Source Tracking Framework and Toolkit

How to find faecal pollution sources at beaches and in stormwater systems

March 2020

A. Weller-Wong, I. Visby

Derwent Estuary Program

The Derwent Estuary Program (DEP) is a regional not-for-profit partnership between local governments, the Tasmanian State Government, businesses, scientists, and community-based groups to restore and promote our estuary. The DEP was established in 1999 and has been nationally recognised for excellence in coordinating initiatives to reduce water pollution, conserve habitats and species, monitor river health and promote greater use and enjoyment of the foreshore. Our major sponsors include: Brighton, Clarence, Derwent Valley, Glenorchy, Hobart and Kingborough councils, the Tasmanian State Government, TasWater, Tasmanian Ports Corporation, Norske Skog Boyer, Nyrstar Hobart Smelter and Hydro Tasmania.

Table of contents

DOCUMENT VERSION CONTROL

Version	Date	Author	Reviewed by
1.0	4/3/2020	A. Weller-Wong	I. Visby

1 Introduction

The Derwent Estuary Program (DEP) coordinates the Derwent Estuary Recreational Water Quality Program (RWQ), a joint initiative between six local councils, Public Health Services, Department of Health (DoH), Environment Protection Authority (EPA) and the Derwent Estuary Program (DEP).

Monitoring of recognised swimming sites, including sampling, conducting sanitary surveys and advising the public of risks to public health are requirements of the *Recreational Water Quality Guidelines 2007* (the Guidelines), issued in accordance with the *Public Health Act 1997* (the Act).

The primary objectives of the RWQ program are to:

- coordinate weekly summer monitoring of swimming beaches and bays,
- communicate potential health risks to the public (via the DEP website and Facebook page), and
- encourage local stormwater investigations that identify and rectify sudden and/or persistent faecal contamination sources, as well as at Poor and Fair rated beaches.

Collaborative investigations between the DEP, local councils and TasWater have been successful in tracking and rectifying a number of sewer to stormwater intrusions (sewage intrusions) in urban catchments in the Derwent estuary. A shining example is Nutgrove Beach (west), where additional end-of-pipe and targeted street sampling, tracking for anthropogenic tracers, hydraulic sewer modelling / pipe pressurisation, dye testing and CCTV investigations successfully identified multiple sewer to stormwater intrusions. This work resulted in the Nutgrove Beach (west) improving its rating from Poor to Fair, after many years of poor water quality.

During the 2018-19 RWQ season, a decline in water quality at some swimming beaches within the Derwent estuary drew significant public attention. At the end of season RWQ meeting it was identified that there were significant gaps in the collective understanding of faecal source tracking regarding:

- planning and implementing strategic investigations,
- the ability to differentiate between human and animal sources of faecal contamination, and
- knowledge and accessibility to new and emerging source tracking methods and techniques.

The purpose of this document is to provide a framework and accompanying toolkit that can be used to locate and potentially identify sources of faecal contamination in urban catchments in the wider Derwent estuary region. The framework and toolkit will assist councils in identifying methods that can be used to conduct targeted investigations, with the aim of detecting and rectifying the source of contamination in drainage sub-catchments. This document identifies methods currently available to Environmental Health Officers (EHOs) and Stormwater Officers in the Derwent region, as well as emerging technologies and methods.

The EPA guideline *Tracing Faecal Contamination in Urban Drains – Toolkit* produced (EPA Victoria, 2007), has provided inspiration in the development of both the framework and toolkit.

2 Structure

This document is presented in two distinct sections: the Source Tracking Framework and the Toolkit. The Framework outlines a standard process for identifying sources of faecal pollution in the Derwent estuary (at the beach) and in its sub-catchments (in the stormwater network). This process will assist councils to develop and implement strategic and targeted investigations in response to poor water quality at swimming beaches. The Framework has been designed with the identification of both animal and human sources in mind, however the focus is on identification of human sources of contamination in stormwater systems. This Framework has been developed to link in with the Derwent estuary RWQ program, however it is applicable to all urbanised catchments. The Framework is visually represented in a decision tree – ‘Source tracking investigation framework’ (Figure 3.1). The steps outlined in Figure 3.1 are described in detailed text in the Framework section of this document (Section 3).

The Toolkit details a range of tools and methods that can be employed in source tracking investigations (Source Tracking Toolkit). The purpose is to identify available tools and review emerging methods and assess if they could be applied to the Derwent estuary. A prescriptive approach is unlikely to be successful, and it is recommended that tools are used in combination. An assessment of the applicability of each tool is provided, and each tool should be employed on a case-by-case basis.

The Framework and Toolkit may assist achieving the DEP’s ambitious goal of ‘all swimming beaches being rated Good by 2024’.

3 Framework

The recommended approach for identifying and rectifying faecal contamination sources is broken in to three phases (Figure 3.1):

- **Screening phase**: identification of problem beaches, sub-catchments or stormwater branches
- **Tracing phase**: identification of contamination hotspots/source
- **Remediation phase**: Rectification of identified issues

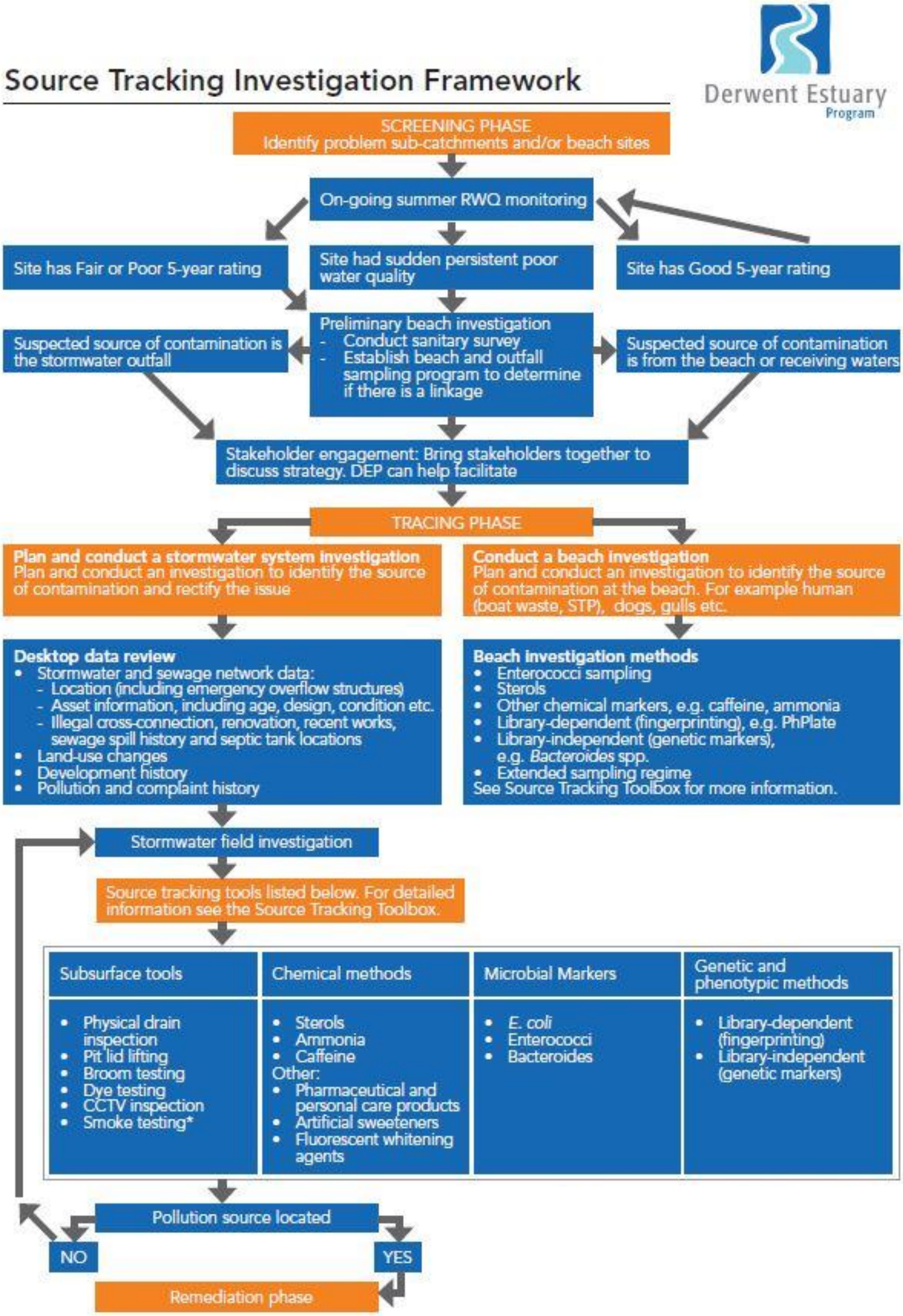

Figure 3.1 Framework for faecal source tracking

3.1 Screening phase: identification of problem beaches, sub-catchments and stormwater branches

The Screening phase involves a long-term or on-going monitoring program. The aim of the screening phase is to identify potential in-situ contamination sources (e.g. dog faeces on beach), and/or stormwater drainage branches that are contributing faecal pollution to a sub-catchment or water body. Data collected in the Screening phase should be used to prioritise follow-up investigations (Tracing phase).

3.1.1 RWQ as a screening tool

The RWQ program has been running for 20 years and currently involves the collection of water samples at 39 sites across the Derwent estuary each summer (December-March). Eighteen sites are classified as 'swimming sites' and 21 sites are classified as 'environmental sites.' The 'swimming sites' are locations that are used regularly by a relatively large number of people for primary contact activities (i.e. swimming). 'Environmental sites' are locations monitored as reference sites, and in some cases to monitor water quality at the mouth of significant rivulets.

All sites are given a five-year long-term rating, calculated using the 95th Hazen percentile. The three rating tiers are:

- *Good:* rolling 5-year 95th Hazen percentile value of < 200 enterococci MPN (Most Probable Number) per 100 mL.
- *Fair:* rolling 5-year 95th Hazen percentile value of 200 - 500 enterococci MPN per 100 mL.
- *Poor:* rolling 5-year 95th Hazen percentile value of > 500 enterococci MPN per 100 mL. In this case, water at these sites is considered to be a threat to public health in the event of primary contact, and the particular local council is required to advise the general public by erecting warning signs to this effect.

The RWQ program acts as a screening tool for changes in water quality at sampling sites in the Derwent estuary. A decline in long-term ratings at a site likely signals a persistent faecal contamination issue. Possible sources of contamination include polluted stormwater discharged to the beach, sewer/stormwater cross contamination, or more localised sources such as dogs, seagulls, boat waste, or sewage treatment plant discharges.

3.1.2 Investigation triggers – Derwent estuary

Poor water quality at major swimming beaches poses a risk to public health. During water-based activities, contaminated water may come into contact with ears, eyes, nasal passages, mucous membranes and cuts in the skin. This can allow disease-causing organisms to enter the body that can cause gastroenteritis, eye, skin and/or respiratory infection. The risks are higher for the young, immuno-compromised and elderly (NHMRC, 2008).

Councils are encouraged to prioritise resources to rectify issues in stormwater branches discharging at major swimming beaches. The DEP recommends that sites, particularly 'swimming sites', with a Poor or Fair rating should be prioritised for immediate follow-up investigations (Tracing phase). Follow-up investigations may also be warranted if a site is experiencing sudden, persistent poor water quality results.

3.1.3 Sampling design and investigation triggers for non - RWQ monitoring

In localities that do not have established long-term monitoring programs, councils should establish a baseline monitoring program to identify problem catchments. Sites should be selected to identify the most significant faecal inputs to the main waterbody (i.e. stormwater outfalls), or to include sites that are highly visited by the public, and thereby targeted to limit impacts on human health. Samples should also be collected from the main waterbody to allow comparison of inflowing stormwater quality with river water quality.

Sites should be sampled during dry weather conditions following two event types – dry-catchment dry weather (no rain in preceding three days) and wetted-catchment dry-weather (5-20 mm. in previous 24 hours). Sampling times in dry-catchment dry weather conditions should match peak sewer flow times (9-10 am) as the target is illegal cross-connections or other polluting events. Wetted-catchment dry-weather sampling requires appropriate flow so that sewer exfiltration from broken or damaged infrastructure can be observed, but not so much rain that the sewerage system is at capacity and spills via emergency relief structures (EPA Victoria, 2007).

Sites should be sampled at least twice for each event type. Samples should be tested for *E. coli* and enterococci, and collected, stored and analysed as described in section 12 of DEP Stormwater Monitoring 2010/2011: Program Protocols and Sampling Strategy (Chrispijn and Agius, 2011).

Trigger levels provide guidance on when and if an investigation should move from the Screening to the Tracing phase. Trigger levels suggested by the EPA Victoria in *Tracing Faecal Contamination in Urban Drains – Toolkit* (EPA Victoria, 2007) are any one of the following:

- stormwater drain or outfall has a measurable flow with an *E. coli* level > 5000 MPN/100mL.
- stormwater drain or outfall has a measurable flow with an enterococci level > 2500 MPN/100mL.
- stormwater drain or outfall has a measurable flow with an ammonia level > 1 mg/L.

Note that these values are specific to the Victorian context, however, may offer an indicative value.

In *A short work-flow to effectively source faecal pollution in recreational waters – A case study,* Tillett et al. (2018) describe a novel approach to categorising catchments and identifying pollution hotspots, utilising ammonia-passive samplers, *E.coli* samples and *Bacteroides* spp. assays.

Once a beach is categorised as Fair or Poor, or, results of weekly sampling have exceeded the trigger levels, follow-up investigations should be prioritised on the basis of:

- Potential impact on human and environmental health.
- Pollutant loads.
- Duration of the discharge (intermittent or continuous).

3.1.4 Preliminary beach investigation

To determine if the contamination source is indeed from stormwater discharge or isolated to the beach, the following should be conducted:

- Sanitary survey.
- Commence monitoring the closest stormwater outfall and the beach at the same time.

As outlined in the Tasmanian Recreational Water Quality Guidelines (Dept of Health & Human Services, 2007), *'sanitary inspections .. [are] to be conducted by the controlling authority whenever a threat to public health is suspected*'. The DEP recommends that sanitary surveys are undertaken at the beginning of each RWQ season, particularly if a site is graded as Fair or Poor. Sanitary surveys should also be conducted if sudden and/or persistent poor water quality results commence. Sanitary surveys help to narrow down the possible sources of contamination, which can include stormwater, birds, dogs, boat-waste, failing sewage pump stations and sewage treatment plants (STPs). For a sanitary survey template, see Appendix 1—Sanitary inspection checklist for natural recreational water bodies 1. For further information, contact the DEP.

In the case that a site is rated Poor or Fair, or sudden and persistent poor water quality results commence, the DEP encourages councils to take additional end-of-pipe samples at the closest stormwater outfall/s, simultaneously with beach sampling. Collecting outfall data will help to characterise 'background' contamination loads versus peaks in outfall contamination and identify if peaks/spikes in outfall concentrations are correlated with poor beach results. Sampling procedures and potential 'trigger values' are referenced in section 3.1.3.

Kingborough Council (KC) have employed this approach at Blackmans Bay, initiating an extensive marine and stormwater outfall sampling regime. The data has been used to inform ongoing stormwater and beach investigations. For more information, see the Blackmans Bay Recreational Water Quality Review (Coughanowr, 2019).

Such an investigation should be designed to inform your Tracing phase investigation and help identify whether resources should be invested at the beach, in the stormwater drainage system, or both.

3.1.5 Stakeholder engagement

If a water quality issue is detected during the preliminary investigation, the next step is to determine if a stakeholder meeting is required, and if so, which stakeholders should be engaged. Stakeholder engagement will differ on a case-by-case basis, however, it is encouraged that engagement should occur at the early stages of an investigation to ensure that relevant parties are involved and/or informed during the initial decision-making process.

If the issue has a broad impact (e.g. public health warnings/advisories against swimming are issued at a prominent swimming beach), then wider engagement may be necessary. Stakeholders may include: council (all relevant staff), TasWater (if there are suspected sewer to stormwater intrusions), EPA, DoH, and consultants. For investigations conducted in the Derwent estuary region, the DEP can help facilitate such meetings. During this meeting the council should notify all stakeholders of their intent and identify the roles stakeholders might be able to play both before and during the Tracing phase of the investigation.

For smaller or isolated issues, councils may be able to identify issues and initiate corrective action without having to engage stakeholders at all. In other cases, notifying or engaging TasWater may be sufficient. These decisions are up to the discretion of the council, however the DEP recommends taking a collaborative approach from the beginning in order to ensure an effective and successful investigation.

3.2 Tracing Phase: identification of contamination hotspots/source

The Tracing phase focuses on implementing follow-up investigations that locate, and if required, identify specific sources of contamination. If the Screening phase identified that the issue was isolated to the beach, then the Tracing phase may comprise a focused beach investigation (section 3.2.1). If the Screening phase identified that a source is likely related to the stormwater outfall, or that poor water quality was present at both the beach and the outfall, then the Tracing phase will involve a focused stormwater system investigation (section 3.2.2).

It is worth noting, that swimming sites that receive stormwater discharges from urban catchments are likely to suffer poor water quality at times. Therefore, some councils have recommended initiating stormwater system investigations (section 3.2.2) from the get-go.

3.2.1 Beach investigation

Beach investigations are likely to differ significantly between localities, and therefore it is unlikely that there is a 'one-size-fits-all' solution to conducting beach investigations. Your 'hypothesis' of the contamination source is likely to determine which investigative approach is most appropriate. Tools that can discriminate between contamination sources are likely to be most useful in a beach type investigation. Tools that can discriminate between human and non-human contamination sources, and are appropriate for use in marine waters, are listed below. A detailed description, as well as the advantages and disadvantages of each method, is described in more detail in the Toolkit. The methods listed below are likely to require specialist assistance to design and implement effective investigations. Some methods are currently in development, for more information, see Source Tracking Toolkit in Section 5.

Appropriate methods for beach investigations may include:

- Sterols.
- Library-dependent fingerprinting e.g. PhPlate.
- Library-independent genetic markers e.g. *Bacteroides* spp.
- Chemical markers e.g. caffeine, ammonia.
- Extended sampling regime.

Analytical Services Tasmania (AST) are currently conducting a beach investigation to investigate faecal pollution at Blackmans Bay. The program includes sampling a combination of chemical markers including sterol biomarkers, caffeine, nutrients and enterococci to determine the extent of pollution at Blackmans Bay and define the sources of pollution to the receiving waters. The project scope is described in AST (2020) and the results are due to be published in mid-2020. The results may help to prescribe a tested approach to source tracking investigations at swimming beaches, and this document will be updated accordingly.

3.2.2 Stormwater system investigation

Stormwater system investigations involve implementing follow-up investigations to identify the source of faecal contamination being discharged into the stormwater system, and ultimately discharged to the main river or estuary. This investigation should be thoroughly planned and includes the following steps:

- Desktop data collection.

- Stormwater field investigations.
  - Stage 1: Locate contamination hotspots.
  - Stage 2: Determine exact location of contamination source.

3.2.3 Desktop data collection

If a stormwater system investigation is initiated, desktop data collection should be undertaken as a first step to inform any planning or decision making. Information to collect at this stage may include:

- Stormwater and sewage network data.
  - location (including Emergency Relief Overflow Structures).
  - asset information, including age, design, condition etc.
  - illegal cross-connection history.
  - renovation history.
  - sewage spill history.
- Land-use changes.
- Development history.
- Pollution and complaint history.

Stormwater asset information is available directly from local councils, and in some cases is made publicly available on local government websites. Sewerage asset information in Tasmania is held by TasWater and is available on theLIST map website.

Information such as the relative elevation of sewer to stormwater pipes can help inform the pollution pathway. For example, sewage is more likely to infiltrate into the stormwater network if a damaged sewer pipe is located above a stormwater drain. However, if the sewerage network is under high-pressure, during high rainfall for example, then sewage is more likely to be discharged via emergency relief overflow structures.

Another possible pathway is via illegal connections or cross-connections from stormwater to sewer. Renovation history and land use changes can provide valuable information, for example, areas subject to new developments sometimes result in illegal cross-connections due to poor workmanship or lack of infrastructure labelling. This knowledge can help refine search areas. Also, older residential areas that are not connected to sewer may have failing onsite wastewater treatment systems due to a number of factors.

This information, in conjunction with preliminary water quality data, can help to pinpoint contamination hotspots and help guide the investment of resources and effort to a specific location, saving time and money in the long run.

3.2.4 Stormwater field investigations – Stage 1

The objective of Stage 1 is to identify contamination hotspots in the sub-catchment. Hotspots refer to branches or areas within a drainage network where faecal pollution is entering the system. Stage 1 will often consist of initial exploration and sampling blitz of the network. The starting point of the investigation should be informed by the information gathered during the screening phase and from the desktop data collection. In a typical Derwent estuary scenario, the starting location would be a site with poor beach and outfall water quality. The investigation should then work methodically upstream from the outfall, following relevant stormwater and sewer system maps.

Tools employed during Stage 1 of investigations generally include subsurface investigation tools, such as pit lid lifting, combined with sampling of microbial and chemical water quality indicators from the feeder drains. Typical markers include enterococci, *E. coli* and ammonia. A key sampling consideration is to sample at post-peak sewer flow periods (i.e. 9-10 am). Sampling considerations and trigger levels are discussed further in section 3.1.3. If hotspots are identified, council may want to confirm the source as human in origin before moving onto Stage 2. This final step is optional and is likely limited by budget and availability of appropriate markers. Options include sterol biomarkers, *Bacteroides* spp. or phenotyping enterococci samples, the latter two of which are currently not commercial options in Hobart (work is underway that may change that, and this document will be updated accordingly).

Two novel approaches to Stage 1 investigations, ammonia testing and broom testing, have been identified as quick, effective and economical options. For these reasons they are detailed below.

3.2.4.1 Ammonia testing

Enterococci and *E. coli* analysis can take up to 24 hours, which may be too long in some circumstances, particularly if the pollution sources are intermittent. Ammonia is a chemical marker that has the potential to accelerate the process of identifying contamination 'hotpots' during Stage 1 investigations.

Tillett *et al.* (2018) describes a 'novel' method for problem identification in the form of an ammonia 'sampling blitz'. In the study, Screening phase monitoring identified an ammonia concentration of 0.5 mg L^{-1} as an appropriate trigger value. Whether this value is appropriate in the Derwent estuary requires assessment. A less conservative trigger-level for ammonia would be 1 mg L^{-1} (EPA Victoria, 2007). Ammonia levels were traced upstream until no elevated levels were detected. Stormwater branches where ammonia concentrations were < 0.25 mg L^{-1} were eliminated, narrowing the scope of the investigation. Sites where ammonia was detected below the trigger level were retested 1 hour later to allow the pollution event to peak. If high-risk catchments did not breach the trigger level, they were resampled a week later. At the site where the contamination signal disappeared, *E. coli* and *Bacteroides* spp. samples were taken to confirm if the source was faecal and of human origin.

Ammonia testing can be used in combination with pit lid lifting and sampling for faecal indicator bacteria (FIB) providing a further line of evidence. An informal DEP workshop trialling this method, in the Clarence stormwater network, also indicated its usefulness (Weller-Wong and Visby, 2019). More recently, investigations in Kingborough have had great success, confirming ammonia testing using API test-kits as a quick, cheap and effective technique for stormwater field investigations.

3.2.4.2 Broom testing

A novel method that has been successfully employed by the City of Launceston (CoL) is broom testing. Brooms are deployed strategically in utility holes to detect the presence of sewage by filtering solids from the stormwater. Once a section of the network has been monitored, and if intrusions are suspected, brooms are deployed in utility holes further upstream until a hotspot is located. Brooms are deployed for 24 hours, or longer if sewage intrusions are expected. CoL have engaged contractors to conduct all investigative work, including broom testing, CCTV footage and dye-testing. The broom method is quick, thorough and a relatively low-cost option that can implemented effectively through an entire catchment. CoL have had good success in locating sewage intrusions using this method.

3.2.4.3 Stage 1 Review

Appropriate tools, markers and methods for Stage 1 investigations include:

- Pit lid lifting on drainage line inspection.
- Broom testing.
- *E. coli.*
- Enterococci.
- *Bacteroides* spp.
- Sterols.
- Ammonia.
- Caffeine.
- Library-dependent fingerprinting e.g. PhPlate.
- Library-dependent genetic markers e.g. *Bacteroides* spp.

For more information on source-tracking tools and markers, see Source Tracking Toolkit.

3.2.5 Stormwater investigations – Stage 2

The objective of Stage 2 is to determine the exact location of sewage intrusions so that the issues can be rectified. If Stage 1 has been successful, the location of possible contamination source/s will have been reduced to a 'hotspot' area. The most common methods for pinpointing intrusions include the use of CCTV footage and dye-testing. CCTV cameras travel through the pipe to identify signs of intrusion. If intrusion is suspected from a property, due to cross-connection for example, dye-testing could then be conducted to confirm the finding. In many cases, a combination of dye-testing and CCTV (or maybe smoke testing) can successfully pinpoint cross-connections, damaged or ageing sewer infrastructure.

If Stage 1 was unsuccessful, an extended stormwater monitoring program may be required to ascertain if the faecal source is following a spatial or temporal pattern, in order to isolate 'hotspot' sections of the drainage network. This might involve sampling on a regular basis, either daily or the same set time (morning or afternoon), weekly or on five consecutive days. The microbial markers selected could include enterococci, *E. coli* or ammonia, as well as tools or markers that might discriminate the faecal source. Sampling at post-peak sewer flow periods, and increasing the number of indicators, should assist in identifying difficult to detect, intermittent sources.

Appropriate tools and markers for Stage 2 investigations include:

- Dye-testing.
- CCTV.
- Smoke testing.

3.3 Remediation Phase: rectification of identified issues

Once a faecal source of contamination has been identified, corrective action must be taken to rectify the source. Likely scenarios for rectification include:

- Source originates from private industrial, commercial or residential premises. In this case, responsibility for rectification lies with the property owner, and local council can enforce if required.
- Sewage intrusion is related to an issue with sewerage assets. In this case the responsibility for rectification lies with the utility provider (TasWater).
- Issues arise from damage to stormwater assets in this case, the utility provider (local council) is responsible for rectifying the issue.
- A combination of the above.

In the scenario that rectification is the responsibility of a property owner, enforcement action is generally achieved by following these three steps:

1. Informal verbal call about sewage intrusion;
2. Informal letter;
3. Abatement Notice or Plumbing Order.

An example of an informal letter has been attached in Appendix 2.

In the scenario that sewage intrusions are related to issues with sewerage assets, TasWater should be notified. TasWater recommends that councils contact them as soon as a problem is identified or suspected. Blockages, overflows, seepages and other minor issues should be immediately logged with the TasWater Call Centre (phone 13 69 92). Log the job as a “sewer leak” and council officers will be provided with a reference number. Once logged, a TasWater crew will be dispatched and be on-site within 60 minutes.

Once on-site, overflows and blockages will be rectified by TasWater crews. For other issues such as seepages, TasWater will work in collaboration with council to investigate, identify and rectify the problem. In this scenario, any information collected during council stormwater field investigations can be emailed to TasWater, referencing the job number, to help inform the investigation.

4 Acknowledgments

The Derwent Estuary Program would like to thank our partners: Tasmanian State Government (including Department of Primary Industries, Parks, Water an Environment, Department of Health, and Public Health Services), Environmental Protection Agency, Brighton Council, Clarence City Council, Derwent Valley Council, Glenorchy City Council, City of Hobart, Kingborough Council, Nyrstar Hobart, Norske Skog Boyer, TasWater, Tasmania Ports Corporation and Hydro Tasmania.

In addition, many people provided valuable time and effort, including specialist advice, detailed information, reviews and other input. A special thanks goes to John Devries (KC), Michael Steele (KC), Dan Holdsworth (AST), Paul Grey (PHL), Andrew Forshaw (CCC), Fran Smith (TasWater), Damian Devlin (TasWater), Helena Bobbi (DoH), Hollie Zimmerman (DoH), Lev Bodrossy (CSIRO) Damian Norman (AST), Glen Napthali (EPA), Sophie Buttery (EPA) and Vincent Pettigrove (RMIT).

5 Source Tracking Toolkit

The Toolkit is divided into three sections:

- Subsurface infrastructure investigation tools.
- Water quality indicators.
- Microbial Source tracking methods.

5.1 Subsurface infrastructure investigation tools

Tool	Description	Comments	Application
Physical drain or drainage line inspection	• Walking up a pipe or open drainage network to identify the location of sewer intrusions.	• Most cost effective, particularly useful for continuous discharges. • Requires specialist qualifications (i.e. confined spaces certification) and involves significant safety and access concerns depending on type and location.	• Stage 1 investigations. • Unlikely in localities where there are few open drainage lines.
Pit lid lifting	• Lifting stormwater pit lids to inspect for visible signals of sewer intrusions.	• Cost-effective technique which can be used in conjunction with water quality indicators such as *E. coli* and enterococci. • Access and safety are dependent on pit location. Pits can be difficult to access if lids have not been maintained, location is not documented, or if their location is not safe for access (i.e. in the middle of a road).	• Stage 1 investigations. • Pit lid lifting can be effectively combined with sampling of water quality indicators such as *E. coli,* enterococci and ammonia field tests.
Broom testing	• Deploying brooms in utility holes to filter stormwater for solids such as toilet paper or faeces.	• Simple and effective method for strategically monitoring an entire sub-catchment. • Does not require sampling for enterococci or *E. coli.* • Particularly useful for identifying intermittent sources.	• Stage 1 investigations. • For more information on broom testing for sewer intrusion, contact Ed Hargraves (CoL).

		• Requires strategic planning and is time-consuming.	
CCTV inspection	• Use of remote camera equipment to survey sewer and drainage lines to identify sewage intrusions or locations where contaminated groundwater has the potential to infiltrate the stormwater system.	• CCTV is a useful tool when access to sewer and stormwater is restricted. CCTV may not identify all types of discharges, especially if they are intermittent, although there may be obvious indicators (i.e. toilet paper). Access may be restricted when sewers are blocked or under high flow conditions. • Specialist equipment and skills may be required and can be expensive if contractors are required. • Some council works crews may have their own CCTV equipment and trained staff, so it is worth checking with the works depot.	• Stage 2 investigations. • CCTV inspection is commonly employed in Stage 2 investigations to determine the exact location of a sewage intrusion.
Dye testing	• Flushing dye into the sewer at the suspected source (i.e. private property) and having observers at stormwater pits to confirm the location of the contamination source.	• Can determine specific point sources of contamination and can also identify intermittent sources. • May require several staff and can be time consuming during low flows. • Some dye products are not safe for discharge to stormwater, be sure to select safe products.	• Stage 2 investigations, • Dye testing is often employed following CCTV inspection to confirm findings and pinpoint exact source location, and is generally the final step in stormwater field investigations.
Smoke testing	• Involves pumping smoke into the sewer to determine if/where there are leaks in the system.	• Smoke testing is most appropriate in situations where CCTV access is restricted. • Is also useful when access to multiple properties is required (i.e. source location has not yet been isolated). • Direction of smoke movement can make it difficult to locate the source of the breach.	• Stage 2 investigations. • Smoke testing is not highly recommended and is suggested for use if CCTV and dye-testing investigations have been exhausted and unsuccessful.

5.2 Water quality indicators

5.2.1 Microbial Markers

Faecal Indicator Bacteria (FIB) describe a range of organisms that inhabit the gut of warm-blooded animals. Many studies have used FIB as microbial markers to evaluate the microbiological quality of water bodies. Traditionally an enumeration of FIB, such as enterococci, *E. coli* and faecal coliforms, has been used as proxy for detecting and quantifying faecal contamination in ambient water samples. *E. coli,* enterococci and *Bacteroides* spp. are discussed below as they are commonly regarded as the most appropriate microbial markers for source tracking studies.

For a comprehensive review of FIB for source tracking investigations see (Tran *et al.*, 2015).

Tool	• **Description**	**Comments**	•**Recommendations**
E. coli and enterococci	• It is widely accepted that concentrations of *E. coli* and enterococci above designated levels is indicative of faecal contamination and a satisfactory indicator of human health risk. • In Australia, enterococci is the recommended FIB in recreational waters (NHMRC, 2008; DHHS , 2007).	• *E. coli* and enterococci have been widely utilised as FIB, largely due to their abundance in faeces, and their cheap and reliable capacity to be cultured. • *E. coli* and enterococci are not host-specific, and therefore cannot differentiate between human and animal faecal sources. • Presence of *E. coli* and enterococci does not necessarily reflect the occurrence of pathogens, as some pathogens (i.e. *Giardia* spp.) are more persistent than FIB in natural waters. • *E. coli* can proliferate in the environment, with no faecal origin. • *E. coli* and enterococci are found in the gastrointestinal system of warm-blooded animals. Therefore, they do not indicate faecal contamination from cold-blooded animals such as fish.	•*E. coli* and enterococci are useful indicators of faecal contamination in recreational and stormwater. •Enterococci results from stormwater sampling will help contextualise results documented at the beaches. •Recommended to use both enterococci and *E. coli* in stormwater investigations. •For source identification, *E. coli* and enterococci sampling is recommended in combination with other available indicators such as *Bacteroides* spp. (when available) and/or chemical markers that have greater host specificity.

Bacteroides spp.	• *Bacteroides* spp. are obligate anaerobes (that is, they are unlikely to propagate outside an animal's digestive system). *Bacteroides* spp. are more abundant in faeces than *E. coli* and enterococci, and display high host-specificity as they have co-evolved within their hosts digestive system (Dick *et al.*, 2005). • *Bacteroides* spp. assays require genetic technologies, such as polymerase chain reaction methods (PCR), see genetic methods.	• *Bacteroides* spp. assays can distinguish the primary source(s) of contamination as human, dog, cow and bird in origin and indicate their rough ratios. • *Bacteroides* spp. assays are commonly regarded as the future of source identification (Tillett and Pettigrove, 2017). • For an example of recent, successful source-tracking investigation using *Bacteroides* spp., *E.* coli, enterococci and ammonia in a multi-tiered approach, see Tillett *et al.* (2018).	• The value of *Bacteroides* spp. assays are greatest in combination with traditional FIB, as well as chemical markers (such as ammonia). • For further discussion see section 5.3.1
Other	Other FIB that have been documented in the literature include bacteriophages, enteric viruses and pathogens (Tran *et al.*, 2015). However, these FIB all suffer from similar limitation to enterococci and *E. coli.* These markers all lack the specificity offered by *Bacteroides* spp. assays.		

5.2.2 Chemical markers

Chemical markers rely on the detection of contaminants that are related to a specific faecal source (mostly humans) and are not found in unpolluted waters. The major advantage of chemical markers is that they show high host specificity (i.e. human faecal pollution). They also have the advantages of rapid and reliable detection and high source specificity compared to traditional microbial markers (i.e. enterococci and *E. coli*). The major classes of chemical markers are artificial sweeteners, pharmaceutical and personal care products, fluorescent whitening agents and nutrients. The chemical markers discussed below are those considered most practical for use in the Derwent estuary. There are many other chemical markers available for use in Tasmania.

For a comprehensive review of chemical markers see Lim *et al.* (2017) and Tran *et al.* (2015).

Tool	Description	Comments	Recommendations
Sterols/stanols	• Sterols are a family of lipid compounds found naturally in the cells of plants (campesterol, stigmasterol and β-sitosterol) and animals (e.g. cholesterol and coprostanol). Sterols are converted to stanols by bacteria present in the gut of warm-blooded animals. • Stanol detection is indicative of faecal contamination, as stanols produced by reducing gut bacteria are only present in faeces. • Sources of pollution are determined by calculating specific ratios of stanols and sterols (e.g. human faecal contamination is indicated by very high ratios of coprostanol to other sterols and stanols). • For more information on ratios of sterols/stanols for source assignment, see the recent review by Lim *et al.* (2017)	• Sterols/stanols can be used to discriminate between human and non-human sources of faecal contamination, and numerous successful investigations have been documented in the literature (Leeming *et al.*, 1996; Leeming and Nichols, 1998; Lim *et al.*, 2017). More specific source discrimination (between animal groups Carnivores, Herbivores, and Birds) is also possible. • Sterols/stanols are persistent in the environment and are detectable in ambient water, however, being hydrophobic compounds, they typically bind to sediment in aquatic environments. • Investigations can be time consuming, costly and require specialist expertise, however, the data obtained is sufficiently detailed that it can be used to trace point-sources of contamination.	• Sterols/stanols should be used as a source identification tool and should be only employed once bacterial counts (or other tests) indicate faecal contamination is present. • Sterols/stanols are an appropriate tool for testing stormwater, marine samples and sediment at beaches and bays. • Sterols/stanols should be considered for point-source identification (e.g. stormwater) and also for longer-term investigations. • For more information in establishing a Sterols/stanols investigation in the Derwent estuary contact Dan Holdsworth or Tim Jordan (AST).

Ammonia	• Ammonia (NH_3) is a by-product from the degradation of proteins, nucleic acid, and urea, typically in organic matter and faeces. • Testing for ammonia is based on the positive correlation between ammonia and FIB (Cabral and Marques, 2006).	• Ammonia is not a specific indicator as it is produced by decomposing organic matter (vegetation, food etc.). Ammonia can therefore be detected in non-faecal contaminated waters. • However, elevated concentrations of ammonia (> 0.5mg/L) are regarded to be a positive indication of faecal contamination and have been used successfully to help inform source tracking investigations. • Ammonia can be tested in the field using real-time test kits, making it a rapid and cheap tool. Ammonia test-kits have been utilised successfully in urban catchments in Victoria (Tillett *et al.*, 2018). • Ammonia is common in commercial and industrial discharges as it is a component of man-made products such as bleach, cleaning products and refrigerants. • Ammonia therefore may not be useful for faecal source tracking investigations in industrial, commercial and agricultural zones.	• Ammonia test kits are recommended for use in the early stages of stormwater field investigations. They can be used in Stage 1 to conduct a sampling 'blitz' to identify contamination hotspots in problem catchments. • Once the potential source has been identified, traditional FIB (enterococci and *E. coli*) and if available, *Bacteroides* spp. fingerprinting are recommended to confirm the high contamination loads and identify the exact source. • For more information, contact Akira Weller-wong (DEP).
Caffeine	• Caffeine is a compound that is found in beverages, including tea, coffee, soft drinks, and pharmaceutical products. Caffeine and its associated metabolites are excreted in urine of individuals who have consumed caffeine in the aforementioned products. • Of the chemical markers, caffeine is the most widely used chemical marker to	• Caffeine is a persistent marker. • Caffeine should be viewed as an indicator of wastewater, and not necessarily faecal pollution, as caffeine can be derived from kitchen sinks, plants etc. • Caffeine should be used in combination with other markers.	• Caffeine should be used as a source identification tool and should be only employed once a high result has been detected. • Caffeine testing is available at AST for ~ $60 sample. Contact Dan Holdsworth or Tim Jordan (AST) for more details.

	assess wastewater contamination (Lim *et al.*, 2017).		
Other	• Artificial sweeteners, pharmaceutical and personal care products and fluorescent whitening agents have all been utilised to detect wastewater contamination in surface and groundwater. Chemical makers are often selected for their benefits of being persistent and stable. • Of the artificial sweeteners that have been studied, acesulfame and sucralose are the most widely used due to their high detection frequencies and low absorption capacity onto soil. • Although fluorescent whitening agents are widespread, they have restricted benefits as chemical markers as their detection by a fluorometer may be limited by organic matter in the water samples. Studies have also shown a lack of relationship between fluorescent whitening agents and FIB. • The literature is in agreement that there is no one universal chemical indicator, and that chemical markers should be considered on a case-by case basis. • For more recent reviews and evaluation of chemical markers see Tran *et al.* (2015) and Lim *et al.I* (2017).		

5.3 Microbial Source tracking methods

Microbial Source Tracking (MST) refers to microbial methods that discriminate between human and non-human sources of faecal contamination. In this toolkit, these methods are divided into two basic groups, genetic and phenotypic, which rely on the use of molecular techniques. These two methods can be further divided into those that are library-dependent and those that are library-independent. Genetic and phenotypic methods that have the potential for establishment for use in Hobart are discussed below.

5.3.1 Genetic methods

Genetic methods use the genetic profile of gut bacteria to discriminate between sources of faecal pollution. The continued development of technologies, particularly polymerase chain reaction methods (PCR) have revolutionised MST, as the choice of FIB is no longer limited to those bacteria that are easily cultured (i.e. enterococci and *E. coli*).

Genetic methods can be classified as either library-dependent or library-independent. Library-dependent methods use techniques such as repetitive PCR (rep-PCR) to generate specific fingerprints, which are used to classify the indicator bacteria by ‘strains’ (or isolates, phylotypes). Library independent methods rely on DNA markers to discriminate pollution sources through the identification of known target gene sequences from the DNA of the target FIB.

Tool	Description	Comments	Recommendations
Library-dependent (fingerprinting)	• Library-dependent methods (such as phylotyping or phylogrouping) refers to several methods that utilise PCR fingerprinting (rep-PCR; Boc-PCR; Quadriplex-PCR). • Unique genetic fingerprints are generated from known sources of faecal pollution and are used to construct a reference database. Strains/isolates are divided into seven phylogroups, whereby the phylogroup can indicate the source host (based on differences in lifestyle, diet etc.). • Phylotyping can be applied to *E. coli* or enterococci, however, from a commercial standpoint, *E. coli* assays are currently available.	• Library based methods have the potential to identify the source as human or non-human and can differentiate sources into the known phylogroups. • Reliable results depend on the geographic diversity within a region, and on the number of isolates in a database. • The capacity of a library to discriminate between contamination sources may be restricted geographically.	• Application of phylotyping is currently limited in Tasmania, given limited access to laboratories that can perform PCR, and costs associated with database/library establishment. • Phylotyping services are commercially available through AWQC (SA), and is costed at approximately $100 per isolate. However, given geographic distance, it is likely that a South Australian database may not provide useful information in a Tasmanian context. • Contact John Devries (KC) or Frances Smith (TasWater) for more information. • Currently, the PhPlate system is recommended as a cheaper and easier to establish option (section 5.3.2).
Library independent (genetic marker)	• Library-independent methods, such as genetic markers, can identify faecal sources through the identification of targeted gene sequences from the DNA of FIB, without the need of a library. • Many qPCR methods have been developed. One of the most widely used methods targets the 16S rRNA gene of human-associated *Bacteroides* spp.	• The major benefit with *Bacteroides* spp. assays is that *Bacteroides* spp. are highly host specific and can discriminate between human and non-human sources. • Host-specific genetic markers that are available include human, dog, ruminant, and birds. • Detected markers can be derived from living or dead cells, making it difficult to discriminate between a current or past contamination event. • Methods are susceptible to methodological and sample related biases.	• *Bacteroides* spp. assays are regarded to have great potential in faecal source tracking investigations due to their ability to differentiate between animal species. • *Bacteroides* spp. assays have not been tested in a stomrwtaer context in Hobart. • Pilot studies may be available through CSIRO and are costed at ~ $200 a sample. Contact Akira Weller-Wong (DEP) for more information. • For an example where *Bacteroides* spp. assays have been used successfully, see Tillett and Pettigrove (2017).

5.3.2 Phenotypic methods

Phenotypic methods involve the detection of phenotypic characteristics (observable characteristics of an individual) specific to different strains of the same bacterial species hosted in humans and/or animals.

The PhenePlate system has been identified as applicable in the Tasmanian management context. Another phenotypic method is antibiotic resistance analysis.

Tool	Description	Comments	Recommendations
Library-dependent (fingerprinting) - PhPlate	• The PhenePlate system (PhPlate) is a biochemical fingerprinting method that characterises bacterial isolates based on the measurement of 'the reaction products formed by the metabolisation of different substrates' (http://www.phplate.se/?page_id=43). • For each isolate, a biochemical fingerprint is produced, which is used by the PhPlate software to determine the level of similarity between tested isolates. • The PhPlate system is applicable to. *E. coli* and enterococci.	• The system has been successfully used in source-tracking investigations to differentiate between human and non-human sources of faecal contamination, see Ahmed *et al.* (2005) for more information. • A limitation of phenotypic methods is that different bacterial isolates may show similar biochemical responses, and therefore not produce a unique phenotypic fingerprint. • Library-based methods such as the PhPlate system, can be restricted geographically depending on the genetic diversity of the target organism.	• The PhPlate, if available, should only be employed once a high enterococci or *E. coli* result has been detected. • To establish a pilot study in Hobart has been costed at $2700 for establishment of a library of 600 isolates ($4.50/isolate), plus $10000 for software and equipment, totalling approximately $13000. The cost for FST of a high result would be approximately $90 (for a 20 isolate population comparison). The Pubilc Health Laboratory (PHL) are exploring the potential of the PhPlate system. Contact Paul Grey (PHL) for more information. • Given the relative 'ease' of establishment and successful implementation in other FST studies, the PhPlate is a valid option for source identification in Hobart, given the high costs and lack of availability of other solutions.

6 References

Ahmed W., Neller R., Katouli M. (2005) Host Species-Specific Metabolic Fingerprint Database for Enterococci and. **71**, 4461–4468.

AST (2020) Proposal – Sampling program to investigate faecal pollution at Blackmans Bay and Kingston Beach 2019-2020 (A pilot study). **2020**, 1–7.

Cabral J.P., Marques C. (2006) Faecal coliform bacteria in febros river (Northwest Portugal): Temporal variation, correlation with water parameters, and species identification. *Environmental Monitoring and Assessment* **118**, 21–36.

Chrispijn J., Agius J. (2011) Derwent Estuary Stormwater Monitoring Program. (Hobart, Australia).

Coughanowr C. (2019) Blackmans Bay Recreational Water Quality Review. (Hobart, Tasmania).

Dept of Health & Human Services (2007) Recreational Water Quality Guidelines (Public Health Act 1997). (Hobart, Australia).

Dick L.K., Bernhard A.E., Brodeur T.J., Santo Domingo J.W., Simpson J.M., Walters S.P., Field K.G. (2005) Host distributions of uncultivated fecal Bacteroidales bacteria reveal genetic markers for fecal source identification. *Applied and Environmental Microbiology* **71**, 3184–3191.

EPA Victoria (2007) EPA Guideline Tracing Faecal Contamination in Urban Drains – Tracing Faecal Contamination in Urban Drains - Toolkit. (Victoria, Australia).

Leeming R., Ball A., Ashbolt N., Nichols P. (1996) Using faecal sterols from humans and animals to distinguish faecal pollution in receiving waters. *Water Research* **30**, 2893–2900.

Leeming R., Nichols P.D. (1998) Determination of the sources and distribution of sewage and pulp-fibre-derived pollution in the Derwent Estuary, Tasmania, using sterol biomarkers. *Marine and Freshwater Research* **49**, 7–17.

Lim F.Y., Ong S.L., Hu J. (2017) Recent advances in the use of chemical markers for tracing wastewater contamination in aquatic environment: A review. *Water (Switzerland)* **9**,.

NHMRC (2008) Guidelines for Managing Risks in Recreational Water. (Canberra, Australia).

Tillett B., Pettigrove V. (2017) Bacteroidales: Revolutionising Microbial Source Tracking. *Water e-Journal* **2**, 1–9.

Tillett B.J., Sharley D., Almeida M.I.G.S., Valenzuela I., Hoffmann A.A., Pettigrove V. (2018) A short work-flow to effectively source faecal pollution in recreational waters – A case study. *Science of the Total Environment* **644**, 1503–1510.

Tran N.H., Gin K.Y.H., Ngo H.H. (2015) Fecal pollution source tracking toolbox for identification, evaluation and characterization of fecal contamination in receiving urban surface waters and groundwater. *Science of the Total Environment* **538**, 38–57.

Weller-Wong A., Visby I. (2019) Source Tracking Workshop October 2019. Derwent Estuary Program, (Hobart, Australia).

7 Appendix 1—Sanitary inspection checklist for natural recreational water bodies (from Draft Recreational Water Quality Guidelines 2018)

Name/location of recreational water body ____

Date and time of sanitary survey____

Reason for survey:

- ☐ recreational water monitoring program - sample failure/s

  date sample collected _______ sample results_______ Lab Certificate Number_________

  date sample collected _______ sample results _______ Lab Certificate Number_________

- ☐ pre-swimming season check
- ☐ complaint ____

Name and title of officers conducting survey ____

Weather conditions at the time of sampling:

- rain/dry ____
- wind (strong/weak/calm) _______________ Onshore/offshore __________________
- other ____

Weather conditions over previous 24hrs ____

Weather conditions over previous 72 hrs ____

Tide at time of survey: in/out ____

High and low tide times from BOM for day of survey __________________________________

Visual assessment of water:

- ☐ turbid
- ☐ clear
- ☐ dark

Details of any nearby stormwater outfalls and if they are flowing or not ____________________

____

____

____

Details and location of any recent, nearby sewage pump stations failures/sewer spills as confirmed by TasWater (TasWater 136992)

____

____

____

Details of any nearby recent repairs to TasWater infrastructure or council stormwater infrastructure as confirmed by TasWater/council officers (TasWater 136992)

____

____

____

Details of any visual pollutants on the beach or in the water:

- ☐ animal faeces
- ☐ seaweed
- ☐ rubbish
- ☐ other

Comments ____

____

____

Other potential sources of pollutants present:

- ☐ birds (estimate numbers) ____________________
- ☐ moored habitable boats
- ☐ cruise liners present
- ☐ cruise liners commonly in the area
- ☐ ferries present
- ☐ ferries commonly in the area
- ☐ cars/traffic on the beach
- ☐ toilet facilities
- ☐ camp grounds/campers on foreshore
- ☐ current or recent special events such as regattas __________________________________
- ☐ domestic waste water systems (septic tanks and others) on nearby properties
- ☐ estimate of number of people swimming ______________
- ☐ other

Details ____

____

____

Details of permanent or temporary public health advisories in place __________________________

____

____

____

Other comments ____

____

____

____

Actions/recommendations ____

____

____

____

8 Appendix 2—Sewage intrusion informal letters

Date

Resident's name

Address

Address

Dear XXXXXX

Address - Sewage intrusion

The City of Launceston has completed an investigation following a complaint from neighbour to your property. We have gathered evidence that shows your private sewage line is connected to the public stormwater system. We have previously notified you of this verbally.

This incorrectly connected sewage line must be disconnected from the public stormwater system and reconnected to the public sewer system at your responsibility. This correspondence has been produced to document this request.

There are legislative avenues Council will take if this issue remains unresolved, however we would like to provide you the opportunity to rectify this situation without serving formal notice. It is not unreasonable to expect this situation to be rectified within 14 days

The discharge of sewage to the public stormwater system can cause a range of unwanted outcomes such as poor water quality downstream, it also poses a public health risk if members of the public were come into contact with the untreated sewage.

I am happy to discuss this issue with you further, please contact me using the details below.

Yours sincerely

Your Name

Your Title

Phone number

Email address

Civic Centre
15 Channel Hwy, Kingston, Tasmania 7050
Locked Bag 1, Kingston, Tasmania 7050
T: (03) 6211 8200
F: (03) 6211 8211
AusDoc: DX 70854
E: kc@kingborough.tas.gov.au

20 January 2020 **Our Ref:**

<<Name>>
<<Address line 1>>
<<Address line 2>>

Dear

SEWER DRAIN TO STORMWATER MAIN (COMP/7-2020) – <<ADDRESS>>

Council is writing to you in relation to your property at <<ADDRESS>>.

It has come to the attention of Council that sewage from your property is discharging directly into Council's stormwater infrastructure.

Council requests that you engage a Plumber to rectify this issue within 21 days. A plumbing inspection will need to be carried out. To arrange an inspection please contact Council's Plumbing Surveyors.

If you have any enquires regarding this matter please call 6211 8107.

Yours sincerely

<<OFFICER NAME>>
SENIOR PLUMBING SURVEYOR