Public health issues associated with stock accessing waterways upstream of drinking water off-takes

A report prepared for the Department of Health

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1. Executive Summary

1.1. Purpose

The purpose of this study was to assemble objective evidence and provide defensible guidance relating to the assessment and management of public health risks associated with stock accessing waterways upstream of drinking water off-takes. It is intended that the results of the study will be used by the Department of Health and the Government of Victoria to support and inform policy positions. In summary, the terms of reference, as augmented during conduct of the study, required the following to be addressed:

- The public health impact of livestock grazing upstream of drinking water off-takes.
- The impact of cattle to be the primary focus, but other types of livestock to be considered.
- Literature relevant to public health risk assessment to be reviewed and summarised.
- Any identified public health risk, and the acceptability of this risk, to be assessed.
- The regulatory and policy context of livestock grazing upstream of drinking water off-takes to be reviewed.
- Management paradigms and buffer distances to be recommended.
- Water treatment and catchment management costs to be compared.
- Waterborne disease outbreak and mitigation costs to be compared.

1.2. Methodology

1.2.1. Overview

The overall framework adopted in conducting this study was based on the environmental health risk assessment approach given in enHealth (2002) and involves four steps:

1. Hazard identification – selecting hazards to be considered in the risk assessment;
2. Exposure assessment – quantifying exposure to the selected hazards;
3. Dose-response analysis – quantifying health effects of exposure to hazards; and
4. Risk characterisation – determining the significance of the assessed risks.

1.2.2. Hazard identification

In relation to drinking water aspects of public health, the most important hazards arising from stock accessing waterways upstream of drinking water supply off-takes were *Cryptosporidium parvum*, *Salmonella* spp., *Campylobacter* spp. and pathogenic *Escherichia coli*. The study focused on oocysts of human infectious genotypes of *C. parvum* arising from cattle and sheep. Of the hazards identified *C. parvum* emerged as the most significant. Cattle and sheep dominated the livestock sources of oocysts within Victoria.

1.2.3. Exposure assessment

A representative 'case study' grazing catchment was used to enable risks to be quantified for a set of defined baseline and intervention scenarios. The case study catchment included cattle and sheep, mature and juvenile stock and some limited stock exclusion. Exposure was estimated for the case study catchment under three conditions:

1. Dry weather - where perennial streams were accessed by stock;
2. Rain events - where ephemeral streams were accessed by stock; and
3. Flood events - where riparian areas accessed by stock were inundated.

Exposure was assessed with and without water treatment being in place. Exposures were estimated using a daily time step via a quantitative catchment pathogen budget estimation model as described in detail previously (Deere et al., 2008).

1.2.4. Dose-response analysis

The study utilised the dose-response meta-analysis completed by Messner et al., (2001) in estimating the probability of infection arising from ingesting oocysts from untreated and treated drinking water. The study assessed disease burdens using the disability-adjusted life year approach that is described in detail in the Phase 1 Australian Guidelines for Water Recycling (2006) and WHO Guidelines for Drinking-water Quality (2008).

1.2.5. Risk characterisation

The study considered risks and their management from multiple perspectives:

- the legislative and policy instruments that could be used to implement interventions;
- the costs of particular interventions; and
- the benefits of particular interventions.

Benefits were expressed as the log_{10} reduction in the risks from pathogens arising from stock accessing waterways upstream of drinking water off-takes. These benefits were estimated for a range of treatment and catchment management interventions for the case study catchment. Costs were assessed as the capital, operating, project and net present value associated of the evaluated interventions. Costs of catchment management interventions, water treatment interventions and waterborne disease outbreaks were compared.

1.3. Key findings

1.3.1. Risks to public health

Risks to public health due to pathogens shed as a result of the uncontrolled access of livestock to waterways above drinking water off-takes were estimated. Risks were assessed on an annual basis by summing the daily risks since the tolerable risk metric used for comparison was an annual disease burden. Therefore, risks for any particular year were considered to include the sum of any storm, flood and dry weather events.

The estimated risks were found to be several orders of magnitude above tolerable levels without adequate downstream water treatment being in place. For the representative case study grazing catchment simulated, risks to public health were estimated to be 5 log_{10} above tolerable levels. Drinking water treatment would be required to reduce risks to tolerable levels under such circumstances.

The Australian Drinking Water Guidelines recommend managing water quality risks at source, within the catchment, to the maximum degree practicable. Managing risks by keeping contamination out of source waters in the first place is considered to be inherently more reliable than attempting to remove contamination through fallible water treatment processes.

In addition to being more reliable, under some circumstances managing risks at source may prove less costly than managing risks through water treatment. Furthermore, although out of the scope of this study, it is noted that protecting source waters for public health objectives may provide multiple additional environmental and economic benefits.

Even where water treatment is used to mitigate risk, the costs of water treatment, and the risks to public health from those consuming treated water, can be reduced through enhanced catchment management. The Australian Drinking Water Guidelines recommend managing water quality risks via multiple barriers so that even where water treatment is used, it is appropriate to further minimise risks through catchment interventions.

In practice, a combination of both catchment management and water treatment are typically used in combination to minimise risks through multiple barrier management. In general, the more effective the catchment management, the lower the risks and costs related to public health, the more inherently reliable the controls become and the lower the costs of water treatment.

1.3.2. Victorian powers to control stock access to waterways

In principle, there are powers to prevent pathogen pollution of Victorian waterways through stock exclusion. For instance (paraphrased and abridged for this summary):

- Under the *Catchment and Land Protection Act 1994* it is necessary to: avoid causing or contributing to land degradation; conserve soil; and protect water resources.
- Under the *Environment Protection Act 1970* there is an offence for polluting waters so that the condition of the waters is so changed as to make or be reasonably expected to make those waters noxious or poisonous, harmful or potentially harmful to human health.
- Under the State Environment Protection Policy (Waters of Victoria) it is noted that discharge of animal waste…though grazing is one of the most imminent threats to Victoria's water environments…animal wastes must not be dumped in waterways….the main contributors of animal wastes are stock access to surface waters…effective farm management practices include controlling stock access to surface waters. Further, an environmental hazard is defined as a state of danger to human beings resulting from any substance having toxic infectious characteristics.
- Under the *Water Act 1989* an Authority may…remove from land that is…adjacent to any waterway…any substance or thing that is…likely to affect the purity of the Authority's water supply system.

In summary, bringing the above objectives and powers together, it could be inferred that a water authority would have the right to exclude stock from waterways to prevent pollution of drinking water sources from infectious pathogens that might be reasonably expected to potentially harm human health. In fact, the ideal from a drinking water quality perspective would be to remove all stock from catchments to entirely control the risk at source and obviate the need for additional water treatment.

In practice, such powers are not likely to be enforced. It would be politically difficult to implement, monitor and enforce such powers. It may not be economically or socially appropriate to enforce such powers in some circumstances. Furthermore, in practical terms, catchment interventions can be cost effective but would typically take many years to physically implement to reach the point where significant reductions in risks to public health would be achieved. Therefore, in most grazed catchments, a prioritised and gradual approach to risk mitigation through targeted catchment interventions is the most likely improvement pathway. Appendix A provides a detailed discussion on instruments to support catchment interventions that are relevant to riparian management.

1.3.3. Prioritising interventions

The overwhelming source of risk posed by *C. parvum* in typical grazing water supply catchments arises from pre-weaned calves and lambs. Removing calves and lambs from catchments, or housing them in fenced areas that are as hydrologically isolated as practicable from waterways that are associated with the supply of drinking water, can reduce risks due to this pathogen by approximately 3 $\log_{10}$ – similar to the reductions achieved by water filtration or UV disinfection systems. This reveals that any intervention in a catchment that grazes both adult and juvenile stock but that only targets adult stock is all but futile with respect to *C. parvum* risk reduction. On the other hand, targeting only juvenile stock is the most cost-effective first intervention that should be applied.

Catchment interventions that do not include physical exclusion of stock from waterways are of little value. For instance, off stream watering and shade structures do little to reduce the risks posed by *C. parvum* in a typical grazing water supply catchment unless stock are also physically excluded from the waterway. To be effective, interventions need to either physically reduce stock densities, or need to physically exclude stock from any waterways that are associated with the supply of drinking water.

Proper exclusion means physical fencing out of stock from any water that flows when water is harvested and, further, setting back stock access from waterways by at least several metres of well vegetated, perennially grassed buffer (filter) strip.

Fencing out needs to be continuous to be effective – gaps in the fencing or designed waterway access points will virtually eliminate the value of the fencing from the perspective of *C. parvum* risk reduction.

The relationship between the extent of stock exclusion from waterways and the benefits are reasonably linearly related. However, in practice, the benefits are typically expressed on a logarithmic scale. To be useful, improvements of 1 or more $\log_{10}$ orders of magnitude are required. This scale of benefit requires extensive catchment interventions. For instance, to reduce risks by 2 $\log_{10}$ would require the exclusion of approximately 99% of juvenile stock. Simply increasing the extent of exclusion by tens of per cent would do little on a log scale to reduce risks to public health and would be unlikely to obviate the need for additional water treatment. To be credible and to make a significant difference to health risks and treatment costs, catchment interventions need to be extensive and well implemented across the catchment.

The nature and scale of riparian buffers that would adequately protect pathogens from stock entering waterways is unremarkable. Typical buffer distances used in riparian restoration programs of 5 to 10 m are quite adequate to entrap most pathogens and reduce their flow into waterways by orders of magnitude. As with all aspects of riparian buffer management, the integrity of the fencing and riparian vegetation must be good for the buffers to be effective. Furthermore, riparian buffers would lose their effectiveness if overwhelmed by major floods or high intensity storms. Under such circumstances water harvesting from drinking water off-takes could potentially be avoided if at other times catchment management were the principal means of control of pathogens from stock.

1.3.4. Benefits and costs

The costs of outbreaks (tens to hundreds of millions of dollars) are overwhelmingly higher than the costs of their prevention. Therefore, as a general conclusion, it is considered appropriate to ensure that waterborne disease outbreaks do not arise due to pathogens entering water supplies via stock accessing waterways upstream of drinking water off-takes.

Catchment interventions can compare favourably to treatment interventions in terms of cost. For instance, a typical UV disinfection system might have a net present value of some millions of dollars, which, for an equivalent cost, could provide for the managed exclusion of stock from tens to hundreds of km of waterways. A typical filtration and UV disinfection system might have a net present value of some tens to hundreds of millions of dollars, which could provide for the managed exclusion of stock from hundreds to thousands of km of waterways.

Targeted catchment management programs that focus on pre-weaned juvenile stock might be able to reduce pathogen risks for a cost similar to, or less than, the costs of UV disinfection, and for a similar or greater benefit. Broadscale catchment management programs that seek to manage all stock might be able to reduce pathogen risks for a cost similar to, or less than, the costs of filtration and UV disinfection, and for a similar or greater benefit.

Compared to water treatment, catchment interventions are inherently more beneficial in overall environmental terms and can be more favourable in terms of the inherent reliability. On the other hand, in terms of time to effect, water treatment interventions are likely to be more amenable to expedient implementation than catchment interventions. In mitigating risks in any particular catchment, the most appropriate balance of investments between catchments and treatment, and the nature of those investments, needs to be assessed on a case-by-case basis. As a general conclusion, it is considered appropriate to compare the time to effect, costs, reliability and benefits of a range of catchment and treatment interventions in various practicable combinations. The resulting analysis would identify the most appropriate investment for any particular circumstance.

1.3.5. Future activity

It is recommended that practical, policy guidance be developed to assist water supply agencies and catchment management authorities implement targeted, cost-effective catchment interventions to help reduce risks to the health of drinking water consumers, reduce water treatment costs and improve the reliability of the safety of public water supplies. The guidance needs to promote the targeted exclusion of juvenile stock from drinking water catchment watercourses – prioritising the most intensely grazed and frequently flowing areas closest to drinking water off-takes – using actively maintained longitudinally contiguous fenced buffers of at least 5 to 10 m width and vegetated with perennial grass filter strips.

The optimal mix of catchment and treatment interventions will vary between situations and is a function of the current versus desired state of catchment and treatment controls as well as the proportion of catchment yield used for potable use. However, the approach illustrated within this document demonstrates that it is possible to develop an approximate evidence base for assessing benefits and costs in mitigating risks from pathogens in a drinking water catchment. Risks, costs and benefits can be estimated for a range of realistic scenarios to support business cases for optimal resource allocation.

2. Introduction

The purpose of this study was to assemble objective evidence and provide defensible guidance relating to the assessment and management of public health risks associated with stock accessing waterways upstream of drinking water off-takes.

The results of the study are to be used by the Department of Health and the Government of Victoria to support and inform policy positions.

The framework adopted in this study was consistent with the environmental health risk assessment approach recommended in enHealth 2002. The approach involves four steps:

- hazard identification – selecting hazards to be considered in the risk assessment;
- exposure assessment – quantifying exposure to the selected hazards;
- dose-response analysis – quantifying health effects of exposure to hazards; and
- risk characterisation – determining the significance of the assessed risks.

The report is broadly structured according to this framework. The initial sections of the report provide concise summary information. The remainder of the report provides substantial supporting sections that provide the evidence base for the initial sections.

Human sewage is thought to be the source of pathogens causing most waterborne disease outbreaks in developed countries. Manure from stock animals is the next most common implicated source.

Whereas there is seldom debate as to the importance of sewage as a source of pathogens that can infect humans, there is often uncertainty about the importance of stock manure. However, the pathogens carried by stock are important and can cause morbidity and mortality in humans via waterborne disease transmission.

Within Victoria there are reasonably strong legislative powers to facilitate the management of human faecal waste, including sewage from sewerage systems and on site wastewater management systems. This high priority given to the management of human faecal waste is appropriate given its primacy as a source of human infectious pathogens. There have been major investments in the management of human faecal waste, e.g. through backlog sewerage programs and the promotion of enhanced on-site sewage management system waste management.

In contrast to the situation with human faecal waste, manure from stock animals is poorly controlled within Victoria. Open defecation by stock animals is more common than not across Victorian agricultural areas. Many Victorians are supplied with drinking water that is harvested from waterways that are not protected from poorly controlled manure contamination. Therefore, within Victoria, poorly controlled manure from stock animals may present a more significant source of waterborne disease risk than the relatively better controlled human waste.

3. Literature review

3.1. Background

Current approaches to ensure the delivery of high-quality water involve a risk management approach from catchment to consumer. An important component of this strategy is to reduce the risk of pathogen contamination by implementing a multi- barrier approach to the protection of raw drinking water quality including the control of contaminant inputs through catchment management. One potential source of pathogens in drinking water watersheds are the faeces of domestic and wildlife animal populations. Pathogens from animal faeces may enter waterways by direct deposition or as a result of overland runoff containing faecal material deposited within the catchment. Stock manure presents arguably the second-most known significant source of pathogens that cause waterborne disease (Figure 3-1).

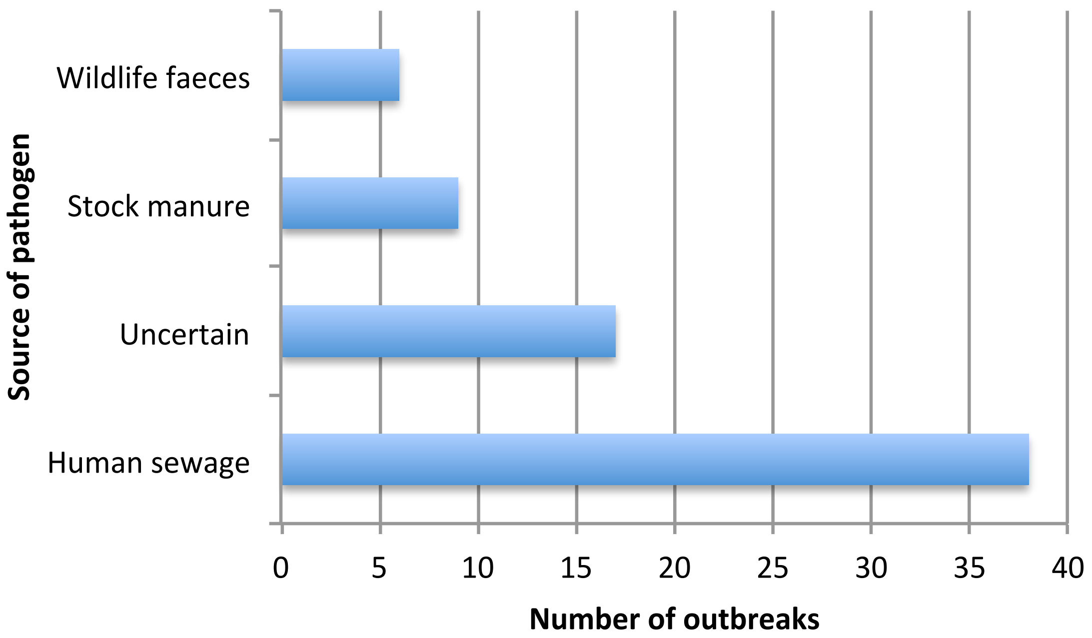

Figure 3-1. Summary of the causes of the waterborne disease outbreaks listed in the review by Hrudey and Hrudey (2004).

In relation to non-bacterial pathogens, such as *Cryptosporidium* spp., it is important to consider the pathogens themselves rather than just indicator bacteria (such as *E. coli*) since reliance on faecal indicator bacteria will result in improper assessment and management of pathogen risks. There may be either an underestimation or overestimation of pathogen risks due to the frequent lack of correlation between the presence of indicator bacteria and pathogens, and the differences in their fate and transport characteristics (Ferguson et al., 2007). Indicator bacteria are more sensitive to inactivation through treatment processes and by sunlight than viral or protozoan pathogens (Hurst et al., 2002; Sinclair et al., 2009). Other limitations have been associated with the application of indicator bacteria including: short survival compared to pathogens

(McFeters et al., 1974), non-exclusive faecal source (Scott et al., 2002; Simpson et al., 2002), ability to multiply in some environments (Solo-Gabriele et al., 2000; Pote et al., 2009), inability to identify the source of faecal contamination (point and non-point) (Field et al., 2003) and low correlation with the presence of pathogens (Pina et al., 1998; Horman et al., 2004; Savichtcheva and Okabe, 2006). As a result, none of the bacterial indicators that are currently used meet all the established criteria for the protection of drinking water quality, or is a reliable surrogate for non-bacterial pathogens such as *Cryptosporidium* spp. oocysts.

In relation to stock animals, the pathogens reviewed in this section of the report, being commonly found in stock and known to be infectious to humans, include *Cryptosporidium parvum*, *Giardia duodenalis, Salmonella* spp., *Campylobacter* spp. and pathogenic strains of *Escherichia coli*. The pathogen of most concern is *C. parvum* due to its resistance to oxidant disinfectants and lack of relationship to indicator *E. coli*.

The number of outbreaks that have been reported throughout the world demonstrates that transmission of pathogens by drinking water remains a significant cause of illness (see for instance Hrudey and Hrudey 2004). However, estimates of illness based solely on detected outbreaks underestimate the problem. A significant proportion of waterborne illness goes undetected by disease surveillance and reporting systems. The symptoms of gastrointestinal illness (nausea, diarrhoea, vomiting, abdominal pain) are usually mild and generally only last a few days to a week, and only a small percentage of those affected will see a doctor. Among these, only a minor proportion will have their stools microscopically examined. Most sporadic cases of waterborne intestinal illness will not be detected or, if detected, may not be recognised as water-related. In industrialised countries, drinking water that meets current water quality standards may still harbour low concentrations of pathogenic microorganisms. These will cause occasional illness throughout the community served. It is very difficult to relate these sporadic cases to drinking water, as they are overshadowed by the endemic level of disease circulating in the population through other routes of transmission (person-to-person, food and animal contact).

3.2. *Cryptosporidium parvum*

Cryptosporidium is an enteric parasite that has a global impact on the health and survival of millions of people and animals worldwide. The resistant oocyst stage of the organism's life cycle is excreted in the faeces of infected animals and humans and can contaminate sources of drinking water. The main symptom of cryptosporidiosis is diarrhoea, which may be accompanied by dehydration, weight loss, abdominal pain, fever, nausea, and vomiting. Disease, although lasting for up to two weeks, is usually self-limiting in immunocompetent and otherwise healthy humans. However, persistent infection can contribute to mortality in individuals with weakened immune systems (Xiao, 2009). Currently, nitazoxanide (NTZ) is approved for treatment of cryptosporidiosis in children and immunocompetent adults in the U.S.A., however NTZ is not effective without an appropriate immune response and is therefore ineffective for the treatment of immunocompromised individuals (Gargala, 2008).

Of the 23 currently recognised species (Table 3-1), two species are responsible for the majority of infections in humans: *C. parvum* and *C. hominis* which cause over 95% of the reported causes of human cryptosporidiosis (Xiao and Ryan, 2008). Within Australia, C. *hominis* predominates in human cryptosporidiosis infections (Morgan et al. 1998; Jex et al. 2008; Waldron et al. 2009).

Table 3-1. Valid species of *Cryptosporidium*

Species	Major hosts	Minor Hosts	Reference
C. parvum	Cattle, sheep, goats, humans	Deer, mice, pigs	Tyzzer, 1912
C. hominis	Humans, monkeys	Dugongs, sheep, cattle	Morgan-Ryan *et al.*, 2002
C. suis	Pigs		Ryan *et al.*, 2004
C. bovis	Cattle, sheep		Fayer *et al.*, 2005
C. ryanae	Cattle		Fayer *et al.*, 2008
C. xiaoi	Sheep		Fayer and Santin, 2009
C. andersoni	Cattle, bactrian camels	Sheep	Lindsay *et al.*, 2000
C. wrairi	Guinea pig		Vetterling *et al.*, 1971
C. felis	Cats	Humans, cattle	Iseki, 1979
C. canis	Dogs	Humans	Fayer *et al.*, 2001
C. meleagridis	Turkeys, humans	Parrots, chickens, cockatiels	Slavin, 1955
C. fayeri	Red Kangaroo, Eastern Grey Kangaroo, Koala		Ryan *et al.*, 2008
C. macropodum	Eastern Grey Kangaroo, swamp wallaby		Power and Ryan, 2008
C. ubiquitum	Sheep, deer, humans		Fayer et al. 2010
C. baileyi	Chicken, turkeys	Cockatiels, quails, ostriches, ducks	Current *et al.*, 1986
C. galli	Finches, chicken, capercalles, grosbeaks		Ryan *et al.*, 2003
C. serpentis	Snakes, lizards		Tilley *et al.*, 1990
C. varanii	Lizards	Snakes	Pavlásek *et al.*, 1995
C. fragile	Frogs		Jirků *et al.*, 2008
C. duismarci	Tortoises		Traversa, 2010
C. molnari	Fish		Alvarez-Pellitero and Sitja-Bobadilla, 2002
C. scophthalmi	Fish		Alvarez-Pellitero *et al.*, 2004
C. muris	Rodents, bactrian camels	Humans, rock hyrax, mountain goats	Tyzzer, 1907

The oocysts are infectious immediately upon being excreted in faeces and can survive for several months in the aquatic environment (Robertson et al. 1992; Johnson et al. 1997). The infectious dose is low; ingestion of as few as 10-30 oocysts can cause a 50% chance of infection in healthy persons (Dupont et al., 1995; Okhuysen et al., 1999; Messner et al., 2001).

Cryptosporidium currently represents the major public health concern for water utilities in developed nations. It is also considered a potential bioterrorist agent (www3.niaid.nih.gov/topics/BiodefenseRelated/Biodefense/research/CatA.htm), because the oocysts produced by *Cryptosporidium* are extremely hardy, easily spread via water, resistant to chlorine and are difficult to inactivate or remove from water intended for consumption without the use of filtration supported by effective coagulation (Striepen and Kissinger, 2004). In a recent review, 325 water-associated outbreaks of parasitic protozoan disease worldwide were reported and the majority of outbreaks, 50.8%, were associated with *Cryptosporidium* (Karanis et al., 2007).

As this organism is resistant to standard chlorine disinfection, conventional water treatment processes, such as coagulation, flocculation, sedimentation, filtration and disinfection, rely on efficient plant performance for the removal of this pathogen. For most other pathogens subsequent disinfection with chlorine (or chloramine) will provide additional inactivation of any pathogens that may break through – but not for *Cryptosporidium*.

Depending on the efficiency of the conventional water treatment plant, oocysts may pass through the treatment process and enter the distribution system, even if no treatment failure has occurred (Solo-Gabrielle and Neumeister, 1996). The oocysts may still be capable of causing infection. Therefore, *Cryptosporidium* represents a threat to public health and an ongoing challenge to water service providers and has been responsible for numerous waterborne disease outbreaks.

C. parvum oocysts have been shown to be able to survive up to 176 days in drinking water or river water stored at 4°C, with inactivation between 89% and 99% of the population (Robertson et al., 1992). Desiccation is detrimental to oocyst survival and low water activity has been reported to result in reduced viability (Rose and Slifko, 1999). A study by Robertson et al (1992) showed air-drying at room temperature resulted in 97% inactivation within 2 hours and 100% inactivation within 4 hours (Robertson et al., 1992).

The C. *hominis*-linked outbreak in Milwaukee, WI, in 1993, which involved over 400,000 infections and at least 54 deaths, is a clear example of a cryptosporidiosis outbreak due to oocyst-contaminated drinking water. The total illness-associated cost of the 1993 Milwaukee waterborne outbreak of cryptosporidiosis was estimated at $96.2 million: $31.7 million in medical costs and $64.6 million in productivity losses (Corso et al., 2003).

Cryptopsoridiosis became a notifiable disease in Australia in 2001. In Australia there were an average of 2,580 cases per year for the five years from 2004 to 2009 inclusive with over 1,000 cased notified within Victoria in 2009 (National Notifiable Diseases Surveillance Program-NNDSP).

The most publicised incident of drinking water contamination in Australia occurred in July-September 1998 in Sydney. High numbers of *Cryptosporidium* and *Giardia* were reported for treated water, and boil-water notices were issued for 3 million residents. No increase in illness was detected in association with the contamination despite increased epidemiological surveillance. The incident highlighted the lack of a method to determine whether detected organisms are infective for humans.

According to the Australian Drinking Water Guidelines (ADWG), a multiple barrier approach operating from catchment to tap should be implemented to minimise the risk of contamination by *Cryptosporidium*. Protection of water catchments from contamination by human and animal wastes should be a priority.

The coliform bacteria are unreliable as indicators of either the presence or viability of *Cryptosporidium* oocysts (Smith and Nichols, 2010). The most common methods used in Australia for *Cryptosporidium* and *Giardia* involve the use of filtration, immunomagnetic separation (IMS) of oocysts from filter-entrapped particulate matter and detection using an immunofluorescence assay, 4′,6-diamidino-2-phenylindole (DAPI) staining, detection by epifluorescence microscopy, and determination of internal morphology using

Nomarski differential interference contrast (DIC) microscopy prior to determining oocyst concentration (Smith and Nichols, 2010).

Environmental monitoring for waterborne pathogens is confounded by a number of factors, including (1) the small size of the organisms, (2) the difficulty in identifying the organisms amongst other particles and debris (3) poor reliability of the test method (4) antibody cross-reactivity, (5) autofluorescence (6) high cost and complexity, (7) time-consuming, (8) inability to identify to species level and (9) difficulties in discrimination of viable from non-viable organisms (Fricker and Crab, 2000). The more turbid the water, the more difficult this becomes.

As a consequence, current methods for the isolation and enumeration of protozoa and bacteria in water concentrates are variable in their performance. In addition, due to these difficulties and the costs involved, many authorities do not test and therefore available data is limited for catchment planning purposes.

3.3. Giardia duodenalis

Giardia duodenalis is a widespread parasite of mammalian species, including humans and has a global distribution causing an estimated 2.8 x 10^8 cases per year (Lane and Lloyd, 2002). In Asia, Africa and Latin America, about 200 million people have symptomatic *Giardia*sis with some 500,000 new cases reported each year (WHO, 1996). There is considerable variation within G. *duodenalis* and several major genotypes/assemblages have been identified: with assemblage A and B associated with human and animal infections. The remaining assemblages (C to G) are likely to be host-specific, as assemblages C and D have been identified in dogs, cats, coyotes and wolves, assemblage E in cattle, sheep, goats, pigs, water buffaloes and muflons, and assemblages F and G in cats and rats, respectively (Caccio and Ryan 2008). The prevalence of assemblages A and B varies considerably from country to country, although assemblage B seems more common (Caccio and Ryan, 2008).

Giardia, has greater susceptibility to environmental inactivation, water treatment disinfection with chlorine and removal by filtration than *Cryptosporidium* and is therefore considered less problematic. In a recent review, 325 water-associated outbreaks of parasitic protozoan disease worldwide were reported and *G. duodenalis* accounted for 40.6% of them (Karanis et al., 2007).

3.4. Campylobacter spp.

Campylobacter species, and in particular *Campylobacter jejuni* and *Campylobacter coli,* are the most common cause of gastroenteritis in humans in the developed world (Moore et al. 2005). The main symptoms are abdominal pain and diarrhoea, which can vary from limited to voluminous stools, which may be watery or bloody. In severe or recurrent cases antibiotics are required, however, the emergence of antibiotic resistance has since made their efficacy less certain.

In Australia, *Campylobacter* is the most common gastrointestinal infection in humans with an average of 16,005 cases reported annually for each of the five years from 2004 to 2009 and 5,838 cases reported in 2009 in Victoia (NNDSP). Human infectious species of *Campylobacter* can arise from stock animal manure as well as wildlife and human faecal sources. Faecal contamination is the main form of transmission and *Campylobacter* are widespread in surface waters. *Campylobacter* spp are highly sensitive to desiccation and do not survive well on dry surfaces (Fernandez, 1985). Even though they are sensitive to desiccation and do not grow at temperatures below 30°C. *Campylobacter* spp., like other bacterial pathogens, survive well at low temperatures, and can survive for several weeks in cold groundwater or unchlorinated tap water. The 50% infectious dose is 500 organisms or less (by ingestion). *Campylobacter* have been identified in some Australian water supplies and there have been reports of infections from drinking water in Australia, particularly from rainwater tanks (see OzFoodNet reports for details).

Campylobacter is highly susceptible to standard disinfection processes, being more sensitive than *E. coli* to chlorine (Westrell et al., 2003). Therefore, this renders the organism less of an issue for the water industry provided treatment conditions are appropriate (Westrell et al., 2003). In developed countries, the potential for issues only arises during system failure or upset, which can be due to heavy rains, breakdown or inappropriate monitoring.

3.5. Salmonella spp.

Salmonella spp. are some of the most common pathogens of humans and diseases caused by *S. enterica* are responsible for over 20 million cases and 200,000 deaths worldwide each year (Crump et al. 2004). Challenges such as antibiotic-resistant *Salmonella* strains pose a significant threat to the development of reliable therapies. In Australia, salmonellosis is the second most common gastrointestinal infection with an annual average of 8,469 cases reported for each of the five years from 2004 to 2009 and 1,647 cases reported in Victoria in 2009 (NNDSS). *Salmonella* has been isolated from a number of source waters in Australia and occasionally from reticulated waters and some waterborne disease outbreaks have been associated with rainwater tanks (see OzFoodNet reports for details). Most illnesses resulting from *Salmonella* infection are derived from contaminated foodstuffs, e.g. poultry and livestock.

Human infectious species of *Salmonella* can arise from stock animal manure as well as wildlife and human faecal sources. The presence of these organisms in waterways is due to faecal contamination. This can be exacerbated by the use of animal excreta on farmland (muckspreading) or intensive farming where there is run-off from dairy farms and feedlots after long periods of wet weather. Treatment by disinfection using chlorine is usually effective against *Salmonella* spp., provided the water has low turbidity. *Salmonella* is highly susceptible to standard disinfection processes, being more sensitive than *E. coli* to chlorine (Westrell et al., 2003). Therefore, this renders the organism less of an issue for the water industry provided treatment conditions are appropriate (Westrell et al., 2003). In developed countries, the potential for issues only arises during system failure or upset, which can be due to heavy rains, breakdown or inappropriate monitoring.

3.6. Pathogenic E. coli

E. coli are members of the family Enterobacteriaceae and are a common part of the normal intestinal flora of humans and other warm-blooded animals. The organisms are described as gram-negative, facultatively anaerobic rod shaped bacteria (Desmarchelier and Fegan, 2003). Although most strains of *E. coli* are considered harmless, the species does contain certain strains that can cause severe illness in humans (Bell and Kyriakides, 1998). Human pathogenic *E. coli* are characterised into specific groups based on virulence properties, mechanisms of pathogenicity and clinical syndromes (Doyle et al., 1997). These groups include:

- enteropathogenic *E. coli* (EPEC);

- enterotoxigenic *E. coli* (ETEC);
- enteroinvasive *E. coli* (EIEC);
- enteroaggregative *E. coli* (EAEC); and
- enterohaemorrhagic *E. coli* (EHEC).

The best known and most widely studied is *E. coli* O157:H7, which belongs to enterohaemorrhagic *E. coli* (EHEC) group. *E. coli* is considered to be an important bacterium to the water industry, both as a cause of waterborne outbreaks by *E. coli* 0157:H7 and as an indicator organism for the detection of faecal contamination. *E. coli* O157:H7 causes diarrhoeal illness and has been responsible for both drinking water and recreational water outbreaks of disease. *E. coli* 0157:H7 has been reported in 31 outbreaks in the US between 1982-2002, accounting for 9% of all outbreaks by this pathogen (Rangel et al., 2005). Most facilities use faecal coliforms or total coliforms as an indicator, but neither group of organisms statistically correlate with pathogenic bacteria removals (except for *Salmonella*) (Koivunen et al., 2003). Dairy and beef cattle are primary reservoirs of *E. coli* O157:H7 (Bach et al., 2002) and they can carry it asymptomatically and shed it in their faeces. *E. coli* O157:H7 is a hardy pathogen that can survive for long periods of time in water, especially at cold temperatures (8°C or less) (Wang and Doyle, 1998). *E. coli* O157:H7 is susceptible to disinfection (Kaneko, 1998; Rice et al., 2000). A multi-barrier approach based upon source protection (where possible), effective treatment, and a well-maintained distribution system will reduce the levels of *E. coli* O157:H7 in drinking water to none detectable or to levels that have never been associated with human illness. *E. coli* O157:H7 is not likely to occur in the absence of generic indicator *E. coli*. As a result, the presence of *E. coli* can be used as an indicator of the presence of *E. coli* O157:H7.

3.7. *Cryptosporidium* in cattle and sheep

Over the past 20 years, cattle and sheep have been thought to be two of the main reservoir hosts for the zoonotic *C. parvum*. On average, a 450 kg steer will excrete a total of 10 tonnes of wet dung per year and a 40 kg sheep about 0.6 tonnes (Anon, 2003). The environmental loading rate of *C. parvum* in cattle has been estimated at between 3,900 to 1.7×10^5 oocysts cow^{-1} day^{-1} (Hoar et al. 2000; Atwill et al. 2003). Cattle can therefore potentially contribute significantly to contamination of drinking water catchments with *Cryptosporidium*.

Cattle are infected with at least five *Cryptosporidium* species: *C. parvum*, *C. bovis*, *C. andersoni*, *C. ryanae* (previously called deer-like genotype) and C. suis (Xiao and Feng, 2008; Xiao, 2010). Of these, only *C. parvum* is considered a significant human pathogen (Xiao, 2010). Therefore, it is important when looking at human health to consider only *C. parvum* in this context.

There appears to be geographical differences in the age-related prevalence of different *Cryptosporidium* species in cattle. In parts of the US, Belgium, Ireland, Germany, Malaysia, the UK and Sweden, it has been reported that the zoonotic *C. parvum* is responsible for the majority of *Cryptosporidium* infections in pre-weaned calves and only a small percentage of *Cryptosporidium* infections in post-weaned calves and heifers (Santin et al., 2004, 2008; Brook et al., 2009; Geurden et al., 2007; Thompson et al., 2007; Xiao et al., 2007; Broglia et al., 2008; Halim et al., 2008; Silverlås et al., 2010). Post-weaned calves were mostly infected with *C. bovis*, *C. andersoni* and *C. ryanae* (Santin et al., 2004; 2008; Fayer et al., 2008). Other studies in China, India, Georgia and western North Dakota however, have reported that *C. bovis* was the most common species found in pre-weaned calves (Feng et al., 2007; Feltus et al., 2008).

In Australia, the prevalence of *Cryptosporidium* in cattle ranges from 22.5-46.3% (Becher et al., 2004; Nolan et al., 2009; Ng et al., 2010). A recent study examined the prevalence of *Cryptosporidium* in faecal samples from 268 individual calves on pasture-based dairy farms in three regions of Victoria, Australia (Northern Victoria, South Gippsland and Western District), (Nolan et al., 2009). The detection tool employed (PCR analysis of the GP60 locus) was specific to *C. parvum/C. hominis* and therefore only *C. parvum* was detected at a prevalence of 46.3% (124/268) (Nolan et al., 2009).

Another study examined the occurrence of ten pathogens and three faecal indicators in eastern Australian cattle feedlot manures using quantitative PCR. High counts of *Giardia* and *Cryptosporidium* ($>10^5$ g^{-1}) were sporadically identified in all manures, indicating high persistence of their DNA targets (Klein et al., 2010). A limitation was the unknown number of intact dead cells detected by qPCR that may lead to an overestimation of risk.

Cryptosporidium has been reported in sheep worldwide, however most studies have been based on microscopy and reported prevalence ranged from 2.6% to 82% (cf. Ryan et al., 2005). It has been estimated that experimentally infected lambs excreted 1-4 x 10^9 oocysts g^{-1} of faeces per day (Blewett, 1989; Bukhari and Smith, 1997).

In Australia, reported prevalence for ewes in Western Australia ranged from 6.3–8.3% (Sweeney et al., 2010) and for lambs from 9.3–56.3% on different properties (Yang et al., 2009; Sweeney et al., 2010).

Genetic analysis of sheep and lamb-derived *Cryptosporidium* isolates in Australia has identified *C. parvum*, C. *hominis*, *C. xiaoi*, *C. bovis*, *C. ubiquitum*, sheep genotype I, *C. andersoni*, pig genotype II, *C. fayeri* and *C. suis* in sheep and lambs (Ryan et al. 2005; Yang et al. 2009; Sweeney et al., 2010), with *C. xiaoi* and *C. ubiquitum* most common, although Yang et al. (2009) found high proportions of *C. parvum* isolates in pre-weaned sheep in Western Australia. Quantitation analysis using quantitative PCR (qPCR) and microscopy indicated that oocysts output in sheep faeces varies widely and ranges from ~1 to 10^6 oocysts per gram (Yang et al., 2009; Ryan et al., unpublished).

3.8. Giardia duodenalis in cattle and sheep

Giardia duodenalis has been implicated as an aetiological agent in dairy and beef calf diarrhoea worldwide (O'Handley et al., 1999; Huetink et al., 2001; Olson et al., 2004; Castro-Hermida et al., 2006; Guerden et al., 2008a). Studies worldwide have reported prevalence ranging from 3% to 64% for *Giardia* in cattle (Trout et al., 2007; Geurden et al., 2008b). Genotype analysis has identified predominantly assemblage E, with lower levels of the zoonotic assemblages A and B (Caccio and Ryan, 2008; Santin et al., 2009).

Few studies have been conducted to examine *Giardia* in pre and post-weaned animals (Becher et al., 2004; Trout et al 2004; 2005; Coklin et al., 2007; Santin et al., 2009). Two studies in the US and Australia reported that assemblage E but not assemblage A was detected in pre-weaned calves (Becher et al., 2004; Santin et al., 2009), whereas others have reported both assemblage A and E in pre-weaned cattle (Trout et al., 2004).

In Australia, the prevalence of *Giardia* in calves from different farms in WA and NSW ranged from 13.5% to 89% (Becher et al., 2004; O'Handley 2000; Ng et al., 2010). Genotype analysis identified that 64.5%-94.6% were the non-zoonotic assemblage E (Becher et al., 2004; O'Handley 2000; Ng et al., 2010). In a study of pathogens in cattle faeces in the Sydney watershed, the prevalence of *Giardia* in cattle was ~77% (Cox et al., 2005).

In sheep, the prevalence of *Giardia* in Western Australia ranged from 20.3%-44% (Ryan et al., 2005; Sweeney et al., 2010). Genotype analysis identified that ~75-90% of positives were infected with the non-zoonotic assemblage E, whereas ~10-25% had the zoonotic assemblage A (Ryan et al., 2005; Sweeney et al., 2010). In a study of pathogens in sheep faeces in the Sydney watershed, the prevalence of *Giardia* in sheep was ~66% (Cox et al., 2005).

3.9. Campylobacter species in cattle and sheep

The role of cattle and sheep in producing human campylobacteriosis, either directly or via contaminated food, remains to be epidemiologically clarified, however studies suggest that the production system, particularly for cattle, may be an important consideration. In a study of faeces from 475 slaughter-age cattle and sheep from 19 herds or flocks in Australia, *Campylobacter* species (*C. jejuni* and *C. coli*) were cultured from all production systems studied and from 73.7 per cent (14/19) of herds or flocks (Bailey et al., 2003). Within individual properties there was a higher prevalence in cattle than in sheep, with *Campylobacter* being most commonly isolated from feedlot cattle. The median prevalence and ranges were: for dairy cattle, six per cent (0-24%), feedlot beef cattle, 58 per cent (12-92%) pasture beef cattle, two per cent (0-52%), mutton sheep, 0 per cent (0-4%) and prime lambs eight per cent (Bailey et al., 2003).

Another study examined the occurrence of ten pathogens and three faecal indicators in eastern Australian cattle feedlot manures using quantitative PCR. *C. jejuni* was initially abundant but was rapidly inactivated (Klein et al., 2010). Another study examined the prevalence of *Campylobacter* in lambs in Western Australia and reported <5% prevalence (unpublished data).

3.10. Salmonella species in cattle and sheep

Salmonella enterica is a diverse bacterial species comprised of over 2,500 serotypes (Callaway et al., 2005) and a wide range of *Salmonella*e have been isolated from cattle worldwide. The most common type of *Salmonella* affecting cattle is *Salmonella enterica* serovar Dublin, which is largely adapted to cattle but can occasionally cause infection in humans. A recent study examined pasture beef cattle, feedlot beef cattle, dairy cattle, prime lambs and mutton sheep from 215 herds and flocks in the four eastern states of Australia (Vanselow et al., 2007). A wide diversity of *Salmonella* serovars, all of which have been isolated from humans in Australia, were identified in both cattle and sheep. The highest herd prevalence of non Dublin *Salmonella* spp. was found in dairies (17%), followed by feedlots (13%). However, prevalence in individual animals was low (0.2-1.7%). Statistical analysis revealed that dairy cattle were significantly more likely to shed *Salmonella* in faeces than pasture beef cattle, mutton sheep and prime lambs ($P < 0.05$) (Vanselow et al., 2007).

3.11. E. coli in cattle and sheep

Cattle and sheep are asymptotic natural reservoirs of *E. coli* O157:H7 and it is believed that about 30-80% of cattle are carriers of this pathogen (Callaway et al., 2003). The bacteria can survive in liquid manure, non-liquid manure and drinking troughs. Foods that are irrigated, washed or prepared with polluted water are also a common cause of infection (Doyle, 1990).

3.12. Cryptosporidium in human sewage

Sewage from humans includes both *C. parvum* and *C. hominis* with some other genotypes, such as *C. meleagridis*, occasionally but relatively rarely reported (see for example Chalmers et al., 2005). The oocysts in sewage (both in sewage systems and onsite sewage management systems) are almost entirely human-derived and human infectious – effectively the proportion of infectious genotypes is 100%, with a concentration of the order 2,000 oocysts per L as a 95%ile as given in the Australian Guidelines for Water Recycling 2006 (AGWR).

Whilst *Cryptosporidium* sourced from humans is a significant risk, the relative contribution of human infectious *Cryptosporidium* is relatively low where catchments have many grazing animals. For example, the number of *Cryptosporidium* oocysts per day from one human would be of the hundreds of thousands on average. In comparison a calf might shed tens of millions of human infectious oocysts per day on average (Table 3-2; Figure 3-2). In practice, the values given per host are highly variable and uncertain, but at a catchment planning scale the effect will average out making these values useful for broadscale risk assessment.

Table 3-2. Approximate average yield of human infectious Cryptosporidium per day per host. Data from Table 3-4 for animals and AGWR (2006) for humans.

Factor	Human sewage	Calf manure	Lamb manure	Dairy cow manure	Beef cow manure	Sheep manure
Prevalence	100%	50.30%	12.90%	11.90%	11.90%	5.30%
Concentration in matrix	2,000/L	24,000/g	18,000/g	1,778/g	1,371/g	2,800/g
Human-infectious proportion	100%	85%	70%	0.70%	0.70%	1.00%
Daily quantity	150 L	5,600 g	1,000 g	55,000 g	2,100 g	1,100 g
Average human infectious oocysts per host per day	300,000	57,462,720	1,625,400	81,459	2,398	1,632

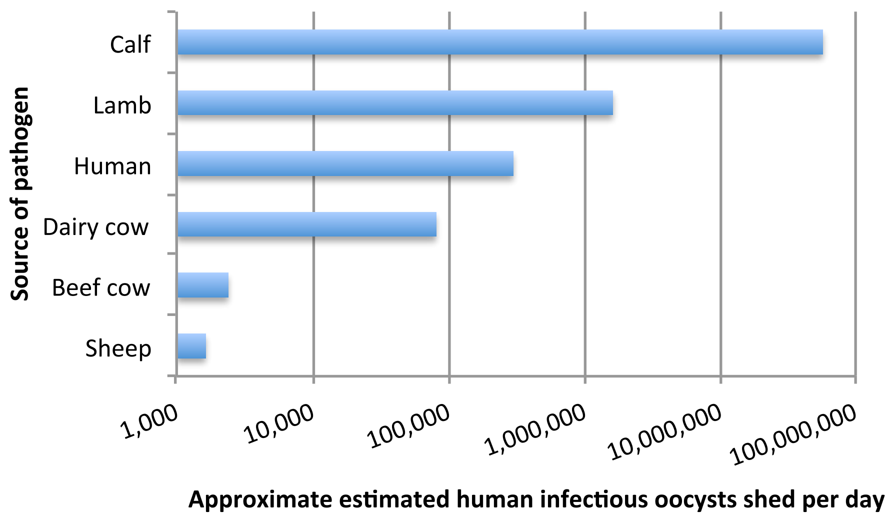

Figure 3-2. Approximate estimated human infectious oocysts shed per day by a human or animal host.

3.13. Summary of pathogens present in cattle and sheep

A summary of the identification of hazardous pathogens in stock animals in Victoria is given in Table 3-3.

Cattle and sheep are both symptomatic and asymptotic natural reservoirs of a range of important human pathogens.

Of the pathogens carried, *E. coli* O157:H7 probably represents the most deadly – with a case fatality rate in humans in developed countries that is higher than for most diarrhoeal disease causative agents. However, because pathogenic *E. coli* and other bacterial pathogens are relatively readily inactivated by common water disinfection methods, and reasonably well indicated by faecal indicator bacteria, protozoan pathogens present a more significant risk.

Among the protozoan pathogens, zoonotic strains of human infectious *Cryptosporidium* are typically more common in stock animals than zoonotic strains of human infectious *Giardia*. Relative to *Giardia*, *Cryptosporidium* are less readily inactivated, more readily transported and less amenable to water treatment. Furthermore, *Cryptosporidium* appears to have caused more waterborne disease outbreaks in developed countries than any of the other single pathogens as well as the largest waterborne disease outbreak reported in modern times (based on the aetiologies and outbreaks reported in Hrudey and Hrudey 2004). Therefore, *Cryptosporidium* has been selected as the principal pathogen of concern and the 'reference' pathogen for the purpose of this study. Note that risks and management interventions assessed and recommended for *Cryptosporidium* from stock will be generally applicable to other pathogens. The purpose of a 'reference' pathogen is to provide a point of reference that allows a microbial risk assessment to be focused on a manageable number of pathogens.

Table 3-3. Summary of the relevance of waterborne pathogens in stock

Waterborne pathogens	Susceptibility to environmental exposure	Susceptibility to treatment processes	Infectivity
Cryptosporidium parvum	Can survive for long periods (> 6 months) in the environment	Unaffected by typical doses of chlorine	Multiple species in meat cattle, only *C. parvum* is infective to humans. *C. parvum* mainly found in dairy calves, in older animals very low prevalence of human infectious species. Few studies in Australia. Multiple species in sheep but non-human infectious species more common.
***Salmonella* spp.**	Can survive for long periods in cold temperatures	Susceptible to chlorine	Dairy cattle more likely to shed *Salmonella* than meat cattle
***Campylobacter* spp.**	Sensitive to desiccation. Will not grow at temps < 30˚C	Susceptible to chlorine	C. *jejuni* and *C. coli* infective to humans and can be found in cattle and sheep.
Pathogenic strains of *Escherichia coli.*	Can survive for long periods in cold temperatures	Susceptible to chlorine	Highly infectious and with relatively high case fatality rate in humans. Present asymptomatically in stock animals.

3.14. Fate and transport in catchments and waterways

Surface soil, vegetation coverage, slope and rainfall runoff are all important factors in assessments of *Cryptosporidium* transport and when managing pathogen inputs from stock grazing near streams within drinking water watersheds. Studies on the dispersion and transport of *C. parvum* oocysts, seeded into artificial bovine faecal pats during simulated rainfall events have revealed that rainfall events mobilised 0.5 to 0.9% of *Cryptosporidium* oocysts and 1.3-1.4% of *E. coli* bacteria (Ferguson et al., 2007). A study in NZ found that *E. coli* concentrations increased more than 100 times after cattle crossed a stream, which could be attributed to direct faecal deposition, wash-off from legs and disturbance of sediments by cattle hooves (Davies-Colley et al., 2004).

Cryptosporidium oocysts present in animal faecal deposits on land have been qualitatively and causally linked to event-related increases in pathogen concentrations in streams and reservoirs (Ashbolt et al., 1998; 2003; Kistemann et al., 2002). Artificial buffer strips can be highly effective at retarding oocyst transport (Atwill et al., 2002). Sloping land (10˚ or more) with little or no vegetation cover and a short burst of rainfall of significant intensity represents a significant risk factor for the dispersion of oocysts from recent animal faecal deposits and their transport into nearby waters (Davies et al., 2004). Based on previous work by the authors, an updated set of assumptions to use in estimating the fate and transport of pathogens in waterways is presented in Table 3-4.

Work by the CRC for Water Quality and Treatment highlighted the important role of reservoir hydrodynamics in pathogen transport. It concluded that catchment inflows (with relatively low temperature) often move through the reservoir quickly and at depth (Brookes and Burch, 2003). The implication is that pathogens can move quickly through a reservoir to the point of off-take and are not necessary diluted by the volume of the storage. The assumption of extensive dilution is not valid in practice. Although potentially highly effective barriers under some conditions, reservoirs are notorious for short-circuiting. Even Australia's most massive drinking water reservoirs provide only minimal detention and dilution time during large storm events. Sydney's Warragamba Dam, at up to 2,400 GL in volume, has been shown to allow stormwater inflows to reach the water supply offtake point in less than one week and with a dilution factor of only two to three-fold (Hipsey et al., 2005). Smaller reservoirs experience less detention and dilution than larger ones. The Myponga Reservoir in Adelaide is typically around 20 GL in volume and even a relatively small storm event was tracked as passing through the reservoir in less than one day and was diluted by only ten-fold (Hipsey et al., 2005). It would be expected that a larger storm event would have traversed the reservoir in even less time and with even less dilution. Dilution and inactivation factors as low as 0.1 $\log_{10}$ have been reported even in very large reservoirs (Crosbie N., pers. comm.).

There would be some dilution and detention between runoff entering reservoirs and that water being extracted into the drinking water supply for consumption. However, based on evidence from modelling and measurement taken for other reservoirs, such as Myponga and Warragamba, it is likely that during large storm events the effect of dilution and detention would be small and possibly even negligible in terms of reducing pathogen concentrations and protecting public health. Therefore, in this risk assessment, dilution and detention effects within reservoirs were not quantified. Within streams, the effects of inactivation and sedimentation would be even less significant than that which would occur in reservoirs. Unless flows take many days to some weeks, the effects of riverine pathogen reduction would be from modest to insignificant.

Table 3-4. Values used in modelling and their basis.

Parameter	Value	Basis for selection of	Reference	Certainty
Manure production rates per day (kg)				
Sheep	1.1	Consistent with other studies	ASAE 1999	High
Lamb	1	Only reference found	Dorner 2004	Medium
Beef cow	21	Consistent with other studies	ASAE 1999	High
Dairy cow	55	Consistent with other studies	ASAE 1999	High
Calf (dairy or beef)	5.6	Consistent with other studies	ASAE 1999	High
Manure deposition rates in stream				
Sheep or lamb	1%	Judgement	Judgement	Low
Beef cow or calf	3.4%	The only study found	Larsen et al 1994	Medium
Dairy cow or calf	3.4%	The only study found	Larsen et al 1994	Medium
Baseline Cryptosporidium concentration/g manure				
Sheep	2,800	Large, long-term study	Sturdee et al 2003	Medium
Lamb	18,000	Large, long-term study	Sturdee et al 2003	Medium
Beef cow	1,371	Large, long-term study	Sturdee et al 2003	Medium
Dairy cow	1,778	Large, long-term study	Sturdee et al 2003	Medium
Calf (beef or dairy)	24,000	Large, long-term study	Sturdee et al 2003	Medium
Baseline Cryptosporidium prevalence				
Sheep	5.3%	Large, long-term study	Castro-Hermida et al 2007	Medium
Lamb	12.9%	Large, long-term study	Sturdee et al 2003	Medium
Beef cow	11.9%	Large, long-term study	Fayer et al 2005	Medium
Dairy cow	11.9%	Large, long-term study	Fayer et al 2005	Medium
Calf (beef or dairy)	50.3%	Large, long-term study	Santin et al 2004	Medium
Baseline Cryptosporidium human infectious proportion				
Sheep	1.0%	U. Ryan pers. comm. (Murdoch Univ)	Expert judgement	Low
Lamb (< 3 months old)	70%	U. Ryan pers. comm.	Expert judgement	Low
Beef cow	0.7%	Large, long-term study	Fayer et al 2005	Low
Dairy cow	0.7%	Large, long-term study	Fayer et al 2005	Low
Calf (beef or dairy; < 3 months old)	85%	Large, long-term study	Santin et al 2004	Low
Baseline manure mobilisation rates				
Manure deposited within connected source areas	10%	Based on field surveys	Chapman, B., pers. comm. 2011	Low
Cryptosporidium mobilisation from land in the absence of riparian fencing and vegetation cover	1%	Recent Australian data	Ferguson 2005	Medium
Cryptosporidium mobilisation from land with riparian fencing with > 5 m setback and good vegetation cover	0.002%	Recent Australian data	Ferguson 2005	Medium

4. Quantitative Microbial Risk Assessment

4.1. Hazard Identification

This section of the report provides a summary of the hazard identification process. The Literature Review should be consulted for the underpinning evidence (Section 3). In practice, the stock animals of most concern within Victoria are cattle and sheep due to their very high numbers within water catchments and their established role as sources of human infectious pathogens implicated in waterborne disease outbreaks. Sheep and cattle (meat and dairy) contribute 99% of the total grazing stock numbers within Victoria (Section 5.1). Therefore, this study focused on cattle and sheep as the pathogen sources of concern. However, the management measures recommended for cattle and sheep can equally be applied to other stock animals in catchments where stock management is relevant. Pathogens commonly found in stock and known to be infectious to humans include *Cryptosporidium parvum*, *Salmonella* spp., *Campylobacter* spp. and pathogenic strains of *Escherichia coli* such as *E. coli* O157:H7. The reference pathogen used as the focus of this study was oocysts of human infectious genotypes of *Cryptosporidium parvum*. This choice was made based on four factors.

- *Cryptosporidium* oocysts are resistant to oxidant disinfectants and are not readily removed by media filtration unless coagulation is fully effective. In contrast, bacterial pathogens, and to a lesser extent *Giardia* cysts, are inactivated by conventionally applied oxidant disinfectant doses. Therefore, for most water treatment processes in Victoria *Cryptosporidium* oocysts represent the pathogen that is least effectively removed by drinking water treatment plants.
- There is a poor relationship between indicator *E. coli* (or thermotolerant, or faecal, coliforms) and oocyst concentrations. In contrast, bacterial pathogens would be expected to be relatively well-controlled in circumstances in which *E. coli* was not detectable in treated waters or at low concentrations in source waters. Since *E. coli* have long been the principal indicator of sanitary condition of drinking water, it is likely that risks from bacterial pathogens are relatively well understood and managed. In contrast, there is very poor understanding of *Cryptosporidium*.
- There is a particular relevance of stock animals as a source of *Cryptosporidium* oocysts. Pathogenic bacteria are sourced from both stock animals and wildlife (including marsupials, birds, amphibians and reptiles). These bacteria need to be managed in all water sources regardless of stock presence. In contrast, within the Australian context, human infectious genotypes of *Cryptosporidium* spp., are primarily sourced only from human and stock animal waste.
- *Cryptosporidium* is the single pathogen most commonly reported to cause waterborne disease outbreaks, caused the largest recent waterborne disease outbreak (Milwaukee 1993) and caused the most significant water contamination incident within Australia (Sydney 1998) (Hrudey and Hrudey 2004).

Although the study is focused on *C. parvum* oocysts, management measures that are designed and targeted to control risks posed by *C. parvum* oocysts from stock manure will also mitigate risks arising from other enteric pathogens arising from that same source. In summary, this study focused on oocysts of human infectious genotypes *C. parvum* arising from cattle and sheep.

4.2. Exposure Assessment

This section of the report provides a summary of the exposure assessment process. The Literature Review should be consulted for the underpinning evidence (Section 3). The overall approach is described in detail in Deere et al., (2008). Exposure to waterborne pathogens from water is highly variable. The concentrations of human infectious pathogens reaching water consumers varies due to the following:

- Stock factors
  - Numbers and density of stock
  - Species of stock present
  - Age of stock animals, particular whether they are pre- or post-weaned
- Pathogen factors
  - Prevalence of pathogens within stock animals
  - Infectivity to humans
- Management factors
  - Fencing and its continuity, integrity and effectiveness
  - Location relative to drainage lines and waterways
  - Intensity and density of stock animal rearing operations
- Catchment factors
  - Vegetation cover
  - Slope
  - Soil type and depth
  - Antecedent conditions, particularly how wet the catchment is
  - Rainfall intensity and location
  - Residence time and temperature in waterways
  - Distance between stock and the offtake point for the water supply
- Water supply infrastructure factors
  - Ability to avoid water harvesting during high flow events
  - Residence time and temperature in raw water storage reservoirs
  - Water filtration and disinfection type and performance

With so many variables, it is not possible to put a single value on either the risk to public health from stock in Victorian waterways nor on the benefits of any particular intervention. It is, however, possible to define simple scenarios and use these to estimate approximate health risks for those scenarios. Scenario analysis provides a generic basis for decision-making that can then be fine-tuned for specific locations if required.

As an example scenario, a generic catchment has been defined as follows:

- The catchment covers 20,000 hectares.
- The majority of land is used for broadscale grazing carrying 30,000 adult sheep, 15,000 lambs, 1,000 adult dairy cattle, 10,000 adult meat cattle and 5,000 calves.
- Runoff to the yield point of the catchment at the water supply off-take point varies but results annually in 1 flood of 10,000 ML/d, 20 rain events of 1,000 ML/d and baseflow dry weather flow rates of 100 ML/d.
- 10% of the properties include frontage perennial waterways.
- 50% perennial waterways have been fenced with a well-vegetated perennial grass buffer strip of at least 5 m width.
- 10% of ephemeral waterways have been fenced with a well-vegetated perennial grass buffer strip of at least 5 m width.

- Juvenile stock are not managed specifically and have access to waterways at the same rate as adult stock.

Exposures were assessed by estimating the concentrations of human-infectious pathogens that might reach water supply off-takes from such a scenario. An overview of how estimates were made is given in Table 4-1. The details of the numerical values, and the basis for their use, are given in Table 3-4. Risks were assessed on an annual basis by summing the daily risks since the tolerable risk metric used for comparison was an annual one. Therefore, risks for any particular year integrated the storm, flood and dry weather event conditions.

The concentration of human infectious *Cryptosporidium* oocyst in waterways for the generic catchment is estimated to be in the order 1 to 10 oocysts per L. These concentrations are within the typical range described in water quality monitoring programs in Australian water supply catchments and were estimated at 5 oocysts per L in dry weather, 10 oocysts per L during wet weather and 3 oocysts per L during a major flood. In practice, reported dry weather concentrations of pathogens are typically lower than 5 oocysts per L – this simple analysis did not take into consideration the inactivation and settling that is likely to occur under lower flow conditions.

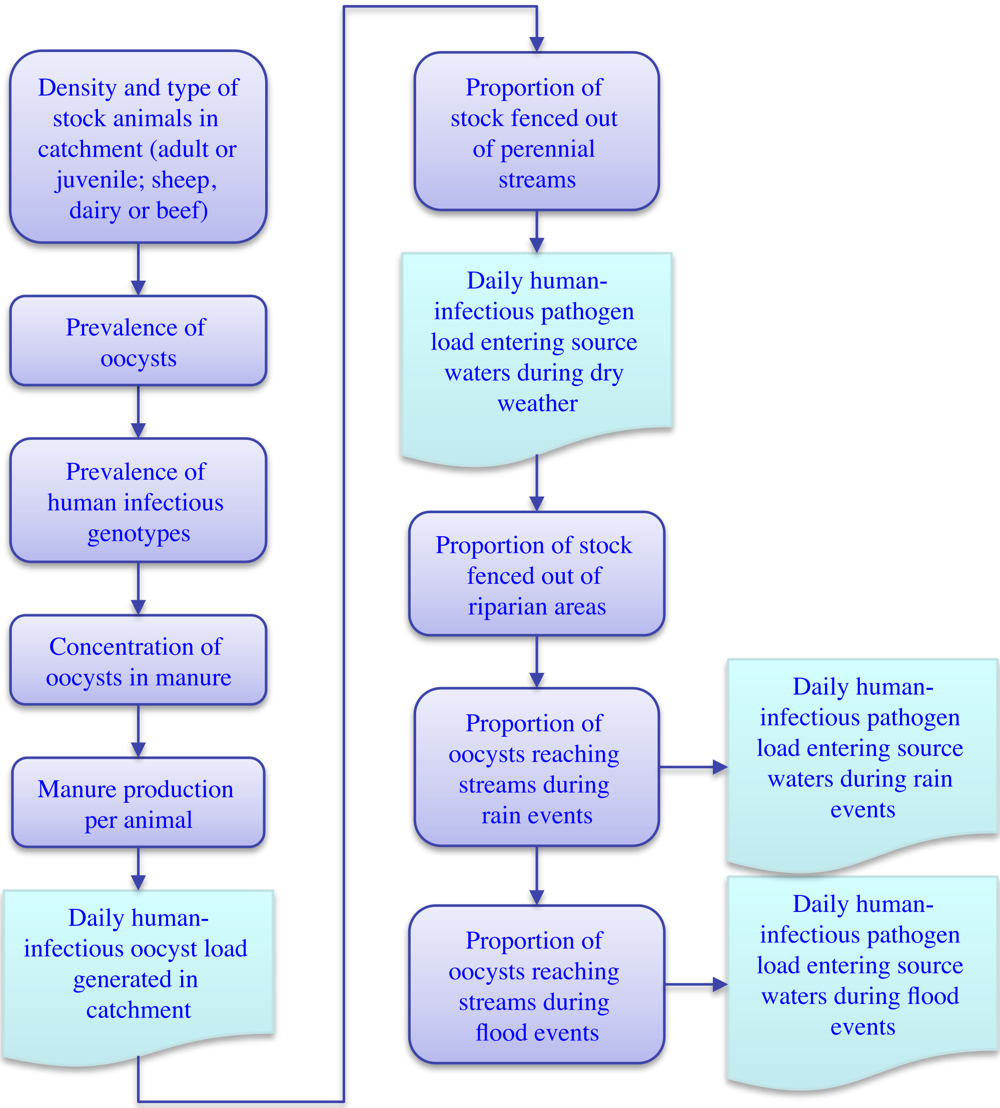

Table 4-1. Overview of approach to estimating exposures.

4.3. Dose-response analysis

This section of the report provides an estimate of the risk that the typically observed and predicted concentrations of oocysts would imply.

Human feeding trials have been undertaken that involved infecting healthy volunteers with *Cryptosporidium* oocysts taken from stock animals. The results provide the basis for relating the dose of pathogens ingested with the risk of infection and illness, and in turn, disease burden. Several such feeding trials have been undertaken, so the meta-analysis of Messner et al., (2001) was used in this study to provide a basis for the estimation. The analysis recommended the use of an exponential dose-response relationship and, for an unknown strain, a constant value of 0.028.

Without effective water treatment the estimated risk of infection for consuming water with a pathogen concentration of 3 to 10 human infectious *Cryptosporidium* oocysts per L was between 15% and 43% per day. The results can also be expressed in terms of disease burden as disability-adjusted life years (DALYs). Assuming a 70% chance of illness per infection, and a DALY (refer Box 1) per case of 0.0015 (based on the Australian Guidelines for Water Recycling 2006, AGWR), the results would predict a disease burden of between 150 and 450 μDALYs.

Box 1 – Disability adjusted life years (DALYs) (source AGWR, 2006)

Disability adjusted life years (DALYs) provide this mechanism for both microbial and chemical parameters. Standard risk assessments determine the likelihood of infection or illness. DALYs convert these likelihoods into burdens of disease.

The basic principle of the DALY is to weight each health impact in terms of severity within the range of zero for good health to one for death. The weighting is then multiplied by duration of the effect and the number of people affected by the effect. In the case of death, duration is regarded as the years lost in relation to normal life expectancy.

Hence, DALYs = YLL (years of life lost) + YLD (years lived with a disability or illness).

In this context, disability refers to conditions that detract from good health. In these guidelines it generally relates to illness, but in other arenas it can relate to physical or mental impairment.

Using this approach, a mild diarrhoea with a severity weighting of 0.1 and lasting for 7 days results in a DALY of 0.002, whereas death of a 1-year old resulting in a loss of 80 years of life equates to a DALY of 80.

Infection with *Cryptosporidium* can cause watery diarrhoea (severity weighting of 0.067) lasting for 7 days with extremely rare deaths in 0.0001% of cases. This equates to a DALY per case of 0.0015.

4.4. Risk characterisation

This section of the report provides an assessment of whether or not the estimated risk would appear to be acceptable. Waterborne disease risks can be considered tolerable if the additional annual disease burden is predicted to be below 1 μDALY (AGWR 2006). Without water treatment to reduce the concentration of human infectious *Cryptosporidium* oocysts, a grazing catchment such as the generic example described for this study would present an unacceptable predicted risk to public health. Predicted disease burdens would be in the order of hundreds of μDALYs per day.

The extent of treatment or catchment management required to reduce risks to tolerable levels, that is, to below 1 μDALY per year, for the example generic catchment is 5 $\log_{10}$. Therefore, it can be concluded that the presence of typical stocking densities of cattle and sheep in Victorian waterways would present health risks that would be well in excess of tolerable levels unless effective water treatment were applied. Water filtration plants would typically be expected to achieve somewhere between 2.5 to 5 $\log_{10}$ reduction of infectious *Cryptosporidium*, varying depending on how they are designed and operated. Water disinfection with typical doses of UV would be expected to achieve between 2 and 4 $\log_{10}$ reduction of infectious *Cryptosporidium*, varying depending on the UV dose applied.

Clearly, it is possible to reduce public health risks to tolerable levels using water treatment. However, it is also possible to reduce public health risks using catchment management.

Catchment management and water treatment can be applied in combination. Although the above analysis is only indicative, the results clearly show that for many water supplies there could be direct trade-offs between possible catchment management interventions to reduce health risks and water treatment interventions. For instance, for a catchment for which a 5 $\log_{10}$ reduction of infectious *Cryptosporidium* oocysts were recommended where the water supply only had a direct filtration plant, achieving 2.5 log reduction in oocyst inputs through catchment interventions might prove extremely beneficial and preclude the need for expensive water treatment upgrades.

5. Broad scale pathogen risk profile

The relative scale of pathogen risks within Victorian drinking water catchments can be broadly assessed based on the consideration of a few critical elements:

- Numbers of stock (including type and age).
- The extent to which grazing animals are excluded from the waterway, weirs and reservoirs.
- The hydrology of the catchment (annual rainfall and magnitude of run-off events).

Data on each of these elements has been divided into three risk classes (low, moderate and high), with the overall risk class determined to be the majority classification. A discussion of each element and its risk characterisation occurs in the following sections, with Table 5-1 describing the risk classes.

Risk profiling has been completed for each Catchment Management Authority (CMA) area as information regarding stock numbers was available from the Australian Bureau of Statistics. The location of water utilities within CMA boundaries has been described to enable the general consideration of risk within the drinking water catchments (NB: the risk profile provides an average for the CMA area, and there would be a considerable degree of variation in the actual risk of each drinking water catchment, depending on grazing practices and hydrology within the area).

5.1. Principal stock found in Victoria

An assessment of stock numbers within Victoria has been completed, by considering the Australian Bureau of Statistics Agricultural Commodities, Australia, 2008-09, which has been summarised on the basis of States and Natural Resource Management Regions - CMA areas, within Victoria (Figure 5-1). The data are based on a response rate of 88% from a sample of approximately 38,000 agricultural businesses selected for the 2008-09 Agricultural Survey. The CMA areas are illustrated in Figure 6.1, along with the urban water utility areas and major urban centres, for means of comparison.

Figure 5-2, shows grazing stock numbers for each CMA in Victoria. Sheep are the predominant grazing animal throughout most CMA's, with only the North East CMA and the West Gippsland having greater numbers of meat cattle and dairy cattle respectively. Sheep and Cattle (meat and dairy) contribute 99% of the total grazing stock numbers and hence these animals were the focus of this study.

The total number of human infectious *Cryptosporidium* from meat cattle, dairy cattle and sheep for each CMA are presented in Figure 5-3, and have been calculated via the following equation:

Number of stock x Manure production rates per day (g) x Cryptosporidium concentration/g within manure x Cryptosporidium prevalence x Cryptosporidium human infectious proportion (as per Table 3-4). Due to the prevalence and high concentration of pathogens in juvenile stock, the numbers of calves and lambs have been specifically included (and are presented in Figure 5-3).

This data helps to indicate which stock types and which CMA areas may have the greatest concentration of pathogens present and has been expressed on a per hectare basis to establish a relative measure of *Cryptosporidium* risk associated with stock across the various CMA's.

Figure 5-3, indicates that by far the greatest source of human infectious *Cryptosporidium* across all CMA areas are juvenile animals (lambs, beef calves and dairy calves). In the Glenelg Hopkins CMA area/region, 99.8% of the contribution of human infectious *Cryptosporidium* across all sheep, meat cattle and dairy cattle is from juvenile animals (less than 1 year old), and this provides a clear requirement for the specific management of these animals.

When the total human infectious *Cryptosporidium* count is considered on a per hectare basis, the CMA's of West Gippsland, Glenelg Hopkins, Corangamite, and to a less degree North East (Victoria), have the highest load, and hence the greatest potential to impact drinking water supplies.

Table 5-1. Pathogen Risk Profile

Item		**Condition of catchment**		**Actions required to minimise pathogen risk**	
Risk Class	Stock	Hydrology	Waterway access	Catchment actions	Water Treatment
Low	Low stocking density Stock that have a low *Cryptosporidium load in faeces* Equivalent to a human infectious *Cryptosporidium* count per hectare of grazing land of less than 6 million	Annual rainfall less than 500 mm per annum, normal run-off events unlikely to result in catchment wide run-off	Juvenile animals located away (>500 m) from perennial waterway Greater than 90% of perennial waterways fenced off Greater 1 km buffer zone around weirs and reservoirs, where grazing animals occur in the catchment	Locate juvenile stock away from perennial waterways Monitoring to enable verification of risk	Chlorination, possible filtration
Moderate	Moderate stocking density Stock that have a moderate *Cryptosporidium load in faeces* Equivalent to a human infectious *Cryptosporidium* count per hectare of grazing land of greater than 6 million and less than 12 million	Annual rainfall less than 650 mm per annum, normal run-off events unlikely to result in catchment wide run-off	Juvenile animals located away (>500 m) from perennial waterway Greater than 25% and less than 65% of perennial waterways fenced off Great than 100 m and less than 500 m buffer zone around weirs and reservoirs, where grazing animals occur in the catchment	Locate juvenile stock away from perennial waterways. Waterway fencing of priority perennial waterways, aiming to achieve a coverage of at least 65% Monitoring to enable verification of risk.	Chlorination, filtration
High	High stocking density Stock that have a high *Cryptosporidium* load in faeces Equivalent to a human infectious Cryptosporidium count per hectare of grazing land of greater than 12 million	Annual rainfall greater than 800 mm per annum, normal run-off events unlikely to result in catchment wide run-off	The majority of juvenile animals with access to perennial waterway Less than 25% of perennial waterways fenced off Less than 100 m buffer zone around weirs and reservoirs, where grazing animals occur in the catchment	Locate juvenile stock away from perennial waterways Waterway fencing of priority perennial waterways, aiming to achieve a coverage of at least 90% Monitoring to enable verification of risk Develop pathogen model for specific catchments	Chlorination, filtration, UV

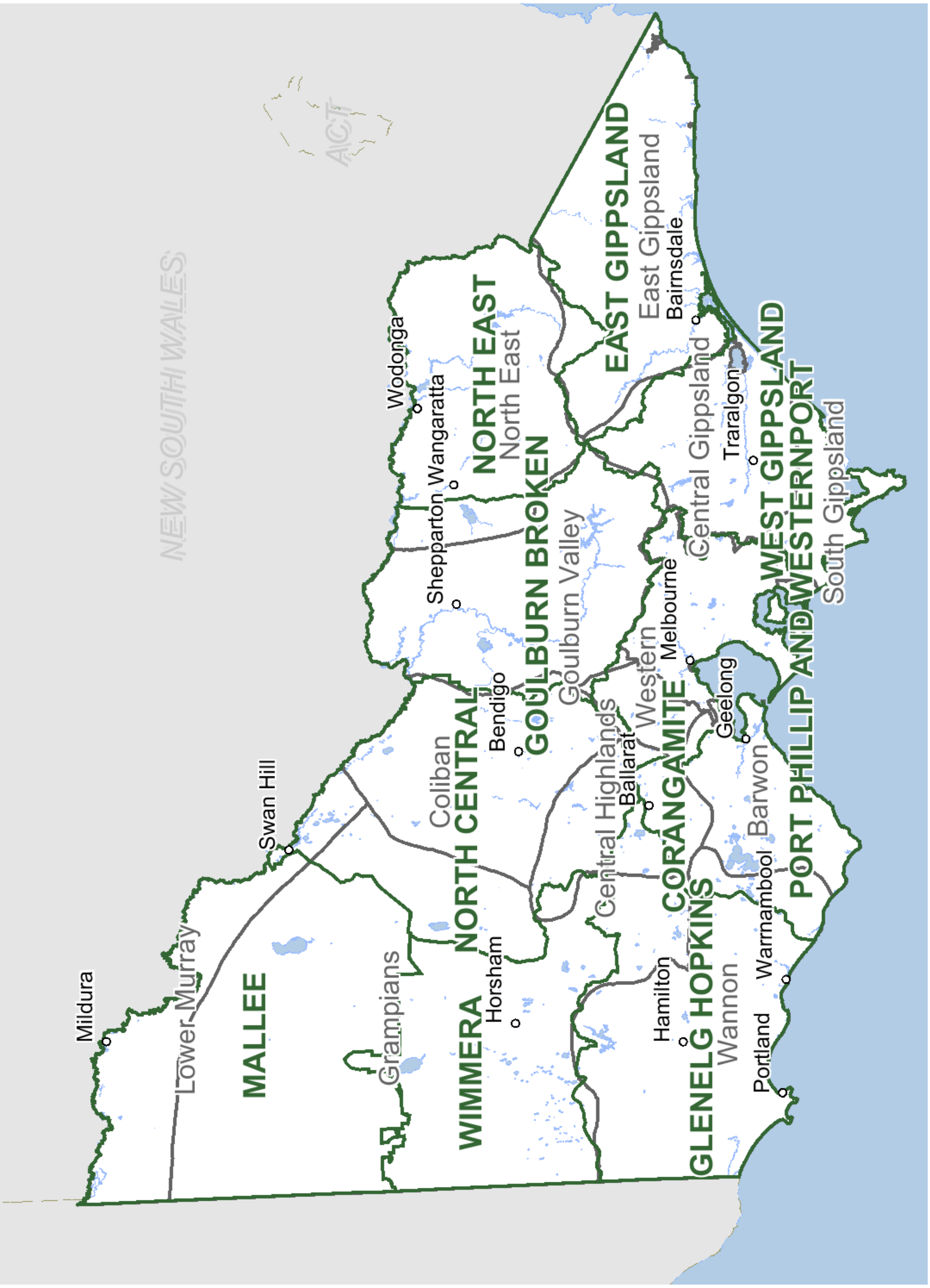

Figure 5-1. Catchment Management Authorities (CAPITALISED), urban water companies (large Sentence Case) and major urban areas (small Sentence Case).

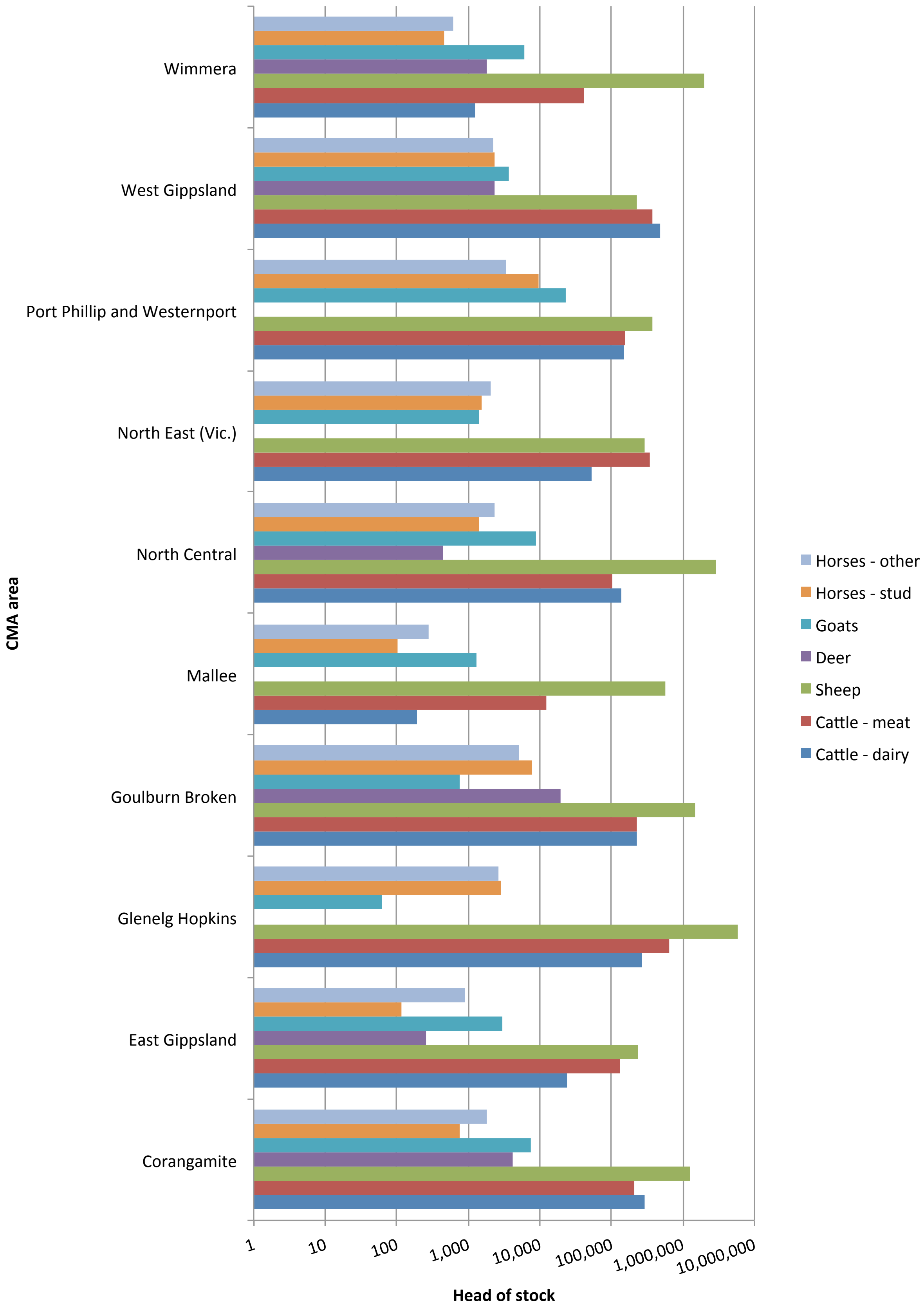

Figure 5-2. Estimated stock numbers within Catchment Management Authorities' area of operation

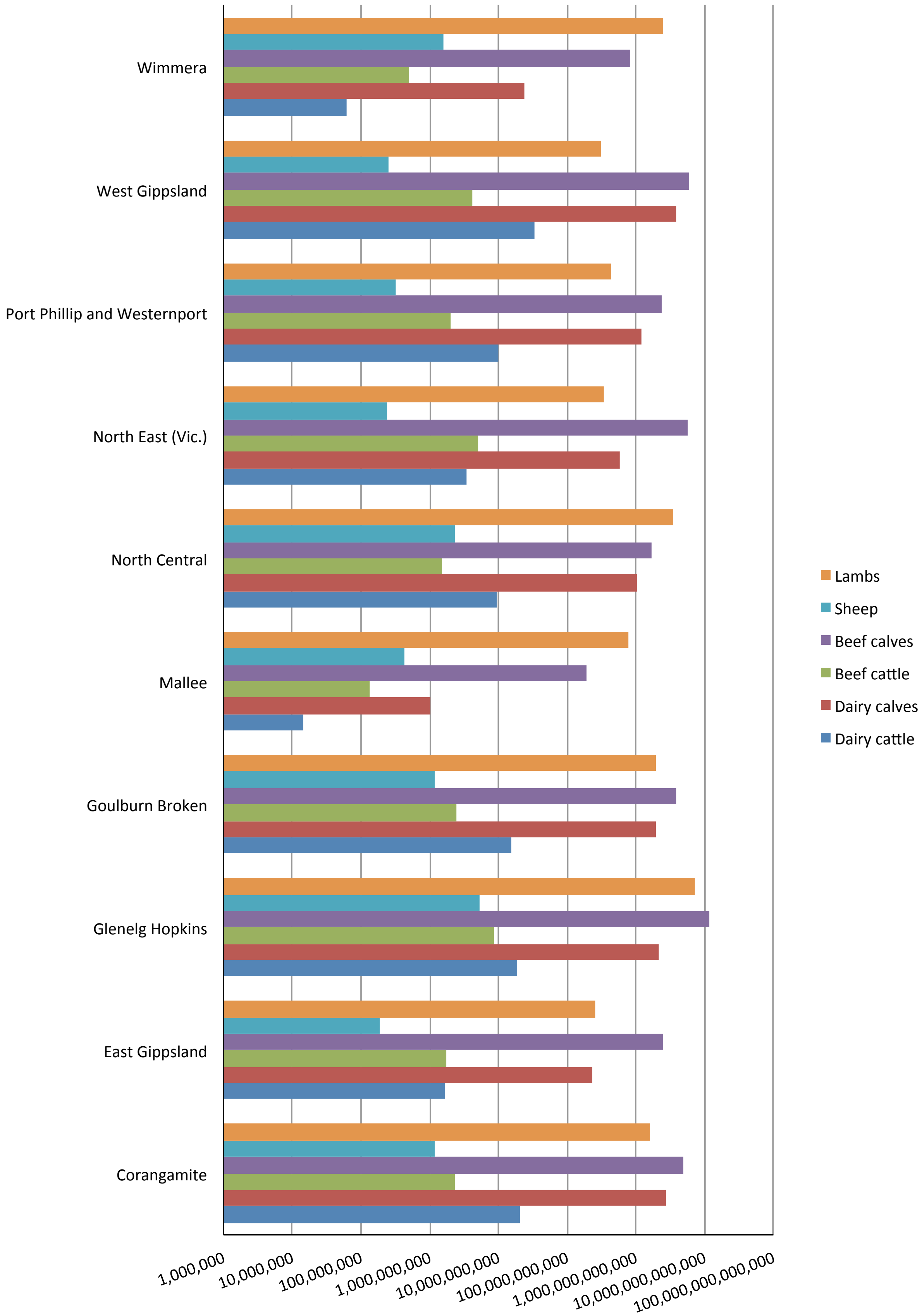

Figure 5-3. Estimated numbers of human infectious *Cryptosporidium* within Catchment Management Authorities' area of operation

The availability of stock numbers within CMA's is very useful, but this information needs to be related to drinking water catchments for the purpose of this study. A map depicting drinking water catchment areas was not readily available for the entire state, and so CMA boundaries have been compared with urban water company boundaries (Figure 5-1).

Within most urban water company boundaries, a proportion of the area would be used for drinking water catchments which are at risk from stock entering streams within the catchment. The exception to this would be the Lower Murray Water, which predominantly takes its water from the River Murray (which is not substantiality impacted by stock access within its boundaries) and the closed catchments which Melbourne Water utilises. The remaining urban water companies have indicated an estimated level of potential impact from pathogens and the current rate of waterway fencing within their areas, as detailed in Table 5-1. It is noteworthy that neither CMAs nor water companies had an accurate inventory of waterways which have been fenced to exclude stock. Most CMA's were able to provide estimates, while two CMA's considered that the lack of information to be so significant that they could not provide an estimate.

Table 5-2. Stock access to waterway estimated by Catchment Management Authorities and Urban Water Authorities within Victoria

Catchment Management Authority	Contains surface water drinking catchment Yes/No	Urban Water Corporations	Potential impact of stock access to waterways in drinking water catchments (Low, Medium, High)	Approximate percentage of waterways fenced in grazed areas (<5%, 5-25%, 25-50%, > 50%)
Mallee	Not significant	Lower Murray Water Northern GWM Water	Not applicable	Not applicable
Wimmera	Yes	GWM Water	Low	< 5%
Glenelg Hopkins	Yes	Wannon Water SE GWM Water Central Highlands Water	Medium Medium Medium	5 – 25% 5 – 25% 5 – 25%
North Central	Yes	Coliban Water Eastern GWM Water Central Highlands Water	Medium Medium	5 – 25% 5 – 25%
Corangamite	Yes	Baron Water Central Highlands Water	Medium	Could not be estimated
Port Phillip & Westernport (open catchment)	Yes	Melbourne Water (and Metropolitan Water Business retailers, Western Water and Westernport Water retailers)	Medium	5 - 25%
Port Phillip & Westernport (closed catchment)	Yes	Melbourne Water (and Metropolitan Water Business retailers, Western Water and Westernport Water retailers)	Low	Not applicable
Goulburn Broken	Yes	Goulburn Valley Water and Western North East Water	High	20 to 50%
North East	Yes	North East Water	High	Could not be estimated
West Gippsland	Yes	Gippsland Water South Gippsland Water	High High	5 to 25% 5 to 25%
East Gippsland	Yes	East Gippsland Water	High	5 to 25%

5.2. Hydrology

Roser and Ashbolt, 2007 state that "the majority of pathogen impacts on reservoirs arose from rainfall-induced runoff", and provide the example that "microbial load estimation showed that as much as 300 year's worth of dry weather pathogen contaminant load could be exported during 1 day in a single small event". Roser and Ashbolt, 2007 highlight that "both water quality and hydrology data were essential to assessing the extent of pathogen risks".

In this report the risk associated with rainfall events has been simply considered by assessing the rainfall isohyets for the State (as provided by the Bureau of Metrology), with the three defined risk classes – low, medium and high (refer Figure 5-4).

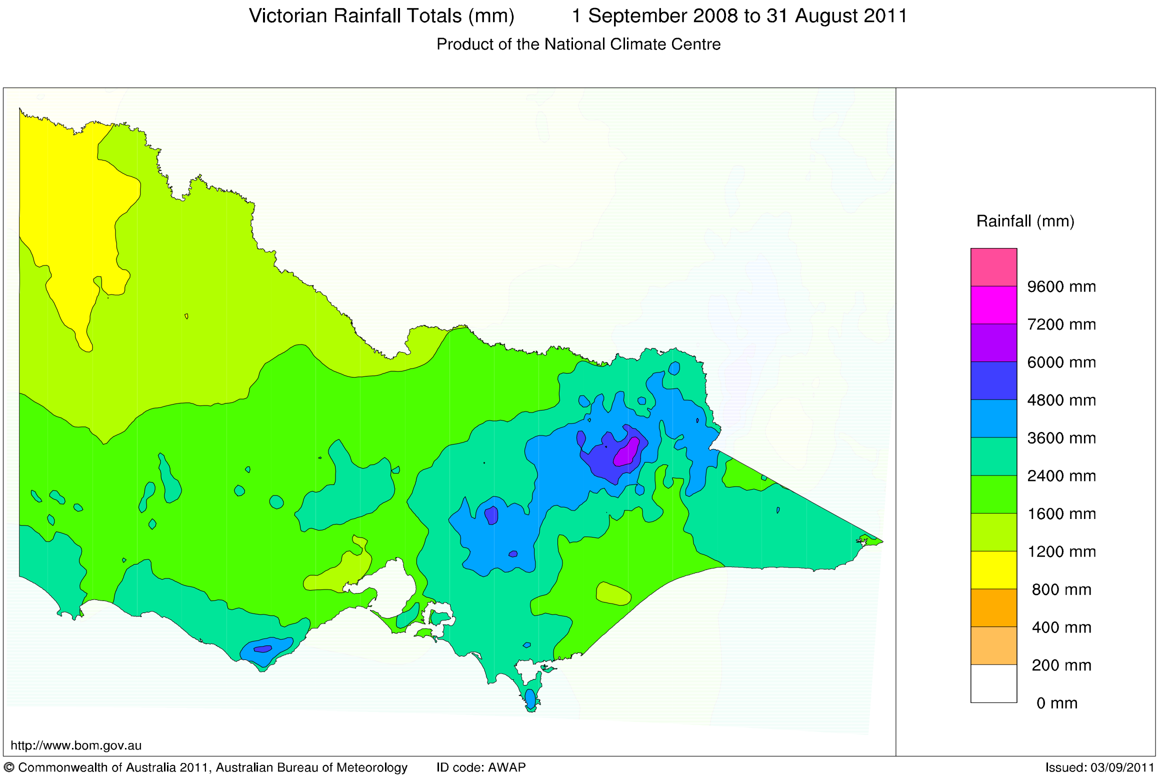

Figure 5-4. Triennial rainfall for Victoria (bom.gov.au)

5.3. Pathogen risk profile

CMA areas which were considered to have the highest pathogen risk profile were West Gippsland, Glenelg Hopkins, Corangamite and North East (Victoria). Other CMA areas had either a drier climate, greater extent of waterway fencing (in the case of Goulburn Broken CMA) and/or lower loads of human infectious *Cryptosporidium* (refer Figure 5-3).

Where the risk profile is considered to be high, potential catchment management options include; locating juvenile stock away from perennial waterways, fencing of priority perennial waterways (aiming to achieve a coverage of 90%), water quality monitoring for risk verification and the development of pathogen model for specific catchments.

This state wide profiling indicates that the risk from pathogens is diverse with no 'typical catchment' or management scenario able to capture the possible variety. While this is the case, in order to assess pathogen risk, intervention measures and the costs and benefits of options, a generic catchment profile has been defined, which is considered to represent an example of a drinking water catchment, with a moderate risk profile.

Section 7 of this report discusses the generic catchment in more detail and then provides a cost benefit analysis of applicable interventions within this catchment.

Table 5-3. Estimated pathogen risk profile for Catchment Management Authorities and Urban Water Authorities within Victoria

Catchment Management Authority	Urban Water Corporation	Risk from Stock	Risk from access to waterways, weirs and reservoirs	Risk associated with hydrology	Risk profile	Potential catchment actions
Mallee Not applicable	Lower Murray Water Northern GWM Water	Not applicable				
Port Phillip & Westernport (closed catchment)	Melbourne Water and Western Water and Westernport Water retailers)	No human infectious *Cryptosporidium*	Not applicable	High	Low	Monitoring to enable verification of risk.
Wimmera	GWM Water	Low	High	Low/Moderate	Low	Locate juvenile stock away from perennial waterways Monitoring to enable verification of risk.
North Central	Coliban Water Eastern GWM Water Central Highlands Water	Low/Moderate	High	Moderate	Moderate	Locate juvenile stock away from perennial waterways Waterway fencing of priority perennial waterways, aiming to achieve a coverage of 65% Monitoring to enable verification of risk.
Goulburn Broken	Goulbourn Valley Water and Western North East Water	Moderate	Moderate	Moderate	Moderate	As above.
Port Phillip & Westernport (open catchment)	Melbourne Water and Western Water and Westernport Water retailers)	Moderate	High	Moderate	Moderate	As above.
East Gippsland	East Gippsland Water	Moderate	High	High	High	Locate juvenile stock away from perennial waterways Waterway fencing of priority perennial waterways, aiming to achieve a coverage of 90% Monitoring to enable verification of risk. Develop pathogen model for specific catchments.
North East	North East Water	Moderate/High	High	High	High	As above
Glenelg Hopkins	Wannon Water SE GWM Water Central Highlands Water	High	High	Moderate/High	High	As above
Corangamite	Baron Water Central Highlands Water	High	High	High	High	As above
West Gippsland	Gippsland Water South Gippsland Water	High	High	High	High	As above

6. Potential interventions

6.1. Pathogen reduction measures in catchments

In order reduce pathogen risks in drinking water catchments one or a number of intervention measures may be required. In most catchments the greatest reduction in pathogen risk will be associated with the management of juvenile stock (age less than three months), so that they are located away from waterways. Alternatively, in selected areas, risk reduction may be achieved through land acquisition or the removal of grazing (e.g. adjacent weirs and reservoirs), while, more generally, it could be combined with specific management of juvenile stock.

The management of riparian zones through waterway fencing could also be considered, and this provides the most stringent and "absolute" measure with which to prevent stock access into waterways. Although this is the case, the extent of waterway fencing which is required in order to significantly reduce the pathogen risk (upwards of 80%), diminishes the practical achievability of this intervention measure.

6.1.1. Land acquisition by government or drinking water corporation

Compulsory acquisition is a familiar, but expensive and insensitive process for gaining control over freehold land (Anon, 2008). In A Review of the Management of Riparian Land in Victoria (Anon, 2008), it was recommended that agencies consider the adoption, in appropriate circumstances, of programs and strategies aimed at gaining a level of control over riparian freehold through the purchase of lesser interests in the forms of covenants, easements, and leaseholds (Anon, 2008). Government acquisition may be considered appropriate within the context of the protection of public drinking water supplies, where the risk cannot be lowered to an acceptable level by other means (e.g. directly upstream of a weir or reservoir or along a riparian zone where stocking rates are high and transmission times to the treatment plant are short).

Changes to landuse may be able to be achieved using Development Controls (under the Catchment & Land Protection Act 1994). It is possible to exclude some types of landuse development in priority areas of drinking water catchments. This has been achieved in Western Australia, where Public Drinking Water Source Areas have been divided into three priorities, with tables developed to inform suitable planning (Department of Environment, 2004). The tables define land uses in terms of their compatibility with the sustainable use of the drinking water source. They promote a priority for the protection of the environmental value: 'drinking water' within a PDWSA has priority over other values that may exist. The three definitions used are 'Incompatible', 'Compatible with conditions' and 'Acceptable'. For example, within a priority area 1, stock grazing is considered Incompatible, while in a Priority area 2 it is considered Compatible with condition.

Within Victoria, the designation of Declared Water Supply Catchments occurs under the *Catchment and Land Protection Act 1994.* Once a catchment is Declared, approvals for activities conducted under other statutes and statutory planning schemes must be referred to the responsible land management authority (Catchment Management Authority or DSE) for approval. Special Area Plans do require considerable work including a consultation process, land use determination, identification of targets and measures, identification and allocation of costs. In Victoria, SAPs have not been used for riparian zone management, although they have been made for 46 water supply catchments and hence there is potential to expand their scope.

6.1.2. Management of juvenile stock

The specific management of juvenile stock (age less than three months) away from waterways can significantly reduce pathogen loads. Generally, juvenile grazing animals remain with their mothers and hence excluding them from paddocks adjoining waterways can be challenging, but where it can be achieved (e.g. dairy calves and possibly through specific stock rotation) the benefits will be significant.

The adoption of this approach requires education of land managers, who generally locate juvenile animals near waterways due to the availability of good quality pasture and shelter from the wind. Infection of juvenile stock can also be managed, with Day (2010) noting that dairy effluent should not be applied to paddocks on which stock less than 12 months of age will graze; doing so minimises the likelihood of juvenile infection.

Current animal husbandry practices often call for the specific management and isolation of juvenile stock to manage diseases such as Bovine Johne's or infectious diseases associated with calves presenting with scours. Hence it is considered that the protection of drinking water catchments can be coupled with the benefits of best practice animal husbandry.

6.1.3. Stock exclusion through fencing

Permanent fencing is the most stringent and "absolute" measure with which to prevent stock access into waterways. This has two effects: (i) the source of direct faecal deposition is removed (specifically relevant to cattle), and from riparian areas proximal to the stream from which surface runoff can deliver pathogens, (ii) a riparian buffer can be created (provided the fencing is set back from the bank) that can entrap microbes washed in from upslope, reducing transport to the water. The 2009 White paper for Land and Biodiversity states:

"Livestock need to be managed to prevent direct access to the beds and banks of streams and wetlands. This is particularly important in streams that provide water for human purposes. The most practical way to achieve this is through fencing.". (DSE, 2009).

Similarly, the review of the management of riparian land in Victoria. 2008 states:

"*The management of stock on riparian land is widely regarded as the most pressing issue facing riparian agencies charged with protecting natural resource systems.*" (Anon 2008).

While the review recommends the adoption of a suite of complementary legislative and regulatory tools relating to fencing, livestock management, and stock-related water pollution; it is clear that the then Victoria Government had invested significantly in this catchment measure and had a focus to deliver this approach for state and regional scale catchment management programs. There is no current indication that this approach will be discontinued under the current Government.

During wet weather, stock exclusion might be extended to those paddocks located adjacent to waterways that are characteristically prone to saturation. Such paddocks are vulnerable to pugging damage in weather conditions (i.e., rainstorms when antecedent soil moisture is already high) that are most likely to generate the surface runoff that can wash faecal matter directly to water bodies (Collins, 2007).

6.2. Waterway fencing

The aim of this section is to provide recommendations on one or more buffer distances that would provide the distance/s deemed appropriate where cattle and sheep are to be excluded from;

- waterways within drinking water catchments and
- areas surrounds weirs and reservoirs used for drinking water.

The following provides a discussion on pathogen transport, the impact of buffers and other specific considerations regarding waterway fencing, while specific case studies have been sourced and are provided in the attachments at the end of the report.

6.2.1. Waterborne pathogen transport and the impact of buffers

Day (2010), reviewed waterborne pathogen research as it relates to the dairy industry and noted the following relative information.

> *When vegetated filter strips are combined with cattle exclusion in a riparian zone, the exclusion of cattle may be a significant factor. A study of cattle exclusion from streams in a 56.7 ha catchment showed a 66% reduction in faecal coliforms and a 57% reduction in enterococci over a 7.5 year period, and another study of riparian fencing and 'farm dirty water containment' in Scotland showed a 66% reduction in E. coli and 81% reduction in enterococci between 'paired catchments' (Kay et al, 2007). However, a study of more than 95% stock removal from a 255 ha catchment in the UK showed only a 'surprisingly slow improvement in water quality'.*
>
> *Stock with access to waterways can be a direct source of pathogens – with cows crossing streams in New Zealand reported to result in spikes of E. coli (up to 50,000 cfu/100ml). It was also reported that cows defecated more per metre of stream crossing than elsewhere on the laneway (Pepper et al, 2006). Cows tend to defecate at similar rates over a property, except when in streams when they are five times more likely (Journeaux, 2005).*

Day (2010), summarises with the following key points

- The movement of pathogens to waterways is driven by rainfall events; with pathogen loads increasing exponentially with flow.
- Different pathogens will move along different pathways and at different rates (e.g. surface or sub-surface flow, either in suspension or attached to soil particles).
- Pathogen export rates are highest when there is the least time between run-off occurring and the most recent grazing (and defecation) taking place.
- The sub-surface movement of pathogens is greatest through macropores in the soil, which tend to be well-developed under pastures.
- The ability of soils to filter pathogens is influenced by the relative size and shape of the pathogens and soil particles.
- Grassed filter strips have widely variable performance in terms of filtering pathogens (possibly influenced by flow rates and concentrations); ranging from significant reductions, to nil affect, to increasing pathogen loads.

- Areas of low-lying wet-soil tend to concentrate pathogens and attract greater deposition from grazing cattle.
- Stock defecate more when they are in streams and also stir up sediments, resuspending pathogens.
- There are management options, suitable for many situations, which may reduce the export of pathogens from dairy farms, such as; not recycling liquid effluent during rain events or when run-off is imminent, recycling effluent on grazed pasture and then with-holding stock, and excluding cattle from streams and wetlands.

6.2.2. Fencing for multiple environmental outcomes

Riparian fencing is generally undertaken to meet multiple environmental outcomes, rather than a single purpose such as stock exclusion. Land and Water Australia, developed a fact sheet on managing riparian widths, and provides a range of buffer widths depending on the aims being sought (such as nutrient management, biodiversity improvements, sediment reduction) refer Table 6-1, Price, 2005. Buffers developed for stock exclusion should be considered in this context. The other aspects that must be considered are the requirements of government agencies and CMA's, which may have specifications relating to incentive payments. Publicly-funded riparian fencing schemes may provide a greater proportion of fencing costs when a greater width is fenced off from open stock access, and often a minimum width of 20 metres from the water edge or from the top of the bank is recommended in order to achieve maximum incentive payments (pers. comm. Wayne Tennant, Goulburn Broken Catchment Management Authority).

Table 6-1. Minimum riparian buffer widths (in metres) (Price 2005).

Management objective	Recommended minimum width
Improve water quality	5–10 metres
Reduce streambank erosion	5–10 metres
Provide food inputs and aquatic habitat	5–10 metres
Provide terrestrial habitat	10–30 metres
Maintain natural light and temperature levels	5–10 metres
Provide habitat for fish	5–30 metres
Manage agricultural production	5–10 metres

Davies et al., (2004) and Atwill et al., (2002) showed that pathogens are readily mobilised from cattle faecal pats during rainfall events. However, for *Cryptosporidium* oocysts, entrapment as high as 4-$\log_{10}$ per linear metre of well-grassed riparian buffer was observed during simulated rainfall events of a magnitude sufficient to create surface runoff. For *E. coli*, entrapment efficiencies were much lower and export over tens of metres has been measured. Poorly vegetated filter strips were much less effective at entrapping pathogens. The riparian buffer design criteria - for well grassed filter strips using perennial grasses and setback distances of 5 to 10 m - as recommended to protect water quality and entrap particulate P and sediment by Land and Water Australia - are considered appropriate for oocyst entrapment.

In a recent review of riparian buffer width, with specific application to Victoria, Hansen et al. 2010, provide a table of recommended minimum widths for various catchment settings and riparian outcomes, refer Table 6-2. Each recommended width is accompanied by a level of scientific confidence (green=high, yellow=moderate, red=low), based upon published evidence from Australia and overseas. Hansen et al. 2010 state that "as width the recommendations provided relate to single functions, to initiate or augment more than one function, greater widths may be necessary. Consequently, full riparian restoration and waterway protection may require widths that substantially exceed those recommended here".

Table 6-2. Minimum width (metres) recommendations for riparian zones in Victoria (Hansen et al. 2010)

Landscape context / Management Objective	Land Use Intensity High	Land Use Intensity Moderate	Land Use Intensity Low	Wetland/ lowland floodplain/ off-stream water bodies	Steep catchments/ cleared hillslopes/ low order streams
Improve water quality	60	45	30	120	40
Moderate stream temperatures	95	65	35	40	35
Provide food and resources	95	65	35	40	35
Improve in-stream biodiversity	100	70	40	Variable *	40
Improve terrestrial biodiversity	200	150	100	Variable *	200

* Variability in width is related to the lateral extent of hydrological connectivity and thus, any recommendation will be site specific.

These riparian buffer widths are wider than that recommended by Land and Water Australia (Price, 2005), which may reflect new developments in riparian research or higher levels of required (or acceptable) riparian efficiency (e.g. a 75% pollutant removal rate verses a 90% pollutant removal rate). While mathematical relationships between width and function have not been defined for many water quality parameters, nitrogen removal studies have demonstrated that in specific contexts (e.g. experimental uniform grass filter strips) attenuation occurs rapidly over the first few metres and subsequent width increases produce lesser gains. Therefore, decreased buffers widths (more in line with current CMA programs) may be sufficient to achieve an acceptable level of efficiency.

Appendix B provides two case study examples where buffer distances to watercourses and or storages have been considered. The first example is from Western Australia and the second considers the New Zealand guidelines for the optimal design of riparian buffers to entrap faecal bacteria, which were developed by the Ministry of Agriculture and Forestry.

6.3. Scale of fencing

Hansen et al. 2010 note that the effectiveness of riparian zones in mitigating anthropogenic impacts on waterways largely depend on their width on both sides of the waterway (Castelle *et al.*, 1994) and their longitudinal continuity from the headwaters to lowland reaches. Rehabilitation or protection of one side of the waterway and not the other will compromise management efforts, such that works on one bank are likely to be nullified by disturbances originating from the opposite bank. In a similar manner, pathogen transfer into streams from higher in the catchment may compromise downstream restoration. Maximising the lateral and longitudinal extent of intact riparian zones, starting in the headwaters, provides the best protection for the waterway. Figure 6-1 shows the impact on pathogen (*Cryptosporidium* oocysts) log reductions where riparian fencing is completed at various proportions over an entire catchment. For example, if 100% of waterways are fenced then an expected 3 log removal of pathogen concentrations would result. However, if this percentage decreases to 80% or 50% then only a 0.7 log removal or 0.3 log removal, respectively, would be anticipated. This data clearly shows the need to ensure that both suitable riparian widths and significant longitudinal continuity are achieved. This requirement clearly identifies that riparian fencing will need to be regulated as incentives programs are unlikely to have sufficient adoption to ensure that enough fencing is undertaken to significantly reduce pathogen risks.

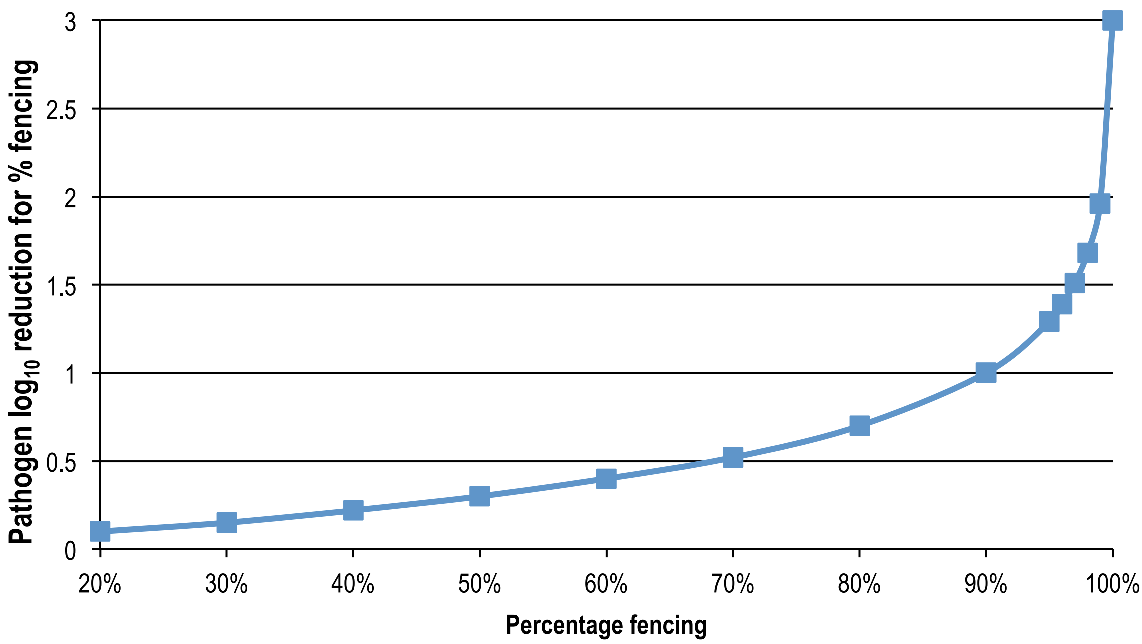

Figure 6-1. Impact of longitudinal continuity of riparian fencing (if 3 log reduction is achieved for 100% fencing).

6.4. Current fencing

Most CMA's have a minimum buffer width of 10 m on minor waterways and 20 m on major waterways, in order for landholders to be eligible for funding. As a result, where waterways have been fenced, most have a buffer distance of between 10 and 20 m, although some landholders may have fenced with small buffers where funding was not sought.

The longitudinal continuity of waterway fencing throughout drinking water catchments is intermittent, with the total percentage of waterways fenced (where grazing occurs) in the order of 5 to 25%. In terms of pathogen management the following points can be concluded regarding current riparian fencing;

- Width currently fenced exceeds the requirements to minimise pathogen transport and
- Longitudinal continuity is generally considerably less than what is required in order for buffers to significantly contribute to pathogen reductions at public water supply offtakes.

Cinque, 2009 has developed a model to predict the reduction in pathogen risk based on increased waterway fencing (defined as buffer ratio, with 100% waterway fencing equating to a ratio of 1), given a buffer distance of 1 metre.

Figure 6-2 shows the relationship between the starting buffer ratio and the expected reduction in peak pathogen flux. The different lines represent different final buffer ratios in the catchment.

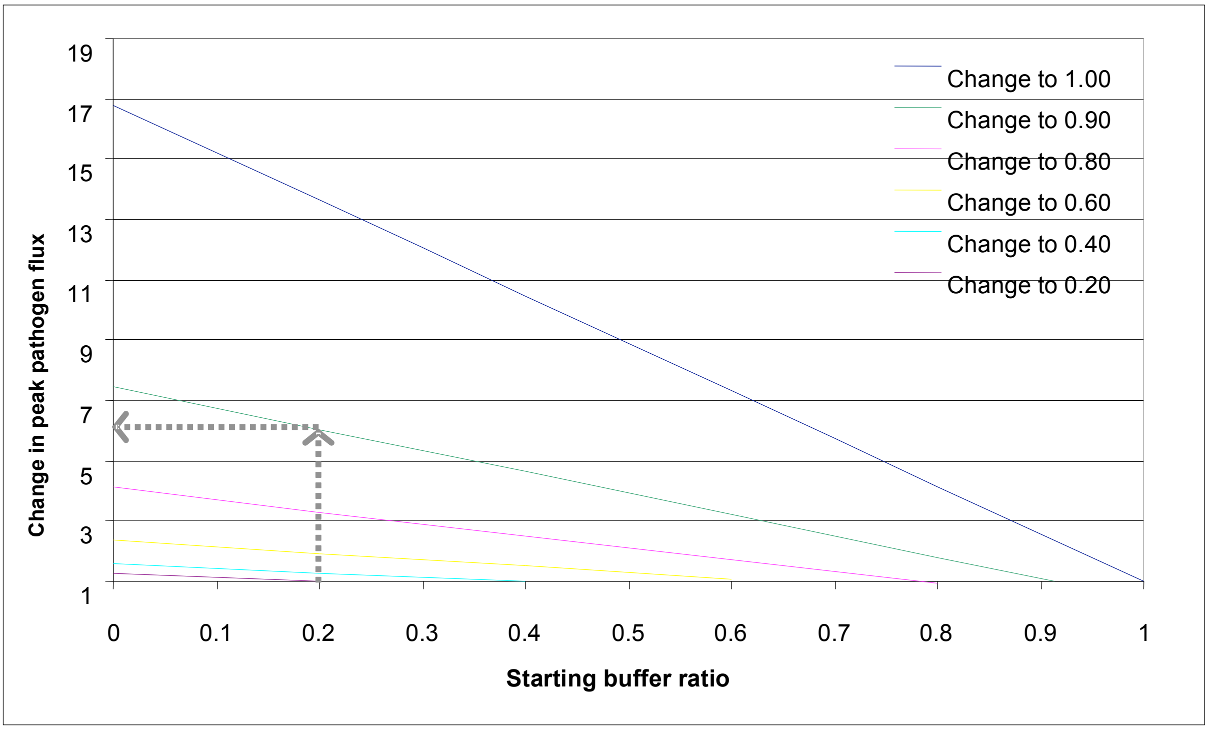

Figure 6-2. Starting buffer ratio against change in pathogen flux for different final buffer ratios.

The graph shows the amount of decrease in pathogen flux that would be expected during a storm event against the starting buffer ratio for different final buffer ratios. If, for example, the current catchment fencing percentage of approximately 20% is considered (buffer ratio 0.2), with a future increase to 90% of waterways fenced (ratio of 0.90) then the expected reduction in pathogen flux during storm events would be around 6.5 times (see grey dotted line on Figure 6-2). Alternatively, if 60% of waterways were fenced, then the expected reduction in pathogen flux during storm events would be around 3 times. Based on this graph, catchment managers from water corporations and CMA's could estimate the required percentage fencing required in order to achieve a given log reduction.

7. Cost – benefit analysis

7.1. Generic catchment

In order to develop a pathogen model and a cost-benefit analysis, a generic catchment has been considered which represents a catchment of moderate risk within the context of Victoria's drinking water catchments.

The generic catchment is described by the following features:

- The catchment covers 20,000 hectares;
- The majority of land is used for broadscale grazing carrying 30,000 adult sheep, 15,000 lambs, 1,000 adult dairy cattle, 10,000 adult meat cattle and 5,000 calves;
- Runoff to the yield point of the catchment at the water supply off-take point varies but results annually in 1 flood of 10,000 ML/d, 20 rain events of 1,000 ML/d and baseflow dry weather flow rates of 100 ML/d;
- 10% of the properties include frontage perennial waterways;
- 50% perennial waterways have been fenced with a well-vegetated perennial grass buffer strip of at least 5 m width;
- 10% of ephemeral waterways have been fenced with a well-vegetated perennial grass buffer strip of at least 5 m width and
- Juvenile stock are not managed specifically and have access to waterways at the same rate as adult stock.

The current rate of implementation may be limited due to the waterway fencing subsidy which is available from the CMA or due to landholder's perception of the management intervention.

7.2. Riparian fencing cost analysis

Relevant factors which may be considered in a waterway fencing cost benefit analysis include;

Direct infrastructure costs

- property planning;
- cost of fencing material (dependent on fence type and terrain);
- installation (dependent on fence type and terrain);
- stock water points and
- stocking crossing points.

Direct operational costs

- maintenance of fence;
- maintenance of buffer (including weed control);
- project officers and
- compliance officers (provided by appropriate State agency).

In-direct costs

- property values (arguably increase or decrease) and
- loss of productive land (subject to managed grazing).

Benefits

- water quality (reduction in pathogen risk and decrease in other water quality parameters nutrients suspended sediment) and
- improvements in buffer zone condition with regard to; vegetation, soil compaction and erosion.

Direct capital costs are a necessary item of any waterway fencing program. The Department of Sustainability and Environment (DSE) has collected unit costs for riparian management activities from CMA's within Victoria and has developed State averaged unit costs for 2009/2010 (that are exclusive of on-cost). CMA funding packages for riparian management activities provide a subsidy (a proportion of total costs), and hence capital costs are shared between public and private stakeholders, with increased public funding generally occurring where ecological values are high, or where fencing directly meets the requirements of the regional Waterway Action Plan.

The consideration of operational costs with regard to funding is less clear, with many operational activities (such as weed management of buffer zones or fence maintenance) considered to be environmental duties (refer figure 2.4) and hence are not within the scope of public funding. Nevertheless, funding for operational costs is required, and if landholders do not, or are not required, through enforcement, to achieve the activities then the value of capital assets can decrease and the environmental condition be diminished due to inaction. As a result, full operational costs have been included in this analysis for a period of 40 years, considered to be the life of the riparian fence.

Benefits of the waterway fencing program will be limited to those related to pathogen risk. While it is appreciated that other water quality benefits would occur (reduction in suspended sediment and nutrients), from a public health perceptive the reduction in pathogen risk is considered to be the single greatest benefit. Aesthetic benefits and improved ecosystem health are also benefits of waterway restoration, but will not be specifically addressed within this analysis.

7.3. Cost analysis

The CMA's typically offer a subsidy of between $2,500/km to $7,000 per kilometre (depending on factors such as, the habitat value, width of buffer or whether a covenant is put in place) while contract fencing costs between $7,000 and $12,000/km (unit cost information provided by the Department of Suitability and Environment, based on 2009/2010 evaluation). In addition to the fencing costs, the landholder has costs associated with stock watering and stream stock crossings, the loss of productive land and the maintenance of the fenced area and the fence itself. Collectively, these costs, and the lack of government policy to direct landholders to undertake waterway fencing (enforced through compliance action), have resulted in many landholders not participating in currently-available programs (or not participating fully).

If waterway fencing was extended at a manageable average rate of 3.5 km per year for the generic catchment, a target of 65% of perennial waterways fencing would be reached by 2024 (assuming a start time of Jan 2012) or 2044 if 100% of perennial waterways were to be fenced. The cost-benefit analysis has also been developed based on a 15 year timeframe, for the scenario where 100% of perennial waterway fencing is achieved, as the 32 year timeframe would be considered too long for most catchment management programs and public drinking water utilities. Even the risk exposure over 15 years may be considered too great, and a further acceleration of a waterway fencing program may be required.

The management of juvenile stock does not specifically require capital investment. Without specific management in place, anecdotal information suggests that juvenile animals are often located near waterways, where pasture is of better quality and where wind strength is lower. Landholders need to be educated on the high pathogen risk associated with these juvenile stock accessing waterways, and be encouraged to manage them away from waterways. As a result, costs related to project officers providing educational material to landholders and industry bodies and following up individual cases have been included. It may be considered that management of stock in this manner indicates best practice and hence incentives for such actions should be offered. At this stage the costs-benefit analysis will be limited to the first stage of juvenile stock management, which is awareness raising, education and follow-up.

Some research has considered the option of establishing off stream watering points with shade, thereby encouraging grazing animals away from waterways. If such a mitigation option was successful, then waterway fencing would not be required (or at least at a significantly decreased rate). However, unpublished recent studies communicated to the authors of this study have found that such interventions do little to reduce stock access to waterways unless accompanied by fencing.

Unit costs, and cost items for riparian management activities are provided in Table 7-1 to Table 7-5. Unit costs are described for capital items including project officer support and on-costs and operational costs over a period of 40 years, which is considered to be the life of the project. These costs represent the full cost, which would be shared by the private landholder and public investment. For the purpose of this analysis the total cost will be used, however the principles of environmental responsibility and stewardship are acknowledged.

Table 7-1. Unit costs - 65% waterway fencing

Scenarios	Item	Total cost ($,000)
65% of perennial waterway fenced (42km of fencing over 12 years)		
Capitals Costs		
	Contract fencing and crossings (@ $8,000/km)	$336
	Property plan (@$1000 x 100 properties)	$100
	Off stream water points (@ $8,000 x 100 properties)	$800
	Stock crossing (@ $5,500 x 100 crossings)	$550
	Project officer (@ 0.5 FTE, $70,000 p.a x 12 years)	$420
	Project officer direct salary on-cost (22%), plus vehicle @ $10,000 p.a per FTE	$152
	Corporate overheads (including accom. IT, support) @$25,000 p.a. per FTE	$150
Sub-total		$2,508
Operations (40 years, considered to the asset life of the fence)		
	Maintenance (including fence maintenance 3% capital cost of fence p.a), and weed/buffer vegetation maintenance @ $500/km/p.a.	$850
	Project officer (@ 0.5 FTE $70K p.a x 40 years)	$1,400
	Project officer direct salary on-cost (22%), plus vehicle @ $10K p.a per FTE	$508
	Corporate overheads (including accom. IT, support) @$25K p.a. per FTE	$500
Sub -total		$3,258
	Development, administration and project closure (5% total)	$288
Total		$6,055

Table 7-2. Unit costs - 100% waterway fencing over 32 years

Scenarios	Item	Total cost ($,000)
100% of perennial waterway fenced *(112km of fencing over 32 years)*		
Capitals Costs		
	Contract fencing and crossings (@ $8,000/km)	$896
	Property plan (@$1000 x 200 properties)	$200
	Off stream water points (@ $8,000 x 200 properties)	$1,600
	Stock crossing (@ $5,500 x 200 crossings)	$1,100
	Project officer (@ 0.5 FTE, $70,000 p.a x 32 years)	$1,120
	Project officer direct salary on-cost (22%), plus vehicle @ $10,000 p.a	$406
	Corporate overheads (including accom. IT, support) @$25,000 p.a.	$400
Sub-total		$5,722
Operations (40years, considered to the asset life of the fence)		
	Maintenance (including fence maintenance 3% capital cost of fence p.a), and weed/buffer vegetation maintenance @ $500/km/p.a.	$867
	Project officer (@ 0.5 FTE $70,000 p.a x 40 years)	$1,400
	Project officer direct salary on-cost (22%), plus vehicle @ $10,000 p.a per FTE	$508
	Corporate overheads (including accom. IT, support) @$25,000 p.a. per FTE	$500
Sub -total		$3,275
	Development, administration and project closure (5% total)	$450
Total		**$9,447**

Table 7-3. Unit costs - 100% waterway fencing over 15 years

Scenarios	Item	Total cost ($,000)
100% of perennial waterways fenced ***(112km of fencing over 15 years)***		
Capital Costs		
	Contract fencing and crossings (@ $8,000/km)	$896
	Property plan (@$1000 x 200 properties)	$200
	Off stream water points (@ $8,000 x 200 properties)	$1,600
	Stock crossing (@ $5,500 x 200 crossings)	$1,100
	Project officer (@ 1 FTE, $70,000 p.a x 15 years)	$1,050
	Project officer direct salary on-cost (22%), plus vehicle @ $10,000 p.a	$381
	Corporate overheads (including accom. IT, support) @$25,000 p.a.	$375
Sub-total		$5,602
Operations (40years, considered to the asset life of the fence)		
	Maintenance (including fence maintenance 3% capital cost of fence p.a), and weed/buffer vegetation maintenance @ $500/km/p.a.	$867
	Project officer (@ 0.5 FTE $70K p.a x 40 years)	$1400
	Project officer direct salary on-cost (22%), plus vehicle @ $10K p.a per FTE	$508
	Corporate overheads (including accom. IT, support) @$25K p.a. per FTE	$500
Sub -total		$3,275
	Development, administration and project closure (5% total)	$444
Total		**$9,321**

Table 7-4. Unit costs – Juvenile stock management

Scenarios	Item	Total cost ($,000)
Juvenile stock management		
	Project officers (@ 0.5 FTE, $70,000 p.a x 15 years)	$525
	Project officer direct salary on-cost (22%), plus vehicle @ $10,000 p.a per FTE	$191
	Corporate overheads (including accom. IT, support) @$25,000 p.a. per FTE	$188
Total		**$903**

Table 7-5. Unit costs – Off stream watering points with shade

Scenarios	Item	Total cost ($,000)
Off stream watering points with shade, no waterway fencing		
Capitals Costs	Off stream water points (@ $8,000 x 200 properties)	$800
	Project officer (@ 0.5 FTE, $70,000 p.a x 3 years)	$105
	Project officer direct salary on-cost (22%), plus vehicle @ $10,000 p.a per FTE	$38
	Corporate overheads (including accom. IT, support) @$25,000 p.a. per FTE	$38
Total		**$1,781**

7.4. Benefit analysis for the generic example catchment

The benefits of some example interventions, expressed as pathogen log reductions (refer Box 2), were estimated for the generic catchment (Table 7-6 and Figure 7-1).

Box 2 – Log reductions

Logarithm - The logarithm of a number is the exponent by which a fixed number, the base, has to be raised to produce that number. For example, the logarithm of 1,000 to base 10 is 3, because 1,000 is 10 to the power 3: $1{,}000 = 10^3 = 10 \times 10 \times 10$. More generally, if $x = b^y$, then y is the logarithm of x to base b, and is written $\log_b(x)$, so $\log_{10}(1{,}000) = 3$.

Logarithmic scale – is a scale of measurement using the logarithm of a physical quantity instead of the quantity itself. A simple example is a chart whose vertical axis increments are labelled 1, 10, 100, 1,000, instead of 1, 2, 3, 4. Each unit increase on the logarithmic scale thus represents an exponential increase in the underlying quantity for the given base (10, in this case). Presentation of data on a logarithmic scale can be helpful when the data cover a large range of values – for the use of the logarithms of the values rather than the actual values reduces a wide range to a more manageable size.

Pathogen log reductions – a reduced pathogen concentration on a logarithmic scale. For example a 3 log reduction is equivalent 1,000-fold reduction.

For the generic catchment, realistic catchment management scenarios could preclude the need for advanced water treatment. For instance, reducing stock access by 90%, or excluding juvenile stock from waterways, would preclude the need to add UV or ozone disinfection in addition to the existing conventional or membrane filtration plant.

For the generic catchment, realistic catchment management scenarios could not preclude the need for some level of water treatment and/or selective abstraction. Even the most rigorous conceivable catchment management paradigm for a grazing catchment, involving full fencing out of all stock from both perennial and ephemeral streams, cannot preclude the need for either additional water treatment following floods, or selective abstraction to avoid inflow under flood conditions.

In summary, for the generic example catchment, catchment interventions could preclude the need for advanced water treatment under all conditions, and could preclude the need for any water treatment targeted to control *Cryptosporidium* if water could be harvested only under dry weather flow conditions provided there were no other sources of *Cryptosporidium* within the catchment. However, under wet conditions, and allowing for the fact that there would probably be other sources of human infectious *Cryptosporidium* within the catchment, and noting that catchment interventions are hard to monitor, in practice, water treatment to remove or inactivate of *Cryptosporidium* would most likely be required for any catchment that carried significant densities of stock animals.

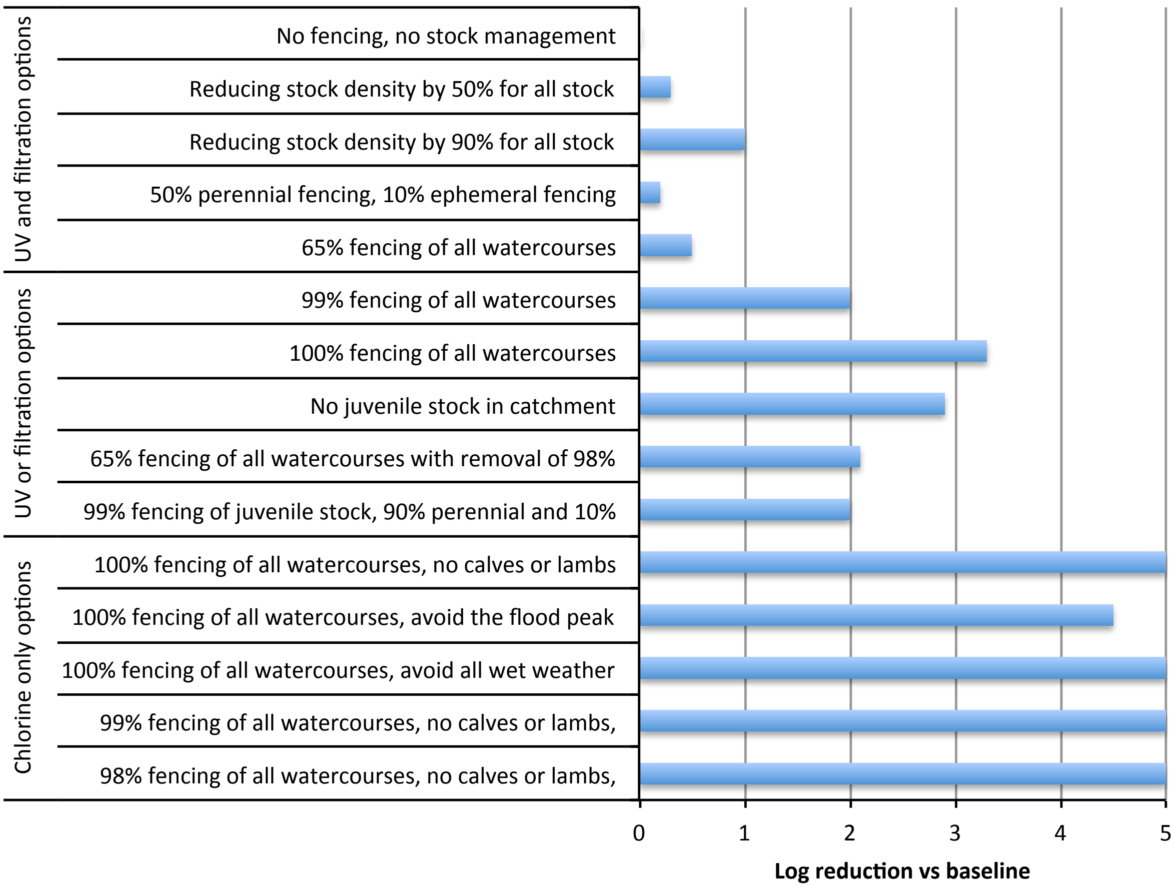

Figure 7-1. Benefits of example interventions in catchment.

Table 7-6. Benefits of example interventions in treatment and catchment.

Intervention	Log reduction	Implications for the case study catchment
Chlorination only	0.0	Insufficient without additional treatment, selective abstraction and/or catchment management
Direct filtration operating at current good practice	2.5	
Full conventional water treatment or DAFF operating at current good practice	3.0	
Full conventional water treatment, DAFF or membrane filtration operating at current best practice	4.0	
UV disinfection to 22 mJ/cm² *Cryptosporidium* validated reduction equivalent dose	4.0	
No catchment intervention	0.0	Sufficient in combination with 4 to 5 log water treatment, e.g. filtration and UV disinfection
Reducing stock density by 50% for all stock	0.3	
Reducing stock density by 90% for all stock	1.0	
Achieve 50% perennial fencing, 10% ephemeral fencing	0.2	
Achieve 65% fencing of all watercourses	0.5	
Achieve 99% fencing of all watercourses	2.0	Sufficient in combination with 2 to 3 log water treatment, e.g. filtration only or UV only.
Achieve 100% fencing of all watercourses	3.3	
Achieve no juvenile stock in catchment	2.9	
Achieve 65% fencing of all watercourses with removal of 98% calves and 90% lambs	2.1	
Achieve 99% fencing of juvenile stock, 90% perennial and 10% ephemeral fencing	2.0	
Achieve 100% fencing of all watercourses, no calves or lambs	5	Sufficient without filtration of UV disinfection, e.g. a chlorine-only water supply
Achieve 100% fencing of all watercourses, avoid the flood peak	4.5	
Achieve 100% fencing of all watercourses, avoid all wet weather	5	
Achieve 99% fencing of all watercourses, no calves or lambs, avoid the flood peak	5	
Achieve 98% fencing of all watercourses, no calves or lambs, avoid all wet weather	5	

7.5. Limiting values for interventions to achieve benefits

A number of scenarios were tested to establish the points at which particular interventions lead to particular step changes in risk and, therefore, treatment requirements. These scenarios are given in Table 7-7.

One very important observation was that the effect of fencing on risk reduction was not a linear relationship between fencing expressed as a percentage and pathogen reduction expressed as a logarithmic value. That is, increasing fencing from, say, 10% to 20% did not “double” the benefit when expressed as a log reduction. This is because the reduction is being expressed on a logarithmic scale whereas the intervention is being expressed on a linear scale. Going from 0% to 90% fencing only achieved a 1 $\log_{10}$ reduction in pathogen risk, all other things being equal. Even with 99% of the catchment fenced, the reduction in risk would only be 2 $\log_{10}$. The unfenced 1% of the catchment would still be contributing pathogens.

Another important observation was that targeting calves and lambs was the overwhelming priority. Fencing out all stock was not significantly more effective than merely fencing out juvenile stock; this is important. If there are calves or lambs with access to waterways, interventions targeted to adult stock that do not influence juvenile stock will not be of significant value to reducing risks associated with *Cryptosporidium* in waterways. The first priority should always be to target juvenile stock. Head for head juvenile stock present approximately 3 $\log_{10}$ orders more risk than adult stock. The difference in *Cryptosporidium* risk between a water supply catchment that has a significant proportion of juvenile stock, and one that only has adult stock contributing to the waterways, can be as much as the difference in risk made by commissioning a new, or upgrading an existing, water treatment plant.

Table 7-7. Limiting values for specific interventions.

Intervention	Intervention condition	Starting condition
Proportion of fencing required to achieve 1 log reduction	90%	0%
Proportion of fencing required to achieve 2 log reduction	99%	0%
Proportion of stock that can be juveniles (calves or lambs) in a grazing catchment to achieve a 1 log reduction	5%	50%
Proportion of stock that can be juveniles (calves or lambs) in a grazing catchment to achieve a 2 log reduction	1%	50%
Proportion of stock that can be juveniles (calves or lambs) in a grazing catchment to achieve a 3 log reduction	0%	50%

7.6. Cost of conventional water treatment plant and UV

The Tarago Water Treatment plant has been used as an example of a recent conventional plant which has been built in Victoria. Tarago Reservoir was not reconnected to the Melbourne water supply system until 2009, when pressure from the drought and increase demands led to the reconnection of this supply to the city's water supply network. Unlike most of Melbourne Water's other catchments, which are closed to the public, the land around the Tarago Reservoir is used for a number of purposes (including grazing), which lead to risks to drinking water quality without treatment. The reconnection involved building a $97 million water treatment plant to provide about 15 billion litres per annum (with a plant capacity of 70 million litres of water a day). The plant uses Dissolved Air Flotation and Filtration (DAFF) and ultraviolet (UV) disinfection, which are commonly used across Australia. For the purposes of this assessment, therefore, a modern DAFF and UV plant is assumed to have a capital project cost of $97 million. A nominal value of $5 million per annum operating cost is estimated.

7.7. Cost of UV treatment

The inclusion of UV treatment will provide an additional 2 to 4 log reduction in *Cryptosporidium* risk, and is a requirement for some water treatment plants (WTPs). The costs of UV can be separated into capital (materials and labour), project costs (development costs, project costs and a contingency) and operating costs (electricity, labour and lamp replacements). SA Water has developed indicative costs associated with UV treatment as a function of plant production in ML/d (refer Figure 7-2). For example UV treatment for a plant with a 70 ML/day (such as the scale of the Tarago WTP) is estimated to have a project and capital cost of $5.6 million and $3.5 million respectively, with an annual operating cost of $280,300.

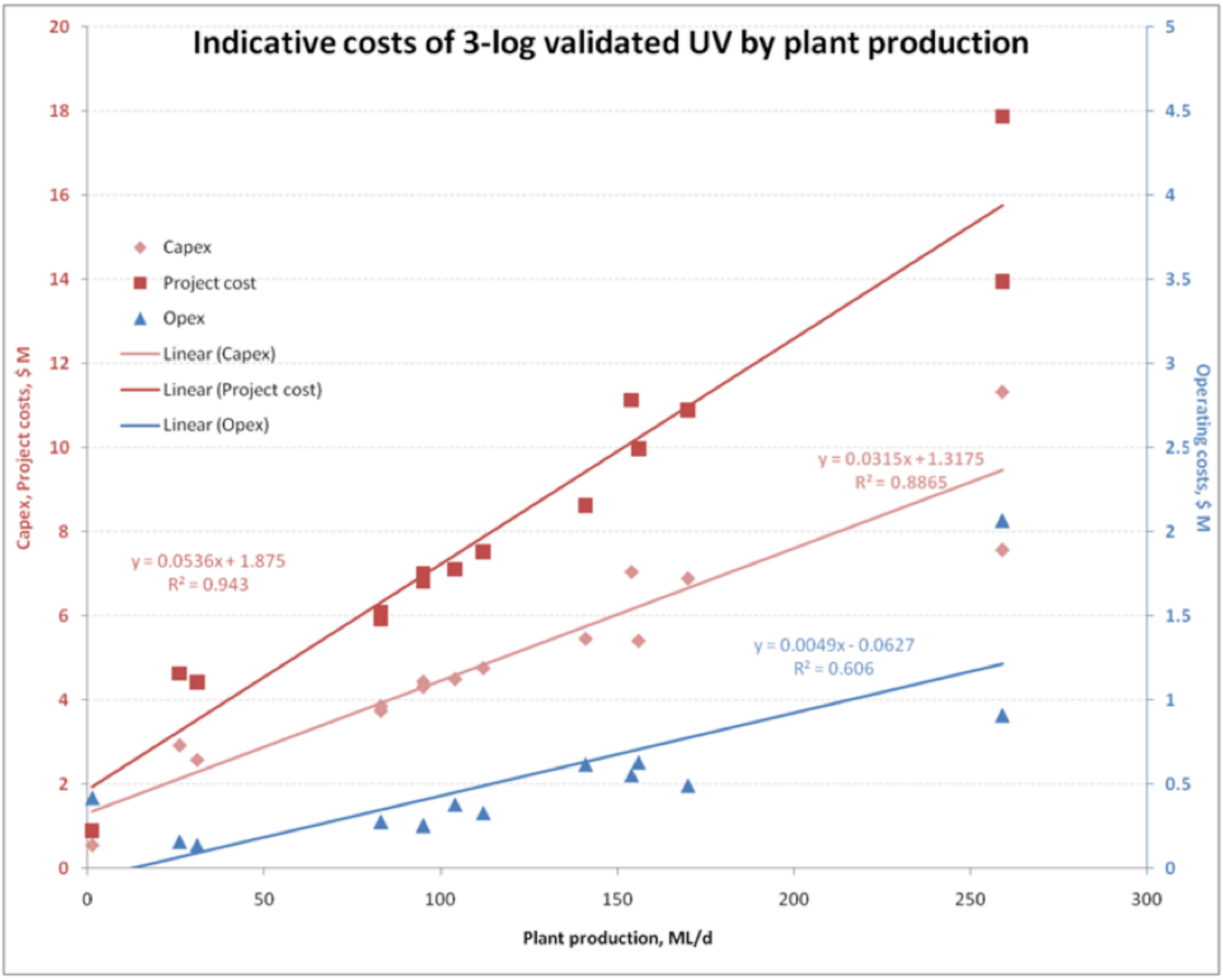

Figure 7-2 Capital and operating cost for UV treatment (Source Jek Rozitis, SA Water).

The information for the Net Present Value (NPV) calculation is very limited and the NPV is considered indicative only. Treatment plant costs are highly variable depending on the volume and quality of water to be treated. Catchment management costs are highly variable depending on the catchment size, current level of management and the extent of current development within the catchment. In both cases, costs are directly related to the desired outcomes. An NPV would need to be completed for the catchment and treatment scenarios for specific catchments and water treatment plants to be directly applicable to any one situation. However, some very important inferences can be drawn from the NPV analysis.

The preliminary assessment of NPV demonstrates that stock exclusion scenarios are of similar overall cost to treatment interventions for similar benefits (Table 7-8), at least for the example case study catchment. For instance, the NPV of a UV disinfection system is of the order of a few to several million dollars. The NPV of tens to hundreds of km of managed stock exclusion would be of similar cost. In some scenarios it may be possible to get better water quality and public health outcomes from excluding stock, particularly targeted exclusion of juvenile stock, through investment in stock exclusion rather than treatment. The NPV for a full filtration and disinfection system could fund hundreds to thousands of km of managed stock exclusion.

It is recommended that rather than simply investing in water treatment options, utilities consider the NPV of catchment management options, particular those targeted to juvenile stock exclusion and other high risk sources of pathogens. In some situations the NPV of the catchment intervention may be very favourable relative to the treatment option. In any case there may be combinations of treatment and catchment management interventions that can work well together to give an overall minimal NPV to achieve the desired outcome.

Although outside the scope of this assessment, it is noted that catchment and treatment interventions can both have benefits beyond merely the management of pathogen risks. These other benefits can include additional water quality and environmental improvements.

One issue not well covered in the NPV assessment is the timeframe. First of all, the capital cost of catchment interventions is likely to be spread over many years and that will potentially alter the NPV in practice. Secondly, catchment interventions may (usually but not necessarily) take many years, even decades, to complete. Extensive stock exclusion could be achieved rapidly but in practice this is rare. Given that some water supply systems may be experiencing risks to public health now or in the short-term, treatment interventions will often win out ahead of catchment interventions even where the latter are most cost-effective simply due to the inherently slow pace of conventional catchment management.

Overall, a carefully considered and balanced strategy involving both short and long term analysis of the risks and costs of a combination of treatment and catchment interventions would be required to arrive at the optimal solution for any particular situation.

Table 7-8 Summary of Net Present Values (NPV) of example fencing and water treatment options (-ve $,000 with discount rate of 0.08).

Scenario	Capital	Operations	Capital	Operat-ional total	Operat-ional annual	NPV period	NPV
Catchment Fencing							
1	65% of perennial waterway fenced (42 km of fencing over 12 years)	Operations (40 years, considered to the asset life of the fence)	$2,508	$3,258	$81	40	$3,479
2	100% of perennial waterway fenced (112 km of fencing over 32 years)	Operations (40 years, considered to the asset life of the fence)	$5,722	$3,275	$81	40	$6,698
3	100% of perennial waterways fenced (112 km of fencing over 15 years)	Operations (40 years, considered to the asset life of the fence)	$5,602	$3,275	$218	15	$7,47
Water Treatment Plants							
4	Based on UV project costs for a plant of around 70 ML/d	Based on UV plant operating costs for a plant of around 70 ML/d	$5,600	$4,204	$280	15	$7,999
5			$5,600	$8,969	$280	32	$8,805
6			$5,600	$11,212	$280	40	$8,942
7	Based on filtration and UV project costs for a plant of around 70 ML/d	Based on filtration and UV operating costs for a plant of around 70 ML/d	$97,000	$75,000	$5,000	15	$139,797
8			$97,000	$160,000	$5,000	32	$154,174
9			$97,000	$200,000	$5,000	40	$156,623

7.8. *Cost of outbreaks*

Labza, 2004 in the Regulatory Impact Statement (RIS) for the Drinking Water Quality Regulatory Framework for Victoria considered the costs associated with outbreaks of epidemic disease. The RIS refers to a general model which was developed by Monash University and the National Centre for Epidemiology and Population Health. The model sets out the major sources of costs due to an outbreak of intestinal infectious disease (IID) and provides relative importance of the quantifiable costs (Table 7-9).

Table 7-9 major sources of costs associated with intestinal infectious disease outbreak

Sources of cost	Relative importance of cost (%)
Direct costs of illness. These include the costs of medical and the associated costs of drugs prescribed to treat the illness;	3.2
Indirect costs of illness. These are the production losses associated with absences from work and, more speculatively, with reduced productivity on days when the sufferer attends the workplace;	19.5
Costs of avoidance behaviour. These are the costs people incur via their attempts to avoid catching the disease in circumstances of an outbreak; and	65.8
Management costs. These are costs borne by governments in investigating and managing disease outbreaks and those borne by water suppliers and consumers in complying with the orders of government regulators.	11.5

Adapted from *Drinking Water Quality: Risk Assessment – Cost Benefit Analysis Report'*. Department of Epidemiology & Preventive Medicine, Monash University, and National Centre for Epidemiology & Population Health, Australian National University (ANU). 1997.

Costs relating to the number of mortalities due to IID and to pain and suffering associated with IID occurrence can be added to the above categories. These costs are, necessarily, more difficult to quantify.

The Monash/ANU study is based on costings for a 'typical' town of 11,000 people. For such a town, the cost of an epidemic outbreak of IID if it occurred was estimated at $1.8 million. Taking the costs estimated by the Monash/ANU study, and applying the assumption that the average costs of an outbreak are directly proportional to the population of the town, the two most recent disease outbreaks in Victoria (Sunbury in 1987 and in Kyabram in 1997) may have entailed costs of the order of $4.2 million (at 1995 prices).

The potential costs of large-scale outbreaks and contamination incidents are considerable with examples discussion of the incident in 1998 in which the Sydney water supply system was contaminated with *Cryptosporidium* and *Giardia*, and the disease outbreak in Walkerton, Ontario (Canada) in 2000. While the costs discussion below should only be considered at an order of magnitude scale, they do serve to show the potential significance of such an event.

7.8.1. Sydney NSW – 1998 contamination incident

The Productivity Commission has published estimates of the costs to Sydney Water Corporation that are attributable to the 1998 contamination incident. Overall, the incident was reported to have resulted in an abnormal operating expense of $55.4 million and foregone revenue of $19.2 million (based on a decision to defer a planned water price increase for twelve months) (Labza 2004). The abnormal operating expense was composed of the following elements:

- $15 payment to affected customers (total, $19.2 million);
- Paid and estimated outstanding insurance claims (total, $14.0 million);
- Additional monitoring and testing costs (total, $12.5 million);
- Costs associated with the McClellan Inquiry (total, $2.0 million); and
- Other costs (total $7.7 million).

Labza states that "*The above represents the costs of the incident only from the viewpoint of Sydney Water Corporation. For the purposes of economic impact assessments of public policy proposals, it is necessary to consider costs from the whole of society viewpoint. From this latter perspective, the bulk of the foregone revenue of $19.2 million represents a transfer from Sydney Water Corporation to its customers, rather than a real resource cost. A similar perspective applies in relation to the $15 rebate to affected customers. Thus, the real resource costs among the total costs borne by Sydney Water represent $36.2 million, rather than the $74.6 million its accounts indicate as the total costs to the organisation".*

The Monash / ANU study argues that estimates of the time and resource costs of avoidance measures such as purchasing bottled water or other tap-water substitutes or boiling tap water must be considered as part of the cost of the outbreak. Labza, 2004 concluded that "If it is speculated that half of Sydney's population of 3,600,000 was affected by the Boil Water Alerts during their 35 days total duration, this would imply total aversion behaviour costs equal to:

$4.89 per day x 35 days x 1.8 million people = $308.1 million

Thus, adding this hidden cost to the cash costs to Sydney Water Corporation noted above, the true cost of the Sydney water contamination incident may have approached $350 million.

7.8.2. Walkerton, Ontario (Canada) – 2000 outbreak

The above estimate of the total costs of the Sydney incident relates to an event in which there were few identifiable adverse health impacts. It is apparent that substantially larger costs are likely to be incurred where there are incidences of illness and death. The potential for this to occur in a developed country context presents itself in an incident principally caused by the presence of a pathogenic (disease causing) form of *E. coli* bacteria in the drinking water supply of Walkerton, Ontario (Canada) in May and June 2000 (Labza, 2004). In this case a total of seven people died, while approximately 2,300 were made ill.

The waterborne disease outbreak in Walkerton led to the establishment of an Inquiry in June 2000, which reported in 2002. Commissioned Paper No. 1413, prepared for the Inquiry, estimated the tangible economic costs of the outbreak and arrived at a total figure of C$64.5 million (A$76.0 million at that time). This figure was arrived at via a survey of 400 households and most businesses in Walkerton to ascertain the impacts on them of the outbreak (Labza, 2004). The cost estimates contained in the study do not include the intangible costs of lives lost or illnesses caused, arguing that such valuation is impossible (although the Value of Life Estimates were latter considers - *Value of Life Estimates in an Economic Cost Assessment'.* John Livernois. Walkerton Inquiry, Commissioned Paper No. 15, Toronto, 2002). While the specific costs of incidents where loss of life occurs is extremely difficult to assess, it is clear that costs will be very much higher when substantial health impacts result from an outbreak.

7.9. Conclusions relating to costs and benefits

The costs of outbreaks (tens to hundreds of millions of dollars) are overwhelmingly higher than the costs of their prevention. Therefore, as a general conclusion, it is considered appropriate to ensure that waterborne disease outbreaks do not arise due to pathogens entering water supplies via stock accessing waterways upstream of drinking water off-takes.

Catchment interventions can compare favourably to treatment interventions in terms of cost. For instance, a typical UV disinfection system might have a net present value of some millions of dollars, which could provide managed exclusion of stock from tens to hundreds of km of waterways. A typical filtration and UV disinfection system might have a net present value of some tens to hundreds of millions of dollars, which could provide managed exclusion of stock from hundreds to thousands of km of waterways.

Targeted catchment management programs that focus on pre-weaned juvenile stock might be able to reduce pathogen risks for a cost similar to, or less than, the costs of UV disinfection, and for a similar or greater benefit. Broadscale catchment management programs that seek to manage all stock might be able to reduce pathogen risks for a cost similar to, or less than, the costs of filtration and UV disinfection, and for a similar or greater benefit.

Compared to water treatment, catchment interventions are inherently more beneficial in overall environmental terms and can be more favourable in terms of the inherent reliability.

In terms of time to effect, water treatment interventions are likely to be more amenable to expedient implementation than catchment interventions.

In mitigating risks in any particular catchment, the most appropriate balance of investments between catchments and treatment, and the nature of those investments, needs to be assessed on a case-by-case basis. As a general conclusion, it is considered appropriate to compare the timeframes to effect, costs, reliability and benefits of a range of catchment and treatment interventions in various practicable combinations. The resulting analysis would identify the most appropriate investment for any particular circumstance.

It is recommended that practical policy guidance be developed to assist water supply agencies and catchment management authorities implement targeted, cost-effective catchment interventions to help reduce risks to the health of drinking water consumers, reduce water treatment costs and improve the reliability of the safety of public water supplies.

8. Recommendations

The purpose of this study was to assemble objective evidence and provide defensible guidance relating to the assessment and management of public health risks associated with stock accessing waterways upstream of drinking water off-takes. General recommendations arising from this study are as follows:

8.1. Targeted stock management

- Juvenile stock (aged less than three months) should form the first target in any catchment management program that is directed to drinking water safety objectives. On a per head basis juvenile animals are of the order 1,000-fold more significant than adult stock and represent the proverbial low hanging fruit in terms of benefit : cost.
- A sensible interim goal in drinking water catchment management would be the targeted confinement of as high a proportion of pre-weaned stock within areas that are as hydrologically separated from waterways as practicable, given the specific situation upon each property and within each catchment.
- Specific education programs are required on the management of juvenile stock within drinking water catchments. These programs could be developed to align with the best management practices for stock health management.
- To the maximum extent practicable, excluding stock of all ages from watercourses in drinking water catchments is worth promoting, but noting the overwhelming priority associated with juvenile stock.

8.2. Buffer zones

- Exclusion of stock from waterways requires physical exclusion from streams and separation from those streams via suitable buffer zones.
- Waterway fencing should be prioritised along perennial waterways since these contribute continually to pathogen inputs to drinking water sources. Fencing of ephemeral streams is also valuable as a second priority behind the perennial streams.
- The priority for fencing would be the sections of the catchment closest to the drinking water supply off-take and the areas with the highest stocking rates and highest proportion of young stock.
- The greater the land use intensity, the wider the riparian zone needs to be to buffer against catchment modifications and disturbances. However, in general, standard buffer distances of 5 to 10 m, as used to manage nutrients and other riparian values are sufficient for orders of magnitude reduction in risk.
- Filter strips of perennial grasses are required to make buffer strips effective at entrapping pathogens. Poorly vegetated buffer strips are far less effective at entrapping pathogens. Grass filter strips require active management which may include mowing or crash grazing.
- In order to maximise functional efficiency, riparian zones should be longitudinally continuous. Fencing and buffers must have full longitudinal continuity within any one paddock – gaps in fencing may not be a major issue for riparian vegetation protection, but will remove the benefits that fencing might otherwise have for pathogen mitigation. Fences need to be actively inspected and maintained.

8.3. Optimal investments in catchment management

- The optimal allocation of resources and the optimal mix and balance of catchment and treatment interventions will be variable between specific catchments and drinking water off-takes. However, the approach illustrated within this document demonstrates that it is possible to develop an evidence-based benefit : cost basis for the assessment and mitigation of risks from pathogens in drinking water catchments. Risks can be estimated and the costs and benefits of a range of realistic scenarios can be assessed to support business cases for optimal allocation of resources.
- Although outside the scope of this document, benefits and costs of catchment interventions to protect drinking water objectives can be broadened to take into consideration other drinking water and environmental objectives.
- Equally outside the scope of this document, it should be noted that stock are not the only source of pathogens in catchments. With respect to bacterial pathogens, wildlife remain a significant source of risk and even with total stock exclusion, disinfection is required to manage risks from these bacterial pathogen hazards. Where there is significant human activity within water catchments, such as on site sewage management systems, sewerage systems, sewage treatment plants and recreational activity, protozoan and viral pathogens are also potentially significant. Interventions to mitigate stock access are likely to be a high priority in grazing catchments with relatively little human habitation, but only once sewage management has been reasonably well addressed.

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Appendix A Instruments to support catchment interventions

Since there is evidence that risks to public health from catchment interventions are not tolerable unless adequately mitigated, it is necessary to explore the mitigation of those risks. This section of the report looks at the powers that could be used to manage these risks through source protection and catchment management.

The management and tenure of riparian land in Victoria is complex. On smaller streams in agricultural landscapes, riparian land is usually in private ownership. The State has a network of public riparian reservations known as Crown frontages, mostly on larger streams where the riparian land forms a boundary between properties. This network of reservations is unique to Victoria, and covers about a fifth of the length of the State's stream network (or 25,000 kilometres of Victoria's 128,000 kilometres of water frontage). Streams that include Crown frontages are often of the highest priority for waterway protection and restoration (DSE, 2009).

1.1 Statutory context

In Victoria, the main Acts/Policies pertaining to catchment and drinking water supply management include the following:

- *Catchment and Land Protection Act 1994*
- *State Environment Protection Policy (Waters of Victoria) ('SEPP WoV')*
- *Environment Protection Act 1970,*
- *Water Act 1989*
- *Planning and Environment Act 1987*
- *Safe Drinking Water Act 2003*
- *Land Act 1958*
- *Crown Land (Reserves) Act 1978*

These Acts and their relevant aspects are summarised in detail in Table 1-1. While the review of these Acts is not intended to be exhaustive, it clearly shows the mandates and objectives for the management and protection of catchments in relation to water supply that are relevant to the control of pathogen pollution.

Victoria's legislation clearly provides a mandate for managing catchments and therefore, managing water pollution, including pathogen pollution, at source (as far as is reasonable) including the sharing of catchment management costs. Both public drinking water corporations and Catchment Management Authorities (CMA's) should continue to apply a duly diligent and proactive approach to catchment management. Those, such as landholders, who are responsible for controlling pollution in the catchment need to comply with the appropriate pollution control requirements. A precautionary approach to protecting the environment is required as is a multiple barrier approach to protecting public health (NHMRC/NRMMC 2004).

Table 1-1. Relevant statutory powers

Statutory Instrument	Relevant Findings
Safe Drinking Water Act 2003	The Safe Drinking Water Act 2003 (SDWA) has as it primary purpose, to make provision for the supply of safe drinking water. In particular, the SDWA (s 1(2)(a)) places obligations on water suppliers and water storage managers to: *".....prepare and implement plans to manage risks in relation to drinking water and some types of non-potable water"* Further, a risk management plan (s 9) in relation to the supply of water is a document: *"(a) that contains a detailed description of the system of supply; and* *(b) that identifies the risks to the quality of the water and the risks that may be posed by the quality of the water; and* *(c) that assesses those risks; and* *(d) that sets out the steps to be taken to manage those risks (including the* ***development and implementation*** *of* ***preventative strategies****) [our emphasis]; and* *(e) that contains any other matters required by the regulations."* The regulations (Safe Drinking Water Regulations 2005) contain the following definition of hazard (s 3): *".....a biological, chemical, physical or radiological agent that has the potential to cause harm"* Obviously a pathogen (in the context of stock manure for the purposes of this report) is a biological agent with the potential to cause 'serious' and in some cases, 'irreversible' harm (see Precautionary Principle section). The management of stock access to surface water should therefore be included within the water supplier's or water storage manager's risk management plan's 'preventative strategies'.
Catchment & Land Protection Act 1994	The *Catchment and Land Protection Act* (CaLP Act) imposes a general duty on the part of land owners to take all reasonable steps to, among other things, avoid causing or contributing to land degradation; conserve soil; and protect water resources (s 20(1)). The CaLP Act also creates a civil liability on the part of the Authority for anything done or omitted to be done (even if in good faith) in the performance of its functions under the CaLP Act (s 19). Many catchments supplying water for domestic, irrigation or other purposes within Victoria are protected under the CaLP Act, through the designation of Declared Water Supply Catchments. These catchments have significant value as sources of water supply, both for domestic and for stock and domestic use. Once a catchment is Declared, approvals for activities conducted under other statutes and statutory planning schemes must be referred to the responsible land management authority (Catchment Management Authority or DSE) for approval. Special Area Plans (SAPs) can be developed for these areas. SAPs are very powerful instruments, which go significantly further than planning schemes made under the *Planning and Environment Act 1987.* Whereas a planning scheme is purely reactive (it responds to a land owner's proposals), a SAP may be pro-active, and cause some change of use or works to occur. Because of this power to intrude into private property, a SAP must include costings of implementation, and a plan for funding the proposed interventions. In Victoria, SAPs have not been used for riparian zone management, although they have been made for 46 water supply catchments. Under the CaLP Act, Victoria is divided into ten catchment regions, with a Catchment Management Authority (CMA) established for each region.

Statutory Instrument	Relevant Findings
Water Act 1989	CMAs are provided with regional waterway, floodplain, drainage and environmental water reserve management powers under the *Water Act 1989*. Each CMA has declared most major waterways as designated waterways and have developed by-laws for the protection of these waterways (but these by-laws do not include pollution into the waterway). The *Water Act 1989* can give rise to a civil liability in damages where a person pollutes water, whether authorised to do so or not, and by that act causes injury, property damage or economic loss to another person (s 15(1)(c)). This provision is generally binding on the Crown (s 5(a)). In certain circumstances, a water authority may need to send a designated officer on to land for certain purposes, and s 133 confers powers on officers of Authorities or authorised persons to enter land. Further, s 167 of the *Water Act 1989* grants powers to officers of Authorities or authorised persons to enter land for the purposes of water supply protection and s 168 provides for immediate action for water supply protection: *"An Authority may, immediately and without notice, remove from-* *(a) any land that is adjacent to any waterway or works forming part of the Authority's water supply system; or* *(b) any water in or adjacent to any such waterway or works-* *any substance or thing that is, in the Authority's opinion, likely to affect the purity of the Authority's water supply system."* It is therefore plausible that should an officer find cows accessing and defecating in waterways, and in the opinion of the officer that the practice is causing pollution of the Authority's water supply system, that the Authority, under the *Water Act 1989*, can remove the cows from the land.
Land Act 1958	Under the Land Act the Department of Sustainability and Environment (DSE) may issue a licence for agricultural use over a Crown water frontage to an owner/occupier of the adjoining private land on behalf of the Minister for Environment and Climate Change ('Minister') (s 130AB(c)). A licence over a Crown land water frontage provides personal permission to enter and use the land for a specified purpose. It does not offer exclusive use to the licensee. Rather, when a Crown land water frontage is licensed, the public retains the right to enter and remain on the land for passive recreational purposes.
Crown Land (Reserves) Act 1978	This Act provides for reservation of Crown land for a variety of public purposes, the appointment of committees of management to manage those reserves and for leasing and licensing of reserves for purposes approved by the Minister for Environment and Climate Change. The principal object of this Act is the protection of public values on Crown land to be retained for some public purpose. DSE state that "*examples of public land values include environmental, historic, recreation, natural resource and cultural significance*".
Planning and Environment Act 1987	This Act establishes a system of planning schemes. These schemes are based on a system of zones (which deal with land uses) and overlays (which generally deal with works), specified in the Victorian Planning Provisions (VPPs). Every river and every frontage is the subject of one zone - plus one or many overlays, which define appropriate uses and developments.

Statutory Instrument	Relevant Findings
Environment Protection Act 1970	The *Environment Protection Act 1970* (**EP Act**) requires that any discharge or deposit of waste into water be in accordance with relevant SEPPs (s 38). As noted above, under the Act the EPA can take enforcement action for breaches of SEPPs. It also creates an indictable offence for polluting waters, where the condition of the waters is so changed as to make or be reasonably expected to make those waters noxious or poisonous, harmful or potentially harmful to human health, wildlife or vegetation or to any beneficial use made of those waters (s 39). 'Waters' is given a reasonably broad definition to include natural and constructed bodies: *"includes any reservoir, tank, billabong, anabranch, canal, spring, swamp, natural or artificial channel, lake, lagoon, waterway, dam, tidal water, coastal water or groundwater"* The inclusion of groundwater in the definition of 'waters' is important as outbreaks in the past have been caused by cattle manure accessing groundwater sources through percolation (see Davison, 2006). Further information of relevance to this project is that of 'beneficial uses' of an environment: *"Beneficial use means a use of the environment or any element or segment of the environment which-* *(a) is conducive to public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from the effects of waste discharges, emissions or deposits or of the emission of noise; or* *(b) is declared in State environment protection policy to be a beneficial use;"* Water supply catchments clearly provide a beneficial use in many of the terms set out above and in the SEPP WoV. Further, the EP Act sets out a definition of 'environmental hazard': *"a state of danger to human beings or the environment whether imminent or otherwise resulting from the location, storage or handling of any substance having toxic, corrosive, flammable, explosive, infectious or otherwise dangerous characteristics"* A pathogen (as borne in cattle faeces for the purposes of this project) can be classified under the above definition as being 'toxic', 'infectious' and having 'otherwise dangerous characteristics' and therefore clearly meets the test for posing an 'environmental hazard' to human beings. While the EP Act does not contain a definition of 'serious' or 'irreversible' environmental damage or harm, case law, as presented in the section pertaining to the precautionary principle below, and the matters set out in Davison et al (2010), provide guidance on this issue. The definition section also provides guidance on whom is responsible as a 'protection agency' under the EP Act and casts the net very broadly to encompass other relevant legislation: *"**protection agency** means any person or body, whether corporate or unincorporate, having powers or duties under any other Act with respect to the environment or any segment of the environment in any part or parts of Victoria"*

Statutory Instrument	Relevant Findings
State Environment Protection Policy (Waters of Victoria) ('SEPP WoV')	The State Environment Protection Policy (Waters of Victoria) ('SEPP WoV') is a statutory policy (subordinate legislation made under the provisions of the Environment Protection Act 1970), which provides a framework for the protection of the uses and values of Victoria's fresh and marine water environments.[1] The SEPP WoV is specifically referenced within the Protect our Waters Protect our Health publication (Vic Department of Health 2010) at p23: *"The SEPP (Waters of Victoria) covers the need for protecting waterways used for drinking water and includes the requirement to protect such waterways from the effects of waste discharges and contaminants."* The SEPP WoV is based on a set of principles, which is outlined within the *Environment Protection Act 1970*. One of these principles is the 'Precautionary Principle', which has its basis in the protection of the environment. However, the precautionary principle can also be applied to the protection of human health as outlined by a recent 'Red Dot' VCAT decision and explained in further detail in Davison et al (2010). This decision is covered in the section relating specifically to the precautionary principle below. Clause 27 of the SEPP WoV specifically deals with the protection of beneficial uses of environments (see below for further discussion on beneficial uses). It should be noted that the definition of a beneficial use includes health protection. Summarizing, clauses 10 & 11, state that a beneficial use does not prohibit or permit the use of surface waters for any particular purpose, but requires surface waters to be of a suitable quality and quantity to support that value"; and "Surface waters and their aquatic ecosystems need to be free of any substance at a level, or human impact, that would pose a risk to beneficial uses". The SEPP WoV (Policy Impact Assessment) identifies the discharge of animal waste into water through grazing as one of 'the most imminent threats to Victoria's water environments'. However, the SEPP mainly deals with point discharges and intensive activities, and has only indirect bearing on dispersed riparian activities. Under Clause 39 of the SEPP, animal wastes must not be dumped in waterways. The intent of Clause 39 is to ensure that all animal wastes are managed effectively, not just point sources but also general animal-contaminated runoff. The SEPP WoV (Policy Impact Statement) contains further guidance on the intent of Clause 39: *"In rural environments, the* ***main contributors*** *[our emphasis] of animal wastes are stock access to surface waters and illegal discharges from intensive agricultural industries."* The SEPP WoV sets out various measures for addressing this and other threats through its 'attainment program'. Clause 50 of the SEPP WoV pertains to Agricultural Activities. The SEPP WoV (Policy Impact Statement) outlines a range of what are considered to be 'effective farm management practices, one of which is: *"….controlling stock access to surface waters…"* Further information pertaining to water contamination is contained in Schedule F8 Waters of Western Port and Catchment. Part of the catchment contained within this Schedule includes waters flowing into Tarago Reservoir.

[1] Note that a SEPP (Groundwaters of Victoria) also exists. However, while it is known that stock manure may percolate into groundwater and indeed has caused waterborne disease outbreaks previously (e.g. Davison, 2006), the groundwater SEPP is not covered in detail in this report as the objective is to concentrate on stock access to surface water.

<table>
<tr><th>Statutory Instrument</th><th>Relevant Findings</th></tr>
<tr><td>

Continued…State Environment Protection Policy (Waters of Victoria) ('SEPP WoV')

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Two of the beneficial uses of water to be protected by this Schedule are:

1. Human consumption after disinfection and
2. Human consumption after disinfection and removal of suspended solids.

Note that Environmental quality indicators and objectives' are set out in detail in Clause 11.

At Annex B – 'Activities that may pose a Significant Environmental Risk to Beneficial Uses' – one of the examples of activities that, if not well managed, may pose a significant environmental risk is:

(16) waste, wastewater and stormwater management.

Item 16 is of particular note for the management of diffuse agricultural pollution as this type of pollution may be typified by the description provided in item 16.

At Annex C – 'Significant Environmental Risks Posed to Beneficial Uses', one of the examples of risks which may pose a risk to the beneficial uses in the schedule area is:

(5) oils and toxicants in water environments.

A literal interpretation of item 5 could include pathogens as being 'toxicants' in water. Further, section 22(1)(c) of the *Safe Drinking Water Act 2003* links with the conceptual interpretation of 'toxicant' in Schedule F8 as follows:

"*S22 Officer to report known or suspected contamination*

(1) This section applies if an officer of a water supplier, water storage manager or council believes or suspects, on reasonable grounds, that water supplied, or to be supplied, for drinking purposes—

(c) may contain any pathogen, ***substance*** *[our emphasis], chemical or blue-green algae toxin, whether alone or in combination, at levels that may pose a risk to human health;"*

</td></tr>
</table>

Statutory Instrument	Relevant Findings
Continued…State Environment Protection Policy (Waters of Victoria) ('SEPP WoV')	In this context, a toxicant could be a 'pathogen' or 'substance' which could cause contamination of a water body to be used for drinking. Further, 'toxin' could be more broadly applied to potentially toxigenic situations such as the presence of pathogens including the enterohaemorrhagic *E. coli* bacteria (found in cattle faeces), which are known to produce a series of enteric toxins. This principle of shared responsibility is also highlighted in the WoV SEPP under Clause 6(6), with clauses 12,13 and 23 providing additional detail; Clause 12 – “”Communities, businesses and protection agencies, including catchment management authorities, regional coastal boards, water authorities, municipal councils and relevant State government agencies, have responsibilities to plan or manage Victoria's surface waters, and activities that impact on them, in an ecologically sustainable manner. Clause 13 – “implementation on a daily basis is the shared responsibility of protection agencies, businesses and communities” Clasuse 23 – “Community members have responsibilities to protect the beneficial uses of Victoria's surface waters. These include a responsibility to manage their activities to minimise direct impacts on surface waters and to efficiently use natural resources to avoid the generation of waste and wastewater”. Schedule F8 Waters of Western Port and Catchment also includes guidance on duty of care and who has a duty to whom, which is covered to some extent in the 'Principle of shared responsibility' in Part II, (6): *“(a) Protection of the environment is a responsibility shared by all levels of government and industry, business, communities and the people of Victoria.* *(b) Producers of goods and services should produce competitively priced goods and services that satisfy human needs and improve quality of life while progressively reducing ecological degradation and resource intensity throughout the full life cycle of the goods and services to a level consistent with the sustainability of biodiversity and ecological systems.”* Moreover, Schedule F8 specifically notes the following in terms of setting out responsibilities: *“Achievement of the schedule purpose will require the co-operative and concerted action of government agencies, businesses, individuals and the wider community.”* Further responsibilities are set out in Clause 12 General Responsibilities: *“The protection and rehabilitation of the environmental quality of Western Port and its catchment is the shared responsibility of relevant government agencies, businesses, non-government organisations, communities and individuals.”* It is therefore clear that the policy requires a concerted effort from all parties to give effect to its purpose. This principle of shared responsibility is also highlighted under the WoV SEPP under Clause 6(6).

A specific application of Victoria's legislation has been considered within a review of crown frontage grazing licences. In a review of legal obligations and risks to water quality and human health, the Environmental Defenders Office in 2009 concluded:

> 1. There is strong policy support for the removal of grazing licences on riparian Crown land. The State of the Environment Report (CES 2008) is the most recent example of a growing, and increasingly vocal, body of evidence in support of the phasing out of uncontrolled grazing of domestic stock. The government is aware of these policy arguments but has not to date followed them up in any meaningful way.
>
> 2. There is also strong legal support for the removal of grazing licences on riparian Crown land. The statutory regime around the use of Crown water frontages and human health create legal risks for the State government, which are likely to increase as time goes on. For example:
>
> - the *Water Act* creates a civil liability for a person who pollutes water, whether authorised to do so or not, and by that act causes injury to another person.
> - The *Public Health and Wellbeing Act* creates a breach where a person causes a nuisance or knowingly allows a nuisance to exist or emanate from any land owned or occupied by or in the charge or that person.
> - the *Wrongs Act* gives rise to a right to damages where the act or omission of a public authority breaches its duty of care. This may arise where the public authority fails to comply with general procedures and applicable standards for the exercise of its functions.
>
> 3. Finally, there is a real risk that any injury to a person or their property arising out of uncontrolled stock access on riparian land could give rise to an action in either common law or statutory negligence. It is not far-fetched to envisage a situation in which the Crown possessed the requisite duty of care, knowledge (or 'forseeability') and control to satisfy the negligence 'test'. Water contamination as a result of grazing on riparian land may also give rise to a claim in public nuisance. Although there are many matters that would need to be considered to determine whether such a liability arose in any individual case, it would clearly be better to avoid such a situation arising the first place.

While these statutory instruments are in place often there is not the policy drivers to utilise specific provisions. There are also considerable complexities in developing clear protection of environmental assets such as riparian areas, due to the number of Acts that are relevant and their interrelationships. A review of the Management of Riparian Land in Victoria (by the Public Land Consultancy, Annon 2008), has made recommendations for statutory reform across the areas of riparian land status, riparian land protection, management and works

Specifically the review states:

> *"There are at least half a dozen heads of power under which one might expect to find tools for regulating stock access to waterways. These include the Impounding of Livestock Act, the Fences Act, the Environment Protection Act, the Land Act and Crown Land (Reserves) Act, the Water Act and the Catchment and Land Protection Act. Each one, however, needs some amendment before it can effectively serve this purpose."*

The White Paper for Land and Biodiversity, which was released 1 November 2009, has a specific action relating to statutory reform regarding riparian management; "Action 6.4.2 Reform administrative and legislative arrangements to enable enhanced riparian land management by 2014". This reform should significantly improve the current situation.

In the absence of fully effective statutory powers with regard to riparian management, governing bodies (predominantly Catchment Management Authorities) and landholders rely strongly on state policies to underpin management practices.

1.2 Principles

Of importance in the catchment management context is the understanding and implementation of principles in decision-making. While principles may be seen as guiding rather than binding, in a recent case before the Victorian Civil and Administrative Tribunal (VCAT), the principles of the Australian Drinking Water Guidelines were called up as being fundamentally applicable in the management of drinking water catchments.

For the purposes of this report, two areas are considered in detail, those principles within the Australian Drinking Water Guidelines and the Precautionary Principle.

1.2.1 Australian Drinking Water Guidelines – Guiding Principles

The Australian Drinking Water Guidelines 2004 (NHMRC/NRMMC 2004) contain a set of six guiding principles for drinking water management:

1. The greatest risks to consumers of drinking water are pathogenic microorganisms. Protection of water sources and treatment are of paramount importance and must never be compromised.
2. The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.
3. Any sudden or extreme change in water quality, flow or environmental conditions (e.g. extreme rainfall or flooding) should arouse suspicion that drinking water might become contaminated.
4. System operators must be able to respond quickly and effectively to adverse monitoring signals.
5. System operators must maintain a personal sense of responsibility and dedication to providing consumers with safe water, and should never ignore a consumer complaint about water quality.
6. Ensuring drinking water safety and quality requires the application of a considered risk management approach.

These principles specifically outline the concept of multiple barrier implementation in drinking water management as well as the protection of water sources – therefore enshrining both as the appropriate standard of duty that a drinking water provider/catchment manager should be following.

Guiding Principle 1 clearly states that pathogenic microorganisms are the greatest risk to consumers of drinking water. Given this clarification, any waste stream or stormwater runoff, or any thing containing human infectious pathogens would be seen to be a 'toxicant', 'contaminant' or other 'substance' as worded in the various pieces of legislation available to the catchment/drinking water manager in Victoria and variously described in this document.

1.2.2 Precautionary Principle

The precautionary principle emerged initially as a principle for managing environmental harm. The precautionary principle is stated within the *Environment Protection Act 1970* (Vic) and also within the SEPP WoV and is particularised as follows:

"Section 1C. The precautionary principle

(1) 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.

(2) Decision making should be guided by-

(a) a careful evaluation to avoid serious or irreversible damage to the environment wherever practicable, and

(b) an assessment of the risk-weighted consequences of various options."

The *Public Health & Wellbeing Act 2008* has defined the *Precautionary Principle* under section 6 – "*If a public health risk poses a serious threat, lack of full scientific certainty should not be used as a reason for postponing measures to prevent or control the public health risk*", with 'serious risk to public health' defined under the Act as "a material risk that substantial injury or prejudice to the health of human beings has or may occur having regard to:

(a) the number of persons likely to be affected;

(b) the location, immediacy and seriousness of the threat to the health of persons;

(c) the nature, scale and effects of the harm, illness or injury that may develop; and

(d) the availability and effectiveness of any precaution, safeguard, treatment or other measure to eliminate or reduce the risk to the health of human beings.

Under section 13 of the Act, it is stated that the Act binds the Crown, and hence this definition of the precautionary principle is specifically relevant.

Further guidance on the application of the precautionary principle in catchment management and human health protection has been provided by Victorian Civil and Administrative Tribunal (VCAT) and the Supreme Court of Victoria in the various cases associated with *Rozen* (the Rozen case).

The Rozen case was initiated based on the application for a planning permit to build four dwellings on a lot within the Campaspe River catchment. The site forms part of the Campaspe River Catchment Area, which is a subcatchment of the larger Eppalock Water Supply Catchment. The Campaspe River drains into the Campaspe Reservoir, which is located downstream from the site and supplies the Township of Woodend. The permit, had it been granted, would have exceeded the dwelling density of 1:40 ha as outlined in the:

- *Guidelines - Planning Permit Applications in open, potable water supply catchment areas, May 2009, Department of Planning and Community Development (DPCD Guideline).*

While the Rozen case primarily concerns itself with planning, the findings in the Supreme Court appeal by Western Water (*Western Water v Rozen & Anor* [2008] VSC 382 (29 September 2008)) have a bearing on catchment management in general and the application of the precautionary principle specifically, and are particularized as follows:

- The Tribunal [VCAT] did not correctly identify or address the concept of risk of "serious", as distinct from “irreversible” damage to the environment;
- The Tribunal did not assess the gravity of the risk against the relevant test but rather substituted a misconceived test requiring a risk of irreversible damage;
- The Tribunal did not in terms find that there was no foreseeable risk of damage to the environment.

Further, Justice Osborn J noted that:

> *“I do not accept that the distinction between the risk of damage to the environment and danger to human life is readily applicable to the present context when the primary beneficial use of the waters in issue is that of potable water………. In summary the Tribunal has misstated and misapplied the precautionary principle in circumstances where it was plainly relevant, because both the Guidelines [ADWG] and the planning scheme policy required the Tribunal to consider the question of the cumulative risk created by otherwise individually appropriate septic tank systems.”*

The Rozen series of cases which are covered in further detail in Davison et al (2010), provide, in particular, further elucidation of the application of the precautionary principle in the context of ‘serious harm’ and ‘irreversible harm’ in relation to environmental and public health end points was provided (refer Table 1-2).

Table 1-2. Comparisons of ‘serious and irreversible harms between the environment and public health (Davison et al, 2010).

Category	Example of Serious Harm	Example of Irreversible Harm
Environment	Fish kill	Salinisation of soils
Public Health	Disease	Sequelae from disease e.g. kidney failure from contracting *E. coli* O157:H7 Death

From the overall Rozen findings, it is possible to conclude that the precautionary principle is readily applicable to public health, as well as environmental health, and indeed that is should be applied to the protection of public health in catchment management decisions.

1.3 Policy context

Unless otherwise stated the following summaries are sourced from the Environmental Defenders Office, within its report “Crown frontage grazing licences, water quality and human health – an analysis of legal obligations and risks”.

1.3.1 State of the Environment report

The State of the Environment report (CES 2008) was released in December 2008. The report highlights the importance of riparian vegetation and the major problems arising from damage caused by uncontrolled stock access, with (VNPA 2010a):

- Only 21% of major rivers and tributaries in Victoria being in good or excellent condition;

- Almost half the river basins in Victoria having less than 10% of major rivers and tributaries in good or excellent condition
- Only 14% of major rivers and tributaries having riparian vegetation in good condition. Uncontrolled stock access to riparian zones continues to be the major pressure on riparian vegetation statewide.

In its key findings and recommendations, the report recommended, among other things, that the Victorian Government consider progressively extending Victorian Environment Assessment Council (VEAC) recommendations (see below) to phase out uncontrolled grazing of domestic stock on Crown land water frontages to the rest of Victoria, beginning with the 2009 licence renewal process. It also recommended that the Victorian Government consider more ambitious targets for the rehabilitation of riparian vegetation for the Victorian River Health Program beyond 2011; that it update and streamline governance arrangements to facilitate protection and restoration of Crown Land water frontages; and that it, together with catchment management authorities, should consider regional-scale connectivity of riparian vegetation in the prioritisation of rehabilitation projects, as part of forming an integrated habitat network across the State.

1.3.2 Victorian Environment Assessment Council

The Victorian Environment Assessment Council ('VEAC') released its Red River Gum Forest Investigation in July 2008 (VEAC 2008). The Investigation recommended that the grazing of stock on parks and state forests cease at once, and proposed a five year phase-out for grazing on public water frontage, in order to ensure the long term viability of biodiversity assets. The Investigation detailed that stock grazing in riparian habitats was detrimental to water quality, caused soil erosion, and increased concentrations of invasive weeds in the area. The VEAC recommended the installation of fencing along water frontage to decrease these adverse impacts, with the economic flow-on effects of riparian protection to be worth an estimated $2.3 million per annum.

1.3.3 Victorian Catchment Management Council

The Victorian Catchment Management Council ('VCMC') published its five-yearly report on the condition of Victoria's catchments in 2007. It found that only one of Victoria's ten catchments had rivers and streams in good condition; two were in moderate condition; three were in moderate/poor condition; and four were in poor condition.

1.3.4 Victorian River Health Strategy

The Victorian River Health Strategy, released in 2002, outlines the then Victorian Government's long-term direction for the management of Victoria's rivers. The strategy identified uncontrolled stock access as being one of the major threats to riparian land. It recommends the introduction of a management framework 'where all managers of riparian land, both public and private, recognise the ecological importance and functions of that land and aim to manage it in a way that protects and restores these functions for river health outcomes.

The Strategy further recognises that poor water quality affects human and livestock health, water supplies, biodiversity, recreational uses and future amenity. However, it also recognises the complex task of addressing the cumulative effects of 'diffuse' pollutant sources (such as agricultural run-off and intensive animal industry effluent).

The Strategy sets specific future targets to measure progress across the State. By 2011, for example, its stated aim was to have 4,800 kilometres of rivers with an improvement of one rating in the measurement of riparian condition; and an increase of 7,000 hectares of riparian areas under management agreements.

1.3.5 Victorian River Health Program

The Victorian River Health Program was developed by the Victorian Government to improve the health of rivers in the State. Where the Victorian River Health Strategy (see above) provides a framework for managing riparian land, the Victorian River Health Program provides funding to improve the condition of Victoria's rivers through a range of programs, including those aimed at protecting and restoring riparian land. The program adopts the Index of Stream Condition – the first complete and comprehensive study of the environmental condition of rivers anywhere in Australia. The ISC is completed every five years.

The ISC benchmark is completed every five years and has been carried out in 1999 and 2004:

"In 2004, the ISC reported that about 21% of major rivers and tributaries in Victoria were in good or excellent condition, 47% were in moderate condition and 32% were in poor or very poor condition. This is due to a combination of factors including changed river flows, poor water quality, poor condition of river bank land, changes to the river channel and reduced habitat (VCMC 2007)".

1.3.6 White Paper for Land and Biodiversity 2009

The White Paper for Land and Biodiversity 2009, while being developed under the previous state government, provides detailed discussion on the management of riparian land and hence is relevant as background to this study.

Outcome 6.4 of the White Paper for Land and Biodiversity (DSE 2009) states:

"Riparian land is the land adjoining a freshwater wetland, estuary, lake or stream. It is highly valued for agriculture and has significant recreational, aesthetic and cultural values".

The paper then provides the following policy position:

> *Well-managed riparian land provides ecosystem services such as pollutant filtration, and sediment and nutrient trapping that give us good water quality and public health benefits. The community is increasingly valuing these important services and demanding better protection of riparian land.*
>
> *The management of Victoria's riparian land will be improved to reflect community standards for good management of aquatic and terrestrial systems and water supplies. Riparian management will contribute to the implementation of biolinks and build ecosystem resilience in flagship areas and across the landscape.*
>
> *Riparian areas will be progressively fenced, vegetated and actively managed to protect the catchment, water quality, public health and biodiversity values of the adjoining waterway. This will be achieved though a cooperative partnership approach including negotiated land management agreements and licensing arrangements.*

The core management objective for Crown frontages is the protection and enhancement of ecosystem services and environmental values. This will be achieved while also delivering other economic benefits such as grazing. Central to these objectives is the management of stock access to the bed and banks of streams to avoid stock contaminating water and eroding banks. Public access for recreation will be maintained, along with high fire protection standards.

In consultation with the community, the Victorian Government will develop a suite of locally relevant standards for the management of riparian land. A mix of financial incentives, statutory mechanisms and institutional arrangements will be utilised to achieve these standards. This will be consistent with the approach to fulfilling the environmental duties and stewardship aspirations of landholders.

Government will assist landholders to meet these standards by contributing towards the cost of fencing, revegetation, and provision of off-stream watering infrastructure for stock. The proportion of the cost covered by Government will depend upon the level of public benefit provided by the works.

On private riparian land, management will be underpinned by regular contact with landholders and by robust legal agreements. These will be negotiated with landholders on a voluntary basis. The Government intends to progressively strengthen and formalise partnership arrangements with landholders.

On Crown frontages, licences will recognise any voluntary agreements and contain performance requirements that reflect the objective of enhancing environmental values to the new management standards. Licenses may be extended to the maximum tenure period permitted under the Land Act 1958, subject to ongoing compliance with the agreement.

The following actions are then provided:

***6.4.1** Complete the current review of licensing arrangements for high priority Crown frontages, in consultation with licensees, by 2010*

***6.4.2** Reform administrative and legislative arrangements to enable enhanced riparian land management by 2014*

***6.4.3** Identify high-priority Crown frontages that are occupied but not licensed. Negotiate management agreements and license these areas by 2014*

***6.4.4** Complete the Riparian Management Framework and incorporate standards for managing riparian lands by 2014*

***6.4.5** Bring all riparian lands up to the new management standards with robust licensee or landholder agreements in place by 2029* (DSE 2009)

Through its various policy statements, the Victorian Government has indicated a high level of commitment to integrated catchment management as an important way of achieving sustainability. In Victoria, the concept of integrated catchment management (ICM) underpins sustainable management of land and water resources and contributes to biodiversity management. CMA’s are the lead agency in this area and provide incentive programs to protect and improve the condition of riparian areas.

1.4 Non-statutory approaches

Through their various policy statements, successive Victorian Governments has indicated a high level of commitment to integrated catchment management as an important way of achieving sustainability. In Victoria, the concept of integrated catchment management (ICM) underpins sustainable management of land and water resources and contributes to biodiversity management. CMA's are the lead agency in this area and provide incentive programs to protect and improve the condition of riparian areas.

1.4.1 Incentive programs or Tender Scheme

CMA's provide two main mechanisms, to fund the protection and improvement of riparian zones and waterways. The first is a package of incentive payments to landholders to fence off waterways (with payment for per kilometre fencing, stock watering points, stock crossing etc). The second approach is through tender schemes, were the landholder provides a list of catchment improvements which will be completed for a total sum of money. The CMA then determines which tender is of most value given its priorities and consideration of costings.

Significant lengths of waterway have been fenced to date. The Our Water, Our Future website reported that;

- Since 2002, over 6000 ha of riparian land have been protected and improved through stock exclusion, weed control and revegetation.
- Over 2000 km of existing riparian vegetation have been fenced, more than 750,000 riparian plants have been established, and 178 km of bank stabilisation works have been undertaken.
- Considerable progress has been made to formalise management arrangements and responsibilities, providing better long-term protection for riparian areas.
- Between 2002 and 2005, a total of 3077 landholder agreements were established, allowing for the protection of around 6000 ha of riparian areas. Predictions suggest the 2011 target of having 7000 ha under management agreements will be surpassed.

Significant state funds have been invested to achieve these riparian zone improvements. For example the Healthy Waterways Program had provided approximately $9.1M annually towards on-ground catchment actions including riparian protection and enhancement including fencing, weed control (including willows) and revegetation, while the Victorian Water Trust - Healthy Rivers Initiative provided $16m over 4 years (2003/04 through 2006/07) to accelerate delivery of the Victorian River Health Strategy (Anon 2008).

On a State-wide basis, it has been identified that there is little if any consistency between the various CMAs' documents establishing agreements with landholders to undertake works, and then to maintain those works. Issues of concern include the legal validity of the documents, the survival of any agreement if the property changes hands, and duplications or inconsistencies between these contracts and Crown frontage licences (Anon, 2008).

A Review of the Management of Riparian Land in Victoria concluded that a continuing program of CMA-funded works on riparian land would benefit from a new form of legal agreement. It should be 'status-neutral' (that is, be applicable to both Crown and freehold land); it should 'run with the land' (that is, survive any change of land ownership); and it should simplify rather than duplicate or add to other statutory consents.

1.4.2 Stewardship agreements

The review of the Management of Riparian Land in Victoria (2008) stated that a further matter for consideration in a wider framework is the idea of Payments for Ecosystem Services. This concept has been the subject of various papers by DSE and the VCMC. Within the review it was proposes that landholders have an environmental duty of care, and that market-like mechanisms may be appropriate to purchase landholder inputs over and above that base level. If the theory finds favour with policy makers, then it will most certainly have relevance for riparian management. For instance, weed control on freehold land might be seen as within the occupier's duty of care, but weed control on an abutting Crown frontage could be seen as an ecosystem service for which the taxpayer should provide recompense to the landholder (Anon, 2008).

The white paper for land and biodiversity states that;

> *It is not appropriate for the government to pay for actions that a land manager is expected to undertake by law, and it is not an efficient use of public funds for government to pay for actions that are already expected by the community. Many land managers across Victoria undertake best practice management, as determined by communities or industries. Best practice management should be recognised through the market price of goods or rewarded through incentives.*

Equally, landholders need to understand their legal requirements (which are often not well defined, communicated or enforced). Action 5.4.1 of the White Paper for Land and Biodiversity addresses this issue with a requirement to "*Provide information to landholders on their responsibilities "to take all reasonable steps to… conserve soil and protect water resources" under the Catchment and Land Protection Act 1994 by 2010*". Once this is complete a framework for environmental responsibilities and stewardship can be implemented, refer Figure 1-1.

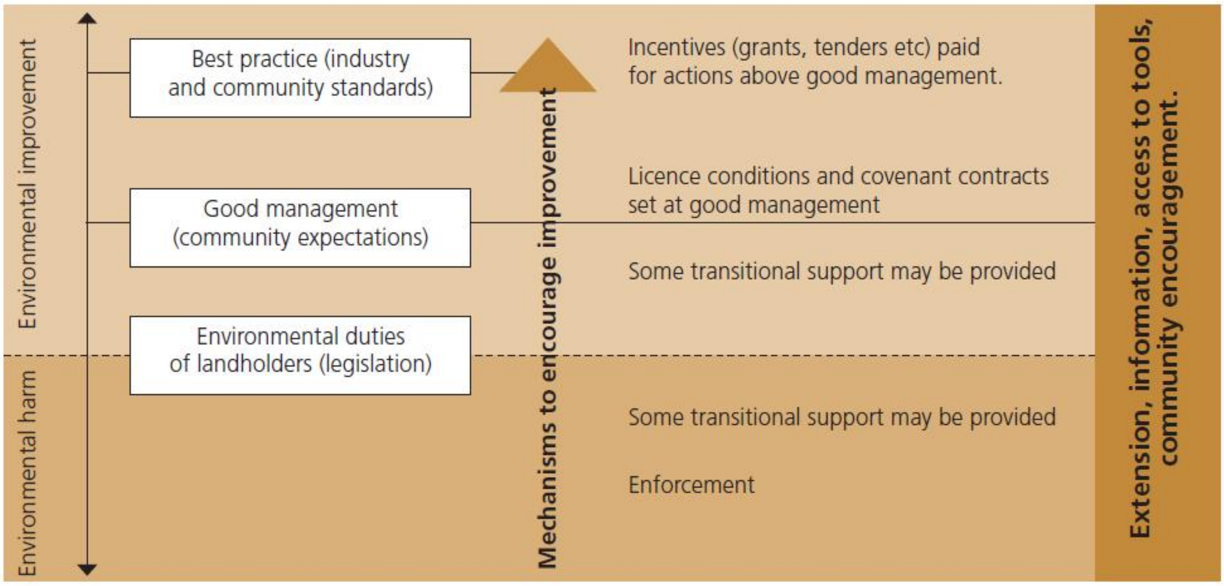

Figure 1-1. Victorian framework for environmental responsibilities and stewardship (sourced from Anon 2009)

Costing regarding the protection of waterways within this study will apply the framework for environmental responsibilities and stewardship.

Further information on the protection of drinking water catchments is provided in the booklet '*Protect our Waters Protect our Health*' (Vic Department of Health 2010). This booklet is explicit about the impacts of land management on drinking water quality and its consequent potential for impact on human health of the communities served by that water. A fundamental component of the booklet is the integration of statute, policy and guidance, which sets out a clear framework for the management of drinking water catchments within a legislative, scientific and social context. In fact the booklet is written in such a way that is gels neatly with the outcomes from the Rozen case outlined above (see Precautionary Principle section). The booklet sets out actions (see Part 2), which landholders may implement to help protect drinking water catchments, with stock access management being one of those actions:

- improve the condition of waterway frontages with vegetation
- **prevent stock access to waterways** [our emphasis]
- maintain onsite wastewater treatment systems
- prevent soil erosion
- use and manage nutrients appropriately
- use and manage agricultural chemicals wisely
- plan and develop thoughtfully.

1.5 Summary

In Victoria, the main Acts/Policies pertaining to catchment and drinking water supply management include the following:

- *Catchment and Land Protection Act 1994*
- *State Environment Protection Policy (Waters of Victoria) ('SEPP WoV')*

- *Environment Protection Act 1970,*
- *Water Act 1989*
- *Planning and Environment Act 1987*
- *Land Act 1958*
- *Crown Land (Reserves) Act 1978*
- *Safe Drinking Water Act 2003*

As well as the statutory aspect, there are other pertinent guidance documents that should be taken into account in catchment management including the Australian Drinking Water Guidelines. Case law in Victoria has led to an interpretation and implementation of the precautionary principle for catchment management not only from an environmental and human health perspective, but also in terms of what impacts constitute 'serious' and 'irreversible' harm ((*Western Water v Rozen & Anor* [2008] VSC 382 (29 September 2008); *Rozen v Macedon Ranges SC* (includes Summary) (Red Dot) [2009] VCAT 2746 (23 December 2009).

There is a clear mandate to properly manage stock access to surface water in drinking water catchments within the Victorian regulatory and formal context, as well as a clearly articulated hierarchy of responsibilities from government agencies though to individuals. There is no retreating from the fact that stock access to surface water in drinking water catchments is legally regarded as a serious impact on waters sourced for drinking water supply and in fact, is made more compelling because of its inclusion within a multitude of statute, policy, guidance and case law contexts.

Appendix B Case studies on buffer distance determinations

1.1 Cedar Grove Weir case study, Queensland

An expert opinion was provided by Water Futures on the requirement for a buffer distance for Cedar Grove Weir in Queensland. The opinion recommended against the proposal to acquire land of a 20 m wide buffer zone for water storage management and control measures as the distance was considered too small to protect water quality at this site. The 20 m width buffer was not to be considered best practice (several km) nor the currently accepted practice (400 m). This assessment highlighted several factors:

- That the buffer zone around public drinking water assets (such as reservoirs, weirs or river off-takes needs to be considerably larger than river or stream buffers as the relative distance to the point of water treatment is shorter;
- The greater the buffer zone width the better in terms of water quality and other environmental outcomes. Therefore, any reduction in buffer zone width from best practice needs to be acknowledged as a compromise. The compromise will lead to a reduced life for the weir banks, increased frequencies of water quality problems, such as algal blooms during low flow periods, increased treatment requirements at capital stage and increased ongoing operational costs as well as increased probability of waterborne disease.
- Were a waterborne disease outbreak to arise from a weir pool with such a narrow buffer strip, those that recommended or accepted such a buffer strip could potentially be considered to have been contributory, at least in the eyes of the community, even if not strictly in law.
- The important feature of minimum buffer distances is that they are only to be applied literally in situations where the contingent factors of geomorphology, soils, climate, stream order, topography, water uses and pollution sources are all, simultaneously, at their most favourable to achieving the desired outcome. In other cases, to achieve the desired environmental outcome requires some buffer of greater distance than the minimum. The Requirements to be met for a minimum quoted buffer distance to be appropriate are provided in Table 1-1, with estimated conditions at Cedar Grove Weir.
- Meeting multiple environmental outcomes (bank slumping, biodiversity or water quality) can not generally be achieved via a common riparian buffer. For example, an optimal pathogen buffer, would be a continuous grass buffer strip of a width between 5 and 30m. However, a riparian buffer strip for biodiversity outcomes, may be a revegetated zone, with trees, shrubs and understorey. Unfortunately, this type of buffer zone does not substantially improve water quality as surface run-off can pass through the buffer too rapidly. Thus, in many cases the requirements for buffer zones would ideally be additive (e.g a 20m revegetated buffer adjacent the waterway with a 20m grass filter strip)

Table 1-1. Contingent factors affecting buffer distances and estimated conditions at Cedar Grove Weir.

Factor	Requirements to be met for a minimum quoted buffer distance to be appropriate	Estimated conditions at the Cedar Grove Weir*
Rainfall intensity	Consistently low, temperate or Mediterranean climate.	Sub-tropical high rainfall at times.
Soil moisture	Consistently moist supporting stable vegetation cover, well-drained, not generally saturated.	Probably semi-arid for part of the year leading to vegetation stress and saturated at other times due to intense sub-tropical rain events.
Sensitivity of receiving water	Of low significance, not for drinking, fishing or aquatic habitat protection.	Highest significance, for drinking.
Stream order	Lowest stream order, ephemeral headwater feeder streams.	High stream order, perennial source water weir.
Soil type	Well drained, deep, good loam to sand ratio to support entrapment of nutrients and pathogens whilst allowing drainage.	Appears to be sandy, probably well drained but not likely to be very effective at trapping pathogens and nutrients.
Slope	Virtually flat.	Appears to be variable with some steep areas.
Intensity of surrounding source	Low intensity pollution source.	Generally medium intensity pollution source with some high intensity sources including irrigated grazing.
Condition of land and cover	Well vegetated stable land.	Appears to be variable with some poorly vegetated, actively eroding areas.

1.2 Western Australian Case Study

Water Futures was requested by the Water Corporation to provide recommendations on buffer zone widths and riparian management within several drinking water catchments. The study concluded the following relevant information:

- Properly implemented programs of riparian buffer protection will significantly reduce pathogen inputs during dry weather flow conditions and in rain events that do not overwhelm the filtration capacity of the buffers. Extreme wet weather events will render riparian buffers ineffective with respect to pathogen entrapment. Therefore, riparian buffer barriers alone are insufficient in the Western Australian catchments under consideration - additional catchment protection, storage management, selective abstraction and/or water treatment barriers are required to ensure reliable drinking-water quality protection. Nonetheless, riparian buffers are an important barrier and should be promoted by Water Corporation as a part of its multiple barrier approach.
- Research by the CRCWQT (Davies *et al* 2004) and from overseas (Atwill *et al* 2002) has revealed that pathogens are readily mobilised from cattle faecal pats during rainfall events. For *Cryptosporidium* oocysts, entrapment as high as 4-$\log_{10}$ per linear metre was observed during simulated rainfall events of a magnitude sufficient to create surface runoff. For *E. coli*, entrapment efficiencies were much lower and export over tens of metres has been measured. Therefore, the riparian buffer design criteria recommended for particulate P and sediment entrapment are considered appropriate for oocyst entrapment but are less appropriate for bacterial pathogen removal.
- A limitation of riparian buffers for pathogen entrapment is that pathogens present a risk to public health even after very brief (acute) exposures so that even momentary failures in barrier performance are problematic. Design criteria recommended for

particulate P and sediment removal are known to be ineffective during very large storm events. Failure of riparian buffers to entrap sediment and particulate nutrients during large storm events might be considered acceptable since, during those same periods, dilution and washout effects help to protect environmental water quality in waterways. However, failure of riparian buffers to entrap pathogens during large storm events is a cause for concern because concentrations may reach levels that are hazardous to public health whilst at the same time the particulate material may make water treatment less effective.

- A further limitation of riparian buffers for pathogen entrapment arises from the build up of pathogens on land during antecedent dry periods. Whilst residing in environmental matrices (faeces, soil, sediment and water), the majority of the pathogens present will be inactivated according to approximately first order linear decay processes. However, a one $\log_{10}$ reduction in pathogen concentrations in the Western Australian climate would be measured in periods ranging from days for bacteria in summer up to weeks for *Cryptosporidium* in winter. Therefore, pathogens persist in a viable state in faeces for long enough that the pathogens contributed to the waterway by an overwhelming rain event will include significant contributions from the faeces deposited in the days to weeks prior.
- Fenced out riparian buffers are effective at eliminating direct deposition of faecal material in waterways and this is a major benefit to customers in terms of reduced pathogen loads to waterways and, therefore, contamination of drinking-water supplies. Beyond that, during rain events, riparian buffers do reduce the extent of indirect pathogen loading to waterways.
- A final limitation of riparian buffers for pathogen entrapment comes from the requirements for fine understorey vegetation such as grasses. Riparian buffer design criteria used by the Department of Environment are sound but are not necessarily ideal if pathogens were the only consideration. A riparian buffer with large trees and shrubs but with poor litter and little grass cover is unlikely to be particularly effective at entrapping pathogens.

The study considered that the best way to use riparian buffers as part of a catchment management strategy is to consider two levels of drinking-water quality risk with riparian buffers being used to manage just one of them:

- Epidemic disease. This is the less frequent but higher magnitude risk to drinking-water consumers who might ingest quite high doses of pathogens on very rare occasions. Typically epidemic disease arises after a combination of factors such as major storm events combined with treatment plant problems (Davison *et al* 1999; Teunis *et al* 2004). Riparian buffers are unlikely to be effective during rare, high magnitude storm event scenarios due to inundation and sheet flow; and
- Endemic disease. This is the more frequent but lower magnitude risk to drinking-water consumers who might ingest pathogens very occasionally, and in very low numerical doses of just one or a few pathogens, leading to very occasional sporadic infections and disease in the community. This level of disease is unknown and is not directly measurable. Riparian buffers are important contributors to the reduction of endemic disease in the community because they reduce the concentrations of pathogens under most circumstances.

1.2.1 Epidemic disease

Riparian buffers will only significantly reduce pathogen inputs during lower magnitude storm events whereas in extreme events that might lead to a waterborne disease outbreak, entrapment will be very limited or nil. Riparian buffers will not be discussed further in the context of the control of epidemic waterborne disease. Alternative controls are required to reduce risks of epidemic disease following major storms in the drinking-water catchments. Operational controls could include triggering extra rigour in water treatment or the use of alternative water supplies following extreme storms. Changing landuses towards native bushland, arable agriculture or forestry industries would be an alternative, particularly in very small catchments.

1.2.2 Endemic disease

Since at the low exposure doses found during the endemic disease burden scenarios the relationship between risk and dose is approximately linear, any pathogen reduction will yield a reduction in public health risk. Therefore, a whole range of control measures, including riparian buffers, will help to support improvements in the safety of drinking-water. However, the support by Water Corporation for riparian buffer programs needs to be based on some understanding of its context within the multiple barrier approach to drinking-water quality protection as well as the broader preventative medical programs of the state.

1.2.3 Design criteria for riparian buffers

The effectiveness of riparian buffers is proportional to:

- Linear width from waterway to fence;
- Evenness of the surface;
- Extent of grassy vegetation cover;
- Longitudinal continuity of the fenced-out buffer strip; and
- Inverse of the slope.

The first priority is the exclusion of stock to prevent direct defecation in water courses. Permitting direct access of stock to streams presents a risk to drinking-water quality even in the absence of rain events with estimates around 10% being made for the proportion of faeces deposited by cattle in waterways to which they have access.

It is worthwhile recognising the need for pragmatism in managing multiple use catchments. If there are benefits to the landholders, such as bank stability, soil conservation and salinisation protection, as well as community benefits through fauna and flora protection, there will be additional reasons for promoting the riparian buffers which will strengthen the case for change and increase the chance of buffers being implemented.

In some cases the riparian buffers will be implemented at locations where Department of Environment and other stakeholders may have no interest, such as on Water Corporation land. In such cases, riparian buffers can be designed to include flood-tolerant perennial grass filter strips as well as woody vegetation to stabilise banks. It is possible to graze the filter strips through crash grazing using adult stock during brief periods during the year when runoff and high-level streamflow is unlikely. This can reduce weeds and maintain filter strips as grass whilst providing economic return to the landholder.

Additional criteria that could influence the priorities for riparian programs between and within catchments could include stocking densities and the current level of water treatment at that source.

1.3 New Zealand case study

The New Zealand Ministry of Agriculture and Forestry has developed guidelines for the optimal design of riparian buffers to entrap faecal bacteria (Collins et al., 2005b). They account for soil type, slope, the degree of bacterial attachment to soil and dung, and entrapment efficiency, but a large number of assumptions have been made in their development (Journeaux, 2005). Collins et al. 2007, explain that it is not possible to derive quantitative riparian zone design guidelines, from the relatively few experimental studies which have occurred across pastoral land within New Zealand. To do so would require experimental work to be undertaken across the whole range of soils, slope angles, buffer types, and magnitude of rainfall events found within New Zealand. Instead, quantitative guidelines for riparian buffer strips with respect to faecal bacteria (Collins et al. 2007) have been derived from those reported for sediment attenuation. These, in turn, were derived from a detailed sediment modelling study that captured the variability of the New Zealand pastoral landscape, and simulated the effects of a permanent buffer characterised by dense vegetation.

A current lack of understanding of the form in which faecal microbes are transported in surface runoff limits the ability to predict buffer effectiveness for bacteria with confidence; microbes transported as single un-attached and dispersed particles will be less readily trapped in a buffer than those transported in aggregates of faecal material or soil. The riparian buffer strip bacteria guidelines attempt to account for this uncertainty by including estimated efficiencies for varying degrees of bacterial attachment (Collins et al. 2005b). This was achieved by assuming that the percentage clay content of each soil in the original sediment modelling could be used as a surrogate for the percentage of dispersed (non-attached) bacteria. In addition, it was assumed that the percentage of soil particles greater than clay-sized represented the percentage of bacteria transported in an attached form. Whilst this approach is a crude approximation, it has the advantage of being based on the similarity in size of clay particles and single faecal bacteria: clay particles are < 2 μm, whilst bacteria typically range between 0.3 and 2 μm, with *E. coli* 1-2 μm. It is appreciated that, typically, the degree of bacteria attachment will be unknown at any given location, and is likely to vary with a number of factors, including the type of faecal material, the amount and type of eroded soil and, rainfall characteristics. However, the inclusion of varying levels of attachment in these bacterial riparian buffer strip (RBS) guidelines provides an indication of the sensitivity of optimal buffer width to this factor (Journeaux, 2006).

The quantitative guidelines for buffer design with respect to faecal bacteria are presented in Table 1-2. These illustrate the optimal buffer width for each combination of slope, soil drainage and bacterial attachment, where the optimal is defined as giving the best return in terms of efficiency for the amount of land given over to the buffer.

Important caveats are associated with the derivation of these guidelines that require the reported efficiencies to be treated as a "best-case". These caveats are as follows:

1. The proportion of bacteria transported as unattached in the derivation of Table 1-2 was assumed to range between 10 per cent and 60 per cent. In reality, however, this figure may, at least on occasion, be higher than 60 per cent, reducing

buffer efficiency. For example, Muirhead et al. (2005) report attachment rates of *E. coli* to sediment of < 25 per cent.

2. Whilst some bacteria may approximate a clay particle in size, other bacteria and all viruses (25-350 nm) are considerably smaller. Unless a large proportion of these smaller microbes attach to other particles their entrapment efficiencies will be lower than those reported in Table 1-2. Furthermore, bacteria are less dense than mineral clays and hence, even if they are of comparable size, are less likely to deposit within a buffer, assuming all other factors are equal.
3. Experiments have shown that microbes trapped in riparian buffer strips (zones) can be remobilised in a subsequent rainfall event some days later. These guidelines do not account for survival and re-mobilisation.
4. The guidelines report long-term average efficiencies over numerous rainfall events of different magnitude and frequency. Efficiency will, therefore, be considerably lower in large rainfall events. Conversely, efficiency will be higher for low magnitude rainfall events.

Table 1-2. Estimated optimal width and efficiency for riparian buffer strips (RBS) with respect to faecal bacteria. Buffer width is given as a percentage of hill slope length. Buffer efficiency is expressed as a percentage reduction, and represents a "best-case" estimate of average efficiency.

Slope	Soil Drainage Rate	Bacterial Attachment	Buffer Width	Buffer Efficiency	Notes
Flat to undulating	Low <1-4 mm/h	High: ≈ 90 percent	1	95	On well-drained soils, RBS may not be warranted since vertical movement of water and microbes dominates. In addition, such land often has artificial subsurface drains. High intensity rainfall, however, can generate significant surface runoff on poor or imperfectly drained soil, even with artificial drainage.
		Medium: ≈ 70 percent	5	90	
		Low: ≈ 40 percent	9	80	
	Medium 5-64 mm/h	High	1	95	
		Medium	2	90	
		Low	4	80	
	High 65->250 mm/h	High	1	95	
		Medium	1	95	
		Low	3	85	
Rolling to moderately steep	Low	High	2	90	Generally, these are the most appropriate slope angles for RBS since sufficient surface runoff is generated, and as spatially diffuse sheet flow rather than concentrated in rivulets or channels.
		Medium	7	70	
		Low	15	50	
	Medium	High	1	95	
		Medium	4	80	
		Low	11	55	
	High	High	1	95	
		Medium	2	85	
		Low	4	60	
Moderately steep to very steep	Low	High	5	45	RBS efficiency can be limited by topographical convergence of surface runoff, causing channelised flow. Buffers may need to extend some distance upslope, following flow pathways. Exclusion of stock from critical source areas (e.g., wetlands, flow pathways) is an important mitigation measure.
		Medium	15	30	
		Low	30	20	
	Medium	High	3	60	
		Medium	7	50	
		Low	13	35	
	High	High	3	75	
		Medium	4	70	
		Low	11	50	