IMPACTS OF SEWAGE OVERFLOWS ON AN URBAN CREEK

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Abstract
The Coastal CRC has been working with Brisbane City Council to determine the impacts of sewage overflows and risks to public and ecosystem health in a pilot study of the tidal waterways of the coastal suburb of Lota. The research shows in a large wet weather event, stormwater and not the overflow was the dominant stressor of ecological health. Even in a dry weather overflow event impacts were low and restricted to the mixing zone at the point of overflow. However, sewage overflows, both in dry and wet weather, did pose an unacceptably high public health hazard to possible swimmers in Lota Creek until the overflow stopped and there was a complete tidal exchange with the estuary. Despite being an intensive study of a single wet weather event there is sufficient data for it to be translated to similar tidal environments, and has provided a sound scientific basis for quantifying overflow impacts and prioritising management of overflows and stormwater.

Background
Sewerage systems in Australia are designed with overflow structures that discharge into local waterways when the capacity of the system is exceeded. A dry weather overflow occurs when there is a system breakdown due to blockages or a pump failure. Wet weather overflows are mainly caused by the infiltration of water into the sewerage system during heavy rainfall to a point where the hydraulic capacity of the system is exceeded. Half of the sewer pipes in Brisbane are on private property and water enters the sewer through the illegal connection of roof and stormwater drains (inflows). Brisbane City Council (BCC) manages the main network where water also enters through poorly sealed access chambers, cracked pipes and defective joints (infiltration).

The public generally is unaware of overflows, their purpose or function nor the extent of the urban catchment run-off. However, they are acutely aware of the gross pollutants associated with them. The appearance of sewage and litter in our rivers during heavy rain can stir the emotions of even the most placid of Brisbane City dwellers, as on the aesthetics of the receiving waters is obvious. However, nutrients, pathogens, organic toxicants and metals also enter the waterway during an overflow event. The aim of this research was to quantify the ecological and public health impacts and potential risks of sewage overflows in the Lota Creek catchment area (including Bowering Street tributary).

Stormwater and not the overflow was the dominant stressor of ecological health, but any overflow posed an unacceptably high public health hazard to possible swimmers.

Study Approach
The study was conducted in the lower Lota catchment waterways. There are seven overflow structures in the study area (Planning Unit LT/010)(Figure 1).

Overflow monitors were installed in all overflow structures with alerts at SP 20 and OF 717 as described by Millar et al. (2002). Samples were collected manually from seven sites and by autosamplers from two sites in four situations:

1. Ambient dry weather event: No rain or overflow in the study area. Samples taken at high and low tide.

2. Dry weather with overflow event: Equipment failure as the only cause of overflow.

3. Wet weather with overflow event: Water infiltration of sewerage network was the only cause of overflow.
### Table 1. Research* summary.

<table>
<thead>
<tr>
<th>Concern</th>
<th>Ambient Dry Weather No Overflow</th>
<th>Stormwater Run-off No Overflow</th>
<th>Wet Weather with Overflow</th>
<th>Dry Weather with Overflow</th>
</tr>
</thead>
</table>
| **Public Health**  
Risk to public health from human enteric bacteria and viruses | None | Faecal coliforms high but low risk from human faecal contamination | Unsafe for recreation during overflow, even though 80% of the faecal coliform count was due to stormwater run-off and was not of human origin | Extremely high as no stormwater or in-pipe dilution |
| **Loss of amenity for recreational activities** | None | Faecal coliforms high but low risk from human faecal contamination | High during overflow | Extremely high |
| **Ecosystem Health**  
Impacts of increased turbidity, nutrients: nitrogen, phosphorus and dissolved organic carbon and to the water column | None | Unacceptably High | Low and restricted to point of release, stormwater run-off was the main contributor | Low and confined to BST close to point of release |
| Reduced oxygen concentrations in the water column | Low in some locations | Low in some locations | Not reduced: physical re-aeration rates of the water column were greater than microbial respiration rates | Little reduction: physical re-aeration rates of the water column were greater than microbial respiration rates |
| **Toxins**  
Adding hormones disruptors to the water column | Not measured | Inconclusive (below detection limit) | Below detection limit however based on hydrological dilution may have impact in BST | Based on hydrological dilution may have impact |
| Adding metals to the water column | None | Not measured | Below trigger values for aquatic ecosystem health | Low and localised, dilution puts all below trigger values outside BST |
| Likely cumulative effects | None | Low based on dry weather re-suspension of sediments | Low based on dry weather re-suspension of sediments | Low based on dry weather re-suspension of sediments |

*Stormwater impacts were only related to contaminants found in the untreated sewage overflow.

BST = Bowering Street tributary
Enteric = of the intestine
Faecal coliform = Thermotolerant coliform

4. Wet weather not influenced by overflow events: Stormwater not influenced by overflow effluent during a rain event normally large enough to cause a wet weather overflow.

We characterised the pollutants in the sewage of Lota to determine its physical, chemical, toxicological and microbiological character (Pollard and Chapman, 2002). The analytes included: organic and inorganic nutrients, sterol biomarkers, microbial faecal indicators, pathogens indicators (bacteria, viruses, protozoa), toxicants, 69 metals, exotic chemicals, radioisotopes and endocrine disrupters. Although the project was not a study of the stormwater impacts, we looked for the pollutants common to both to distinguish the impacts of the overflow during the wet-weather event.

The next stage of the project determined the ambient (normal) water-quality of Lota's waterways in relation to the pollutants found in the untreated sewage. This was the most cost-effective approach.

CSIRO Mathematics and Information Service designed a sampling strategy based on the ‘Weight of evidence’ for dry and wet-weather sampling (Harch and Toscas, 2002). As wet-weather events were infrequent (one in two years), repetitive event sampling was not possible. The seven overflow structures were monitored for two years. Of these, six had no impact on the local waterway because they did not overflow.

Pathogen indicator analysis is expensive. We found the most cost-effective approach was to test samples for faecal coliform contamination during the event at all locations and times. Faecal coliform (thermotolerant coliform) tests were completed within 10 h to identify areas of greatest contamination. The more expensive and time-consuming analyses, such as human sterols, enterococci, *Clostridium* and coliphage were then used as confirmation tests for the presence of human faecal contamination.

Knowing the ambient water-quality of the receiving waterway, we were able to compare changes caused by the overflow events. Human faecal contamination in the waterway was used to assess the public health hazard and potential risk assessment based on pathogenic indicators and human sterol biomarkers. Quantitative risk assessment (QRA) was then based on the WHO (2003) microbial water-quality guidelines. The enterococci abundance was then used in the risk assessment model to determine potential human public health risks.

Risk assessment requires knowledge of the extent of human exposure, such as in swimming. While we observed children swimming and canoeing in the study area, a quantitative assessment of the use (exposure to hazard) of the waterway was beyond the scope of this study.

Two different systems were used for assessing public and ecosystem health impacts. The dose-response research for
QRA is well advanced compared to that of ecosystem health assessment. Hence the public health hazard is well quantified and based on key pathogen surrogates. Consequently, we compared changes to ambient physical and chemical conditions caused by the overflow and pollutants exceeding trigger values recommended by ANZECC (2000) and BCC water-quality guidelines and objectives for aquatic ecosystem protection. This study took into account dry- and wet-weather overflows focusing on the potential impacts and hazards. Table 1 summarises the concerns and observations from the research.

**Tidal Prism**

The tidal prism was 2.6 ML (neap tide) 5.6 (spring tides) for the Bowering Street tributary. Details of the hydrological tidal influence are described by Hargraves (2002), as part of the urban rainfall run-off model task of the project.

**Overflow Events**

The cause of the dry overflow was equipment failure on 4 June 2002. Sewage entered the Bowering Street tributary (BST) at a rate of approximately 65 m$^3$h$^{-1}$ for 5 h (0.33 ML). The overflow coincided with the falling tide in the receiving waters of BST. The sewage was diluted 1:6 with the tributary water at the overflow site. The first obvious sign of untreated sewage was toilet paper caught in the vegetation on the waterway, an obvious loss of the visual amenity (Figure 2).

The wet weather overflow occurred on 15 May 2003 because of a rainfall event of 60 mm over 12 h. Untreated sewage (1.1 ML) overflowed into the BST and Lota Creek for 36 h where it mixed with 53 ML of stormwater run-off. A 'mixing zone' immediately in front of the overflow structure was difficult to define because of tidal movement. This study showed the plume of untreated sewage did not readily disperse in the receiving environment. The sewage had been diluted by inflow and infiltration 1:5 in the sewer at the start of the overflow and this increased to 1:6. The dilution rate of the untreated sewage varied as it entered the BST from 1% to 5.5% (v/v) on 15 May 2003. Stormwater was the predominant dilution factor as the tide contributed only 10% (v/v) of the dilution.

**Public Health Risks**

**Microbial Water Quality Assessment**

Details of the microbial water quality results can be found in the reports by Pollard and Leeming, 2002; 2003; Pollard et al., 2004. Generally, during both the dry and wet weather overflow event the faecal indicators (faecal coliform, E. coli, *Clostridium*, enterococci and coliphage) increased several orders of magnitude above public health guidelines for primary contact (swimming). Based on measurements of the human sterol biomarker all of the faecal contamination was of human origin during the dry-weather overflow event (Figure 3). During the wet weather event, stormwater contributed 80% of these indicators; only 20% being of human origin (Figure 4a, b and c). However, the unacceptably high public health hazard remained during the wet weather overflow despite the dilution due to the rain.

The dry and wet weather overflows produced a sewage plume that did not readily mix with seawater. The risk to public health was of greatest concern following the initial overflow. For areas affected the unacceptably high risk to potential swimmers and loss of the recreation amenity persisted until the overflow stopped and there were one to two complete tidal exchanges. The plume contaminants were exported beyond the limits of Lota Creek Study area into Moreton Bay (Fig and 4).

Water quality guidelines are often based on pathogen indicators that cannot separate human faecal contamination from other warm-blooded animals. Hence stormwater run-off often causes waterways and coastlines to exceed these standards (Nobel et al., 2003) and in tropical waters may result from growth and erosion of faecal coliforms (thermotolerant coliforms) and enterococci in soils (Fujitaka et al., 1999).

We found that much of these breaches may not be due to human faecal matter based on human sterol analysis. During a wet weather sewage overflow a lesser public health hazard remains from potential bacterial, viral and parasitic protozoa pathogens compared to a dry weather event.

**Quantitative Microbical Risk Assessment (QMRA)**

QMRA is a means of identifying a potential public health risk. For Lota Creek the risks are to recreational swimmers and people eating shellfish (although harvesting is not known in the study area). QMRA identifies the groups most at risk and defines the pathways. The selected reference pathogens suggested for the Lota Creek study showed viral risks were highest, as previously seen for Sydney’s coastal beaches (Ashbolt et al. 1997). To provide a 'second opinion' on the risk estimates, an estimate of potential disease was obtained by assuming that only 20% of the enterococci in the bathing waters came directly from sewage (the primary material expected to contain infectious human enteric viruses during a wet weather event). This was based on the human sterol work that showed most of the pathogens indicators were not of human origin. This gave expected risks in the range of 10% to 100% indicating the waterway was unsuitable for recreation for at least the duration of the overflow (36 h) with a further 24 h before the waterway returned to background levels of contamination. For the dry weather event this unacceptably high risk would have persisted for, during and 12 h after the overflow had stopped.

Both approaches suggest that the risks to bathers during overflow events both during high rainfall and in dry weather should be considered unacceptably high.
Table 2. Five key microbial water quality parameters for future monitoring programs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Essential</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Faecal coliform/E. coli</em></td>
<td>Yes</td>
<td>Most practical and cost-effective way to track plume. Used to identify 'hot spots' which can be followed up by confirmation test of parameters below.</td>
</tr>
<tr>
<td>Enterococci</td>
<td>Yes/No</td>
<td>Basis of WHO (2003) guidelines and QMRA</td>
</tr>
<tr>
<td>Clophage</td>
<td>Yes/No</td>
<td>Used to model the highest risk category - viral pathogen survival and likely to be in future guidelines.</td>
</tr>
<tr>
<td>Human sterols (Biomarkers)</td>
<td>Yes/No</td>
<td>Essential in wet weather to determine human proportion of sewage mixed with stormwater run-off.</td>
</tr>
<tr>
<td>Clostridium</td>
<td>No</td>
<td>Useful as more robust indicator of faecal pollution over long periods.</td>
</tr>
</tbody>
</table>

*Same as Thermotolerant coliforms
1. Ashbol et al., 2001

an early management action, signs should be erected to warn swimmers of risks during overflow periods.

The areas most affected are the Bowering Street tributary, lower branches of Lota Creek and into Moreton Bay (depending on the direction of the sewage plume). How far the plume extended and persisted as a potential hazard in Moreton Bay and the bathing area at Wynnum and Manly was beyond the scope of this study, but warrants investigation (Figures 3 and 4).

Ecological Health

Details of the abiotic water quality can be found in Pollard and Leeming, 2002; 2003; Pollard et al., 2004. Figure 5 shows a conceptual model of the ecological processes in Lota Creek. During the wet weather overflow event, inorganic (e.g. nitrogen and phosphorus) and organic nutrients and suspended solids in the overflow effluent were rapidly diluted in the sewer network and the waterway. Concentrations were either below those associated with a healthy aquatic ecosystem and/or below those of the stormwater concentrations. Possible adverse impacts of chemical and physical stress on ecosystem health were due primarily to stormwater run-off and not the overflow.

Dissolved oxygen (DO) concentrations in the water column are often the basis of judging ecosystem health. As DO is ultimately governed by the growth rates of heterotrophic bacteria, we were interested in their abundance and growth. Lota Creek and the Bowering Street tributary had high numbers of bacteria and viruses with the bacteria growing extremely rapidly compared to ambient (normal) conditions.

In wet and dry weather overflows increased heterotrophic bacterial growth rates in the waterways were above ambient concentrations. This growth parameter was the first to demonstrate the influence of the overflow effluent on biological processes in the waterway. Despite this, there was no deterioration in the water column’s dissolved oxygen due to the overflow event. The rate of physical re-aeration of the water column was mostly greater than the rate at which the bacteria used the DO.

During the dry-weather overflow nitrogen and phosphorus, in the Bowering Street tributary below the overflow, were at concentrations 10 fold higher than the water quality objectives of BCC. However, once these nutrients reached Lota Creek, they were diluted by more than a factor of 100 and approached the ambient water quality concentrations and objective of BCC for Lota Creek and the ANZECC (2000) guidelines. Overall, the water quality changes were confined to the period of the overflow within 500 m of the overflow structure with little changes to the dissolved oxygen concentrations due to the overflow itself.

The Lota Creek and Bowering Street tributary results suggest that the ecological health of other tidally exchanged creeks can be determined in part by measuring the rate of the physical re-aeration of the water column and the rate of sewage dilution. These need to be in conjunction with a knowledge of the nutrient-loading rate in the waterway that could potentially drive the heterotrophic bacterial growth rates in the sewage to extremes.

Some metals (aluminium, copper and zinc) were of concern in the sewage before dilution. However, the combined in-pipe and stormwater dilution left them below ANZEC trigger values in wet-weather. Estrogenic hormones were found in the undiluted sewage and were monitored in the waterways of this study. However, they were below the detection limit of the assay i.e. 5 ng L⁻¹. The dilution of the estrogen in the untreated sewage suggested the concentrations could have ranged from 0.1 to 2 ng L⁻¹ in Bowering Street tributary in the wet and <5 ng L⁻¹ in the dry weather overflow event. In these ranges estrogenic hormones may be biologically active in aquatic environments (Anderson et al., 2004).

In Sydney and Perth research on the impacts of sewage overflows (Sydney Water, 1998; Water Corporation Perth (2003) citing DA Lord (1997)) showed the loss of recreation amenity outweighed the potential risk to ecological health, just as we found in this Lota study. Others have also separated health impacts and risks from those of the stormwater to find also that the risks to ecological health were often the result of stormwater rather than sewage overflows (Bickford et al., 1999).

![Figure 3. Faecal coliform (cfu. 100mL⁻¹) at the time of peak sewage overflow during the dry weather event 4 June 2002. The public health risk remained unacceptably high during and 12 h after the overflow had stopped. The movement of the sewage plume into Moreton Bay needs investigating. (MAP)](image-url)
Implications for Other Tidal Estuaries

We found that the important factors to consider for determining ecological health in other tidally exchanged creeks are the rate of the physical re-aeration of the water column, the hydrological in-pipe and stormwater dilution in conjunction with the nutrient-loading rate. A waterway 'Index' could be developed to compare hydrological characteristics and water column re-aeration rates of Lota Creek to other tidally influenced creeks in Brisbane. This would allow extrapolation of Lota Creek findings to other waterway contaminants and provide insight to potential management options and help prioritise creeks for overflow abatement.

Future Direction and Conclusions

The greatest gap in our knowledge of the waterways in the study was of the extent of human exposure to the public health hazard. This information is essential for the final risk-assessment and should form the basis of a larger risk management framework. With this information, the knowledge gained here of the hydrological dilution of the untreated sewage can be used to predict the public and ecosystem health risks of other similar tidally influenced coastal environments in Brisbane. From this study we learnt the most cost-effective and practical way to monitor the sewage overflow plume was to follow its movement in time and space, while assessing the public health hazard based on WHO (2003) Microbiological Water Quality Guidelines. Table 2 lists five key parameters, not all are essential in future monitoring programs.

If the community wants to increase recreational amenity in Lota Creek, future research could focus on developing methods that optimise rapid pathogen removal at the overflow structure. (Long-term management could consider methods to reduce the use of water and pipe networks to carry domestic waste to large wastewater treatment plants). However, while the sewer pipe networks exist, emergency sewage overflows will remain part of the sewerage system. They are an emotive issue for the public but the concern needs to be well founded and properly directed. This study has shown that stormwater should be of much greater concern for ecosystem health, while the overflow is responsible for the public health hazard and loss of recreation amenity. Environmental concern for waterway pollution should shift from sewage to stormwater for, as we have shown, stormwater is the chief source of environmental pollution during wet-weather overflows.

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References


Figure 4. During the wet weather overflow the potential public health risks were unacceptable even though most (80%) of the faecal coliform count was associated with the stormwater runoff and was not from human origins. The distribution of faecal coliforms (CFU/100mL) during the overflow on 15 May 2003; morning (A), late afternoon (B) and on 16 May 2003 in the evening (C) is shown. The sewage plume moved into Moreton Bay and these impacts need investigating.


