Centre for ecosystem management

EDITH COWAN UNIVERSITY
PERTH WESTERN AUSTRALIA

June 2010

Mine Voids Management Strategy (II): Review of potential health risks associated with recreational use of the Collie pit lakes

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Mine Water and Environment Research/Centre for Ecosystem Management
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Frontispiece

Plate 1. Recreation users from Collie camping, riding, swimming and marroning around Lake Black Diamond, November 2009.

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Australian Government

Water for the Future

Executive Summary

1. This report is the second report in a series of five that were commissioned by the Department of Water as a collective on 'Understanding Pit Lake Resources Within the Collie Basin'. The findings are based on a desktop review of pit lakes, their characteristics and the potential for health impacts; a survey on recreational use of the pit lakes; and a screening level risk assessment on the potential for health impacts from recreational use of the pit lakes.

2. Pit lakes can form in open cut mining pits, which extend below the groundwater table. Once dewatering ceases, groundwater, surface water and direct rainfall contribute to the formation of a pit lake.

3. Pit lakes are common in the Collie Basin in Western Australia (WA). They form a lake district consisting of 15 lakes, although two are currently being re-mined. As other mine operations in the Basin finish further pit lakes are anticipated, many of these potentially much larger than existing pit lakes (e.g., Muja). It is estimated that the total volume of water in Collie pit lakes exceeds 40 GL.

4. Collie pit lakes have different physico-chemical characteristics than natural lakes, such as a small catchment vs. relatively great depth, less nutrients, low pH but high metal concentrations. The current demand for water in WA and its increasing scarcity means that Collie pit lakes present a potentially valuable resource to both the environment and the community.

5. The potential for health impacts from recreational pit lakes use in the Collie Basin was assessed by a review of available literature; the results of a community based questionnaire and a screening level risk assessment. Three pit lakes were the subject of the assessment, Black Diamond, Lake Stockton and Lake Kepwari. Results of this assessment need to be considered in light of a small response to the questionnaire (20% of the survey population) and a paucity of good quality water quality characteristics. Some recommendations have been made to address the shortfall in information.

6. A review of the literature reveals that there is limited information on recreational use of pit lakes. Nothing was found on the potential for health impacts other than injury. Results from health studies of the effects of pH, temperature, clarity and water quality (both biological and chemical) in other settings suggest these factors can have a significant impact on health depending on the type of activities an individual undertakes and their underlying health status.

7. Sixty two percent of respondents to the community based questionnaire used the lakes for recreational purposes. Most respondents were male aged >50 years and spent an average of 2 days per month at the lakes in the warmer months of the year. There were few respondents who recreated at the lakes all year round. A fifth of respondents had young children who visited the lakes. Most respondents who visited the lakes visited Black Diamond and Lake Stockton and while Lake Kepwari was closed to the public, nearly 30% reported visiting and undertaking water based activities at the Lake. Most respondents reported swimming, wading and picnicking as the most popular recreational pursuits.

8. Thirty eight percent of respondents reported one or more health effects following use of the pit lakes. It must be noted that no information was collected on pre-existing health status. Of the symptoms reported, sore eyes was the most common followed by skin rashes and irritations. Only 3% of respondents reported symptoms every time they used the lakes and this was reported most often in relation to Black Diamond. Acidity could lead to such symptoms and potentially affect sensitivity to metals from skin barrier disruption by low pH.

9. Water quality of the pit lakes is variable with most parameters measured at detection limits well above current ANZECC/ARMCANZ (2000) recreational water quality guidelines for swimming. To date, assessment of water quality at the lakes has been undertaken with an environmental focus. Water samples have been used to assess remediation techniques and ecological values. This has reduced the ability to comment on whether water quality parameters do or do not present health risks. These results differed from existing data with fewer metals at

elevated concentrations. It is recommended that future monitoring should be undertaken using detection limits suitable for assessing health. These can be found for each physical and chemical parameter in the Australian Drinking Water Guidelines (ANZECC/ARMCANZ 2000).

10. Of the small amount of data available (from the MiWER database) to assess the potential for health effects, mercury concentrations at Black Diamond are significantly higher than recreational water quality guidelines. Arsenic concentrations at Lake Stockton were also elevated and aluminium is above ANZECC/ARMCANZ (2000) recreational water quality guidelines at all three lakes. Iron and manganese were above recreational water guidelines at Lake Kepwari. An *ad hoc* collection of water samples in 2010 with analysis using detection limits below ANZECC/ARMCANZ (2000) guidelines was undertaken during the preparation of this report. The limited data from the analysis undertaken in April 2010 indicates that current mercury and arsenic concentrations are below ANZECC/ARMCANZ guidelines. Aluminium concentrations are elevated and above guidelines values at all three lakes.

11. No vector borne disease potential has been identified and the presence of the nuisance midge Ceratopogonidae is not viewed as a significant health risk. Respondents to the questionnaire did not indicate midges or other species were an issue of concern. The potential exists however for biological factors and in particular microbial contamination to be an issue with the pit lakes. Future monitoring and management should address this issue.

12. A screening level health risk assessment was conducted for mercury, aluminium, manganese and arsenic concentrations in surface water. It found that the frequency of recreational use was too low to result in significant health effects despite the elevated concentrations. The potential for health impacts from exposure to mercury increases significantly if seafood is consumed. Because of the low response fraction to the survey, the true frequency and duration of use of the lakes cannot be estimated with any certainty. The results must also be treated with caution due to the lack of information on other parameters such as dermal

absorption rates and inhalation of water whilst swimming or a comprehensive water quality data set. Children would be a sensitive sub group and it is felt that measures to reduce exposures in this group should be considered. Further, the metals concentrations in surface water are above acceptable recreational water quality guidelines and hence management may be required once this is confirmed by more comprehensive and targeted monitoring. This will be important if the potential exists for use of the lakes for marron farms or aquaculture where the risks of metals uptake is high.

13. There are still many questions about the potential for health risks. To clarify whether current concentrations are impacting on health it is recommended a comprehensive water quality monitoring program be implemented with appropriate detection limits for metals and includes testing for micro-organisms, biological pathogens, and vector borne diseases. To ensure that exposure to metals is not a significant issue, a short term human exposure study could assist in assessing human health risks and confirm the results of the screening health risk assessment.

14. If further monitoring of the water quality in the pit lakes confirm elevated mercury, we advise the Department of Water to develop a communication plan to advise users of the potential issues. As noted, the recent samples analysed in April 2010 for mercury and arsenic recorded concentrations below recreational water guidelines

15. Respondents to the survey were concerned about management of the pit lakes with sixty percent wanting some form of active management by placement of facilities such as toilets. Nearly eighty percent want the lakes used for water based recreational areas.

16. Of urgent attention is the need to address management of the lakes with the provision of appropriate facilities such as toilet blocks with cleaning and rubbish bins and collection. This would reduce the risks of injury from broken glass

bottles and other wastes left in the areas. Installation of toilet facilities would reduce the potential for health effects from faecal contamination.

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1 Introduction

This project aimed to assess the potential for health impacts from recreational use of the Collie Pit Lakes. It was conducted in three main stages. The first was a literature review of pit lake characteristics and water quality using existing reports, peer reviewed literature and historical data from the studies undertaken by Lund (2000). The review focussed on identifying any previous studies of health effects of pit lake use and in the absence of this information sought to use the historic pit lake characteristics to see whether health effects may be likely given the setting. This review is outlined in Chapter 1. The second stage was a community survey of recreational use of the lakes in the Collie region. This involved mailing a questionnaire to a random selection of residents in the Collie region as well as asking special interest groups and individuals to complete the questionnaire. The questionnaire sought information on the type of recreational use undertaken at the pit lakes as well as frequency duration, health and management issues. The community survey findings are outlined in Chapter 2. Chapters 3 and 4 review in more detail the chemical and biological qualities of the pit Lakes in Collie using the MiWER database. The community survey data was then used in a screening health risk assessment which sought to identify the nature of the risk of recreational use of the pit lakes in Collie. The results are provided and also included in Chapter 3. The process, results and conclusions of the screening health risk assessment are outlined in Chapter 5. Chapters 6 and 7 provide a summary of the results of this work and recommendations on future monitoring and assessment.

1.1 Literature Review of Pit Lakes, Characteristics and Water Quality

This review identifies the potential health impacts from exposure to Collie pit lakes, in particular on potential health impacts of recreational use of pit lakes. Research of the pit lakes in the Collie region undertaken by Lund *et al* (2000) has been used to define water quality characteristics in this section. These authors determined water quality for Black Diamond, Blue Waters, Ewington and Stockton lakes with a focus on bacterial strategies for remediation and recorded pH, TDS and metal concentrations. These data were used for the preliminary identification of potential health impacts. For the screening risk assessment in Chapter 5 more recent water quality data was available for use.

1.1.1 Mine Voids and Pit lakes

Australia has many open cut mines with over 1800 open cut mines in Western Australia (Johnson & Wright, 2003). Once mining has ceased and the mining lease has been relinquished, the legacy of the site post closure is often a large open pit that may become filled with surface and groundwater and become a pit lake. The aim of mine lease and pit closure is to minimise not only environmental harm but also the social impacts (Doyle & Runnells, 1997), through ensuring a geologically stable and safe void (Johnson & Wright, 2003). Closure has included backfilling the remaining void, but this is often not viable due to prohibitive costs (McCullough, 2007). Therefore many mining companies simply leave a hole in the ground or allow the voids to fill gradually over time forming a pit lake.

Filling of mine voids can occur naturally through groundwater seepage and surface water runoff or more rapidly by diversion of nearby water bodies. The characteristics of the water in the newly filled void may vary markedly. Factors which influence final water quality include oxygen concentrations, pH, depth, biological activity, composition of wall rock, hydrogeological flow system, initial ground water quality, evaporation and precipitation rates and the surrounding landscape (Castro & Moore, 2000; Johnson & Wright, 2003; Doupe & Lymbery, 2005). It becomes difficult to predict final water quality when there are many factors influencing this outcome (McCullough *et al.*, 2009a).

In recent years both the mining industry and its regulators have begun to recognise the importance of the visual and social impacts of closed mine sites (Johnson & Wright, 2003). Research has recognised that remaining voids may have potential beneficial end uses that could contribute economic, health, welfare, safety or aesthetic benefits back to the community (Doupe & Lymbery, 2005; McCullough & Lund, 2006a). Regulators are now beginning to assess the mine voids and the potential closure options as part of the upfront stage of planning (Johnson & Wright, 2003).

A review undertaken by Doupe (1997) highlighted potential beneficial end uses. Activities included recreation and tourism (swimming, fishing and boating), wildlife conservation (creation of wetland area), research and education, aquaculture, irrigation, water for livestock, potable water, industrial water source and mineral extraction (Doupe & Lymbery, 2005; McCullough & Lund, 2006a). However, little research has been undertaken to assess the risks and health effects of human activities undertaken at mine lakes. If recreational activities such as boating, swimming, skiing and fishing and tourism are to be considered as viable post closure options, the potential risks and possible adverse health effects need to be clearly defined and understood. This includes the chemical, biological and physical qualities of the water as well as the physical characteristics of the pit lake and the pattern and extent of use by the community.

1.1.2 Collie Pit Lakes

1.1.1.2.1 Formation

Collie is located in the South Western region of Western Australia and has a Mediterranean climate consisting of cool winters and hot dry summers (Lund 2008). Situated in the Collie Basin, the town of Collie experiences higher rainfall than many other areas of the state with average rainfall of 850 mg/L and an evaporation rate of 1600 mm/y (Beckwith Environmental Planning Pty Ltd, 2007).

The Collie Basin is a small shallow intra-cratonic basin with outlying Permian sediments surrounded by Archaen granitic rocks (Beckwith Environmental Planning Pty Ltd, 2007). The Permian sediments contain a number of coal measures that are inter-layered with a freshwater aquifer system (Beckwith Environmental Planning Pty Ltd, 2007). The majority of mines in the area are below the ground water table, which means they will gradually fill with water (Varma, 2002).

The Collie area has been mined since 1888, with coal used predominantly for generation of electricity (Stedman, 1988). Discontinued mine voids have been present in the area for approximately 50 years (Lund 2008). As more of the mines reach completion, planning for sustainable usage is a significant issue. Currently the Stockton and Black Diamond pit lakes are used for recreational activities. Lake Kepwari is being developed as a recreational area and is not yet open to the public. Other Collie pit lakes that may also be used include Ewington, Blue Waters (Ewington 2) and Chicken Creek. The WO5 mine comprises six individual mine voids, of which none are open to the public. The largest of the six voids is WO5B

(Johnson & Wright, 2003). WO5 has previously been used for aquaculture and W03 is being currently under preparation for an aquaculture venture (Beckwith Environmental Planning Pty Ltd, 2007).

1.1.1.2.2 Pit Lake Characteristics

The size and water quality of pit lakes in Collie differ markedly. The pit lakes range from <1 ha up to 10 ha in surface area with depths ranging from <10 m up to 70 m (Zhao *et al*., 2009).

pH

Water found in pit lakes may have a low pH, caused by the presence of sulphide rich materials such as pyrite. When these compounds are oxidised they can generate acid (Banks *et al.*, 1997). Areas of high sulphur coal tend to be sources of acidic water (Castro & Moore, 2000) with the acidity produced in pit lakes influenced by the sulphidic content in the pit wall. Other inputs contributing to acidity may arise from run-off from remaining waste dumps that contain sulphidic material. If the surrounding rock contains carbonate, this may provide an acid buffering effect (Miller *et al.*, 1996).

Collie has sediment with low levels of pyrite associated with the Collie basin (Doupe & Lymbery, 2005). The coal mined exhibits low sulphur content which produces low levels of acidity from pyrite oxidation, ferrolysis and secondary mineralization (Lund 2008). Lund (2000) measured pH, in four pit lakes including Black Diamond and Stockton Lake over a one to two year period and the averages ranged from 4.0 to 5.5. A one off measurement for the Blue Water Lake showed a pH measurement below 3 (Lund *et al.*, 2000). While the pH of Ewington varied little over the study period, Stockton Lake showed considerable variation particularly between the layers within the water body. Consideration needs to be given to fluctuating levels of pH if health impacts are to be adequately assessed.

Clarity

Clarity (transparency) is a measure of the depth of light penetration and is dictated by the colour and turbidity of water (ANZECC/ARMCANZ, 2000). Transparency may be measured using Secchi depth. Transparency can be affected by suspended microscopic plants and animals, suspended mineral particles, stains that impart colour such as iron, detergent foams and dense mats of floating and suspended debris (WHO, 2003). The surrounding geology will influence the colour of the water impacting clarity. Pit lakes have the potential to have high levels of turbidity from suspended mineral particles. On the other hand if pH is very low, water may be very transparent as few organisms can survive. Algal blooms may also increase the turbidity of the pit lakes if nutrient concentrations are sufficient.

Clarity is considered an aesthetic characteristic which may or may not impact upon the physical quality of the water (WHO, 2003; National Health and Medical Research Council, 2008). Clarity is important when undertaking recreational activity so swimmers may estimate the depth of the water (WHO, 2003). Water should also be clear enough so users can see subsurface hazards and submerged bodies (National Health and Medical Research Council, 2008). The recent *Guidelines for Managing Risk in Recreational Waters (2008)* do not provide a guideline value for clarity. The *Australian Recreational Water guidelines* (ANZECC 2000) advocate a Secchi depth of greater than 1.6m. The *Australian Drinking water Guidelines* (2004*)* state turbidity of water should be 5 NTU. This is a measure of aesthetic quality and is not designed to protect health.

The transparency of the pit lakes in Collie has been measured using Secchi depth in four lakes (Lund *et al.*, 2000). Black Diamond recorded a mean Secchi depth of 3.3 m +/- 0.3 m, Blue Waters recorded 4.1m +/- 0.3 m, Ewington 3.8 m +/- 0.3 m and Lake Stockton recorded a mean Secchi depth of 3.8 m +/- 0.4 m. The ANZECC Recreational Water Guidelines (2000) indicate that a Secchi depth to 1.6 m is sufficient for water bodies used for swimming. The *Upper Collie Water Management Plan* (Beckwith Environmental Planning Pty Ltd, 2007) notes that the Black Diamond lake has poor visibility and the bottom of the void is difficult to see due to a blue green colour. The Secchi depth recorded at Black Diamond is within previous ANZECC Recreational Water Guidelines (2000).

Temperature

The temperature of water affects the ability of an individual to regulate their temperature.

The temperature of the lakes in Collie may be influenced by seasonal weather conditions, the depths of the voids, and stratification. Humidity can affect perceived temperature by up to 18°C (National Health and Medical Research Council, 2008).

The lakes exhibit different temperatures at different times of year. Lund & McCullough (2008) report the lakes in the Collie region are monomictic and are thermally stratified between November and March each year, however water temperature was not provided for individual lakes. In spring, water temperatures ranged from approximately 16ºC to 20ºC and in summer, temperatures ranged between 20ºC to 25ºC (Lund *et al*., 2000).

Metals

Metals present in pit lakes will be dependent on the geology of the pit lake catchment and walls. Pyrite is an iron disulphide which is frequently associated with coal deposits and is often found with a range of other metals and metalloids including arsenic, cadmium, cobalt, copper, mercury, molybdenum, lead, antimony, tin and zinc (Banks *et al.*, 1997). When oxidised, pyrite releases iron hydroxides, sulphate and acid (Banks *et al.*, 1997). This acid generation allows further leaching of heavy metals from the surrounding landscape into the environment. Leached metals from remaining overburden dumps have the potential to enter existing water bodies (Gyure *et al.*, 1987).

Elevated levels of metals are likely to be found in pit lakes due to a continuous input from the underlying surface area and no pathways for removal. The availability and toxicity of the metals will be determined by the pH and the oxidation reduction potential (ORP) of the water body (Nordberg *et al.*, 1985). Under anaerobic conditions the metals are likely to bind to sediments at the bottom of the lake reducing bioavailability (Di Nanno *et al.*, 2007). If the water body is stratified seasonally, metals that are bound to sediments are likely to remain at the bottom of the pit lakes until they turn over reducing the likelihood of human exposure. The warm monomictic character of the lakes (mix once a year) and thermal stratification between November and March (Lund *et al*. (2000; 2008) could lead to a spike in metal concentrations at a time of mixing, leading to the presence of higher than expected heavy metals concentrations.

During sampling between 1997 – 1999 the following metals and metalloids were identified as being present in four of the Collie pit lakes, (Black Diamond, Blue Waters, Ewington, Stockton): aluminium, boron, barium, calcium, cadmium, cobalt, chromium, copper, iron, indium, potassium, lithium, magnesium, manganese, nickel, rubidium, strontium, titanium, uranium and zinc (Lund *et al.*, 2000). However concentrations were very low in all four voids with most below the *Guidelines for Recreational Water Quality* (2008). Analyses were not undertaken for arsenic, lead, tin and mercury, which have been identified as potential heavy metals present in pit lakes (Banks *et al.*, 1997; Castro & Moore, 2000).

1.1.1.2.3 Physical Characteristics

A distinctive feature of pit lakes are the steep sides associated with the mining process. Naturally occurring lakes often have a gradual incline into the water body (Doyle & Runnells, 1997). Pit lakes are also deep with higher relative depths compared with naturally occurring lakes (Doyle & Runnells, 1997; Castro & Moore, 2000). Relative depth is calculated using the lake's maximum depth and the width. A common pit lake will have a range of relative depth between 10-40% whereas a typical naturally occurring lake will have a relative of depth of 2% up to 5% (Castro & Moore, 2000).

Absolute and relative pit lake depth is likely to influence it's physical limnology. Pit lakes may undergo stratification due to the typically large depth. On the other hand, natural water bodies may undergo stratification but are likely to mix seasonally as the stratification is weaker and more likely affected by smaller seasonal temperature changes. Many pit lakes are meromictic, that is the layers will not mix, creating a permanent anoxic bottom layer (Doyle & Runnells, 1997). Under anoxic conditions metals may bind to sediments and this contains them within the lower layer, therefore stratification can influence water quality (Doyle & Runnells, 1997). However, the lakes in the Collie region, unlike most, are monomictic and the upper and lower layers undergo mixing once a year (Lund 2000). The epilimnion extends from 6-10 metres deep with the bottom layer becoming anoxic after 1 -2 months (Lund & McCullough, 2008). They are thermally stratified between November and March (Lund & McCullough, 2008). This is important when considering exposure to metals. With normally low concentrations a peak in metal concentrations may occur in the water column at the time of mixing. Stratification also influences dissolved oxygen levels, temperature, salinity and pH in the individual layers (Doyle & Runnells, 1997).

1.1.1.2.4 Biological Characteristics

The biological characteristics of a water body include algal and bacterial activity. Pit lakes are noted for having low biological activity but a high level of chemical interactions (McCullough & Lund, 2006a). The biodiversity of acidic lakes is typically low, and lakes exhibiting a pH less than 4 are not likely to support higher trophic aquatic ecosystems (Gyure *et al.*, 1987). The biodiversity of algae reduces with decreasing pH (Nixdorf *et al.*, 2001). Lund (2008) found low diversity and a low abundance of macroinvertebrates in the Collie pit lakes.

Cyanobacteria, which exhibit characteristics of both bacteria and algae, (Roberts & Zohary, 1987; Pilotto *et al.*, 1997) favour warm water temperatures and calm stable weather conditions. While cyanobacteria have the ability to colonise in extreme habitats (Stewart *et al.*, 2006),it is likely pH or temperature of Collie pit lakes would prohibit cyanobacterium colonisation. Gyure (1987) suggests that low pH does not reduce photosynthesis, rather there is less photosynthesis due to a lack of nutrients. Cyanobacterial (blue green) algal blooms occur in waterways that experience increased nutrient input. Lund (2000) found low nutrient levels at t four pit lakes in the Collie region. It is therefore unlikely that cyanobacterial blooms will occur.

Water bodies used for recreation are likely to contain faecally derived pathogenic organisms that may be detrimental to health (National Health and Medical Research Council, 2008). Their presence can be attributed to sewage, livestock, farming activities, wildlife, and humans undertaking recreational activities. The pit lakes in Collie have the potential to contain faecally derived pathogens from these activities.

The most common faecal coliform *Escherichia Coli* is used as an indicator of the presence of faecal pollution (NHMRC/NRMMC, 2004). Its presence may indicate the presence of other waterborne pathogens (NHMRC/NRMMC, 2004). As *E. coli* is used as an indicator of faecal contamination, its viability in the Collie Pit lakes may be used as an indication of the viability of other waterborne pathogens such as *Salmonella* and *Camplyobactor* spp.

E. coli is tolerant of acidic conditions and the pH of the Collie lakes would not be likely to affect its viability (Joseph & Shay, 1952) Other factors which could reduce the viability of fecal matter are the presence of fungi and protozoa, elevated levels of dissolved oxygen and UV light, the concentration of ferric and ferrous compounds and elevated salinity (Flint, 1987). The range of water temperatures in the Collie Lakes will not reduce viability of the coliforms as Flint (1987) showed *E. coli* were viable from 4º – 25ºC. *E. coli* also has the potential to accumulate in sediment as it absorbs onto particulates (Boland & Padovan, 2002). Boating activities have the potential to resuspend *E. Coli* from sediment which in turn could increase coliform levels in the water column (Boland & Padovan, 2002). The depth of the Collie pit lakes would suggest this situation is less likely to occur.

The likelihood of faecal coliforms being present in the pit lakes would be dependent on a number of factors such as source, other biological activity, salinity and solar radiation.

Cryptosporidium and *Giardia spp*. are faecally derived protozoa that can survive for extended periods outside their host organism and are the main parasites of concern for drinking water bodies (WHO, 2002; Buckley & Warnken, 2003). *Cryptosporidium hominis* and *Giardia lambia* in particular are human pathogens. Buckley (2003) reports on the spread of C*ryptosporidium* oocyst*s* and G*iardia* cysts and found they were present in all streams or rivers in Australia they tested, even those that were extremely remote and in protected areas although they did not determine individual species.

Potential sources of the cysts and oocysts are similar to that of *E. coli*. The pit lakes in the Collie region have not been tested for the presence of *Cryptosporidium* or *Giardia* spp. It is possible catchment runoff may infect the lake as could recreational activity. *Cryptosporidium* oocysts and *Giardia* cysts are very robust and viability is not likely to be affected by the temperature found in the Collie lakes. Robertson (1992) states that oocysts viability may be affected by high >9 and low pH <1.5 , which could affect viability in the acidic pit lakes. The pH ranges suggested are outside those found in the Collie lakes and not likely to inhibit the viability of these parasites.

1.1.1.2.5 Vector borne disease

Vector borne diseases such as Ross River Virus (RRV) and Barmah Forest Virus (BFV) can be transmitted when humans are bitten by a vector such as infected mosquitoes. Ross River virus is the most common arboviral disease in Australia (Kelly-Hope *et al.*, 2004). An infected host will carry RRV or BFV without showing symptoms of disease. Mosquitoes (Diptera: Culicidae) feed on an infected host and become carriers (Weinstein, 1997). The virus is then transmitted to humans after being bitten by an infected mosquito. One in three persons bitten by an infected mosquito will show symptoms of the disease. The most common host of RRV in the south west of Western Australia are Western Grey Kangaroos although other vertebrates may play a role (Weinstein, 1997; Mackenzie *et al.*, 1998). It is possible for hosts to develop immunity to the virus decreasing the spread through kangaroo communities (Carver *et al.*, 2009).

In Australia three species of mosquitoes have been identified as the main Ross River Virus vector species, these are *Aedes camptorhynchus*, *Aedes vigilax* and *Culex annulirostris*. Conditions required for mosquitoes to become prevalent are suitable breeding habitats, which often occur after sufficient rainfall and warm temperatures (Kelly-Hope *et al.*, 2004). Water bodies with steep deep edges provide less suitable breeding habitat (Russell, 1999). However, areas used for recreation increases mosquito proliferation potential by providing artificial breeding habitats mainly by people leaving rubbish behind (Patz & Norris, 2004). Macroinvertebrate levels can affect population numbers by feeding on larvae.

In south west WA transmission of RRV has been shown to increase with increased populations of *Aedes camptorhynchus* and *Aedes vigilax* mosquitoes in late spring and summer (Lindsay *et al.*, 1996). RRV and BFV are usually prevalent from September through to May, the spring/summer period. Some characteristics of the pit lakes such as the steep sides, low nutrient content and the low macroinvertebrate levels may inhibit mosquito proliferation, while other characteristics such as alteration to surrounding landscape and the intended recreational use may encourage it (Patz & Norris, 2004).

1.2 Desktop Assessment of Potential Health Impacts

1.2.1 Exposure Pathways

An exposure pathway is the physical course that a pollutant takes from its source to a receptor, whereas an exposure route is the way a substance enters the body (Nieuwenhuijsen, 2003). The exposure route determines the amount of uptake and will depend on the biological, chemical and physical characteristics of the substance as well as the location and duration and frequency of the activity and characteristics of the individual (Nieuwenhuijsen, 2003).

Exposure must occur for physico-chemical and biological properties of water to impact on health. Recreational activities such as swimming, water skiing, boating and fishing are all currently undertaken at Stockton and Black Diamond lakes. Lake Kepwari has also been proposed as a recreational area for these activities. These activities will present different exposure pathways and routes.

The *Guidelines for Recreational Water Quality and Aesthetics* (ANZECC/ARMCANZ, 2000) recognise two different types of activities. Activities such as swimming and water skiing where the user comes into frequent direct contact with water as part of the activity, is considered primary contact. Primary contact exposure routes include dermal contact, inhalation and ingestion. Secondary contact occurs when the activities undertaken have less frequent body contact with the water body such as boating and fishing. Secondary contact exposure routes also include dermal contact, inhalation and ingestion however the level of exposure is likely to be lower.

Comparison of water quality data has been made with *Guidelines for Managing Risks in Recreational Water* (National Health and Medical Research Council, 2008) to identify potential health impacts. The guidelines were developed using a critical review of literature and the use of risk assessment and a management framework. The severity, nature and frequency of health outcomes were evaluated and used to developed guidelines that will reduce the likelihood of health impacts occurring. If literature was not available to develop concise dose response relationships, a safety factor was incorporated.

Non contact activities may be undertaken around a water body which impact on health but are not related to the water quality. Activities could include motorcross riding and bushwalking. These activities may lead to falls from heights associated with the abrupt steep edges of the pit lakes. These will not be covered here.

Fish and crustaceans have the capacity to take up and accumulate metals in their bodies. This may become a potential route of exposure for heavy metals. Metal concentrations in the water column in the Collie lakes are generally low, but may be higher in the sediments where seafood may feed, concentrating the amount. No data on concentrations in sediment are available. The level of uptake varies between species and on the form of the metal. Human exposure can then occur through consumption of contaminated seafood. The amount of absorption after ingestion varies for different metals. Preliminary studies have shown elevated levels of metals in certain species of shellfish (McCullough *et al.*, 2009b). Further data would be required to determine potential risks to human health.

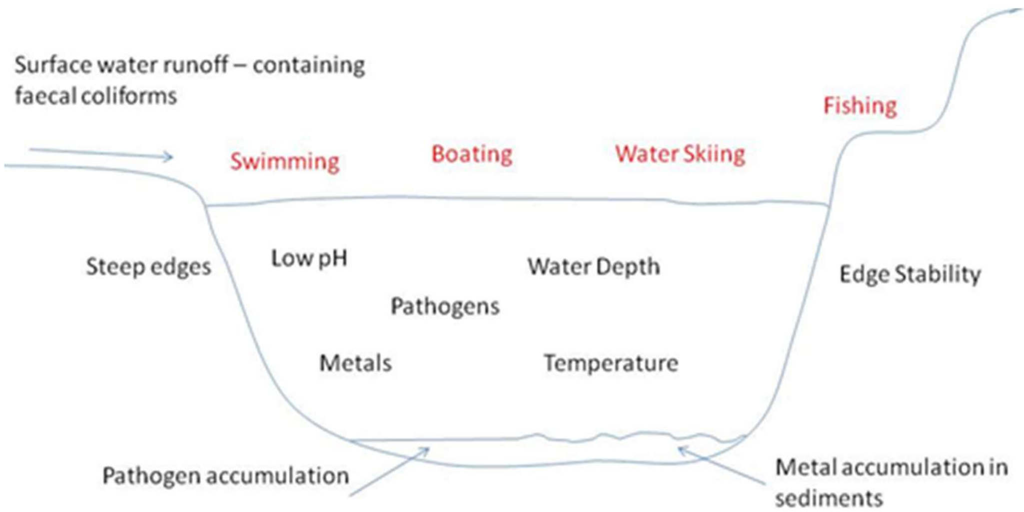

Figure 1.1. Schematic of contact and non-contact pit lake activities (after McCullough & Lund, 2006b).

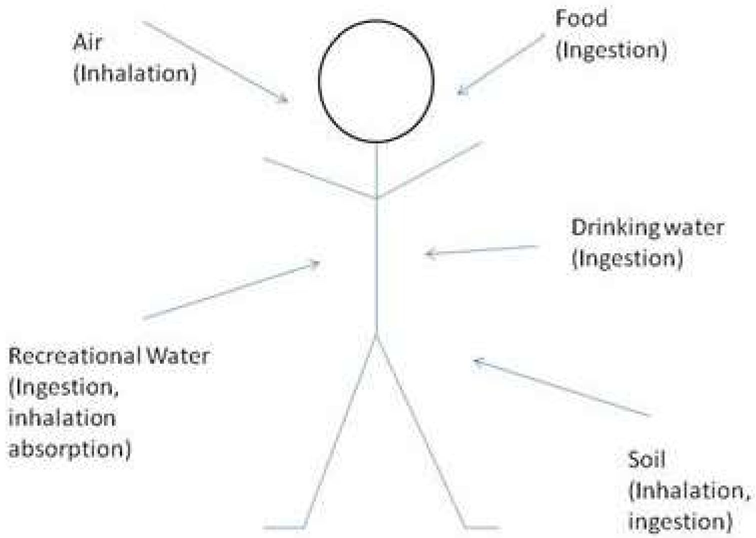

Figure 1.2. Exposure pathways for recreational swimmers in Collie pit lakes.

1.3 Potential Health Effects from Physico Chemical Characteristics

1.3.1 pH

Impacts to health may be directly contributed to water having low pH levels. Heavy metals are released from soil at low pH, which has the ability to create another set of health concerns. pH is identified in international and Australian water quality guidelines as a parameter that needs to be considered when assessing suitability of water for recreational use (WHO, 2003; National Health and Medical Research Council, 2008).

Health authorities state that eye irritations and skin irritations may occur due to water with a low (<4.5) or high (>9) pH (Health and Welfare Canada, 1992; WHO, 2003; National Health and Medical Research Council, 2008). Krishnaswami (1971) concluded that eye irritations may occur due to changes in the physico-chemical properties of water such as the pH and buffering capacity. Mood (1968) cited in (Health and Welfare Canada, 1992) undertook a literature review on the relationship between pH and aquatic activity. This review found that most research on eye irritation to swimmers was undertaken in regard to preparation of ophthalmic solutions (Health and Welfare Canada, 1992). These studies determined that solutions that would cause the least irritation to eyes would be of similar pH to tears and ideally be pH 7.4 (Health and Welfare Canada, 1992). Mood (1968) cited in (Health and Welfare Canada, 1992) identified that a solution with a pH of < 4.3 or > 7.5, may cause pain in the eyes. The likelihood of pH causing irritation is dependent on the solution's buffering capacity. If water is free of dissolved solids and has low buffering capacity it is likely that a larger range of pH values (from 5.0 to 9.0) can be tolerated and less likely to cause irritation (Health and Welfare Canada, 1992).

Basu *et al* (1984) undertook an exposure study of rabbits and humans to water from two inland lakes with pHs of 4.5 and 6.5 respectively to determine the health effects of pH on the eye. They observed no significant differences with exposure of up to fifteen minutes to either rabbits or humans. The authors concluded that no external ocular tissue damage occurred at a pH of 4.5.

Primary irritation of the skin appears to be to linked to high pH not low pH (WHO, 2003). Contact with water which has low pH, is not likely to directly cause irritations of the skin (WHO, 2003), rather secondary irritations such as dermatitis are more likely to be exacerbated in sensitive sub groups. Fluhr *et al*. (2008) report that one of the main pathological mechanisms for skin irritancy is skin barrier disruption. Low pH can cause destruction of the barrier layer of the skin which increases absorption of ionisable molecules (USEPA, 1992).

Although there is limited research available, regulatory authorities agree that a safe pH range for recreational waters is 6.5 to 8.5, and if the water has a low buffering capacity the acceptable pH range may be extended from 5.0 – 9.0 (NHMRC, 2008).

1.3.2 Temperature

The human body can regulate its temperature and is able to function best within the range of 20^{0}C to 28^{0}C. The body has more difficulty regulating its temperature in water than when exposed to air. Water temperature contributes to how long a person can stay in the water. Cold water removes heat from the body 25 times faster than cold air (International Life Saving Federation, 2003).

Prolonged immersion in cold water <16ºC (for more than 30 minutes) may cause hypothermia (Health and Welfare Canada, 1992; National Health and Medical

Research Council, 2008). Immersion in cold water for shorter periods may also cause drowning without the onset of hypothermia (Tipton *et al.*, 1999).

An individual's rate of body cooling is a function of body size, fat content, prior acclimatisation and overall physical fitness and will contribute to an individual's survival in cold water. (Health and Welfare Canada, 1992). Some individuals are more susceptible to exposure to temperature as they have more difficulty regulating their body temperature (Golden & Hardcastle, 1982; Tipton *et al.*, 1999). Susceptible individuals include young children, elderly persons, and those with some impaired mobility, people with pre-existing illnesses and those frequently consuming alcohol (Haight & Keatinge, 1973; Tipton *et al.*, 1999; International Life Saving Federation, 2003; WHO, 2003).

There are no specific thresholds for when temperature becomes dangerous. The potential for health impacts varies with water temperature, immersion time and the metabolic rate of the swimmer (Health and Welfare Canada, 1992). NHRMC (2008) guidelines state that a comfortable range of temperature for water is 20-28°C. Combined air temperature and humidity can affect actual temperature by up to 18°C. Humidity reduces the body's cooling ability which may increase heat stress (National Health and Medical Research Council, 2008).

Difficulties occur for swimmers when they can no longer regulate body temperature. NHRMC (2008) state that swimming in water at 21-28°C, shivering and sensation of cold can occur in less than one hour. Swimming in water with a temperature of 16-21°C has the potential to induce a diving reflex, particularly significant in young children and elderly people, where the body makes cardiovascular and metabolic changes to conserve oxygen (National Health and Medical Research Council, 2008). Between 10-16°C a diving reflex is more likely to occur (National Health and Medical Research Council, 2008).

Sudden immersion in cold water <15°C can be debilitating (Golden & Hardcastle, 1982). A number of drownings have occurred after a very short time following immersion in cold water. Within 2-3 minutes a reflex response called cold shock can set in. In less than 30 seconds a person's response can be uncontrollable rapid breathing which impairs a person's ability to hold their breath which may lead to drowning. Other cardiovascular effects, constriction of blood vessels near the body surface can substantially increase heart rate leading to heart attack, stroke and death from drowning.

Keatinge (1969) found that at 4.7ºC capable swimmers could not swim a distance of 250m with one swimmer failing to swim 30m. Golden and Hardcastle (1982) found swimming impairment at 6ºC. Exercise (swimming) increases heat loss. Tipton *et al.* (1999) found that swimming in water at 10ºC can noticeably change a person's swimming stroke. The study found that oxygen consumption for a given swim speed increased with decreasing water temperature due to shivering, this in turn decreased swimming efficiency. If an individual's swimming efficiency (swim distance/oxygen consumed) reaches < 5m/L then drowning is likely to occur.

Consumption of alcohol contributes to drowning by inhibiting the body's the ability to regulate its body temperature. Haight and Keatinge (1973) found that a combination of exercise and ingestion of alcohol caused blood glucose levels to fall. This in turn led to a failure in metabolic response to cold which elicited a rapid fall in body temperature. Haight and Keatinge (1973) concluded that hypoglycaemia inhibited the hypothalamic centre which would normally activate the mechanism for heat conservation and heat production.

Other health impacts which are less likely to occur from exposure to cold water are cold urticaria and swimming induced pulmonary oedema (International Life Saving Federation, 2003). Cold urticaria is an allergy like reaction occurring from contact with cold water. Within minutes the skin can become itchy red and swollen. An individual may have shock like symptoms with low blood pressure and fainting (International Life Saving Federation, 2003).

Lund, Mahon, Tanen and Bakhda (2003) found that swimming in cold water <19.2ºC induced pulmonary oedema. Observations were made in military personnel undertaking swimming exercises. Acute pulmonary oedema occurs when fluid accumulates in the lung because the heart does not pump adequately. The study highlighted that swimming induced pulmonary oedema occurred by undertaking strenuous swimming at 19.2ºC. The study concluded that recreational swimmers may experience mild symptoms but are more likely to stop swimming before drowning occurs.

There is the potential that people swimming in the pit lakes may be exposed to cold water temperatures and due to the depth and steepness of some of the sides may have difficulty making it out of the water.

1.3.3 Metals

Aluminium

Aluminium exposure has the potential to impact on the central nervous system, skeletal and haemapoietic systems of humans (Jansson, 2001) Aluminium within the body has the potential to pass through the blood brain barrier and to a foetus (IPCS, 1997; Kaizer, 2008). Individuals with kidney disease may experience bone or brain disease from continual exposure to aluminium (Yokel & McNamara, 2001; ATSDR, 2007). Studies have provided inconsistent results to determine whether exposure to aluminium is associated with an increased risk of Alzheimer's disease (Yokel & McNamara, 2001).

The Australian Recreational Guideline (ANZECC/ARMCANZ, 2000) for aluminium is 200 µg/L and Australian Drinking Water Guidelines (2004) states that aluminium should not exceed 0.002 mg/L (2 µg/L) but preferably should be 0.001 mg/L (1 µg/L) which is set for aesthetic purposes only. Typical values in Australian drinking water range from 0.01 mg/L to 0.9 mg/L with some supplies being above the recommended guidelines. Drinking Water contains less than 2% of an adult's daily intake of Aluminium with only 0.3 – 0.4% absorbed. Intermittent exposure has a NOAEL of 26 mg/kg/day and chronic exposure has a LOAEL 130 mg/kg/day both from animal studies (ATSDR, 2007).

Concentrations found at Blue Waters and Lake Ewington both exceed the recreational drinking water guideline with mean concentrations of 2047 ± 167 µg/L and 663 ± 29 µg/L respectively. The risk of potential health effects is likely to be dependent on the route, duration and frequency of exposure. The uncertainty of health outcomes associated with aluminium exposure is of concern considering the high levels found at the Collie lakes.

Arsenic

Inorganic Arsenic is more toxic than organic arsenic (ATSDR, 2007). Short term exposure to low concentrations of inorganic arsenic may produce nausea, decreased red and white blood cell production, tingling hands and feet (ATSDR, 2007). Long term exposure to low concentrations may cause skin pigmentation, skin lesions, gastrointestinal symptoms, peripheral vascular diseases and neuropathy (Armentia *et al.*, 1997; Jarup, 2003; Vahidnia *et al.*, 2007). Inorganic arsenic is considered a Group 1 carcinogen with increased risk of urinary bladder, lung and skin cancer (IARC, 2004). Armentia (1997) states consumption of 0.4 mg/day may produce health effects such as hyperkeratosis and hyperpigmentation and hypopigmentation. Exposure to arsenic can impact on the hepatic system causing cirrhosis and hypertension (Armentia *et al.*, 1997). Symptoms may not be immediately visible with symptoms often developing 6 months to 2 years after exposure (IPCS, 2001; Rahman *et al.*, 2001). Rahman (2001) identified a relationship between the amount of arsenic ingested, concentrations of arsenic in drinking water and the nutritional status of individuals. The higher the concentration of arsenic in water and the larger the intake of water the earlier symptoms will appear (Rahman *et al.*, 2001). Animal studies show ingestion of some forms of organic arsenic can induce diarrhoea and kidney damage (ATSDR, 2007).

The Australian Drinking Water guideline (2004) for arsenic is 0.007 mg/L (7µg/L) and the Australian Recreational Guideline (ANZECC/ARMCANZ, 2000) is 50 µg/L.

No data are available on arsenic concentrations in the Collie pit lakes to enable comparison with guideline values.

Cadmium

Potential health impacts from exposure to high concentrations of cadmium by oral ingestion are vomiting, diarrhoea and stomach irritations (Jarup, 2003). Long term exposure has the potential for cadmium to accumulate in the kidneys causing kidney damage, tubular dysfunction and decreased bone density with general population studies showing kidney damage at 2-3 µg Cd/g creatine (Zeigler *et al.*, 1978; Järup *et al.*, 1998; Järup *et al.*, 2000). Studies show low level exposure over time increases the risk of osteoporosis (Staessen *et al.*, 1999; Alfvén *et al.*, 2000; Alfvén *et al.*, 2004).

The Australian Drinking Water guideline (2004) states that concentrations should not exceed 0.002 mg/L (2 µg/L) and the Australian Recreational Water Quality Guidelines (ANZECC/ARMCANZ, 2000) should not exceed 5µg/L.

The study undertaken by Lund (2000) found cadmium at concentrations below detection (< 2 µg/L). The risk of potential health impacts from cadmium exposure is expected to be low.

Lead

Exposure to lead may affect all organs and systems in the human body causing a number of health impacts (ATSDR, 2005a). Potential health effects include kidney damage, impaired intellectual damage in children, anaemia and impacts to the nervous system (Nordberg *et al.*, 1985; Jarup, 2003). Menke (2006) found that blood concentrations in adults of 10 µg/dL were associated with increased peripheral arterial disease, impaired renal function and elevated blood pressure. Lead has the potential to cross the blood brain barrier in children (Jarup, 2003). Many studies show that children with an increased blood concentration of 10 µg/dL IQ may decrease by up to 2 points (Jarup, 2003) With higher absorption rates and a permeable brain barrier, children become the most susceptible to potential health impacts from lead exposure. Lead exposure may also cause miscarriage in pregnant women and decreased sperm production in males (ATSDR, 2005a).

Lead accumulates in the body and the elimination process is slow. Lead found in the blood has a half life of approximately 1 month, once deposited within the bones lead can have a half life of 20-30 years (Jarup, 2003; ATSDR, 2005a). Adults will absorb 10-15% from ingested lead. Absorption from ingestion in children is up to 50% (Jarup, 2003).

The Australian Drinking Water guideline (2004) for lead is 0.01 mg/L and recreational guideline is 0.05 mg/L. There is no data available on lead concentrations in the pit lakes and therefore an assessment cannot be made on the potential for health impacts from exposure.

Mercury

The major route of exposure for mercury is by ingestion of contaminated food mainly consumption of fish (IPCS, 1990; ATSDR, 1999; Iavicoli *et al.*, 2009). Health impacts from inhalation occur mainly in the form of metallic mercury vapour (ATSDR, 1999). Other forms of mercury such as organic mercury are not considered a risk to human health via inhalation (ATSDR, 1999).

The target organ for mercury is the kidneys with the central nervous system also impacted. Exposure to chronic or high levels of inorganic mercury can damage the brain, symptoms being irritability, shyness, tremors, changes in vision or hearing and memory loss (Jarup, 2003). Damage is reversible when exposure has ceased. Exposure to inorganic mercury may cause kidney damage and impacts the gastro intestinal system (Jarup, 2003). Metallic mercury can act as an allergen causing eczema on contact (Agency for Toxic Substances and Disease Registry, 1999; Jarup, 2003).

Acute exposure to organic mercury can damage the central nervous system up to a month after exposure (Jarup, 2003). Symptoms include parestesias, numbness in the extremities and co-ordination difficulties (Jarup, 2003). There are contradictory studies on the increased risk of coronary heart disease associated with high consumption of contaminated fish. (Guallar *et al.*, 2002; Yoshizawa *et al.*, 2002). Mercury can impact on the endocrine system. It can stimulate progesterone and effect estrone and estradiol levels (positive correlation with blood concentrations), reduce plasma levels of testosterone and reduce sperm motility and sperm count (Iavicoli *et al.*, 2009). Exposure may impact on a developing foetus and cause spontaneous abortion (Iavicoli *et al.*, 2009). There is a 30% (high) risk of neurological disorders in offspring when the mercury levels detected in the hair of the mother reach 70 µg/g (IPCS, 1990). At 10-20 µg/g there is a 5% (low) risk of damage to the foetus. Consumption of contaminated fish (blood concentrations of 200 µg/L) is predicted to increase the risk of neurological disorders in adults by 5%. A daily intake of 3-7 µg/kg will cause adverse effects on the central nervous system in a normal adult (IPCS, 1990)

Food is the main source of mercury exposure with an average Australian consumption of 0.004 mg/day. Typically Australian drinking water supplies contain 0.0001 mg/L ranging up to 0.001 mg/L. The types of health impacts are dependent not only on the route of exposure but also the form of the mercury. Organic mercury is more toxic than inorganic mercury (NHMRC/NRMMC, 2004). Ingestion of inorganic mercury in drinking water is lower than organic mercury. Less than 15% of inorganic mercury would be absorbed through the gastrointestinal tract whereas nearly all organic mercury would be absorbed (Nordberg *et al.*, 1985; NHMRC/NRMMC, 2004).

The Australian Drinking Water Guideline (2004) and Australian Recreational Water guideline (ANZECC/ARMCANZ, 2000) is 1 µg/L of total mercury.

A prediction of the potential for health impacts cannot be made as there is limited historic data available on mercury concentrations at the pit lakes. Determination of the form of mercury would be required to accurately assess potential health impacts. Pregnant women and the unborn foetus are at the highest risk of experiencing health impacts from exposure to mercury. If concentrations of mercury are determined to be lower than guideline values it is unlikely that health impacts will occur from exposure. Recreational activities are not likely to be a daily year round experience therefore exposure is likely to be short term. Consumption of fish from the lakes may be an issue if bioaccumulation of mercury occurs.

Manganese

Manganese is a dietary requirement and is contained in many foods. Concentrations found in natural water bodies may range from 10 to 10,000 µg/L with average levels of 1,000 µg/L (IPCS, 2004). Animal studies have shown that a high oral dose may affect the nervous and reproductive systems (ATSDR, 2008; Iavicoli *et al.*, 2009). Symptoms may vary depending on dose, duration of frequency and individual susceptibility. Less severe health effects include tremors, weakness, muscle pain to more severe symptoms such as slow speech, altered gait, clumsy movements, nervousness, and other behavioural changes (IPCS, 2004; Agency for Toxic Substances and Disease Registry, 2008). Three human studies show mild neurological symptoms at 0.059 to 0.7 mg/kg/day over 5-10 year periods (Kondakis *et al.*, 1989; Wasserman *et al.*, 2006; Vanita Sahni *et al.*, 2007). At higher levels of 0.103 mg/kg/day with intermittent exposure over a 5 year period serious health impacts were noted such as personality changes, speech impairment, loss of balance and inability to walk. Increased fatality in children under a year old has been reported at exposure levels of 0.26 mg/kg/day (Hafeman *et al.*, 2007).

The current Australian Drinking Water Guideline is 0.5 mg/L (500 µg/L) for no health impacts and 0.1 mg/L (100 µg/L) for no aesthetic impacts (NHMRC/NRMMC, 2004). Manganese is present in the collie pit lakes in ranges of 21.4±1.3 – 116±6 µg/L (Lund *et al.*, 2000). These concentrations are below Guideline values and are not likely to increase the risk of health impacts

Other elements

From the data reviewed, copper and chromium were below detection limits of <50 and <100 μg/L (Lund *et al.*, 2000). Copper concentrations were below both the Australian Recreation Guideline (2000) and Australian Drinking Water Guideline (2004). Further analysis is required for chromium to ascertain if there are potential health impacts from exposure. The Australian Drinking Water Guidelines (2004) for chromium to protect health is 50 $\mu g/L^{-1}$.

Cobalt was also below detection limits except for Blue waters which had average concentrations of 32 ± 2.7 to 33 ± 1.6 μg/L(top and bottom respectively)(Lund *et al.*, 2000). Boron, barium, and zinc were detected at ranges of between 17 ± 1.7 to 37 ± 3.9 , 29 ± 5 to 73 ± 11.5, and 16 ± 2.2 to 82 ± 12.9 $\mu g/L^{-1}$ respectively (Lund *et al.*, 2000). Cobalt, Boron, Barium and Zinc were below Australian Drinking Water Guidelines (2004) and Recreational Water Guidelines (2000).

Two of the four lakes studied by Lund *et al.*, 2000 had water iron concentrations below guideline values. Blue Waters and Ewington iron concentrations exceeded the Australian Drinking Water Guideline (2004). Mean concentrations detected at Blue Waters were 344 ± 45.5 and 774.6 ± 246 μg/L (top and bottom respectively) (Lund *et al.*, 2000). Ewington has mean concentrations of 348±29.8 and 370±34.6 μg/L (top and bottom respectively) (Lund *et al.*, 2000). The Australian Drinking Water guideline (2004) for iron is set to protect aesthetic values as there is insufficient data to set a guideline value to protect health. The guidelines indicate that health impacts are unlikely unless the concentration in water is well above 3000 $\mu g/L^{-1}$. At 3000 $\mu g/L^{-1}$ the taste of the water is objectionable and would not likely be consumed. Blue Waters and Ewington are well below this concentration, therefore it is unlikely that exposure will cause potential health impacts.

Nickel concentrations detected in the Lund (2000) study ranged from 3 ± 0.2 to 35±1.7 $\mu g/L^{-1}$. Nickel concentrations were also below the Australian Recreational Guidelines (2000) and Australian Drinking Water guidelines (2004) for Stockton Lake, Black Diamond and Ewington. The concentrations detected at Blue Waters exceeded the Australian Drinking Water Guidelines (2004) of 20 $\mu g/L^{-1}$. Oral intake of nickel may cause skin rashes, eczema and dermatitis in sensitive individuals (WHO, 1991). Ingestion of 0.0083 mg/kg/day has been shown to cause contact dermatitis (NHMRC/NRMMC, 2004). Limited human studies are available for assessment of health impacts from ingestion of nickel (studies focus on inhalation in occupational settings). One human study showed symptoms of vomiting, cramps, diarrhoea, giddiness, headaches and weariness after ingesting 7.1–35.7 mg/kg nickel (ATSDR, 2005b). Animal studies show kidney damage after oral exposure at 108 mg/kg/day for intermediate exposure (ATSDR, 2005b). Effects on the lungs were observed from intermediate exposure to nickel in animal studies at 8.6 to 20 mg/kg/day (ATSDR, 2005b) . The concentration of nickel found at Blue Waters may increase the risk of developing nickel sensitivity, skin rashes, eczema and dermatitis.

1.3.4 Potential Health effects from Physical Characteristics

The physical aspects of abandoned pit lakes have the potential to contribute to adverse health impacts. The Department of Mines in Queensland (Mines Inspectorate, 2009) recorded a fatality by a member of public who jumped from a 38m high wall into water in an open cut excavation at an inactive coal mine. In 2008 a drowning death was recorded in Collie, Western Australia, where it was likely that a novice swimmer experienced difficulty and could not save himself due to the depth of the water (Taylor, 2007). Drowning was identified as the major cause of death in accidents that occurred in inactive or abandoned US mine sites. From 2000-2006 a total of 211 fatalities occurred at inactive or abandoned sites and of these 144 were due to drowning (King, 2009). The majority of these incidents involved males (Mine Safety and Health Administration, 2008). The age range is varied, with incidents occurring involving young children to the elderly (Mine Safety and Health Administration, 2008).

Pit lakes have steep edges and are typically very deep, making it hard for a swimmer to get out of the water if they get into difficulty. Other contributing factors may be the clarity and colour of the water. These characteristics can make the depth of the water difficult to assess. The Upper Collie Management Plan scoping report states that the bottom of the Black Diamond Void is difficult to see due to a blue green colour of the water. This void is used by for recreational activities such as swimming even though it is not sanctioned as such (Beckwith Environmental Planning Pty Ltd, 2007).

The second highest cause of death in pit lakes is attributed to falls from heights whilst using recreational vehicles (Mine Safety and Health Administration, 2008) . Pit lakes often have high rock walls or embankments. If recreational vehicles or motorcycles are driven too close to edges or sightseers walk to close to the edge there is the potential for a fall resulting in injury or death (Mine Safety and Health Administration, 2008). Alternatively, embankments may become unstable with time and cause rockslides potentially causing death or injury.

The exact number of incidents in Australia is unknown as there is no central database.

1.3.5 Potential Health Effects from Biological Agents

1.1.3.5.1 Cyanobacteria

Health effects from exposure to cyanobacteria are well documented (Falconer, 2001; WHO, 2003; Stewart *et al.*, 2006). Different forms of cyanobacteria produce different cyanotoxins. There are three types of toxins: cyclic peptides which include microcystins; alkaloids which includes neurotoxins; and cylindrospermopsin and lipopolysaccharides (National Health and Medical Research Council, 2008). Each produces different types of health impacts (Codd, 2000; WHO, 2003) and the primary target organs differ for the cyanotoxins. Cylic peptides attack mainly the liver. The alkaloid toxins may attack the nerves, liver, skin, gastro intestinal tract and the lipopolysaccharides are mainly an irritant affecting exposed areas (National Health and Medical Research Council, 2008). Case reports describe illness from recreational exposure to cyanobacteria as cold and flu like symptoms, pruritic skin rashes and gastrointestinal illnesses (Pilotto *et al.*, 1997).

Cyanobacteria which produce neurotoxins are common throughout Australia. Neurotoxins produce the most debilitating effects of the toxins. Neurotoxins can induce strong salivation, cramps, tremor, diarrhoea, vomiting and death (WHO 2003 (Humpage *et al.*, 1994) . The health impacts are not ongoing and will cease after treatment or removal from the body.

Microcystins are the most common cyanotoxin in parts of South Eastern Australian and other countries (Burch, 2002; WHO, 2003; National Health and Medical

Research Council, 2008). Health effects include liver damage and tumour promotion (Burch, 2002). Microsystin L-R has been identified by IARC as a possible carcinogen to humans whereas microcystis extracts are not classifiable (IARC, 2006)

Cyanobacteria which produce cylindrospermopsin toxin are found in tropical areas and not likely to be found in the Collie area (Falconer, 2001).

Ingestion is the most common route of exposure for recreational swimmers. Gastrointestinal illnesses have been reported on ingestion of recreational water containing large quantities of cyanobacterial cells. Symptoms include cramping, abdominal pain and nausea (Behm, 2003; Stewart *et al.*, 2006). Other symptoms arising from ingestion of cyanobacteria include headaches, muscular pains, diarrhoea, pneuomina, myalogia, vertigo, vomiting, flu like symptoms, mouth ulcers and eye and ear irritations (Pilotto *et al.*, 1997; Falconer, 2001). These symptoms become apparent within 2-7 days of exposure. Toxicity has the potential to accumulate. A study by Fitzgeorge (cited in WHO 2003) showed that where a single oral dose of microcystin toxin did not produce any changes to the liver, the same dose over several days produced an 84% change in liver weight (a measure of liver damage).

Of concern is the lack of visible symptoms prior to liver damage becoming severe (WHO, 2003). Deaths from renal failure were recorded in Brazil where 26 of 130 patients died from exposure to cyanobacterial toxins during dialysis (Jochimsen *et al.*, 1998). One hundred and sixteen individuals showed symptoms of visual disturbance, nausea and vomiting. The level of toxin was not measured. Exposure from ingestion has been associated with tumours of the gastrointestinal tract but cyanobacteria toxins have not been positively confirmed as a potential carcinogen (Ueno *et al.*, 1996; Carmichael, 1997). Health impacts are similar for exposure via inhalation.

Dermal contact is likely to produce allergic and irritative skin reactions (Yoo *et al.*, 1995).

Freshwater algae are also found in many water bodies. Freshwater algae are less likely to be an issue in recreational water as they lack the mechanisms of accumulation apparent in cyanobacteria that allows them to accumulate on mass (WHO, 2003). Skin reactions are the most likely health outcome from exposure, this occurs from irritation caused by algal cells lodging in bathing or wetsuits.

Guideline values for Australia state that recreational freshwater should not contain ≥10 µg/L of microcystins or ≥4 mm^3/L combined total cyanobacteria if a known toxin is present. Where known toxins are not present the guideline value is ≥10 mm^3/L. There is a relatively low probability of adverse health effects if the level of cyanobacteria is 20,000 cells/mL and a moderate probability of adverse health effects at 100,000 cells/mL (WHO, 2003). At this level there is the potential for some long term health impacts, with short term health impacts such as skin irritations and gastrointestinal illness.

Cyanobacteria blooms occur due to increased temperature, high light, water column stratification and nutrient loads. It is unlikely that large blooms of cyanobacteria will occur due to the low level of nutrients found in the Collie pit lakes which limits productivity. The potential would increase if there was a large influx of nutrients

1.1.3.5.2 Faecal Pathogens

Contact with recreational water bodies that contain faecally derived pathogens have been shown to cause a range of gastrointestinal and respiratory infections (National Health and Medical Research Council, 2008). The types of infections and illness are usually mild (National Health and Medical Research Council, 2008). The number of organisms which may have a health impact varies between organisms. *Cryptosporidium* and *Giardia* will be discussed as they are known for their environmental robustness, persistence in water and the low numbers required for infection (WHO, 2002).

Cryptosporidium

Cryptosporidium spp have the potential to cause large scale health impacts in recreational waters (WHO, 2003). According to the NHMRC(2008), infection associated with exposure to recreational water is mild. There have been numerous cases of cryptosporidiosis reported in Australia and Western Australia (Department of Health and Aging, 2009). Cryptosporidiosis leads to watery diarrhoea, headache, fever, cramps, weight loss, nausea, vomiting and arthralgia (Current & Garcia, 1991; Fleisher *et al.*, 1996; Meinhardt *et al.*, 1996; Kramer *et al.*, 1998; Chen *et al.*, 2002; WHO, 2003; National Health and Medical Research Council, 2008). The incubation period reported by Kramer (1998) was 6 days, but this may vary. The most common symptom is diarrhoea which can last from 3 – 20 days (Current & Garcia, 1991).

Individuals with compromised immune systems are likely to experience more severe and longer lasting health effects (Meinhardt *et al.*, 1996; Chen *et al.*, 2002). There are no effective treatments and symptoms usually spontaneously resolve (Current & Garcia, 1991; Environmental Health Directorate, 2006) The number of microorganisms that are likely to cause an adverse health impact is dependent on the pathogen, its form, the conditions of exposure, the hosts susceptibility and their immune status (National Health and Medical Research Council, 2008). Transmission can occur from human to human contact, food, and water supplies. The number of oocysts which are likely to cause infection may be as low as 10-100 oocysts. The degree of illness is associated with duration of exposure and intensity (Kramer *et al.*, 1998).

Giardia

Due to the robustness of the *Giardia* cysts there is a possibility they will be found in the Collie Pit lakes. Input is likely to stem from faecally contaminated surface runoff and human shedding. Like *Cryptosporidium* they are viable in extreme environments. *Giardia* is more temperature dependent on survival than *Cryptosporidium* with higher mortality rates of the cysts at 23ºC (WHO, 2002). DeReigner *et al.* (1989) found higher survival of cysts in lower temperatures. This study found higher rates of viable cysts below the thermocline of a lake due to the lower temperatures.

Giardiasis is contracted from exposure to Giardia spp. Symptoms include diarrhoea, abdominal cramps, flatulence, malaise with other symptoms including vomiting, chills, fever and headache occurring less frequently (CDC, Health Canada 2009, (WHO, 2002). Sixteen to eighty-six percent of individuals infected will be asymptomatic (WHO, 2002). Factors affecting the likelihood of infection include age, nutritional status, predisposing illness and previous exposure (Flanagan, 1992; Gerba *et al.*, 1996). From the infected population 30-50% will develop chronic infections which may last up to 1 year (WHO, 2002, 2008).

A dose response relationship has been established between the probability of infection and an ingested dose (Rendtorff, 1954; Rose *et al.*, 1991). There is a daily risk of infection of 2.0 x 10^{-4} if there are 0.005 cysts per litre of drinking water (assuming consumption of 2 Litres a day) (WHO, 2008). The risk increases to 4 x10^{-3} for 10 cysts/Litres. Human studies have shown that there is a risk of infection at <10 cysts (WHO, 2008).

Five species of Giardia are found in forty animal species including humans (WHO, 2002). Transmission is most commonly from person to person, however transmission via recreational water bodies and drinking water supplies is also common particularly in unprotected water bodies (WHO, 2008). *Giardia* spp are found in many surface waters bodies, stemming from faecal contamination of surface water runoff associated with livestock, native animals, domestic animals, agricultural activities and human activities (deRegnier *et al*., 1989; Rose *et al*., 1991; National Health and Medical Research Council, 2008). There is the potential for faecal contamination to occur at the pit lakes (Table 1.1). The temperature found at the lakes during the spring/summer (period most likely for recreational activity) ranges from 16º-25ºC and this may decrease viability of the cysts for longer periods (1 -3 months) but it will not prevent their occurrence. Viability decreases the number of cysts which reduces or decreases the risk of potential health impacts.

Table 1.1 Potential Health Risks for Biological Agents at the Collie Pit lakes.

Biological Contaminant	Guideline	Likelihood of occurrence	Potential Health Risk (based on likelihood of occurrence).
E. coli	The median bacterial content in samples of fresh or marine waters taken over the bathing season should not exceed: 150 faecal coliform organisms/100 mL or • 35 enterococci organisms/100 mL	Possible - dependent on potential sources	Unknown
Cyanobacteria	Fresh recreational water bodies should not contain: >10 µg/L total microcystins; >50 000 cells/mL toxic *Microcystis aeruginosa*; or biovolume equivalent of >4 mm3/L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or >10 mm3/L for total biovolume of all cyanobacterial material where known toxins are not present; or • Cyanobacterial scums consistently present.	Presence not identified. Blooms unlikely to occur due to lack of nutrient input.	Low
Cryptosporidium parvum oocysts	No guidelines, health impacts may occur as low as 10 oocysts	Possible - dependent on potential sources	Low- medium
Giardia lambia cysts	No guidelines, health impacts may occur as low as 0.005 cysts/L	Possible – dependent on potential sources	Low- medium

1.3.6 Potential Health Effects from Vector borne disease

There are two main mosquito borne diseases which are likely to be found in Western Australia, Ross River Virus (RRV) and Barmah Forest Virus (BFV) (Environmental Health Directorate, 2008). A third mosquito borne disease Murray Valley Encephalitis (MVE) is not usually found in the lower regions of the state (Environmental Health Directorate, 2006).

Ross River Virus is typified by polyarthritis, rash and fever (Kelly-Hope *et al.*, 2004). Common symptoms are painful and/or swollen joints, sore muscles, aching tendons, skin rashes, fever, tiredness, headaches and swollen lymph nodes (Condon, 1991; Condon & Rouse, 1995; Fryer, 2006). Other less common symptoms are sore eyes and throat, nausea and tingling of the palms and soles of feet. Symptoms appear anywhere from 3-21 days and can persist from 2-6 weeks, lasting up to 3 months (Fryer, 2006). In some cases symptoms can last sporadically for up to a year. There are no cures or vaccines available and patients are usually treated to ease symptoms. Symptoms for RRV and BFV are similar and will vary between individuals.

In Western Australia in 2007 there were 87 cases of BFV and 510 cases of RRV reported (Communicable Disease Control Directorate, 2008b). For the same period there were 6 cases of BFV and 39 cases of RRV recorded in the south west (Communicable Disease Control Directorate, 2008b). In 2008 the southwest recorded 50 cases of RRV and 9 cases of BFV (Communicable Disease Control Directorate, 2008a).

Activities undertaken such as camping and the degraded nature of an area are likely to be conducive for mosquito breeding by providing breeding habitat, potentially increasing the risk of infection of RRV and BFV (Patz & Norris, 2004). Degraded areas provide more breeding habitats in the form of pot holes from erosion and a decrease in biodiversity (predators for mosquitoes) (Patz & Norris, 2004). It is likely that recreational activities will be undertaken in periods which are also most conducive to mosquito breeding increasing the potential for exposure. Suitable environmental factors such as seasonal rainfall and temperature can impact on the potential for infection (Kelly-Hope *et al.*, 2004). The presence of the virus in the south west increases the potential for exposure.

The pH of the lakes is not conducive to mosquito breeding and the steep sides of the pit lakes would not provide the shallow areas of water required for good breeding habitat. This could inhibit the likelihood of a disease outbreak. The number of host animals located in the area is unknown.

2 Recreational Use of Pit Lakes – A Community Survey

Black Diamond, Stockton Lake and Lake Kepwari are pit lakes already known in the region to be used by local residents and those in and outside the region. Black Diamond and Stockton Lake are currently being used as recreational areas for swimming, boating and water skiing. In the future there is the potential for more pit lakes to be used for recreation and aquaculture, for example, Lake Kepwari is currently being prepared for public use. By understanding potential health impacts, early planning and management strategies can be implemented by mining companies and government agencies so that post closure, the lakes can be used as recreational areas or for other ventures such as aquaculture safely.

To ascertain the potential for health risks, it is necessary to determine how often and for what purposes people are using the lakes for recreation so that the level of exposure to physical, chemical and biological characteristics can be estimated. The aim of this community survey was to assess the extent, frequency and nature of the use of the pit lakes by the local community.

Information from the questionnaire was used in combination with identified water characteristics as well as information from the literature review to determine the potential for risks to human health associated with recreational activity at the pit lakes.

1.4 Methods

1.4.1 Study Design

A cross sectional survey using a questionnaire was undertaken in November 2009. Residents living within the Shire of Collie were chosen as the study population as they were more likely to use the lakes regularly as opposed to transient users. The Shire of Collie has a population of 9104 people (Australian Bureau of Statistics, 2008). A survey random calculator was used generate the number of questionnaires required for a mail out based on a 20% response fraction (Custom Insight, ND-b). The random sample calculator required input of the Collie population along with the selection of the amount of error/confidence interval and the level of confidence required. A 5% error was selected along with a 90% confidence level. This meant that the survey results would have no more than 5% error (i.e. if we repeated the survey a number of times the results would be ± 5%) and the 90% confidence level would indicate a level of accuracy of the repetition (Custom Insight, ND-a). With a population of 9000 people, it was estimated that 264 responses were required to achieve the necessary number of responses;. Two hundred and fifty completed questionnaires were received. The questionnaire asked how much time respondents and their families spent using one or more pit lakes for recreational activity. Questions included how much time was spent in contact with the water and what type of activities they undertook (Appendix A). Respondents were also asked about any health symptoms they experienced following use of the lakes and potential uses of the pit lakes.

Black Diamond and Stockton Lake were selected for specific inclusion in the questionnaire as they are popular recreational areas for Collie residents. Lake Kepwari was chosen as an additional lake to highlight due to its potential future development as a recreational area by the local shire. Lake Kepwari is not currently open to the public however information from Department of Water staff indicated people were still accessing the lake. There are another 12 lakes in the area and an ‘Other’ category was included to address this. Respondents to the questionnaire needed to be 18 years and over

1.4.2 Study Population and Recruitment

Two methods were used to recruit participants; a random postal survey of Collie Shire residents and a targeted survey. A mailing list of 1300 random postal addresses in the Collie Shire was obtained from the Edith Cowan University Survey Research Centre. The addresses were generated via the random number generator using the 2004 White Pages but were limited to residents with a postcode of 6225. Towns in this postcode included Collie, Allanson, Buckingham, Collie Burn, Noggerup, and McAlinder. An information package was prepared and posted to 1200 households from the mailing list. The package included a letter of invitation to participate (Appendix B), the questionnaire (Appendix A), an information sheet (Appendix C) and a Reply Paid envelope for return of questionnaires. One person from each household was asked to answer the questionnaire.

Of the 1200 invitations sent 159 envelopes were returned undelivered. If the envelope was marked “Not at this address’ the envelope was relabelled “To the Resident” and sent to the same address. If the envelopes were marked ‘Return to Sender” they were readdressed with a new address from those remaining on the mailing list and posted. Two weeks after the initial mail out another 105 questionnaires were returned and not resent.

A second stage of recruitment took place after the initial mail out. Forty information packages were sent to special interest groups. Member names from these groups were supplied by Department of Water.

An information booth was also set up at the local shopping centre to recruit more participants and to provide information about the study. The researchers targeted people at the local shopping centre, over a 2 day period in November asking them to complete a questionnaire. There were 63 questionnaires completed in Collie with 37 questionnaires taken away with reply paid envelopes.

Copies of the questionnaire were made available at the local council and library. Reply Paid envelopes were left at both locations for return of questionnaires.

Questionnaires were given a code to distinguish between the random sample and the targeted population. Questionnaires which were posted out were marked with an R for random followed by a four digit number from 0001 to 1299. Questionnaires which were given out at the local shopping centre, library and council offices were marked with a T for targeted followed by a number from 1300 to 1500.

In total 250 questionnaires were available for analysis. From the randomly selected group 176 questionnaires were obtained from 1095 delivered giving a response fraction of 16%. A total of 74 from the 170 given to the targeted audience were received, providing a total response fraction of 19.7%.

1.4.3 Data Management and Analysis

Questionnaire data were entered into a Microsoft Access database and then exported to excel and checked for accuracy. Data entry was set up to minimise entry error e.g., by using drop down menus. Descriptive statistical analysis was performed using SPSS version 17.0. The random sample and the target sample was used to identify the activities among users. Swimming, wading and water skiing were classified into one category called water based recreational activities to determine time spent undertaking water based activities.

1.5 Results

1.5.1 Population Characteristics

Respondent ages ranged from 18 to 90 years. The median age of all respondents was 56 years. The male respondents had a slighter higher mean age than the females (Table 2.1). The majority of respondents were male (57.2%); four people (1.6%) did not respond to this question.

Of the 250 questionnaires 70.4% were from the randomly selected group, the targeted group made up the remainder. A higher percentage of males answered the targeted survey compared with women. From the randomly selected group 58.5% used the pit lakes in the last 2 years where 68.9% of the targeted respondents used the pit lakes an average of approximately 62% from all respondents (Table 2.1). Both males and females used the pit lakes with a slightly higher percentage of males using the lakes for recreational purposes (Table 2.1).

Table 2.1 Demographic Characteristics of Total Population and Categorised by Pit Lake Use.

	People who did not use pit lakes	People who used pit lakes	Total Population
Total Population *(n=250)*	38.4%	61.6%	
Random Questionnaire Population (%) (*n*)	41.5% (*176*)	58.5% (*176*)	70.4% *(250)*
Targeted Questionnaire Population.(%) (*n*)	31.1% *(74)*	68.9% *(74)*	29.6% *(250)*
Median Distance lived from lakes (km) (range (km))	10 (0.5-65)	8 (0.4 – 80)	10.6 (0.4-80)
Age mean (yrs), range, *(n)*	60yrs 19-90 *(94)*	50 yrs 18-82 *(150)*	54yrs 19-90 *(244)*
Gender (Male %) *(n)*	38.5 % *(143)*	61.5 % *(143)*	57.2% *(143)*
Children 13-18yrs (%)	n/a	16.6%	
Children 2-12 yrs (%)	n/a	21.9%	
Children <12 yrs (%)	n/a	1.3%	
No. of residents per household (people)	n/a	2.8	
Range (people)		1-8	

The mean distance travelled to the pit lakes was 10.6km (Table 2.1). The majority of households who used the lakes had 2 residents, with a mean of 2.8 people per household (Table 2.1). Seventeen per cent of households had young adults 13-18 years old who also had used the pit lakes in the last 2 years. 22% had children aged 2-12 years old (Table 2.1). Few households with younger children (<2yrs) reported using the pit lakes (Table 2.1).

It is difficult to estimate the true population use of the lakes due to the high non-response, it is likely that non users were a greater proportion in the non responders. However among the users of the lakes these data provide reasonable estimates of the nature of the use.

1.5.2 Overview of Pit Lakes Visited

Adults

One hundred and fifty four people indicated they had visited and used the pit lakes in the last two years. Of the people who said they had visited the pit lakes in the last 2 years Black Diamond had the most visitors, followed by Stockton Lake (Table 2.2 & Table 2.3).

The median number of days per month where respondents visited Black Diamond, Stockton Lake and 'Other' was 2. Lake Kepwari had the lowest median number of days visited per month. Most visitors to the pit lakes spent time at both Black Diamond and Stockton Lake (Table 2.2**.** There was no difference between the random and targeted responses.

The number of children who visited the lakes was lower than adults with only 34 children under 12 years of age identified as using the lakes, and as would be expected most visited Black Diamond and Stockton Lake. Families with children <12years did not tend to visit "Other" pit lakes with only one household visiting another lake in January and February. Attendance at Black Diamond, Stockton and Kepwari was seasonal with most occurring in the warmer months of November through to March. In January, 23 households who had children <12 yrs old visited Black Diamond and 18 households visited Stockton Lake (Appendix D).

Table 2.2 Percentage of visitors to different pit lakes among those who used the pit lakes (n=154 adults, 34 children).

	Black Diamond	Lake Kepwari	Stockton Lake	Other
Adult Visitors (no. of people) %	130 (84.4%)	45 (29.4%)	129 (84.3%)	11 (7.2%)
Children <12yrs (no. of people) %	27 (79.4%)	5 (14.7%)	27 (79.4%)	2 (6.5%)

Table 2.3 Median number of day's respondents visited each pit lake, among those who used the pit lakes.

	Black Diamond	Lake Kepwari	Stockton Lake	Other
Median no. of days a month visited	2	1	2	2
Range	1-30	1-4	1-20	1-10
(n)	*(125)*	*(32)*	*(115)*	*(6)*
Median no. of days a year visited	10	2.5	8.5	6
Range	1-360	1-20	1-300	1-36
(n)	*(122)*	*(34)*	*(115)*	*(6)*

The lowest proportion of visits to pit lakes occurred in August (Figure 2.1).

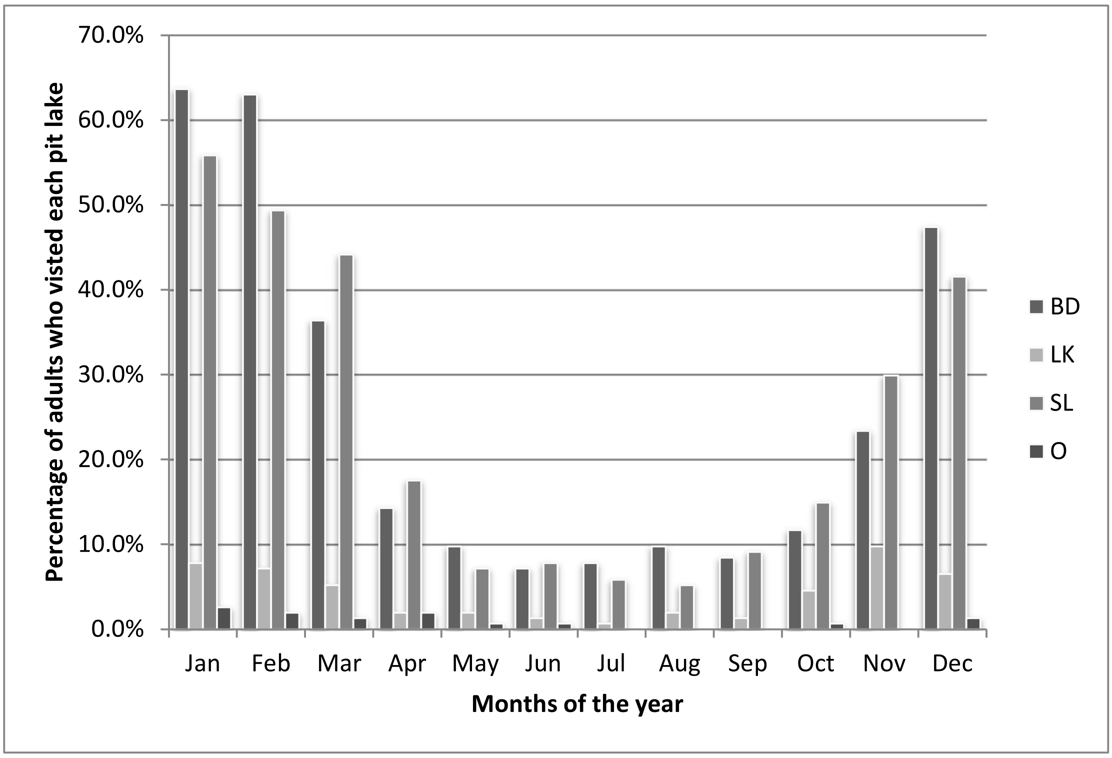

Figure 2.1 Distribution of respondent visits to lakes by month of year.

The majority of adults who attended the lakes visited in the afternoon and spent on average between 3 to 5.5 hours undertaking water based activities (Table 2.4).

Table 2.4. Reported time of day people most likely to visit the pit lakes (n=149).

Time most likely to go to pit lake	Percentage (%)	Average time Spent undertaking water-based activities (h)
All Day	21	5.4
Morning	7.7	5.5
Afternoon	66	3.3
Dusk	3.4	3
Night	1.3	0

1.5.3 Types of Activities undertaken at the Lakes

Adults

To identify the types of activities people were undertaking, respondents could select from eight different recreational activities or list another recreational activity. Activities included swimming, kayaking, wading, boating, water skiing, marroning, picnicking, camping. For the water based activities, swimming was the most popular recreation amongst adults at each of the lakes (Table 2.5). Black Diamond had the highest percentage of users who went swimming. Boating and water skiing were undertaken more often at Stockton Lake than the other lakes. Of the non water based activities, picnicking at Stockton Lake was the most common activity (Table 2.5). Camping was also most popular at Stockton Lake (Table 2.5). Among the 'other' category, fishing and walking were identified as the most frequent recreational activities. The types of activities undertaken at each lake did not differ by gender except at Lake Kepwari. At Lake Kepwari men undertook all of the listed activities whereas women swimming, wading, boating and picnicking.

Table 2.5. Types of recreational activities undertaken by pit lake users at each of the lakes (%).

	Black Diamond *(n=127)*	Lake Kepwari *(n=32)*	Stockton Lake *(n=123)*	Other *(n=6)*
Swimming	83.5 (%)	53.1 (%)	72.4 (%)	50.0 (%)
Kayaking/Canoeing	15.0 (%)	3.1 (%)	15.4 (%)	33.3 (%)
Wading	31.5 (%)	21.9 (%)	24.4 (%)	16.7 (%)
Boating	6.3 (%)	9.4 (%)	40.7 (%)	0.0(%)
Water skiing	2.4 (%)	3.1 (%)	27.6 (%)	0.0 (%)
Marroning	11.0 (%)	9.4 (%)	12.2 (%)	33.3 (%)
Picnicking	42.5 (%)	40.6 (%)	47.2 (%)	50.0 (%)
Camping	20.5 (%)	9.4 (%)	30.9 (%)	33.3 (%)
Walking	7.9 (%)	9.4 (%)	2.4 (%)	0.0 (%)
Fishing	1.6 (%)	0.0 (%)	1.6 (%)	16.7 (%)
Other	7.1 (%)	28.1 (%)	11.4 (%)	0.0 (%)

Eighty nine percent of children went swimming at Black Diamond and Stockton Lakes (n=28) (Appendix E). This represents 18% of all households where the respondents had used the lakes in the last 2 years (n=154). Wading was also popular with 53.6% undertaking this activity at the same lakes (Appendix E). Non water based activities such as camping and picnicking were undertaken most frequently at Black Diamond and Stockton Lake (Appendix E). Of the families with children in this age range 39.3% and 46.4% picnicked at Black Diamond and Stockton Lake respectively, 21.4% and 35.7% went camping at these lakes (n=28). The number of children who used the lakes represented a very small percentage of total users.

1.5.4 Amount of Time Spent Undertaking Recreational Activities at the Pit lakes

Of the water based activities more time was spent water skiing and boating than swimming at Black Diamond and Stockton Lake. The number of people boating and water skiing was higher at Stockton Lake followed by Black Diamond. Of those who went swimming, Stockton Lake had the highest average hours spent swimming (Table 2.6). When calculating the average time spent undertaking each activity, variables with >12 hours (3 questionnaires) were not used as it was deemed unlikely that an individual would spend over this amount of time per visit undertaking one activity (excluding camping). Respondents who used the pit lakes for camping spent most time at Stockton Lake. The range of responses given for the amount of time taken when undertaking each activity varied greatly as shown in Table 2.6.

Table 2.6 Time (h) spent undertaking recreational activity at each of the pit lakes.

				Black Diamond				
Activity by Lake	Swimming	Kayaking	Wading	Boating	Water skiing	Camping	Fishing	Other
Mean (h)	**2.59**	**1.72**	**2.15**	**3.00**	**4.33**	**11.00**	**3.25**	**1.25**
Min (h)	0.5	0.5	0.5	1	4	8	1	0.5
Max (h)	12	4	10	5	5	12	6	3
n	*(101)*	*(16)*	*(38)*	*(10)*	*(3)*	*(10)*	*(4)*	*(4)*
				Lake Kepwari				
Activity by Lake	Swimming	Kayaking	Wading	Boating	Water skiing	Camping	Fishing	Other
Mean (h)	**2.50**	**1.00**	**1.17**	**1.60**	**2.00**	**12.50**	**n/a**	**1.17**
Min (h)	1	1	1	1	2	1	n/a	0.5
Max (h)	6	1	2	2	2	24	n/a	2
n	*(14)*	*(2)*	*(6)*	*(5)*	*(1)*	*(2)*	*(0)*	*(3)*
				Stockton Lake				
Activity by Lake	Swimming	Kayaking	Wading	Boating	Water skiing	Camping	Fishing	Other
Mean (h)	**2.90**	**2.75**	**2.47**	**3.69**	**4.36**	**20.95**	**4.00**	**2.56**
Min (h)	0.5	0.5	0.5	0.5	2	1	2	0.5
Max (h)	12	10	10	12	12	60	6	8
n	*(80)*	*(14)*	*(34)*	*(37)*	*(25)*	*(39)*	*(3)*	*(9)*
				Other				
Activity by Lake	Swimming	Kayaking	Wading	Boating	Water skiing	Camping	Fishing	Other
Mean (h)	**2.50**	**1.50**	**1.50**	**-**	**-**	**10.00**	**-**	**1.50**
Min (h)	1	1	1	-	-	8	-	1.5
Max (h)	4	2	2	-	-	12	-	1.5
n	*(4)*	*(2)*	*(2)*	*(0)*	*(0)*	*(2)*	*(0)*	*(1)*

The total amount of time spent undertaking water based activities was calculated for each lake by adding the amount of time taken for each activity together. An average was then taken of all respondents who had spent time undertaking water based activities. The amount of time spent camping was not included and outliers were also excluded as defined earlier. Activities included swimming, kayaking, wading, boating, water skiing, fishing and other.

Respondents attending Black Diamond would spend on average 2 hours undertaking water based activities (Table 2.7). At Lake Kepwari respondents also spent 2 hours undertaking the same activities. Stockton had the highest average with respondents spending on average 4 hours on water based activities (Table 2.7). Stockton also had the greatest range of time ranging from 0.5 to 36 hours. At 'Other' lakes the median was 3 hours (Table 2.7).

Table 2.7 Total time (h) spent undertaking water based activities per visit per lake.

	Black Diamond	Lake Kepwari	Stockton Lake	Other
Median (h)	2.0	2.0	4.0	3.0
Minimum (h)	0.5	0.5	0.5	1.5
Maximum (h)	12.0	9.0	36.0	6.0
n	*(105)*	*(20)*	*(104)*	*(5)*

1.5.5 Consumption of Seafood

The number of people who indicated they ate seafood caught from the pit lakes was higher than the number of respondents who said they went marroning. Forty two respondents said they ate seafood caught from the pit lakes (Appendix F).

Of the people who went marroning 90% (n=31) ate their catch. Of the respondents who said they did not go marroning 13 indicated they ate seafood which was caught from the pit lakes. One respondent did not respond to whether they went marroning but indicated they ate seafood from the pit lakes.

1.5.6 Reported Health Effects

The questionnaire asked respondents whether they experienced any health effects after using the pit lakes. These results provide some indication of the potential for adverse symptoms but a causal relationship cannot be determined from a cross sectional survey. They are based upon self reports and may be the result of other exposures occurring at the same time.

Health effects were reported by 38% of participants. The most common health effect experienced by adults was sore eyes with 18.7% experiencing this symptom sometimes, and 3.6% experiencing sore eyes most times they undertook recreational activity at the lakes (Table 2.8). Skin irritations/rashes, runny noses, headaches, sore throats and feeling tired were other symptoms experienced (Table 2.8)

The most common health effect reported for children <12yrs old was sore eyes (Table 2.8). In children other health effects were also reported and included feeling tired, runny nose, skin rash, headaches or sore throat. In the 'Other' category the health effects reported was ear infection and this was for only 1 individual.

Males experienced more health effects than women reporting 9 out of the 11 symptoms whereas females reported experiencing 7 out of the 11 symptoms (Table 2.9). Males reported having sore eyes more often than females whereas females experienced headaches more often than males, this was despite females reporting more swimming.

Table 2.8 Percentage of respondents who reported health symptoms after visiting the pit lakes.

	Never		Sometimes		Most times	
	Adult (%) *(n=140)*	Children (%) *(n=32)*	Adult (%) *(n=140)*	Children (%) *(n=32)*	Adult (%) *(n=140)*	*Children (%) (n=32)*
Skin rashes/irritation	90.6	93.8	7.2	6.3	2.2	0.0
Sore Eyes	77.7	81.3	18.7	18.7	3.6	0.0
Feeling sick	97.8	100.0	2.2	0.0	0.0	0.0
Vomiting	100.0	96.9	0.0	3.1	0.0	0.0
Diarrhoea	99.3	100.0	0.7	0.0	0.0	0.0
Runny nose	89.9	90.6	7.9	9.4	2.2	0.0
Headaches	91.4	93.8	7.2	6.3	1.4	0.0
Feeling tired	90.6	90.6	7.9	9.4	1.4	0.0
Temperature	97.1	100.0	2.2	0.0	0.7	0.0
Sore throat	91.4	93.8	6.5	6.3	2.2	0.0
Other	98.6	96.9	0.0	0.0	1.4	3.1

Analysis of health effects by lake was undertaken by selecting residents who visited only one lake. Further analysis was undertaken comparing those who had used only one lake with those who indicated they had used two lakes and those who indicated they had used 3 or more lakes.

No respondents visited only Lake Kepwari, 18 respondents visited only Black Diamond, 10 visited only Stockton Lake and 1 visited only ‘Other’. No health effects were reported by people who went to only ‘Other’ pit lakes noting the small number of respondents in this category.

Table 2.9 Distribution of reported health effects by gender experienced after using the pit lakes.

	Never		Sometimes		Most times	
	Female (%) *(n=50)*	Male (%) *(n=60)*	Female (%) *(n=50)*	Male (%) *(n=60)*	Female (%) *(n=50)*	Male (%) *(n=60)*
Skin rashes/irritation	92.0	91.7	8.0	5.0	0.0	3.3
Sore Eyes	86.0	70.0	14.0	26.7	0.0	3.3
Feeling sick	96.0	100.0	4.0	0.0	0.0	0.0
Vomiting	100.0	100.0	0.0	0.0	0.0	0.0
Diarrhoea	100.0	98.3	0.0	1.7	0.0	0.0
Runny nose	90.0	88.3	10.0	10.0	0.0	1.7
Headaches	88.0	93.3	12.0	6.7	0.0	0.0
Feeling tired	88.0	90.0	10.0	8.3	2.0	1.7
Temperature	98.0	98.3	2.0	1.7	0.0	0.0
Sore threat	94.0	90.0	4.0	6.7	2.0	3.3
Other	98.0	98.3	0.0	1.7	2.0	0.0

Respondents who visited Black Diamond only indicated they experienced more health effects than those who visited Stockton Lake. This does not appear to be related to the pH as Stockton has similar pH levels, however a larger percentage of people went swimming At Black Diamond as opposed to Stockton Lake. Ten percent of respondents who visited only Black Diamond experienced sore eyes (Table 2.10). Other symptoms experienced included runny noses, headaches, feeling tired, sore throats and 'Other' symptoms. Respondents who visited only Stockton Lake experienced only one health effect, sore eyes (Table 2.10).

Table 2.10 Percentage of responders who experienced health effects after using the pit lakes.

	Black Diamond *(n=18)*			Stockton Lake *(n=10)*		
	Never	Sometime	Most times	Never	Sometime	Most times
Skin irritation	94.4	0.0	5.6	100.0	0.0	0.0
Sore Eyes	88.9	5.6	5.6	80.0	20.0	0.0
Feeling sick	100.0	0.0	0.0	100.0	0.0	0.0
Vomiting	100.0	0.0	0.0	100.0	0.0	0.0
Diarrhoea	100.0	0.0	0.0	100.0	0.0	0.0
Runny nose	83.1	11.1	5.6	100.0	0.0	0.0
Headaches	94.4	5.6	0.0	100.0	0.0	0.0
Feeling tired	88.9	11.1	0.0	100.0	0.0	0.0
Temperature	100.0	0.0	0.0	100.0	0.0	0.0
Sore throat	83.3	11.1	5.6	100.0	0.0	0.0
Other	94.4	0.0	5.6	100.0	0.0	0.0

Adults who visited 2 lakes reported experiencing 8 different health effects. The most common health effect was again sore eyes with 24.6% reporting this symptom (Table 2.11). The next most common health effect was skin rashes/irritations. Adults who visited 3 or more pit lakes reported being affected by 9 different health effects. The most prevalent health effect was sore eyes with 22.6% of adults reporting this outcome (Table 2.11).

Table 2.11 Health effects experienced (%) by the number of lakes attended.

	1 Lake (n=29)			2 Lakes (n=73)			3 lakes (n=31)		
	Never	Some time	Most time	Never	Some time	Most time	Never	Some time	Most time
Skin irritation	96.6	0.0	3.4	87.5	11.1	1.4	90.3	6.5	3.2
Sore Eyes	86.2	10.3	3.4	75.3	20.5	4.1	77.4	19.4	3.2
Feeling sick	100.0	0.0	0.0	95.9	4.1	0.0	100	0.0	0.0
Vomiting	100.0	0.0	0.0	100.0	0.0	0.0	100	0.0	0.0
Diarrhoea	100.0	0.0	0.0	100.0	0.0	0.0	96.8	3.2	0.0
Runny nose	89.7	6.9	3.4	93.2	5.5	1.4	80.6	16.1	3.2
Headaches	96.6	3.4	0.0	90.4	8.2	1.4	87.1	9.7	3.2
Feeling tired	93.1	6.9	0.0	90.4	8.2	1.4	87.1	9.7	3.2
Temperature	100.0	0.0	0.0	95.9	4.1	0.0	96.8	0.0	3.2
Sore throat	89.7	6.9	3.4	91.8	5.5	2.7	90.3	9.7	0.0
Other	96.6	0.0	3.4	100.0	0.0	0.0	96.8	3.2	0.0

A comparison was made of the total amount of time spent undertaking water based activities and the health effects respondents reported. Water based activities used in the calculation included swimming, wading and water skiing. Those who spent less than 2 hours in the water experienced a wider range of health effects (Figure 2.2) reporting 9 out of the 11 health effects after using the pit lakes. More people reported health effects if they spent over 10 hours in undertaking water- based activities however the numbers reporting health effects is small to draw any firm conclusions.

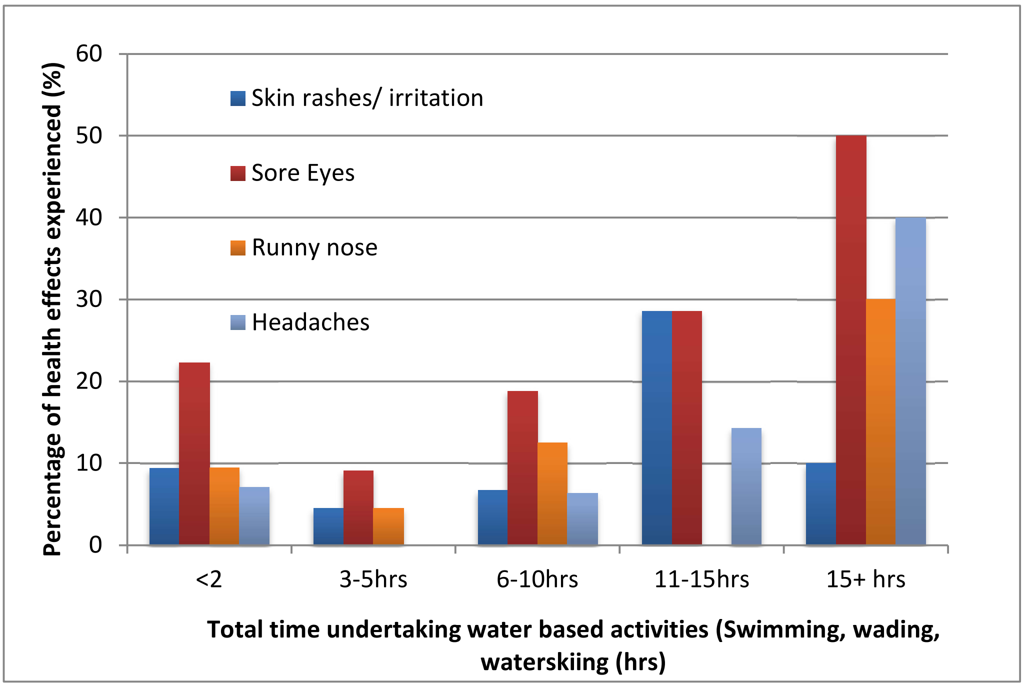

Figure 2.2 Percentage of health effects by the amount of time spent undertaking water based activities.

People who went waterskiing experienced having sore eyes more than those respondents undertaking other activities (Table 2.12). Respondents who went boating reported feeling tired, having a runny nose and a sore throat more often those taking part in other activities. The health effects reported were not recorded in relation to the types of activities were undertaken, therefore if a person stated they undertook swimming and boating it was not possible to determine which activity contributed to the health effect occurring. Analysis does not differentiate between the health effects in relation to the activities undertaken at each of the lakes.

Table 2.12 Percentage of health effects experienced by people undertaking specific recreational activities.

% of People	Skin Rash	Sore Eyes	Nausea	Vomit	Diarrhoea	Runny Nose	Headache	Tired	Temp	Sore Throat	Other
Swimming *(n=117)*	8.5	24.0	1.7	0.0	0.9	10.3	8.5	10.2	2.6	8.6	1.7
Water skiing *(n= 34)*	5.9	32.4	0.0	0.0	2.9	5.9	5.9	14.7	2.9	5.8	0.0
Wading *(n=44)*	9.1	22.7	0.0	0.0	2.3	6.8	6.8	9.1	0.0	4.5	0.0
Boating *(n = 47)*	8.5	27.6	0.0	0.0	2.1	12.8	6.4	17.1	2.1	12.8	2.1

Of the small number of children visiting the pit lakes only a few who visited only Black Diamond experienced a sore throat and 'Other' health effects most times (Appendix G).

The 'Other" health effect noted was an ear infection. No health effects were experienced by children who visited only Stockton Lake. Eleven children <12yrs old visited one lake only, 15 children <12yrs old visited 2 lakes and 3 children <12yrs old visited 3 or more lakes. Children <12yrs old who visited 2 lakes experienced a wider array of health effects. Sore eyes were reported by 6 children. Children <12yrs old who visited 3 or more lakes experienced a runny nose and feeling tired these were reported by one child.

1.5.7 Concerns raised by Survey Participants

Survey participants were given the opportunity to identify any factors which influenced whether they used the pit lakes. They could also express concerns or give comment on uses for the pit lakes. Given the popularity of camping these concerns are important.

Of the people who used the pit lakes 60.2% of participants identified that the lack of toilet blocks was the main factor most likely to influence whether they used the pit lakes (Table 2.13). Other factors identified were the attractiveness of the location and they enjoyed the pit lakes more than the beach.

Table 2.13 Extent to which factors relating to amenities around the lake influenced use, as identified by respondents.

Factors	Don't Know %	Not at all %	Not much %	Quite a bit %	A lot %
Lack of toilet blocks	0.0	24.3	15.5	33.8	26.4
Enjoy pit lakes more than the beach	0.7	36.5	16.2	23.6	23.0
The location is attractive	0.7	39.2	15.5	25.7	18.9
Availability of picnic areas	0.0	39.2	22.3	23.6	14.9
Lack of shade	0.0	36.5	29.7	22.3	11.5
Being bitten by mosquitoes	0.7	37.8	28.4	23.0	10.1
Temperature of water	0.7	47.3	23.6	19.6	8.8
Adequate walking paths	0.0	48.6	23.0	19.6	8.8
Safe walking tracks (no steep edges)	0.0	46.6	25.0	17.6	10.8
Worry about injury from boat users	0.7	42.6	30.4	15.5	10.8

An open ended question was included and in this section the most common comments people made in the survey were that they would like toilet facilities (19.9%, $n=250$) at the pit lakes (Appendix H). The second most frequent comment stated that people would like to see the pit lakes under some type of management (18.7%), that is, have rubbish collection or a ranger looking after the area. The third most common comment was that people would like to see BBQs and picnic tables installed at the pit lakes (15.1%). Other comments included provision of more shade, boat ramps and better access to the sites. A number of respondents commented that they were concerned about their safety at the pit lakes, though exact concerns were not outlined..

People who did not use the lakes were given the opportunity to comment on the reasons why they did not use them. Thirty one percent of 96 respondents stated they were not interested in the types of activities such as swimming or boating, 30% stated they preferred other sites, 23% stated they were concerned for their safety in regards to the physical characteristics of the pit lakes. Twenty two percent stated they were concerned for their safety in regards to the other users of the pit lakes and 19% did not use the pit lakes as they were concerned about the health impacts arising from water quality.

Respondents were asked what they would like to see the pit lakes used for. Only 2% (*n=250*) of participants stated they would not like the pit lakes used at all. The activities people would like to see the pit lakes used for were water based recreation (79%), bushwalking (90%), Marroning (49%), aquaculture (40%) and water storage (28%) and 10% suggested other uses. Other suggestions included regattas, festivals, camping grounds and boat hire facilities.

In summary the health survey indicated that the most common uses of the lakes are camping, swimming, fishing, boating and water skiing. Health symptoms were reported by 38% of respondents who used the lakes. Sore eyes was the symptom most frequently reported after exposure to the lakes, with sometimes or most times reported to by 22% of respondents.

The response to the survey is too low to draw conclusions about the proportion of persons in the Collie region who use the lakes. However among users it provides useful data on the nature and use of the lakes. The respondents are more likely to be persons who use the lakes on a regular basis.

3 Summary of Surface Water Quality Data 2007-2009

The data used for the determination of water quality for this section of the report was taken from the database collated by Mine Water Environment Research Group (MiWER, ECU) (Zhao *et al* 2009). Surface water data for each of the three pit lakes were used for identifying potential health impacts, as people are most likely to come into physical contact with the surface of a pit lake. This database was not available during the literature review on water quality of the Collie pit lakes described in Chapter 1 and as such, the data on water quality documented in this chapter may be different. This data will also differ to the other accompanying reports as only surface water data from the database was used. For results below detection limits, half the detection limit was used to calculate an average concentration. The 1 year average was calculated using 2009 data, the 3 year average was calculated using 2007-2009 data. The 3 year averages were calculated for comparative purposes.

The data available from the MiWER database has primarily been collected to look at the success of remediation techniques used on the pit lakes and to assess environmental and ecological values and not to consider health impacts. As such detection limits used were often too high and therefore not suitable to be used in a health risk assessment.

1.6 Physico-chemical characteristics

1.6.1 pH

The recommended recreational guideline range for pH is 5 to 9 to protect swimmers undertaking activities which involves primary contact, e.g. swimming. The 1 year average pH at Black Diamond and Stockton Lake were within the recreational water guideline range, although some individual data points from 2009 are lower than acceptable pH levels for recreational water quality use (Table 3.1). The 1year average pH at Lake Kepwari is below the *Australian Recreational Waters Guidelines* (RWG)(ANZECC/ARMCANZ, 2000) (Table 3.1). The 3 year pH average for Stockton Lake is marginally outside recreational water quality guidelines.

1.6.2 Temperature

All the pit lakes recorded temperatures within the *Australian Recreational Water Guidelines*)(ANZECC/ARMCANZ, 2000) range for temperature (Table 3.1). It should be noted that the *Guidelines for Managing Recreational Waters (NHMRC 2008)* suggest that there is the potential for health effects to occur between 16- 21^0C.

1.6.3 Turbidity

There are no Australian Recreational Guidelines for Turbidity. *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) suggest a turbidity of 5NTU should not be exceeded. None of the pit lakes exceed the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) (Table 3.1).

Table 3.1. Physico-chemical Properties of the Collie Pit Lakes ¥ .

		Black Diamond	Lake Kepwari	Stockton
pH	ADWG*		6.5 -8.5	
	RWG **		5.0-9.0	
	1y (2009) Av	5.5	4.5	5.4
	Min	4.4	4.3	4.5
	Max	6.8	4.9	6.3
	n	*(3)*	*(7)*	*(8)*
	3y Av		4.4	4.9
	Min		4.3	3.8
	Max		4.94	6.3
	n		*(31)*	*(20)*
Temperature (^{0}C)	ADWG*		No guideline	
	RWG **		15.0-35.0	
	1y (2009) Av	21.1	20.1	24.4
	Min	20.3	20.1	20.7
	Max	21.9	20.1	30.9
	n	*(2)*	*(2)*	*(6)*
	3y Av		20.1	22.5
	Min		20.1	13.4
	Max		20.1	30.9
	n		*(2)*	*(18)*
Turbidity (NTU)	ADWG*		2	
	RWG **		5	
	1y (2009) Av	0.65	0	0.26
	Min	0	0	0
	Max	1.3	0	1.03
	n	*(2)*	*(2)*	*(4)*
	3y Av		0	0.99
	Min		0	0
	Max		0	2.9
	n		*(2)*	*(8)*

* Australian Drinking Water Guidelines (NHMRC/NRMMC (2004)
**Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
¥ Surface water values except for turbidity which is a measure of depth.

1.7 Metal Concentrations

1.7.1 Arsenic

The interpretation of results for arsenic are influenced by the detection limit, which was higher than the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004). Black Diamond and Lake Kepwari each had 2 data points available for review and were at the limit of reporting. It is therefore unknown whether concentrations are at or below the relevant guideline values. More data were available for analysis for Stockton Lake however only one data point was above the detection limit (Table 3.2).

1.7.2 Cadmium

The detection limit for cadmium was above the *Australian Drinking Water Guidelines* and all samples collected at Black Diamond and Lake Kepwari recorded concentrations below the detection limit and hence interpretation against the guidelines cannot be made. At Stockton, 2 detection limits have been used in the analysis of samples. In 07/08 data the detection limit was 0.001 mg/L which is below the drinking water guidelines and some cadmium concentrations exceeded the detection limit. The detection limit in 2009 was 0.01 mg/L which is higher than the drinking water guidelines. This has made any comment on cadmium concentrations difficult (Table 3.2).

1.7.3 Mercury

Mercury concentrations at Black Diamond were elevated and well above *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) (The detection limits for lead were also above the Australian Drinking Water Guidelines (NHMRC/NRMMC 2004) and further investigation would be required to determine whether concentrations could be of concern (Table 3.2). Interpretation of mercury concentrations at Lake Kepwari and Stockton Lake were influenced by detection limits which were higher than the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004). Interpretation of data against existing criteria for Lake Kepwari and Stockton lake is therefore not possible as all samples are reported as being below the detection limit noting the differing detection limits used.

1.7.4 Lead

The detection limits for lead were also above the Australian Drinking Water Guidelines (NHMRC/NRMMC 2004) and further investigation would be required to determine whether concentrations could be of concern (Table 3.2).

Table 3.2 1 year and 3 year mean metal concentrations at the Collie Pit lakes (µg/L).

		Black Diamond	Lake Kepwari	Stockton
Arsenic	ADWG*		7	
	RWG **		50	
	D.L. (µg/L)	**50**	**50**	**1, 50**
	1y (2009) Av	37.5	<DL	44.5
	Min	<DL	<DL	25
	Max	50	50	64
	n	*(2)*	*(2)*	*(2)*
	3y Av		<DL	15.2
	Min		<DL	0.5
	Max		50	64
	n		*(2)*	*(22)*
Cadmium	ADWG*		2	
	RWG **		5	
	D.L. (µg/L)	**10**	**10**	**0.1,10**
	1y (2009) Av	<DL	<DL	3.4
	Min	<DL	<DL	0.1
	Max	10	10	5
	n	*(2)*	*(2)*	*(3)*
	3y Av		<DL	1.4
	Min		<DL	0.05
	Max		10	5
	n		*(2)*	*(21)*
Mercury	ADWG*		1	
	RWG **		1	
	D.L. (µg/L)	**100**	**100**	**10, 100**
	1y (2009) Av	170.6	<DL	27.5
	Min	100	<DL	5
	Max	241.17	100	50
	n	*(2)*	*(2)*	*(2)*
	3y Av		<DL	27.5
	Min		<DL	5
	Max		100	50
	n		*(2)*	*(2)*

		Black Diamond	Lake Kepwari	Stockton
Lead	ADWG*		10	
	RWG **		50	
	D.L. (µg/L)	**100**	**100**	**100**
	1y (2009) Av	100	<DL	50
	Min	100	<DL	50
	Max	100	100	50
	n	*(1)*	*(2)*	*(1)*
	3y Av		<DL	11.4
	Min		<DL	0.5
	Max		100	25
	n		*(5)*	*(5)*

* Australian Drinking Water Guidelines (NHMRC/NRMMC (2004)
**Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Ch. 5 Recreational water) (2000)
<DL = Below Detection Limit, some metals used more than one DL for different analysis.

1.8 Other Metal Concentrations

1.8.1 Aluminium

Aluminium concentrations at Lake Kepwari and Stockton Lake were above the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) and recreational water guidelines (ANZECC/ARMCANZ 2000) (Table 3.3). No data were available for 2007 or 2008 and hence assessment was made on data from 2009. Guideline values were not exceeded at Black Diamond.

1.8.2 Iron

Lake Kepwari had elevated concentrations of iron (Table 3.3). The amount of iron in Lake Kepwari has more than doubled in the past 3 years from an average of 270 µg/L in 2007 and 2008 to 1355 µg/L in 2009. The 1 year and 3 year means exceeded *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) and recreational water guidelines (ANZECC/ARMCANZ 2000). Iron concentrations at Black Diamond and Stockton Lake did not exceed the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) or recreational water guidelines (ANZECC/ARMCANZ 2000).

1.8.3 Manganese

Lake Kepwari manganese concentrations exceeded *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) and recreational water guidelines (ANZECC/ARMCANZ 2000) (Table3.3). Black Diamond and Stockton Lake samples did not exceed guideline values.

1.8.4 Nickel

The three pit lakes exceeded the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) for nickel however samples taken at all three lakes are below recreational water guidelines (ANZECC/ARMCANZ 2000) (Table3.3).

Table 3.3. 1year and 3year mean for other metal concentrations at the Collie Pit lakes (µg/L).

		Black Diamond	Lake Kepwari	Stockton
Aluminium	ADWG*		7	
	RWG **		50	
	D.L. (µg/L)	**100**	**100**	**100**
	1y (2009) Av	<DL	3577	452.6
	Min	<DL	1648	23
	Max	100	5506	1360
	n	*(2)*	*(2)*	*(5)*
	3y Av		3577	529.2
	Min		1648	23
	Max		5506	1800
	n		*(2)*	*(27)*
Iron	ADWG*		200	
	RWG **		200	
	D.L. (µg/L)	**50**	**50**	**10**
	1y (2009) Av	51.5	1354.5	69.8
	Min	<DL	120	5
	Max	53	6926	140
	n	*(2)*	*(6)*	*(5)*
	3y Av		633.2	121.8
	Min		25	5
	Max		6926	310
	n		*(30)*	*(23)*
Manganese	ADWG*		300	
	RWG **		300	
	D.L. (µg/L)	**NS**	**30**	**10,30**
	1y (2009) Av	134	335	86.3
	Min	51	250	5
	Max	217	616	140
	n	*-2*	*(6)*	*(4)*
	3y Av		275.7	58.2
	Min		220	5
	Max		616	140
	n		*(30)*	*(26)*
Nickel	ADWG*		100	
	RWG **		100	
	D.L. (µg/L)	**NS**	**NS**	**10,30**
	1y (2009) Av	37.5	89.5	47.7
	Min	33	85	20
	Max	42	94	81

	Black Diamond	Lake Kepwari	Stockton
n	*(2)*	*(2)*	*(3)*
3y Av		89.5	24.6
Min		85	5
Max		94	81
n		*(2)*	*(25)*

* Australian Drinking Water Guidelines (NHMRC/NRMMC (2004)
**Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Ch. 5 Recreational water) (2000)
NS = Not Specified
<DL = Below Detection Limit

1.9 Other Metals

Boron, chromium, copper and zinc concentrations were well below drinking water and recreational water guidelines and were unlikely to pose a health risk. Magnesium concentrations were elevated however there are no Australian Drinking Water Guideline values (NHMRC/NRMMC 2004) or Recreational Water Guidelines (ANZECC/ARMCANZ 2000) available for benchmarking. Exposure to magnesium is not considered a potential health issue. There is no drinking water or recreational water guideline for Copper. Copper concentrations at the pit lakes were found to be low with Black Diamond having a 2009 average of 5µg/L, and Stockton and Lake Kepwari 11.6 and 25µg/L respectively.

1.10 Summary of Data Quality

The majority of the 2007-2009 data available is unsuitable to perform a comprehensive health risk assessment due to high detection limits and low sample numbers. As stated earlier sampling has previously been undertaken for environmental investigations and not human health and as such the analytical methods and detection limits used are inappropriate for a health risk assessment. Seasonal variation has not been taken into account due to the lack of data. Factoring this into an ongoing monitoring plan would increase the usefulness of future assessments.

1.11 Follow Up Water Quality Data

Ad hoc surface water samples were collected in April 2010 to determine current metal concentrations at the three pit lakes using detection limits below Australian Guideline values. Two samples were taken from the surface of each lake, one of these samples was filtered. Arsenic, cadmium, lead and mercury were found to be below all Australian Guideline values at all three lakes (Table 3.4).

Nickel, and Manganese were below Australian Guideline values at all 3 lakes. Iron was found to be elevated at Lake Kepwari. Aluminium was found to be above guideline values at all three lakes, however concentrations only just exceeded Australian Recreational Guideline values at Black Diamond (Table 3.5).

Table 3.4 Metal Concentrations from samples taken April 2010 from the pit lakes in Collie (µg/L)

		Black Diamond	Lake Kepwari	Stockton
Arsenic	ADWG*		**7**	
	RWG **		**50**	
	D.L. (µg/L)	**1**	**1**	**1**
	Total	<1	<1	<1
	Filtered	<1	<1	<1
Cadmium	ADWG*		**2**	
	RWG **		**5**	
	D.L. (µg/L)	**0.1**	**0.1**	**0.1**
	Total	<0.1	0.6	0.4
	Filtered	<0.1	0.5	0.3
Mercury	ADWG*		1	
	RWG **		1	
	D.L. (µg/L)	**0.1**	**0.1**	**0.1**
	Total	<0.1	<0.1	<0.1
	Filtered	<0.1	<0.1	<0.1
Lead	ADWG*		**10**	
	RWG **		**50**	
	D.L. (µg/L)	**0.1**	**0.1**	**0.1**
	Total	0.1	8.4	1
	Filtered	0.7	8.1	1.2

Table 3.5 Other metal concentrations from samples taken April 2010 from the pit lakes in Collie (µg/L)

		Black Diamond	Lake Kepwari	Stockton
Aluminium	ADWG*		**7**	
	RWG **		**50**	
	D.L. (µg/L)	**5**	**5**	**5**
	Total	55	1600	1000
	Filtered	54	1500	980
Iron	ADWG*		**200**	
	RWG **		**200**	
	D.L. (µg/L)	**5**	**5**	**5**
	Total	10	290	55
	Filtered	16	280	49
Manganese	ADWG*		**300**	
	RWG **		**300**	
	D.L. (µg/L)	**1**	**1**	**1**
	Total	190	280	120
	Filtered	180	290	110
Nickel	ADWG*		**100**	
	RWG **		**100**	
	D.L. (µg/L)	**10**	**10**	**10**
	Total	<10	70	30
	Filtered	<10	70	30

4 Summary of Biological Data

Available literature and data were reviewed for the presence of nuisance or disease carrying species. There was no data available on microbial water quality.

1.12 Ceratopogonidae – Biting Midges

Most recent aquatic macroinvertebrate data (2003–2009) indicates the presence of Ceratopogonidae (developmental stages not recorded) at Black Diamond and Lake Kepwari (Zhao *et al.*, 2009). An unpublished report by Lund (1997) observed Ceratopogonidae pupae at Stockton Lake. Ceratopogonidae pupae were also found at Black Diamond in 1997 during the months of April, June, July and December and in 1998 during January and February (Lund *et al.*, 2000).

1.13 Culicidae – Mosquitoes

Data from (Zhao *et al.*, 2009) for 2003–2009 does not indicate the presence of Culicidae at any of the three pit lakes, however, these data are from April when water temperatures are cooler and mosquito larvae are not breeding. Lund *et al.* (2000) surveyed four pit lakes including Stockton Lake and Black Diamond monthly using a 500 µm mesh dip net and this study indicated the presence of the genus *Culex* at Stockton during April 97 and Januray1998.

1.14 Summary

Although Ceratopogonidae were found at the pit lakes in Collie, they are considered a nuisance insect and are unlikely to have a significant impact on human health (Environmental Health Directorate, 2009). Potential health issues may include secondary skin irritations from bites and allergic reactions such as redness and swelling at the site of the bite. A study by Santamaria, *et al* (2008) indicates that nuisance midges bites may cause dermatitis. Respondents to the questionnaire did not report symptoms associated with insect bites in the ‘Other” symptoms. The data available are insufficient to determine the likelihood of potential health impacts.

Most recent data indicates that Culicidae are not present in the pit lakes in high abundances and therefore not likely to be a significantly contributing factor to vector-borne disease in the area at this time.

5 Potential for Health Effects from Recreational Use of Pit Lakes – A Screening Risk Assessment

A health risk assessment provides a defined method for assessing risks to health. It is a systematic approach to weigh up effects on the health of communities, groups or individuals caused by environmental factors or hazards. The health effects may be caused directly or indirectly by these factors and they may be actual health effects or potential health impacts. A screening risk assessment is used as a preliminary tool to determine whether an in depth assessment is required. It is more cost and time effective than a full risk assessment.

A screening risk assessment was undertaken to determine the potential for health risks associated with recreational use of the Collie Pit Lakes. The data for cadmium and lead concentrations were unable to be used as the detection limits were too high and sample numbers too few to enable an assessment of the potential for health effects, hence a screening risk assessment has not been undertaken for these metals. Mercury concentrations were found to be elevated at Black Diamond and elevated levels of arsenic concentrations were found at Stockton Lake. A screening risk assessment was performed to determine the health risks associated with mercury exposure at Black Diamond and arsenic exposure at Stockton Lake.

Other metals were also found to be elevated. Aluminium was elevated at Lake Kepwari and Stockton Lake. Manganese and iron were found to be elevated at Lake Kepwari. A screening risk assessment for aluminium exposure was undertaken on the concentrations found at Lake Kepwari as these were higher than those at Stockton Lake. Another screening risk assessment on manganese was undertaken using the concentrations found at Kepwari. Although iron concentrations were higher than Australian Drinking Water Guidelines a screening risk assessment has not been performed as exposure to iron is not considered a risk to human health (WHO, 1996). Australian Drinking Water Guidelines are implemented for aesthetic purposes.

Two scenarios were considered to determine the likelihood of health impacts occurring from exposure to elevated contaminant levels. The first scenario considered a worst case situation, where a female will be exposed to the highest level of contaminant for a long period of time. The second scenario considers an average person's exposure based on average contaminant concentrations and average exposure times. For mercury a third scenario has been included to consider a child's exposure to the mercury concentrations found at Black Diamond.

1.15 Exposure Pathways

The types of activities undertaken at the pit lakes were identified during the survey (Chapter 2: Recreational Use of Pit Lakes – A Community Survey). Swimming, wading and water skiing were amongst the water based activities. People undertaking these activities have the potential to be exposed to elevated metals concentrations in surface water. The potential pathways of exposure are identified in Table 5.1.

The World Health Organisation (2003) acknowledges that inhalation of water is a significant exposure route when water skiing however they are unable to provide default figures for the amount of water likely to be inhaled whilst undertaking this activity. Therefore exposure to metals from inhalation of water cannot be included in this assessment.

Absorption of toxins via the skin is also a potential exposure pathway when undertaking water based recreational activities (WHO, 2003; USEPA 1992). US EPA (1992) provides a formula for calculating an Absorbed Average Daily Dose, however it states this formula is not practical to use when calculating absorption rates during water based activities because of the difficulty in assessing the total amount of water a person has contacted. This is further complicated where acidity may be a factor which may increase dermal absorption. Hence dermal absorption has not been included in this assessment.

Approximately 12% of survey participants identified that they went fishing at Black Diamond and 90% ate the seafood they caught from the lake. Some metals such as mercury are known to accumulate in aquatic animals, particularly shellfish (Simon & Boudou, 2001). The type of seafood most likely caught at Black Diamond is marron or gilgie (McCullough *et al.*, 2009b). Data from 2005 have been used in this assessment.

Table 5.1 Potential Exposure Pathways.

Pathway Name	Source	Media	Point of Exposure	Route of Exposure
Contaminated Recreational Water	Pit Lake	Water	Mouth - nose/Respiratory System	Inhalation
Contaminated Recreational Water	Pit Lake	Water	Mouth/Gastrointestinal Tract	Ingestion
Contaminated Recreational Water	Pit Lake	Water	Skin	Dermal Absorption
Contaminated Seafood	Pit Lake	Marron	Mouth/Gastrointestinal Tract	Ingestion

1.16 Length of Exposure

Survey participants identified the time they spent undertaking each activity per visit at the lakes. The mean time spent undertaking swimming, wading and water skiing at Black Diamond was 3.5 hours per visit, with people spending a minimum of 0.5 hours and a maximum of 12 hours undertaking these activities (Chapter 2). The maximum length of exposure was calculated for the worst case scenario. The mean number of hours at a pit lake was used to calculate the average exposure.

1.17 Concentration (Level of Exposure)

The 2009 mean metals concentrations were used for assessing the potential health risks and are outlined in Table 5.2. Mercury concentrations at Black Diamond was used to determine the potential for exposure to mercury and also used for the determination of a worst case scenario. The 2009 mean arsenic concentration at Stockton Lake was used to determine the potential for arsenic exposure, as this lake had the highest concentrations. Data from the corresponding lakes for crayfish metal body burdens were used in the risk assessment (Table 5.3). For determination of a child's exposure to mercury, the average mercury concentration was used.

Table 5.2 Elevated metal concentrations in surface water at the pit lakes.

	Hg (µg/L)	As (µg/L)	Al (µg/L)	Mn (µg/L)
2009 mean	170.6	44	3577	335
Min	100	25	1648	250
Max	241.2	64	5506	616
(n)	*(2)*	*(2)*	*(2)*	*(6)*

Table 5.3.Elevated Shellfish metal body burden at the pit lakes (2005).

	As mg/kg (Stockton Lake)	Hg (mg/kg) (Black Diamond)
Average	0.12	0.44
Min	0.05	0.35
Max	0.24	0.50
(n)	*(10)*	*(4)*

1.18 Exposure Scenarios

1.18.1 Default Factors

EnHealth Guidelines (2004) indicates that during a normal swimming session a person may ingest a maximum of 100mL of water. More recent NHMRC (National Health and Medical Research Council, 2008) *Guidelines for Managing Risk in Recreational Waters* advocate that consumption of water during recreational activities contributes 10% of daily intake of water. This equates to 200mL day. This figure is taken from the WHO (2003) guidelines which estimate consumption of 200mL per day which consists of 2 sessions of swimming with an individual consuming 100mL per session. Therefore 200 mL was used for the worst case scenario (longer exposure) and 100mL was used for the default factor for determination in the average scenario.

The 1995 National Nutritional survey indicates that women aged 16-44 years had a mean consumption rate of 95 gm/day of fin fish (FSANZ, 2004). The high consumption rate was 265gm/day. This figure was used in the worst case scenario. The same survey found the general population ate a mean of 115g/day of finfish (FSANZ, 2004). This was used for the average scenario. For determination of a child's level of mercury exposure a default factor of 115g/day was used, this is taken from the 1995 National Nutritional Survey and is the mean consumption rate of finfish (FSANZ, 2004).

The body weight of 58kg was used as the default factor for females and scenario 2 used 64 kg for an average person's body weight (Enhealth, 2004). The default factor used for a child's (2 yrs) body weight was 13.2kg (Enhealth, 2004).

1.19 Screening Health Risk Assessment - Mercury

1.19.1 Mercury Exposure at Black Diamond

Scenario 1 – Worst Case Scenario

A female swimming for 12 hours exposed to the highest level of contaminant and consuming contaminated seafood.

Exposure Level = ((Ingestion rate x level of contaminant x duration of exposure) + (Ingestion rate of seafood x level of contaminant))/(body weight)/day

Duration of exposure = 12 h or 2 sessions of swimming.

EL = (0.2 L x 0.241 mg/L) + (265 gm/day x 0.5 mg/kg)/58 kg/day

= (0.0482 mg + 0.13 mg/day)/58 kg/day

= 0.1782 mg per day/58kg/day

= 178.2 µg per day/58kg

= 3.07 µg/kg

Scenario 2 – Average Exposure Scenario

An average person swimming for 3.5h exposed to the average level of contaminant and consuming average amounts of contaminated seafood.

Exposure Level = ((Ingestion rate x level of contaminant x duration of exposure) + (Ingestion rate of seafood x level of contaminant))/(body weight)/day

Duration of exposure = 3.5h or 1 session of swimming

EL = (0.1 L x 0.17 mg/L) + (115 gm/day x 0.44 mg/kg)/64kg/day

= (0.017 mg + 0.051 mg/day)/64kg/day

= 0.068 mg/day/64kg/day

=68 µg per day/64kg/day

= 1.06 µg/kg/day

Scenario 3 –Average Exposure Scenario for Child

An child (2yrs) swimming for 3.5h exposed to the average level of contaminant and consuming average amounts of contaminated seafood.

Exposure Level = ((Ingestion rate x level of contaminant x duration of exposure) + (Ingestion rate of seafood x level of contaminant))/(body weight)/day

Duration of exposure = 3.5h or 1 session of swimming

EL = (0.1 L x 0.17 mg/L) + (115 gm/day x 0.44 mg/kg)/13.2kg/day

= (0.017 mg + 0.051 mg/day)/13.2kg/day

= 0.068 mg/day/13.2kg/day

=68 µg per day/13.2kg/day

= 5.15 µg/kg/day

1.20 Risk Characterisation

1.20.1

1.20.2 Ingestion

The health impacts from mercury exposure are dependent on the form of mercury. Health impacts from metallic mercury are less likely as absorption of mercury into the body in this form is low. Organic mercury is more toxic to humans as is more readily absorbed through the gastrointestinal tract. WHO (2005) indicate that metallic mercury is unlikely to be a health risk when found in drinking water whereas methyl mercury does pose a health risk in drinking water.

The chemical analysis of mercury at the pit lakes has not been used to identify which form of mercury is present. This makes the accuracy of predicting health impacts more difficult. WHO (2005) recommends a Tolerable Daily Intake for inorganic mercury of 2 µg/kg of body weight. This is based on a NOAEL of 0.23 mg/kg of body weight taken from an animal study. A Provisional Tolerable Weekly Intake (PTWI) for methyl mercury is recommended at 1.6 µg/kg of body weight. The worst case scenario estimates an exposure level of 3.07 µg/kg per day. The average scenario estimates exposure at 1.06 µg/kg per day. For a child aged 2yrs spending 1 session swimming exposure to average concentrations the estimate of exposure is 5.15 µg/kg/day which is well above acceptable guidelines.. The Provisional Tolerable Daily Intake for methyl mercury for Australian children is 3.3 µg/kg of body weight/week (FSANZ, 2004). If the mercury analysed at Black Diamond was in the form of methyl mercury and a person was exposed to an average dose the risk of health impacts occurring is low. However in a worst case scenario if a person was to spend an entire day swimming and consumed a large amount of seafood that they caught from the lakes (for example if they were camping at the lakes) the potential for health impacts is higher. Therefore the mercury concentrations at Black Diamond are an issue particularly for children where attempts should be made to reduce exposure.

The screening risk assessment has a number of limitations. Compilation of more data would increase confidence in the analytical results of mercury found at Black Diamond. The dose used in the calculations needs to be treated with caution as the results were heavily influenced by high mercury concentration. The additional water samples analysed in 2010 indicates mercury levels are not above guideline values.

This would alter the outcome of the screening risk assessment in a minor way as the main contributing factor to exposure is the consumption of contaminated seafood and although the concentrations are low, the data needs to be viewed cautiously as they are ad hoc samples and do not take into account any seasonal variation or fluctuations. The samples taken were surface water samples but there is no indication of the position within the lake where they have been taken from, e.g., the middle or on the edges.

There is the potential for the level of exposure to be higher than the screening risk assessment shows. The dermal and inhalation exposure pathways have been excluded from the exposure calculation due to the difficulty in accurately calculating actual exposure. It is possible that inclusion of these exposure routes would increase the dose (amount of exposure) received by individuals.

The data used for this assessment shows that crustaceans from the Black Diamond do have elevated concentrations of mercury. The crustacean data from 2005 ranges from 0.35 mg/kg to 0.5 mg/kg, with an average of 0.44 mg/kg. This increased has the amount of exposure assessed in the risk assessment. The Australian Food Standards (2010) have set a maximum level (ML) of 0.5 mg/kg for Mercury in crustaceans. This includes all species of mercury. Although the levels are below the ML for Australian Food Standards mercury has an accumulative effect. The crustaceans found within Black Diamond could contain higher levels than the 2005 data indicates. Consideration should be given to undertaking more extensive research on current levels of contamination in the seafood to accurately assess its impact on health outcomes.

1.20.3 Susceptible groups

Methyl Mercury has the ability to cross the placental barrier causing brain damage to the foetus (Iavicoli *et al*., 2009). Therefore pregnant women should be considered susceptible to exposure of methyl mercury. To accurately assess who are the most sensitive groups distinction needs to be made about the form of mercury found at the pit lakes. Children are also a susceptible group, smaller body weights and less efficient body systems are likely to increase the level of exposure.

Inorganic forms of mercury are unable to cross the placental membrane reducing health impacts to pregnant women (ATSDR, 1999).

1.20.4 Other considerations

There is the potential for alternative routes of exposure to mercury. Collie is a coal producing area which also has coal fired power station. Metallic mercury may be emitted from coal fired power stations hence exposure to airborne emissions could increase exposure as would deposition of mercury on market garden produce. Air emissions from these sources may also contribute to levels of mercury in the pit lakes if they are deposited at these sites. Once in the pit lake there is the potential for the metallic mercury to be converted into methyl mercury by bacteria. If the mercury remains in the metallic form it is more likely to settle in the sediments of the lake reducing likelihood of exposure. However if metallic mercury was converted to methyl mercury by bacteria this would increase already elevated levels at the lakes making mercury exposure a significant issue. The likelihood of this happening is unknown.

1.21 Screening Risk Assessment - Arsenic

1.1.21.1.1

1.21.2 Arsenic Exposure at Stockton Lake

Scenario 1 – Worst Case Scenario

A female swimming for 12 hours exposed to the highest level of contaminant

Exposure Level = ((Ingestion rate x level of contaminant x duration of exposure) + (Ingestion rate of seafood x level of contaminant))/(body weight)/day

Duration of exposure = 12 h or 2 sessions of swimming.

EL = (0.2 L x 0.064 mg/L)) + (265 gm/day x 0.24 mg/kg)/58 kg/day

= (0.0128 mg + 0.0636 mg/day)/58 kg/day

= (12.8 µg + 63.6)/58kg/day

= 1.3 µg/kg/day

Scenario 2 – Average Exposure Scenario

An average person swimming for 3.5h exposed to the average level of contaminant.

Exposure Level = ((Ingestion rate x level of contaminant x duration of exposure) + (Ingestion rate of seafood x level of contaminant))/(body weight)/day

Duration of exposure = 3.5h or 1 session of swimming

EL = (0.1 L x 0.0.0445 mg/L) + (115 gm/day x 0.12 mg/kg)/64kg/day

= (0.0114 mg/per day + 0.0138 mg)/58kg/day

= (11.4 µg per day + 13.8 µg)

= 18.25 µg per day/64kg/day

= 0.29 µg/kg/day

1.21.3 Risk Characterisation

The most common type of exposure to arsenic is in the organic form and this may be through air, drinking water or food. Organic arsenic is the form found in seafood and is generally considered non toxic. Exposure may however occur through consumption of inorganic arsenic present in seafood. The Minimum Risk Level (MRL) for oral exposure to inorganic arsenic for short term exposure (14 days or less) is 0.005 mg/kg/day (ATSDR, 2007). This equates to 5µg/kg/day. The worst case scenario and the average scenario estimate exposure below this level. Studies have shown that ingestion can lead to skin lesions, this can occur at exposure levels of 2 - 20 µg/kg/day (ATSDR, 2007). Cardio vascular and respiratory systems may be impacted at exposure levels of 8-40 µg/kg/day.

The inclusion of other exposures pathways may increase the level of exposure, although the ingestion of water when undertaking recreational pursuits and consumption of seafood would contribute the highest level of exposure. The form of arsenic in seafood is different to that found in drinking water and therefore the scenarios may overestimate exposure levels. It is unlikely that the level of exposure contributed by other exposure pathways would significantly change the outcome of the risk assessment.

The risk of health impacts from exposure to arsenic at Stockton lake is therefore considered to be low.

1.22 Screening Risk Assessment - Aluminium

1.1.22.1.1

1.22.2 Aluminium Exposure at Lake Kepwari

Scenario 1 – Worst Case Scenario

A female swimming for 12 hours exposed to the highest level of contaminant

Exposure Level = (Ingestion rate x level of contaminant x duration of exposure)/(body weight)/day

Duration of exposure = 12 h or 2 sessions of swimming.

EL = (0.2 L x 5506µg/L))/58 kg/day

= 1101.2 µg/58 kg/day

= 18.99 µg/kg/day

Scenario 2 – Average Exposure Scenario

An average person swimming for 3.5h exposed to the average level of contaminant.

Exposure Level = (Ingestion rate x level of contaminant x duration of exposure)/(body weight)/day

Duration of exposure = 3.5h or 1 session of swimming

EL = (0.1 L x 3577 µg/L)/64kg/day

= 357.7 µg per day/64kg/day

= 5.59 µg/kg/day

1.22.3 Risk Characterisation

Aluminium and its associated compounds are poorly absorbed by humans (IPCS, 1997). There is a lack of certainty about the association between Alzheimer's Disease and aluminium exposure through drinking water. The typical intake of aluminium is

20 mg/kg/day. WHO (1989) indicate a provisional tolerable daily intake (PTWI) of 7 mg/kg. Even with the highly elevated levels found at Lake Kepwari, the worst case scenario gives an exposure concentration of 19 µg/kg/day. This is well below the PTWI. Although contaminant levels are above Australian Drinking Water Guidelines, these guidelines are designed for aesthetic purposes and not to protect human health. Inclusion of other exposures pathways may increase the level of exposure but it is highly unlikely to increase exposure levels high enough to surpass the PTWI. Consumption of seafood has not been considered as aluminium is not known to bioaccumulate in shellfish.

1.23 Screening Risk Assessment Manganese

1.1.23.1.1

1.1.23.1.2 Manganese Exposure at Lake Kepwari

Scenario 1 – Worst Case Scenario

A female swimming for 12 hours exposed to the highest level of contaminant

Exposure Level = (Ingestion rate x level of contaminant x duration of exposure)/(body weight)/day

Duration of exposure = 12 h or 2 sessions of swimming.

EL = (0.2 L x 616µg/L))/58 kg/day

= 123.2µg/58 kg/day

= 2.12 µg/kg/day

Scenario 2 – Average Exposure Scenario

An average person swimming for 3.5h exposed to the average level of contaminant.

Exposure Level = ((Ingestion rate x level of contaminant x duration of exposure)/day

Duration of exposure = 3.5h or 1 session of swimming

EL = (0.1 L x 33.5 µg/L)/64kg/day

= 33.5 µg per day/64kg/day

= 0.52 µg/kg/day

1.23.2 Risk Characterisation

The Tolerable Daily Intake (TDI) for manganese is 0.06 mg/kg/day (WHO, 2004) Human studies show some low level neurological effects at 0.059 to 0.7 mg/kg/day, this was over an extended period of time (Kondakis *et al.*, 1989) (Vanita *et al.*, 2007). The worst case scenario at Lake Kepwari indicated a person would be exposed to 2.12 μg/kg/day, and the average scenario a person would be exposed to 0.52 μg/kg/day. These are below the TDI set by WHO, therefore the risks of health effects from exposure to manganese are low. Inclusion of other exposure pathways is unlikely to increase the risk of health impacts from increasing exposure levels. Consumption of seafood has not been included in this assessment as although it is naturally found in foods it is not known to bioaccumulate in the food chain.

1.24 Limitations of research

There are a number of limitations associated with this research.

1.24.1 Survey Response

The high non response to the survey limits the generalisability of the survey data. We cannot estimate the population level of exposure with any level of certainty with these data. However we expect that users of the lakes were more likely to respond. For users of the lakes there is no reason to believe that the response of the participants regarding the nature of the use differ from non-responding users of lakes. A greater response to the questionnaire would have given a better representation of the recreational habits of the Collie community and visitors from other regions at the pit lakes. The responses received provides data which can be used for the screening risk assessment but does not give a complete and comprehensive idea of recreational use of the pit lakes.

1.24.2 Questionnaire Data

Participants were asked to recall the activities and times they had spent at the pit lakes over the past 2 years. The accuracy of their recall may have affected the results. To improve the accuracy about the amount of time spent at the spent lakes, a survey of persons over the summer period could be undertaken. There is also the potential for bias to be introduced into the health effects recorded from survey participants. No information was available on existing health effects nor other potential cause of these health effects. Participant perception may also have been that the research was being conducted to prevent people from using the pit lakes for recreation hence there is the possibility of people understating the health effects experienced.

1.24.3 Water Quality Data

There are two significant limitations with the data used for determining water quality. The first was the lack of recent data available for use. For 2009 there were a limited number of results and they did not have detection limits suitable for assessing health impacts. More extensive data were available for 2008 and 2007 for some of the metals however the value of this extra data was limited due to the high detection level. It was found that most of the data was below the analytical detection limit which was in turn higher than Australian Drinking Water Guidelines. The second set of data collected in April 2010 must be considered with caution. They do not take into account any seasonal variance and are indicative of metal concentrations only of the day they were taken. Even though the values are below guidelines the level of exposure in the risk assessment is not changed greatly for arsenic or mercury as the main source of exposure is from the consumption of contaminated seafood.

1.24.4 Biological Data

There are insufficient data to determine the potential health impacts from biological characteristics of the pit lakes. Further sampling for specific species identified would assist in future health assessments. The lack of toilet facilities and the amount of time people indicated they spent at the lake has the potential to increase risk of exposure to microbial contaminants.

1.24.5 Long term exposure

The questionnaire was limited to activities undertaken within the last 2 years. A number of residents stated that they had used the pit lakes for years. This research does not allow for examination of long term exposure, in particular to heavy metals. Historical water data indicates that contaminant levels have been higher in previous years and as such there could be the potential for long term exposure.

6 Summary

1.25 Pit lake Use

It is clear from those people surveyed that there is a high level of recreational use of the Collie pit lakes, and especially Black Diamond and Stockton Lake. Use is high in the warmer months of the year from November to March. Families, the elderly and the young use the pit lakes for water based activities, particularly swimming. The lakes were popular locations for picnicking and boating activities were popular at Stockton Lake. Another popular activity was camping. A small number of people reported fishing and marroning, however other residents also consumed seafood from the lakes even if they did not fish themselves.

1.26 Health Effects

Health effects were reported by 38% of respondents who visited the lakes. Visitors to Black Diamond and Stockton Lake reported experiencing the most health effects and the most common heath effect experienced by both adults (22.3%) and children (18.8%) was sore eyes followed by reports of skin irritations and rashes. There was no clear correlation between the amount of time spent in the water and health effects experienced and the only parameter likely to results in sore eyes was acidity. Previous research has shown that low pH can result in both eye and skin irritation (WHO, 2003). Low pH can also remove the outer layers of the skin making the body more susceptible increased absorption of ionisable molecules (Fluhr *et al*, 2008). It is possible that this could occur at the Collie pit Lakes, although it is Black Diamond where most people reported symptoms, yet Stockton Lake has the marginally lower pH.

1.27 Water Quality and Pit Lake Characteristics

In general pH was low and temperature and turbidity were within recommended water quality guidelines. A number of metals were found to be above *Australian Drinking Water Guidelines* at the different pit lakes. Mercury concentrations were elevated at Black Diamond and possibly Stockton Lake and arsenic concentrations were elevated at Stockton Lake. Aluminium concentrations were high at Lake Kepwari and Stockton Lake with iron and manganese both elevated at lake Kepwari. One of the major problems in interpreting the water quality data was the high analytical limits of detection and low sample numbers.

Analytical detection limits affected the quality of a large amount of the water data as they were above Australian Drinking Water Guidelines, particularly as there was only limited surface water data available for assessment.

The second set of samples taken during April, 2010, using detection limits below Australian Drinking Water Guidelines indicate that arsenic, cadmium lead and mercury are below Australian Drinking Water Guidelines. Aluminium and iron were found to be elevated at Lake Kepwari.

The 2010 results differs from the original water quality data available to researchers and supports the need for further monitoring. There was insufficient biological data to assess risks associated with exposure to biological contaminants and it is not possible to assess risks to physical hazards by undertaking a risk assessment.

1.28 The Potential for Health Risks from Recreational Use of the Pit Lakes.

The initial results of the risk assessment indicate low levels of risk to health from exposure to metal concentrations in the pit lakes as a result of low frequency and duration of use, nevertheless the concentrations of the heavy metal mercury and other metals arsenic, aluminium and manganese are high and hence a precautionary approach is advised in terms of exposure. Children are likely to be at a higher risk of adverse health effects due to their developing status and potential for higher intakes of metals. The risk assessment for children's exposure to mercury supports a level of exposure that is unacceptable. The results were limited by the low numbers of samples available and a lack of information on other sources of exposure could increase the risks depending on findings. The 2010 water quality data makes interpretation of the risk assessment even more difficult as the metal concentrations were below guideline values and therefore a simple comparison of these analytical results with guidelines would indicate that it is unlikely that health impacts would occur, however caution should be taken if using this approach. If the lakes are to be used for aquaculture or marroning then attention to the potential for bioaccumulation of metals is necessary. The risks of this source of metals in addition to normal exposures could result in unacceptable impacts.

The risks of swimming in low pH water are evident and the potential for increased exposure to metals from low pH warrants further attention. Temperature and clarity of the water do not appear to be significant risks to recreational users.

It has not been possible to assess the potential for health effects from recreational use of the pit lakes stemming from the physical characteristics. It should be noted however that the risk of injury exists in some parts of the lakes due to steep sides and depth of water can impact on human health and should be included when summarising the causes for potential health impacts. Management of these potential risks may be abated by educating users and signage.

1.29 Management Issues

The lack of active management was a key factor in many responses to the questionnaire. Lack of toilet facilities was the main factor which influenced whether people used the pit lakes and many wanted an agency or organisation to be made responsible for rubbish collection and facilities to enable full recreational use of the lakes.

Respondents would like to see the lakes placed under some type of management.

While the results of the risk assessment suggest the health risks for users is not great there are many unanswered questions. It is strongly recommended that attention is paid to the water quality aspects of the lakes and that a more rigorous monitoring program be put in place to ensure water quality characteristic are acceptable and that health risks are significantly reduced. Monitoring for human exposure could resolve whether the lakes are an issue or not in terms of human exposure. No monitoring has been undertaken for *E. Coli* or other faecal pathogens.

7 Recommendations

1. It is recommended a comprehensive monitoring plan be developed for the water quality of the Collie Pit Lakes (also see Zhao *et al.* (2010)). Both physico-chemical (e.g., pH, metal concentrations) and biological parameters (e.g., mosquito and midge macroinvertebrates, fecal coliforms) need to be included in this plan. Ongoing frequent monitoring of all surface waters used for recreation is required, particularly during the summer period when there is the greatest use. Analytical methods appropriate for comparison with Australian Drinking Water (NHMRC/ARMCANZ, 1996) or Recreational Water Guidelines (ANZECC/ARMCANZ, 2000) should be used. Australian Drinking Water Guidelines (NHMRC/ARMCANZ, 1996) provides a method of analysis for each physical and chemical parameter to be monitored. It is recommended that these methods be followed. To date most of the analyses undertaken have not been suitable for comparison against guidelines due to too high levels of detection. The ad hoc monitoring undertaken in April 2010 indicated that 'heavy' metal concentrations were low. The conflicting data should be used as an indication that ongoing monitoring is required using appropriate analytical detection limits. Speciation of certain metals and metalloids is also required to accurately assess potential risks to health.

2. Elevated mercury found at Black Diamond may increase the risk of potential negative health effects. Confirmation of mercury concentrations would assist in identifying potential risks as current data suggests that mercury is a potential health issue, particularly to children. If high mercury concentrations are confirmed it is recommended that Department of Water develop a communication strategy to advise the community of the potential health impacts of recreational use in this lake.

3. Approximately 10% of people who used the pit lakes went marroning/fishing with 90% eating the seafood they caught. Historic data (2005) indicate a number of the lakes contain various crayfish species that contain elevated concentrations of heavy metals. A study of crayfish bioaccumulation would

give both an indication of the accumulative nature of the heavy metals and the potential to impact on human health. It is recommended a human exposure study be simultaneously completed to assess the biological data and concentration of metals and hence likely health impacts.

4. Management of the pit lake sites would decrease the risk of recreational use to health. Management would include rubbish collection and toilet maintenance. One of the biggest concerns raised by survey respondents was the amount of rubbish left at the pit lakes (19%). Participants from the survey noted that broken glass was common at the pit lakes. Australian Recreational Water guidelines recognise litter as a potential hazard and identify methods for reducing risks to health. The Australian Recreational Water Guidelines define recreational water bodies as “any public coastal, estuarine or freshwater areas where a significant number of people use the water for recreation” and as such should be considered when addressing health issues regarding the pit lakes.

5. Another major concern identified by users of the pit lakes was the lack of facilities at these locations (20%). The lack of toilet facilities increases the potential for health impacts to occur from faecally derived coliforms. In summer, the number of visitors to the lake can be quite large. Twenty one percent of people attended the lakes all day spending approximately 5.4 h per visit, another 66% went only of an afternoon and would spend on average 3.3 hours at the lakes. The installation of toilet facilities would reduce the risk to human health from exposure to faecal coliforms. Consideration also needs to be given to the placement and type of toilet installed. In some circumstance it is possible for contamination of groundwater from drop toilets to occur.

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8 Appendices

3.1 Appendix A Questionnaire

Questionnaire completed by both random and targeted respondents.

3.2 Appendix B Information Letter

Dear Resident,

Re: An invitation to provide your views and experiences on the Collie Lakes

We are conducting research to find out whether the pit lakes in the Collie region are used for activities like boating, fishing and swimming. We are interested in your views on the benefits of the pit lakes and whether there are any health or safety concerns.

We would like you to fill out a questionnaire which should take 10 minutes to complete. Your participation is completely voluntary and answers will be kept confidential. Even if you have never used the lakes for boating or swimming we would value your outlook on the lakes. By answering the questions you will be providing important information which will benefit your community.

A reply paid envelope has been provided to return your responses. As we need to finalise our research we would appreciate if you could respond by the 18th December.

If you have any questions about this study, please contact Helen Tanner on 6304 5765.

If you have any complaints about the research project you may contact:

Research Ethics Officer
Human Research Ethics Committee
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

I thank you for your time,

Dr. Andrea Hinwood
Senior Lecturer
Edith Cowan University
School of Natural Sciences

3.3 Appendix C Information Sheet

Invitation to participate!

Use of Pit Lakes in the Collie Region

ECU is conducting research to find out whether the pit lakes in the Collie region are used for activities like swimming, boating and camping. We are interested in your views on any benefits of their use and also whether there are any health or safety concerns. We are also interested in your views on other ways in which the pit lakes could be used. Could you please assist us by ***completing a questionnaire*** about how often you are using the lakes in the region, what they are used for and if you or your children have had any health issues after using the lakes.

This questionnaire is completely **voluntary** and Participants **will not be identified**

This study has been approved by the ECU Human Research Ethics Committee. If you have any concerns about this project an independent Ethics Officer may be contacted on (08) 6304 2170. This project is joint funded by the Department of Water, Western Australia and the Australian Government under its $12.9 billion Water for the Future plan.

Background Information

About the Collie Lakes
Collie has a number of open cut mine pits that are no longer mined. Over time some have been filled by water. These new water bodies are sometimes called pit lakes. Examples of pit lakes in the Collie region include Black Diamond Lake, Stockton Lake and Lake Kepwari.

Benefits for the Community
Research shows that pit lakes can have positive uses, which may provide economic and health benefits to the local community. Possible uses for the lakes include swimming, water skiing or boating, fish farming, a water source for irrigation or industry, wildlife habitat, or research and education. However, we need to ensure that any risk to public health and safety is acceptable. There is little research available on the possible health effects from occasional use of pit lakes.

This study will inform us about what types of activities people carry out at the lakes and how often people are using the lakes. Together with information on water quality and the physical features of the lakes, this information will then be used to assess if there are any risks to human health.

How to participate?
You are invited to complete a short questionnaire. Questions will ask you how often you and your family use the pit lakes. We are also interested in the types of activities, for example, do you use the lakes for boating, skiing, swimming or marroning?
We are also looking for people's opinions on what the pit lakes should be used for. You can tell us if there are any reasons why you wouldn't use the lakes or let us know if there is something that would encourage you to use the lakes. The questionnaire should only take 10 minutes to complete.

Water Quality
Collie pit lakes contain acidic water with higher than normal concentrations of some dissolved metals. This is because soils associated with coal contain sulphides, which can oxidise when exposed to air, producing acid. The acid may dissolve metals such as aluminium, iron, manganese and zinc and also small amounts of lead and cadmium and other less common metals from the surrounding rocks. Surface water and groundwater inflows may contribute to the acidity and metal concentrations found in pit lakes.

Other Characteristics of Pit Lakes
Collie pit lakes typically have steep sides and are deeper than natural lakes. The water can also be very cold. The Collie pit lakes also have low nutrient concentrations and low numbers of wildlife species. Some areas surrounding the lakes may have been rehabilitated by reducing bank steepness or by planting. This can improve the quality of surface water runoff entering the lakes. Rehabilitation may also increase the number of wildlife species in the area.

Potential Health Impacts
If pit lake water is acidic or contains high enough concentrations of metals there is the possibility of health issues occurring. Exposure to some metals may cause nausea, vomiting or more serious ailments. Contact with water which is acidic has been known to cause skin and eye irritation. Germs excreted in waste from people and/or wildlife has the potential to cause stomach upsets and diarrhoea. The steepness of pit lake walls or the cold temperature of the water may increase the risk of drowning.

Please contact Helen Tanner on (08) 6304 5765 if you would like more information

3.4 Appendix D Time of year children visited the pit lakes.

		Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
January	Not visited	10	30.3	32	100.0	12	40.0	31	96.9
	Visited	23	69.7	211		18	60.0	1	3.1
February	Not visited	11	33.3	31	96.9	11	36.7	32	97.0
	Visited	22	66.7	1	3.1	19	63.3	1	3.0
March	Not visited	20	60.6	31	96.9	16	53.3	0	0
	Visited	13	39.4	1	3.1	14	46.7	0	0
April	Not visited	27	81.8	31	96.9	26	86.7	0	0
	Visited	6	18.2	1	3.1	4	13.3	0	0
May	Not visited	31	93.9	32	100.0	29	96.7	0	0
	Visited	2	6.1	211	0	1	3.3	0	0
June	Not visited	31	93.9	32	100.0	28	93.3	0	0
	Visited	2	6.1	211	0	2	6.7	0	0
July	Not visited	0	0	32	100.0	0	0	0	0
	Visited	0	0	211	0	0	0	0	0
August	Not visited	28	84.8	32	100.0	29	96.7	0	0
	Visited	5	15.2	211	0	1	3.3	0	0
September	Not visited	30	90.9	32	100.0	29	96.7	0	0
	Visited	3	9.1	211	0	1	3.3	0	0
October	Not visited	28	84.8	30	93.8	25	83.3	0	0
	Visited	5	15.2	2	6.25	5	16.7	0	0
November	Not visited	23	69.7	28	87.5	19	63.3	0	0
	Visited	10	30.3	4	12.5	11	36.7	0	0
December	Not visited	16	48.5	31	96.9	16	53.3	0	0
	Visited	17	51.5	1	3.125	14	46.7	0	0

3.5 Appendix E Activities undertaken by children at the pit lakes (%).

	Black Diamond n(28)		Lake Kepwari n(8)		Stockton Lake n(28)		Other n(5)	
	Frequency	Percent %	Frequency	Percent %	Frequency	Percent %	Frequency	Percent %
Swim	25	89.3	3	37.5	25	89.3	1	20.0
Kayak	5	17.9	0	0	3	10.7	1	20.0
Wading	15	53.6	1	12.5	15	53.6	1	20.0
Boating	1	3.6	1	12.5	9	32.1	0	0
Waterskiing	1	3.6	1	12.5	8	28.6	0	0
Marroning	3	10.7	0	.0	3	10.7	0	0
Picnicking	11	39.3	3	33.3	13	46.4	1	20.0
Camping	6	21.4	1	12.5	10	35.7	1	20.0
Walking	2	7.1	0	0	0	0	0	0
Fishing	0	0	0	0	0	0	0	0
Other	1	3.6	1	12.5	2	7.1	0	0

3.6 Appendix F Percentage of respondents who went marroning and the lakes they went marroning at.

	Frequency	Percent (%)
Don’t Go	100	76.3
Black Diamond	8	6.1
Stockton Lake	8	6.1
Other	3	2.3
Black Diamond & Stockton Lake	9	6.9
Stockton Lake & Other	1	0.8
Black Diamond, Lake Kepwari & Stockton Lake	1	0.8
Black Diamond, Lake Kepwari & Other	1	0.8

3.7 Percentage of people who ate the seafood they caught.

	Frequency	Percent (%)
Don't consume seafood	9	17.6
Consume seafood caught	42	82.4

3.8 Appendix G Percentage of health effects experienced by children who visited the specific lakes. No child visited only lake Kepwari or 'Other' lakes.

		Black Diamond n(6)		Stockton Lake n(5)	
		Frequency	Percent (%)	Frequency	Percent (%)
Skin rash	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Sore eyes	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Nausea	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Vomiting	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Diarrhoea	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Runny nose	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Headaches	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Feeling Tired	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Temperature	Never	6	100.0	5	100.0
	Sometimes				
	Most				
Sore throat	Never	5	83.3	5	100.0
	Sometimes	1	16.7		
	Most				
Other	Never	5	83.3	5	100.0
	Sometimes				
	Most	1	16.7		

3.9 Percentage of health effects experienced by children by the number of lakes they attended.

		1 Lake *n(11)*		2 Lakes *n(15)*		3 Lakes *n(3)*	
		Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Skin Rash	Never	11	100.0	13	86.7	3	100.0
	Sometimes			2	13.3		
	Most times						
Sore eyes	Never	11	100.0	9	60.0	3	100.0
	Sometimes			6	40.0		
	Most times						
Nausea	Never	11	100.0	15	100.0	3	100.0
	Sometimes						
	Most times						
Vomiting	Never	11	100.0	14	93.3	3	100.0
	Sometimes			1	6.7		
	Most times						
Diarrhoea	Never	11	100.0	15	100.0	3	100.0
	Sometimes						
	Most times						
Runny nose	Never	11	100.0	13	86.7	2	66.7
	Sometimes			2	13.3	1	33.3
	Most times						
Headache	Never	11	100.0	14	93.3	2	66.7
	Sometimes			1	6.7	1	33.3
	Most times						
Feeling tired	Never	11	100.0	13	86.7	2	66.7
	Sometimes			2	13.3	1	33.3
	Most times						
Temp	Never	11	100.0	15	100.0	3	100.0
	Sometimes						
	Most times						
Sore Throat	Never	10	90.9	14	93.3	3	100.0
	Sometimes	1	9.1	1	6.7		
	Most times						
Other	Never	10	90.9	14	100.0	3	100.0
	Sometimes						
	Most times	1	9.1				

3.10 Appendix H Concerns expressed by survey respondents.

Concern	Frequency	Percent %
Toilets	50	19.9
Management	47	18.7
Facilities	38	15.1
Boat Ramps	14	5.6
Access	13	5.2
Safety	12	4.8
Shade	11	4.4
Stock Fish	11	4.4
Restrict Boats	7	2.8
Camping	5	2.0
Power	4	1.6
Drinking Water	4	1.6
Bike tracks	2	0.8
Parking	2	0.8