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West Coast Regional Council

Investigating the sources of *E. coli* contamination at Marrs & Shingle beaches: Using Systems Thinking with a Stakeholder Reference Group.

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Report by:

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Table of contents

1 Introduction

In January 2018 (after ongoing discussions through the second half of 2017), Deliberate and the University of Waikato were engaged by the West Coast Regional Council (WCRC) to deliver a two-workshop process using systems thinking to investigate *E. coli* contamination in the Buller River at Marrs and Shingle Beaches. Ongoing monitoring of these sites for swimming purposes in summer months indicated that *E. coli* contamination was still a periodic problem.

The two-workshop process used a Group Model Building process to develop a Causal Loop diagram of the contamination issue. This had successfully been used elsewhere in the West Coast Region previously. These two workshops were held on Wed 8th and Tuesday 20th March 2018.

The group who were involved in this process was the Stakeholder Reference Group that had been brought together to consider this issue. These two workshops were the first two meetings of that group.

This report summarises both the process and the insights gained from it. These insights and outputs can be used by the reference group moving forward, as they seek to develop recommendations to WCRC to help manage this issue.

Funding for this work was provided by Envirolink. Peer review and technical advice for this work was provided by Graeme Doole, Professor of Environmental Economics at the University of Waikato.

2 What is systems thinking?

The world that we live in is a highly interconnected place of causality and effect. The work of policy development often seeks to respond to undesirable behaviour or patterns being experienced in our natural environment and therefore seeks to influence these causes, to alter or improve the desired behaviour.

Systems thinking is a conceptual framework and set of tools that have been developed to help make these patterns of interconnectedness clearer (Senge, 1990)[1]. They help us understand the structure of a set of various interacting factors that present in behaviour we are trying to understand. This helps us understand where change or intervention may be best targeted, to maximise leverage and change the undesirable behaviour.

The name for the academic discipline of which 'Systems Thinking' is a part is 'System Dynamics'. System Dynamics originated from the Sloan School of Management at the Massachusetts Institute of Technology, Cambridge, Massachusetts in the late 1960's. The term systems thinking as it is used in this report refers to the concepts articulated by the discipline of System Dynamics (Sterman, 2000).

[1] For a detailed introduction to the concepts of Systems Thinking, the reader is referred to *The Fifth Discipline – the art and practice of the learning organisation* by Peter Senge (1990) as an accessible introduction.

3 Methodology

This work is undertaken using a mixed-methods approach. Participants used a qualitative tool from System Dynamics called a Causal Loop Diagram (CLD) to build a map of the system believed to be causing the issue in focus. The relationships described on this CLD were then *relatively weighted* on a scale of 0 to 1 (see section 7.2.3) to determine if this provided a descriptive insight to participants as to which relationships and factors were believed to be contributing more to the issue.

Participants were then asked to identify those factors that the discussion and the development of the CLD had highlighted to them as being the points of best leverage to influence the problem. This included participants suggesting a *relative change* within the factor identified, according to the same scale as used to weight the relationships.

This information was then entered into an online modelling tool designed to calculate the *impact of the relative change* in all factors in the CLD, after an adjustment to account for the *suggested relative change* in the intervention factors was made. This tool was called *Mental Modeler*[2] and is described in section 3.2.

This additional step using the *Mental Modeler* tool was designed to add additional quantitative information to the system described by the participants. This was intended as a pragmatic process to help a group who had built a qualitative understanding of a problem move toward a more nuanced, quantitative understanding. The objective was to help participants *refine* where further detailed investigation should be targeted, with the limited budget available to the council. This builds on a CLD workshop process recently refined during master's research undertaken at the University of Waikato (Connolly, 2017).

This methodology is intended as a pragmatic approach to building understanding of an issue with limited resources, so as to best direct where further limited resources may be applied.

It should be noted that the approach taken here is not intended to *replace* detailed scientific investigations. Rather, it acknowledges several things. Firstly, that a stakeholder reference group has been constituted to help council understand the issue from a human point of view. Secondly, that this stakeholder group possesses substantial embedded knowledge around how the system operates and how these impact diverse values. Thirdly, this stakeholder-driven process is critical to establish a shared understanding of the system, identify future directions, and bring together diverse views in a constructive, solutions-focused forum. Fourthly, that while many scientific investigations could be carried out to further determine the factors contributing to the issue at hand, these are likely to be expensive, extensive and time-consuming. Lastly, that the council has limited resources and is not able to undertake extensive and expensive scientific studies.

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[2] See http://www.mentalmodeler.org/. The north American spelling of this software is used here, so as to remain consistent with its brand.

3.1 Causal Loop Diagrams (CLD)

The main tool that is used within this workshop approach is a Causal Loop Diagram (CLD). A CLD is a qualitative tool that can be used to help map out the structure of a system of causality. This helps to better understand the nature and interconnectedness of a range of factors that are generating a particular behaviour. They can be quick to generate; good for capturing the combined understanding of a system across a range of people; and good for communicating and understanding of a system (Sterman, 2000).

To develop a CLD one begins with a clear articulation of the behaviour or trend over time that is trying to be understood. A range of factors are then described and connected by arrows denoting the influences that generate this behaviour. Interconnection and feedback loops that may help to provide insight into the causes of such behaviour are identified, as are the best places in the system to intervene to alter the undesirable behaviour. These key components of a CLD are described in the following sections.

3.1.1 Factors

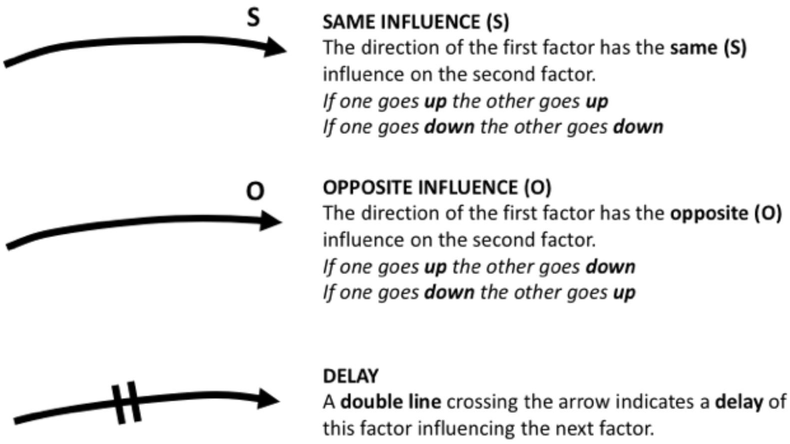
A factor (or variable) should be a noun (or noun phrase) that articulates something that may either increase or decrease (Sterman, 2000). They should be described in a manner that means they can clearly increase or decrease, qualifying directional adjectives should be avoided.

For example, an appropriate factor would be the *Price* of something. An inappropriate factor would be *Price rises,* as this predetermines a direction of change.

3.1.2 Influences (or relationships)

Influences are described by arrows that connect factors and describe their influence. These can either be *same* or *opposite* (Senge, 1990, Sterman, 2000). A *same* influence is one where the two connected factors move in the *same direction*. With an *opposite* influence, the two connected factors move in the *opposite direction* (see Figure 1). A double line crossing an arrow indicates a relative delay of some kind. This is not defined due to the qualitative nature of the tool but may be elaborated on in supporting descriptions.

Figure 1. The different types of influences



While these may be supplemented by supporting descriptions or detail, a good rule of thumb is that they should be obvious when read in conjunction with the two connected factors.

3.1.3 Balancing and reinforcing loops.

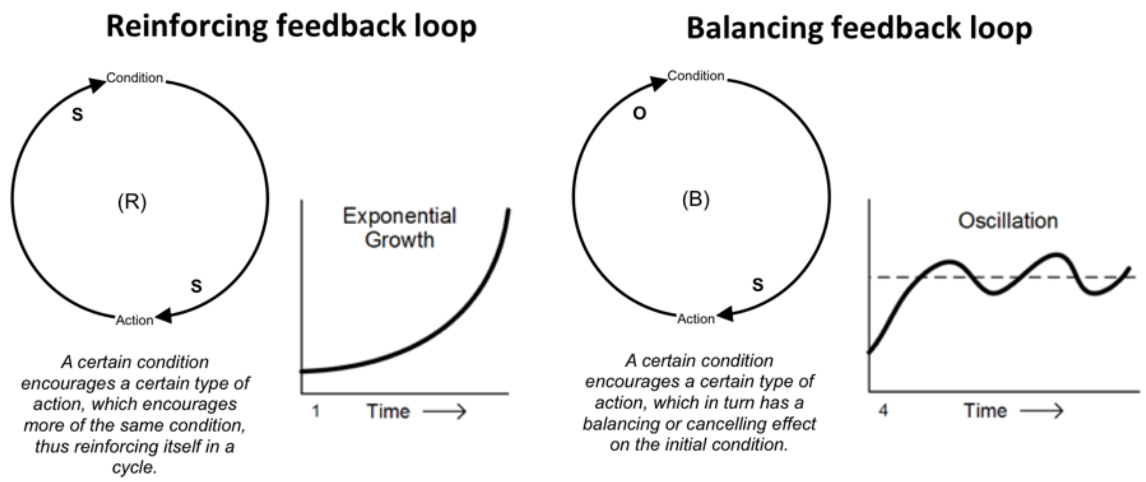
Systems thinking is especially interested in systems where loops of causality are identified – these are called *feedback loops*. There are two types of feedback loops, *balancing* and *reinforcing* (Senge, 1990).

In a *balancing feedback loop*, the direction of influence (i.e. same or opposite) provided by one factor to another will transfer around the loop through that one factor (or series of factors) and influence back on the originating factor in the *opposite* direction. This has the effect of *balancing out* the direction of the original influence.

In a *reinforcing feedback loop*, the direction of influence (i.e. same or opposite) provided by one factor to another will transfer around the loop and influence back on the originating factor in the *same* direction. This has the effect of *reinforcing* the direction of the original influence, and any change will build on itself and amplify.

The two types of feedback loop are described in Figure 2.

Figure 2. The two types of feedback loops



Adapted from Senge (1990) & Ford (2010)

3.2 Mental Modeler

The online software tool of *Mental Modeler* is used to quantify the impact of a relative change in a factor on those elements that are linked 'downstream' from it within the CLD. The effect of a relative change depends on three things.

1. The size of the change in the initial factor.
2. The direction of the relationships present between subsequent elements in the CLD.
3. The strength of these relationships in subsequent elements in the CLD.

First, the direction and strength of all links in the CLD (items #2 and #3 in this list) were determined with the stakeholder group. Each link was allocated a number between -1 and 1, where -1 denotes a very strong negative relationship, 0 denotes no relationship, and 1 denotes a very strong positive correlation.

Second, the stakeholder group generated scenarios that involved identifying the initial factor to change and by how much (item #1 in the list above).

Third, the model was run. The output of the model outlined how the change in the initial factor imposed relative changes on other elements that were linked to it, downstream in the CLD.

3.2.1 Scale used to weight influences

The weighting scale used to weight both the influence of factors and the proposed change in factors under various scenarios is outlined below. Note it is a *relative* scale not an *absolute* scale. This means that it is not able to provide any authoritative quantitative insight into any relationship described. Rather, this is intended as a way of strengthening the qualitative insights provided by the CLD.

The relative weighting scale is made up of 5 steps. These can apply to either the level of influence or the amount of change made to a factor through an intervention. These are Very Low (VL); Low (L); Medium (M); High (H) and Very High (VH) (see Table 4).

Table 1. Scale used to weight both strength of influence and potential change in a scenarios factor(s)

Weighting definition	Numerical weighting (on a relative scale of -1 to +1)
Very High (VH)	**+/- 0.9**
High (H)	**+/- 0.75**
Medium (M)	**+/- 0.5**
Low (L)	**+/- 0.25**
Very Low (VL)	**+/- 0.1**

Note: This scale can be used in either a positive or negative sense. For example, a *high influence in the same direction would be +0.75*, while a *high influence in the opposite direction would be -0.75*.

3.2.2 Example output from Mental Modeler

An example output graph from the Mental Modeler software is shown in Figure 3. This shows the *relative* impact of a change in one or more factors on the other factors within the CLD.

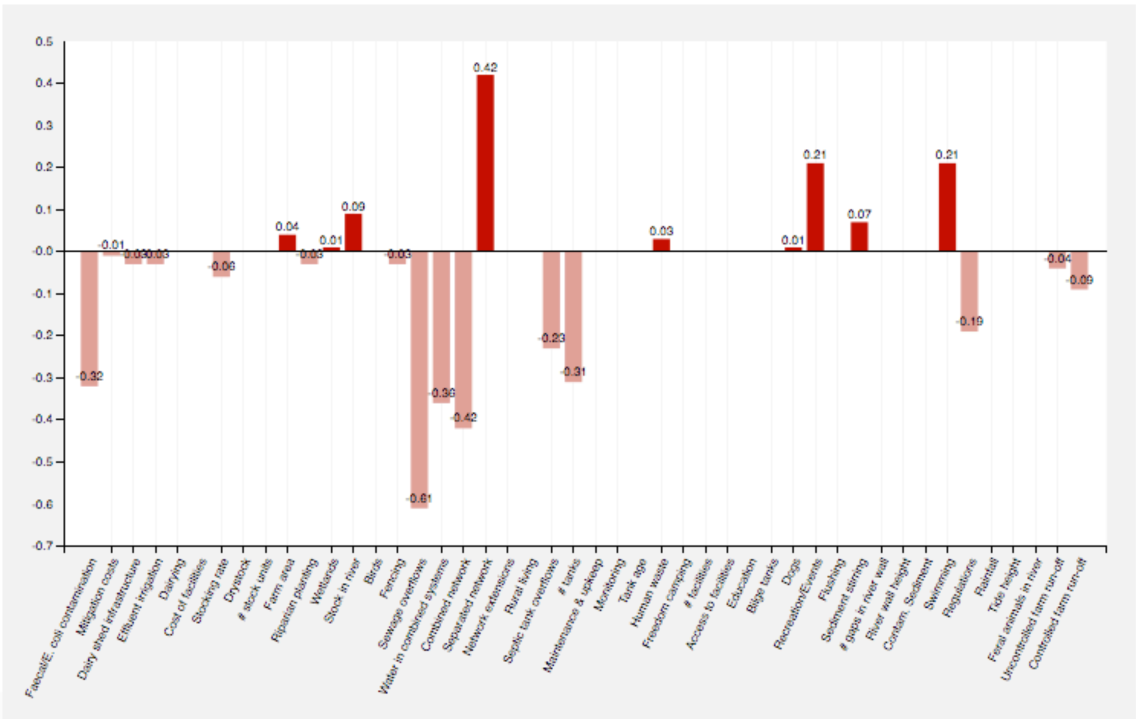
The scenario feature allows one or more factors within the CLD to be *increased or decreased by a relative amount* according to the same scale outline in section 3.2.1 (for example and increase by a *high* amount or decrease by a *very low* amount). In this example (which is discussed in section 7.6) the proposed scenario of increasing *system upgrades by a medium amount* is being explored.

Outputs are in graphical form. The horizontal axis lists the factors in the CLD, excluding any factor(s) that have been amended – it only shows the impact on non-adjusted factors. The vertical axis is the *relative scale of change* as outlined earlier on the scale of -1 to +1. The dark red bars above the line are *positive* numbers and therefore reflect an *increase* in that factor, while the light red bars below the line are *negative* numbers and therefore reflect a *decrease* in that factor.

The actual numerical change in the factors is labelled on the bars on the graph.

Note that while the scale on the vertical is always somewhere between -1 and +1, this will change for each graph delivered by the software. So, while the output numbers are directly comparable, bear in mind that bars that look the same height on different graphs, may in fact be at slightly different scales.

Figure 3. Example output from Mental Modeler



4 The issue – *E. coli* contamination at Marrs and Shingle beaches.

The West Coast Regional Council (WCRC) monitors water quality at the popular swimming beaches of Marrs and Shingle beaches during the summer months. This monitoring has found that *E. coli* levels at these beaches frequently exceed the limits for Alert/Amber and Action/Red surveillance modes set by the New Zealand Microbiological Water Quality Guidelines for Marine and Freshwater Recreation (Ministry for the Environment (MfE) and Ministry of Health (MoH), 2003).

Figure 4. E. coli testing results at Marrs Beach (2001-2018). Data supplied by WCRC.

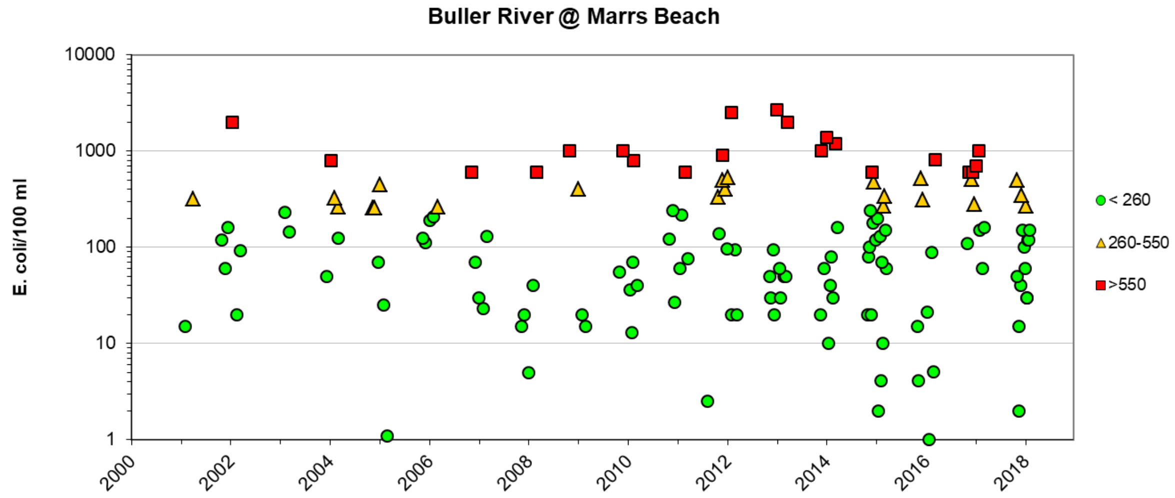
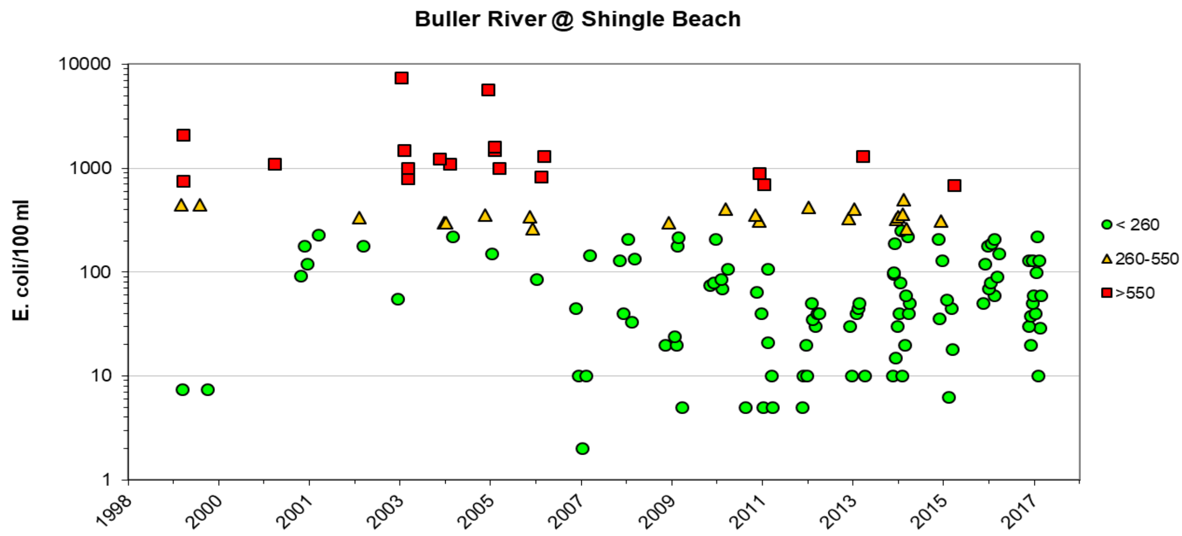


Figure 5. E. coli testing results at Shingle Beach (1999-2017) . Data supplied by WCRC.



The Councils wanted to further investigate the issue of contamination at these swimming beaches with stakeholder involvement so as to best understand the issue from as many perspectives as possible.

Limited faecal source tracking (FST) has been undertaken what has been undertaken was fairly inconclusive. This lack of firm data emphasises how important the broad scale approach with stakeholders outlined in this report was. A narrower scientific focus is usually predicated by definitive, or very good source tracking data as well as other forms of sampling and flow data.

5 Workshop attendees

The following people attended the two workshops.

Table 2. List of workshop attendees

Name	Perspective or organisation	Workshop 1	Workshop 2
Participants			
Mona Andreas	WCDHB	✓	✓
Jamie Cleine	Buller District Councillor	✓	✓
Neal Clementson	West Coast Region Councillor	✓	✓
Chris Coll	Surf Lifesaving	✓	✓
Alice Gilsenan	House beside Marrs Beach	✓	✓
Dave Vercoe	Attending with Alice	✓	
Joan Hamilton	Swimmer	✓	✓
Robert Higgins	Farmer (near scheduled wetland)	✓	✓
Mick Hopkinson	Kayaking/Tourism (Murchison)	✓	
Erica Jar	Teacher	✓	✓
WCRC staff			
Hadley Mills	Planning Manager	✓	
Emma Perrin-Smith	Freshwater Scientist	✓	✓
Alyce Melrose	Planner	✓	✓
Jonny Horrox	Freshwater scientist		✓
Justin Connolly	Facilitator (Deliberate)	✓	✓

6 Workshop 1 (8 March 2018)

The first workshop was held on Thursday 8th March 2018. This section outlines the process for the day and the outputs from it.

6.1 Process for the day

The process for the first workshop was as follows:

1. Introduce participants to each other (as they were meeting for the first time).
2. Introduce them to the concepts of a CLD (factors and influences/relationships).
3. Elicit factors from the group that were perceived to be contributing to the *E. coli* contamination issue.
   (E. coli contamination is a general, cost-effective indicator used by Councils to test for the presence of other pathogens, most often thought to indicate faecal contamination.)
4. Describe how these factors influenced *E. coli* and each other, while drawing a CLD as a group.

6.2 Focus question

The discussion was guided by the following focus question throughout the day:

> ***"What are the factors that influence E. coli contamination at Marrs & Shingle beaches?"***

6.3 Outputs from the day

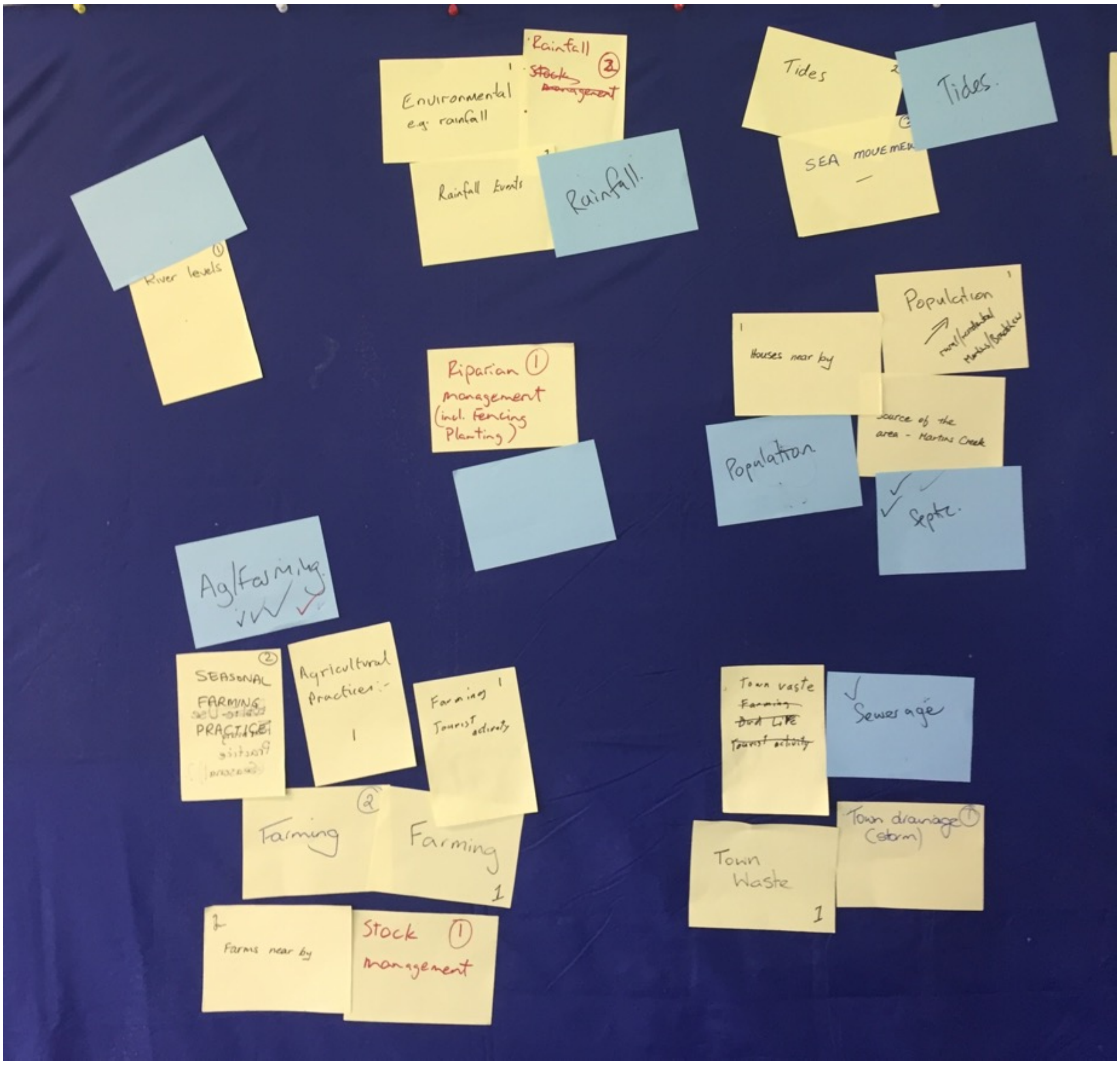
The focus question generated a high level of quality discussion amongst participants across the day. The resulting outputs are described below.

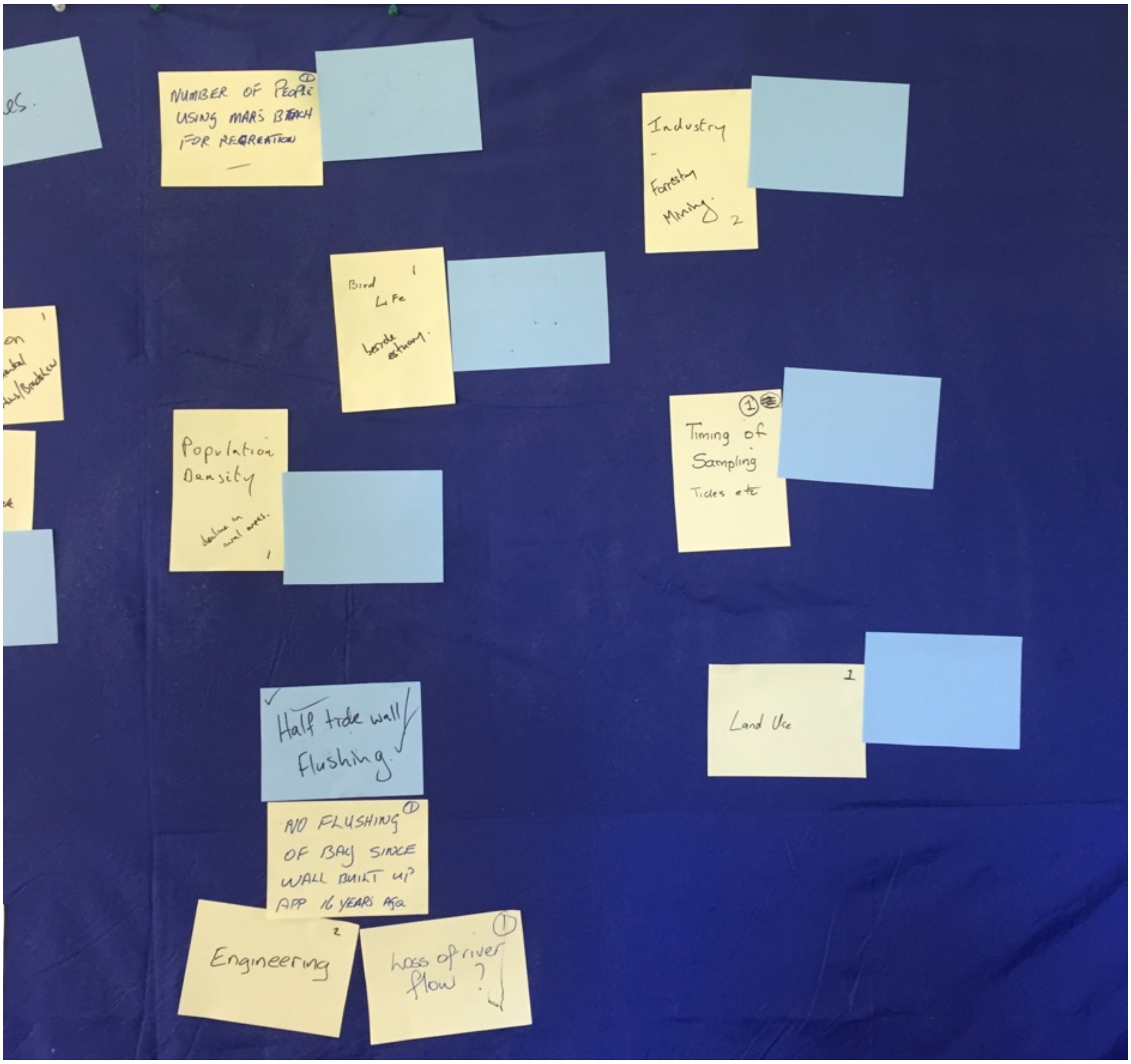
6.3.1 Factors

An initial list of factors believed to be influencing *E. coli* contamination was generated by the group. This was done by participants each contributing three factors and then the group sorting these into agreed factors. These were then prioritised via a simple voting mechanism. This was intended to prioritise the factors for discussion, not to allocate any of them more importance than any others.

The initial factors identified by the group are shown in Figure 6.

***Figure 6.** Initial factors identified by participants (two photographs). The factors have been grouped according to their similarity and labelled with apiece of blue paper. Blank pieces of blue paper are where there was no need to determine a separate name for the variable.*



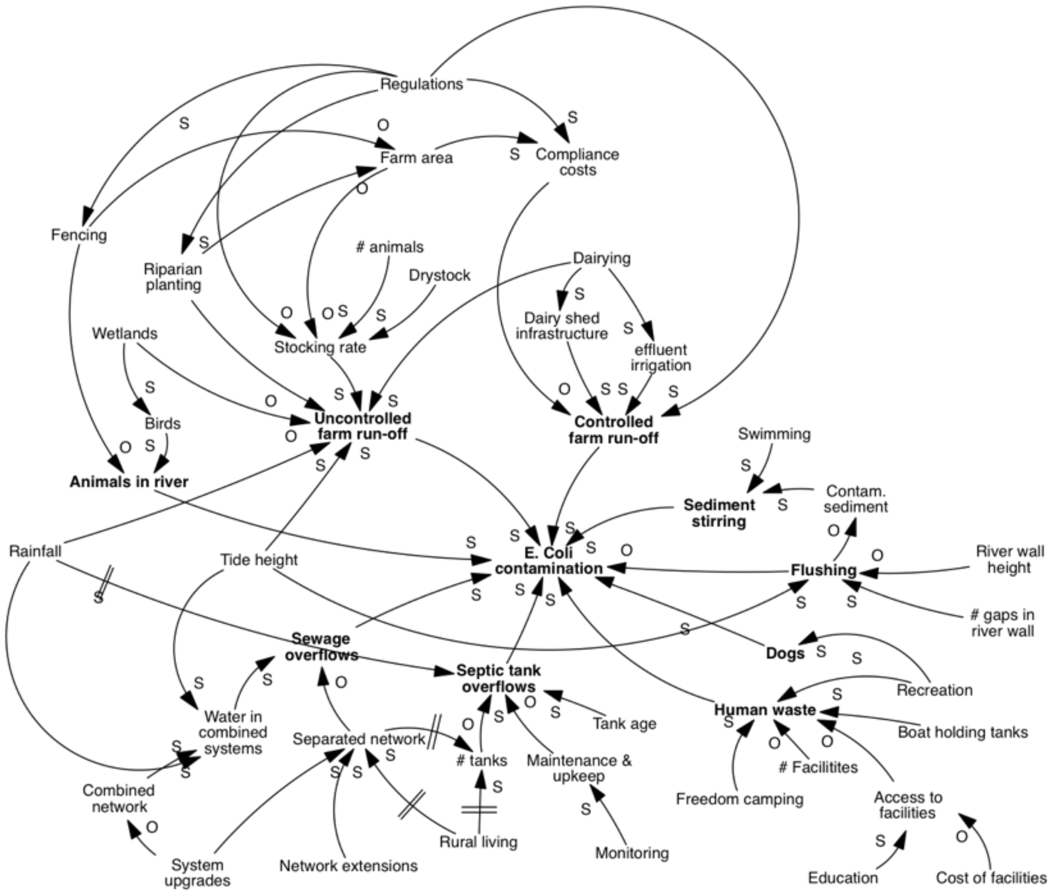


During the workshop discussion, these factors were described and added to the CLD.

6.3.2 Causal Loop Diagram

The rich discussions throughout the day resulted in a draft causal loop diagram at the end of the first day. This CLD, as at the end of the first workshop, is shown in Figure 7.

Figure 7. Causal Loop Diagram after first workshop



This shows several contaminant pathways were identified as were a range of causal factors contributing to those pathways. The pathways were broadly human waste and animal waste.

Human waste was understood to enter the river via sewage overflows from the sewerage system; overflows from septic tanks; and a collection of other human activities such as recreation (e.g. hiking and hunting) and major events, freedom camping; and potentially tanks (or lack of) from fishing boats.

Animal pathways were mostly farming orientated, with two major pathways identified. The first was *uncontrolled farm run-off* from pasture, which was generally mitigated via interventions such as fencing, riparian planting and the development of wetlands. The other was *controlled farm run-off* from infrastructure designed to capture, possibly partially treat, and release run-off in a controlled way. This included such things as effluent irrigation and good management practices, as well as physical infrastructure such as effluent tanks attached to dairy sheds.

Other animal pathways included animals in the river (both stock and wild animals), as well as dogs related to human recreation activity.

One final contributor to *E. coli* was the impact of *flushing* and *sediment stirring*. These were factors that were identified from a discussion around how the river walls had reduced the flushing capacity of the river and the identification of potentially high levels of organic matter in the sands that remained, being a possible contributor to *E. coli* contamination. While not a contamination pathway itself, this was seen as a moderating influence. It should also be noted that it applied more to Marrs Beach than Shingles Beach.

6.4 Summary of discussion points

A very good discussion was had during the workshop and a huge range of views on the potential factors influencing the issue were shared. Discussion amongst participants and the facilitator at the end of the day indicated that most participants gained insights from other people about the problem, this was in addition to those they had held as their own before the day.

A range of some key discussion points are summarised below.

The workshop began with some participants expressing views that a greater level of monitoring and data collection was required. While improved levels of data were also desired by WCRC staff, they explained that there was an extremely limited budget available to do this. Their resources were stretched across the region and that this workshop approach was a way of informing how best to target any additional action going forward. While there was initially some resistance to this stance, WCRC staff explained that they were inviting the participants into the challenge they were dealing with to help make it most practical.

E. coli contamination was identified as coming from a familiar range of sources. Farm run off was one source and was defined as uncontrolled (run-off from pasture) and controlled (managed settlement and run-off, or re-use after collection at dairy sheds). Human waste from residential settlement was also identified as a source, both via the combined sewerage system in urban areas and septic tanks in more rural areas. There was some discussion around other human waste pathways from freedom camping; recreation (general use as well as major events like marathons); and possible toilet tank flushing from the fishing boat fleet. Animals in the river (wild, farm stock and domestic pets) were also identified as pathways for faecal contamination (and therefore *E. coli* contamination).

There was extensive discussion around the impact of the river wall on *E. coli* contamination. The river wall is an historic feature that was originally built to help direct and concentrate the flow of the river. This reduces the need for dredging of both the river and the bar at the river mouth. The river wall was repaired and enlarged in the last 10-15 years.

While the river wall was not identified as a *direct source* of *E. coli* contamination, it was identified as a factor that heavily *influenced* this due to its impact on the reduced level of flushing action of the river. It is also important to note that the river wall is only located on – and therefore only viewed as having an impact on – the **Marrs Beach side of the river**. This should be kept in mind during any discussion of possible action in the future.

In general, it was acknowledged that rainfall and tidal events seemed to have a large impact on the levels of *E. coli*. It also only seemed to be major tidal events that had an impact, and then only around the lower area around Westport town. It was noted that this traditionally seemed to impact on the efficacy of the sewerage system, yet there were differing views amongst participants as to the extent that tidal events still had a direct effect on the sewerage system.

It was generally agreed that the wastewater treatment station itself was of a large capacity and worked well (it was recently upgraded). The discussion tended to focus around the potential impact that the infiltration of tidal/rain water might have on the system. Some participants noted that the sewerage system had holding tanks throughout the network which were intended to provide capacity for any such infiltration to be stored for up to 48 hours. While there was an awareness of this storage capacity, there remained confusion as to exactly how it worked, where it was positioned and how much capacity there was.

7 Workshop 2 (20 March 2018)

The second workshop was held on Tuesday 20th March 2018. The two workshops were deliberately scheduled close together to ensure that the subject matter from the first workshop was as fresh as possible in participants' minds.

This section outlines the process for the day and the outputs from it.

7.1 Process for the day

Building on the rich discussion and understanding generated in the first workshop, the process for the second workshop was as follows:

1. Better introduce participants to each other (feedback indicated that this could have been more comprehensive in the first workshop).
2. Review what was achieved in the first workshop, describing the CLD constructed.
3. Revise any elements that may seem counter intuitive.
4. Describe any factors on the CLD that the factor of *E. coli* itself influences.
5. Weight the factors on a relative scale.
6. Generate scenarios for intervention and explore the indicative changes that these scenarios will have on *E. coli*, via Mental Modeler .

7.2 Outputs from the day

This section summarises the main outputs from the day.

7.2.1 Summary of discussion and amendments

The second workshop began with a reflection on how the current CLD was developed and the rich conversations that were had by participants. There was a reminder that there was an extremely limited budget for WCRC to undertake investigations, and that the insights provided by this group would help focus where any further council funds, or additional funds applied for elsewhere, would be spent.

The insight provided by the initial CLD was discussed. This focused on the range of pathways that were identified (summarised in section 6.4) and how these were all linear due to the focused nature of the question that was asked. The CLD was expanded and strengthened by the addition of influences from the factor of *E. coli* contamination itself to other factors already identified on the CLD. This resulted in the addition of influences from *E. coli* contamination to *swimming*, *recreation & events* and *regulation*. This ensured that the CLD better reflected the reality of the interconnections within the system.

Some minor adjustments were also made to the connections between factors within the parts of the CLD that described the impacts of farming. These adjustments ensured that both *Dairying* and *Drystock* appeared in a consistent manner.

There was a robust discussion about the nature of *wetlands* and how they both influenced water quality and were valued and used by humans. It was acknowledged that *Dairy shed infrastructure* was taken to incorporate the infrastructure that treated sewage from cows collected during milking and that this could include a series of treatment ponds with the terminal stage being a constructed wetland. There remained a strong question with a minority of the group about whether the factor of *wetland* needed to be separated into a factor of *natural wetland* and *constructed on-farm wetland*. The difference seemed to be the value that may be placed on natural wetlands due to their additional use for human recreation and leisure. Given the focus on the ability of wetlands to improve water quality through filtration, this factor was kept as one and not split into two. Yet, the point made was noted by the group.

7.2.2 Final factor list

During the discussion in the workshop some factors names or definitions were refined. This made them and the relationships between them clearer and easier to understand. The final list of factors is tabulated in Table 3.

Table 3. Final factors described by group in the CLD

Final factor	Final description
***E. coli* contamination** *(main factor of interest)*	This is the level of *E. coli* as registered by testing at Marrs & Shingle beaches. *E. coli* is used as an indicator species for pathogens that may be present in the water.
Sewage overflows *(directly connected to E. coli)*	The overflows of sewage from the combined sewerage system of Westport town. This includes both frequency and volume.
Septic tank overflows *(directly connected to E. coli)*	The overflows of sewage from septic tanks in the area of Westport town and the wider catchment. This includes both frequency and volume.
Uncontrolled farm run-off *(directly connected to E. coli)*	The direct run-off of faecal matter deposited on farm by animals into waterways.
Controlled farm run-off *(directly connected to E. coli)*	The controlled release or run-off of faecal matter from animals on farm. This is controlled via some sort of management practice or infrastructure.
Feral animals in river *(directly connected to E. coli)*	The number of feral animals able to access and enter the river system. Includes all feral animals such as deer, pigs, birds, possums etc.
Stock in river *(directly connected to E. coli)*	The number of farm stock able to access and enter the river system. For the Buller catchment this was noted as usually being dairy/beef cattle or sheep. Dairy/beef cattle are noted as the more predominant stock type, as it is noted that sheep tend to avoid having their feet in water, if possible.
Human waste *(directly connected to E. coli)*	The amount of human faecal matter that is able to enter the river system. This is *outside* of that captured by the various sewerage and septic tank systems.
Dogs *(directly connected to E. coli)*	The number of dogs able to directly enter (and therefore potentially defecate in) the river system.

Final factor	Final description
Flushing	The flushing effect created by river or tidal flow in the river. River flushing applies to the entire length of the river, while tidal flushing applies to the lower area around Westport only.
Sediment stirring	The extent to which fine sediment, specifically at Marrs beaches, is stirred up by the entry of humans and animals for recreational purposes. When this sediment is stirred up, it is perceived to release fine organic (and possibly faecal) matter which may contain *E. coli*.
Contaminated sediment	The accretion or deposition of fine organic (and possibly faecal) matter which may contain *E. coli* in the sediments of riverine beaches. This was specifically perceived as a feature at Marrs beach yet could potentially occur at any riverine beach where still conditions allow.
Swimming	The level of swimming that occurs in a river.
Separated network	The part of the sewerage network dedicated to the transportation of *sewage only* to the wastewater treatment plant. This *does not include stormwater* as this is carried in a separate dedicated system (not noted on this CLD).
Combined network	The part of the combined sewerage network dedicated to the transportation of *both sewage and stormwater* to the wastewater treatment plant.
Water in combined systems	The amount of water that accesses the combined system, as it was originally intended, through stormwater connections to the system. This also includes water that accesses the combined system via high or king tides.
System upgrades	The process of *upgrading an existing* sewer system with a new system. This generally involves the replacement of the old combined system with new separated systems. This action *does not result* in an increase in overall sewerage capacity.
Network extensions	The process of *extending* the sewer system to new housing areas or housing areas previously serviced by septic tanks. This *does result* in an increase in overall sewerage capacity.
Rural living	A general description used to indicate land that is residential in nature, but with a rural feel. These are slightly larger sections and smaller ‘lifestyle blocks’. These are currently predominantly serviced by septic tank systems.
# tanks	The number of septic tanks servicing houses in the catchment, predominantly around Westport.

Final factor	Final description
Maintenance & upkeep (of septic tanks)	The level of maintenance and upkeep undertaken on septic tanks by the owners. Septic tanks require periodic monitoring, cleaning and maintenance. When this is done they operate more effectively.
Tank age	The average age of septic tanks in the catchment, predominantly around Westport. Tank age is used by the group as a proxy to indicate the design capability of the tank. In general, this recognises that newer tanks have been designed to a better standard than older tanks.
Monitoring (of septic tanks)	Investigation and monitoring of septic tanks by external parties such as council.
Freedom camping	The number of freedom campers that visit the Buller catchment and the Westport area and camp near the river.
# facilities	The number of toilet facilities that are available to the public in the catchment.
Access to facilities	The extent to which members of the public are aware of the toilet facilities in the catchment, and therefore have a greater likelihood of using them, as they are more aware of them.
Education about facilities	The level of active advertising and education of members of the public concerning the number and location of toilet facilities in the catchment.
Cost to access facilities	The cost to a member of the public to access any toilet facilities. For example, are they free or is there a charge?
Boat holding tanks	The number and capacity of holding tanks for toilets on fishing boats moored in Westport.
Recreation & Events	The level of recreation in or near the river (e.g. camping, tramping and hunting) where humans may need to defecate without access to toilet facilities. Also, the number of sporting events that may attract a large number of people (such as marathons and triathlons), which may create pressure on toilet facilities (fixed or temporary). This may lead to situations where humans may need to defecate without access to toilet facilities.
River wall height	The height of the in-stream river wall. This wall directs and concentrates flow in the river in order to scour sediment off the river bed as well as minimise the size of the river bar. These both minimise the amount of dredging required to allow boat access.
# gaps in river wall	The number of gaps in the river wall where water can flow through downstream. While this was not an original feature of the wall, over time some small holes (or low points) appeared in the wall and were seen by group members as a contributing factor to the flushing capability of the river within the river wall area.

Final factor	Final description
Dairying	The amount of dairy farming as a land use in the Buller catchment.
Dairy shed infrastructure	The number of dairy sheds and, more specifically, the associated infrastructure that captures and controls dairy cow effluent. At a summary level this infrastructure is understood to include different types of settlement ponds, oxidation ponds and constructed wetlands that treat effluent to a certain level before it is released to a waterway.
Effluent irrigation	The irrigation of effluent back onto pasture as a controlled management practice. This is both a way of fertilising pasture as well as treating effluent. This only occurs within certain management protocols, such as it can only be done when it is not expected to rain.
Drystock	The amount of drystock farming as a landuse in the Buller catchment. This includes beef cattle, sheep, deer etc.
#stock units	The number of stock units on a farm. This is a common measure for standardising the amount of stock across different industries for comparison purposes.
Stocking rate	The number of stock units per hectare.
Farm area	The size of a farm, measured in hectares.
Riparian planting	The amount of planting of riparian margins along streams and rivers (stream/river edges). This is a commonly used mitigation for reducing the run-off from pasture via overland and subsurface flow. Usually done in conjunction with *fencing*.
Fencing	The amount of fencing as a means to exclude stock from waterways. Often done in conjunction with *riparian planting*.
Wetlands	The quantity of wetlands, natural or man-made, in the catchment that filter overland run-off. Wetlands act as a filter for a range of contaminants found in run-off, including *E. coli*. This excludes infrastructure constructed specifically under *dairy shed infrastructure*, which may contain elements of man-made wetlands as a final step in a multi-step treatment process. The main difference is that dairy shed run-off is effluent captured within the dairy shed. This factor of wetlands captures run-off from other overland flow pathways.
# Birds	The number of birds in the catchment, often water fowl. This includes both native and non-native species, as all are potential contributors of faecal matter to the river. However, it was an understanding of the group that any potential action arising in this regard would be focused on non-native or invasive species.

Final factor	Final description
Regulations	The number and intensity of regulations put in place by local or central government. These generally require some kind of action, usually a mitigation, to be undertaken by landowners.
Cost of mitigation	The costs incurred by someone who undertakes any kind of mitigation. This recognises that any mitigation action will incur some kind of cost to establish and/or manage. At the same time, this recognises that the level of costs incurred from a mitigation will directly impact a person's desire to continue to incur costs associated with mitigations. For example, lower costs would encourage greater action and vice-versa.

7.2.3 Scale used to weight influences

The weighting scale used to weight both the influence of factors and the proposed change in factors under various scenarios is once again outlined below. Note it is a *relative* scale not an *absolute* scale. This means that it is not able to provide any authoritative quantitative insight into any relationship described. Rather, this is intended as a way of strengthening the qualitative insights provided by the CLD.

The relative weighting scale is made up of 5 steps. These can apply to either the level of influence or the amount of change made to a factor through an intervention. These are Very Low (VL); Low (L); Medium (M); High (H) and Very High (VH) (see Table 4).

Table 4. Scale used to weight both strength of influence and potential change in a scenarios factor(s)

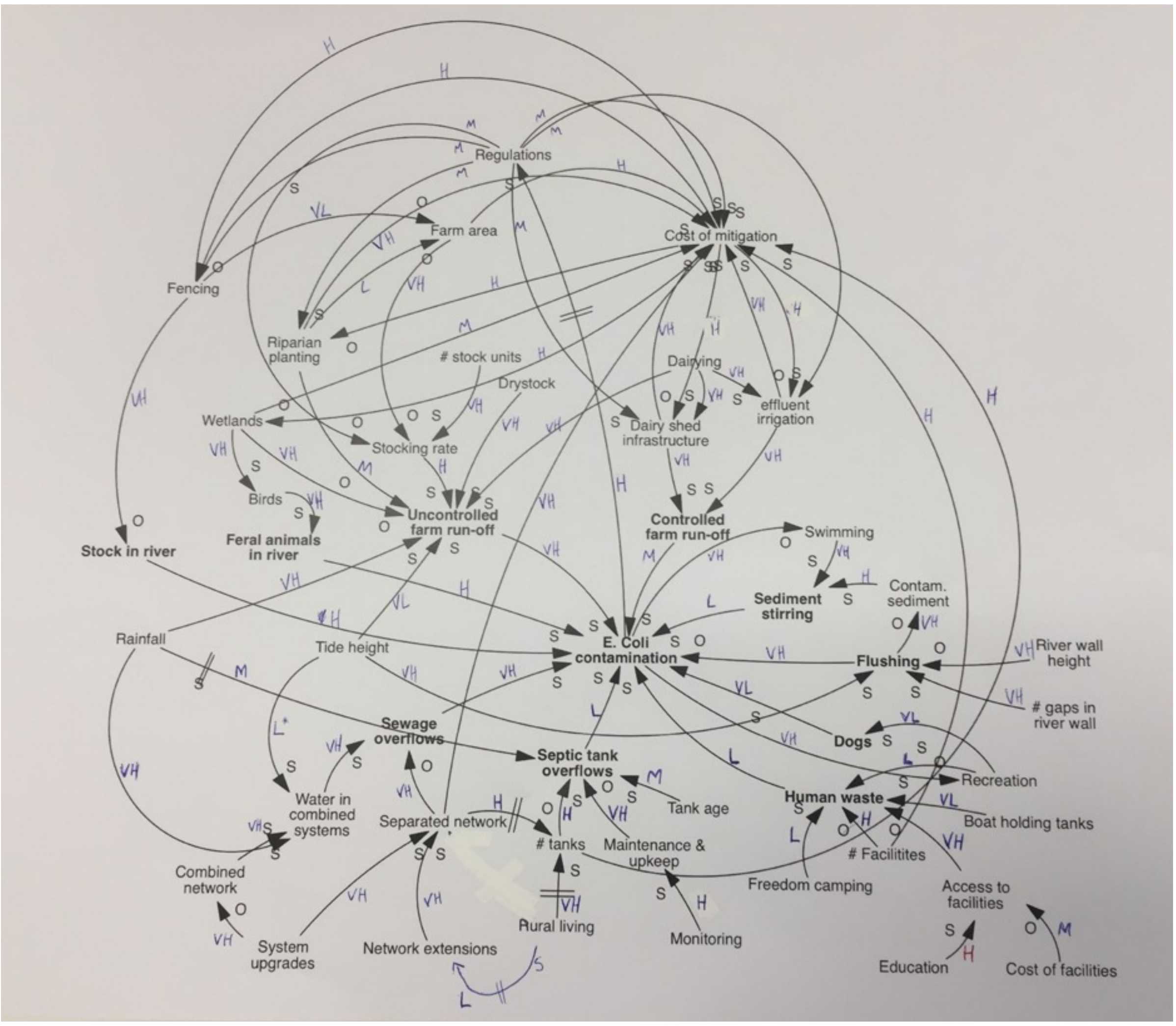
Weighting definition	Numerical weighting (on a relative scale of -1 to +1)
Very High (VH)	**+/- 0.9**
High (H)	**+/- 0.75**
Medium (M)	**+/- 0.5**
Low (L)	**+/- 0.25**
Very Low (VL)	**+/- 0.1**

Note: This scale can be used in either a positive or negative sense. For example, a *high influence in the same direction would be +0.75*, while a *high influence in the opposite direction would be -0.75*.

7.2.4 Weighting of influences

Discussion for the bulk of the rest of the day then focused on weighting the influences between factors. The scale for this is outlined in section 7.2.3. The result of this long and robust discussion was for all influences between factors to be weighted. The results of this are shown in Figure 8.

Figure 8. Revised CLD with influences relatively weighted (Scale: VL, L, M, H, VH)



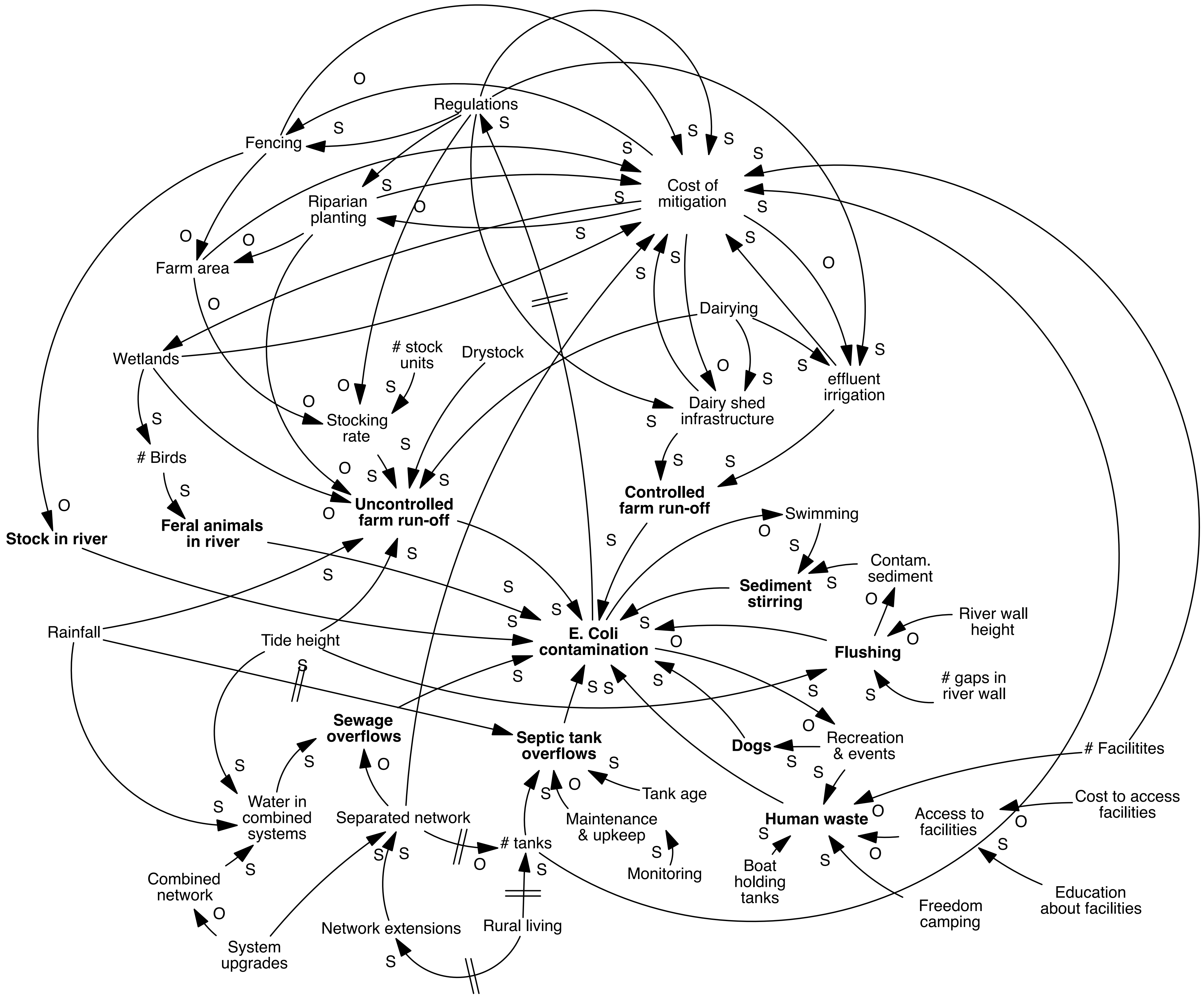
The final weightings are also shown visually in Figure 10. Both Figure 9 and Figure 10 are useful as they show the following:

- *E. coli* itself influence the levels of *swimming*; *recreation/events*; and *regulation*
- The main contaminant pathways identified in workshop 1 remain, with the exception that *animals in river* has been separated into *feral animals in river* and *stock in river*
- *Cost of mitigation* is a highly influential factor – as many factors influence this as influence *E. coli contamination* itself
- There is a strong reciprocal interaction of factors both to (same relationship) and from (opposite relationship) *cost of mitigation*. This indicates the presence of balancing loops between these factors, which is likely to be a loop causing stability in the system. This may be an area for the group to consider further intervention in at a future date.
- While it is not possible to determine a clear pattern relating to the *strength* of relationships, it does appear that the more dominant relationships relate to the contaminant pathways from farmland and sewerage/septic systems. Other human influences are considered less impactful.

7.2.5 Final Causal Loop Diagram – unweighted

The final CLD as developed by the Stakeholder Working Group, *without weightings included in the influences*, is shown in Figure 9.

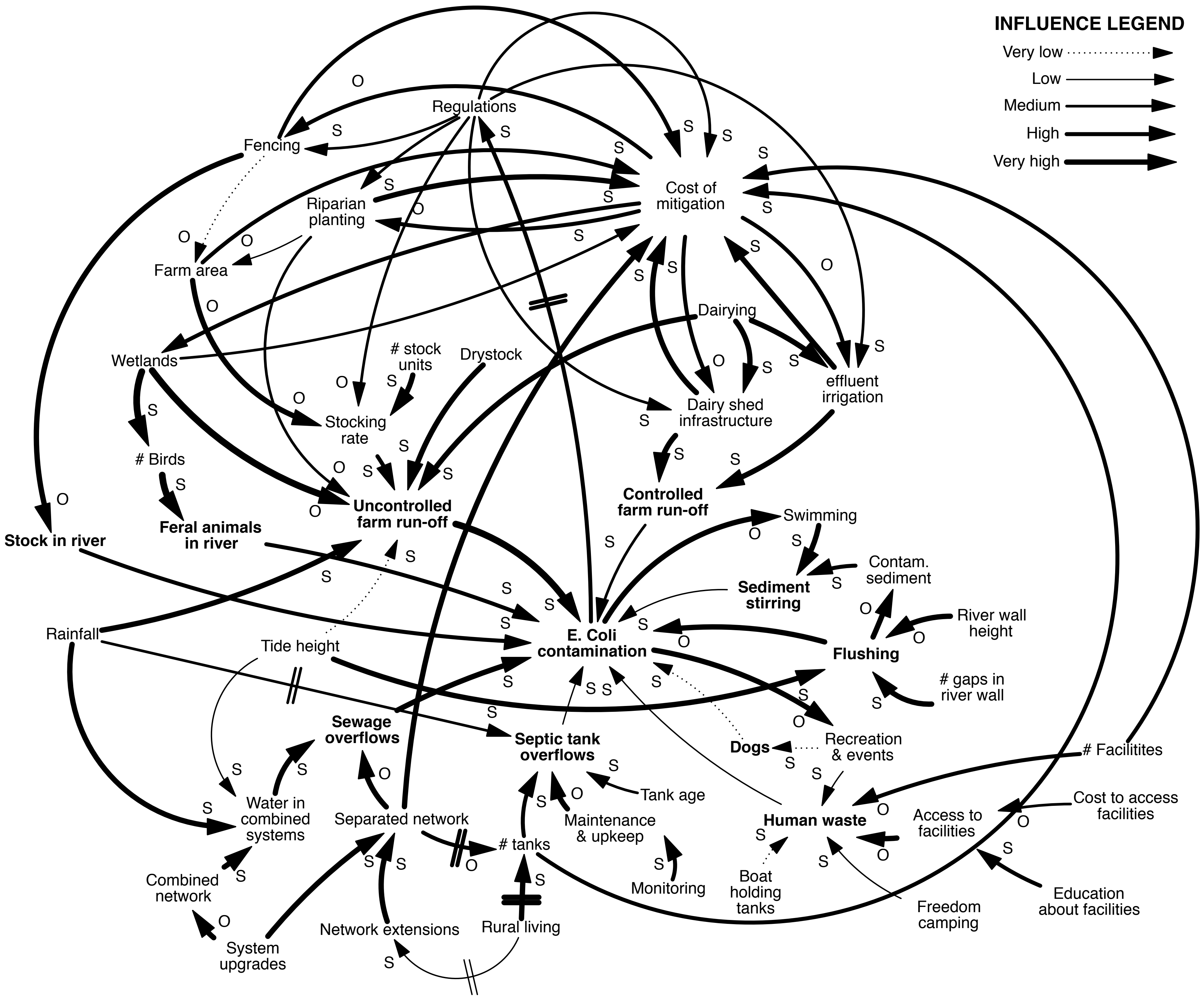
Figure 9. Final CLD with unweighted influences after Workshop 2, as developed by the Stakeholder Working Group



7.2.6 Final Causal Loop Diagram –weighted

The final CLD as developed by the Stakeholder Working Group, *with weightings included in the influences*, is shown in Figure 10.

Figure 10. Final CLD with weighted influences after Workshop 2, as developed by the Stakeholder Working Group



7.3 Interventions (scenarios) suggested

Once the CLD had been finalised and the weightings for each influence agreed, the final step for the day was for the group to identify factors where they thought intervention would have the greatest impact in the system.

This was a perception-based, card-storming exercise. (A card-storming exercise is where…) Participants were making suggestions based on the two days of rich discussion that identified factors and weighted the influences.

Once suggested factors for intervention were generated and grouped on the sticky wall, they were prioritised. Priority went first of all to those factors that had been suggested by multiple people. Then, participants were asked to allocate votes to the factors that had only been suggested once, to identify which of those should follow in priority. A photograph of the wall is shown in Figure 11. The results are shown in Table 5.

Figure 11. Photograph of the interventions (scenarios) suggested

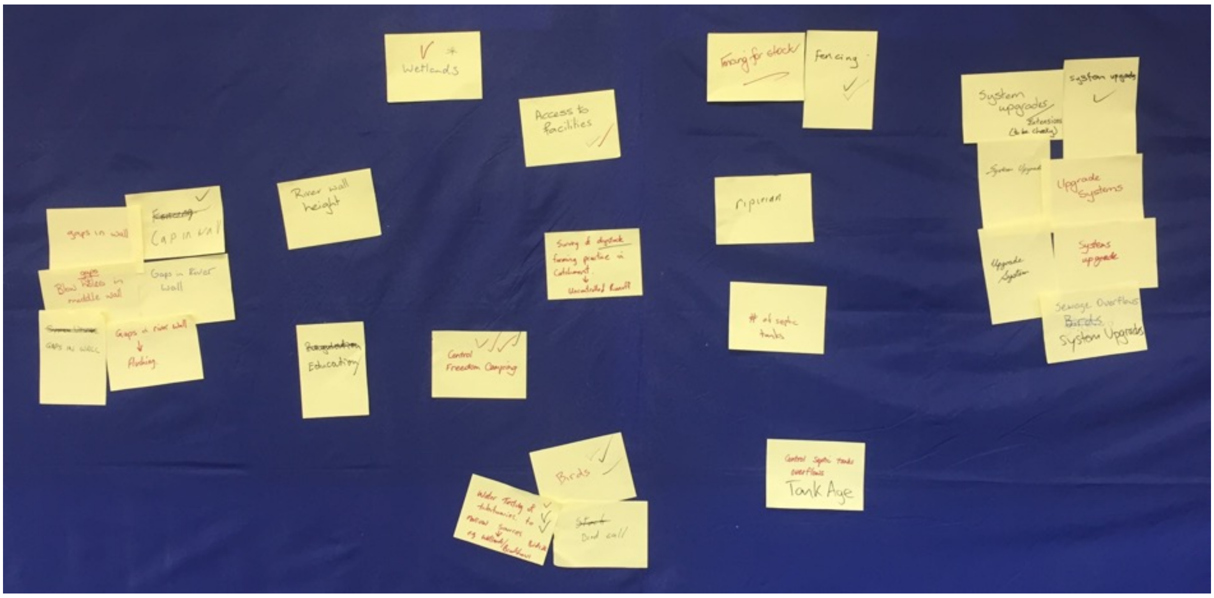


Table 5. Table of the interventions (scenarios) suggested and prioritised.

Rank	Factor	Number of times suggested in first round	Number of votes received in prioritisation round
1	***System upgrades***	7	N/A. Suggested by multiple people.
2	***# Gaps in river wall***	6	N/A. Suggested by multiple people.
3	***# Birds***	3	N/A. Suggested by multiple people.
4	***Fencing***	2	N/A. Suggested by multiple people.
5	***Freedom camping***	1	4
6	***Access to facilities***	1	2
7	***Wetlands***	1	1
8	***Education about facilities***	1	1
-	***River wall height***	1	-
-	***Riparian planting***	1	-
-	***# Septic tanks***	1	-
-	***Septic tank age***	1	-
-	***Drystock***	1	-

7.4 Interventions (scenarios) tested

Once 8 interventions (scenarios) had been prioritised by the group, the group then discussed and agreed a weighting for the relative change they suggested in the factors identified. The same relative scale as outlined earlier was used.

It is important to note that again, these are *relative changes* and not absolute changes. For example, a high positive change would be to suggest "if we increased factor A by a high amount, what would happen?".

The relative changes in prioritised factors agreed by the group are outlined in Table 6.

Table 6. Relative changes suggested by the group to factors they had identified and prioritised.

Rank	Factor	Relative change agreed
1	*System upgrades*	Medium increase
2	*# Gaps in river wall*	Medium increase
3	*# Birds*	High decrease
4	*Fencing*	Medium increase
5	*Freedom camping*	Low decrease
6	*Access to facilities*	Low increase
7	*Wetlands*	Low increase
8a	*Education about facilities*	Medium increase
8b	*Education about facilities*	High increase

The following section compares the impact of each factor change on *E. coli*, while following sections briefly describe these results as well as other flow-on impacts with each scenario.

Due to a technical error on the day, these graphs were generated after the workshop and were not seen by the group altogether. While this is unfortunate, it is expected that they will be used in future discussions with the group to inform next actions.

7.4.1 Testing scenarios - A note on the software and its capability

The causal factors and influences described in the CLD were built in a piece of software call Mental Modeler[3] (Gray, 2013). The scenarios outlined above were then entered into the software as separate scenarios within which relative changes to

[3] Mental Modeler is a piece of software developed at the University of Hawaii. See www.mentalmodeler.org

selected variables could be made. Each scenario could be tested independently of the others.

Before reviewing the scenarios, please note that the software used calculates the *relative impact that flows on to other factors* from a *relative change in a certain variable(s)*. This calculation takes into account the various pathways that flow-on from a changed factor. Further, it only calculates the overall assumed impact and is not able to take into consideration the time-delay associated with many interventions. Therefore, in some scenarios, flow-on effects that may take years to present will appear on the graphs. While these may appear counter-intuitive at first, they reflect the relationships described by the group and captured in the CLD. These results are important to show how long-term effects may play out. However, it also emphasises the inherent inability of CLD models, as conceptual frameworks that help to understand how a system functions, to describe temporal movements in key variables.

As a general rule-of-thumb, the larger bars on the graphs are the more direct impacts that any change in a factor will have. The lesser smaller (and often minor) bars are the impacts of flow-on effects, some of which may take many years to occur, as identified by the group.

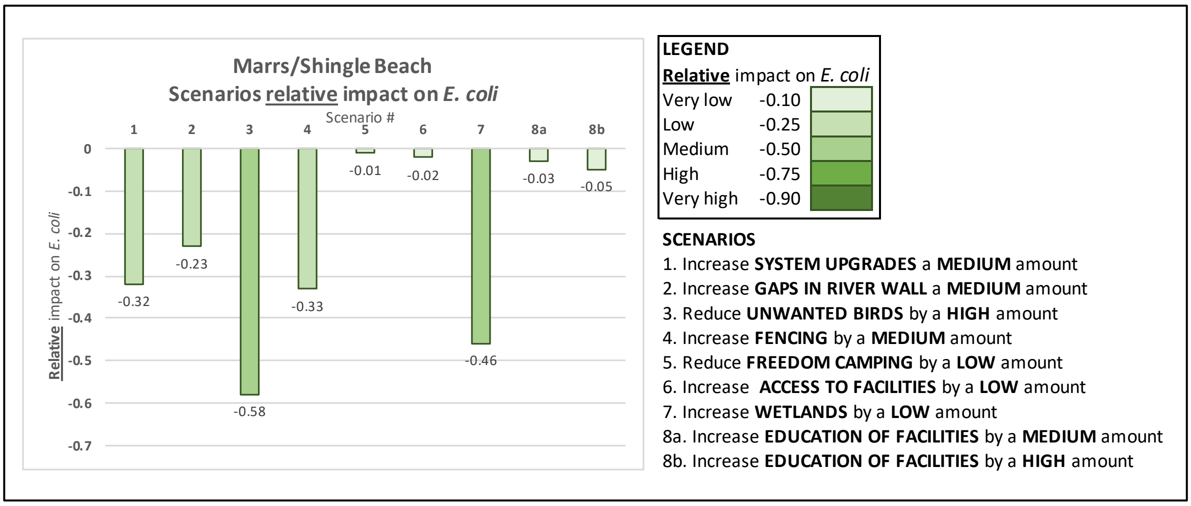
When reviewing the graphs under each scenario, please also be aware that the scale changes for each scenario. That is, the scales for each graph are all independent of each other. While some bars on some graphs may appear as equally large as those on other graphs, please note the scale on the graph and/or the actual relative weighting change labelled on the bar, before making a direct comparison.

7.5 8 interventions (scenarios) compared

The below graph shows the impact that each intervention factor, when changed by the relative amount suggested by the group, is expected to have on *E. coli*.

Note that this is based on the perceptions of the group and is not endorsed as a replacement for complimentary scientific investigation of knowledge. See section **Error! Reference source not found.** for a description of the role of the results of this process.

Figure 12. Relative impact on E. coli of the 8 identified interventions (scenarios).



7.6 Scenario 1: Increase system upgrades by a medium amount

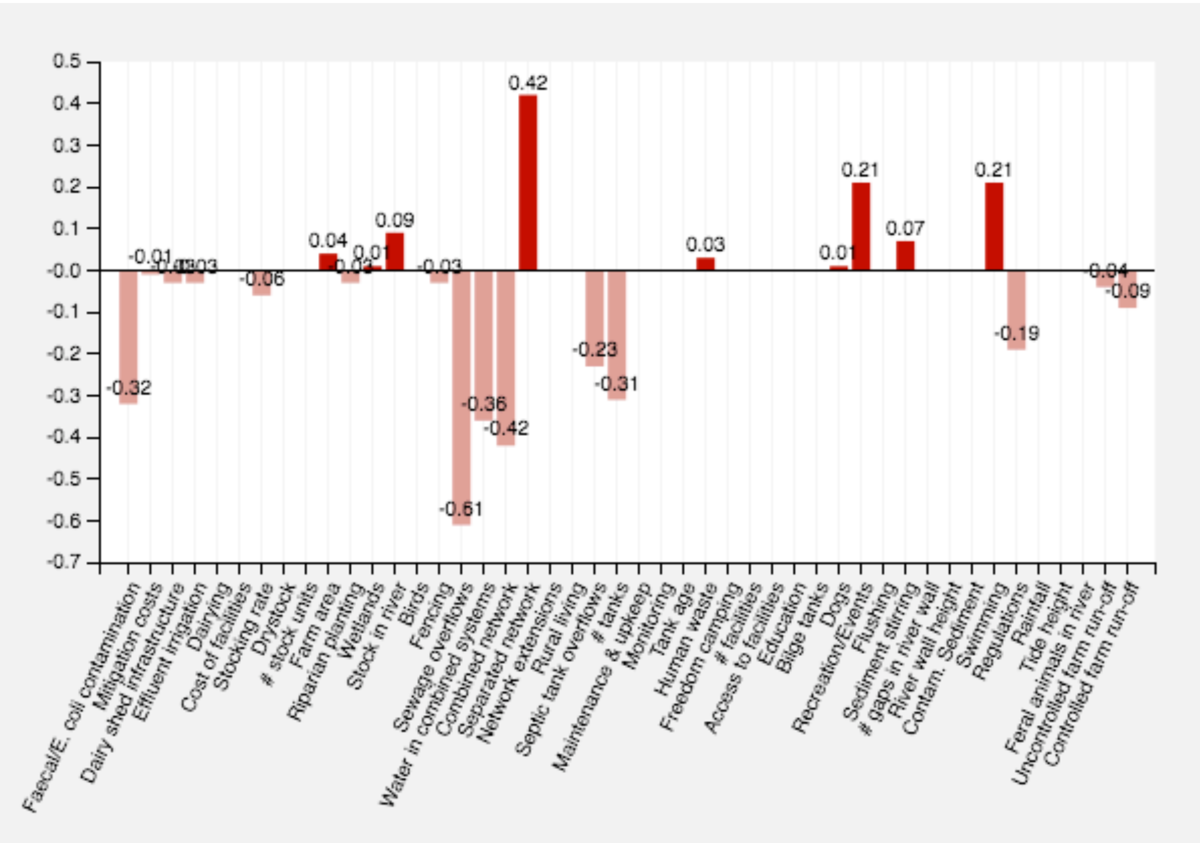
If system upgrades are increased by a medium amount, there will be a noticeable yet relatively low-medium impact on *E. coli* levels.

System upgrades will dramatically impact the amount of separated sewerage network that there is, which will reduce both the total size of the combined system as well as the water that is able to enter the combined system. These factors will have a significant impact on sewage overflows, which in turn will have an impact on the level of *E. coli*.

According to the CLD, an increase in the separated network will, over the much longer term, potentially impact the number of septic tanks and associated tank overflows. As *system upgrades* referred specifically to the upgrading of *existing* sewerage, this result would appear to be counter-intuitive and indicates that perhaps the opposite influence on the # *septic tanks* should in fact come from the factor of *network extensions*, not *system upgrades*. If this change was agreed, the relative impact of a system upgrade would be expected to decrease, as it is would no longer take into account the potential reductions from less septic tanks.

A minor drop in new regulations longer term is indicated which is logical if *E. coli* reduces, as is the increase indicated in *swimming* and *recreation & events*.

Figure 13. Scenario 1: Increase system upgrades by a medium amount



7.7 Scenario 2: Increase the number of gaps in the river wall by a medium amount

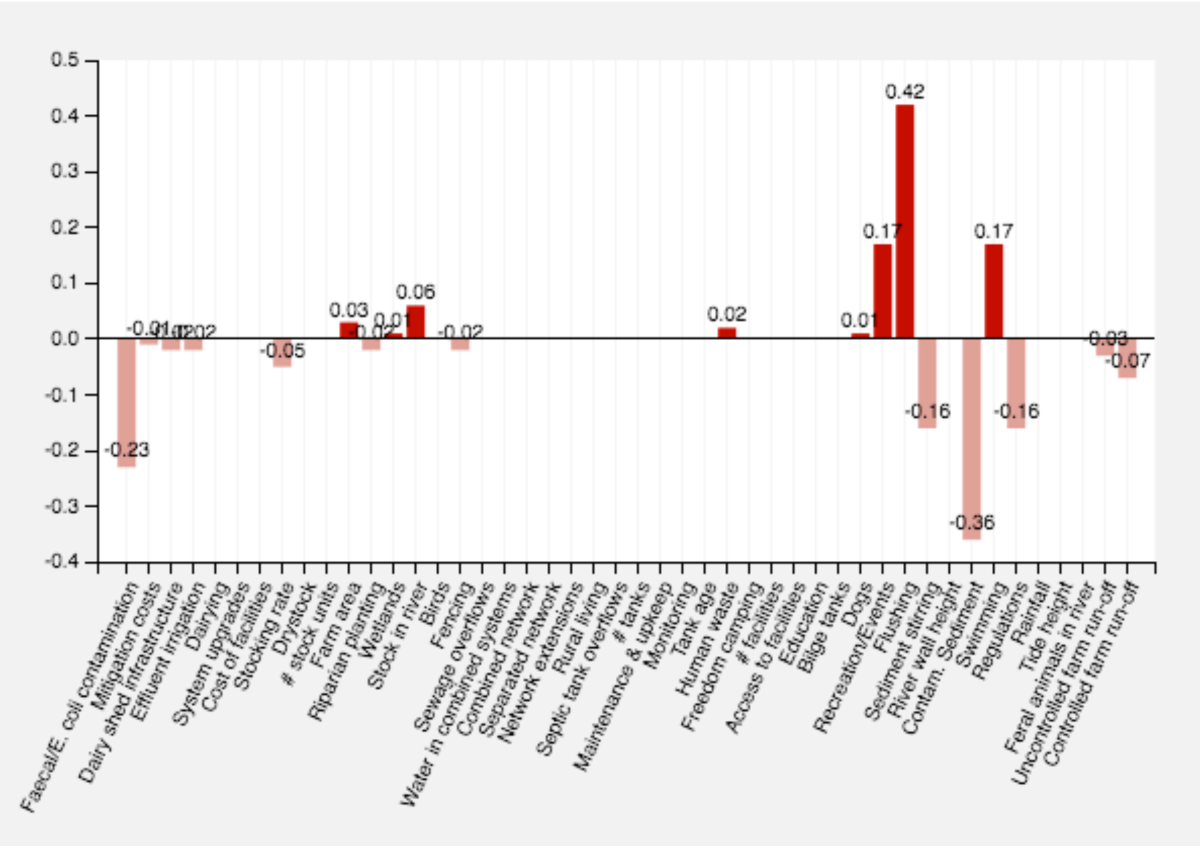
Increasing the number of gaps in the river wall by a medium amount will have a low impact on *E. coli* levels.

However, it should be noted that this is more of a specific issue at Marrs beach, and so it is likely to have a greater impact at that beach directly, given the specific weighting of this issue at that beach, rather than at both Marrs and Shingle beaches together.

More gaps in the river wall will have a medium impact on *flushing, a low-medium impact on contaminated sediment* and, in turn, a low impact on the amount of sediment stirring that goes on. According to the CLD and the calculations, this is likely to have a low impact on both *swimming* and *recreation & events*, although as noted, Marrs beach may itself realise a more positive local impact in these areas.

In the longer term there may be a low impact on the need for new regulations, given the reduction in *E. coli* levels.

Figure 14. Scenario 2: Increase the number of gaps in the river wall by a medium amount



7.8 Scenario 3: Reduce unwanted birds by a high amount

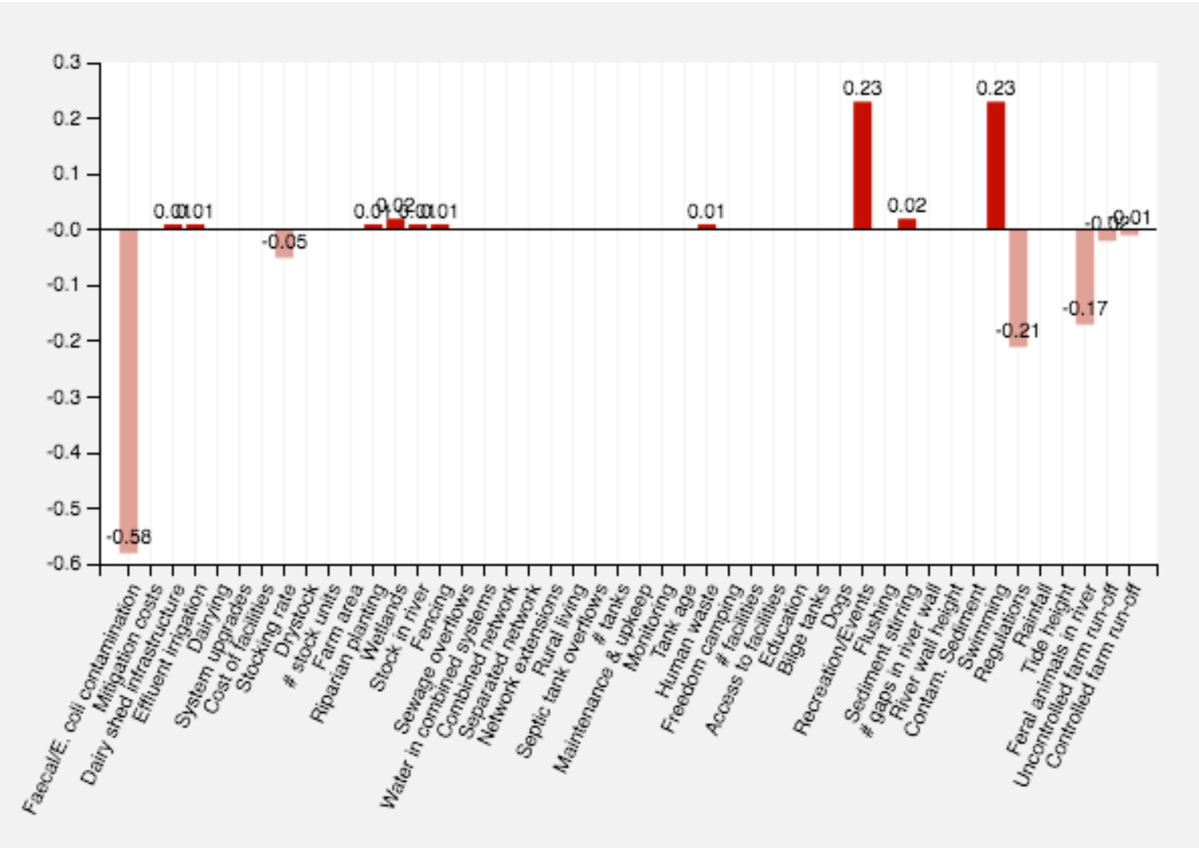
Reducing the number of unwanted birds was one of only two scenarios where the relative change suggested was high. The other was Scenario 8b, which involved a high increase in the *education about facilities*.

Reducing unwanted birds (not natives) by a high amount is expected to have an impact on the number of feral animals in the river, which in turn has a medium-high impact on *E. coli* levels.

Recreation & events and *swimming* both increase by a low amount, while in the much longer term, there is likely to be a low reduction on the need for new regulations.

The strength of the influences connecting the *# birds* to *E. coli*, and the high degree of movement suggested, means that this scenario has the *highest impact* on *E. coli*.

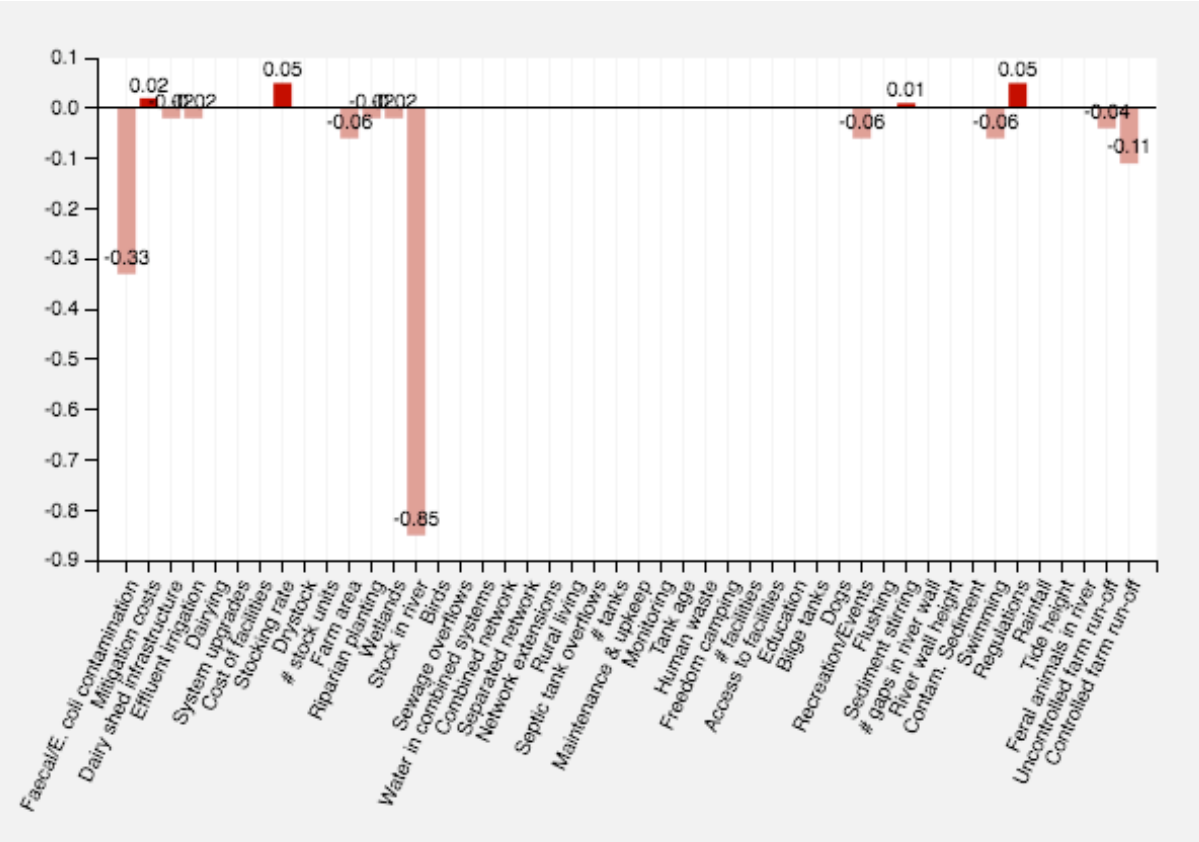
Figure 15. Scenario 3: Reduce unwanted birds by a high amount



7.9 Scenario 4: Increase fencing by a medium amount

Increasing fencing by a medium amount will have a very high impact on the *number of stock in the river*, as a direct source of *E. coli* contamination. There is some very low residual impact via the pathway of *uncontrolled run-off*.

Figure 16. Scenario 4: Increase fencing by a medium amount

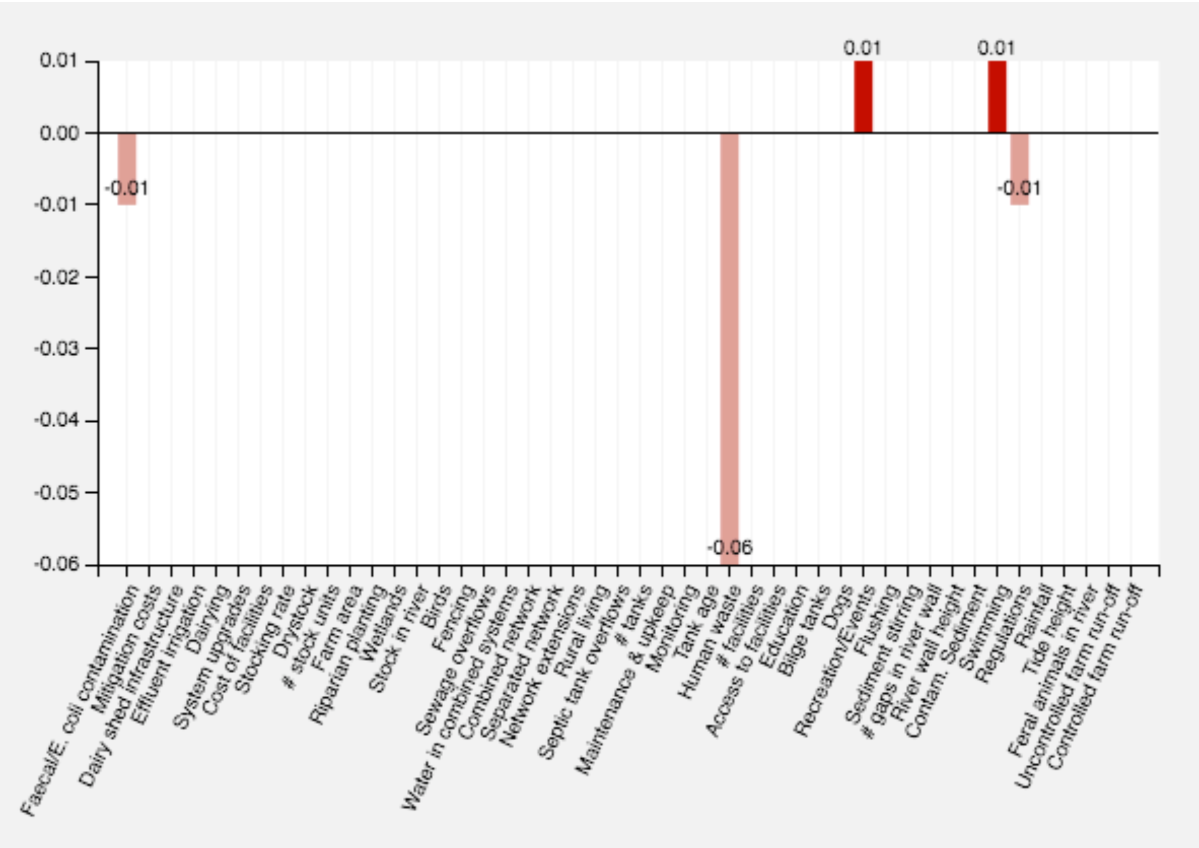


7.10 Scenario 5: Reduce freedom camping by a low amount

Reducing *freedom camping* by a low amount has negligible perceived impact on the amount of human waste that may make its way into the river. Other flow-on effects are similarly negligible.

This is mostly a product of the low strength of the relationships identified by the group between *freedom camping*, *human waste*, and *E. coli* in the river. Even a very high relative impact in this factor would be expected to have a low impact on *E. coli*.

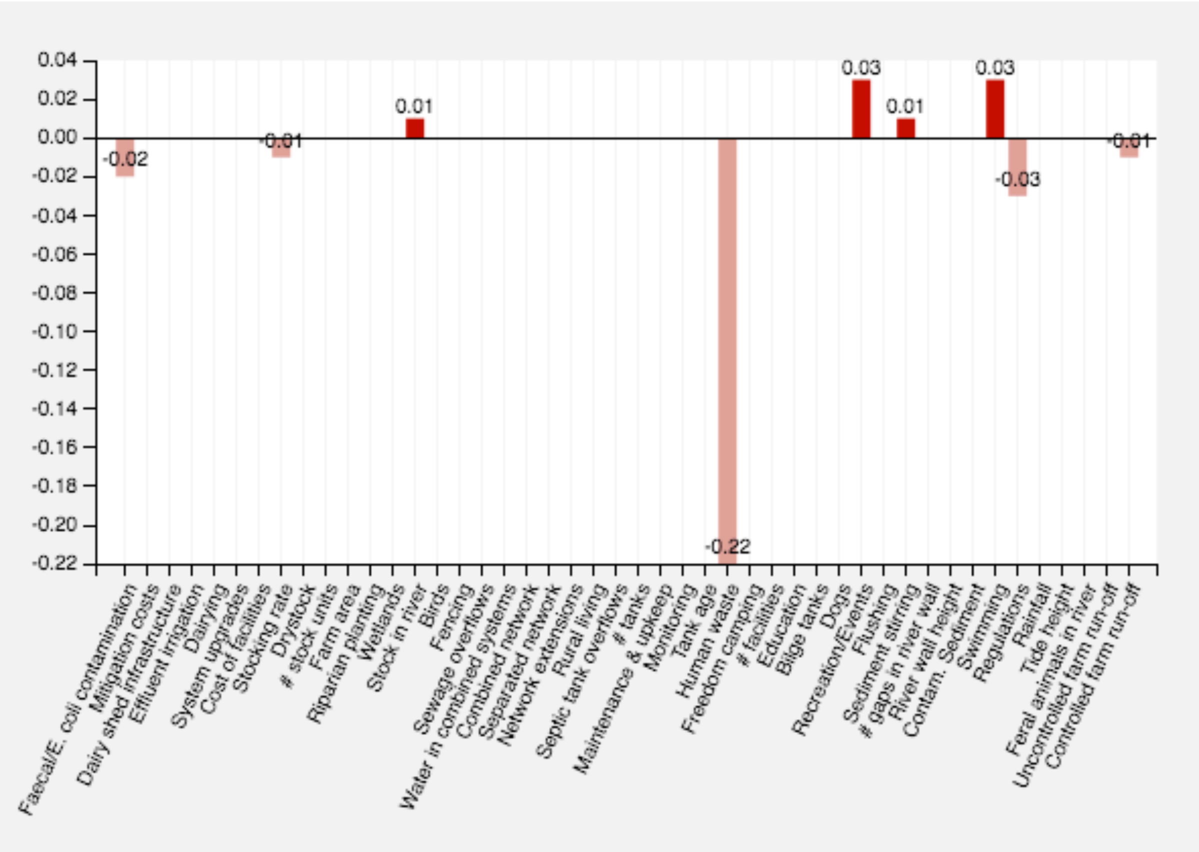
Figure 17. Scenario 5: Reduce freedom camping by a low amount



7.11 Scenario 6: Increase access to facilities by a low amount

Similarly, a low relative increase in the level of *access to facilities* that people have would also have a negligible impact on *E. coli* levels in the river. While it indicates that this may have a low impact on the amount of human waste entering the river, the low relationship that this has with the *E. coli* issue means that the consequential impact is negligible.

Figure 18. Scenario 6: Increase access to facilities by a low amount



7.12 Scenario 7: Increase wetlands by a low amount

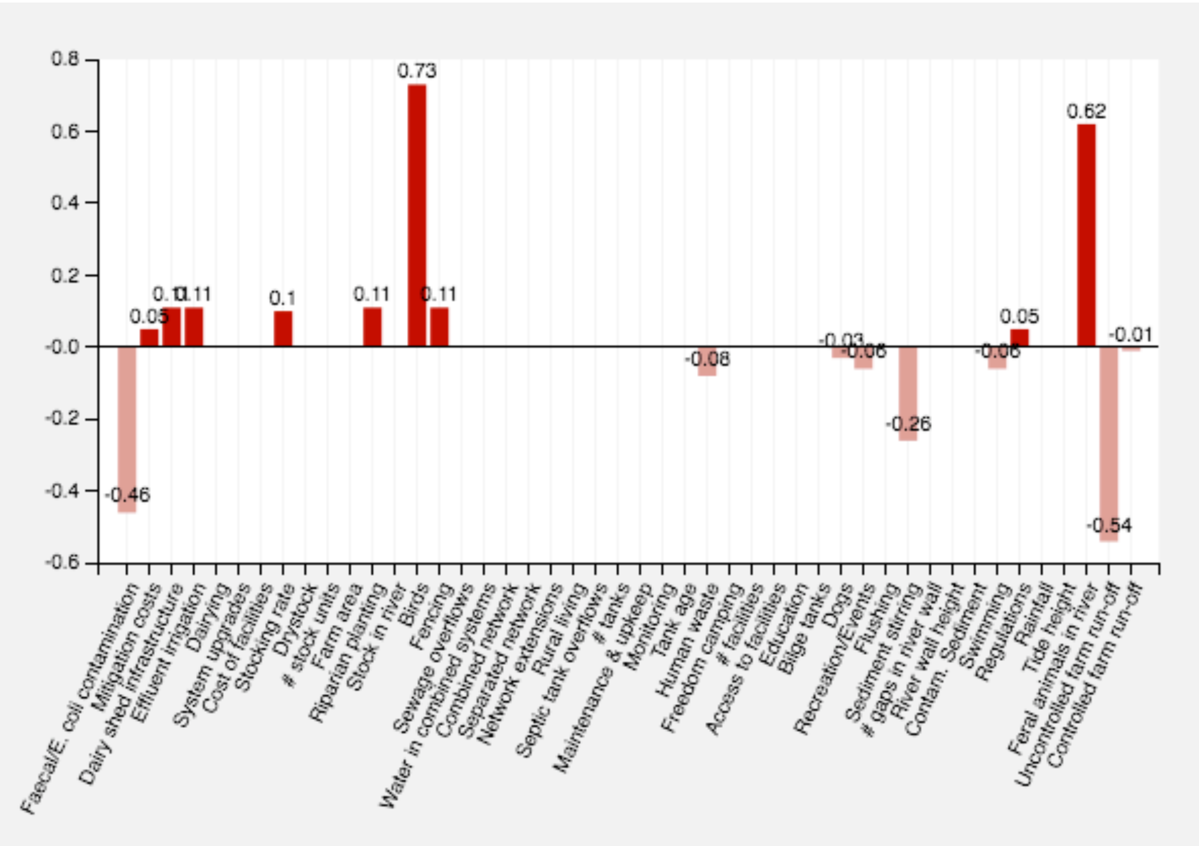
An increase in wetlands by a low amount is expected to have a medium impact on *E. coli*. This is primarily through the direct pathway of wetlands reducing the amount of *uncontrolled farm run-off*, also by a medium amount.

Interestingly however, increasing the volume of wetlands is also expected to increase the *number of birds* which, in turn, is a contributor to the *number of feral animals in the river*, which increases *E. coli*.

So, while increasing wetlands will *decrease E. coli* levels, it will also increase bird life which will *increase E. coli* levels. The reduction in *E. coli* levels expected here then is a *net* reduction in *E. coli* levels, after the increase from more birds is taken into account.

This scenario has the *second largest relative impact* on the levels of *E. coli*. As the two most impactful scenarios identified by the group are closely related – reducing the *number of birds* and increasing the volume of *wetlands* – future deliberations by the group may look at a combination of these two interventions, in order to maximise the potential reduction in *E. coli*.

Figure 19. Scenario 7: Increase wetlands by a low amount



7.13 Scenario 8a & 8b: Increase education about facilities both a medium and high amount

The group was unable to agree on a set amount by which to increase the level of education about facilities. Therefore, increasing this by both a medium and high level was tested.

Both scenarios had a very low impact on *E. coli* levels. While they both had a low-medium impact on *access to facilities* and the amount of *human waste* entering the river, both of which had a low influence on *E. coli*, the overall impact was negligible.

Figure 20. Scenario 8a: Increase education about facilities a medium amount.

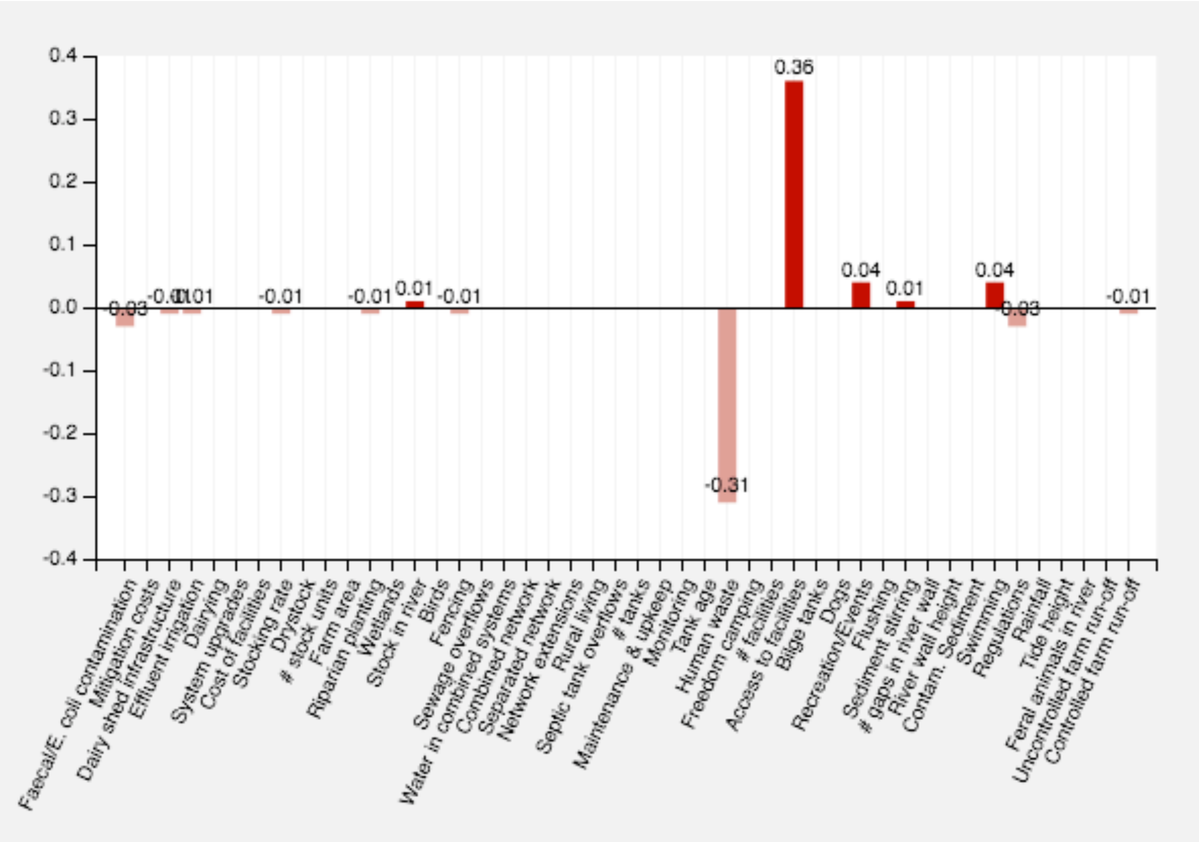
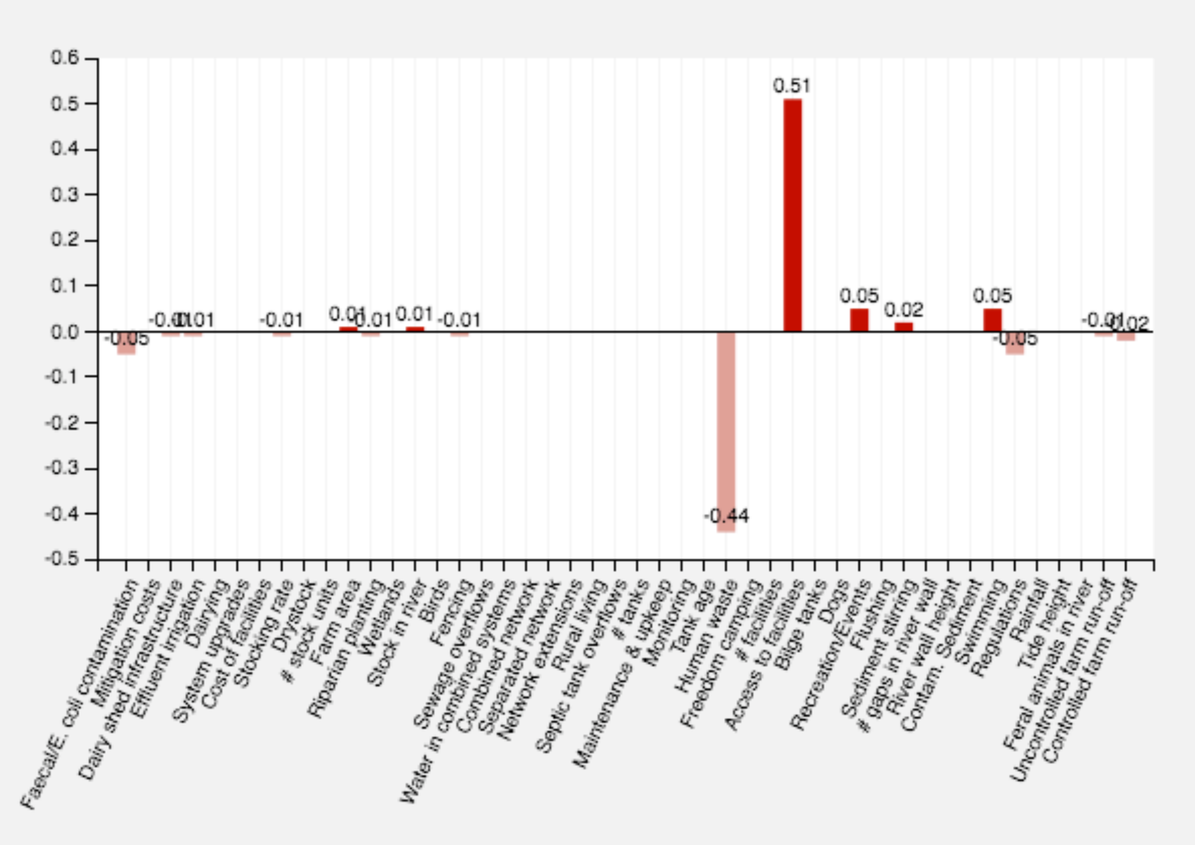


Figure 21. Scenario 8b: Increase education about facilities a high amount.



8 Summary and recommendations

E. coli contamination at Marrs and Shingle Beaches on the Buller River remains an ongoing issue, albeit of a sporadic nature. The upgrade of the Westport wastewater treatment plant (a previous source of contamination) in recent years means that the potential for *E. coli* contamination from this source is much reduced. Therefore, the source(s) of the ongoing problem are less obvious and more difficult to understand than at other sites. Scarce longitudinal data and limited resources at WCRC mean that a participatory approach to determining where to focus further investigation and action on this problem was required.

As a result, a Stakeholder Reference Group was brought together by Council and the first two sessions of this group utilised systems thinking as a framework to attempt to understand the problem with the limited data available, supplemented by local knowledge. The process undertaken by that reference group and the insights they gained have been described in this report.

A comprehensive causal diagram (CLD) was developed by the group in an initial workshop and refined in a second workshop. This described various pathways of potential contamination and also described ways that these pathways interconnected with each other. The interconnected nature of the influences is a core feature of systems thinking, as it helps to identify where well-intended action may in fact be reduced or even cancelled out due to the net effect of other influences.

The influences within this diagram were *relatively weighted* by the group. Potential intervention points/action were also identified and changes in desired *relative changes in these variables* were suggested and tested under a number of different scenarios. The results of these have been described earlier.

The following recommendations are made based on the testing of scenarios as described by the group:

- A significant impact may be made on *E. coli* levels through the management of pest birds. Reducing the amount of (pest) birds by a high amount had the largest potential impact on *E. coli*. The group may consider investigating the extent to which birds are a problem through attempting to quantify this issue and investigating bird management as an option.
- A small increase in the relative quantity of wetlands in the catchment may have a reasonable impact on *E. coli* levels. The pathway for this reduction is the filtering capacity that is provided by wetlands.
- The CLD constructed by the group would suggest that if wetlands were considered in conjunction with management of pest birds (as wetland will provide more habitat for birds), then these mitigations have a strong combined impact on *E. coli* levels.
- A relative medium increase in fencing of streams may have an impact on *E. coli* levels. This mitigation option should be investigated and may already be a mitigation being progressed by various landowners or industry programmes.
- Continuing upgrades of the combined sewerage network to a separated network may also have an impact on *E. coli*. It is noted that sewage overflows only tend to occur at times of high rainfall/tides when swimming and recreation

are less likely to occur. Yet the relevance of this as a contaminant pathway should not be discounted.
- Increasing the number of gaps in the river wall to increase flushing was the other proposed mitigation that may have an impact. While the CLD drawn by the group indicated that this may be less impactful on *E. coli* levels than some of the other mitigations, there may be an opportunity for some pragmatic engineering solutions to be investigated that may contribute to reduced *E. coli* levels. *<u>It is important to note that any changes in the river wall are only expected to impact Marrs Beach, not Shingle Beach.</u>*

In addition, the following recommendations are made based on the observations and experience of the facilitator:

- WCRC staff should continue to develop skills using CLDs and the Mental Modeler software. This will enable them to continue to explore further scenarios and update them as their discussions with the group progress.
- No possible scenarios relating to septic tanks were tested. This may be a useful area for further scenarios to be identified and tested.

The electronic files for the Mental Modeler software have been provided to WCRC with an electronic copy of this report.

The pragmatic and targeted application of this mixed methods approach has enabled WCRC to begin an investigation into a complex *E. coli* contamination problem, using a stakeholder reference group, on the best terms possible. Within a short period of two weeks and at minimal cost, two workshops were held with a nascent stakeholder group.

In that time, they have shared perspectives on and learned about the issue they are tasked with dealing with investigating; built up a joint-shared understanding of that problem from their perspective; and begun to develop a working relationship with each other and as a group. This will ensure that WCRC can progress the project from this point forward in the best possible manner. The insight and interest within the stakeholder group can be used to help inform what further detailed investigations may need to occur, and where precious council resource should be directed to understand and then address the contamination issue.

9 References

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1 Hand drawn CLD from workshop 1

The below is a hand drawn image of the CLD from the first workshop. See

Figure 22. Hand drawn CLD from first workshop