FAECAL WASTE AND THE NATURAL ENVIRONMENT: WATER QUALITY AND EPIDEMIOLOGICAL IMPLICATIONS

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1. ABSTRACT

With the development of coastal areas, microbial water quality and its implication for the health of recreational users is an emerging public health issue. A survey was undertaken of faecal contamination levels resulting from poor agricultural and urban waste management in the Peel Harvey estuarine system in Western Australia. Indicator levels were compared to maximum values recommended by Australian and international guidelines. Exposure to contamination was estimated though social surveys so that the health risk of the recreational population could be assessed.

Pathogen levels exceeded the guideline values recommended by NHMRC and WHO at most locations all year through. The social survey provided information of exposure of the population per age group. Only 31% of the recreational users belonged to the healthy adult group upon which the QRA model is based, and the limitations of this approach are discussed. Conclusions were drawn on the implications of poor waste management practices on water recreational users' health and on the validity of the current national and international guidelines.

Keywords: Faecal contamination, Recreational water, Health risk

2. INTRODUCTION

Faecal-contaminated water may expose swimmers to a range of infectious gastrointestinal and respiratory illnesses (NHMRC, 1990; WHO, 1998), particularly if farm, animal, and sewage wastes are dumped into streams and lakes. WHO (1998) has conducted many studies on bacterial contamination of recreational bathing waters, concluding that a causal relationship does exist between gastrointestinal symptoms and recreational water quality as measured by indicator-bacteria concentration. As early as 1953, researchers were conducting epidemiological studies to assess the risk illness associated with contact recreation in surface water; those were the first in a series of attempts to demonstrate that high levels of bacteria in natural waters can cause illness among swimmers (Stevenson, 1953). Outbreaks of gastroenteritis associated with recreational water exposure are recognised with increased frequency. Recent reports confirmed that, from 1991 to 1992, 1,825 people from 21 US states became ill in outbreaks involving recreational waters (Moore et al., 1993). Since 1989, approximately 170 outbreaks associated with recreational water venues have been reported in the US with almost half resulting in gastrointestinal illness (Anonymous, 2000). Most outbreaks occurred during summer (peak swimming season), and 45% of cases were directly related to lake and river water exposure. The investigators also noted that "swimming and other recreational activities in which unintentional ingestion of water can occur are known to increase the risk of gastrointestinal illness, even in non-outbreak settings" (Moore et al., 1993). The disease-producing potential of water recreational areas is currently estimated...
according to certain bacteriological factors associated with the presence of faecal contamination, such as faecal coliform, Escherichia coli and Enterococci (Nuzzi & Burhans, 1997).

The recreational amenity of Peel Inlet and Harvey estuary is an invaluable asset, and its health and water quality are vital for the sustainable development of the region and the safety of aquatic activities. Due to its size and location, it is the most popular estuary for recreational fishing in the South West of WA. The Peel Inlet Management Authority (1994) has identified that the catchment supports a range of land uses, virtually all of which contribute to the increased input of plant nutrient and faecal material. Stock-grazing and pasture development are the most common agricultural activities, while residential development is continuing to intensify on the shores of the estuary.

Sources of faecal contamination from catchment areas include stock-holding yards, piggeries, unsewered residential areas, leaky sewers, leachate from landfill, septic systems and storage drains, particularly after rainfall events. In addition, domestic pets, birds, wildlife and recreational users themselves may be sources of faecal contamination. Useful insights into the effects of faecal pollution on human health can be obtained from Quantitative Risk Assessment (QRA). Rather than disease types being characterised, QRA attempts to predict infection or illness rates from given densities of particular pathogens, assumed rate of ingestion and appropriate dose-response models for the population exposed.

QRA data relating to the health effects and dose-response curves, developed for drinking water and food, may be applied to the assessment of health risks from recreational waters. However it is necessary to have information on the levels and the distribution of each pathogen in recreational waters and the degree of exposure of the recreational population, before one can estimate the risk to these populations. A panel convened by WHO formulated a harmonised approach to risk assessment and risk management for microbial hazards across drinking, recreational and reused waters (WHO, 2001). This involves a qualitative ranking of faecal loading in recreational-water environments, supported by direct measurement of appropriate faecal indicators.

Factors affecting contamination levels are outlined by the Great Lakes Commission (2002), Van Hess and Harding (1999) and WHO (1998) as being: low water levels, hot weather and higher temperatures, and both high winds or calm weather. Storm events can cause pathogen-rich surface run-off to be flushed into near-shore areas via streams, rivers and combined sewer overflows. Sheltered and particularly shallow areas may also be subjected to accumulation of sediments, which may be associated with high microbial loads and may be re-suspended by water users.

The Peel-Harvey estuary provides a valuable example of the need to identify possible health hazards in terms of recreational water areas, as it is shallow, connected to problematic catchments and has recreational areas frequently used by a growing population. The study estimated the level of pathogens represented by Faecal Streptococci in specific recreational areas of the estuary over several months. Assessment of exposure includes a survey of users in popular recreational areas. Correlation of the survey with the level of bacterial indicators provided an estimation of the risk posed to the population according to the WHO guidelines.
3. MATERIAL AND METHODS

3.1. Description of the site and sample collection

The Peel-Harvey estuary is a pair of linked shallow coastal lagoons of approximately 136 km², located 70 km south of Perth near the city of Mandurah (Figure 1). Hydrodynamic information about the catchment is presented by Woodcock (1992) and Kinhill Engineers (1988) and consists of various sub-catchments covering an area of 11,300 km² (200,000 ha) of which some 1,800 km² is excluded because of reservoir construction. The subcatchments are those of the Serpentine, Murray and Harvey Rivers. The mean annual flow the Murray is 305 gigalitres, the Harvey 215 gigalitres. The Peel-Harvey coastal catchment extends from Kwinana and Byford in the North to Harvey in the south. Water movement in the Peel-Harvey is caused by tidal currents, wind-driven circulation, density-induced circulation and river flow. It has strongly seasonal river inflow and limited oceanic exchange. The system, which is connected to the ocean by a narrow inlet channel at Mandurah and an artificial channel at Dawesville is a very shallow body of water, more than half the area being is less than 0.5 deep. Peel Inlet Management Authority (1996) has reported a dramatic improvement of water quality since the opening of the Dawesville channel, with reduced algal and blue-green blooms.

The Peel region covers nearly 5,500 km² and is home to a rapidly expanding population of over 69,000 people (Peel Development Commission, 1999) expected to rise to 113,500-150,000 by 2010. Current land uses have caused severe environmental deterioration of the estuary. Runoff from gardens and leachates from septic tanks and sewage treatment plants contribute nutrients and pathogens to the estuary. Stock-grazing and pasture development are the most common agricultural activities, particularly from the region east of the estuary to the Darling Scarp. This type of land use represents a significant source of faecal material, washed into the estuary after heavy rains. Some heavy industry is located toward the Darling Scarp, while various stock-holding yards, wiggeries and unsewered residential areas exist throughout the catchment (Fig. 1).

Currently, there are 548 farming establishments in the region, covering 182,112 hectares. Traditionally beef cattle and sheep have provided most income for the region, but within the shires of Murray and Serpentine/ Jarrahdale, there are now extensive piggery operations, with production representing approximately 13% of the state total (Peel Development Commission, 1999). There are 26 piggeries in the Peel-Harvey catchment, mostly in the Serpentine catchment, containing about 30,000 pigs. Effluents from washing the pens are currently drained to on-site settling ponds. Large numbers of sheep are held in paddocks prior to live export, and large quantities of waste are produced in a relatively small area, which are carried in run-off from the yards. Most yards are located near Baldivis, in the Northern Serpentine catchment. In the same catchment, high concentrations of kennels also result in the production of unknown quantities of wastes, with run-off entering the Serpentine River and the ground water. Farming, constituting 9.6% of the state total is present in the Murray, Serpentine-Jarradale and Waroona shires. There are 123 market gardens on the coastal plain catchment, mostly in the Serpentine catchment. These use heavy and frequent applications of fowl manure and chemical fertilizers. The major thrust of residential development has centered on Mandurah, and especially around the northern, northeastern and western shores of Peel Inlet, including an extensive canal development, light industrial estates as well as urban and semi-rural living. Runoff from gardens and leachates from septic tanks and sewage treatment plants contribute nutrients and pathogens to the estuary.
Most land use within the coastal catchment has remained predominantly agricultural. However the nature of the agricultural activities has altered significantly in the last 20 years, with a marked increase in intensive agriculture activity, particularly in the Serpentine River catchment.

There are a considerable data on the types and popularity of recreational activities in the Peel-Harvey (Kinhill Engineers, 1988; Chalmers and Thurlow, 1990; Campbell, 1997; West Coast Recreational Fishing working group, 2000). The major recreational pursuits, both active and passive, include fishing, crabbing, prawning, boating, sailing, swimming, water skiing, picnicking and holidaying (Chalmers and Thurlow, 1990). Summer holiday periods result in a heavy burden on recreation areas and facilities, particularly those centered close to major boat

Figure 1. Peel-Harvey Estuary system: Land uses and sampling locations
ramps. Promotion for both tourism and housing development in the region relied heavily on the image of a high quality lifestyle and abundant fish and crab stocks for recreational use.

A first survey of faecal contamination was conducted across the estuary in March 2002 (PH1-PH10 and selected locations), followed by a temporal monitoring (2002-2003) at selected locations: Dawesville Boat Ramp (BR), Mandurah Town (MT), Ocean (OC) and the mouth of the Murray-Serpentine Rivers (MS) (Figure 1). Dawesville Boat Ramp (BR), Mandurah Town (MT) are popular recreational areas.

3.2. Faecal contamination

For safe recreational water environments the indicators are numerical values for Faecal Streptococci/Enterococci related to defined levels of risk under the Annapolis Protocol (Havelaar et al., 2001). Kay et al. (1994) showed faecal streptococci to be the only indicator organism that predicted gastroenteritis among bathers. WHO (2001) now recommends FS as indicator for the quality of marine water, and faecal coliforms as an indicator for fresh-water quality.

Duplicate samples for the determination of faecal streptococci in waters were collected and analysed according to the Australian Standard Method (AS 4276.9-1995). In addition, nutrient concentrations (ammonia and nitrogen) as well as physical-chemical parameters and weather conditions were monitored.

3.3. Exposure assessment

Exposure for recreational usage of water environments is detailed by WHO (1998). Primary contact (direct contact) ranges from a direct contact where there is a negligible risk of swallowing water such as wading, to extensive direct contact with full body immersion, to an associated higher risk of swallowing water such as swimming. Children frequently appear in this latter group as they play longer in recreational waters, are more susceptible to infections than adults, and are more likely to swallow (or even intentionally drink) recreational water. The NHMRC (1990) characterises recreational primary contact as a bodily immersion or submersion where there is direct contact with the water and includes such activities as swimming, diving, water skiing and surfing. People engaged in primary contact recreation may swallow significant amounts of water either deliberately or accidentally, although they probably do not exceed 100 ml per individual per day. In this study, "one exposure" as reported as any visit to the estuary exceeding 30 minutes where the recreational user swam, paddled or/and played in the wet sand above the shoreline, these activities being considered here as primary contact. The surveys were conducted on 5 occasions during the bathing season 2002-2003 (November 2002 to March 2003) at Dawesville Channel (DC) and Mandurah Town (MT) recreational areas. On each occasion, the survey was conducted for 4 hours, with participation ranging from 75 % to 90 % of the recreational users present in the area. The interviews focused on the frequency length and period of visits, on the activities undertaken and on the age of the users. They were conducted face-to face, with the surveyor completing the questionnaire.

4. RESULTS AND DISCUSSION

4.1. Faecal contamination
Table 1 presents mean Faecal Streptococci counts from sites PH1-10, BR, MT, OC, and MS obtained in March 2002. Faecal contamination was evident at most sites. The combination of high FS and nutrients reflected agricultural land use and run-off of animal and human waste from rivers to estuary.

Table 1. Spatial Variation of faecal contamination indicators in the Peel-Harvey estuary (March 2002) Sampling sites are shown in Figure 1.

<table>
<thead>
<tr>
<th></th>
<th>PH1</th>
<th>PH2</th>
<th>PH3</th>
<th>PH4</th>
<th>PH5</th>
<th>PH6</th>
<th>PH7</th>
<th>PH8</th>
<th>PH9</th>
<th>PH10</th>
<th>M</th>
<th>S</th>
<th>M</th>
<th>T</th>
<th>BR</th>
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<tbody>
<tr>
<td>Turbidity (NTU)</td>
<td>9.8</td>
<td>8.4</td>
<td>7.5</td>
<td>7.3</td>
<td>7.3</td>
<td>9.6</td>
<td>11.3</td>
<td>10.8</td>
<td>7.8</td>
<td>10.0</td>
<td>17</td>
<td>8.6</td>
<td>15.2</td>
<td>8.3</td>
<td></td>
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</tr>
<tr>
<td>FS (CFU/100 ml)</td>
<td>76</td>
<td>136</td>
<td>12</td>
<td>35</td>
<td>82</td>
<td>12</td>
<td>91</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>75</td>
<td>58</td>
<td>48</td>
<td>79</td>
<td></td>
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</tr>
<tr>
<td>NH₄ (µg N/l)</td>
<td>17</td>
<td>19</td>
<td>18</td>
<td>7</td>
<td>11</td>
<td>21</td>
<td>9</td>
<td>10</td>
<td>26</td>
<td>29</td>
<td>13</td>
<td>23</td>
<td>22</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₂/NO₃ (µg N/l)</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>12</td>
<td>15</td>
<td>8</td>
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Figure 2 includes faecal streptococci concentrations above the Australian guidelines for most of the year. Only the water collected in the ocean had constant levels below the guideline value in winter. Increased concentrations during the bathing season in recreational areas reflect the impact of recreational users on water quality. There was also an increase during high outfall period (June). The mouth of Serpentine and Murray rivers had the highest concentrations all year around, except during June when urban run-off led to higher contaminations in Mandurah. The high concentrations in Mandurah and at the mouth of the Serpentine and Murray Rivers suggest that urban run-off and waste from agricultural activities were the main source of faecal contamination in the estuary.

4.2. Exposure

Out of a total of 340 people interviewed during the bathing season (January-February 2003), 76% identified swimming to be one of their recreational activities, followed by playing in wet sand (74%), fishing (51%), crabbing (48%), relaxing and having a picnic/BBQ (42%), and boating (27%). Most interviewees participated in several activities during their visit to the estuary. Figure 2 associates the number of exposures with a percentage of users claiming primary contact activity according to age. Twenty three percent of the users have only 1 or 2 exposures per bathing season. Forty nine percent have primary contact 3 to 8 times per bathing season. Sixteen percent claimed 20 to 40 exposures within the same period, while 12% accumulated more than 40 exposures. Children (age 15 and under) made up 58% of the primary contact water users. Users aged 16 to 45, considered here as "healthy adults", contributed only 31% of the primary contact users. Adults aged 46 and over were in minority (11%).
Recreational waters generally contain a mixture of pathogenic and non-pathogenic microbes. The Great Lakes Commission (2002) and WHO (1998) have extensively researched the sources of microbial contamination. These microbes may be derived from sewage effluents, the recreational population using the water, livestock (cattle, sheep), industrial processes, combined or sanitary sewer overflows, unsewered residential and commercial areas, farming activities and wildlife in addition to indigenous microorganisms (WHO, 1998). Other sources may be agricultural runoff (such as manure); faecal contamination from animal/pet waste washed from soil by heavy rains, wildlife waste, as from large population of gulls, and direct discharge for example from holding tanks. Carpenter et al. (1999) added that routine use of recreational venues by diapered-children also increased the potential for water-borne disease transmission.
This study indicates that contamination of the water is strongly related to land uses around the estuary. Contamination of the water is also consistent with the recreational use of water during the bathing season. Crabbing is very popular in the shallow waters of Harvey Estuary and has an impact on water quality as displayed by the contamination of Boat Ramp and other sites (PH1-6) along the western edge of the Harvey estuary. Agricultural activities on the floodplain towards the darling scarp have a definitive impact with very high levels of bacteria at the mouth of the Serpentine and Murray rivers and near the mouth of the Harvey River. Contamination at Mandurah town is related to the popular recreational use of the foreshore, which attracts primary contact water users as well as large numbers of birds to the foreshore and water.

Guidelines operate from the premise that pathogens do occur in the environment, and that there is a susceptible population (Payement and Hunter, 2001). Ideally, a scientifically-supported guideline value is defined to provide a required level of public health protection, measured either in terms of "acceptable" disease burden and/or some percentage attack rate of illness in the population which, again, is felt to be acceptable. The Environmental Protection Authority (1993) has outlined guidelines for water quality in recreational waters based on those developed by the NHMRC: Median bacterial content in fresh and marine waters taken over the bathing season should not exceed 150 faecal coliform organisms per 100 ml; 35 Enterococci organisms per 100 ml; and pathogenic free-living protozoans should be absent from bodies of fresh water. The World Health Organisation (WHO, 2001) has developed a series of normative guidelines that present an authoritative assessment of the health risks associated with exposure to health hazards through water and of the effectiveness of approaches to their control. Regulations are set at a level of...
exposure at which no adverse health effects are expected to occur. Fewtrell and Bartram (2001) highlight that guidelines essentially are health risk assessments and are based upon scientific consensus, best available evidence and broad expert participation. The guidelines advocate that a risk-benefit approach, whether quantitative or qualitative, be taken to the control of public health hazards associated with water.

According to the WHO guidelines (2001), recreational users swimming at any of the selected locations during the bathing season have an unacceptable risk of contracting a GI illness (1 % to more than 10 % according to the location) each time they swim (Figure 2). However this approach using QRA model for estimating the risk of GI illnesses is limited because i) data on the concentrations and distribution of pathogens in recreational waters are limited, so estimation of exposure to these organisms is difficult; ii) there is no adequate dose-response data for most of the pathogens present in recreational waters.

QRA provides estimates based on assumptions and extrapolations from existing data. It does not represent actual estimated incidence of disease and therefore each estimate needs to be taken in the context of the uncertainties upon which it is based. Issues such as the nature of populations used in dose-response studies, the rarity of pathogens with dose-response data, and the technical difficulties associated with the detection of pathogens in recreational waters, need to be carefully considered when interpreting QRA data.

The dose-response curves used in QRA have been generated using healthy adult volunteers without existing diseases. In this study only 31 % of the recreational water users (primary contact) belonged to that category. Moreover, a considerable proportion of the community has some degree of underlying immunosuppression, or chronic medical conditions that may make them more susceptible to infection or to its serious consequences. Levels of immunity are also important. For example, for one strain of Cryptosporidium parvum tested in previously infected individuals, the ID50 for those with existing immunity to Cryptosporidium was 20 fold higher than those with no serological evidence of immunity (Hamlyn-Harris, 2001). A large number of pathogens have been detected in organic waste but only about a dozen of these have dose-response data suitable for QRA. It is difficult to extrapolate to the remaining organisms when these crucial data are missing. Finally, an essential part of the exposure calculation in any risk assessment is an accurate understanding of the type, concentration and distribution of pathogens in waste and recreational waters. This information is critical to estimating the human health risk at different concentrations.

The WHO guidelines only predict the occurrence of GI illnesses as no reliable data can be found to link the occurrence of respiratory illnesses to the exposure of recreational waters. An epidemiology study conducted by Simmonds (1999) showed that exposure to composted biosolids resulted in an increase in respiratory illnesses. Recreational users exposed to high levels of faecal contamination in the water are therefore expected to have higher risk of contracting respiratory infections resulting from inhalation/ingestion of contaminated water.

For these reasons, epidemiological studies, particularly observational studies, have been preferred to risk assessment, as they take into account the burden of disease associated with exposure to an infection agent as well as social data characterising the immune status of the population. However to compare the outcomes from both approaches, it is necessary to adjust the probability of infection to reflect the probability of disease. Lopez et al. (1980) demonstrated that 76 % of Giardia infections were asymptomatic. The epidemiological
approach would therefore not detect any increased rate of GI, which would be predicted in the quantitative risk assessment (Simmonds, 1999).

5. CONCLUSIONS

This study integrating behavioural surveys of recreationists with water monitoring provided data amenable to determining/applying QRA models. It also demonstrated clearly the need for improved waste management practices in the water catchments of the Peel-Harvey estuary, or alternatively closure of parts of the Estuary to recreational use (based on immersion) at certain times of year. Faecal contamination in surface waters exceeded national and international guideline values for safe recreational water use. However, quantitative risk assessment models could not be applied to this system, as only 31% of recreational users belonged to the category of users upon which the QRA models are based. An epidemiological approach would be necessary to link pathogen levels to the burden of disease in that particular population of users, as children are likely to be more vulnerable to illnesses.

For management of the contamination, the source of the faecal contamination could be ascertained by genotyping protozoans present in the water and in the sediments. This would determine whether the source of contamination is from humans either directly wading and swimming in the water, or indirectly through stirring up sediment containing contaminants, from birds depositing faecal material, or from run-off of animal or human waste from the watershed.

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