industry tend to have a low probability of occurrence but can have significant consequences. Unlike treatment plants and water distribution systems, which are man-made and operated, sources of drinking water are more difficult to understand due to complex interactions between geological, hydrological and biological processes. It is this complexity that drives the need for a tailored approach to risk assessment in drinking water source areas.

It also is considered essential that such a process is compatible with other risk management programs used for treatment, assets and distributions systems, so that outputs and information can be integrated across the water supply system. This will provide a logical, consistent and effective plan for managing recreational access and the drinking water system generally. However, with the broad level of variation of sources across Australia, the approach requires flexibility. Sources can vary in size (quantity), water quality, type (e.g. direct, indirect), the level of risk, climatic and geographic conditions, barriers present, remoteness, level of stakeholder involvement, treatment options, social issues and historical precedents, just to name a few.

Currently, risk assessment outcomes and further scientific research are indicating that a more restrictive approach to recreational use of drinking water sources is required. Indeed, scientific research on quantifying risk from recreation on and around water sources has indicated that there is a significant increase in risk if recreation is introduced (Stewart *et al.*, 2002). However, more empirical information is needed to make these risk assessments more accurate and reliable.

Risk management helps an organisation meet its objectives through the allocation of resources to undertake planning, make decisions and carry out productive activities. Risk management is unique in that it focuses on uncertainties that an organisation faces:

- Uncertainties in the probability of occurrence of events;
- Uncertainties in the value to the organisation of consequences of events; and
- Other uncertainties that fall outside the normally expected range of variation.

Risk management is recognised as an integral part of good management practice. The risk management process involves the application of a logical and systematic method, which can be applied at the strategic or operational level, to specific projects or decisions, or to manage recognised risk areas.

4.1.1 Key Steps in the Risk Management Process

Due to the variability in catchments and storages and the type and extent of recreational activities around Australia, this provides a general guide only. It is not intended as a detailed ‘how to’, but rather a summary of key issues that should be considered when undertaking a source-base risk assessment.

Based on AS/NZS 4360:2004, HACCP and the Framework, the generic key steps in any risk management process should comprise the following components:

Risk Management Context

Establishes the goals, objectives, strategies scope and parameters of the activity that is the subject of the risk management process.

Risk Identification

Identifying hazardous events and sources of risks –what can happen and how.

Risk Analysis

Consideration of the sources of risks, their consequences and the likelihood those consequences will occur, within the context of existing controls.

Risk Evaluation

Comparing the level of risk found during the analysis against previously established criteria. The output of a risk evaluation is a prioritised list of risks for further action.

Risk Treatment

Identification of the range of options for treating risks, assessment of those options and preparation and implementation of risk treatment plans.

Monitor and review – communicate and consult

For source risk assessments, using this generic approach, any source-specific information can be inserted at key steps in the process. These can include such information fields as GIS mapping, field land condition assessments and reservoir dynamics just to name a few. This then allows the organisation to develop their monitoring and information systems around the requirements of the risk assessment and management process.

After reviewing several different risk assessment processes in previous chapters for their strengths, weaknesses and applicability, a recommended approach was developed and outlined in Figure 1. This approach has the following steps:

1. Establish the context
    a. Assemble the team
    b. Describe and document the source water system, possible sources of contamination and the nature of any barriers present, by utilising information on land use and sanitary surveys
    c. Construct and validate a schematic diagram for the source water system

2. Screening-level risk assessment and risk prioritisation
    a. Screening-level risk analysis (likelihood x consequence), noting certainty and risk knowledge, risk evaluation and prioritisation
    b. Develop raw water quality objectives and compare to water quality data
    c. Detailed assessment and refined scoring for priority risks

3. Risk Assessment
    a. Identify catchment improvement strategies
    b. Develop target criteria and critical limits, water quality objectives and monitoring procedures
    c. Establish and record corrective action responsibilities and procedures

4. Validate plan

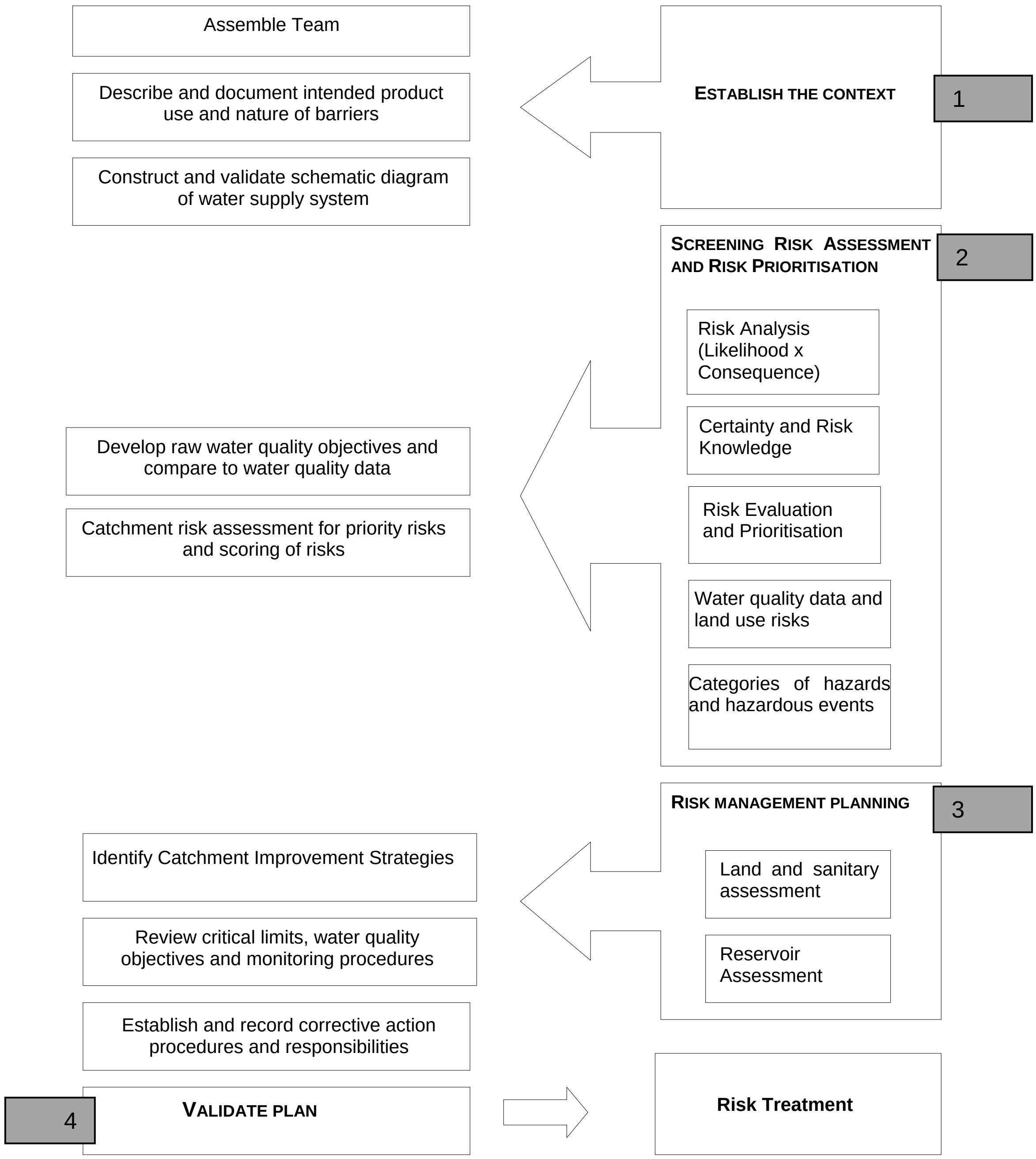

Figure 1 Summary of a possible risk assessment process for drinking water catchments

5 METHODOLOGY FOR UNDERTAKING RAW WATER SOURCE RISK ASSESSMENT

5.1 Step 1. Establishing the Risk Assessment Context

Key Objective: To assemble the team of key stakeholders to be involved in the catchment risk assessment, assign roles and responsibilities, resources and develop a plan of timelines and milestones.

Action 1. Assemble the team

Action 2. Describe and document the intended product use and the nature of the barriers

Action 3. Construct and validate schematic diagram of water supply system

5.1.1 Action 1. Assemble the team

Considerations:

- The size of water supply utility and available local resources;
- The level of consultation and input of external stakeholders;
- Organisational or individual bias; and
- Advice from external sources such as consultants' reports, research findings.

As the Framework states, stakeholder involvement is vital in drinking water quality management. This is particularly true in catchments and groundwater sources, where land ownership and management responsibilities cover numerous parties outside of the water industry or government. Multiple stakeholders bring multiple objectives and agendas, which is often the major impediment to the implementation of mitigation strategies or water quality protection control measures. Thus, recognising this and bringing internal and external representatives into drinking water quality catchment management is essential to ensure long term source protection.

A team comprising a broad range of expertise and skill in all areas of the process needs to be assembled to develop the risk assessment system. This ensures the practicality of the plan and reduces the chance that potential hazards or preventative measures are overlooked.

The multi-disciplinary team should possess appropriate product-specific knowledge and expertise in all aspects of the water distribution system. The project team is formed based on their specialist areas and should include the lowest level of operators through to experienced experts. The team is responsible for the planning, development, verification and implementation of the risk management outcomes. Members of the team should therefore come from the strategic planning, operational and design/development sections of the organisation.

To assure the effectiveness, a core team of more experienced personnel is formed to direct the overall process. Included on this team would be a champion to co-ordinate and manage the system overall. It is also important that the team be appropriately trained in catchment risk assessment.

There is the assumption with internal staff that source protection and water quality are already understood as one of the principal issues for any water utility. As such the sense of value and importance would already be present and well understood. However, if this is not the case, building a case of importance and a sense of urgency may be required. This can be in the form of an internal educational campaign, with senior management championing the program. It should be noted that this action is also recommended in the ADWG Framework.

Stakeholder involvement within a water utility means considering bringing into the risk assessment process representative from the following areas:

- Source planning
- Asset management
- Land management
- Surveillance
- Water treatment
- Statutory planning
- Water quality management
- Bulk water delivery

Unlike internal stakeholders, external stakeholders may not consider drinking water quality and source protection are important values. Indeed, water quality may have little to no importance, or a negative image. Despite this possibility, external stakeholder involvement is considered essential. This problem can be addressed through an educational program on the bigger picture scale, or alternatively stakeholders can be encouraged to be involved as a mechanism to express their objectives and positions. This may mean a larger, more complex conflict resolution-based process, but in the end the resultant education strategies are required for long term solutions to water quality problems.

Stakeholder involvement within a catchment or groundwater source area means considering bringing them into the risk assessment process. Participation would be required if the risk controls require the stakeholder's action/intervention or cooperation. To invite involvement, formal contact is recommended in writing. External stakeholders in catchment risk assessment may include those outlined in Table 6. below.

Table 6 Potential external stakeholders

Government organisations	**Non-Government organisations**
Local councils/authorities	Landowners, lease-owners and native title groups
Land, conservation or environmental management authorities	Community groups or representatives
Health Regulators	Landcare or water management groups
Agricultural Departments	Recreational, environmental or conservational groups
Land Planning Authorities	Industry groups (agriculture, mining etc.)
Mineral/Resource development departments	
Downstream water treatment operator or distribution supplier	

5.1.2 Action 2. Describe and document intended product use

Considerations:

- Information sources to identify all users of the water supply
- Specific industry requirements for water quality
- Perception that water utility supply means "potable" supply for all societal groups
- Quality of water depends on location in the water supply system
- Other values of water may also be appropriate e.g. ecological needs.

The key objective in this action is to define catchment risk endpoints for water. Water supply operators would be the best source of information, especially for uses that are not primary, such as "farmland" or off-supply uses that are common from long pipeline infrastructure. The nature of the water product is based on its use, the quality of the water and the level of treatment.

By stating that the water is intended to be consumed by the majority of the population, it excludes the necessity to cater for minority groups with special needs such as young, old, pregnant or immune-compromised or industries with specific requirements. These users should be advised that the water received at their tap may require further treatment such as boiling or filtration.

Water can be supplied in the following forms of product, and each should be considered when describing the primary and secondary natures of the product:

- Water for drinking purposes;
- Untreated – by agreement (such as recreational camps);
- Chlorinated;
- Chlorinated and fluoridated;
- Chlorinated, fluoridated and filtered (screen or sand filtered);
- Chlorinated, fluoridated, filtered (screen or sand filtered) with UV;
- Water for irrigation purposes;
- Untreated;
- Treated based on industry requirements (e.g. Agricultural regulation or Industry Code of Practice requirements set for organic produce);
- Water used for industrial purposes; and
- Treated based on industry requirements (e.g. Water used for cooling purposes in industrial processes).

It is also important to quantify the amount of each product supplied to the consumer.

Understanding the product will also define the appropriate raw water quality targets to achieve. To assist in determining this, refer to appropriate guidelines and legal requirements that may apply. Such documents to reference may include:

- Operating licences;
- Government acts;
- Environment protection policies;
- Customer charters;
- Bulk water supply agreements; or,
- Health guidelines such as the ADWG or the World Health Organisation Guidelines for Drinking Water.

Generally, the product can be described as *“potable water intended for consumption by the majority of the population”*.

Raw materials used in operations such as disinfection products need to be specified. Information included in the description should include relevant safety information such as: composition, storage conditions, physical/chemical structure and method of distribution. This information is commonly found in Material and Safety Data Sheets obtained from the suppliers of the product.

5.1.3 Action 3. Gather catchment information and construct a flow diagram of water supply system from catchment to consumers and describe the nature of barriers

Considerations:

- This component of a risk assessment is very time and resource intensive, so it is recommended to allow sufficient time;
- Information covering the source characteristics and water supply system is often spread over different databases, asset management reports, surveillance reports and in anecdotal form; and
- Some information may be sourced from other organisations and have confidentiality or intellectual property issues.

The key objective is to collect pertinent information for the catchment risk assessment. For a risk manager to effectively conduct a risk assessment, they must have an intimate knowledge of the source as well as the characteristics and operation of the water supply system.

In regards to the source, the importance of “knowing your catchment” cannot be over-emphasised. It is essential to understand the characteristics of the drinking water system, what hazards may arise, how these hazards create risks, and the processes that affect drinking water quality. This principle is an essential component of the Framework.

CRC for Water Quality and Treatment Research Report 11 (2004) outlines key characteristics of the drinking water supply system. Key sections of which are relevant to this manual include the catchments, source water, groundwater, storage reservoirs and intakes. This should be referred to as a guide on the types of information fields required to be collected. Information on the location of key information sources is outlined in Table 7 below.

Table 7 Required information – potential locations

Information type	**Potential Source/Location**
Catchment - environment	Land Management Regulator, Department of Agriculture, Local Council, Land Planning Regulator
Water quality	Water utility, Water Regulator
Water quantity	Water utility, Water Regulator
Land uses, planning conditions and stakeholders	Land Management Regulator, Department of Agriculture, Local Council, land Planning Regulator
Water supply infrastructure (bores, sampling points, reservoir, intake etc.)	Water utility
Climate	Bureau of Meteorology
Contaminated sites	Environmental Regulator, Land Planning Regulator

Appendix 3 outlines a checklist of information to gather in order to compile the required information for the risk assessment and construction of the flow diagram and a system information proforma for structuring the collated information.

For large catchments or groundwater areas, breaking the source down into sub-catchments may be advantageous.

It is important to understand the linkages of the source area to the rest of the water supply system. This helps to identify barriers for water quality protection, as well the simple or complex nature of the water supply system, which is valuable in risk assessment workshops. As such the assessment and evaluation of a drinking water system are enhanced through the development of a flow diagram. Such diagrams provide an overview description of the drinking water system, including characterisation of the source, identification of potential pollution sources in the catchment, control measures for source protection (and any other natural resources), treatment processes, storage and distribution infrastructure (WHO, 2004).

The project team is required to construct a flow diagram (e.g. Figures 2 and 3) that depicts all processes and operations throughout the water distribution system. It should illustrate what happens to the water from the time it is received (either at the catchment or from the interface point with the bulk supplier) until it reaches the customers’ taps. The flow diagram also provides assistance in defining the scope of the risk assessment. It should contain adequate detail to identify potential entry points for hazards and any detected contamination to be traced.

This will involve not only a figure of the source itself showing key features and land uses, but also the water supply infrastructure at the source (dam wall, product bores, wells, artificial recharge areas) as well as that below the source, such as water treatment plants, run-of river components, pipelines, storage tanks, chlorination treatment and distribution systems.

It is essential that the flow diagram is conceptually accurate so all elements of the drinking water system should be considered concurrently and that interactions and influences between each element and their overall effect are taken into consideration (WHO, 2004).

Validation of the flow diagram should then occur, which will confirm that all operations in the water distribution system are being considered and evaluated. By verifying the flow diagram you are ensuring it's accuracy as a true representation of the system for distributing water and process steps involved.

Outlined below is a specific example of a water supply schematic for a surface water catchment and a groundwater source area (Figures 2 and 3). The flow diagram of the water supply system should show features such as:

- Statistics of the catchment/recharge area (size, depth, slope, vegetation);
- Key land uses and their location in catchment/recharge area;
- Key barriers (land management, riparian buffers, reservoir management etc.);
- The reservoir or aquifer (key quality and quantity characteristics);
- Dam wall/abstraction points;
- Pipelines or "run of river" systems; and
- Water treatment plants.

The symbols used in the flow diagram should straightforward and illustrate key processes:

- storages ("open" or "closed" such as tanks, reservoirs, basins);
- transport (water is moved from one place to another either by gravity or pumping);
- inspection points (monitoring occurs often resulting in a decision); and,
- operation (an intentional change in the product occurs such as disinfection).

For some catchments, information will be complex covering numerous drainage and topographical features, land use activities and soil and vegetation types. In this situation, mapped information may also be useful to support the flow diagram. This may include a developed chart of such features:

- The designated catchment boundary and protection zones (if any);
- Planning zones;
- Land vesting;
- Land use – point and diffuse sources;
- Vegetation type;
- Soil type;
- Topography;
- Water quality and quantity sampling points;
- Past water quantity incident or issue sampling points; and
- Bushfire or catastrophic areas of impact.

Recognition should be given to the location of sampling points to land uses and the ability to determine cause and effect relationships.

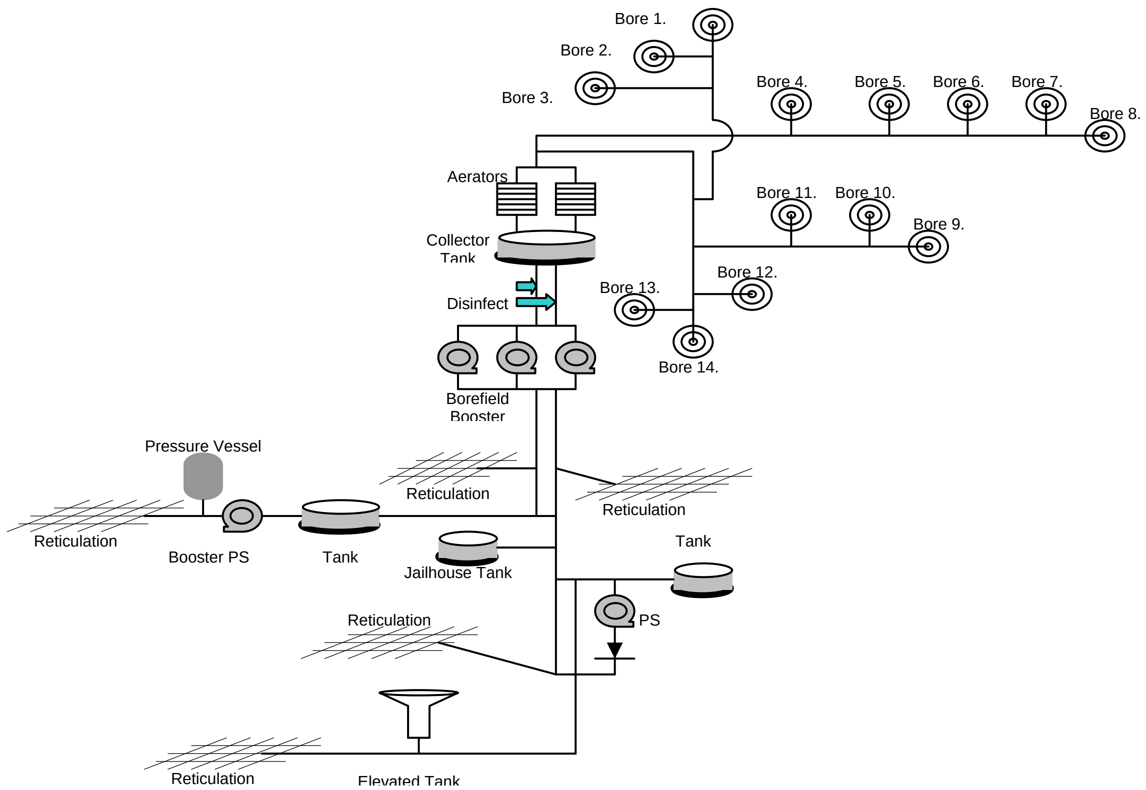

Figure 2 Ground water source schematic

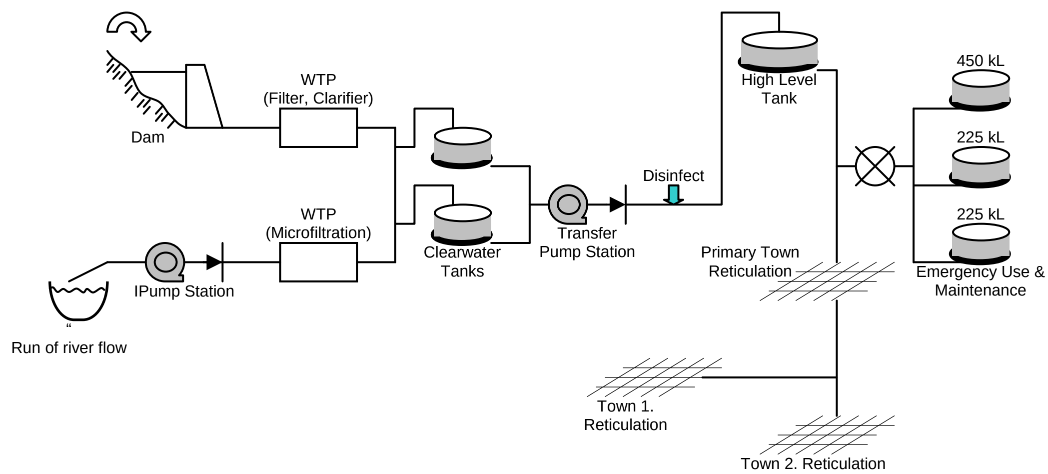

Figure 3 Surface water source schematic

The water supply flow diagram and chart information developed are useful tools for identifying the location of water quality barriers within a catchment. Barriers within catchments can include:
Land use activity control – through planning mechanisms, legislation, public education or industry best practice;

- Riparian buffers along watercourses;
- Reservoir protection zones;
- In-reservoir water treatment processes (such as alum dosing);
- Reservoir detention; and
- Reservoir dilution processes.

Once barriers are identified for a catchment, it is important to understand their nature and then investigate their effectiveness in mitigating water quality hazards to the raw water. During this task, the following things need to be considered:

- Type of barrier and key features;
- Location within water supply system and extent;
- Current condition of the barrier – e.g. fencing, vegetation condition of riparian areas;
- Condition/events where barriers are known to breach (through anecdotal advice or research) – e.g. storm events causing reservoir short-circuiting, access in reservoir protection zones for specific activities;
- Limitations with achieving fail-safe barriers – land activity controls, surveillance restrictions with effectively preventing access to reservoir protection zones; and
- Water quality hazards that the barrier mitigates.

Information out of this task will be used within the risk assessment to determine the likelihood of a hazardous event occurring, but also during the risk treatment process where appropriate mitigation actions are determined.

5.2 Step 2. Screening Risk Assessment and Risk Prioritisation

Key objective: To define the level of intensity required for the catchment risk assessment.

Action 1. Determine the appropriate risk tier level for the assessment

5.2.1 Action 1. Determine the appropriate risk tier level for the assessment

Considerations:

- Suitability of tiered matrix to the source type and CRA issues;
- The need to gain external stakeholder acceptance of the selected tier level;
- Conditions associated with sources/catchments may change over time and thus tier levels may change between CRA reviews; and
- Information collected to determine tier level will be useful in Step 4.

It is well understood that sources and their associated risk profiles vary greatly. To this end the authors of this report believe that in turn, so should also the level of intensity in the risk assessment; i.e. not all source risk assessments need to be simple, nor complex. More in-depth assessments should occur for higher risk sources and low risk sources should have simple risk assessments. This differentiation of risk assessment thus allows the utility to expend the highest level of resources to the greatest risk sources, as opposed to trying to maintain a high level for all sources, and ultimately failing through resource limitations. Naturally, being able to confidently determine which tier level is appropriate weighs heavily on the utility knowing their source, based on detailed information resources.

It is important to express that due to the significant variation in source types across Australia, and no source being the same as another, the information outlined in Tables 8 and 9 is generic and thus should be interpreted with the appropriate level of subjectivity by the user. This is because many sources may not exactly fit the criteria set out and so the user will need to use a certain level of judgement as to where the source should fit. For instance, new sources often require in-depth source risk assessment due chiefly to the political and social issues, even if they have low source vulnerability or land-use risk hazards. This could also apply for existing sources that service large cities. However, it is recognised by the authors that many small and isolated country sources can often be prone to high risk runoff events due to climatic and geographic conditions and so the source or catchment barrier is less robust, and thus require in-depth risk assessment to ensure effective barriers upstream and downstream are in place to mitigate these events.

The differentiation of risk assessment intensity is logically based predominately on the level of risk to raw water posed by the source, which is made up of the level of source vulnerability and microbiological risk of contamination to raw water quality. Other secondary issues also contribute to the level, such as chemical risk of raw water contamination, political (new source development or planning programs) and social (potential land planning conflict). However, these issues and their importance need to be weighed up against the microbial water quality risk which, as noted in the ADWG, is the most important water quality risk from a public health perspective. A description of each risk tier level and the associated source information pertaining to it is outlined in Table 8.

Table 8 Explanations of risk tier level

Risk Tier Level	Source vulnerability	Water quality risk microbial	Water quality risk chemical	Political or social issues	Downstream barriers present	Resourcing requirements
1	Source recharge area is well protected; source itself has good dilution and detention barriers.	Risk of raw water contamination by microbial parameters is low	Risk of raw water contamination by chemical parameters is low	Limited to none, few stakeholders	Source has robust downstream barriers that address all known raw water risks	Desktop study with supervisory support from project team
2	Source recharge area having some protection, source itself has good dilution and detention barriers, but they can fail during high risk events.	Risk of raw water contamination by microbial parameters is moderate	Risk of raw water contamination by chemical parameters is moderate	Some local issues in past and predicted occasionally for the future	Source has robust downstream barriers that address most raw water risks, except under event conditions	Preliminary desktop study and then verification through workshop-based process
3	Source recharge area having only limited effective protection, source itself having good dilution and detention barriers, but they can fail during high risk events.	Risk of raw water contamination by microbial parameters is high	Risk of raw water contamination by chemical parameters is high	Local and/or state based political and social issues in the past and anticipated for the future	Source has robust downstream barriers that address most raw water risks, except under event conditions	Workshop-based process – including external stakeholders (if required)

Appropriate information requirements to undertake this determination would include:

- The size of the serviced population (i.e. city, small town);
- The remoteness of the source;
- The level of risk present and the vulnerability of the source;
- The number of reportable events based on internal compliance and whether they involve chemical, aesthetic, physical or microbiological issues;
- Other economic factors such as political, social or economic issues or precedents
- The available information resources for the sources such as water quality monitoring, geographic or spatial databases, hydrodynamic and hydrological characteristics;
- Land tenure; and
- The number and type of stakeholders involved.

Once the above information is gathered as per the previous action and taking into account the above considerations, Table 9 should be used to determine the level of risk assessment required.

Table 9 Tiered process of risk assessment

Description source features	Level of risk	Other factors – political, social, economic	Resources	Stakeholders	Recommended risk tier level	Intensity of risk assessment
Small isolated source, population served 1-500	• Not well understood; or minimal water quality trends of concern (none microbiological) • Rare reportable issues • Land uses or activities present that pose minimal water quality risk • Some barriers in place, but never validated • Source storage time exceeds 30 days	No known historical or current issues	• Compliance water quality monitoring data • Basic land uses surveyed and listed, on-ground practices not well understood • Limited understanding of hydrological characteristics	Limited, land is almost entirely under utility/Crown ownership	**1**	Desktop study with project team coming together only for review and issue resolution
	• Not well understood; or some water quality trends of concern (including microbiological) • Rare reportable issues • Land uses or activities present that pose water quality risk with the potential for increased risk • Some barriers in place, but never validated • Source storage time is less than 30 days	Potential future land use issues	• Compliance water quality monitoring data, limited investigative data • Basic land uses surveyed and listed, on-ground practices not well understood • Limited understanding of hydrological characteristics	Land ownership is a mixture of private and Crown	**2 (or 3 if source storage time is less than 30 days at times of highest risk)**	Desktop study for data collation, regular workshops for project team
Medium – large source, regional population served 500 – 100 000	• Rare reportable events • Less than 5 water quality trends of concern (non microbiological) • Barriers in place have some limitations validated • Past risk assessments indicate some land uses/activities of risk to water quality	Some local; community or stakeholder concern	• Compliance water quality monitoring data • Some limited investigative monitoring data • Land uses surveyed, practices reasonably well understood and possibly mapped simply • Very few licensed premises • Good understanding of hydrological characteristics	Numerous as land within source area is under mixed ownership, LGA's, state government authorities, industry, private land owners	**2**	

Table 9 Continued

Description source features	Level of risk	Other factors – political, social, economic	Resources	Stakeholders	Recommended risk tier level	Intensity of risk assessment
Medium – large source, regional population served 500 – 100 000 cont	• 1 – 3 reportable events per year (including microbiological) • Barrier failure suspected but not confirmed • Less than 5 water quality trends of concern • Barriers in place have some limitations validated • Past risk assessment indicates several land uses/activities of risk to water quality	Some local; community or stakeholder concern in past, and increased potential for the future	• Compliance water quality monitoring data • Some limited investigative monitoring data • Land uses surveyed, practices reasonably well understood and possibly mapped • Some licensed premises • Good understanding of hydrological characteristics	Numerous as land within source area is under mixed ownership, LGA's, state government authorities, industry, private land owners	**3**	Workshop for all key stages in risk assessment process
Large Metropolitan source population servicing 100 000 +	• 1-5 reportable events per year (including microbiological) • Any water quality issues/trends of concern • Most barriers in place effective but some have limitations • Barrier failure confirmed for very occasional events • Past risk assessment indicates minimal land uses/activities of risk to water quality	Highly political, community very interested in water quality and public health, several social issues	• Extensive investigative and compliance monitoring • Land uses and practices very well understood and documented. GIS mapping • Licensed premises • High level understanding of hydrological characteristics	LGA's, state government authorities, industry, private land owners, community as a whole	**3**	
	• 1-5 reportable events per year • Any water quality issues/trends of concern • Barriers in place have some limitations • Barrier failure confirmed for some events • Past risk assessment indicates land uses/activities of risk to water quality	Highly political, community very interested in water quality and public health, numerous social issues	• Extensive investigative and compliance monitoring • Land uses and practices very well understood and documented. GIS mapping • Numerous licensed premises • High level understanding of hydrological characteristics	LGA's, state government authorities, industry, private land owners, community as a whole	**3**	

5.3 Step 3. Identify Hazards, Hazardous Events and Sources

Key Objective: Review potential hazardous agents in the catchment or source recharge area that can affect the quality of the raw water. Identify sources of those hazards.
Investigate hazardous events that can lead to the presence of water quality hazard in the raw water supply system.

Action 1. Identify water quality hazards
Action 2. Identify hazardous events
Action 3. Identify sources of hazards

Considerations:

- Ensure a comprehensive evaluation of catchment or groundwater area;
- Use information collected during previous step to support actions;
- Interviews with key staff (operational and maintenance, regulators) may be useful to clarify and confirm hazards, hazardous events and sources;
- Should involve a review of historical water quality information and any "near misses" or incidents and past events where specific hazards appeared or associated issues were witnessed or reported;
- Inspections of key locations or operational activities; and
- Identify circumstances that may cause hazards, hazardous events or sources to change in the future.

All potential source-related hazards, hazardous events and sources should be included in the assessment regardless of whether or not they are under the direct control of the drinking water utility. Continuous, intermittent or seasonal pollution patterns are recommended to be considered as well as extreme and infrequent events such as droughts, floods or bushfires. A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified.

5.3.1 Action 1. Identify water quality hazards

WHO (2004) states that "effective risk management requires the identification of potential hazards, their sources and potential hazardous events". By definition (WHO, 2004):

- A hazard is a biological, chemical, physical or radiological agent that has the potential to cause harm; and
- A hazardous event is an incident or situation that can lead to the presence of a hazard (what can happen and how).

In addition, a site, area or other entity where a water quality hazard(s) comes from, or where a hazard event can occur is termed a hazard source (SCA, 2004). Hazards to raw water can be divided into two key groupings; those that impact on drinking water, and those that cause direct or indirect effects on ecosystems.

Drinking water hazards can be grouped into the following categories:

- Microbial pathogens – including bacteria, protozoa and viruses;
- Algae – including algal impacts, cyanobacteria and associated toxicology;
- Metals – including but not limited to aluminium, calcium, iron, manganese, and heavy metals;
- Pesticides; and
- Hydrocarbons/oils.

Causal water quality hazards include:

- Natural organic matter – which can cause eutrophication, effect disinfection processes, and impede natural breakdown by sunlight of microbiological contamination;
- Nutrients – causing algal and eutrophication issues; and
- Sediment – which can trigger turbidity issues as well as being a transport mechanism for other contaminants.

Other non-raw water contaminants not addressed in this manual include: non-metals (free chlorine, iodide), physical indicators and radiological.

Identifying hazards can be achieved by:

- Reviewing water quality data from within the source (raw water) for specific trends or issues; and
- Recognising land uses and activities in the source that may constitute specific risks to water quality.

When reviewing water quality data for a specific catchment, water quality hazards can be identified through:

- Exceedance of an ADWG guideline or health value;
- Anecdotal information and observation; and
- Trending of data over a time series.

Specific land uses and activities pose certain water quality hazards. When reviewing land uses within a catchment, it is important to recognise the water quality hazards they may pose, and the specific event conditions under which the hazard may occur. Some water quality hazards from typical land uses found in peri-urban catchments are outlined in Table 10. More detailed hazard information can be found in CRC for Water Quality and Treatment Research Report 11 (2004).

Table 10 Some typical water quality hazards in peri-urban catchments in Australia

Land use or activity	**Typical water quality hazard/s**
Farming – including cropping and horticulture	Microbiological contamination Turbidity from erosion See hazards associated with pesticide/herbicide spraying below See hazards associated with application of fertilisers below
	Chemical contamination in runoff Taste and odour compounds from contaminated runoff Turbidity from erosion
	Chemical contamination of runoff (including nutrients) Taste and odour compounds from contaminated runoff Cyanobacteria toxins Taste and odour compounds from algae
Bushfire	Turbidity from particulate fallout Turbidity from erosion Microbiological contamination from dead animals Chemical contamination from fire retardants
Recreational or illegal access	Chemical contamination from dumping of chemical and medical waste Microbial contamination from dumping of household waste and human waste Turbidity due to erosion from 4WD See bushfire hazards
Mineral exploration and processing	Turbidity from erosion and wash-off from dust suppression systems Chemical contamination from petrochemicals and other materials being mined

Source: CRC for Water Quality and Treatment Research Report 11 (2004).

To better understand water quality hazards in the risk assessment process, conceptual models or process maps have been developed for water quality hazards groups. These include:

- Microbial Pathogens;
- Algae;
- Metals;
- Pesticides;
- Natural Organic Matter;
- Nutrients; and
- Sediment.

Process maps are important for describing the multiple physical, biological and chemical factors in a system, their sources and the pathways by which they are likely to impact on multiple sources (SCA, 2004). They provide a structure to identify causes of hazards and methods for controlling them whilst recognising the level of information certainty. Generic process maps can be sourced from many organisations through websites and books but it is important to document and tailor them for your own source conditions.

Interviews with key staff can also clarify and confirm hazards, hazardous events and sources. Key control measures and their effectiveness, including circumstances where they fail.

Key staff to be interviewed can cover the following areas of expertise:

- On ground surveillance (rangers);
- Dam and water treatment plant operators;
- Water quality and quantity sampling;
- Land planning or source planners;
- Environmental officers and
- Land management (internal and external).

Interviews should focus on current information but also on historical incidents, “near-misses” or events of specific hazards that were witnessed or reported.

Site inspections are also recommended at key locations within the source, water supply infrastructure (sampling points, reservoir offtakes, water treatment plants and/or during operational activities. These can also include spot-checks to assess control measure effectiveness. Although a site inspection is seen as a critical step, it also recognised that resource limitations may hamper this. In this case, the review of regular site inspection reports (such as rangers’ log books) and unplanned maintenance records may be used to replace a detailed site inspection. Available reports and other documentation should be collected and reviewed to obtain a good understanding of the hazards.

The hazard identification and risk assessment should be reviewed and updated on a periodic basis; changing conditions may introduce important new hazards or modify risks associated with identified hazards.

5.3.2 Action 2. Identifying hazardous events

The hazardous event is the incident or situation that can lead to the presence of a hazard. Whilst hazards from specific sources are fixed, hazardous events can be more easily manipulated. More specifically, the hazardous event is usually the mechanism at which mitigation control actions are directed. Table 11 below illustrates a range of hazardous events, for the generic land uses outlined earlier.

Generally, the hazardous event relates to either a natural event like rainfall causing runoff, which carries contamination into a nearby watercourse, reservoir or infiltration into a groundwater body; or a man-made direct-discharge incident like a person dumping animal waste as bait into a reservoir, or swimming in the water body.

Table 11 Some typical water quality hazardous events in peri-urban catchments in Australia

Land use or activity	Source of hazard	Hazardous event	Typical water quality hazard/s
Farming – including cropping and horticulture	Intensive farming – reduced vegetation after ploughing and overgrazing	Runoff into waterways from ploughed paddocks Spray drift into reservoir following herbicide spraying	Microbiological contamination Turbidity from erosion See hazards associated with pesticide/herbicide spraying below See hazards associated with application of fertilisers below
	Pesticide/herbicide spraying – including baiting	Spray drift into reservoir following herbicide spraying Runoff from sprayed areas into waterways	Chemical contamination in runoff Taste and odour compounds from contaminated runoff Turbidity from erosion
	Application of fertilisers	Runoff from fertilised areas into waterways	Chemical contamination of runoff (including nutrients) Taste and odour compounds from contaminated runoff Cyanobacteria toxins Taste and odour compounds from algae
Wildfire	Wildfire	Intense rainfall following a wildfire	Turbidity from particulate fallout Turbidity from erosion Microbiological contamination from dead animals Chemical contamination from fire retardants
Recreational or illegal access	Illegal access to catchment lake, shoreline/illegal dumping of waste	Recreationalists swimming, fishing and defecating in reservoir Surface wash of dumped waste into reservoir Littering	Chemical contamination from dumping of chemical and medical waste Microbiological contamination from dumping of household waste and human waste Turbidity due to erosion from 4WD See bushfire hazards
Mineral exploration and processing	Mining activities and wastes	Runoff from exposed cleared areas Runoff from chemical storage areas	Turbidity from erosion and wash off from dust suppression systems Chemical contamination from petrochemicals and other materials being mined

Source: CRC for Water Quality and Treatment Research Report 11 (2004).

5.3.3 Action 3. Identifying sources of hazards

Hazards can be either from point or diffuse sources. Point source pollution is generated from pipes, tunnels, channels, conduits or other discernable discrete conveyances and generally it contributes a known amount of contamination in terms of parameters and concentrations. Diffuse pollution results from less discernable positions, like runoff, drainage, seepage or rainfall.

Due to the nature of discernability, point sources tend to be easier to investigate, evaluate and manage than non-point pollution sources. CRC for Water Quality and Treatment Research Report 11 (2004) outlines potential sources of hazards and hazardous events in catchments and groundwater systems and reservoirs and basins. This should be used as a generic starting point to prompt the identification of key hazards and their related hazardous events. Some examples include:

- Catchment and groundwater system
    - Environmental hazards within catchments
        - Storm events causing high pollution load
        - Bushfire
        - Native and feral animal population (including dead animals)
        - Geology (slope stability/erosion, sediment, and groundwater, including groundwater contamination/salinity).

Table 12 below outlines the generic hazards, sources and transport processes from orchard land use and activities.

Table 12 The sources of hazards from orcharding

Model scheme text and interpreted type of land use	Contaminants	Hazard group	Sources	Transport process
Agriculture - intensive Orchards	Sediment	Causal - sediment	Soil	Surface runoff, direct discharge
	Herbicides	Drinking - pesticides	Sprays	Surface runoff, infiltration, direct discharge
	Insecticides	Drinking - pesticides	Sprays	
	Phosphorus	Causal - nutrients	Fertilisers	
	Nitrogen	Causal - nutrients	Fertilisers	
	Pathogens	Drinking – microbial pathogens	Animal manures	

As expected, the intensity of the hazard event can greatly affect the level of risk. The risk is further increased if there is a higher intensity of source of hazard, such as a higher level of land development. This is best illustrated in Table 13, sourced from the CRC for Water Quality and Treatment Technical Fact Sheet *Pathogen movement and survival in catchments, groundwaters and raw storages (2004)* which provides advice on the level of qualitative risk, based on the level of protection of the source, the type of source (large or small reservoir, river or stream operation) and the weather/event condition (baseline, small event or large event).

Table 13 Proposed microbial qualitative risk assessment categories

(sourced from factsheet 8 in CRC for Water Quality and Treatment Technical Fact Sheet *Pathogen movement and survival in catchments, groundwaters and raw storages (2004)*)

Impact Level	**Source Class**	**'Run-off' Conditions**		
		Dry Weather/Baseline Conditions	**Baseline Event-Small Event**	**Large Event - Extreme Event**
Low (protected catchment)	Large Reservoir	Very Low	Low	Moderate
	Small Reservoir	Low	Moderate	Moderate-High
	River/ Stream	Low	Moderate-High	High
Moderate (partly impacted catchment)	Large Reservoir	Low	Moderate-High	High
	Small Reservoir	Low	High	High-Very High
	River/ Stream	Moderate	High	Very High
High (heavily impacted catchment)	Large Reservoir	Low-Moderate	High	Very High
	Small Reservoir	Moderate	Very High	Extreme
	River/ Stream	High	Very High-Extreme	Extreme

Once hazards, hazardous events and sources have been identified, they should be documented so that their associated risks can be estimated and prioritised in the risk assessment (Step 6.) and effective risk management strategies developed. It is important to note that this should be an exhaustive process that covers all hazards, hazardous events and sources, regardless of their management responsibility. Just as sources can be transient (recreation) or permanent (housing), events that are intermittent or infrequent (bushfires) or continuous (leachate from septic tanks), all need to be considered and documented.

5.4 Step 4. Assessment of Water Quality Data for Hazard Identification

Key objective: Review drinking water quality data for trends or evidence of hazards. Use data as a tool to determine priorities for hazards and hazardous events.

Action 1. Develop a risk-based source water quality monitoring program
Action 2. Collate data and review for hazard, hazardous event and source verification

Considerations

- The purpose, question or hypothesis needed to be answered by the water quality monitoring program i.e. what do you need to know
- The timeframe of the objectives, i.e. long-term, specific research and/or targeted operational incident-based sampling;
- Available collection and laboratory analysis resources (i.e. internal or external);
- Data input post analysis;
- Water quality database requirements (for sources and integration with existing databases) and management;
- Data review, performance of data with water quality targets and trending resources;
- Incident response notification;
- Ongoing review, auditing and feedback; and
- Reporting requirements and functionality (internal and external reporting).

5.4.1 Action 1. Develop a risk-based source water quality monitoring program

Water quality monitoring is a fundamental measurement of the condition of a drinking water resource. The key objective with source water quality monitoring programs is to provide good data for catchment management professionals on the optimal design of water quality monitoring programs for use in the steps of risk assessment and management. This sampling is monitoring that is conducted beyond the requirements for performance monitoring, i.e. the results are not used in the assessment of compliance with Operating Licence or agreed levels of service.

The Framework recommends for an “assessment of water quality data” (Element 3.2.2). However it provides no clear guidance on how to undertake this action. In addition, Element 3.5.1 of the Framework also recommends for drinking water quality monitoring to verify drinking water quality and act as a final check that “overall the barriers and preventative measures implemented to protect public health are working effectively”. Water quality data needs to be explicitly used in catchment risk assessment to realise the full value from this important and costly information resource. This requires focus on the “plugging in” of monitoring to the decision-making processes of catchment management.

Monitoring programs in the past have been primarily focused on compliance with analyte guidelines, and a belief that the existence of a baseline monitoring program and the collection of data provides effective catchment water quality monitoring. However, it is now recognised that to gain a better understanding of the source behaviour and yet also providing the best preventative management of high risk source water quality events, a source monitoring program must be based on two key components:

- Baseline source water quality monitoring – understanding the full source system (streams, rivers and reservoir) behaviour seasonally; and
- Event-based water quality monitoring – where monitoring is enacted when recognised conditions occur that are known to cause source water quality problems such as high runoff or point-source discharge such as wastewater discharge to a river or post bushfire.

Water quality databases as such, tend to have a mixture of different types of data, those from historical baseline monitoring, event-based programs, or specific research projects. In the case of catchment risk assessment and management, water quality monitoring is an important source of information to input to risk assessment, as it indicates water quality characteristics in baseline and event conditions, the impact of specific land uses and other key features of a catchment. Naturally the water quality information needs to be easily interpretable as to what level of response is required to mitigate the risk. The development of raw water quality targets to achieve this means is outlined below later in this section.

To this end, effective sampling programs facilitate effective management of water quality to minimise risks to public health and the environment. More specifically source or catchment based sampling aims to:

- Provide a baseline record (including peaks and troughs) of water quality data for individual sources;
- Monitor seasonal and natural trends in water quality;
- Provide information on trends and issues identified by the program;
- Provide information on impact of water quality from incidents such as natural disasters and spills;
- Monitor impacts of various land uses and activities (diffuse and point sources) on water quality;
- Understand how certain land use activities contribute to water quality issues;
- Allow action towards risk mitigation actions to be targeted;
- Validate the effectiveness of source protection mitigation strategies;
- Evaluate the effectiveness of existing water quality barriers;
- Obtain early notification of contamination detection to protect public health;
- Identify emerging water quality issues; and
- Report on water quality within key components of the catchment system.

Thus, taking the above information into account, when developing a raw source water quality monitoring program, the following issues need to be considered:

- The purpose, question or hypothesis needed to be answered by the water quality monitoring program i.e. what do you need to know;
- The assessment criteria;
- The kind of data that should be collected;
- The appropriate time frame for sampling and length of program;
- The spatial scale for monitoring – power analysis reduces variability but can be cost prohibitive;
- The temporal scales – the timing of sampling depends on the purposes of the monitoring program;
- Loads – then sample events (see later for risk relating to loads and storm events)
- Regulatory compliance requirements;
- Specific events or conditions like algal blooms – sample during peak times and base interval rate on the event;
- Long term monitoring is also required to separate out annual trends and seasonal effects from random fluctuations;
- Sampling site selection, strategies and methods - what to sample/measure should be based on the key parameters/indicators selected to answer the "question";
- Analysis methods;
- Indicators – the ADWG specify 'compliance' with a range of indicators. Traditionally these are physico-chemical characteristics and are relatively easy to measure. For understanding the health of an ecosystem, biological indicators (i.e. living entities) are very effective but far more time consuming (& expensive). Indicators can also be combined to track water quality over long time periods;
- What to measure/parameters - physico-chemical conditions indicate the characteristics/state of a water body. Waters can show rapid changes in concentrations and this is especially evident in urban systems with multiple inputs. Some pollutants dissipate rapidly (e.g. hydrolysis of organophosphate pesticides. Sediments accumulate nutrients, metals, radionuclides and organic contaminants;
- Determine appropriate data analysis - performance of data with water quality targets (see below);
- Ongoing review and feedback; and
- Reporting.

Using conceptual models to assist the development of raw water quality monitoring programs

As already recommended earlier, conceptual models are useful tools in pictorially illustrating the catchment system. Within this, models can also aid in developing risk-based water quality monitoring programs by illustrating the system, defining the problem, framing and testing the hypothesis and are useful in selecting indicators and temporal and spatial scales (Grace, pers. com., 2004). They are also excellent communication instruments. Within the development of a program purpose or hypothesis, conceptual models can assist in providing a visual description of the system (e.g. Figure 4).

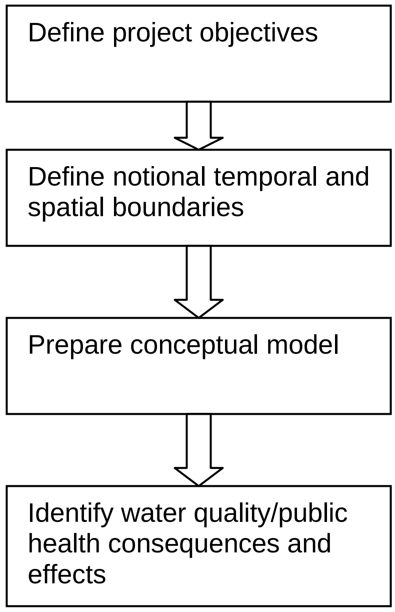

Figure 4 Using Conceptual Models in the formation of the purpose or monitoring question

To build a conceptual model, information first needs to be collated. This can often be sourced from that collected in earlier steps. The reliability of the data sources is important. Data sources may include operational, compliance, historical and anecdotal sources of water quality, hydrological, meteorological and biological information.

Then the appropriate type of conceptual model needs to be determined for the purpose or hypothesis. Broad scale conceptual models involve a picture of the system showing system components, spatial scales and the interaction between issues within the catchment. It can also assist in identifying key issues or relationships that can be overlooked. Issue-specific conceptual models aim to draw a schematic that outlines the understanding of processes and relationships behind and issue. It can also help to identify where knowledge gaps are and thus focus research priorities.

Water quality targets or objectives for catchments

Water quality targets are essential for interpreting raw water data. Depending on the type of product defined earlier, the raw water targets will vary. However it should be noted that in any supply with multiple products, depending on the endpoint, at common endpoints the tightest targets should be used to ensure that all levels of safety are in place.

For each parameter, the water quality target has been based on the relevant guideline, water treatment criteria or on specific scientific research. These sources have included ADWG, ANZECC, water treatment operation requirements, or key scientific research outcome. It is anticipated though that some of the targets below will be somewhat fixed and others that will have some flexibility based on site-specific conditions.

Drinking water raw water quality targets are often referred to as raw water “trigger values”, as they are not completely defined or set in any formal guideline, as they are usually source-specific, in other words, the trigger values can vary from source to source based on what is recognised by past behaviour as being “out of compliance” for that source. Usually they are made up as either a proportion of the ADWG, if knowledge of the source water quality behaviour is low, or based on a percentile of the data collated readings if historical raw water quality information and knowledge of source behaviour is good. This allows the understanding and recognition of the source water quality when it is operating normally, when it is under some stress (nearing “out of specification”) and source-based mitigation is required, and when it is under significant stress ("out of specification") and only downstream mitigation (water treatment, source shut-off etc.) is appropriate. This capacity to use water quality data as an "early warning system" is valuable to any water utility as it avoids internal and often external water quality incidents.

5.4.2 Action 2. Collate data and review for hazard, hazardous event and source verification

Once the raw water quality monitoring program has been established and data is collated as per all of the requirements of Action 1, data review should be undertaken. Indeed, data should be regularly trended and reviewed to establish an understanding of the behaviour of the water quality under varying land-use and climatic events, seasonal conditions and water supply operations. To this end the review should include the examination of water quality trends throughout the source system (bores, streams, rivers, reservoirs etc.) and behaviour in relation to:

- Baseline water quality patterns;
- Seasons and generic climatic change;
- Significant climatic-driven events;
- Significant land use-driven events;
- Conditions under which downstream water quality incidents or notifications occur;
- The impact of source operational changes (e.g. turning bores off or on, augmenting new sources etc.) and
- Risk mitigation strategy effectiveness.

As mentioned earlier, the formation of raw water quality trigger values does allow a relative benchmark for raw water quality. This can then be used with confidence within the risk assessment table to accurately validate hazards, events and sources identified earlier in the risk assessment.

5.5 Step 5. Uncertainty Scoring

Key objective: Review the basis of the knowledge behind the hazards, hazardous events and sources to define the level of confidence in the information.

Action 1. Define the uncertainty score

Considerations

- Sources and level of integrity of knowledge/information; and
- A scientific literature update may be required if the last review was undertaken more than 2-5 years previously.

5.5.1 Action 1. Define the uncertainty score

The use of a certainty or uncertainty score is a valuable addition to any risk assessment, as it allows further confirmation of the level of confidence the author has in the information used in the risk assessment. Characterising certainty or uncertainty can provide a better understanding of the limitations of risk assessments, and how these limitations can be reduced (Deere *et al.*, 2008).

Certainty or uncertainty scoring should be based on anecdotal observations and scientific testing or water quality data verification preferably from the source/catchment in question or from generic scientific understanding. Naturally, the higher score for certainty, the more verification has been found for the risk at the specific source/catchment. The lower level of uncertainty and thus confidence, facilitates the grounding for implementing capital-intensive risk mitigation. If uncertainty is high, then the most reasonable approach for risk mitigation is a precautious approach. This can involve generally inexpensive or interim capital solutions to mitigate the perceived risk whilst conducting verification research on-site to reduce the uncertainty.

The important aspect of defining uncertainty is that it draws anecdotal advice from on-ground staff, quantitative water quality data and scientific research literature findings and validates them with each other. Table 14 outlines the basis behind the uncertainty scoring that is recommended for source risk assessments.

Table 14 Uncertainty scoring for catchment risk assessment

Uncertainty rank/score	Water quality data verification	Anecdotal observation	Scientific validation
High	Water quality data indicates no clear trend on risk	No reports from staff on risk occurring in that source, but suspect risk occurs	Some small-scale scientific studies nationally or internationally
Medium	Water quality data indicates some sporadic trends in risk	Occasional reports from staff on risk occurring in that source	Risk confirmed through national or state-based research
Low	Water quality data indicates a statistically significant trend of the risk	Numerous reports from staff on risk occurring in that source	Risk confirmed through national or state-based research and/or local research studies

5.6 Step 6. Risk Assessment – Determine the Likelihood, Consequence of each Risk and then Prioritise

Key Objective: Estimate the probability and consequence of the risk occurring and then determine priorities for management.

Action 1. Estimate risk likelihood and identify factors affecting likelihood
Action 2. Estimate risk consequence and identify factors affecting consequence
Action 3. Determine maximum risk and residual risk
Action 4. Rank risks based on semi-quantitative risk analysis matrix

Considerations

- Identify existing catchment improvement (control measure) strategies;
- The Precautionary Principle;
- Cumulative/incremental impacts;
- Review any past risk assessments or a risk inventory to ensure consistency;
- The ability to conduct a quantitative risk assessment; and
- Maximum and residual risk.

The objective of the risk assessment is to analyse the hazards and their sources and events and then estimate the impact (based on likelihood and consequence) of that risk on raw water quality. This then allows for the identification of very high and low risks so that priorities for risk management can be established and documented (CRC for Water Quality and Treatment Research Report 11 (2004)). Resources can then be directed to the risks which present the highest threat to raw water quality.

The level of risk for each hazard/hazardous event can be estimated by identifying the likelihood of occurrence (e.g. certain, possible, rare) and evaluating the severity of consequences if the hazard/event occurred (e.g. insignificant, major, catastrophic) (CRC for Water Quality and Treatment Research Report 11 (2004)).

Qualitative approaches only assign a verbal description of the risk. Semi-quantitative approaches assign numerical rankings to the description of the risk. The difference in outcome is only a number result over a written descriptor. What the numerical rankings do is easily identify high and low risks and thus allow practitioners to prioritise areas for work.
As CRC for Water Quality and Treatment Research Report 11 (2004) expresses, these rankings provide a relative indication of the likelihood, consequences (severity) and risk and should not be assumed in subsequent analyses to have accuracy in absolute terms.

The important function overall is the need for consistency in applying the judgments behind defining the consequence, likelihood and uncertainty. It is very advantageous to develop a register or inventory of risks pertaining to that organisation or source area that can be referred to later to ensure this consistency.

Likelihood, consequence and overall risk tables used to estimate the level of risk are provided in Tables 16, 17 and 18, based on what is recommended in CRC for Water Quality and Treatment Research Report 11 (2004). These tables have been adapted from AS/NZS 4360:1999 *Risk Management* and can be modified to meet the needs of an organisation. Detailed explanation of how to use the tables is outlined in the advice below.

Information on hazards is outlined in detail in the Hazard Fact Sheets section of CRC for Water Quality and Treatment Research Report 11 (2004) and should be referred to where required. An example risk assessment table is provided in Table 18.

Identify existing catchment improvement (control measure) strategies
For most hazards and hazardous events, some form of control measure, even minor in effect, is usually in place to mitigate risk thanks to the implementation of a risk-based approach by practitioners long before the risks were clearly defined. These may be riparian buffer zones down slope of agricultural activity, fencing of creeks, rivers and reservoirs to prevent animal access or cone-shaped floating offtakes to prevent bird perching and defecating in the reservoir, just to name a few.

It is important to verify and collate the effectiveness of these measures in preventing raw water contamination by these activities and include this information in the risk assessment, in order to provide a realistic edge to the results. The impact of the control measure usually centres on the likelihood score only, the consequence does not change.

The Precautionary Principle
The precautious approach used in drinking water (including raw water used for drinking) risk assessments for the protection of public health is based on the Precautionary Principle of ecologically sustainable development. It states that 'if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation' (Deere *et al.*, 2008).

Cumulative/incremental impacts
There is increasing concern amongst source protection practitioners about land use developments that individually may pose limited risk, but in large numbers may have a significant cumulative impact on raw water quality. As such, Deere *et al.* (2008) acknowledge that there remains the need for improved approaches, to capping the magnitude or density of impacts in a precautionary way, which are built in to the land planning process. Until this has been properly addressed, where-ever possible, practitioners should recognise cumulative impact effects in risk assessments and mitigate appropriately within their means.

Qualitative, semi-quantitative or quantitative risk assessments
Generally risk assessment will require the practitioner to make subjective judgments in regards to likelihood and consequence based on their own, organisational or project team's experience. As such, the type of risk assessment will at best be qualitative or semi-quantitative. Rarely will enough knowledge be available to complete a detailed quantitative risk assessment. This is because sources and catchments are natural systems and thus have complex ecosystem processes that are problematic to monitor holistically to any realistic intensity required for a risk assessment. For this reason, the approach outlined below is a qualitative method, tailored from CRC for Water Quality and Treatment Research Report 11 (2004) to apply specifically to source and catchments so that it will also fit with downstream water quality risk assessments.

If, however, there is sufficient information and data to conduct a quantitative risk assessment, practitioners should investigate such methods as the ecological-based ERA method described earlier (and later in Appendix 1.) or a quantitative microbial risk assessment (Deere and Davison 2005).

Maximum and residual risk
Risk should be assessed at two levels, maximum and residual risk. Maximum risk is estimated to identify the highest priority risks and provide an indication of worst case scenarios, such as in the event of system and/or barrier failures. Secondly, residual risk is determined through the evaluation of existing preventive measures. This provides key information on the effectiveness of existing strategies and the need for improvements.

5.6.1 Action 1. Estimate risk likelihood and identify factors affecting likelihood

Table 15, based on CRC for Water Quality and Treatment Research Report 11 (2004), was tailored to apply specifically to source and catchments so that it will also fit with downstream water quality risk assessments. Using this table as a tool, and the information based on the hazard, event, source, water quality data, existing control measures and uncertainty assessment, it is possible to rank the likelihood of the hazard and event occurring.

Table 15 Qualitative measures of likelihood

Level	Descriptor	Example Description
A	**Almost certain**	Is expected to occur in most circumstances as it has been observed and recorded regularly in the field and it also confirmed by water quality data.
B	**Likely**	Will probably occur in most circumstances as it has been observed and recorded occasionally in the field and is also confirmed by water quality data.
C	**Possible**	Might occur at some time/the event should occur at some time as it has been observed occasionally with few recordings in the field but water quality data has no significant trends that confirm risk.
D	**Unlikely**	Could occur at some time but has not been observed in the field and water quality data has some outliers but no trends that confirm risk.
E	**Rare**	May occur only in exceptional circumstances but has not been observed in the field and water quality data show no indication of any risk.

5.6.2 Action 2. Estimate risk consequence and identify factors affecting consequence

Table 16 has been tailored from CRC for Water Quality and Treatment Research Report 11 (2004) to apply specifically to source and catchments so that it will also fit with downstream water quality risk assessments. Using this table as a tool it is possible to determine the consequence of the hazard and event occurring.

Table 16 Qualitative measures of consequence or impact

Level	Descriptor	Example Description
1	**Insignificant**	Insignificant impact, little disruption to normal operation, low increase in normal operating costs
2	**Minor**	Minor impact for small population, some manageable operation disruption, some increase in operating costs
3	**Moderate**	Minor impact for large population (raw water quality notification to Health Regulator), significant modification to normal operation (individual sources shut-down, emergency treatment) but manageable, operating costs increased, increased monitoring
4	**Major**	Major impact (water quality contamination incident) for small population, systems significantly compromised (small town water supply system shut down, emergency treatment) and abnormal operation if at all, high level of monitoring required
5	**Catastrophic**	Major impact (water quality contamination incident) for large population, complete failure of systems (metropolitan water supply system shut-down, alternative source required)

5.6.3 Action 3. Determine maximum risk and residual risk

Table 17 outlines the level of risk based on the likelihood and consequence ranking. Using this table, assigned a level of risk to each hazards, for the maximum and residual risk.

Table 17 Qualitative risk analysis matrix – level of risk

Likelihood	Consequence				
	1 Insignificant	**2 Minor**	**3 Moderate**	**4 Major**	**5 Catastrophic**
A Almost Certain	Moderate	High	Very High	Very High	Very High
B Likely	Moderate	High	High	Very High	Very High
C Possible	Low	Moderate	High	Very High	Very High
D Unlikely	Low	Low	Moderate	High	Very High
E Rare	Low	Low	Moderate	High	High

5.6.4 Action 4. (Optional) Rank risks based on semi-quantitative risk analysis matrix.

This Action is only recommended if the source area provides a large number of hazards to assess, making it often difficult to identify the high priority risks. It also allows sources to be compared to one another, based on the overall numerical risk score for each source. This allows sources to be ranked and thus prioritised. Using the matrix below, assign a number value to each risk result (both maximum and residual risk).

Very high = 10
High = 5
Moderate = 2
Low = 1

Based on the relative ranking of risks (both maximum and residual), significant hazards can be determined for each source or catchment, plus important generic hazards can also be identified for whole regions or operating areas. In both cases often further information and research are required as well as interim or permanent control measures (upstream or downstream). Also, evaluating the major sources and types of uncertainty associated with the hazards can assist in understanding the limitations of the hazard identification and risk assessment as well as how these limitations can be reduced (CRC for Water Quality and Treatment Research Report 11 (2004)). The result of the assessment can be captured in a summary table, such as that given in Table 18.

Table 18 Example risk assessment table (including example hazards and events)

Source name, supply system, product supplied and town serviced (including population):		Catchment A, Country Town Water Supply System B, Servicing Town C (population 800) with drinking water as the sole local source																	
Source type, risk tier level with basis:		Surface water catchment, risk tier level 3 due to significant risks of illegal water-based recreation in reservoir and agricultural farming practices (some intensive 500m+ from reservoir, microbiological water quality trends of concern, source shut-down regularly in high runoff events where E . col exceeds 20 MPN.																	
Hazard	Hazardous Event/ Source	Description information	Water Quality Data Verification	Uncertainty	Maximum Risk				Existing Preventative Measures			Residual Risk				CCP	Source of information	Additional Required Control Measures	Further comments
					Likelihood	Consequence	Risk	Score	On-site	Riparian	Reservoir	Likelihood	Consequence	Risk	Score				
E.g *Cryptosporidium*	Illegal swimming in the reservoir	Occurs in the summer months, rangers observe family groups, including young children, and teenager groups of about 30 maximum at any one time swimming for 4-6 hour periods over the weekends from Dec - March	*E. coli* exceeding 20 MPN found regularly in summer months reservoir monitoring point 3, 300m upstream of offtake. At offtake *E. coli* has only exceeded 20 MPN in Feb 2006 and 2008, March during significant rainfall event.	Medium	Likely	Major	Very High	10	Ranger patrols, signage, prosecutions	NA	Ranger patrols, signage, prosecutions	Likely	Major	Very High	10	Avoid human contact with the waterbody	Rangers reports	Increased ranger patrols, local community education, advertise alternative locations	Catchment land Management and Health Regulator advised of illegal activity
Eg. PAH Pesticides	Spray drift from adjacent crops reaching the reservoirs	Spraying occurs in spring and autumn periods at concentrations of 100ml/1 ha. Distance from reservoir is 500m, distance from feeder stream is 100m. riparian buffer around feeder stream is 50m wide and woody vegetation. Reservoir has 500m vegetation buffer around it of natural forest vegetation.	PAH pesticides found at raw water point below ADWG 2004 (detection) guideline limit on only 3 occasions in autumn of 1996, 1999, 2003 not correlating to high wind events. No detections at feeder stream monitoring point downstream of site.	High	Possible	Major	Very High	10	BMP, education Buffer 100m Buffer 500m			Unlikely	Major	High	5		Ranger reports	Local landowner education, arrange for landowner to notify planned spraying timings for targeted water quality monitoring	Catchment land Management Regulator advised but activity is approved under local town planning scheme
	Runoff from rainfall		PAH pesticides found below ADWG 2004 (detection) guideline limit on and only 3 occasions in autumn of 1996, 1999, 2003 correlating to runoff events. Detections above ADWG 2004 (detection) guideline level at feeder stream monitoring point downstream of site in autumn of 1996, 1998, 1999, 2002, 2003, 2005.	Medium	Likely	Major	Very High	10				Unlikely	Major	High	5				
Maximum risk score								30	Residual risk score							20			

5.7 Step 7. Select Catchment-Based Critical Control Points (CCPs)

Key Objective: All significant hazards in the process should be identified as being controlled by Catchment-based CCPs depending on whether or not they posed a significant water quality and/or safety risk.

Action 1. Identify and record catchment-based CCPs for all significant hazards

5.7.1 Action 1. Identify and record catchment-based CCPs for all significant hazards

Catchment-based CCPs are steps in the process where there is potential to have a negative impact on the water but as this is within the raw water context, has not reached the stage where the water has become unsafe to drink (i.e. detrimental to the consumers' health). Identifying the CCPs in the catchment assists in the later development of the risk treatment strategies, as they are usually then targeted at the CCP location/area. CCPs also then provide a defined location to monitor not only the raw water quality characteristics operationally but also the effectiveness of the mitigation strategy. The CCP should be recorded in a summary table in the form of an operational risk management plan, similar to the example given in Table 19. In practice, CCPs might not be the best term to use for controls within catchments, and terms such as Catchment Risk Management Programs or Supporting Programs are often used. Such programs would following the same monitoring/limit/corrective action control logic of a CCP but would not be so precisely defined.

5.8 Step 8. Develop Operational Risk Assessment Action Plan

Key Objective: Develop a plan which structures the risks based on priority, and facilitates decision-making on appropriate risk treatment strategies into an operational form for ease of implementation.

Action 1. Develop operational risk assessment action plan

5.8.1 Action 1. Develop operational risk assessment action plan

The critical stage after undertaking any risk assessment process is ensuring that it is implemented. This can be made easier by developing a simple operational action plan. This plan takes the outcomes of the risk assessment, including risk mitigation/treatment (not included in this report) and turns them into actions milestones and timelines, responsibilities and the required resources.

This should be developed, and agreed to, by the project team after the risk assessment table is completed and endorsed. An example operational risk assessment action plan is outlined below in Table 19.

Table 19 Operational risk assessment action pPlan

Date:						
Source:						
Hazard	Hazardous event / Source	Residual Risk Score	Risk Mitigation / Treatment	Responsibility	Milestone	Action Completion Due Date
E.g. *Cryptosporidium*	Cattle defecating in stream flowing into reservoir	10	Fence riparian areas	Regional Manager, Catchment Officer	Contact landowners and request fencing (offer 50% support)	End June 2010
					Field inspection to ensure fencing in place	End July 2010
					Include fence inspections as part of on-going site inspection program by rangers	Ongoing
					Update risk assessment	No later than August 2010

5.9 Step 9. Documentation

Key Objective: Record all required information in appropriate databases or storage systems to ensure continuous improvement and learning.

Action 1. Record and store risk assessment table
Action 2. Develop and update generic and source specific risk register/inventory

5.9.1 Action 1. Record and store risk assessment table

It is well known that all organisational knowledge is worthless if it is not well documented (Thompson, pers. com., 2007). This is especially true of all information used in a risk assessment. Organisations should develop and manage effective databases and reference materials for use by risk assessors, to ensure learnings are implemented and consistency of information use. It is particularly important that these documents are part of the overall corporate or organisational document management system to ensure they link with associated documents, are easy to find and are regularly updated.

5.9.2 Action 2. Develop and update generic and source specific risk register/inventory

The risk assessment table (see Table 18) is one area to record all information pertaining to that individual assessment, but as also mentioned earlier, a risk register or database is also valuable as a reference guide. This can show the hazards and events, anecdotal observations, sources or information and advice on how subjective decisions were made. Both sources of hazard and likely hazards of importance are identified along with preventive measures that can be used to prevent or minimise the risk. Details of each hazard source and ranking of its likelihood and significance should be documented. The specific locations of the sources of hazard and the means by which important hazards can enter the water supply should be recorded where possible, as this will assist with the development of appropriate preventive measures and effective monitoring programs (CRC for Water Quality and Treatment Research Report 11 (2004)).

This should be in the form of a list of generic risks, possibly organisation-wide, as well as one for each specific source. Both will become an essential reference tool for later risk assessment reviews, and for when the practitioner is identifying how the risk profile of a source has changed over time.

5.10 Step 10. Monitor and Evaluate

Key Objective: Verify the risk assessment through monitoring and research.

Action 1. Establish and implement a verification monitoring program for the risk assessment
Action 2. Identify knowledge gaps that require operational or strategy research and implement a research program

The value of the risk assessment process is that it provides a structured mechanism to identify areas for validation. Risks with high uncertainty identify significant knowledge gaps strategically and operationally and as such usually require research projects to cover both fields. And risks with low uncertainty where mitigation strategies are recommended require verification of how the strategies are working to effectively reduce risk.

5.10.1 Action 1. Establish and implement a verification monitoring program for the risk assessment

The risk assessment verification monitoring program should accompany the compliance-based and operational water quality monitoring program already in place. It will however, not only be made up of water quality results, but also field-based observation data such as indications of trespass into fenced and protected areas, observations of people or dogs swimming in reservoirs or evidence of cattle access for watering purposes into a riverbed. Naturally this information is not the same as water quality data and thus it cannot be recorded in the same manner, but it essential information to verify water quality information. For this reason, all of this information needs to be programmed to occur as data collection, and recorded for updating into a database that links the information to the water quality data on a spatial scale so that issues and trends can be identified and reported on.

Leading-edge systems are now using “rugged” personal data applications (PDA’s) or laptops that collect information easily in the field in consistent templates which are then updated regularly into the corporate data system.

5.10.2 Action 2. Identify knowledge gaps that require operational or strategy research and implement a research program

As mentioned, in addition to the verification of risks, risk assessment also highlights areas of knowledge gaps. The risk assessment can then be used to identify key operational areas (in-house) where uncertainty is medium to high or strategic (state-based or national) research projects where uncertainty is high. Most water utilities and regulator organisations have internal research programs or opportunities to undertake strategic research through university or national research institutions. The risk assessment results should be used as part of the justification for either research opportunity.

5.11 Step 11. Review

Key Objective: Ensure that the risk assessment is updated so that the catchment-based risks can be continuously effectively managed, despite the any changes in land-use, source operation climate or source condition.

Action 1. Develop a review strategy for the risk assessment

5.11.1 Action 1. Develop a review strategy for the risk assessment

Continual improvement is one of the underlying philosophies of the Framework. Thus it is important that this exercise be reviewed and updated on a periodic basis as changing conditions may introduce important new hazards or modify risks associated with identified hazards. It is recommended that generically a risk assessment review should occur at least every 5 years. However, this should be reduced for sources that are highly vulnerable based on the nature of the source, the level of risk present, downstream barriers in place and the population serviced (i.e. Risk tier level 2. or 3.) or where changes in land use, conditions or activity are potentially increasing the risk. In these situations, every 2 years is recommended.

5.12 Summary of Actions

Table 20 outlines a summary of all of the actions outlined in this document, and the associated sources of advice or information recommended earlier in this document to undertake them.

Table 20 Summary of actions and relevant section of this report.

5.1	**Step 1. Establishing the Risk Assessment Context**
5.1.1.	Action 1. Assemble the team
5.1.2.	Action 2. Describe and document intended product use
5.1.3.	Action 3. Gather catchment information and construct a flow diagram of water supply system from catchment to consumers and describe the nature of barriers
5.2.	**Step 2. Screening Risk Assessment and Risk Prioritisation**
5.2.1.	Action 1. Determine the appropriate risk tier level for the assessment
5.3.	**Step 3. Identify Hazards, Hazardous Events and Sources**
5.3.1.	Action 1. Identify water quality hazards
5.3.2.	Action 2. Identifying hazardous events
5.3.3.	Action 3. Identifying sources of hazards
5.4.	**Step 4. Assessment of Water Quality Data for Hazard Identification**
5.4.1.	Action 1. Develop a risk-based source water quality monitoring program
5.4.2.	Action 2. Collate data and review for hazard, hazardous event and source verification
5.5.	**Step 5. Uncertainty Scoring**
5.5.1.	Action 1. Define the uncertainty score
5.6.	**Step 6. Risk Assessment – Determine the Likelihood, Consequence of each Risk and then Prioritise**
5.6.1.	Action 1. Estimate risk likelihood and identify factors affecting likelihood
5.6.2.	Action 2. Estimate risk consequence and identify factors affecting consequence
5.6.3.	Action 3. Determine maximum risk and residual risk
5.6.4.	Action 4. (Optional) Rank risks based on semi-quantitative risk analysis matrix.
5.7.	**Step 7. Select Catchment-Based Critical Control Points (CCP's)**
5.7.1.	Action 1. Identify and record catchment-based CCP's for all significant hazards
5.8.	**Step 8. Develop Operational Risk Assessment Action Plan**
5.8.1.	Action 1. Develop operational risk assessment action plan
5.9.	**Step 9. Documentation**
5.9.1.	Action 1. Record and store risk assessment table
5.9.2.	Action 2. Develop and update generic and source specific risk register/inventory
5.10.	**Step 10. Monitor and Evaluate**
5.10.1.	Action 1. Establish and implement a verification monitoring program for the risk assessment
5.10.2.	Action 2. Identify knowledge gaps that require operational or strategy research and implement a research program
5.11.	**Step 11. Review**
5.11.1.	Action 1. Develop a review strategy for the risk assessment

5.13 Useful References

The authors would like to suggest several key existing reference books and papers that would be useful to source protection practitioners and thus complimentary to this report. These are outlined in Table 21 below.

Table 21 Useful reading and references

Subject	Reference
Groundwater Protection	Schmoll O, Howard G, Chilton J and Chorus I (2005) Protecting Groundwater for Health. WHO, IWA Publishing, London. Kady AE (2008) Tools for Groundwater Protection. In: Watershed Management for Drinking Water Protection. American Water Works Association and Australian Water Association.
Surface Water Protection	Deere D, Stevens M and Davison A (in preparation). "Risk management strategies" In Protecting Surface Water for Health: Managing the Quality of Drinking-water Sources, (Eds) Chorus I., Schmoll O, Deere D, Appleyard S, Hunter P and Fastner J. World Health Organisation, Geneva.
Water Safety Plans	Davison A and Deere D (1999) "Safety on tap", *Microbiology Australia*. **20** 28-31. Deere DA (1998) Interpreting pathogen monitoring data in terms of public health risk. Cooperative Research Centre for Water Quality and Treatment. Project 1.1.1 Project Report. Deere DA (2003) HACCP, Catchments and Environmental Management. Conference abstract. Water Safety, Berlin April. Deere D and Davison A (1998) "Safe water – are food guidelines the answer?" *Water* (Aust). **25** 21-24. Deere D, Cole C, Williams JA, McConnell S, Bethel M, and Ashbolt N J (1998) "Assessment of human health risks to support decision-making on wastewater treatment options", Proc. AWWA/IWA Recoverable Resources Conference, Moama, NSW, 7-9 May. Deere D and Davison A (2003) "Integrating public health and environmental risk management strategies in catchments". Specialist Conference on Water Safety – Risk Management Strategies for Drinking-water. World Health Organization, Berlin, 28-30 April. Invited. Deere D and Davidson P (2005) The Ps and Qs of risk assessment. *Water* March. Deere D, Stevens M, Davison A, Helm G, Dufour A (2001) Management strategies. In: Fewtrell 1 L, Bartram J, editors. Water 2 quality: guidelines, standards and health, London: IWA Publishing; 2001. p. 257-288. CRC for Water Quality and Treatment Research Report 11 (2004) A Guide To Hazard Identification & Risk Assessment For Drinking Water Supplies.
Ecological Risk Assessment	Suter GW and Barnthouse L (1993) Assessment Concepts. In GW Suter (Ed.), Ecological Risk Assessment (pp. 21-48). Michigan: Lewis Publishers. Hart BT; Burgman M, Grace G, Pollino C, Thomas C and Webb JA (2001) Risk-Based Approaches to Managing Contaminants in Catchments. Human and Ecological Risk Assessment, 12: 66–73. Burgman MA (2001) Flaws in subjective assessments of ecological risks and means for correcting them. *Australian Journal of Environmental Management* 8:219–26

Subject	Reference
Qualitative Risk Assessment	Deere D, Walling JP, Selvarkumar A; Whitehill B and Miller R (2008) Risk Management. In: Watershed Management for Drinking Water Protection. American Water Works Association and Australian Water Association.
Semi-Quantitative Risk Assessment	Ministry of Health (2002) *Public Health Risk Management Plan Guide – Surface and Groundwater sources*. Version 2, Ref S1.1 Wellington New Zealand.
Quantitative Risk Assessment	Haas CN, Rose JB, and Gerba CP (1999) Quantitative Microbial Risk Assessment. Hart BT, Burgman M, Grace G, Pollino C, Thomas C and Webb JA (2001) Risk-Based Approaches to Managing Contaminants in Catchments. Human and Ecological Risk Assessment, 12: 66–73. Deere D and Davison A (2003) “Risk assessment of water supply options for arsenic mitigation – Quantitative Health Risk Assessment” Proposal for British Department of International Development.
Hazards and Risks in Catchments	CRC for Water Quality and Treatment Research Report 11 (2004) A Guide To Hazard Identification & Risk Assessment For Drinking Water Supplies. CRC for Water Quality and Treatment Technical Fact Sheet Pathogen movement and survival in catchments, groundwater’s and raw water storages-Management implications from the Cooperative Research Centre for Water Quality and Treatment Catchments and Storages Research program.
Control Measures in Catchments	CRC for Water Quality and Treatment Research Report 11 (2004) A Guide To Hazard Identification & Risk Assessment For Drinking Water Supplies. Charles KJ and Ashbolt NJ (2004) Quantitative Microbial Risk Assessment: a catchment management tool to delineate setback distances for septic systems. IWA 2nd Young Researchers Conference, May, Wageningen, the Netherlands, IWA.
Source-based Water Quality Monitoring and Activity Surveillance	Lance C, Schulte J and Feehan P (2008) Monitoring. In: Watershed Management for Drinking Water Protection. American Water Works Association and Australian Water Association. Lance C, Schulte J (2008) Surveillance. In: Watershed Management for Drinking Water Protection. American Water Works Association and Australian Water Association.

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APPENDIX 1 - RISK ASSESSMENT METHODS

HACCP

Probably the most commonly used approach is that of the qualitative subjective risk ranking, mainly implemented through recognised methods such as the Hazard Analysis and Critical Control Points (HACCP), which was first established to assess risks to the food industry, and then adapted for drinking water quality management. Under the HACCP process the HACCP team must assess all potential risks to water quality, and cover the full water supply system, from catchment to tap. Naturally this method is appropriate for organisations that operate the full water supply system. The first report of the application of HACCP to catchments was by Barry *et al.* (1998). The HACCP approach to risk assessment has now been widely accepted by the Australian Water Industry, mainly because it contains certification processes which fit well into organisational quality management systems and ensures effective reporting. The key steps to HACCP are as follows:

Step 1 assemble team
Step 2 describe product
Step 3 identify intended use
Step 4 construct flow diagram
Step 5 confirm flow diagram

Principles of HACCP

Principle 1	List all potential hazards Conduct a hazard analysis Determine control measures
Principle 2	Determine CCPs
Principle 3	Establish critical limits for each CCP
Principle 4	Establish a monitoring system for each CCP
Principle 5	Establish corrective actions for derivations that may occur
Principle 6	Establish verification procedures
Principle 7	Establish record-keeping and documentation

A number of risk management approaches can form part of HACCP and may at first appear equivalent to HACCP provided public health impacts are included as part of the hazard analysis and risk assessment process. These include:

- FMEA (Failure Mode and Effect Analysis);
- HAZOP (Hazard Operability) studies, also known as PHA (Process Hazard Analysis);
- EMS (Environmental Management System).

The World Health Organisation (WHO) Approach

The revision of the WHO Guideline for Drinking Water Quality (GDWQ) is proposing a more effective approach to safeguarding drinking water in order to help focus available financial and institutional resources on the risks most relevant to public health in the specific setting (Schmoll and Chorus, 2003). Although multiple barriers, including protection of sources, have been recommended by WHO for some time, the current revision is aiming to introduce a management framework for safe water, namely Water Safety Plans (WSPs). WSPs are a systematic approach to understanding the specific hazards relevant in a given water supply and to effective management of the processes most suitable for their control in the given system. Like the Framework, attention is shifted from compliance monitoring to a quality management approach. WSPs have the following key elements:

- Health based targets – developed by WHO using quantitative microbial risk assessment;
- System assessment- determines the system capability to meet health based targets;
- Effective management – control measures – understanding the capabilities and limits of barriers;
- Management plans – document system assessment and monitoring, describe actions to be taken during normal operation and incident conditions, including upgrade and improvement and documentation and communication (WHO GDWQ); and
- Public health surveillance – verifies that the elements of the WSP are operating properly, including auditing.

Australian Standard for Risk Management AS4360:2004

AS/NZS 4360:2004– Risk Management provides a generic framework to establish a risk management process in an organisation. It is targeted as a strategic tool and operational business tool, designed to help any organisation minimise the losses and maximise the opportunities generated by different types of risk.

This Standard outlines procedures which you can implement to help establish context, identify, assess, analyse, treat, monitor and communicate with regard to risk.

It involves the key steps outlined below:

1. Establish the context
2. Identify risks
3. Analyse risks
4. Evaluate risks
5. Accept risks
6. Treat risks

With input from organisations worldwide, this Standard:

- Ensures consistent terms and definitions are used in different industries;
- Explains the role of stakeholders;
- Emphasises the need to communicate at all points of the risk management process;
- Stresses the need for prioritising risk treatment; and
- Clearly conveys the requirements in a risk management system and process.

ADWG (2004) Framework for the Management of Drinking Water Quality

The most recent release of the ADWG contains a new component, a framework designed to guide the design of a structured and systematic approach to the management of drinking water quality from catchment to consumer, to assure its safety and reliability. The Framework incorporates a preventative risk management approach by including elements of HACCP, ISO 9001 and AS/NZS 4360 but applies them in a drinking water supply context to support consistent and comprehensive implementation by the water industry. Out of the four major components to the Framework, the second relates to the risk management process – System Analysis and Management. It contains the following elements:

- Element 2 – Assessment of the drinking water supply system;
- Element 3 – Preventative measures for drinking water quality management;
- Element 4 – Operational procedures and process control;
- Element 5 – Verification of drinking water quality; and
- Element 6 – Management of incidents and emergencies.

However it should be noted that although listed as discrete components, all 12 elements are interrelated and each supports the effectiveness of others. Whilst being built on HACCP, the Framework approach aims to be a fully comprehensive management system, unlike HACCP which was designed to integrate into existing management practices (good manufacturing practices and quality management systems, termed “HACCP Supporting Programs”), thus limiting its scope. The Framework integrates additional (and yet important) factors of commitment, stakeholder involvement, emergency response, employee training, community consultation and research and development. In that sense both the Framework (and incidentally the WSP) is the equivalent of the Food Safety Plans (FSP) required for food suppliers which must consist of both HACCP and the Supporting Programs.

Ecological Risk Assessment (ERA)

Ecological Risk Assessment is a relatively new technique that holds promise as a quantitative method for assessing the level of risk to the health of river ecosystems from management actions (Hart *et al.*, 2001). The ERA process has evolved as a tool in assessment of multiple stressors on complex ecosystems (Suter and Barnthouse, 1993). Generally, the process covers the following steps:

1. Problem formation – establishes the goals, breadth and focus of the risk assessment involving consultation, examination of data, consideration of policy and regulatory issues and site specific factors;
2. Risk analysis and assessment – profiles of environmental exposure (likelihood) and ecological effects (consequences) of the stressor(s) are developed for each key issue;
3. Risk characterisation – exposure and effect profiles are integrated to provide an estimate of the level of risk (risk = likelihood x consequence). Results can be expressed qualitatively or quantitatively; and
4. Risk management – ERA information is used to define the appropriate actions and highlight the priority factors to be addressed.

There are some differences between qualitative/quantitative risk management methods used principally for drinking water, and the ERA process used for environmental values. Obviously, there is differing terminology, making the process steps appear to be different. Deere (2003) found these differences to be almost entirely semantic and illustrated them in the table below.

Table 22 Comparison of HACCP with examples of ERA principles.

Some HACCP principles and steps	Examples of similar ERA steps
Assemble team	Assemble team
Describe product and intended use	Define risk endpoints
Construct and verify flow diagram	Construct conceptual model
Hazard analysis	Inventory of pressures
Critical control points	Describe responses
Critical limits	Target setting
Monitoring	Measurement of response
Verification	Measurement of state

However, Deere (2003) also suggested that there are some differences between the two approaches, by suggesting that this was due to different endpoints (health vs environment) for each assessment, and these are outlined in the table below:

Table 23 Examples of risk assessment paradigms and their differences when health and environmental endpoints are considered.

Paradigm	Environment endpoint	Health endpoint
Timing	Chronic	Acute
Reporting	Continuous	Categorical
Monitoring	Populations and systems	Individuals and groups
Hazards	Cumulative	Specific
Endpoint	The broad natural system	Humans

This report was focussed on the components that make up risk assessment only for drinking water sources. The contribution of ecological or “catchment health” values to protecting water quality is well recognised and the alignment of the outcomes of this project with the ERA process is a key project objective.

APPENDIX 2 – CASE STUDIES OF RISK ASSESSMENT APPLICATION

WA Water Corporation Methodology

The WA Water Corporation committed to adopt the ADWG Framework by 2007 and is doing so by using the modular approach of dealing with catchments and storages, treatment and distribution as provided for in the Framework. As part of this program it is developing a Source Protection Operations Manual for catchments and storages that addresses Elements 2 to 6 and that will link into downstream processes that are also being developed.

As part of this manual the WA Water Corporation uses a risk assessment methodology that is a modified version of the sanitary survey methodology, which was developed in response to the ADWG recommendation to conduct sanitary surveys to reduce the risk of *Cryptosporidium* and *Giardia*. However, this methodology also integrates HACCP principles to the catchment of the source, and can accommodate all hazards, not just microbiological issues. This methodology has been further developed to better meet the requirements of the Framework.

It focuses on the approach of identifying the hazard through all possible sources of risk including the initial screening of water quality data and land uses and activities. Hazard sources or events associated with each land use or activity are then identified. Likelihood, severity and maximum level of risk are then estimated using information gathered. The quantity and distance of the hazard are introduced as further inputs into the likelihood estimation.

Current barriers are then considered but do not include any downstream of raw water outlet (especially water treatment) as these are dealt with in downstream procedures.

This process also identifies catchment barriers and mitigation strategies that are critical control points.

Residual likelihood and risk are then determined. The outcomes of the approach are as follows:

- An information source on risks to raw drinking water quality in the catchment and what is currently being done to manage those risks;
- The basis for public consultation in the development of a Drinking Water Source Protection Plans, to identify further mitigation to reduce risks;
- Provide staff with a information tool to “know your catchment”;
- Provide staff with information useful in determining resourcing priorities; and
- Provision of input information to the downstream risk assessment processes.

New Zealand Ministry for Health Public Health Risk Management Plan

Another key approach is that used by the Ministry for Health in New Zealand. This approach integrates the method outlined in WHO Water Safety Plans. Under this method, like HACCP, the full water supply system is assessed. However, CCPs are not used as the key pointer for action in a water supply system. The process instead aims to assess the level of protection a supply has to contamination and the impact to public health of any improvements made to the barrier system. Risks are then ranked for the full supply system according to their size (taking into account the seriousness of the health risk from each event, the likelihood of the event occurring, and sum up all the risks from the various process elements).

The key processes in preparing Public Health Risk Management Plans are:

1. Risk Assessment

1.1. Make a flow diagram of the supply.
1.2. Identify the elements in the supply so you can select the Guides (guidance information) you need.
1.3. Make a list of the four “barriers to contamination” needed in a supply and note which of these your supply has and which it does not have.
1.4. Prepare a Risk Information table for your supply that lists the preventative measures, and checks on preventative measures that you should have in place to reduce risk.

1.5. Prepare a list of improvements you need to make by comparing what you should have (Step 4) and what you actually have.
1.6. For each improvement needed, estimate the level of public health risk if the improvement is not made.
1.7. Rank the risks from the whole supply according to their size (take into account the seriousness of the health risk from each event, the likelihood of the event occurring, and sum up all the risks from the various process elements).

2. Risk Management

2.1. Work out the resources (dollars, staff, expertise, equipment) needed for each improvement.
2.2. Work out a final overall priority for each improvement taking account of the level of health risk and the resources needed (Step 8) (use a cost-benefit approach).
2.3. Develop a three-year program for managing each risk.
2.4. Prepare a summary of regular checks and maintenance that needs to be carried out.
2.5. Prepare contingency plans that might be needed for your supply.

3. Plan evaluation and communication

3.1. Prepare a list of instructions for reviewing the performance of the plan.
3.2. Prepare a list of instructions for reporting.

Sydney Catchment Authority

The Sydney Catchment Authority approach is based primarily on Australian Standard 4360 as required by the SCA's Operating Licence (Sydney Catchment Authority, 2000).

The SCA is a bulk raw water supplier to Sydney Water Corporation. For those organisations responsible for raw water delivery only, a method that reflects the complicated nature of the source water system is more applicable. Generally, these operations have extensive raw water monitoring programs and as such have well-recognised water quality issues that require priority during risk assessment. These issues may be linked to a dominant land use in the source protection area, such as application of pesticides onto horticultural areas close to the water body, or may be prevalent trends in water quality data taken in the reservoir or at the raw water off take. It is in these raw water delivery systems that semi-quantitative risk ranking models are appropriate. As a result, priority of mitigation action can be focussed on addressing these key issues.

The SCA risk assessment process follows this approach by using water quality as a screening level to identifying risks. Water quality issues are then divided into water quality evaluation parameters or catchment health parameters. It then follows an estimation and allocation of a score to the likelihood and consequence and then a calculation of the estimated level of risk by multiplying the score for probability and consequence. Risks can then be ranked in order of priority for action.

Melbourne Water Corporation

Melbourne Water uses a HACCP approach to risk assessment to the drinking water supply system. See the earlier description of HACCP.

South East Queensland Water Corporation

SEQ Water Corporation has built its risk assessment methodology on the foundations of HACCP. It covers the catchment and Water Treatment Plants (WTPs) section of the supply system and has the following steps:

1. Establish the context	Identify activity aspects (work process) and their potential impacts (on environment/people/operations)
2. Identify the hazards	Determine what contaminant/chemical/action can cause impacts/injury/nuisance
3. Analyse risks that may result because of the hazard	Determine: Probability/Likelihood of an incident occurring, Exposure/Duration – the duration of, and exposure to or interaction with the hazard by people or environment; Consequence – expected outcome of an incident.
4. Evaluate the risk	Use the risk Calculator that helps to determine & qualitatively quantify the level of risk by defining Probability/Likelihood, Exposure/Duration and consequences.
5. Treat the risks	Identified risks must be addressed by implementation of Control Measures, prioritising according to Risk Rating and taking into consideration the Hierarchy of Control Measures. Examples: A toxic chemical may be replaced by a harmless one. An inadequate procedure may be upgraded to be more effective. Certain activities or public access may be curtailed to prevent erosion or fire.
6. Review and Monitor the risk	Undertake Regular Monitoring, Review and Records of the effectiveness of control measures.

A risk calculator is used to calculate risk based semi-quantitative scoring or categorising of the following;

- Probability/Likelihood;
- Exposure/Duration; and
- Consequence – based on the number of people affected, area affected financial cost, environmental impact and operational impact.

And the using the following equation to calculate the overall risk to gain a risk score using the following equation:

Risk = Probability/Likelihood x Exposure/Duration x Consequence.

APPENDIX 3 CATCHMENT INFORMATION COLLATION

Proforma for Catchment Information

Catchment:				
Region:				
Information required	**Detail**	**System information**	**Information source location**	**Information storage location**
Water supply system nomenclature and supply type	Name of water source Name of supply system Name/title catchment No. of customers Type of water supplied			
Water supply system (assets-based) information	Type of water supply system Time established Town/city of supply Period of use Barriers present Infrastructure information Type of treatment and efficiencies Reservoir detention time Reservoir design (size, materials, storage capacity, depth of storage) Reservoir seasonal variations (stratification, algal blooms) Storage and catchment protection (covers, access) Intake location and operation Bulk transport (pipeline material, length etc.)			

Catchment:				
Region:				
Information required	**Detail**	**System information**	**Information source location**	**Information storage location**
Catchment/ groundwater recharge area Information	Location of catchment geographically Proximity to customers Region, system characterisation Geology and soils Streams and rivers Vegetation type and cover Wildlife Topography and drainage patterns Riparian conditions General catchment and river health			
Source water characteristics	Surface water – sub catchments, size Ground water – aquifer name and type, nature of geology Geomorphological features Climate – annual rainfall (range and average) Hydrological information (flows, - peaks, ranges, average)			
Source/raw water quality	Sampling locations and parameters – timelines, frequency Investigative sampling programs – storm events Compliance sampling Trends, key features, baseline trends for characteristics parameters Exceedances – justifications, actions taken (if any) Key conditions for water quality incidents			

Catchment:				
Region:				
Information required	**Detail**	**System information**	**Information source location**	**Information storage location**
Land use within recharge area	Land tenure – Water Protection Reserve, Crown, private, other Static land use – surveys, locations, type, contamination risks, intensity, seasonal variations Transient activity – locations, type, contamination risks Past land uses – that may be a continued contamination risk Contaminated sites Regulation on land uses and activities (development and planning restrictions) Land rehabilitation and other water quality protection activities Land irrigation practices Land management practices Future planning activities			
Contamination risks	Point sources – type, location, management, barriers Diffuse sources– type, location, management, barriers Sanitary survey			
Stakeholders	Water supply system – other utilities Government – land management Government – regulation Local Council Land owners – private Transient activity – groups or individuals Community/stakeholder groups			

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CRC for Water Quality and Treatment

The Cooperative Research Centre (CRC) for Water Quality and Treatment operated for 13 years as Australia's national drinking water research centre. It was established and supported under the Australian Government's Cooperative Research Centres Program.

The CRC for Water Quality and Treatment officially ended in October 2008, and has been succeeded by Water Quality Research Australia Limited (WQRA), a company funded by the Australian water industry. WQRA will undertake collaborative research of national application on drinking water quality, recycled water and relevant areas of wastewater management.

The research in this document was conducted during the term of the CRC for Water Quality and Treatment and the final report completed under the auspices of WQRA.

Water Quality Research Australia Membership at December 2008

Industry Members

- Australian Water Association Ltd
- Degrémont Pty Ltd
- Barwon Region Water Corporation "Barwon Water"
- Central Highlands Water
- City West Water Ltd
- Coliban Region Water Corporation
- Department of Human Services (Vic)
- Goulburn Valley Regional Water Corporation "Goulburn Valley Water"
- Grampians Wimmera Mallee Water Corporation
- Hunter Water Corporation
- Melbourne Water Corporation
- Power & Water Corporation
- South East Water Limited
- Sydney Catchment Authority
- Sydney Water Corporation
- United Water International Pty Ltd
- Wannon Region Water Corporation
- Water Corporation of WA
- Yarra Valley Water Ltd
- South Australian Water Corporation
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- Australian Water Quality Centre
- Centre for Appropriate Technology
- Curtin University of Technology
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- University of South Australia
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- Cradle Coast Water
- Department of Water (WA)
- Esk Water Authority
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- NSW Department of Health
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