

**Development of decision analysis
trees for faecal source tracking
in surface waters**

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Development of decision analysis trees for faecal source tracking in surface waters

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1 SUMMARY

A website based on faecal source tracking (FST) has been established to facilitate identification of the sources of animal/human/bird faecal contamination in waterways. The website is temporarily located at http://www.pulsenetinternational.org/fsid_httpdocs, and will be moved to be hosted by the ESR website by end of July. The permanent URL for access to the website will be <http://www.waterquality.org.nz>. A series of three non-interactive decision analysis trees has been developed and incorporated into the FST website. The decision analysis trees provide step-by-step guidance through the process of determining which of the molecular and chemical tools are appropriate for FST in a particular environmental site. It is envisaged that implementation of the decision trees and supplemental information provided on the website will improve cost and time efficiencies when dealing with surface water contamination issues. Each step of the decision tree incorporates a colour code which specifies the cost, timeframe and degree of certainty associated with individual and combined molecular/chemical tools. It is envisaged that this process will allow environmental protection dollars to be used to their best advantage, and alleviate the long wait for certain test results which may, in the past, have delayed remediation of the pollution problem. The decision trees have been developed in consultation with water managers, in particular, Trevor James of the Tasman District Council.

The website contains background information on each of the molecular and chemical tools applied to FST, including peer reviewed papers relevant to each subject. The website provides a streamlined system for understanding the logistical requirements for investigating a faecal contamination site. Visitors to the site are guided through the various steps from the initial site survey to sample collection and transport. The site survey determines the potential faecal sources, and thus impacts on which of the three decision trees is to be applied. Forms for the Site Survey and Sample Request Forms are presented as PDFs downloadable directly from the website.

Application of the toolbox of FST tests is discussed in a series of real world case studies which illustrate the potential effectiveness of the toolbox approach to tracking the source(s) of faecal contamination and why using tools in isolation may yield erroneous results. It is also envisioned that this website will play a role in connecting water managers with other laboratories/events/personnel helpful to an investigation of faecal contamination in a waterway.

Application of the decision analysis tree to water contamination issues will be trialled by water managers in regional councils and ESR will actively seek their advice on modifications to the system/website. The website and decision tree system was presented to the Surface Water Integrative Management (SWIM) meeting in April 2008.

1. INTRODUCTION

Faecal source discrimination in surface waters is an important step in the management of New Zealand's environmental waters. Identification of high levels of the microbial faecal indicators such as *Escherichia coli* during routine sampling of waterways must be followed up to determine the source of the faecal contamination. Mitigation of the pollution requires identification of the faecal source and this step has become more complex as the number of tools available for analysis has increased. This has led to a need for clear guidance on the usage of these tools and the interpretation of the results they generate.

The Tasman District Council (TSDC) sought guidance on which tools are most effective for determining the source(s) of faecal contamination when high levels of *E. coli* are detected in waterways. The development of the decision analysis tree to support the use of faecal source identification tools was a direct request from TSDC to the service provider, ESR. TSDC perceived the wider need for help among regional councils to understand the various tests available for faecal identification, their relative costs and the need for guidance in the assessment of their usefulness for a particular environmental catchment. The proposal was for the development of new, readily usable, documented guidelines that could be applied by environmental managers or others, to facilitate the prudent application of tools for faecal identification. At present, much of the information about faecal source identification is held in research institutes, partly, because this field is a rapidly developing area of research.

The development of the decision analysis tree will simplify the tools selection process. Furthermore, it will avoid situations that have occurred in the past where environmental managers have requested the tools that are the most expensive and take the longest analysis time. This means that environmental protection dollars are not being used to their best advantage, and the long wait for some test results may lead to significant delays in the remediation of the pollution problem. These delays can have a negative impact on recreational water use, and shellfish growing industries that rely on continuous supplies of clean water.

1.1 Background

Microbial faecal indicators such as *E. coli* identify the presence of faecal contamination, but do not identify whether the source is from birds, farm animals, humans or other animals e.g. feral species. A range of tests has been developed that aid the discrimination of faecal sources. They are referred to as a “toolbox” and include molecular and chemical markers that distinguish between animal, bird and human faecal sources. Proposed indicators of faecal contamination include genetic markers from host-specific micro-organisms, and chemical indicators, including faecal sterols (FS) and fluorescent whitening agents (FWAs). Each one of these tools is relevant for a particular purpose and, when used in conjunction with other tools, can increase the certainty that pollution is derived from a specific source. However, each test has widely different costs associated with it, different levels of certainty, particular situations where it works best and varying time delays. Therefore, it is difficult for an end-user to understand which combination of tools will provide the desired information in a particular situation for the least financial outlay, and within the required timeframe.

It is envisaged that transferring the knowledge about faecal discrimination from the research scientists to the regional councils via the decision analysis trees will reduce the dependence of the regional councils on ESR for the provision of scientific interpretation of results. Furthermore, increased confidence in the results of faecal source testing will enable resource scientists to resolve contamination problems. The output will be available to *all* regional and district councils and was perceived by members of the Surface Water Integrative Management (SWIM) group (formerly SWIG, Wellington, 2007) as a valuable asset to faecal discrimination.

1.2 Objectives of the study

This project aims to develop a non-interactive decision analysis tree that provides step-by-step guidance through the process of determining which tools are appropriate for a particular environmental site. It will assist resource scientists and officers in determining **when** and **how** to use faecal source tools, and then **what** the results mean.

In this way, cost and time efficiencies will be improved for environmental management.

The deliverables from this project will be:

- A web-based decision analysis tree for helping to decide how to use faecal source identification (ID) tools. At each step on the tree there will be information such as the situations where the tool is best applied, the cost of each tool and analysis timeframe.
- A web-based decision analysis tree for interpreting the results of investigations using faecal source ID tools.
- Documentation available on-line supporting the web-based decision analysis tree with full explanations of the process and tools, including an interpretation of the uncertainty surrounding the use of each tool, individually, and in combination with other tools.
- A workshop to provide training, particularly for council staff, in the use of the decision analysis tree.

2 THE WEBSITE

2.1 Outline of the design of the website

Following discussions with water managers in regional councils, a website has been developed which is temporarily located at http://www.pulsenetinternational.org/fsid_httpdocs. This will be integrated into the ESR website by accessing www.waterquality.org.nz by the end of July 08. The permanent URL will be widely advertised.

The FST website contains information which supports the implementation of FST tools with more complete explanations of the processes behind each step in the decision tree. The website contains seven major theme headings (Figure 1) in the primary row of tabulated categories and each of these primary tabs has ancillary tabs which further expand on the subject area and contain links to other relevant WebPages within the FST website. These seven major category headings and ancillary subjects are discussed briefly below and it is suggested that the following explanatory text should be accompanied by a simultaneous review of the live website at http://www.pulsenetinternational.org/fsid_httpdocs.

2.2 Home Page

The home page is titled “Faecal Source Tracking: Sophisticated Techniques to Identify and Mitigate Water Contamination Issues” and introduces the concept behind FST by providing short descriptions of case studies which illustrate its value as an environmental management tool. This page also describes the four fundamental methods that ESR currently employs in FST: the microbiological methods of PCR markers and library-based methods, and the chemical methods of FS analysis and FWAs.

Faecal Source Tracking

Using science to help inform water management decisions



Home

Decision Trees

Toolbox

Case Studies

Research

Publications

Contacts

An information source for those interested in identifying sources of faecal contamination

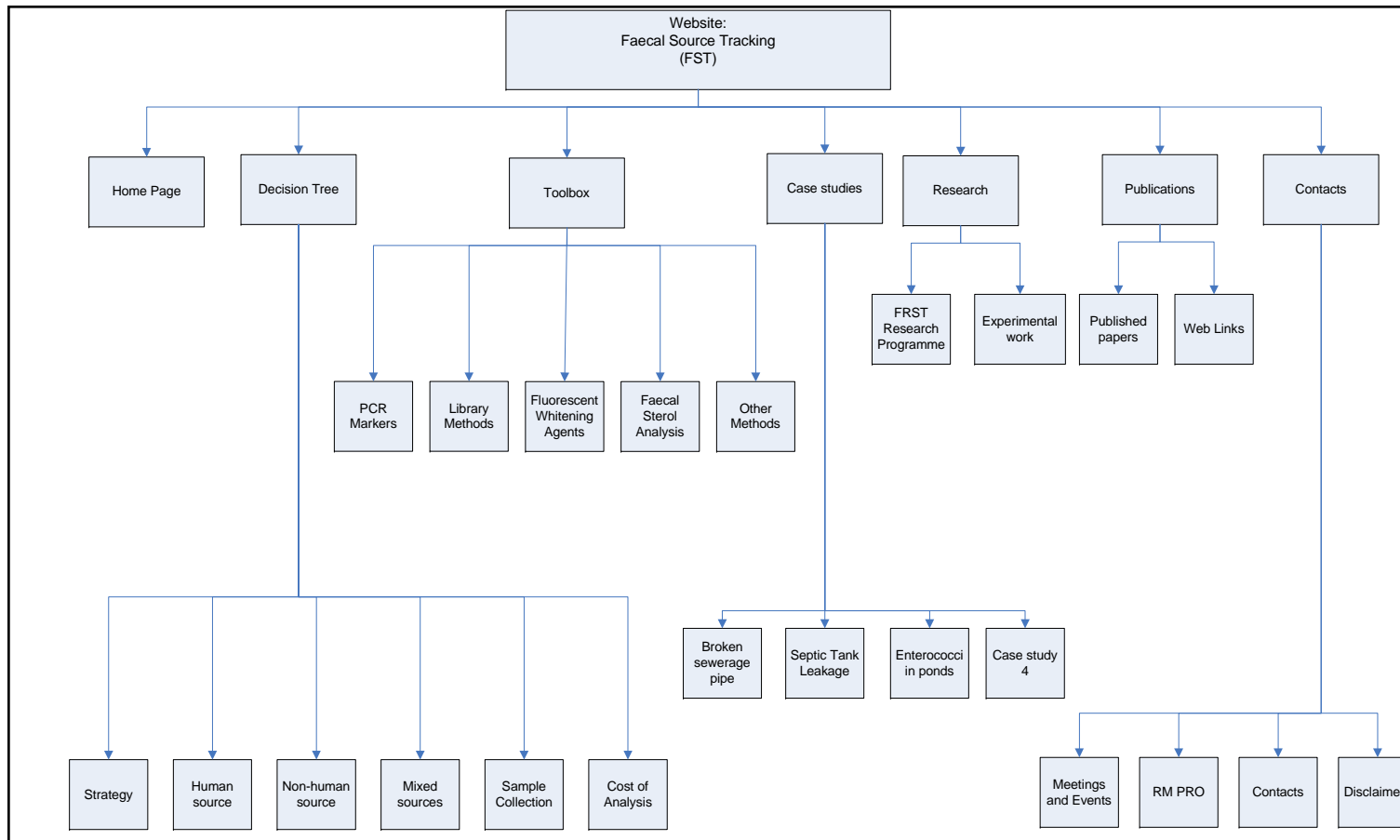


Figure 1: Diagram of web layout for the Faecal Source Tracking information and Decision Trees

2.3 Decision Tree

The Decision tree tab is split into six sections and contains the majority of the information required by water managers when beginning an investigation into the sources of faecal contamination in a waterway. The first tab labelled “Strategies” begins with a description of the strategy employed to investigate a faecal source and includes links to a site survey questionnaire to enable water managers to classify the potential faecal inputs into a specified waterway(s). There is also a link to the ESR sampling request form. Once the investigator has determined the likely potential source of pollution they are directed to the next three tabs which outline the decision tree processes for specifying which of the FST tools are useful for identifying faecal contamination from:

- human sources,
- non-human (animal and/or bird) sources, or
- mixed sources (human /animal/bird faecal events).

Each decision tree includes a colour-coded system denoting the cost of analysis, the relative certainty associated with each test, and the timeframe for analysis. The colour coded system is applied to individual tests and also combines sequential tests, so that the investigator can assess the cumulative effect of individual steps in the decision tree.

Guidance on the usage of these tools should avoid situations that have occurred in the past where environmental managers have requested the tools that are the most expensive and take the longest analysis time. It is envisaged that this process will allow environmental management dollars to be used to their best advantage. Furthermore, it will alleviate the long wait for certain test results which may, in the past, have delayed remediation of the pollution problem. These delays can have a negative impact on recreational water use and shellfish growing industries that rely on continuous supplies of clean water.

Each decision tree page contains explanatory information to add context to the decision process and each tree is downloadable as a PDF from these pages. Figure 2 shows an example of a decision tree for analysing a site where human faecal pollution is suspected as the source of contamination. Figure 3 shows the Colour Key used to identify the costs, certainty and timeframe associated with each step in the decision tree.

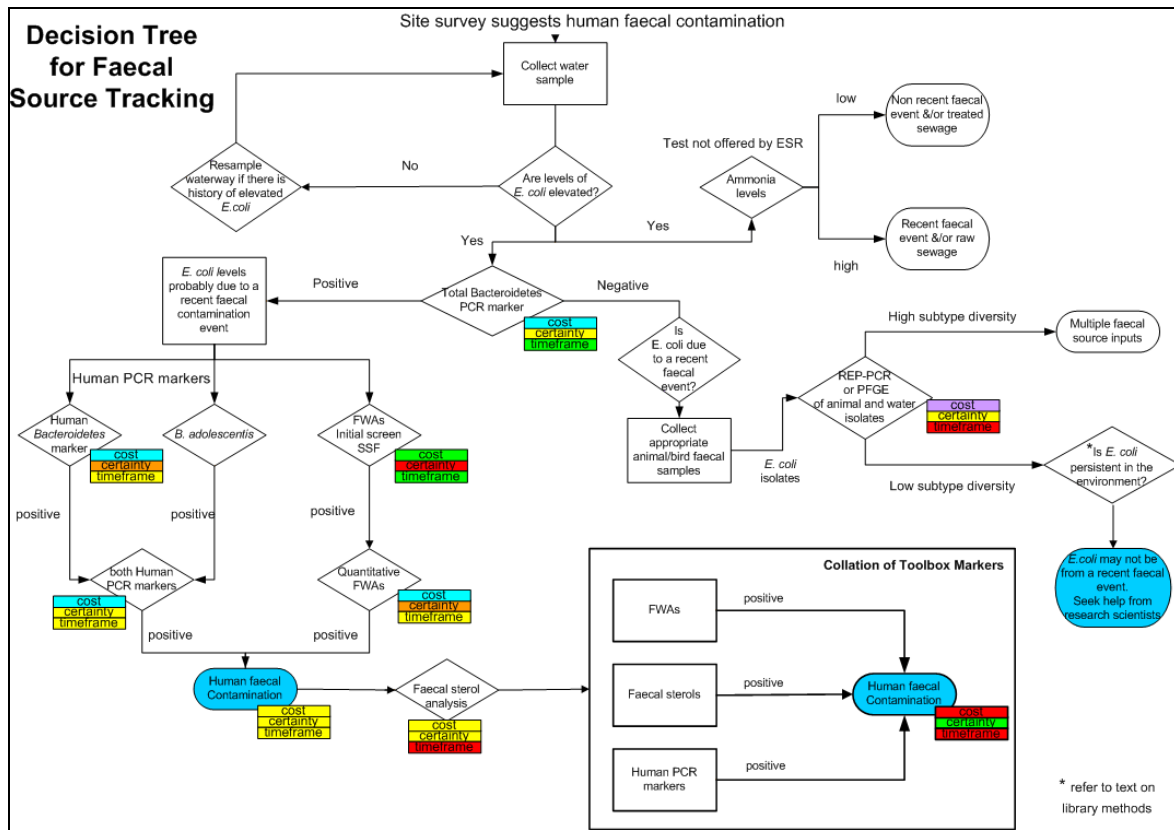


Figure 2: Website pictorial of decision tree for human faecal contamination

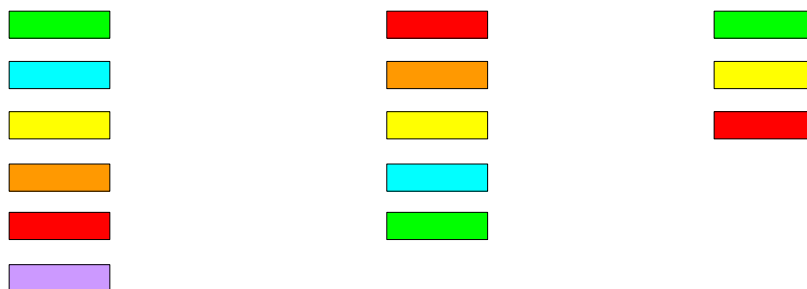


Figure 3: Colour Key for Decision tree

The information for sample collection and transport to ESR and a page outlining the cost of each analysis is under the same major decision tree category.

2.4 Toolbox

The toolbox theme is divided into five WebPages which expand on the information about each of the analytical tests available for FST and potential new areas for additional research tools:

- Polymerase Chain Reaction (PCR) Markers
- Library Methods
- FWAs
- FS Analysis
- Other Tools

Methods evaluated under the ancillary tab 'Other Tools' include the use of F-RNA bacteriophages to distinguish human faecal pollution. A new approach being investigated by ESR is identifying phages that invade bacteria of the *Bacteroides* genus which are specific to humans. This section could also include information on other faecal contamination tests perceived as useful by SWIM members but not performed at ESR.

Each webpage contains links to information on literature relating to the particular method under discussion, and to the page on Costs of Analysis. A screenshot of the FWA page is shown on the following page.

Figure 4: Website pictorial of FWA webpage in the toolbox category

Faecal Source Tracking
Using science to help inform water management decisions

Home | Decision Trees | **Toolbox** | Case Studies | Research | Publications | Contacts

PCR Markers | Library Methods | **FWAs** | Faecal Sterols | Other Tools

Fluorescent whitening agents

The presence of FWAs indicates human effluent.

Washing powder manufacturers regularly add organic compounds called fluorescent whitening agents (FWAs) that adhere to woven fabrics, and which adsorb the short (ultraviolet) wavelengths from sunlight and emit most of the absorbed energy as higher wavelength blue light. This fluorescence, which is more noticeable with white fabrics, makes clothing appear brighter and cleaner.

Most household plumbing mixes the effluent from toilets with 'grey water' from washing machines and, consequently, FWAs are usually associated with human faecal contamination from both individual septic tank systems and community wastewater schemes.

Although a range of FWAs is available, only one (4,4'-bis[4-anilino-6-morpholino-1,3,5-triazin-2-yl]-amino]stilbene-2,2'-disulfonate) is used in New Zealand (FWA 1), which simplifies their analysis.

NaS(=O)(=O)C1=CC=C(C=C1)/C=C/C2=CC=C(C=C2)-C3=CC=C(C=C3)/C=C/C4=CC=C(C=C4)S(=O)(=O)[Na]

A1557 (FWA1)

The key features of FWAs include:

- They are not known to occur in nature.
- They are highly polar adsorbing strongly to the polysaccharides of paper and clothing.
- Irradiation by sunlight causes them to bind irreversibly to cellulose of protein, enabling binding to cotton and nylon fabrics.
- They are highly water soluble.
- They undergo photochemical degradation; the half-life is several hours under summer noon sun.
- There are no known health effects of FWAs at levels seen in effluent or water.

Synchronous scanning spectrofluorophotometry

A Synchronous Scanning Spectrofluorophotometer (SSS) is programmed to scan through a defined wavelength range for both the excitation and emission wavelengths of a fluorescent compound. This analysis produces a plot of fluorescence intensity versus emission wavelength and

2.5 Case Studies

This primary tab currently contains four WebPages outlining case studies where the FST tools have been applied. The case studies are of particular interest to water managers as they provide worked examples of how and why these tools have been applied, the sort of results that might be obtained, and how these have been interpreted. We envisage expanding this section significantly. With the permission of water managers, additional details could be included which may add to the value of these currently anonymous examples.

2.5.1 Stormwater drain investigations

This scenario investigates a series of intersecting stormwater drains where high levels of *E. coli* were observed and the toolbox was able to trace the human pollution along the watercourse allowing water managers to narrow their search for leaking sewer pipes.

2.5.2 Three streams and a duck pond

An investigation of very high levels of *E. coli* in four separate waterways illustrates the benefits of the FST toolbox where multiple tools are applied. This case study discusses the results in light of the variables encountered during testing.

2.5.3 River Investigations

This case study utilises the non-library tools in the toolbox to investigate faecal pollution along the course of a waterway and highlights where lower levels of *E. coli* can still lead to the identification of a faecal source.

2.5.4 Enterococci

This case study illustrates an investigation into the sources of high levels of enterococci in oxidation ponds using the library-based typing methods of antibiotic resistance and pulsed field gel electrophoresis.

2.6 Research

The two WebPages under 'Research' outline ESR's research programme for the FRST foundation which provides fiscal support for the FST research and the application of the toolbox.

2.7 Publications

This webpage provides the viewer with additional research information on FST including review articles, and papers from which the methods in the toolbox have been developed.

2.8 Contacts

There are four WebPages under this category which are outlined below:

- Meetings and Seminars

Provides information on up and coming events where topics relevant to FST will be discussed.

- **RMPRO**

An Auckland based consultancy firm for investigations of contamination in waterways

- **Contacts**

A list of ESR personnel who work in the area of FST

- **Disclaimer:**

“References in this website to any specific commercial products, process, service, manufacturer, or company does not constitute its endorsement or recommendation by any ESR employee.”

3 CONCLUSIONS

A series of non-interactive web based decision analysis trees have been developed in consultation with Trevor James from the Tasman District Council and were presented at the SWIM meeting in New Plymouth on April 16 2008. A website based on FST has been established to incorporate the decision trees along with information to support their use in water contamination situations. The website is temporarily located at http://www.pulsenetinternational.org/fsid_httpdocs, and will be moved to the permanent URL: <http://www.waterquality.org.nz> by the end of July 08. The website contains background information on each of the molecular and chemical tools applied to FST, including peer reviewed papers relevant to each subject.

The website streamlines understanding about the logistical requirements for investigating a faecally contaminated site. Personnel are guided through the various steps from the initial site survey to sample collection and transport. The site survey determines the potential faecal sources, and thus impacts on which of the three decision trees is to be applied. The decision analysis tree aids the water manager to decide which tools are appropriate for FST, based on the issues of cost, timeframe and the degree of certainty required by the investigator. Forms for the Site Survey and Sample Request Forms are presented as PDFs downloadable directly from the website.

Application of the toolbox of FST tests is discussed in a series of real case studies which illustrate the potential effectiveness of the toolbox approach to tracking the source(s) of

faecal contamination and why using tools in isolation may yield erroneous results. It is also envisioned that this website will play a role in connecting water managers with other laboratories/events/personnel helpful to an investigation of faecal contamination in a waterway. This last point will facilitate a holistic view of water testing beyond the capabilities of ESR.

4 RECOMMENDATIONS

Future directives for the FST website and decision tree analysis

- Presentation of the decision tree and website at conferences and meetings relevant to FST to encourage the use of the system by water managers. Additional training beyond the workshop as requested by interested parties.
- Publicise the website through industry and ESR publications.
- Update of statistical parameters around certainty analysis for individual tools
- Incorporation of new methods identified by the ESR research team and international studies as useful tools for addition to the FST “toolbox”, including:
 - Develop PCR markers based on microbes specific to feral animal and bird species
- Continual update and modification of the website and decision tree as requested by RC water managers.
- Explore the feasibility and usefulness of an interactive system which can be employed by water managers to input the results from a site survey to determine a customised investigation strategy with the incorporation of a second level of interaction for the interpretation of results by the decision tree.