EPA GUIDELINE

TRACING FAECAL CONTAMINATION IN URBAN DRAINS – TOOLKIT

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1. INTRODUCTION

In September 2005 the Victorian Government launched the Yarra River Action Plan (the Plan) to improve the condition of the Yarra River (Victorian Government 2005). The Plan recognises that more work is needed to manage the impacts of expanding urban development and aging sewerage infrastructure on the Yarra River.

One of the priorities is to identify and eliminate faecal pollution within the Yarra River catchment. In response to this, EPA Victoria and Melbourne Water are working with asset owners to identify and remediate sources of faecal pollution.

The first stage of this process involved an extensive sampling program to identify key stormwater drains and tributaries contributing significant faecal pollution to the Yarra River. (EPA Victoria 2007).

The purpose of this guideline is to detail a standard framework and a set of tools that can be used to locate faecal pollution sources in the drainage sub-catchments of the Yarra River. It is intended to enable consistent application of faecal tracing investigations in this and other urban catchments. The framework will continually evolve as new methodologies and tools are developed.

The methods set out in this toolkit reflect those developed and trialled by Melbourne Water and supported by EPA and other key agencies.

2. PURPOSE

This guideline outlines a framework for investigations to trace sources of faecal pollution to the Yarra River and its sub-catchments. The framework includes standard investigation methods and a set of tools to locate, identify and rectify key point sources of faecal pollution. While the framework was developed for the Yarra catchment, it can be applied to all heavily urbanised catchments.

The framework focuses on locating and identifying human faecal pollution sources. These are key issues in achieving the primary goal of the Yarra River Action Plan: 'Water quality in the Yarra River to be safe for water sports and that fish caught in the Yarra are safe for human consumption.' (Victorian Government 2005).

The priority, in terms of reducing health risks associated with recreational use of the Yarra River, is to focus on tracing and remediating human faecal sources discharged under dry weather conditions. This is based on the following:

- Sources of human faecal contamination pose a greater risk to public health than non-human sources.
- Most intensive recreational use of the Yarra occurs under dry weather conditions.
- Evidence of human faecal contamination should not be found in dry weather if our stormwater and sewerage systems are performing well.
- Methods and tools for tracing faecal pollution are more effective under dry weather conditions.

A prescriptive approach to tracing sources is likely to fail due to the potential range of discharge locations, frequencies and types. This framework therefore details a range of methods and tools that can be applied on a case-by-case basis.

This does not preclude the use of the framework in identifying non-human faecal sources or its use under wet weather conditions. However, the use of methods and tools outlined in this document may require further assessment prior to use in these situations.

3. DEFINITIONS

For the purposes of this guideline:

Discharge frequency

Discharge frequency can be described as continuous, intermittent or sporadic.

Continuous – discharges occur most or all of the time, are usually easier to detect and generally carry the greatest pollutant load.

Intermittent – discharges occur over a shorter period of time (for example, a few hours per day or few days per year). They are harder to detect because of their infrequency.

Sporadic – discharges are generally one-off events. They are very difficult to detect with routine monitoring, but may have a severe impact on the quality of the receiving water.

The framework is most practical and cost-effective in its application for continuous and intermittent discharges.

Discharge types

Sewage and septic effluent – produced from sewerage and septic systems.

Industrial wastes and washwaters – illegal discharges of liquid wastes into the stormwater system and washwaters from commercial and residential activities.

Non-point sources – run-off from adjacent land uses into the stormwater system.

The framework may be used to trace all these sources (except non-point), but is most practical and cost-effective for human faecal sources (in other words, sewage).

Mode of entry

Discharges into the stormwater system can either direct or indirect.

Direct entry is generally where the discharge is directly connected to the stormwater system via a sewerage pipe, commercial, industrial or other pipe.

Indirect entry generally means the discharge is generated outside the stormwater system and infiltrates via pipe joints or a pipe infrastructure fault, or occurs from overland flows.

This framework is designed to track both direct and indirect modes of entry.

4. METHODOLOGY

The use of desktop (computer-based) investigations, water quality analysis or field inspections in isolation does not generally lead to accurate location and identification of a faecal source or to the prediction and/or assessment of the health risk associated with the discharge. The recommended approach for tracing and rectifying faecal sources involves three phases (refer to Figure 1):

- screening
- tracing (follow-up)
- remediation.

4.1 Screening phase

Significant sources of faecal pollution are generally discovered through regular screening and/or surveillance monitoring programs, although pollution reports may also initiate a tracing investigation.

The objective of the screening phase is to identify drainage network branches potentially contributing faecal inputs to a sub-catchment and, through a ranking process, prioritise follow-up investigations.

4.1.1 Screening phase sampling design

Sampling sites are initially selected to identify the most significant faecal inputs to the river from a sub-catchment and/or drainage network. This is most effective in detecting continuous and intermittent faecal inputs.

Sites should also be monitored in the main river during this phase. This allows comparison of inflowing water quality with river water quality (and, hence, the impact of the in-flows), while taking into account the potential impact of surface run-off water quality. This information is then used to inform priorities for follow-up investigations (tracing phase).

Screening samples should be taken under dry weather conditions. This includes samples taken under two general event types – dry-catchment dry-weather and wetted-catchment dry-weather. Understanding the health risks associated with wetted-catchment dry-weather events is important as these events do not usually trigger avoidance behaviour by recreational users.

Dry-catchment dry-weather events are defined as having no rain in the three days preceding the sampling day. Wetted-catchment dry-weather events are defined as rainfall greater than 5 mm but less than 20 mm in the 12 hours or greater than 10 mm but less than 20 mm in the 24 hours prior to sampling for large catchments. A rainfall event of this magnitude is chosen because it represents a consistent event of appropriate intensity where sewerage system exfiltration is emphasised, but not the spilling of raw sewage from emergency relief structures (EPA

Victoria 2007). These definitions may vary depending upon the size of the sub-catchment and extent of impervious cover.

Each site should be sampled at least twice for the two event types, as there can be significant variability in inputs between the same types of events.

Where appropriate, screening sampling times should be matched to peak sewer flow periods in dry-catchment dry-weather event sampling (where this can be practically determined). For wetted-catchment dry-weather events, a consistent point/s over the hydrograph should be identified. This helps to distinguish discharge frequencies, loads and potential types of discharge.

4.1.2 Sample collection and analysis

Samples should be collected, analysed and stored in accordance with procedures outlined in *A guide to the sampling and analysis of waters, wastewaters, soils and wastes* (EPA Victoria 2000) or, where relevant, other appropriate quality-assured methods.

4.1.3 Evaluation of results

Screening results should be reviewed and priority areas for follow-up investigations determined on the basis of load, potential to cause adverse health and water quality impacts, and the triggers outlined in section 4.2.2.

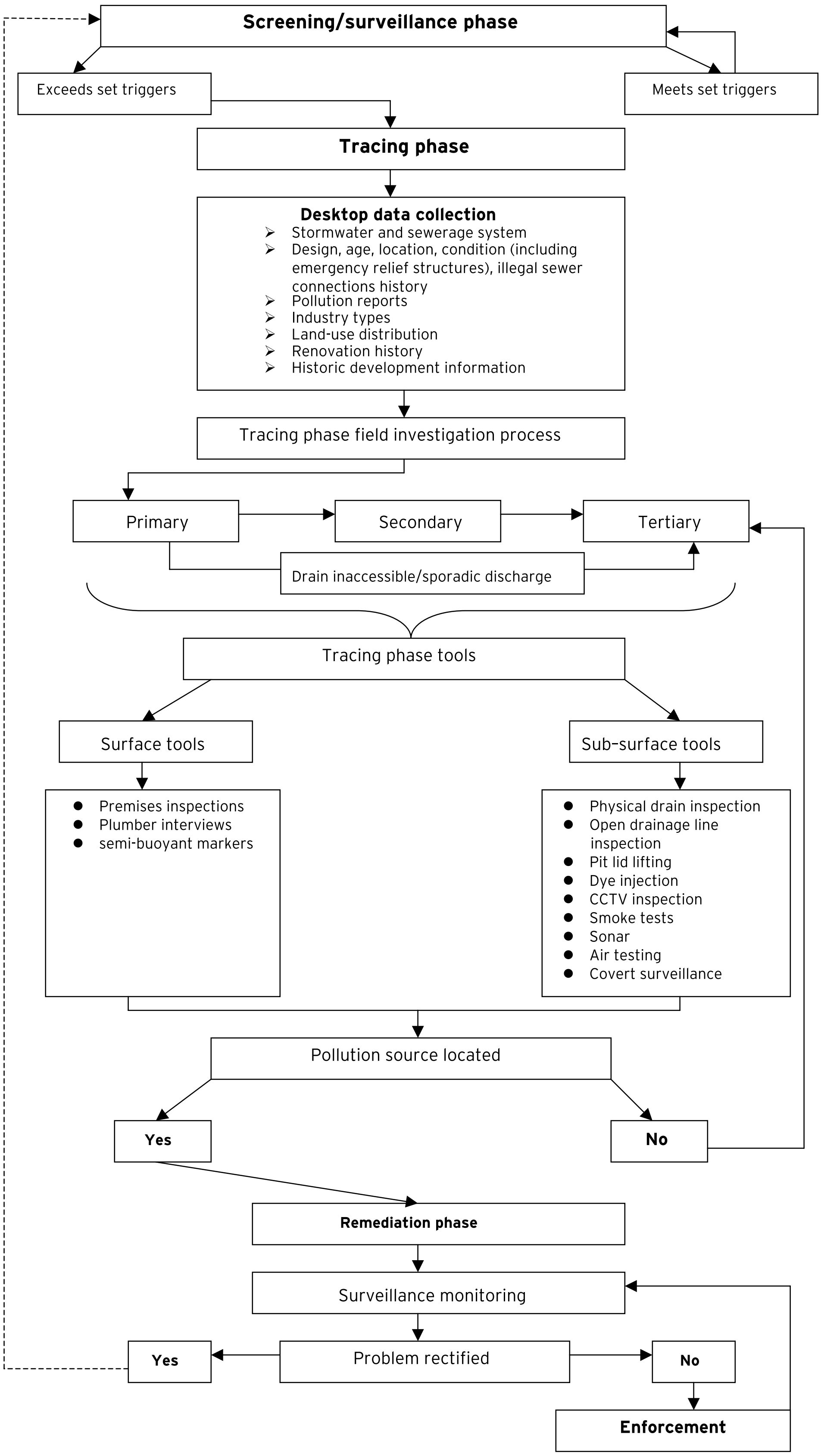

Figure 1: The three phases in tracing and rectifying faecal sources of pollution

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4.2 Tracing sources phase

This phase focuses on implementing follow-up investigations to locate and identify specific faecal discharges to the stormwater system.

Steps involved in the tracing phase include:

- data collection and analysis for the sub-catchment of concern (desktop investigation)
- source-tracing methods – field investigations using primary, secondary and/or tertiary methodologies and the appropriate tools.

4.2.1 Desktop data collection and analysis

If a tracing investigation is required, desktop data collection and analysis should be undertaken in the first instance.

The information collected may include:

- stormwater and sewerage networks –
  - location (including emergency relief structures)
  - asset design
  - age
  - condition
  - renovation history
  - illegal sewer connections history
- land-use distribution
- historic development information
- pollution complaint history
- types of industry.

This information, in combination with water quality data, will assist in tool selection and improve the efficiency with which faecal sources can be located (refer to Appendix 1).

4.2.2 Investigation triggers

Trigger levels provide guidance for assessing whether a follow-up investigation is required.

The suggested trigger levels for assessing whether an investigation moves from the screening phase to the primary investigation phase under dry weather conditions are any one of the following:

- stormwater drain has a measurable flow with an *E. coli* level above a maximum of 5000 organisms/100 mL
- stormwater drain has a measurable flow with a enterocooci level above a maximum of 2500 organisms/100 mL
- stormwater drain has a measurable flow with an ammonia level above a maximum of 1 mg/L.

Once a trigger is activated, priorities for follow-up investigations should be made on the basis of:

- the associated pollutant load (flows x concentration)
- duration of the discharge (continuous versus intermittent)
- location of the discharge (distance from receiving waters and the proximity to recreational activities)
- potential impact on the receiving water quality and health risk (human versus non-human source).

4.2.3 Investigation methods

Tracing-phase methods can be described as primary, secondary or tertiary investigations. The tracing process may involve implementing one or a combination of these, depending upon the discharge frequency, discharge type, mode of entry and the structure and design of the drainage system.

Primary investigation

The objective of the primary investigation phase is to identify obvious locations and sources of faecal contamination through an initial exploration and sampling of the drainage network.

Site selection may be determined in the field based on maps of the drainage system. Tools employed generally include a selection of less-sophisticated subsurface tools, including lifting manhole lids and sampling run-off water in pits and from feeder drains to pits.

Occasionally, sampling may be conducted from within the drainage network by walking upstream and sampling those inlets contributing flowing water. Analysis of water quality data often relies on rapid turnaround to guide further investigations and sampling, particularly if intermittent sources are suspected. *E. coli*, enterococci and ammonia are generally employed as the core water quality indicators during a primary investigation.

Secondary investigation

If the source(s) of faecal pollution can't be found using the method and tools commonly applied in a primary investigation, the investigation should move to a secondary phase.

The decision on whether a secondary investigation is undertaken or the investigation moves on to the next priority source should be determined on the basis of a cost-benefit analysis, which will include an assessment of the potential severity of the impact of the discharge.

Secondary investigations are generally required for intermittent discharges, as they can be difficult to detect using primary investigation methods.

The identification of the causes of intermittent faecal sources is challenging. If, however, the source(s) can be shown to be human in nature and significant in terms of load (not purely sporadic), it should be followed up. These investigations will also provide a greater understanding of the underlying causes of intermittent contamination and guide future investigations.

The objective of a secondary investigation is to ascertain whether a faecal source is following a pattern, either at a specific site or time, in order to isolate potentially problematic sections of the drainage network.

The method involves selecting sampling sites at key locations in the drainage network that will provide evidence indicating which drainage arm may be contributing to the contamination. Tools employed will generally be chosen from the subsurface category, depending upon the suspected location and source (refer to section 4.2.4).

Samples should be taken at the selected sites on a regular basis, either daily or at specific times (such as mornings and afternoons) for, say, five consecutive days. The core water quality indicators measured are generally *E. coli,* enterococci and ammonia. In addition, one or a combination of further indicators may be used to identify and distinguish the suspected source (refer to section 4.2.5).

Secondary investigations may have more success in detecting intermittent sources where:

- sampling times are matched to post-peak sewer flow periods (if this can be determined practically)
- an increased number of water quality indicators are used to distinguish the source and type of discharge prior to the application of more expensive field investigation tools
- a combination of one or more sophisticated tools are implemented after further water quality analysis (refer to Appendix 2).

Tertiary investigation

Tertiary investigations may be necessary where a source of contamination is significant, yet intermittent or sporadic, and has not been identified using secondary investigation methods.

This method involves the use of more sophisticated tools and the collection of water quality data over time, either through deployment of automatic samplers in the drainage system, continuous measuring probes or through rising stage hydrograph sampling methods. At least two sets of automatic samplers or probes separated by distance within the drainage network are required to isolate suspect drainage network sections. Probes that measure surrogates for faecal contamination (nitrogen species) can be used. Samples are also generally analysed for the core water quality indicators (for example, *E. coli* and enterococci).

Often, the identification and remediation of sporadic discharges relies on real-time community complaints and reporting of spill/pollution events, backed up by prompt follow-up investigations using surface tools. Where pollution is sporadic and a source(s) cannot be readily determined, a decision will need to be made whether to proceed with further investigation at that time or to focus efforts on other identified priority sources.

4.2.4 Tool selection

A range of tools can be used in tracing-phase investigations. Appendix 2 outlines the advantages and disadvantages of each tool and describes their general application. The challenge is to select the most appropriate tool or combination of tools.

The selection of tool(s) will largely be determined by the level of understanding of the drainage system and analysis of information collected in the screening phase. Factors that will significantly influence the choice of tool(s) include the:

- nature and distribution layout of the stormwater and sewerage systems
- age, size and condition of the pipe(s)
- discharge frequency, discharge type and its suspected mode of entry.

Each tool has advantages and disadvantages and no single tool can be assigned to any specific level of investigation. The range of tools described in Appendix 2 should not be viewed as exclusively for use in any investigation phase.

The tools may be categorised as 'subsurface' and 'surface.' Use of subsurface tools involves field investigations and/or data collection within the subsurface infrastructure (for example, in drains and sewers). Use of surface tools involves the collection of information from the surface and requires interaction with the catchment community.

Generally, subsurface tools are preferred to surface tools, due to the reduced degree of reliance on public information and the increased efficiency with which the sources can be located and rectified. Surface tools are more applicable in field investigations before a faecal source has been identified.

Nine subsurface tools have been identified. All involve some degree of inspection or access within the drainage system:

- physical drain inspection
- open drainage line inspection
- pit lid lifting
- dye injection

- CCTV inspection
- smoke testing
- sonar
- air testing
- covert surveillance.

Three surface tools have been identified. Each requires some understanding of the plumbing infrastructure, either by direct inspection or via consultation with relevant individuals:

- premises inspections
- plumber interviews
- semi-buoyant markers that are added to the sewerage system from toilets.

The location of faecal source(s) may require stepping through the various investigation levels. In general, as the investigation advances, more sophisticated tools are required at a greater cost.

4.2.5 Water quality indicators

No single water quality indicator can distinguish and identify the exact type of discharge. For each investigation, a combination of indicators should be chosen to distinguish human from non-human faecal sources and to assist in the selection of the most appropriate investigation tools.

The following water quality indicators are recommended to locate and identify faecal sources:

Core indicators:

- *E. coli*
- enterococci
- ammonia.

Additional indicators (as necessary):

- faecal sterols
- nitrogen species
- caffeine
- surfactant/detergent analyses (i.e., AAAS).

Appendix 3 outlines the general application for each of the water quality indicators.

The core indicators are generally employed for primary and secondary investigations. These indicators are usually present in sewage at measurable concentrations, but are not specific to human faecal contamination.

The generic microbial faecal indicators (*E. coli* and enterococci) can be used at all investigation levels, rather than measuring specific microbial pathogens, which are not cost-effective for general investigations. This is based on the assumption that high levels of generic microbial faecal indicators contain human-derived contamination until field investigations prove otherwise.

Both *E. coli* and enterococci are used to assess the generic level of microbial faecal contamination. *E. coli* has been shown in epidemiological studies to consistently relate to health outcomes for freshwater recreational water users (Wade *et al.* 2003; Wiedenmann *et al.* 2006). In marine/estuarine waters, *E. coli* is more readily inactivated than enterococci and does not correlate as well to health risk as enterococci in these systems.

If screening results indicate low faecal contamination (in other words, below the trigger levels), follow-up investigations should not be given high priority. Further assessment of the source of contamination through the use of additional indicators, such as faecal sterols, is also of limited value.

Where results indicate faecal contamination above the trigger levels, additional indicators may be used to provide more information on the source of the discharge and to assist in the differentiation between human and non-human faecal sources. This should be done as part of the early stages of the investigation to better inform the choice of tools for the follow-up investigation.

Sterol biomarker analysis should be used as the first step to help distinguish between human and non-human faecal sources. An important advance in using faecal sterols has been the realisation that it is critical to measure both the ratios and absolute concentration of at least four of these related compounds to attribute faecal source contributions between humans, herbivores, and birds (Ashbolt and Roser 2003). If analysis of sterols does not assist in identifying the source of microbial contamination, further water quality indicators – such as surfactants – may be used.

Caffeine has been examined as a tool for assessing human influence on aquatic systems. Although caffeine is metabolised when consumed, a small amount of ingested caffeine remains intact when excreted (Peeler *et al.* 2006). Overall, concentrations of caffeine are typically less than those of faecal sterols, but caffeine tends to stay in solution, whereas sterols associate with fine particulates (Peeler *et al.* 2006). Consequently, where sterol analysis provides no definitive answer on distinguishing human versus non-human faecal sources, the use of caffeine may prove useful.

Nitrogen species, such as ammonia nitrogen (NH_3-N), are associated with the breakdown of faecal material in water. They can be sampled using in-situ continuous probes and can give a quick and inexpensive indication of potential faecal source discharges. Nitrogen species are not, however, specific to human faecal matter nor effective in distinguishing human versus non-human sources. This indicator is best used during field investigations where automatic samplers are deployed and quick turnaround times are required.

Tertiary investigations generally rely on a small, specific set of water quality indicators. In the case of continuous probes, only one indicator may be relevant (for example, ammonium). Automatic samplers may allow for the analysis of several water quality indicators, but the set will be constrained by small collection volumes and sample preservation requirements.

The higher costs associated with using additional indicators dictate they should only be used where there is a high microbial faecal indicator result or where needed to resolve a particular source.

4.3 Remediation phase

Once a faecal source has been identified and located, action must be taken to fix or eliminate the source. To determine how to proceed in rectifying the problem, the four following questions should be answered for each individual source (Center for Watershed Protection, 2004):

- Who is responsible for the discharge?
- What methods can be used to fix it?
- How long will it take to fix?
- How will remediation be confirmed?

The answer to each of these questions will depend on the source of the discharge.

Discharges will generally originate from one of the following sources:

- residential premises due to an illegal internal plumbing connection
- commercial premises due to an illegal or cross-connection
- an infrastructure failure within the sewer
- an indirect, sporadic discharge resulting from leaks, spills or overflows from residential, commercial or industrial premises.

The roles and responsibilities for the notification and remediation of each discharge source will generally be defined on the basis of the responsibility or ownership for the asset and the Act/s under which the responsible protection agencies operate.

Where a source originates from industrial, residential or commercial premises it is the responsibility of the property owner to rectify the issue.

For local drainage issues, the property owner and/or local government (depending upon the location) are generally responsible for rectifying the source. For an infrastructure failure within the sewer, Melbourne Water or the relevant water retail company is generally responsible for remediation.

Responsibility for notifying the asset owner will depend on the location of the discharge. For local drainage and septic tank issues (systems under 5000 litres capacity), local government is generally responsible for notifying the asset owner and ensuring compliance with the Local Government Act (Victorian Government, 1989) and the Environment Protection Act (Victorian Government, 1970).

For industrial premises, EPA is responsible for notification. For sewerage infrastructure, Melbourne Water is generally responsible for notifying the relevant retail water company, with support from EPA if required.

Enforcement action that the responsible parties can implement to rectify a faecal source may comprise a:

- warning (verbal or letter)
- notices requiring remedial action
- prosecution

or

- any combination of the above.

The choice of enforcement tools will be influenced by:

- the seriousness of the offence due to the harm or potential harm to the environment or risk to public health
- the extent of the offence, the public concern generated and the need for deterrence, both specific and general
- the cooperation given and whether enforcement measures have been taken against others arising from the same incident
- the previous history of the offender and whether enforcement measures are necessary to ensure compliance with the Act/s
- the precedent which may be set by any failure to take enforcement action
- the culpability of the offender, whether it be a corporation or employee, including mitigating or aggravating circumstances.

If the asset owner is reluctant to rectify the issue or it is not clear who the asset owner is, EPA will work with the relevant protection agency/agencies to determine an appropriate course of action.

Clear guidance should be provided by the responsible agency on a time frame to remediate a faecal source. Time frames should be guided by the seriousness of the discharge in terms of the harm or potential harm to the environment. A discharge that poses a significant threat to human health or water quality must be rectified immediately.

Monitoring may be required to confirm that the remediation has been effective. Melbourne Water and/or the asset owner are generally responsible for undertaking monitoring to ensure the problem has been rectified and does not reoccur. This may be done through a surveillance or targeted monitoring program.

5. IMPLEMENTATION OF THE GUIDELINE

The purpose of this guideline is to detail a standard framework and a set of tools that can be used to locate faecal pollution sources within the drainage sub-catchments of the Yarra River. Four Victorian Government sectors are involved in the implementation of this guideline:

- Melbourne Water
- EPA
- water retailers; (South East Water, City West Water and Yarra Valley Water)
- local government.

The guideline may also be used in other urban catchments, with appropriate input from the key waterway and drainage managers for the particular catchment.

Melbourne Water: Melbourne Water is responsible for leading the screening and tracing-phase field investigations. As the regional drainage authority, it is responsible for the management of the regional drainage network and waterways (generally in catchments of greater than 60 hectares). It is also generally responsible for surveillance monitoring to ensure remediation of the source(s) has occurred and remains effective.

Environment Protection Authority: EPA Victoria is responsible for documenting and reviewing this guideline, in consultation with Melbourne Water and other appropriate agencies. EPA will also work with all responsible parties to develop clarity in remediation and enforcement roles.

EPA also provides a support role (resources and advice) for Melbourne Water in undertaking above-ground tracing activities, particularly associated with industrial premises.

Water retailers: As the key sewerage asset owners, City West Water, Yarra Valley Water and South East Water provide information on the sewer assets and emergency relief structures (ERSs). If a faecal source is identified as originating from the sewer, the water retailer is responsible for leading the investigation and remediation of the source and seeking assistance where required.

Local Government: Local government, as a local drainage authority, is responsible for management of the local drainage network (generally drains and waterways with catchments of fewer than 60 hectares) (EPA Victoria, Municipal Association of Victoria and Melbourne Water, 2005) and septic tank systems with a capacity under 5000 litres. It is responsible for notifying asset owners where a faecal source from a commercial or residential (septic tank) source has been identified as discharging into the local drainage network.

6. SUMMARY

This guideline will assist in achieving the key goals of the Yarra River Action Plan (Victorian Government 2005). In particular, implementation of the framework will enhance the abilities of responsible Victorian government agencies to address faecal contamination in urban stormwater drains in a coordinated and consistent manner.

The components of the framework comprise:

- procedures and processes to be applied, including –
  - audit of the existing system/catchment (screening phase)
  - desktop assessment of the catchment/sub catchment
  - field investigations to identify faecal contamination sources
- remediation of identified sources of faecal contamination
- surveillance monitoring to ensure the process has been effective
- roles and responsibilities for the implementation of the framework
- evaluation of the framework, based on past investigations and future advances in source-tracing tools and methodologies.

This guideline should be used in addition to other catchment management programs that address practices contributing to faecal source pollution. In some circumstances, significant faecal pollution may be directly linked to these broader catchment issues, rather than specific point-source pollution. Therefore, it is important that sanitary inspections and sewerage audits are undertaken to support faecal source tracing and remediation.

EPA envisages that this guideline will be updated as technology advances, leading to the broadening of the tools in the toolkit and further improvements in methodologies. This will potentially include adoption of new microbial source-tracing methods, particularly for indicators specific to human faecal sources.

Improved interaction between agencies will further enhance the implementation of this framework and its effectiveness in tracing and remediation of faecal inputs to waterways from urban drains.

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APPENDIX 1: DESKTOP DATA COLLECTION

Data collection	Application/source
Sewerage and stormwater assets (including ERS locations/operation)	Current sewerage information is available electronically from water retailers. Current stormwater asset information is generally provided in electronic form by local government sources. The elevation data contained within each individual asset item (i.e., the relative heights of the sewer and stormwater drains) shows whether the sewerage pipes are located above or below the stormwater drains and, so, indicates the likely pollutant pathway in the event that a fault in the sewerage network is the source of contamination. When a sewer pipe is above the stormwater drain, there is more opportunity for sewage to leak from the sewerage network into the stormwater drain than where the drainage infrastructure is located above the sewer. However, when the sewerage network is under pressure, such as during heavy rain periods, the potential for sewage to be surcharged to the environment through emergency relief structures into the drainage network increases. Seepage of sewage into the stormwater system can also occur via illegal connections, or a cross-connection from sewer to the stormwater drain.
Drainage/sewer system condition/ audits	Information obtained through drainage and sewerage audits may be useful in identifying potential faecal sources. Tributary pipe networks can also be a source of faecal pollution. This information, where known, is available from water retailers.
Illegal connections history	Where available, this information can be obtained from the Plumbing Industry Commission (PIC). PIC investigates areas that have a high proportion of substandard workmanship. If these areas correlate to locations with high bacterial loads, this may indicate illegal connections are a significant source of faecal pollution.
Renovation history	Renovation history within a target catchment is usually held by local government and is useful in assessing the likelihood of a faecal pollution incident in a particular area. Areas of significant land-use change, for example, may result in illegal connection of sewerage pipes into the stormwater system, primarily due to the lack of labelling on such infrastructure. The nature of historic development within a target catchment may suggest other types of activities that may have resulted in cross-connections or illegal connection of sewer to the stormwater system. Local government may be a good source of this type of information.
Septic tank locations	There may be small pockets of older residential areas that are not connected to sewer. These areas may have inappropriate on-site wastewater systems (as a result of their age). Local government is a good source of this type of information.
Land use/zoning	Land-use/zoning distribution data assists in guiding the selection of appropriate tool(s) for investigations. For example, a tool that works well in an industrial catchment may not be as effective in a residential catchment. This data can be obtained from local government and EPA.
Pollution complaint history	This information is available from EPA and other agencies that may receive community reports of pollution. Pollution complaint history may indicate potential faecal pollutant sources.
Industry types	EPA, local government and retail water companies hold information that can contribute to developing an understanding of industry types within a sub-catchment.

APPENDIX 2: TOOLS FOR INVESTIGATION OF FAECAL SOURCES IN DRAINS

Tool	Description	Advantages/disadvantages	Application
Subsurface tools			
Physical drain inspection	Walking up the drainage network to determine the physical location of sewer ingresses into the stormwater system.	Most cost-effective method for identifying faecal sources, particularly continuous discharges, where access allows. Requires specialist qualifications, including personnel with confined-space certification and experience. Access and safety issues depend on drain type and location.	Primary and secondary investigations.
Drainage line inspection	Walking the open drainage line, observing any flows/ discharges in order to identify pollution sources.	Open drainage lines are rare in urban environments. Faecal pollution may not be visible, requiring sampling to confirm pollution.	Primary investigations.
Pit lid lifting	Lifting of stormwater pit lids and observing the flow characteristics within the network.	Most cost-effective method combined with visual observations, where access to the system is not constrained. Similar range of constraints to a physical drain inspection.	Widely applied during primary investigations. Most applicable for primary and secondary investigations.
Dye testing	Flushing of dye into the sewer at a specific location and having observers at other locations to determine the location of breach from sewer to stormwater. It is an excellent tool to identify illegal sewer connections. Numerous products and colours.	Does not require confined-space entry. Can pinpoint a specific source, generally from specific premises. Effective in identifying intermittent source from premises. Property owners must be notified. Cannot be undertaken at multiple premises at a time and requires at least two staff. Can be difficult to see dye during high-flow or turbid conditions. Can be time-consuming during low flows and gradients. Some of these products are not inert and may themselves constitute pollution at incorrect concentrations.	Most applicable after primary, secondary and tertiary inspections, where illegal connections are suspected.
CCTV inspection	Use of remote camera equipment in stormwater and sewerage systems to determine the location of breaches where sewer or other groundwater is or has the potential to infiltrate the stormwater system.	Useful tool where access to the stormwater or sewer system is constrained. Will not detect all types of discharges, particularly if discharge is not happening at the time of inspection. Televising is not practical under high flows or where sewers are obstructed. Specialist equipment and skills required. Can be expensive.	Most applicable where access to the stormwater or sewer system is restricted.

Tool	Description	Advantages/disadvantages	Application
Smoke testing	Pumping smoke into either sewer or a septic to determine whether there are leaks in the system.	Direction of smoke flow may make identifying the source of the breach difficult. This tool is most appropriate for drainage networks where pipe diameters are too small for CCTV and/or multiple access to individual properties is required (i.e., source has not been isolated to one location).	Most applicable where access to the stormwater or sewer system is restricted.
Sonar	Use of sonic waves to determine the structural integrity of the pipe.	Specialist knowledge regarding their operation is required.	Not widely applied. Most applicable after primary, secondary and tertiary investigations fail to detect a source.
Air testing	Similar to smoke testing, but the leak is defined by bubbles. Can be investigated using off-the-shelf equipment and detects small fractures in piped networks.	Generally applies only to areas where pipes are submerged below a fluid to enable identification. Less effective in porous pipes.	Not widely applied. Most applicable after primary, secondary and tertiary investigations fail to detect a source and where pipes are submerged below a fluid.
Rising-stage hydrograph sampling (i.e., rising-stage bottles)	Rising-stage samplers are low-cost alternatives to automatic samplers and can be used to collect representative water quality samples over a hydrograph event.	Collecting representative samples manually over a hydrograph event is generally impractical using a manual sampling program. Simple rising-stage samplers are very successful for event-based sample collections.	Most applicable for secondary and tertiary investigations. Effective method to identify intermittent discharges.
Automatic data collection	Makes use of automatic equipment programmed to collect samples in response to changes in stage, flow and time.	Not as labour-intensive as manual sampling. Effective in taking a large number of samples over a set time scale and typically characterises water quality over a longer period. Effective in identifying intermittent discharges and sporadic discharges. Effective in assessing and evaluating the variable nature of faecal source discharges. Costly. Considerations when using automatic sampling methods include cost, vandalism, power failure, flood damage or programming errors. Some parameters are not amenable to collection by an automatic sampler.	Most applicable for tertiary investigations due to cost. Effective method to identify intermittent and sporadic discharges.

Tool	Description	Advantages/disadvantages	Application
Surface tools			
Premises inspection	The inspection of premises identified as a potential source of faecal contamination. May be undertaken in conjunction with dye tracing and/or another subsurface technique.	May need to be undertaken during non-standard working hours in areas with high employment. Issues associated with access in areas where occupation is sporadic/transient. Resource-intensive if an entire block is to be inspected.	Secondary and tertiary investigations.
Plumber interviews	Cold-calling of plumbing contractors within a specific area to determine the degree of illegal connections.	This is considered to be largely 'hit and miss' as the trade may be very transient in some areas.	Desktop data collection phase.
Semi-buoyant markers	Flushing buoyant devices down the toilet with address details from where they were flushed to determine which houses have leaky sewer systems.	Application relies on having a fairly clear indication of the premises suspected of being the pollutant source. Getting devices of the correct buoyancy and size to be transferred from the sewerage system into the stormwater system may be problematic. Furthermore, a capturing device must be fitted to the stormwater outlet to ensure that all devices are caught.	Not widely applied. Secondary or tertiary investigations.
Covert surveillance	Undertaking surveillance of areas suspected to be dumping points for illegal operators. This can involve the use of personnel working covertly or remote video equipment.	Resource intensive. Can be costly.	Most applicable for tertiary investigations and sporadic discharges.

APPENDIX 3: WATER QUALITY INDICATORS

Indicator	Comment	Recommendation
Core water quality indicators		
E.coli	*E. coli* is an excellent indicator of fresh faecal contamination at high levels in freshwater. Not specific to human faecal sources.	Recommended in conjunction with chemical indicators. Relatively easy and inexpensive analyses. Most applicable in freshwater environments. Cannot be measured using automated sampling techniques. Applicable to all investigations.
Enterococci	There is evidence that enterococci are better associated with health effects in marine and estuarine recreational waters than *E. coli*. However, this relationship has not been established for freshwaters. Either indicator is relevant to assess the generic level of microbial contamination in stormwater. Not specific to human faecal sources.	Recommended in conjunction with chemical indicators. Relatively easy, inexpensive analyses. Most applicable in saltwater/estuarine environments. Enterococci is used to complement *E. coli* in assessments where natural *E. coli* multiplication is suspected. Cannot be measured using automated sampling techniques. Applicable to all investigations.
Ammonia	Ammonia in concentrations of greater than 1 mg/L is generally considered to be a positive indicator of sewage contamination. It can be analysed in the field, allowing for rapid results. Ammonia by itself is not always an accurate indicator of sewage contamination, particularly if the discharge is diluted by 'clean' water. Commercial and industrial discharges can contain high ammonia concentrations, so it cannot accurately distinguish between human and non-human faecal sources.	The ammonium/potassium ratio may be utilised as a single-parameter approach to accurately characterise a faecal source discharge in the field. A ratio of one or more generally indicates a sewage discharge and less than one generally indicates a washwater source. Applicable to all investigations.
Additional indicators		
Caffeine	Caffeine is a compound that is present in several beverages such as coffee, tea and carbonated drinks, and in pharmaceutical products. Caffeine and its metabolites are excreted in the urine of individuals who have consumed beverages and pharmaceuticals containing caffeine. It has been speculated that it could be used as an indicator of human faecal pollution if the population being studied uses caffeine.	Should only be employed to distinguish human contribution to the faecal load once a high level faecal result has been obtained. Requires further assessment and validation to determine accuracy and applicability before it can be recommended as an effective target indicator of human faecal contamination. Its routine use in this framework to track faecal sources is not supported.

Indicator	Comment	Recommendation
Detergents/surfactants	Detergents (based on their presence or absence) can be used as an indicator of 'contaminated water' as opposed to clean water in a stormwater drain. Use of detergents alone cannot distinguish between human and non-human pollution sources (i.e., washwater). Analysis can be expensive.	Not recommended as a standard indicator for primary or secondary investigations, without the use of a further additional indicators to distinguish between human and non-human faecal sources.
Faecal sterols	Faecal sterols are able to distinguish human from herbivore faecal matter. They can persist in the environment for significant time and, therefore, are not specific to recent pollutant sources. Analysis can be expensive.	Faecal sterols as an indicator should only be employed once a generic high-level faecal result has been obtained, in order to distinguish the human contribution to the faecal level. At this time, it is the preferred indicator to establish human contribution to the faecal load. Applicable to screening investigations.
Physical observations		
Odour, colour, turbidity, litter/floatables, damage to structures	These visual/physical observations are very important for any field investigation because they are the simplest method of identifying a gross faecal pollution source. It can be difficult to identify and isolate the discharge type using these observations.	Cost-effective indicators of contamination. Not necessarily specific to sewage. Most applicable to primary and secondary investigations.