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Complex Sociotechnical Problems: Insights from the Investigation of the Maintenance of Stormwater Control Measures in Melbourne

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Abstract

The expansion of urban development across the globe has brought with it significant environmental impacts. Prominent amongst these impacts is the degradation of marine and freshwater environments caused by conventional approaches to stormwater management infrastructure that facilitate the rapid conveyance of untreated stormwater to waterways. Stormwater control measures (SCMs) are a sustainability innovation developed to redress these environmental impacts. However, there are growing concerns that SCMs are not receiving sufficient maintenance and that, consequently, their long-term performance may be compromised. By taking a mixed methods approach, this study sought to gauge the veracity of these concerns and ascertain the barriers and challenges to the maintenance of SCMs. Nine local councils in Melbourne, Australia were engaged to provide condition data for their SCMs and access to their professional staff to collect perspectives on the barriers and challenges to SCM maintenance. Condition data analysis triangulated against survey data and similar studies from other jurisdictions indicate that concerns about insufficient maintenance have merit. Grounded Theory informed analysis identified 55 inter-dependent barriers and challenges across nine sociotechnical categories, confirming SCM maintenance as a complex multi-causal sociotechnical problem, and one potentially symptomatic of a loss of momentum towards mainstream adoption. Termed *Failure to Thrive*, this loss of momentum is considered a function of three over-arching issues: An under-developed stormwater industry, government policy inertia and, importantly, the invisibility of SCMs in the community. Using sociotechnical systems thinking and theory, three 'intervention pathways' are postulated to redress shortcomings in the maintenance of SCMs by Victorian local government and, likewise, address the *Failure to Thrive* scenario. In doing so, this study provides an example of how explorative, inductive research and sociotechnical systems theory can be used to decipher complex sociotechnical problems. Based on the findings of this study, an alternative transition pathway for Sustainability Transitions is proposed that accounts for the complex path-dependencies involved in the transition of sustainable innovations like SCMs and the need for pro-active institutional work accordingly to minimise the risk of partial or total failed transitions.

Declaration

I declare that the work in this thesis titled “Complex Sociotechnical Problems: Insights from the Investigation of the Maintenance of Stormwater Control Measures in Melbourne” is an original piece of work carried out by me [Andrew Oliver Thomas]. Other works that have been used in the creation of this work have been duly cited in the text and subsequently listed in the bibliography. The thesis is fewer than the maximum word limit in length, exclusive of tables, maps, bibliographies and appendices as approved by the Research Higher Degree Committee.

Andrew Oliver Thomas 29 May 2020

Preface

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1 Introduction

1.1 The Problem of Urban Stormwater Runoff

Urbanisation significantly alters landscapes over very short temporal scales, resulting in acute alteration of ecosystems, with subsequent and profound impacts on biodiversity (Fischer *et al.* 2007, McKinney 2008, National Research Council 2009). These environmental impacts translate to social and economic consequences (Whipple 1978, Farahmand *et al.* 2007, Cressey 2016). World population growth projections and an increasing proportion of people moving to urban living means that urban expansion and densification will likely accelerate into the next century (United Nations 2018). Consequently, urbanisation is one of the most important environmental issues facing humanity (Czech *et al.* 2000, Marzluff *et al.* 2001, McKinney 2006, Duh *et al.* 2008, Wu 2008).

The alteration to surface water runoff by urbanisation represents one of the most significant of these consequences and is attributed to two key processes: (1) altered catchment hydrology and (2) altered water quality (Duncan 1995, US EPA 2002, Goonetilleke *et al.* 2011). These alterations are a function of the introduction of impervious services (e.g. roads, footpaths, driveways and roofs) and the use of conventional, conveyance focused approaches to stormwater management (Herricks 1995, Reed 1999, Sansalone 2003, Walsh *et al.* 2005, Burns *et al.* 2012). Conventional stormwater management typically consists of a network of drains, pits, pipes and channels designed to rapidly remove rainwater collected by impervious surfaces away from urban areas (Burns *et al.* 2012).

In order to minimise the costs associated with the construction and maintenance of such networks, stormwater collected by conventional stormwater networks typically discharges into nearby local waterways. Such conventional approaches to stormwater management have proven very effective at minimising localised flooding (Osman Akan *et al.* 2003a). However, their use also compromises the capacity of the affected catchment to retain rain water through infiltration and groundwater recharge, thereby reducing the rainfall threshold at which run-off events occur relative to their natural state (Osman Akan *et al.* 2003a). Therefore, the introduction of impervious surfaces and conventional stormwater networks can significantly alter the hydrology of receiving waterways, reducing time of concentration and baseflows whilst increasing peak flows and annualised flow volumes (Figure 1-1) (Warner 1976, Reed 1999). Such changes result in reduced stream and riparian biodiversity due to increased bank erosion and accelerated stream migration, changes in benthic environments (e.g. sediment distribution and channel geometry), reduced water quality, rapid waterway thermal fluctuations and altered hydrobiological rhythms (Reed 1999, Kaushal *et al.* 2010, Walsh *et al.* 2016) .

The urbanisation of catchments also introduces a wide range of pollutants that would either not be present under natural conditions (e.g. petrochemicals) or are now present in greater amounts (e.g. nutrients) (Duncan 1995, Goonetilleke *et al.* 2005, Duncan 2006). Urban runoff and conventional stormwater systems act as a vector for the highly efficient transportation of these pollutants to local and downstream aquatic environments. Resultant increases in nitrogen and phosphorus availability can have a significant impact on ecological processes in surface waters, leading to reduced biodiversity, reduced resilience and, in some cases, complete system collapse (Harris 2001, Rabalais 2002, Conley *et al.* 2009). This includes the eutrophication of water bodies which can, under the right conditions, result in significant assemblage changes in aquatic plants and microorganisms (ANZECC *et al.* 2000, Harris 2001, Ansari *et al.* 2010). Eutrophication processes can trigger additional ecological events, such as fish kills, due to the release of toxins and deoxygenation of the water column (Müller *et al.* 2004). Stormwater is also a major contributor to the presence of gross pollutants in waterways,

particularly plastics, which have seen increased focus in recent years due to their growing and prolific presence in the world's oceans (Ryan *et al.* 2009, ABC 2019a, ABC 2019b).

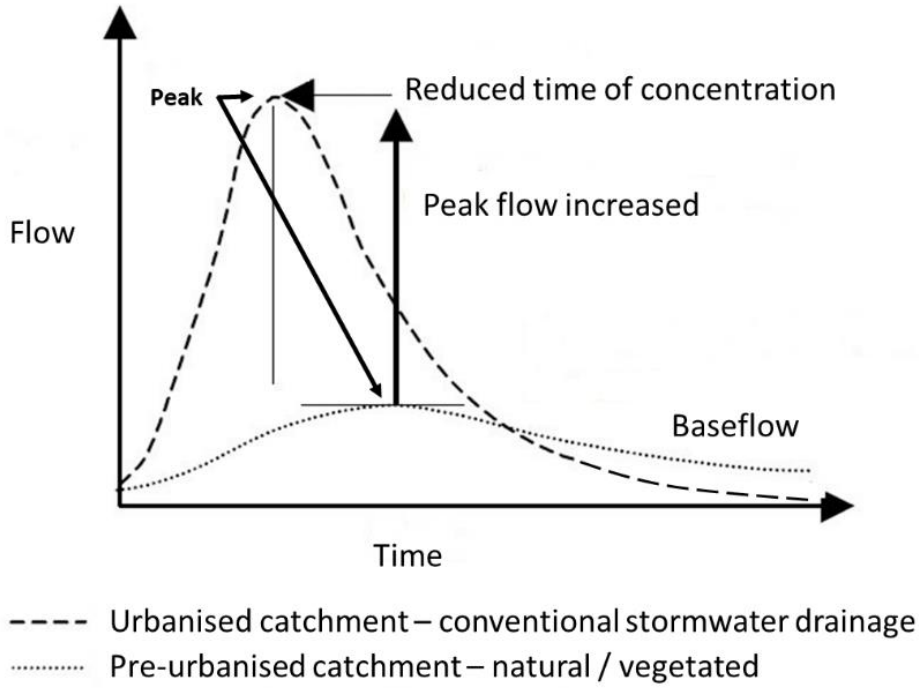


Figure 1-1: Idealised hydrograph for a typical catchment before and after urbanisation for the same rain event (Warner 1976, Reed 1999)

The environmental impacts of urban stormwater managed via conventional stormwater systems create a range of economic and social problems. Eutrophication, for example, can impact on downstream agricultural beneficial uses by poisoning stock and rendering water unsuitable for the irrigation of crops (ANZECC *et al.* 2000, Fisher *et al.* 2004, Walsh *et al.* 2005). Conventional approaches to stormwater management can, paradoxically, also increase the occurrence of urban flood events by increasing the flashiness (ferocity) of downstream flows (Marsalek *et al.* 1993, Chocat *et al.* 2001). Such flooding events can also be caused by the blocking of stormwater pipes and the damming of channels via the deposition of sediments and the prolific growth of invasive vegetation due to increased nutrient availability (Ashley *et al.* 2007, Bornette *et al.* 2011). Accelerated stream migration can cut into urban property boundaries and put public and private assets at risk (Duncan 2006). Degraded waterways also represent a lost opportunity to provide green space to urban communities that add to urban aesthetics and the general wellbeing of communities (Jackson 2003, Dean *et al.* 2011, Korfmacher *et al.* 2015). As these examples demonstrate, efforts to address the detrimental effects of stormwater should be a priority for societies that depend on healthy waterways for their long-term viability.

1.2 Stormwater Control Measures – A Sustainable Alternative to Conventional Practice

The term *stormwater control measures* (SCMs) describes a suite of stormwater management infrastructure solutions designed to redress the aforementioned negative impacts of conventional approaches managing urban runoff (Fletcher *et al.* 2014). Originally introduced into Australia in the late 20th Century in accordance with Australia's ecologically sustainable development commitments, SCMs were given specific national importance in 2004 under the

Intergovernmental Agreement on a National Water Initiative (ESDSC 1992, Wong *et al.* 2000, Choi *et al.* 2017). Also referred to using terms such as 'sustainable urban drainage systems (SUDS), 'low impact development' (LID), 'best management practice' (BMP), green infrastructure (GI) and nature based solutions (NBS) (Fletcher *et al.* 2014); SCMs combine civil ('grey') and environmental ('green') engineering to facilitate improved stormwater quality and hydrology outcomes for urban catchments to ameliorate the environmental, social and economic impacts of urban development (Wong *et al.* 2000, Belmeziti *et al.* 2015).

SCMs are a physical infrastructure response based on modern urban stormwater philosophies that, to varying degrees, conform with the general principles of Integrated Water Management (Fletcher *et al.* 2014). These philosophies look beyond the conventional stormwater management wisdom that focuses purely on conveyance and flood mitigation. They incorporate broader issues such as urban aesthetics and microclimate improvement, waterway ecosystem protection, urban habitat islands and water supply security (Hatt *et al.* 2006, Brown *et al.* 2009b, Fletcher *et al.* 2014, Walsh *et al.* 2016). Typical examples include sediment basins, constructed wetlands, raingardens, street tree pits, permeable pavement, green roofs, infiltration systems, water quality control ponds and gross pollutant traps (EPA Victoria 2008, Water by Design 2010c, Fletcher *et al.* 2014). Therefore, SCMs, while designed to improve catchment hydrology and stormwater quality, also provide other services in line with these philosophies.

Figure 1-2: Examples of Stormwater Control Measures (SCMs), clockwise from left: roadside swale; constructed wetland system; porous pavement; gross pollutant trap; street tree pit; kerb side raingarden (Pfleiderer 2008, Landcom 2009b, MWC 2012, MWC 2017b)

Unlike conventional stormwater infrastructure, which can be traced back to between 3000 and 5000 BC (Chocat *et al.* 2001, Burian *et al.* 2002), SCMs are a far more recent innovation. The philosophy underpinning their development, Integrated Water Management, can be traced back to the Dust Bowl Era of the 1930s in America and Canada which saw the enactment of the United States (US) Soil Conservation Act of 1935 (Ice 2004). This Act is thought to be the first formal instrument that legislated the philosophy of land management from a catchment scale perspective (Craddock *et al.* 1949, Ice 2004). The next major shift towards Integrated Water Management occurred four decades later, again in the US. In the 1970s, amendments were

made to the US Federal Water Pollution Act which enshrined the concepts of point and non-point sources of pollution into law (Ice 2004). Shortly thereafter, the concepts of *Low Impact Development* and *Green Infrastructure* emerged and, along with them, the trialling of some of the first SCMs (Radcliffe 2019). In 1999 the first formal guidelines incorporating what are now considered to be typical of SCMs were released by Maryland's then Department of Environmental Resources (DER 1999, Radcliffe 2019).

The application of SCMs has spread to other parts of world, including Canada, Europe, Australia, New Zealand and parts of East Asia (Fletcher *et al.* 2014, Radcliffe 2019). They have done so under various semblances of Integrated Water Management, such as *Sustainable Urban Drainage Systems* (Britain, Germany and Spain), *Techniques Alternative* (France), *Sponge Cities* (China), *ABC – Active Beautiful Clean* (Singapore), and *Water Sensitive Urban Design* (Australia) (Fletcher *et al.* 2014, Radcliffe 2019). For the most part, the primary purpose of adopting SCMs in different countries has been one of environmental protection and the preservation of natural waterways. However, some countries have adopted SCMs for additional reasons. In South Korea, for example, the establishment of SCMs has been driven by the need to reduce flash flooding events brought about by rapid urbanisation (Shafique *et al.* 2018, Radcliffe 2019). Consequently, South Korea has favoured methods that facilitate the retention of water within the highly urbanised landscapes, such as permeable pavements, green roofs, and infiltration trenches (Shafique *et al.* 2018). SCMs have also seen application to the harvesting of stormwater for potable and non-potable uses (Radcliffe 2019). For example, Singapore, while still applying SCMs to waterway protection, also applies them to the purpose of water harvesting for potable use (Lim *et al.* 2016). The application of stormwater harvesting for this purpose is a function of the city-state's dense population, with some built-up areas also acting as water supply catchments (Liao *et al.* 2017). Similarly, China, through its *Sponge City Initiative*, also utilises SCMs for water supply purposes (Biswas *et al.* 2017, Xia *et al.* 2017). While waterway protection is a consideration, the primary focus of the *Sponge City* concept in China is to address issues caused by "blind urbanisation" (Xia *et al.* 2017, p. 653), in particular ineffective water supply systems and urban waterlogging (Wang *et al.* 2017, Xia *et al.* 2017).

Despite their spread across the globe, there are growing concerns about just how well SCMs are being managed and maintained, and what effect this might be having on their long-term performance (Li 2015, Al-Rubaei *et al.* 2017, McDonald 2018). These concerns are further complicated by a lack of research focused on how the performance of different types of SCMs change over time, and what maintenance measures are required and when (Cherqui *et al.* 2019). Coinciding with these concerns about the effective management of SCMs are broader concerns about the acceptance of SCMs as a stormwater management solution and their transition from novel concept to mainstream practice (Rogers *et al.* 2015a, de Haan *et al.* 2015b). While it is possible that the two issues are related, the question remains as to how closely these two issues are related, and what the relative cause and effect relationships might be.

1.3 Research Purpose

The history of SCMs in Victoria, Australia, where this study takes place, can be traced back to the mid-1990s with the establishment of a nitrogen reduction target and the creation of an inter-agency committee for stormwater (Brown *et al.* 2007). While some industry frontrunners (Melbourne Water and a small number of local councils) had established SCMs beforehand, the rate of construction of new SCMs accelerated after 2006 (Rogers *et al.* 2015a). This acceleration in construction is largely attributed to the introduction of state government regulatory requirements that required residential subdivisions to meet stormwater quality targets[1] (Brown *et al.* 2007, Rogers *et al.* 2015a). Greater Melbourne is now recognised as an

[1] Changes to the Victorian Planning Provisions, Clause 56

international participant in the area of Integrated Water Management and the application of SCMs accordingly (Brown *et al.* 2007, Madsen *et al.* 2017). This includes research and development initiatives such as the Little Stringybark Creek project and the Cooperative Research Centre (CRC) for Water Sensitive Cities (Radcliffe 2019). Initiated in 2005 and still underway today, the Little Stringybark Creek project is one of few continuous longitudinal studies in the world designed to investigate technical and social aspects of SCMs at a catchment scale (Walsh *et al.* 2015, WERG 2019). The CRC for Water Sensitive Cities was established in 2012 in order to bring together a range of disciplines and expertise to help shift existing socio-technical and socio-institutional mindsets concerning urban water management (CRCWSC 2017). However, despite Melbourne's international standing, the transition of SCMs from novel concept to mainstream practice is arguably yet to occur in Victoria, and has been slow in progress relative to other forms of urban water innovations (e.g. desalination and wastewater recycling) (Brown *et al.* 2007, Rogers *et al.* 2015a).

Thanks to the aforementioned regulatory changes, as well as incentive programs such as Melbourne Water's Living Rivers Program, the number of operational SCMs in Greater Melbourne has risen significantly over the past two decades (DSE Victoria 2006, Eggleton *et al.* 2012, Hussey *et al.* 2015, Madsen *et al.* 2017). But with this growth has come growing concerns that SCMs in Victoria are being undermaintained (Eggleton *et al.* 2012, Beardshaw 2019), with similar concerns being raised about SCMs constructed in other parts of the world (Hunt *et al.* 2011, Blecken *et al.* 2017, McDonald 2018). If the anecdotal concerns are accurate, investments made towards developing and implementing SCMs as a stormwater management solution will be compromised. Likewise, the environmental and social benefits they were designed and constructed to provide will likewise be compromised. Such an outcome could undermine decades of sustainable stormwater management progress in Melbourne, with the potential to raise questions about the long-term viability of SCMs as a stormwater management solution. Further, given the attention the Melbourne experience continues to receive concerning Integrated Water Management, such an outcome could act to discourage actors in other parts of the world from moving beyond unsustainable conventional practices. Hence, the purpose of this research is to address the concerns regarding the under-maintenance of SCMs using empirical evidence, and to explore underlying reasons as to why this might be the case with a view to improving the *status-quo*.

1.4 Research Questions

To address the purpose of the research outlined above, three research questions were proposed (Table 1-1) within the context of local government, Victoria, Australia. While SCMs are not solely the purview of local government (some are delivered by Melbourne Water, and others privately), local government is responsible for the majority of SCMs currently operating within Greater Melbourne.

Table 1-1: Research Questions

Research Question 1	How well are SCMs being maintained by municipal government?
Research Question 2	What barriers and challenges effect SCM maintenance within Victorian local government?
Research Question 3	What intervention pathways might see long-term improvement to SCM maintenance outcomes in Victorian local government?

Given the paucity of research into the effectiveness of SCM maintenance in Victoria, the aim of Research Question 1 was to determine the veracity of the concerns about SCM under-maintenance. To this end, Research Question 1 sets out to provide empirical evidence on the status of SCM maintenance and how this compares to the maintenance of far more established

('conventional') forms of public infrastructure (e.g. roads). Accordingly, the intent of this question is to (1) determine if SCM under-maintenance is demonstrably a problem and (2) if the problem is best understood from a SCM-centric perspective, or if it is best understood as a function of a broader infrastructure management problem.

The aim of Research Questions 2 is to explore the causes of SCM under-maintenance. Given the paucity of research on the topic of SCM maintenance globally, and its potentially complex nature, there is currently insufficient information available to reliably determine the barriers and challenges concerning SCM maintenance. Hence, rather than make assumptions, the intent of this question is to seek out what these barriers and challenges are, and what they say about the current status of SCM maintenance in Melbourne, Victoria.

Research Question 3 was originally worded towards the identification of specific solutions to the problem of SCM maintenance. However, as the study progressed, it became apparent that the complex sociotechnical nature of the problem would render such attempts premature. This is because likely existence of feedback loops within such complex systems that may cause delayed effects, amplification, unforeseen emergent behaviours and new learnings (Norman *et al.* 2015) . Accordingly, attempting to identify specific 'solutions' under such uncertainty is not only likely to be extremely difficult, but also inappropriate.

In light of this, Research Question 3 was altered such that its aim is now to instead investigate where attention should be focused to see lasting improvement to SCM maintenance outcomes. The use of the term 'pathway' in Research Question 3 is to articulate the aim of identify potentially important inter-relationships between key issues, thereby providing policy makers with an understanding of where effort might be best focused towards addressing SCM maintenance (i.e., a strategic basis upon which to address the problem and its underlying causes). To this aim, the intent is to draw on the findings of Research Question 2 and the broader SCM / urban water management scholarship to identify such intervention pathways by understanding the relationships between the barriers and challenges determined from Research Question 2.

1.5 Research Contributions

The research contributions offered by this study can be divided into three areas. The first is to industry, providing empirical evidence for the under-maintenance of SCM and its causes, then suggestions for its amelioration based on these findings. The second is methodological, providing a working example of how explorative research and sociotechnical systems thinking can be coupled to decipher highly complex societal complex problems. The third is theoretical, where the findings of this study are used to further develop *Sustainability Transitions* research, a relatively new area of the innovations transitions scholarship that focuses on the complexities of innovation adoption at the societal level (Markard *et al.* 2012, Loorbach *et al.* 2017).

As articulated in Section 1.3, the impetus for this research is growing concerns about the level of maintenance SCMs are receiving and why this is the case. Accordingly, providing improved clarity around the current effectiveness of SCM maintenance to the stormwater industry, and how to go about addressing short-comings, is a primary concern of this study. To establish whether or not SCMs are under-maintained, asset condition inspection data was examined, being supplied by a group of councils within the greater Melbourne metropolitan area. Further, to give relative context, the findings of the examination of this condition data was compared to similar studies published from jurisdictions beyond Victoria's borders. To understand what lies behind SCM under-maintenance, explorative analysis of qualitative data collected from these same councils was undertaken to establish a wide range of barriers and challenges to SCM maintenance. Finally, this study provides a strategic approach to see lasting improvements to SCM maintenance in Victoria via the postulation of 'intervention pathways' that is grounded in these findings.

Methodologically, this study adds to the scholarship by applying sociotechnical systems thinking beyond its usual focus. In their paper *Advancing socio-technical systems thinking: A call for bravery* Davis *et al.* (2014) notes that the sociotechnical systems thinking scholarship has been too narrow, focusing mostly on technology adoption. They argue that it has far wider potential, such as conceptualisations of what constitutes "a system", diagnosing complex systemic problems, and a wide range of applications to include global challenges such as sustainability. Consistent with Davis *et al.* (2014)'s claims, most studies concerning SCMs have taken such a perspective, focusing on the adoption of SCMs as a sustainable means of managing urban stormwater runoff (Brown *et al.* 2009a, Brown *et al.* 2011, Madsen *et al.* 2017). This study approaches the question of SCMs differently in two important ways. Firstly, it approaches them from a public infrastructure management perspective rather than a transition perspective *per-se*, providing a unique perspective to the question of SCMs and their application to the management of urban stormwater. Secondly, it uses sociotechnical concepts and theory that underpin Sustainability Transitions research to not just explain the current situation, but also provide a strategic approach to improve the maintenance and management of SCMs under the remit of local government. In particular, it draws on the sociotechnical concepts of *path-dependency*, *destabilisation* and system *mis-alignments* to draw out and propose strategic 'intervention pathways' towards improve maintenance outcomes (Geels 2004, Van der Brugge *et al.* 2007). In doing-so, it provides a working example of how sociotechnical systems thinking can be used in conjunction with explorative research techniques to explore and understand complex sociotechnical problems, providing an answer to the 'call for bravery' made by Davis *et al.* (2014).

Because SCMs represent a form of sustainability innovation, the purpose and design of this research provides an opportunity to test and reflect on the relatively new area of Sustainability Transitions research (Markard *et al.* 2012, Loorbach *et al.* 2017). Sustainability Transitions, a subset of the broader transitions science scholarship, refers to theory specifically concerned with the adoption of innovations designed to correct the long-term consequences of conventional practices adopted at a societal level (Elzen *et al.* 2004, Brown *et al.* 2008, Markard *et al.* 2012, Loorbach *et al.* 2017). The need for theory specific to sustainability innovations has arisen due to the complex sociotechnical nature of such transitions and the unique challenges they face accordingly (de Haan *et al.* 2011, Markard *et al.* 2012). As described in the previous study, this study first applies existing Sustainable Transitions concepts as a means of identifying strategic 'intervention pathways' to improving SCM management and maintenance outcomes. It then goes on to use the findings of this study, along with works by others, to further develop Sustainability Transitions by postulating an alternative pathway for the sustainability innovations. It also directly addresses the question of adoption, at what this really means when considering sustainability innovations.

1.6 Thesis Structure and Outline

Chapter 1 of this thesis introduces the research topic and its defining elements. It begins by discussing the problem of urban stormwater runoff and how conventional urban infrastructure approaches are contributing to waterway degradation. It then introduces SCMs, describing their intended role in mitigating the impacts of conventional practices, and giving an overview of their constitution, developmental history and adoption across the globe. The chapter then shifts its attention to the study itself, describing its purpose followed by the introduction of the three research questions that inform and direct the research. It then concludes with a summary of the intended research contributions.

Chapter 2 provides a discussion of the literature considered relevant to the research topic. Because SCMs delivered by local government are a form of public infrastructure, the chapter begins with a discussion of why maintenance is important, and its crucial link with the broader practice of public infrastructure asset management (AAMCoG 2012, IAM 2014). The chapter

then discusses asset management as performed by local government, including a detailed examination of the challenges and barriers local government face in performing this task. Given the intent of this study was to investigate the under-maintenance of SCMs within local government, this information provides important context to the study. This included helping to understand and differentiate issues specific to the maintenance of SCMs relative to those associated with broader local government public asset management issues. Chapter 2 then shifts the focus to sociotechnical systems thinking and theory by first identifying the parallels between the definition of sociotechnical systems and the practice of asset management in local government. On this basis, it is then proposed that problem of SCM under-maintenance in Victorian local government is therefore likely to exhibit sociotechnical complexity. Accordingly, the chapter then provides a discussion on sociotechnical systems thinking and theory, drawing the discussion focus towards its application to SCMs by other studies. This includes a discussion on the relatively new area of Sustainability Transitions and its relevance to SCMs.

Chapter 3 provides a detailed description and discussion on the research design of the study. In the interests of transparency and scientific rigour, it begins by discussing the research paradigm taken by the researcher. For the same reasons, a reflexivity statement is also provided along with a discussion on ethical considerations and their management with the context of this study. The chapter then shifts attention to the study's methodological design, describing its explorative and inductive approach, the study area and the methods used to identify and select local councils to participate in the study. Included is an analysis of council and respondent recruitment outcomes, incorporating the numbers of councils and respondents recruited and the diversity of this sample group. The Chapter then shifts its attention to describing the analysis methods used to address each research question, incorporating a description of the methods used and why. Those methods used to address Research Question have been developed specifically for this study and, accordingly, a description of the basis of their development is also provided.

Research Question 1 relied predominately on qualitative data, being concerned with assessing the veracity of concerns about the under-maintenance of SCMs in by local government. Chapter 4 presents the results and findings to Research Question 1 in two parts. The first part focusing purely on the question as it applies Victorian local government, drawing on SCM condition audit data and closed ended questionnaire responses to do so. The second part focuses on jurisdictions beyond Victoria by drawing on the findings of similar studies conducted in other parts of the world. It then concludes by considering the findings for both parts together, revealing that the concerns about the under-maintenance of SCMs have merit and that this situation is not necessarily unique to Victorian local government.

Because the findings of Research Question 2 inform and provide the basis to addressing Research Question 3, the analysis and findings for both are presented in Chapter 5. This chapter first provides an overview of the inductive, Grounded Theory informed analysis of the qualitative data collected for this study (Glaser 2001, Charmaz 2006, Glaser *et al.* 2006). It then provides a detailed description of the various concepts and categories abstracted from the qualitative data, followed by a discussion on the over-arching issues considered to be fundamental to the problem of SCM under-maintenance in Victorian local government. It then concludes the presentation of results for Research Question 2 by discussing how the overall finding and the concepts and categories elicited from the data set confirm the complex sociotechnical nature of the problem, and one likely symptomatic of issues with the transition of SCMs from novel concept to mainstream practice. Chapter 5 then presents the findings to Research Question 3, being structured according to the stepwise process developed for this study as described in Chapter 3. The chapter then presents three 'intervention pathways' and the basis for their postulation relative to the findings of research questions 2 and 3 and the literature review findings of Chapter 2.

Chapter 6 then presents a discussion of the study's findings within the broader context of stormwater management and the sociotechnical systems scholarship. It beings by offering a discussion of the implications of the overall finding for Research Question 2, using Sustainability Transitions related theory as an interpretive lens to inform this discussion. The chapter then reverses this interpretive lens by offering an alternative transition model to explain the overall finding to Research Question 2 within the broader context of Sustainability Transitions. The chapter then shifts its focus back to the problem of SCM under-maintenance by first discussing the unique nature of SCMs and how this may, in particular, make SCMs vulnerable to under-maintenance. It then provides a discussion concerning the findings of Research Question 3 and their implications and application to ameliorating the problem of SCM under-maintenance in Victorian local government. Chapter 6 then concludes with a discussion of key findings of this study in terms of defining what constitutes successful transitions for SCMs and sustainability innovations generally.

Chapter 7 provides a concluding summary for this study. It begins by providing a brief summary of the intent and approach of the research. This is then followed by a summary of the key findings, presented as direct answers to each of the research questions (Table 1-1). It then provides a summary of how this research contributes to the scholarship in terms of theory, methodology and practice. Chapter 7 then concludes by offering a discussion of the study's limitations and the opportunities that these limitations present for further research in the areas of urban stormwater management, deciphering complex sociotechnical problems and Sustainability Transitions research.

2 Literature Review

2.1 Introduction

The word ‘maintenance’ has many different meanings depending on context (Butler *et al.* 2017). Its use in this study relates to the upkeep of public infrastructure, where public infrastructure refers to long-lived capital facilities created for the purpose of providing services to local communities (Alm 2015, Professionals Australia *et al.* 2016). More specifically, its use refers to the processes and procedures required to ensure that public built assets, including stormwater control measures (SCM), deliver their required levels of services throughout their intended operational life. (Tsang 2002, NAMSG *et al.* 2006). Without such mechanisms for replenishment, public infrastructure, whether it be roads, buildings, utilities, stormwater systems, etc., will decay, resulting in reduced service capacity, increased probability of failure, and increased risk to public safety and the environment (Denbigh 1989, Frangopol *et al.* 2007). Consequently, in order to maximise return on investment, effective maintenance programs are needed to ensure that public assets reach their optimal operational life, and that they continue to provide their intended levels of services (Amadi-Echendu 2006, Brown *et al.* 2006, AAMCoG 2012). Effective maintenance programs are also necessary to protect public safety and the environment, and to avoid reputational damage. Hence, the establishment and execution of effective public infrastructure maintenance programs must be a core component of the responsible entity’s standard operating practices. SCMs are no exception, as illustrated by Figure 2-1, which shows a basket type gross pollutant trap that had not been cleaned over an estimated period of 12 years. Due to resultant damage, the gross pollutant trap had to be decommissioned.

Figure 2-1: Example of asset failure attributed to ineffective maintenance: unrepairable wet sump stormwater gross pollutant trap left un-maintained following construction 12 years earlier – (a) basket (b) sub-surface superstructure and wet sump (Author 2012).

As is the case for any form of public infrastructure, effective SCM maintenance is a function of effective ‘asset management’ (IPWEA 2011). This chapter begins by giving an overview of the practice of managing public infrastructure. Given that SCM maintenance in Victorian local government is the focus of this study, asset management within local government is given particular attention. The chapter then considers sociotechnical systems thinking, first describing what a sociotechnical system is and why asset management within local government can be described as a sociotechnical system. Given the complexities associated with sociotechnical systems (and therefore asset management in local government), this chapter then discusses the potential for the problem of SCM under-maintenance to likewise exhibit complexity in its causes and, *ipso-facto*, its rectification. The chapter then explores sociotechnical systems related theory, narrowing the focus to that applied to SCMs in order to gain insights into how

sociotechnical systems thinking might be utilised in relation to SCM maintenance in local government and this study's research questions (Table 1-1).

2.2 Managing and Maintaining Public Infrastructure

Institutionalised maintenance of public infrastructure is evident in ancient Rome (Assante 2009), and can be traced as far back as five millennia to the water and waste water systems of the Indus Valley civilisation (Neuman 2012). Maintenance continues to be a key component of public infrastructure management in modern cities, forming an essential component of what is now generally referred to as the practice of *asset management* (Halfawy 2008, Dwight *et al.* 2013, IAM 2014, Brown *et al.* 2014b, Alm 2015). As illustrated by Figure 2-2, the maintenance of public infrastructure is a component of a much larger interconnected and interdependent 'asset management' system. Hence, in order to investigate maintenance, it is essential to understand it within the context of organisational asset management systems and the external factors that influence them.

Modern asset management is concerned with consistency in asset service delivery through the whole-of-life management of built assets, including their planning, design, acquisition, care, refurbishment and disposal (AAMCoG 2012). The international asset management standard series ISO 55000 defines asset management as a coordinated activity of an organisation to realise value from assets, where an asset is an item, thing, or entity that has potential or actual value to an organisation. The over-arching objective of asset management is to optimise the delivery of the services built infrastructure provide, whilst balancing the associated risks and costs of this endeavour (AAMCoG 2012, IAM 2014).

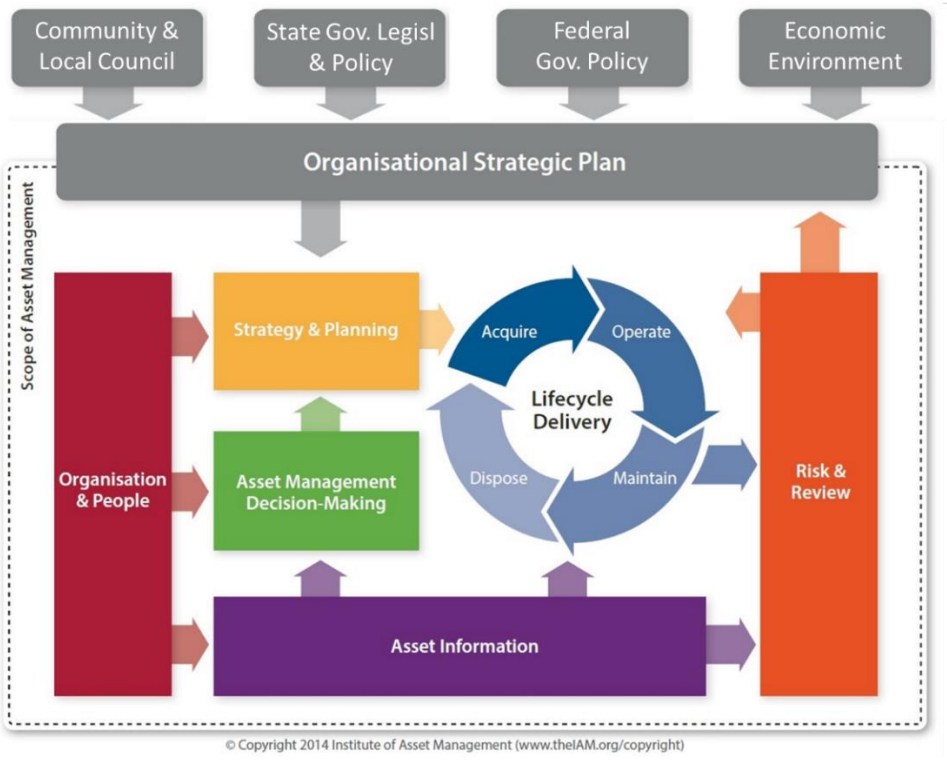


Figure 2-2: Diagrammatic illustration of Integrated Asset Management of public infrastructure by Local Government (IAM 2014 with modifications)

In practice, asset management is a complicated, multi-layered and multi-disciplined process, spanning different temporal scales and organisational levels (IAM 2014, Brown *et al.* 2014b). This requires high levels of organisational sophistication, relying on interdepartmental integration of human resources and information management systems (Brown *et al.* 2006, Van

Riel *et al.* 2014). This complexity is further compounded by external political, economic and environmental factors that impact on decision-making processes in public agencies (Brown 2005, Schraven *et al.* 2011, Van Riel *et al.* 2014).

2.3 Australian Local Councils as Asset Managers

2.3.1 Best Practice Asset Management in Local Government

Australian local government is responsible for approximately $345 billion in infrastructure, and has the largest infrastructure commitment relative to Australia's state and federal governments (Verity *et al.* 2018). It is responsible for a wide array of public infrastructure, including local roads; footpaths; stormwater systems; waste collection facilities; water supply and sewerage (non-metropolitan only); parks and gardens; and recreation & sporting facilities (Hawker 2003, DIRDC 2013, Productivity Commission 2017). Consequently, the provision of public infrastructure by local government plays a central role in the economic and social prosperity of urban communities in Australia (Alm 2015, LGPASA 2015).

Current industry standards describe best practice asset management in local government as an integrated management hierarchy aligned with the hierarchal structure of the local council (Figure 2-3) (AAMCoG 2012, IAM 2014, LGV *et al.* 2015). At the apex should be an asset management policy and strategy. The asset management policy represents a formal statement of the intentions and directions of the council concerning how it will manage its assets (IAM 2014). The asset management strategy acts as road map that defines the council's asset management portfolios (usually by asset class) and links them to other council plans, indicating which council services are delivered through which asset portfolio (LGV *et al.* 2015). It should include an assessment of service level targets against the council's existing asset base and its long-term financial sustainability, defining how risks will be managed and communicated to the community (LGV *et al.* 2015).

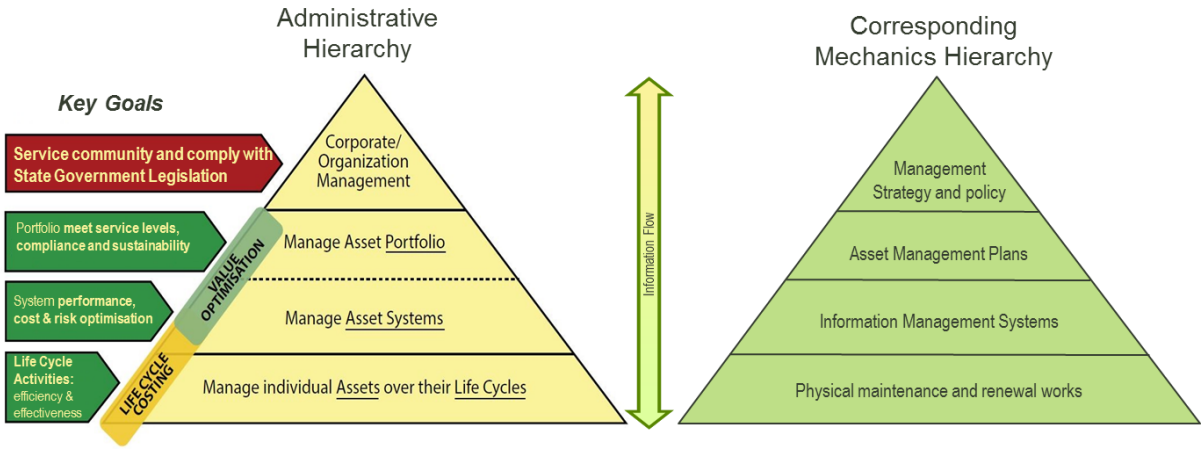


Figure 2-3: Diagrammatic illustration of integrated asset management in local council (IAM 2014 with modifications)

Subordinate to the asset management strategy and policy are asset management plans. An asset management plan should be established for each asset portfolio defined in the asset management strategy (AAMCoG 2012, LGV *et al.* 2015). Each plan should set out specific targets, goals and actions geared towards achieving the aims and objectives of the council's asset management strategy (NAMSG *et al.* 2006, LGV *et al.* 2015). A key feature of asset management plans should be the articulation of *service levels*, against which the council's asset management performance can be assessed (AAMCoG 2012, Brown *et al.* 2014b, LGV *et al.* 2015). Service levels define the quality, quantity, reliability and responsiveness that a given asset portfolio will provide balanced against cost and budgetary limitations (Malano *et al.* 1999,

NAMSG *et al.* 2006, Lateef 2010, Brown *et al.* 2014b). Accordingly, service levels inform the nature and timing of asset maintenance and renewal activities (NAMSG *et al.* 2006, Dollery *et al.* 2007a, Dollery *et al.* 2010, AAMCoG 2012).

Below the asset management plans in the asset management hierarchy (Figure 2-3) are the information Management Systems. Information Management Systems are the applications, software, and administrative systems that facilitate asset 'knowledge management'. They are designed to store, collate and analyse the information necessary to manage a council's public assets over their entire life cycle (AAMCoG 2012, IAM 2014). Ideally, these should be a coherent integration of a council's asset register and asset management software with its other applications and administrative systems, particularly its document management system, geographical information system, and financial management system (NAMSG *et al.* 2006, AAMCoG 2012).

At the base of the hierarchy is where the intent of the council's asset management strategy and policies manifest as actions, primarily in the form of the planning and execution of maintenance and related activities including condition auditing, cleaning, and repair. (AAMCoG 2012, Brown *et al.* 2014b, LGV *et al.* 2015). Importantly, good practice in asset management dictates that information flows are three dimensional, moving up and down the asset management hierarchy and between teams and departments (IAM 2014, FAIR 2020)[2]. This three-way flow of information is essential for ensuring budgets and actions reflect community service levels. Thus, strategically driven asset management requires that asset management is not isolated from other business processes. Rather, it must by fully integrated within a council's corporate, financial, business, budgetary, operational, human resources and information technology systems (LGV *et al.* 2015).

2.3.2 Challenges and Barriers to Asset Management in Local Government

In practice, asset management process depicted by Figure 2-2 and Figure 2-3 are rarely achieved (Dollery *et al.* 2007a, VAGO 2014, Infrastructure Australia 2015, Aris 2016). Over the past 20 years, numerous inquiries into the sustainability of local government have been undertaken in most Australian states. All of these inquiries identified deficiencies in asset management practices within local government, resulting in a growing infrastructure backlog and asset renewal gap into the billions of dollars (Burns *et al.* 1998, LGA SA 2005a, LGI 2006, Access Economics 2007, Deloitte 2012, TCorp 2013, VAGO 2014, QAO 2016). These investigations consistently identify the following key asset management shortcomings within local government as the cause of this situation (LGA SA 2005a, LGI 2006, Access Economics 2007, Deloitte 2013, VAGO 2014, QAO 2016):

- Insufficient asset management expertise.
- Underinvestment in the maintenance and renewal of public infrastructure
- Inadequately developed asset management frameworks.
- Poor financial management.
- Confounding asset acquisition mechanisms.
- Deficiencies in asset information management.
- Financial stress.

Deficiencies in asset management knowledge of the executive and elected officials of local government have been found to be particularly problematic, resulting in poor understanding of

[2] FAIR (2020) refers to a two-way flow or 'tactical handshake' between strategic planning and operational asset management. The third flow direction discussed here accounts for the various departments that typically compartmentalise service delivery and administration functions within local councils.

the strategic nature of public infrastructure management (Burns *et al.* 1998, LGA SA 2005a, Deloitte 2012, TCorp 2013). This poor understanding at the executive level has been linked to under-developed asset management frameworks in local councils, along with a lack of awareness of the long-term impacts to community services and the financial sustainability of the councils themselves (Burns *et al.* 1998, QAO 2016).

As discussed earlier, effective asset management is highly dependent on three-way information flows, hence organisational asset management systems need to be extremely well integrated into a council's broader administrative systems. However, inquiries conducted across Australia have found such integration to be commonly lacking, with a degree of variability between councils (Hawker 2003, LGA SA 2005a, LGI 2006, PWC 2006, Access Economics 2007, Deloitte 2012, Dollery 2012, TCorp 2013, VAGO 2014, IPWEA 2016, QAO 2016, TAO 2017). Accurate asset information is also essential as it informs every aspect of asset management, from long-term planning through to day to day maintenance and inspection programs (NAMSG *et al.* 2006, AAMCoG 2012, IAM 2014). Yet many Australian local councils have been found to struggle with asset information management in two interdependent ways (Access Economics 2007, VAGO 2014). The first is a lack of protocols and resources in place to appropriately capture asset information at the point of asset acquisition (Burns *et al.* 1998, VAGO 2014, QAO 2016). The second is a function of 'system fragmentation' where individual functional silos establish stand-alone systems, often exacerbated when councils amalgamate and, in-so-doing, immediately create a multi-system paradigm that can take years to correct (Deloitte 2012, VAGO 2014, Aris 2016).

Under-spending on the maintenance and renewal of public assets continues to be a problem in Australian local government (Hawker 2003, LGI 2006, Access Economics 2007, WALGA 2007, Dollery 2009b, Dollery 2012, Deloitte 2013, TCorp 2013, VAGO 2014). While this under-spending has, in-part, been attributed to a lack of skills and expertise in asset management (e.g. the failure to properly account for asset life-cycle costs), it has also been found to be an intentional strategy to cover costs in other areas (Burns *et al.* 1998, LGA SA 2005a, LGA SA 2005b, Deloitte 2013, TAO 2017). This strategy has resulted in the build-up of asset maintenance and renewal backlogs, effecting the long-term financial sustainability of many councils (Dollery 2009b, VAGO 2014, Drew *et al.* 2016). Somewhat paradoxically, state and commonwealth grant / funding initiatives, developer contributions[3] and the 'gifting' of previously state-owned assets to local councils has added to this backlog (Burns *et al.* 1998, VAGO 2014, QAO 2016). While such external sources enable councils to more readily acquire public infrastructure, they also add to local government infrastructure maintenance and renewal burdens as such sources rarely come with ongoing maintenance and renewal funding (Burns *et al.* 1998, VGC 2013, WALGA 2015).

Adding to the long-term financial pressures facing local government is the ongoing practice of devolution by higher tiers of government (Dollery 2009b). Devolution or 'cost-shifting' is the transference of decision making power and service provision from a higher tier of government to a lower one. The underlying justification for this practice is to improve decision making and service provision by localising it (Jeffery 2006, LGA 2018). In principle, such a practice can have merit providing it also includes the transference of associated funding and resourcing. However, in Australia, devolution has rarely been accompanied by a comparable transference of comparable funding and resources (Dollery *et al.* 2012, LGN 2017). Examples of devolution practices that increase the financial burden on local councils include:

- Withdrawal or reduction in financial support
- Transfer of assets without ongoing funding support

[3] Public infrastructure assets constructed by developers under a state's planning provisions, then handed over to local government on completion.

- Requirements that local councils provide concessions and rebates without compensation
- Increased regulatory and compliance requirements
- Failure to provide for indexation of fees and charges
- Another tier of government stops providing a service and local government steps in to fill the gap (Hawker 2003, Brackertz 2013).

The practice of devolution, along with growing community expectations of their local council, has contributed to the rapid expansion of services being offered by local government since the 1970s that has seen the rise costs outpace rises in revenue (Dollery *et al.* 2006b, Dollery *et al.* 2010, Brackertz 2013, ALGA 2018).

Importantly, shortcomings in asset management in local government and the financial stress of local government exist in a potentially dangerous positive feedback loop (Dollery 2009b). This is because, asset management shortcomings are, in part, caused by financial stress, causing cash-strapped councils to defer investment in asset management training, systems, and maintenance and renewal. However, the long-term implications of this practice increases the likelihood that councils will not properly maintain, renew and expand their existing asset base (Dollery *et al.* 2007a, Dollery *et al.* 2010). Consequently, unless measures are taken to address current asset management practices, infrastructure backlogs, and appropriate funding levels for councils, asset renewal gaps are expected to grow into the billions of dollars due to underinvestment in the maintenance and renewal of public infrastructure (LGA SA 2005a, LGI 2006, Access Economics 2007, Deloitte 2013, VAGO 2014, QAO 2016).

2.3.3 Stormwater Management Responsibilities in Victoria

In Victoria, stormwater management is predominately the purview of local government, with most of the associated public infrastructure owned and operated by councils (DSE Victoria 2006). The only major exception is large metropolitan drainage systems greater than 60 hectares (known as the '60 hectare convention'), which come under the management of Melbourne Water (DSE Victoria 2006, DELWP 2020). However, there remains a substantial degree of ambiguity about exactly what local governments responsibilities are concerning stormwater, particularly when it comes to the management of stormwater drainage infrastructure and the protection of urban waterways[4] (Brown 2005, DELWP 2020).

A review of the Victorian *Local Government Act 1989* reveals scant mention of local councils responsibilities in relation to stormwater, and none directly make a connection between stormwater and environmental protection. While not making any direct mention of stormwater or waterways *per-se*, it could be argued that Section 3C of the *Local Government Act 1989* infers responsibility onto councils to mitigate the environmental effects of stormwater. This section states that within the context of delivering services, councils must "promote the social, economic and environmental viability and sustainability of the municipal district." However, it could also be argued that such obligations only extend to the boundaries of the municipality, negating responsibilities to downstream waters beyond a council's boundaries. Section 3G could also be argued to infer responsibility upon councils to mitigate the environmental effects of stormwater, but again only indirectly. It outlines local government obligations to the recently passed *Yarra River*[5] *Protection (Wilip-gin Birrarung murron) Act 2017*, requiring a council to not

[4] Responsibilities concerning stormwater management are now being reviewed by the Victorian State Government as part of the *Melbourne Urban Stormwater Institutional Arrangements Review* (DELWP 2020).

[5] The Yarra River is an iconic Victorian river that runs through the centre of Melbourne, holding significant cultural and historic heritage to the indigenous and non-indigenous peoples of Victoria. The *Yarra River Protection (Wilip-gin Birrarung murron) Act 2017* is currently the only Act to apply to a specific river system in Australia.

act inconsistently with a Yarra Strategic Plan that specifically identifies that council as being bound to the Plan. However, the Yarra River Act itself makes no mention of stormwater *per-se*. Rather, it emphasises the need to protect the health of the river and that land use framework plans must recognise flood risks and climate change.

Victoria's *State Environment Protection Policy (Waters of Victoria)* is the central policy instrument for the protection of Victoria's waterways. While it gives mention to councils and the preparation of stormwater management plans (s46(1)), the language used does not state that councils 'must' do this. Further, it does not state that councils are 'obligated' to ensure new and retrofit developments include effective measures to manage stormwater flows and pollutants. Rather, it simply states that Victoria's Environment Protection Authority "will … work with municipal councils" in this regard, and only for new developments. Another important instrument effecting local government stormwater responsibilities is Clause 56 of the Victorian Planning Provisions. This clause sets out the integrated water management requirements that must be met for new residential subdivisions in urban areas (DSE Victoria 2006). Clause 56.07-4 of the Victorian Planning Provisions requires that new developments do not result in associated waterways being degraded by urban runoff and that urban stormwater management systems be "designed and managed in accordance with the requirements and to the satisfaction of the relevant drainage authority". Yet Clause 56 is silent on the responsibilities of the drainage authority or any other entity once those stormwater systems are transferred to local government by the developer following practical completion.

2.3.4 Implications for Investigating the Maintenance of SCMs

The review of asset management within the local government context reveals that SCMs have been introduced into an environment beset by a range of problems and challenges that are likely to affect its management and maintenance outcomes. Many of these problems and challenges have built up over decades, with more recent publications and reports showing little improvement (Bell *et al.* 2016, Productivity Commission 2017). A contributing factor to the intractable nature of the problem of asset management in local government is that the barriers and challenges are not merely a function of shortcomings within local government, but also forces and pressures beyond. This includes issues with the regulative and institutional functions of federal and, in particular, state governments, and changing expectations of communities. This situation has created a complex mix of multi-causal and inter-dependent factors that cross institutional, technical and social boundaries. As a result, despite the decades of reporting, effective solutions to the looming infrastructure backlog are yet to materialise (Dollery *et al.* 2004, Dollery *et al.* 2013b, Tiley 2017). Hence, in order to determine if SCMs are, in particular, being under-maintained and why, it will first be necessary to establish a methodology that is able to untangle issues that are specific to SCMs from those issues that a function of the broader sociotechnical system beyond.

2.4 Public Asset Management as a Complex, Adaptive Socio-technical System

Socio-technical systems are generally defined as (1) consisting of individual parts; (2) affected by and affecting an external environment; (3) reliant on separate but interconnected social and technical subsystems to function; (4) requiring decisions to achieve goals, and (5) performance being dependent on optimising social and technical subsystems (Badham *et al.* 2000, Rotmans *et al.* 2009, Chini *et al.* 2017). These defining features of sociotechnical systems lend themselves to complexity because of the high degree of interdependencies exhibited between multiple parts both within and beyond the system as illustrated by Figure 2-4 (Geels 2004, Davis *et al.* 2014, Norman *et al.* 2015). Hence, attempting to understand and influence phenomena that occur within a sociotechnical system cannot be achieved by simply understanding its

individual parts (Pahl-Wostl 2007, Van der Brugge *et al.* 2007, Sittig *et al.* 2015). Rather, it is necessary to also understand the synergistic mechanism or 'path-dependencies' behind how these parts inter-relate and co-evolve under the influence of relevant external factors (Kim *et al.* 2006, Van der Brugge *et al.* 2007, Davis *et al.* 2014).

A comparison between the management of public infrastructure in local government and the defining features of sociotechnical systems reveals a high degree of alignment. All elements in the Local Government Integrated Asset Management framework (Figure 2-2) are consistent, either explicitly or implicitly, with a socio-technical system (Figure 2-4). For example, effective asset management is heavily dependent on information management, and most councils now rely on digital technology to collect, collate, store and analyse the mass of information required to manage their assets effectively. Further, organisational cultural factors, while not explicitly depicted, are an unavoidable reality of human actors within the system, made more complex by the administrative necessity of departments and teams in local government operation (Tett 2015). Figure 2-2 also clearly shows interaction with an external environment (likewise coloured grey) consisting of the community (through councillors), state governments (which have legislative authority over councils), federal government policy (mainly funding), and external economic factors (state, national and global).

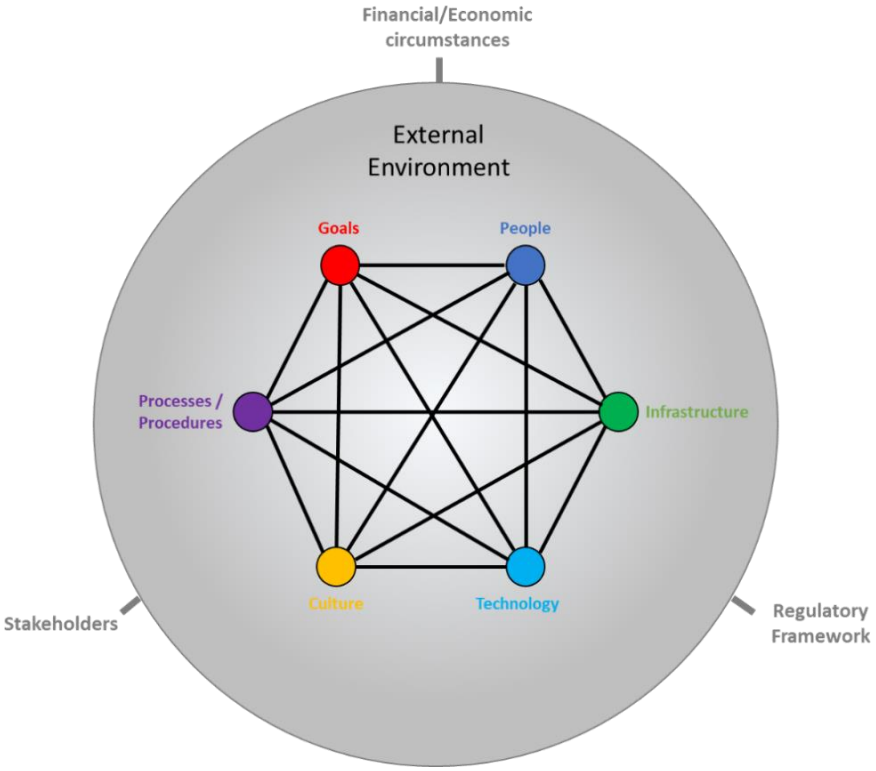


Figure 2-4: Conceptual model of sociotechnical systems (reproduced from Davis *et al.* 2014 with minor modification). The hexagon represents any complex organisational system whereas the grey circle represents the external environment within which the system is located.

Given the alignment between the definition of a sociotechnical system and the management of public infrastructure by local government, it is plausible that problems with the management of public infrastructure, such as the under-maintenance of SCMs, will exhibit sociotechnical complexity. This being so, problems associated with SCM under-maintenance are unlikely to be amenable to simple, binary solutions (Norman *et al.* 2015). Rather, it is quite possible that problems with the management of SCM will be multi-causal and inter-dependent, and will not lend themselves to easy identification and rectification (Geels 2004, Davis *et al.* 2014, Norman

et al. 2015). Therefore, the application of sociotechnical systems thinking to better understanding problems concerning the management of public infrastructure, include SCM maintenance, would seem to have merit. However, despite a thorough search of the available literature concerning asset management in Australian local government (Section 2.3.2), no articles were found that applied a sociotechnical system perspective to understanding issues with public infrastructure delivery. Hence, investigating the maintenance and management of SCMs by local government not only presents an opportunity to apply sociotechnical systems thinking and theory to the SCM maintenance, but also a case study in its application to problems in public infrastructure management.

2.5 Applying Sociotechnical Systems Theory to SCM Maintenance in Local Government.

2.5.1 Overview

The use of sociotechnical systems thinking dates back to the work of Trist *et al.* (1951) investigating the adoption of long-wall mining technology by coal companies in England. Since then, sociotechnical systems thinking has continued to focus on innovation adoption, with over 96 theories now associated with the scholarship (Sovacool *et al.* 2017). While acknowledging the utility of sociotechnical systems thinking to new innovations, Davis *et al.* (2014) argue that sociotechnical systems thinking has far wider application than technology adoption, including providing structure and systematic ways of analysing complex systems, problems and events. As discussed in the previous section, this argument would seem to have merit, given the similarities between sociotechnical systems thinking and the constitution and execution of public infrastructure asset management.

Approaching the management of public infrastructure from a sociotechnical perspective brings two important advantages. Firstly, it recognises and facilitates the need to consider not just the various parts of a system, but also how these parts interact and are co-dependent, and how the external environment impacts on the system (Davis *et al.* 2014, Sovacool *et al.* 2017). Secondly, sociotechnical systems thinking provides a diverse range of heuristic theories and models (Sovacool *et al.* 2017). Given the complex and unique characteristics of individual sociotechnical systems (Berkhout *et al.* 2004, Geels 2005a, Davis *et al.* 2014, Sovacool *et al.* 2017), such diversity is advantageous, providing researchers with ample options to decipher phenomenon from different perspectives.

Recognising that the vast bulk of sociotechnical systems research has focused on innovation diffusion (Davis *et al.* 2014), it may seem counter-intuitive to apply it to the problem of SCM maintenance in local government. However, there are now compelling reasons to do so. The first is that SCMs are a very recent addition to the public infrastructure realm (Section 1.2) and, therefore, connections between maintenance outcomes and its diffusion as an innovation cannot be discounted. Secondly, as argued by Davis *et al.* (2014), the dominance of applying sociotechnical systems thinking to innovation diffusion is not a limitation of the approach, but rather a limitation of its *application*. Third, the practice of asset management in local government bears a high degree of consistency with the key features of a sociotechnical systems (Section 2.4). Finally, because problems that manifest in sociotechnical systems are likely to exhibit complex characteristics borne of those systems, innovation diffusion theories built around sociotechnical systems thinking are likely to provide a means of deciphering such problems. Given the large number of sociotechnical systems related theories to choose from (Sovacool *et al.* 2017), it is not possible to provide a review of all of them. Rather, a select few are discussed below based on their eminence, alignment with the nature of the research questions, and previous application to SCM transition.

2.5.2 Diffusion of Innovations

Everret M Rogers is considered to be one of the preeminent researchers and theorists on the diffusion of innovation (Lundblad 2003, Singhal 2012), and his influence is evident in the myriad of sociotechnical theories and models available today (Lundblad 2003, Sovacool *et al.* 2017). Rogers first published his theory, *Diffusion of Innovations* (DOI) in 1962 (Rogers 1962). DOI continues to see application, both singularly and as a fusion with other models, across a diverse range of fields such as health (Lien *et al.* 2017, Dearing *et al.* 2018); virtual reality in workplace design (Ellman *et al.* 2019); energy (Franceschinis *et al.* 2017); manufacturing (Mamun 2018); education (Costa *et al.* 2018) and public stormwater infrastructure (Olorunkiya *et al.* 2012, Madsen *et al.* 2017), demonstrating both the utility of DOI and the flexibility of sociotechnical systems thinking generally.

The roots of DOI theory can be traced back to the German-Austrian and British schools of diffusionism in anthropology, and the French sociologist Gabriel De Tarde who pioneered the innovation diffusion S-curve concept (De Tarde 1903, Rogers 1976, Rogers 1983). What distinguished Rogers' theory from earlier works was the placement of social factors and, in particular, the *perceptions* of individual actors, at its locus (Rogers 1983, Rogers 2003, Dearing *et al.* 2018). In so-doing, Roger's acknowledged that rational decisions concerning the suitability and efficiency of an innovation did not alone determine its fate. Rather, subjective factors also played an important role in innovation adoption, which could see otherwise highly effective innovations fail to be adopted.

Rogers gave definition to innovation as not just being technological, but also applicable to ideas and practices, and that the innovation did not necessarily have to be 'new' in the literal sense, but just needed to be perceived to be so (Rogers 1962, Rogers 1976). DOI theory holds that the diffusion of an *innovation* occurs within a *social system* where individuals and groups disseminate information about the innovation through *communication channels* over *time* (Rogers 2010). Building on the seminal works such as De Tarde (1903) and Ryan *et al.* (1943), Rogers conceptualised innovation adoption diagrammatically in the form of an S-curve, with the *rate of adoption* set as the dependent variable (Figure 2-5).

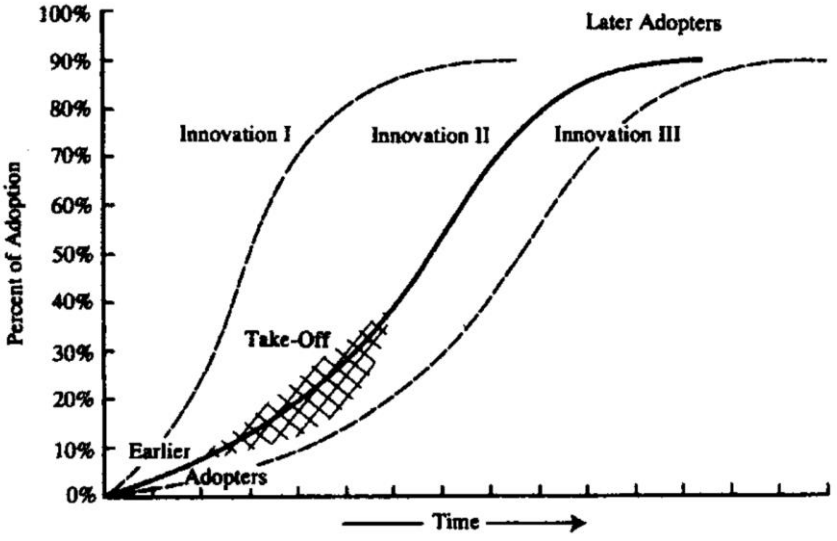


Figure 2-5: Rate of Adoption of Innovations (Rogers 2010, Fig. 1-2)

The emphasis Rogers puts on subjectivity is clear in the five key variables he identifies as influencing the rate of adoption (Figure 2-6). Importantly, the adoption rate of an innovation is *not* a function of actual usefulness of an innovation, but rather its *perceived* usefulness (Rogers 2010). DOI explicitly recognises that individuals do not necessarily form their perspectives independently nor entirely objectively. Rather, they do so according to subjective factors within

their broader social context, such as the established behavioural norms within the social group concerned (e.g. organisation, industry, professional) and how connected individuals are (Rogers 2003). The importance of this shift in emphasis away from objectivity and towards subjectivity lies in its recognition that human beings make decisions based on their perceptions which are informed not just by objective considerations, but also overt and covert subjective factors, including emotions, past experiences, cultural norms and sense of identity (Lazarus 1991, Sabatier 2007).

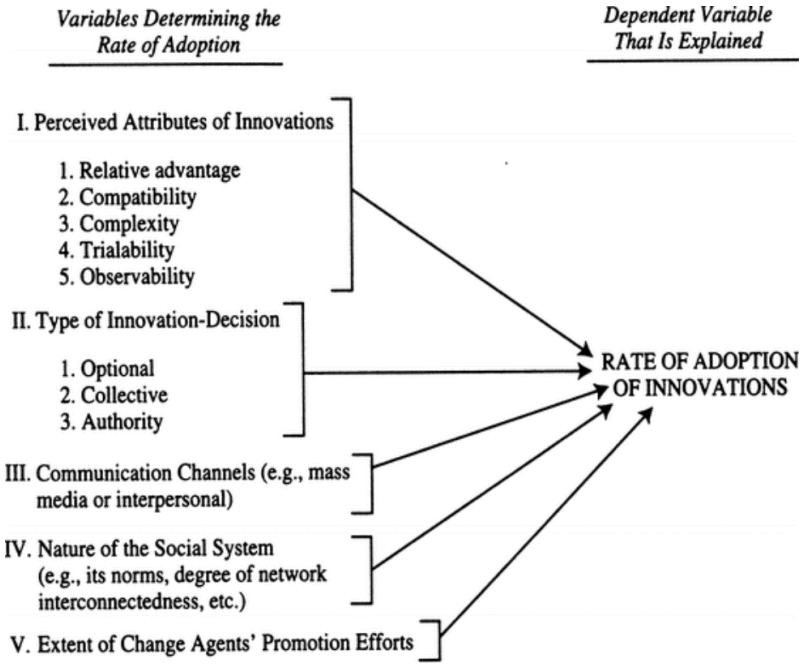


Figure 2-6: Variables determining the rate of innovation adoption (Rogers 2010, Fig. 6-1)

2.5.3 Technology Adaption Model

A more recent and widely utilised sociotechnical systems theory is the *Technology Adaption Model* (TAM). Where DOI provides a heuristic model for describing the rate of adoption, TAM provides a multifactorial model for quantifying the risk of users rejecting an innovation. Originally developed by Davis during the early 1980s (Davis 1985), the model has since seen two updates (TAM2 & TAM3) (Venkatesh *et al.* 2000, Venkatesh *et al.* 2008). The TAM models hold that an individual's *intention to use* a 'new' technology is a function of how they perceived its usefulness and ease of use. That is, objective deductions of how useful a person believes the innovation will enhance their performance and the degree to which it will be free from effort (Davis 1985, Davis 1989). The TAM models are now a frequently applied model for the quantitative predicting for human decisions regarding the acceptance or rejection of an innovation (Marangunić *et al.* 2015).

TAM has seen specific application to the acceptance of SCMs in municipal government in the United States (Carlet 2015). Using TAM as a basis, and borrowing also from DOI and organisational theory, Carlet (2015) proposed two multi-factor research models for testing attitudes towards green infrastructure (Figure 2-7). From these models, Carlet (2015) derived and tested 11 hypotheses, where Research Model 1 focused only on cognitive factors and Research Model 2 included two additional non-cognitive factors (respondent age and municipality size). Carlet (2015) was able to quantifiably demonstrate that all hypthotheses except for H2, H4 and H9 were supported in both models, whereas Research Model 2 found that while respondent age did have a significant impact on their attidude (H10), the size of their municipality did not (H11).

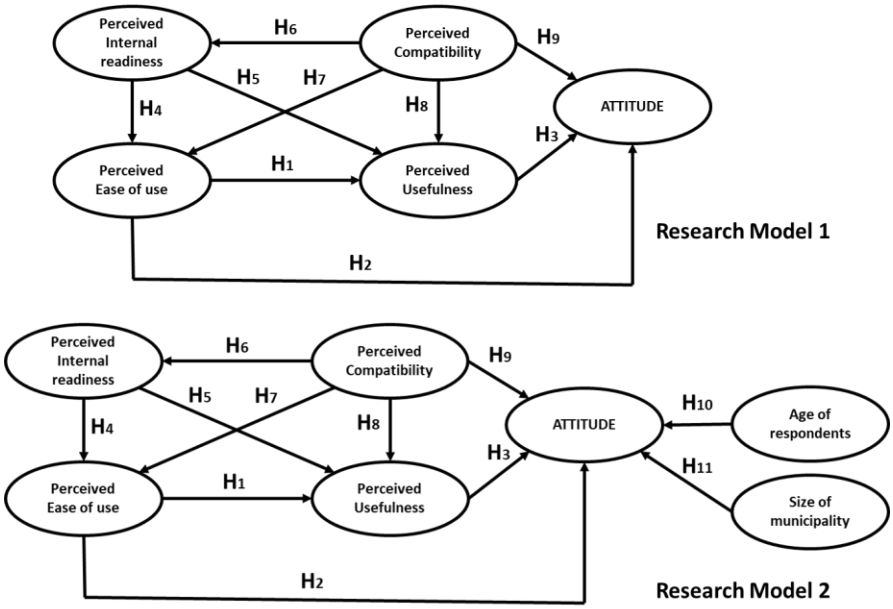


Figure 2-7: Research models for testing attitudes towards green infrastructure developed by Carlet (2015)

While it is recognised that TAM was able to predict user behaviour relatively well, it was also heavily criticised for assuming only objective considerations were of importance to user behaviour (Davis 1989, Mathieson 1991, Hartwick *et al.* 1994, Gefen *et al.* 1997). To address these shortcomings and improve interpretive power, Venkatesh *et al.* (2000) revised and tested the TAM, incorporating social processes (subjective norm, image and experience and voluntariness) along with the additional objective factors (experience, result demonstrability, output quality and job relevance), establishing TAM2 accordingly (Figure 2-8).

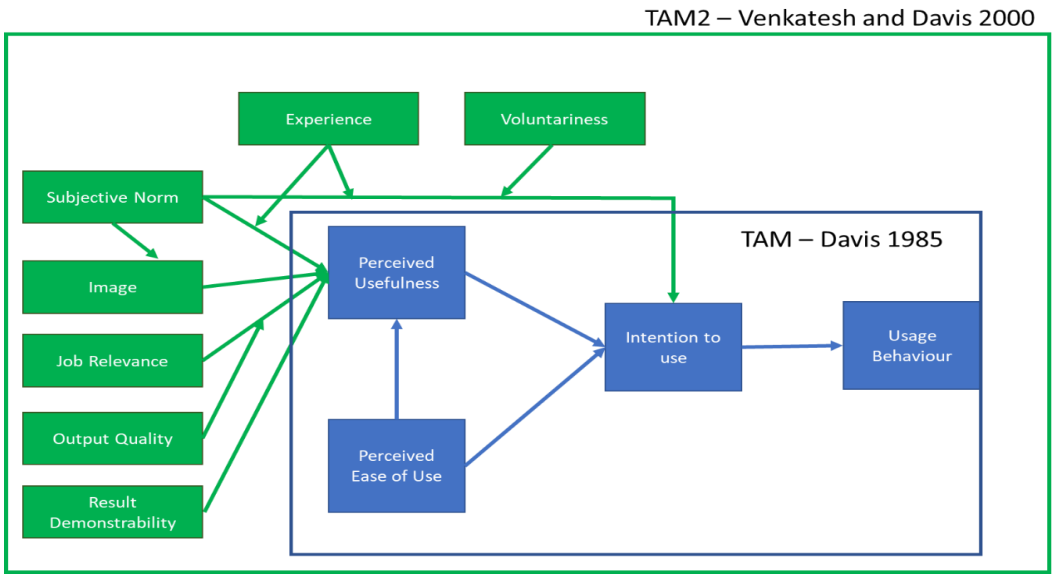


Figure 2-8: Illustration of the Technology Acceptance Model (TAM) incorporating TAM2 revisions (Venkatesh and Davis 2000).

A chief criticism of TAM and its subsequent revisions is their simplicity and parsimony (Venkatesh *et al.* 2007). While these characteristics have been shown to increase the predictive ability of the TAMs and their various incarnations, this only holds true for the factors incorporated into the respective model (Lucas *et al.* 2007). Consequently, the ability of the TAMs to avoid errors of omission is highly dependent on a researcher's reflexivity or access to

previous exploratory research concerning the same phenomenon. This is due to the reductive parsimony of the TAMs which acts to narrow the focus onto specific factors, reducing its capacity to illuminate broader behavioural and psychological aspects (Lucas *et al.* 2007, Schwarz *et al.* 2007). This shortcoming of the TAMs is apparent in Carlet (2015) in two ways. First, as is required for quantitative analysis, only closed ended Likert questions were used, preventing respondents to clarify and expand on their answers. Second, the author did not specify *how* they determined their closed-ended questions other than to say they were based on "variables assumed to affect attitudes" (p. 69). Hence, in lieu of any additional information, the possibility of other important factors that influence attitudes, but are not identified in Carlet (2015), cannot be discounted. Compounding this shortcoming is the researcher's decision to not use the expanded TAM2 model developed by Venkatesh and Davis in 2000, hence subjective factors such as voluntariness, subjective norms and image are ignored.

Carlet (2015) exemplifies another important limitation of TAM models, i.e., their application to innovation adoption at social scales beyond the individual (Lucas *et al.* 2007, Bradley 2012). Because public infrastructure decisions occur at the organisation scale, the decision to change existing practices are rarely taken by mid-level professionals. Rather, they are typically a function of a complex interplay of social groups at the organisational and industry scale (of which council employees are one of many) and pressures exerted from the external societal environment (Brown *et al.* 2007, Farrelly *et al.* 2008, Van de Meene *et al.* 2011, de Haan *et al.* 2015b, Madsen *et al.* 2017). Hence, while the analysis conducted by Carlet (2015) robustly quantifies the importance of the incorporated factors on professional attitudes, this doesn't necessarily directly translate to the adoption of green infrastructure by the organisations they work for. Similar criticisms have also been levelled at DOI theory, given it was founded in seminal research consisting of small social groups associated with farming in the US in the mid twentieth century (Mahajan *et al.* 1990, Lyytinen *et al.* 2001, Lundblad 2003). Consequently, neither TAM nor DOI are explicitly designed to account for sociotechnical phenomena across group divides, such as within organisations consisting of multiple departments, with different mandates, agendas and sub-cultures (Dollery *et al.* 2004, VAGO 2014, Tett 2015). Therefore, while they offer important insights into the subjective and objective factors that influence the uptake and acceptances of innovations by individuals and groups, they lack the necessary sociotechnical scale to effectively consider broader organisational and societal factors that may impact on SCM maintenance.

2.5.4 Theory of Sociotechnical Transition – Multi-Layer Perspective

Two other important limitations of earlier sociotechnical theories and models, including DOI and TAM, are the implicit assumptions that sociotechnical systems are (1) closed systems into which (2) innovations, developed by neutral (and otherwise ignored) inventors, diffuse as discrete packages (Tornatzky *et al.* 1982, Premkumar *et al.* 1994, Lyytinen *et al.* 2001). However, this is rarely the case in reality, with external environmental factors acting to both stimulate and stifle innovation adoption, and innovations often co-evolving as a function of feedback loops from the various social groups involved (Di Stefano *et al.* 2012).

A more recent and highly cited theory that directly addresses both of these limitations is the theory of Sociotechnical Transitions, otherwise known as the Multilevel Perspective model (Sovacool *et al.* 2017). Sociotechnical Transitions Theory does not hold that innovation diffusion is a wholly dependent variable, but rather one that co-evolves and co-constructs as it transitions, being both changed and changing the social groups and paradigms involved (Geels 2002). Conceived by Geels in the early 2000s, Sociotechnical Transitions primary intent was to provide a heuristic model for understanding innovation adoption that results in major, long-term changes in the way societies function (Geels 2002). As with DOI, it holds that innovation transitions follow a non-linear fashion conceptualised as the 'transition S-curve'. However, unlike preceding theories, Sociotechnical Transitions Theory conceptualises transitions across

three sociotechnical scales (Figure 2-9), described by Geels as a “nested hierarchy or multi-level perspective” (Geels 2002, p. 1261).

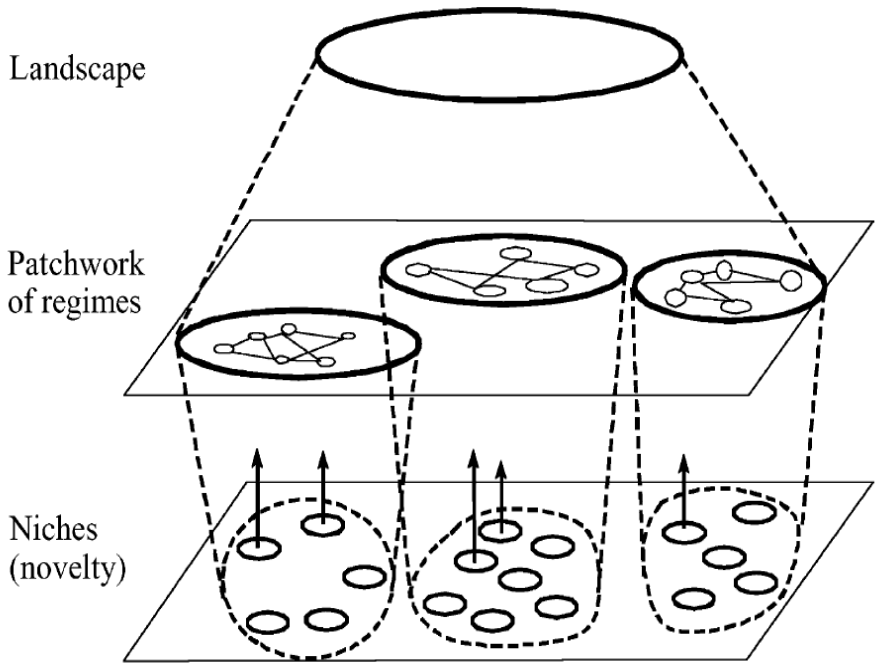


Figure 2-9: The multi-level perspective (MLP) framework of Sociotechnical Transition Theory (reproduced from Geels, 2002, Fig. 3)

These sociotechnical scales, termed *niche*, *regime* and *landscape*, provide analysts with a sociotechnical framework for examining the adoption of innovation where innovations co-evolve with the various parts of the system, resulting in the system itself transforming to a new paradigm (Figure 2-10). The Niche or *micro* level represents the protected spaces in which innovations are conceived and developed, such as R&D laboratories, subsidised demonstration projects or niche markets consisting of advocates who support the emerging innovation (Geels 2011, Sovacool *et al.* 2017). The Regime or *meso* level refers to the established sociotechnical archetype that has manifested around particular artefacts and practices that are ‘locked-in’ by self-referencing mechanisms such as fuel types, supporting infrastructure, codes of practice, established training and education paradigms, professional bias and user preferences (Unruh 2002, Geels 2011, Steinhilber *et al.* 2013, Geels *et al.* 2018). The Landscape (or macro) level is the external environment within which a given regime operates, exerting *exogenic* pressures that act on the regime to either stabilise it or disrupt it (Geels 2004). These exogenic factors may be broad social trends that change slowly over time, or rapid changes that act to disrupt existing regimes (Van der Brugge *et al.* 2007). Examples of such exogenic pressures include changes in oil prices, economic growth, war, environmental crisis (e.g. climate change), changes in socio-demographic trends, and major socio-political upheavals (Geels 2002, Geels 2004). Such disruptions act to stimulate change by altering the circumstances confronting the actors within the established regime, creating opportunities for actors in the Niche level to establish their niche-innovations as an alternative to meet the new circumstances and, thereby, change the architecture of the regime (Geels 2002, Sovacool *et al.* 2017).

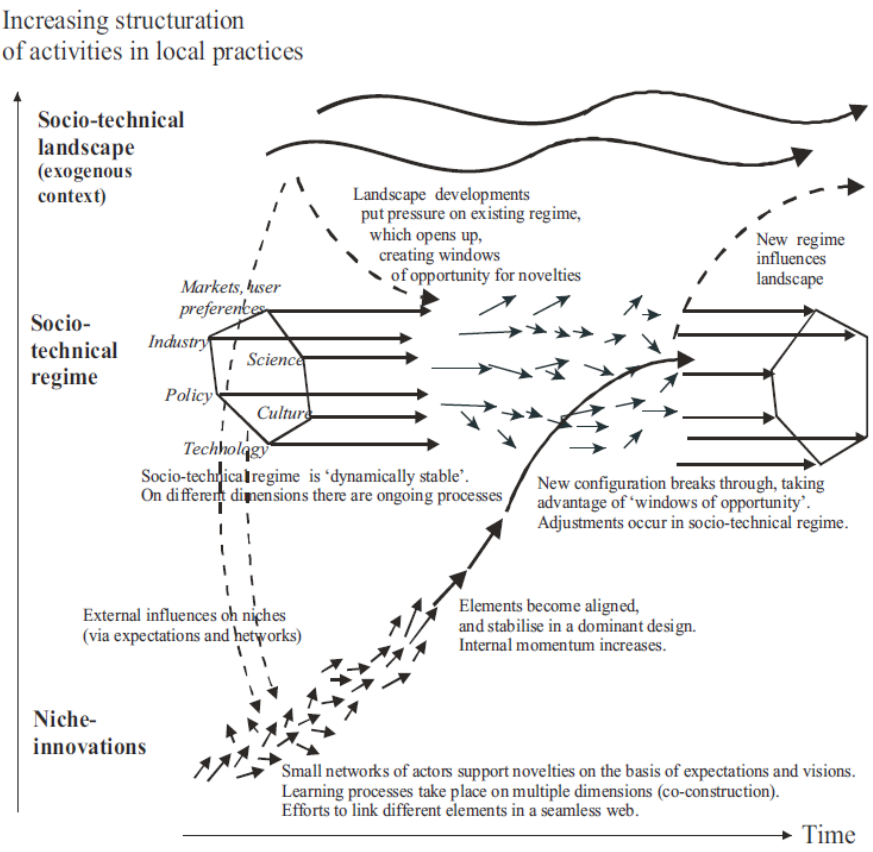


Figure 2-10: The dynamic nature of transition as conceptualised by Sociotechnical Transition Theory (Geels 2004, Fig. 9).

Sociotechnical Transition Theory also clarifies a number of key concepts concerning sociotechnical transitions that, in part, give rise to the emerging research area of Sustainability Transitions discussed in the proceeding subsection (Markard *et al.* 2012, Loorbach *et al.* 2017). These include *path-dependence* and *mis-alignment* and their respective roles in stabilised and destabilised sociotechnical systems (Geels 2004). Path-dependency refers to those inter-related factors that keep established regimes stabilised (Loorbach *et al.* 2017). The path-dependencies are imbedded in the history of the conventional regime and the formation of sociotechnical alignments that facilitate the coordination of activities and functions of established practices without the need for a centralised direction (David 1994, Geels 2004). While such pathways significantly aid efficiency in human organisations and institutions, they also act to restrict the capacity for change, hindering innovation transitions by narrowing routines and expectations concerning goals and future directions (David 1994). Conversely, mis-alignments represent where such path-dependencies are not effectively aligned, leading to outcomes that are not consistent with, for example, user preferences or the actions or activities required to sustain long-term service delivery (Geels 2004). These two concepts are given representation at the sociotechnical regime scale in Geels's Multi-level Perspective model (Figure 2-10), where the straight arrows represent established path-dependencies of the established regime, and the small multi-directional arrows in between them are mis-alignments. Importantly, Geels's model shows that mis-alignments occur when the innovation begins to compete with the conventional practice (destabilisation), with successful regime change occurring only once these mis-alignments become settled and new path-dependent trajectories are established that facilitate and support the innovation (Geels 2004).

Several recent studies have been published applying Sociotechnical Transitions Theory in the urban water space (Brown *et al.* 2013, Chini *et al.* 2017, Madsen *et al.* 2017, Diep *et al.* 2019). For example, Chini *et al.* (2017) synthesised Sociotechnical Transitions Theory with policy

feedback cycles[6] proposed by Hildén (2009) and Pennell *et al.* (2013) to establish a policy feedback cycle specifically for SCMs. In so doing, Chini *et al.* (2017) created a policy feedback cycle that defined and illustrated the process by which SCM is co-evolving with the various aspects of the regime into which it is diffusing. Brown *et al.* (2013) also synthesised Sociotechnical Transition theory with other theory. However, where Chini *et al.* (2017) formulated their theoretical framework to understand a specific sociotechnical phenomenon (adoption of SCM), Brown *et al.* (2013) used the adoption of SCM to provide guidance on how the sociotechnical phenomenon of regime lock-in might be proactively destabilised. They combined the Multi-layer Perspective with 'multi-phase' perspectives and 'transition management' (Markard *et al.* 2012), along with 'institution work' as described by Lawrence *et al.* (2006). In so doing, Brown *et al.* (2013) were able to establish an analytical framework that, along with the thematic categorization techniques of Grounded Theory, enabled them to illuminate regime lock-in processes and the interactions that led to their destabilisation at different sociotechnical scales. That is, they developed a heuristic framework that helped to compartmentalise the complex sociotechnical processes and the connectivity between them.

The popularity of Sociotechnical Transition Theory and its Multi-layer Perspective framework is attributed to its capacity to illuminate the complex, dynamic and interdependent factors that act to drive innovation and re-stabilize regimes accordingly (Sovacool *et al.* 2017). Yet Sociotechnical Transitions Theory is not without its critics. In its initial form it was criticised for being bottom-up focused concerning regime change, where regime change was solely a function of the niche-innovation (Berkhout *et al.* 2004). This shortcoming was addressed by Geels *et al.* (2007) through the incorporation of four transition pathway typologies, i.e.: *technological substitution*, *transformation*, *reconfiguration*, and *dealignment and re-alignment*. Technological substitution refers to landscape regime actors actively replacing an existing technology or practice due to changes in landscape variables (*landscape pressures)* where a viable niche-innovation exists. Transformation occurs under similar circumstances, but where a niche-innovations are not sufficiently developed. In such situations, regime actors proactively influence and even drive niche-innovations to suit the landscape pressure(s) accordingly. Reconfiguration occurs when not only the existing technology or practice is replaced due to landscape pressures, but also changes in the architecture of the regime itself occur as part of the sociotechnical transition process. Dealignment and re-alignment occurs when there is a seismic shift in the landscape, however no clear niche-innovation presents itself as the appropriate response. In these circumstances, multiple niche innovations compete until one becomes dominant, around which a new regime manifests.

Sociotechnical Transitions theory has also been criticised for ambiguity concerning the operationalisation and specification of regimes, and the landscape level lacking clear definition, acting as a catch-all analytical category for many kinds of contextual factors (Berkhout *et al.* 2004, Smith *et al.* 2005, Markard *et al.* 2008, Geels 2011). As a consequence, application of Sociotechnical Transitions theory relies heavily upon the choices and interpretations of the analyst (Genus *et al.* 2008). Geels notes that his landscape category is at risk of becoming a catch-all analytical category that accounts for many kinds of contextual factors (Geels 2011). Van Driel *et al.* (2005) sought to clarify the landscape category through differentiation: (1) factors that do not change, or change very slowly, such as climate (2) rapid external shocks, such as wars or economic crises and (3) long-term changes in a certain direction, such as demographical changes. Irrespective, the heuristic nature of sociotechnical systems thinking is what makes it such a powerful tool for understanding complex socio-technical systems. Hence, attempts to continually tighten definitions around the sociotechnical scales risks making the Multi-layer Perspective framework too rigid and reductive, rending it less adoptable and, therefore, less effective. As Geels himself argues, because no two transitions are the same, the

[6] These policy feedback cycles bear close similarity with the Plan Do Check Act cycle brought to prominence by Dr W. Edwards Deming in the 1950s (Moen and Norman, 2006)

analyst necessarily needs to fit the framework to their given circumstances in order to account for the nuances of their subject and research objectives (Geels 2011).

2.5.5 Sustainability Transitions

Sustainability Transitions is a relatively new area of scholarship within the broader innovation transition scholarship (Markard *et al.* 2012, Loorbach *et al.* 2017). What identifies Sustainability Transitions as a specific sub-set of inquiry is its specific focus on the transitions of innovative ideas that are intended to correct the long-term consequences of conventional practices adopted at the societal level that underpin modern societies (Rotmans *et al.* 2001, Elzen *et al.* 2004, Brown *et al.* 2008, Markard *et al.* 2012). Examples of the kinds of societal services where Sustainability Transitions occur include energy supply, transport, public health, education, waste management, resource acquisition, and urban water management. The rise of Sustainability Transitions as a sub-field of the transitions sciences is attributed to their unique complexity and corresponding high rate of failed or incomplete transitions (Markard *et al.* 2012). Drawing heavily on transitions science (particularly the multilevel concept described in the previous section) and incorporating complex adaptive systems theory, post-normal science, governance concepts and evolutionary economics; it emphasises the broader societal factors that lead to the disruption of conventional practices and, conversely, also act against the innovation (Van der Brugge *et al.* 2007, de Haan *et al.* 2014, Loorbach *et al.* 2017). That is, the forces or pressures that precipitate the formation of the niche and act to destabilise the conventional regime (e.g. environmental damage), and the 'path-dependencies' that work against the innovation (e.g. sunken investments, benefits of scale and cultural behaviours) cause systemic tensions and transition problems respectively (de Haan *et al.* 2011, Loorbach *et al.* 2017). Therefore, Sustainability Transition research fundamentally shifts the emphasis from systems being characterised by co-evolution, to systems also being characterised by external societal pressures that act upon them (de Haan *et al.* 2014).

To illustrate how external pressures act on conventional regimes to effect sociotechnical system change, Rotmans *et al.* (2001) developed a four phase transition model (Figure 2-11). Reminiscent of much earlier works by Rogers (Figure 2-5), the four phases are demarcated by the inflection points on the S-curve (Figure 2-11), and can be described as follows (Rotmans *et al.* 2001, Geels 2002, Van der Brugge *et al.* 2007):

- *Pre-development* (*approaching criticality*)*:* A dynamic equilibrium where the existing sociotechnical systems does not visibly appear to be altering. However, due to changing socio-technical conditions, stresses are building on the existing regime such that system re-organisation becomes imminent. Innovations are typically still fragmented and under-developed relative to existing regime.
- *Take-off* (*change triggered*): Pressure on the existing regime has reached a critical point such that innovations begin to compete with conventional practices. All system domains are affected and, assuming pressure is sufficient, a domino-like effect initiates, triggering a cascading change, affecting the system and the technologies alike.
- *Acceleration* (or *breakthrough*): System reconfiguration (Geels 2002) is underway, signifying that the necessary concurrent socio-cultural, economic, ecological, institutional, etc. changes are taking place to facilitate the adoption of the innovation. This period represents a period of continuing cascading effects, where technologies and the system undergo co-evolution, effecting and influencing changes in each other, ideally moving towards a new system.
- *Stabilisation*: sociotechnical reconfiguration slows as the new system begins to emerge and a new dynamic equilibrium is reached. The transformation processes that have led to stabilisation now turn to optimisation processes.

While simple in concept and presentation, the underlying dynamics of the four phase transition model are a complex array of interdependent processes between markets, networks, institutions, technologies and human behaviour, as well as independent trends in economic, ecological, socio-cultural and institutional landscape (Van der Brugge *et al.* 2007).

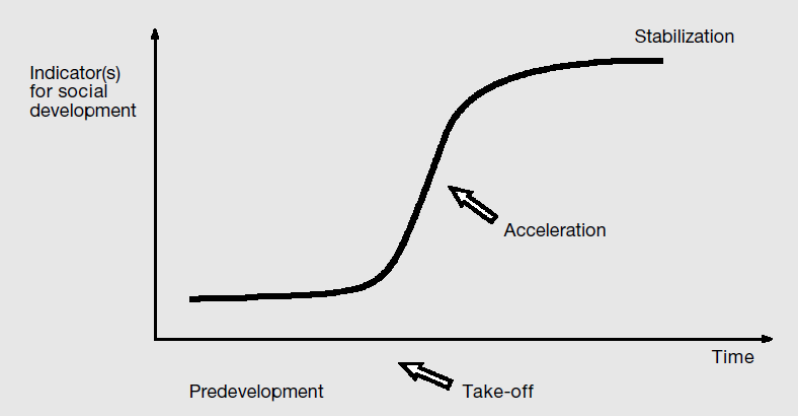


Figure 2-11: The four phases of transition as presented in Rotmans *et al.*, 2001.

The need for such a specific focus for sustainability innovations arose due to the complex sociotechnical nature of such transitions and the unique challenges they face accordingly (de Haan *et al.* 2011, Markard *et al.* 2012). Sustainability innovations, while being driven by societal pressures, must also compete with the established societal path-dependencies of the conventional practice they are meant to replace (Loorbach *et al.* 2017). Such established path-dependencies are a function of the history associated with conventional practice, which has co-evolved with existing society. Examples include complementary technologies, business models, governance systems, wealth flows, education and professional institutions, political structures, user practices and lifestyles, regulation and institutional structures (Van der Brugge *et al.* 2007, Markard *et al.* 2012). Therefore, successful adoption of sustainability innovations typically requires the re-alignment of not one, but multiple societal subsystems, referred to collectively as "constellations" (de Haan and Rotmans 2011, p. 93).

Consequently, emergent sustainability technologies are prone to significant barriers to mainstream adoption and, therefore, are more likely to lose momentum before achieving mainstream stabilisation (Brown *et al.* 2008, de Haan *et al.* 2011). Van der Brugge *et al.* (2007) offer three additional pathways to that proposed by Rotmans *et al.* (2001) that sustainability innovations may take as a consequence of these barriers, i.e.,: *Lock-in*, *Backlash* and *System breakdown* (Figure 2-12). These pathways were developed to give explanation to the potential fates of sustainability innovations that lose momentum before sustainable practice is achieved due to the complexities associated with Sustainability Transitions (Geels 2002, Van der Brugge *et al.* 2007). Lock-in occurs where the innovation, while gaining influence, fails to completely replace conventional practice (Van der Brugge *et al.* 2007, de Haan *et al.* 2011). This may occur when schemes designed to counter conventional practice path-dependencies ('interventions') are only partially effective or where the innovation is only partially compatible with existing structures and demands (Van der Brugge *et al.* 2007, de Haan *et al.* 2011). In contrast, *backlash*, refers to a rapid uptake of an innovation that initially appears to be on-track for complete system reconfiguration, but part way through the reconfiguration processes, suffers a rapid and un-recoverable loss of transition momentum. The end result being a return of the system to its original state (de Haan *et al.* 2011). This may happen if growth or swings are such that they exceed the ability of the niche to respond, or when an unforeseen risk or problem becomes apparent that is so catastrophic that the innovation is abandoned (de Haan *et al.* 2011). The *System breakdown* pathway captures the extreme end of the alternative pathways,

where the combined external pressures on the regime and the nature of the innovation(s) are not sufficient to destabilise the existing regime (de Haan *et al.* 2011).

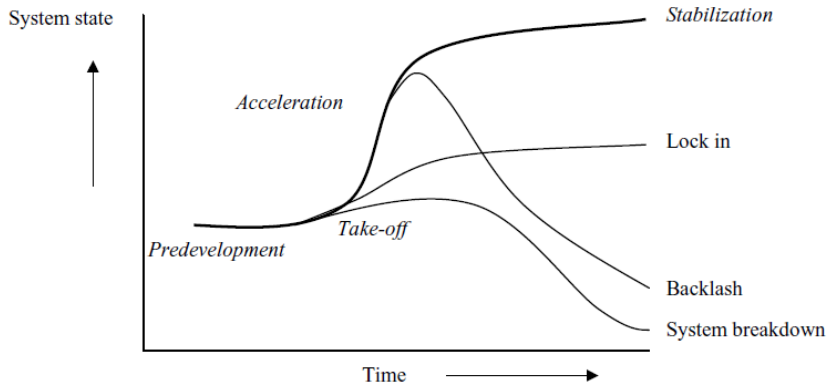


Figure 2-12: Different pathways for sustainability transitions in complex adaptive societal systems (Van der Brugge and Rotmans 2007, Fig. 3).

To further develop the theoretical concepts summarised above, and to provide additional analytical power accordingly, de Haan *et al.* (2011) proposed three generic transition patterns through which, they claim, ".. any transition story can be told" (de Haan and Rotmans 2011, p. 9). These are *empowerment*, *adaptation* and *reconstellation*. Empowerment refers to bottom-up system change and involves the emergence of a new system equilibrium driven from the niche, i.e., "niches growing into niche regimes" (de Haan and Rotmans, p. 95). Typical processes include gaining recognition (e.g. patents, emergence of standards, certification for products and professionals); forming unions (e.g. workers, trade unions, cartels, collusions, and lobby groups); and professionalisation (e.g. specialisation, education and learning, research and development, acquiring expertise). Adaption refers to internally driven system change in response to growing external pressure in the landscape. Examples include energy companies diversifying from oil to include alternative energy sources and the inclusion of alternative health care options in conventional insurance schemes. Typical processes are *re-positioning* (towards new groups or markets, or assuming a new role or identity), *re-organising* (growing or shrinking, forming or merging groups, divisions or specialties), and *innovation* (mechanisation, automation, modernising infrastructure, implementing new technology, knowledge and expertise). 'Reconstellation' refers to top-down driven change from beyond the regime. The most prominent example is change driven by government using a range of stick (e.g. legislation and regulation) and carrot (e.g. funding, tax breaks) pressures. Typical processes including reformative legislation (e.g. environmental law), installation of infrastructure (e.g. introduction of trams) and regional re-orientation (e.g. altering land zoning).

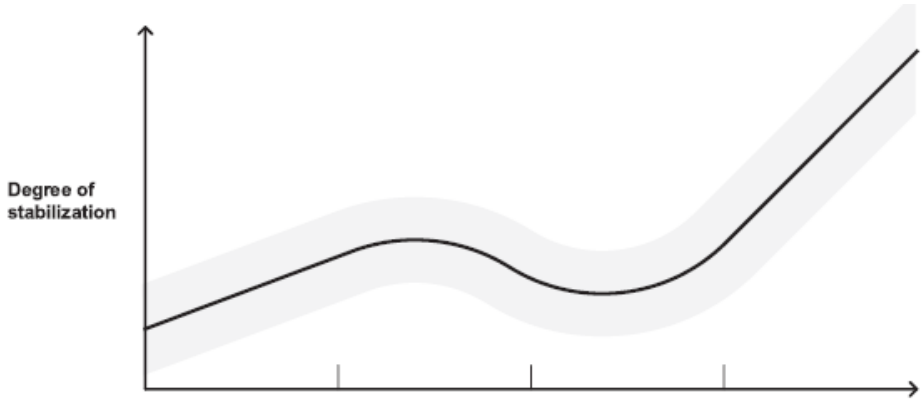
2.6 Examples of Sociotechnical Systems Theory as Applied to SCMs

The application of sociotechnical systems theory to SCMs to date has focused only on the transition of SCMs as an innovation, and challenges and barriers thereof. Since the early 2000s, there have been multiple such studies that have considered SCMs specifically, or have considered them as part of broader sustainable urban water management studies. More recent examples include those discussed in Section 2.5 (Brown *et al.* 2013, Carlet 2015, Chini *et al.* 2017) as well as Madsen *et al.* (2017), Cettner *et al.* (2014b), de Haan *et al.* (2015b) and Diep *et al.* (2019). What is generally missing from these studies is adequate consideration of what constitutes full diffusion / adoption of SCMs. That is, what constitutes the adoption of SCMs such that they are demonstrably no longer divergent, but rather a mainstream, 'business-as-usual' infrastructure solution. While these studies consider indicators such as the development of guidelines, changes to government policy, agreement of concepts, and proliferation of SCMs

to be indicators of the general acceptance of this new class of asset, this may not necessarily be sufficient for such long-lived assets.

A key reason for this is that public infrastructure, including SCMs, must be managed, maintained and renewed by public organisations such that their societal benefits can be realised. Accordingly, any measures that are used to gauge the degree to which sustainability innovations have transitioned towards mainstream stabilisation must include indicators that gauge the degree to which the responsible organisations have integrated them into their 'business-as-usual' practices. That is, the degree to which the responsible organisations have integrated the new practice into their existing practices, procedures and systems, and the degree to which human actors within those organisations have accepted the innovation as standard practice. Only then can it be considered that transformation processes have achieved stabilisation (Figure 2-12). Where public infrastructure innovations like SCMs are concerned, this means the innovation is subject to the same management practices as other more established types of public infrastructure, and that the organisations responsible for them have accepted them as part of their normal operations (i.e., 'business as usual').

Madsen *et al.* (2017) provides a more recent example of the application of transitions theory to SCM adoption in Melbourne, Australia and Copenhagen, Denmark. However, their intent was not to determine if SCMs had achieved mainstream adoption *per-se*, but rather if SCM innovation system itself had stabilised. Their proposition being that for SCMs to achieve mainstream adoption, their innovation system must first achieve stabilisation, where stabilisation is based on agreement on meanings about what the technology is and what it does. In order to assess the degree of stabilisation of the innovation systems in each city, Madsen *et al.* (2017) developed a conceptual framework based on the different pathways to system change (Figure 2-12) and the Social Construction of Technology (SCOT) framework, reproduced here as Figure 2-13. Based on 16 interviews representing stakeholders (eight from each city) and a review of relevant literature, Madsen *et al.* (2017) concluded that Melbourne had achieved the 'Agreement' stage whereas Copenhagen was still at the 'Opportunity' stage. Therefore, Melbourne's SCM innovation system had stabilised based largely on low interpretive flexibility on meanings. Importantly, Madsen *et al.* (2017) note that agreement between stakeholder groups does not necessarily mean that the technology itself has achieved mainstream adoption. Works published relatively recently suggest they were right to do so (Choi *et al.* 2017, Furlong *et al.* 2019), revealing the limitations of relying purely on social constructs as a means of detecting mainstream adoption (Sovacool *et al.* 2017).



	New technology	Testing	Opportunity	Agreement
Description	The technology emerges as a result of an issue with the current system.	Test cases are used. Only few actors involved.	New actors are involved because there is dissatisfaction. Leads to new confrontations that need to be settled.	Confrontations are settled over time, agreement arises.
Technologies in play	Few emerging technologies	Few more complex technologies	More complex technologies	Complex technologies
Main actors in play	Researchers Industry frontrunners Government Citizen	Researchers Industry frontrunners	Researchers Industry Government Citizens	Government Industry Citizens
Meanings in play	New technology is needed. Improvements of new technology are needed.	Improvements are needed. Benefits and risks are weighed.	Dissatisfaction with current system. LAR/WSUD are the solution.	LAR/ WSUD are a significant supplement to the original system and integrate several values.

Figure 2-13: Innovation S-Curve variant as proposed by Madsen et al. (2017) (Fig. 3)

An alternative perspective is offered by Rogers *et al.* (2015a), based on their investigation of the transitions of desalination, water recycling and stormwater harvesting[7] in Melbourne, Australia. By examining the transitions of these water supply innovations relative to each other and the conventional municipal supply (dams, reservoirs and filtration), Rogers *et al.* (2015a) developed a hypothetical model describing the types of institutional work required to support the transition of sustainability innovations from predevelopment through to stabilisation (Figure 2-14). This model brings together Rotmans *et al.* (2001)'s four phases of transitions, de Haan *et al.* (2011) ideas concerning 'constellations' and their relative influence ('power') on societal systems, and Scott's (2008) Three Pillars of Institutions to describe the various types of institutional work required to support the successful transition of sustainability innovations. Importantly, Rogers *et al.* (2015a) emphasise that successful transition is dependent on pro-active institutional reforms at each stage of their model, referring to them collectively as "institutional work. Given the similar topic area and its alignment with intent to utilise sociotechnical systems thinking to understand SCM maintenance, this model is given further consideration in the proceeding paragraphs.

[7] It is noted that this study does not strictly focus on SCMs, however, stormwater harvesting is considered to fall within the general meaning of SCMs (Fletcher *et al.* 2014)

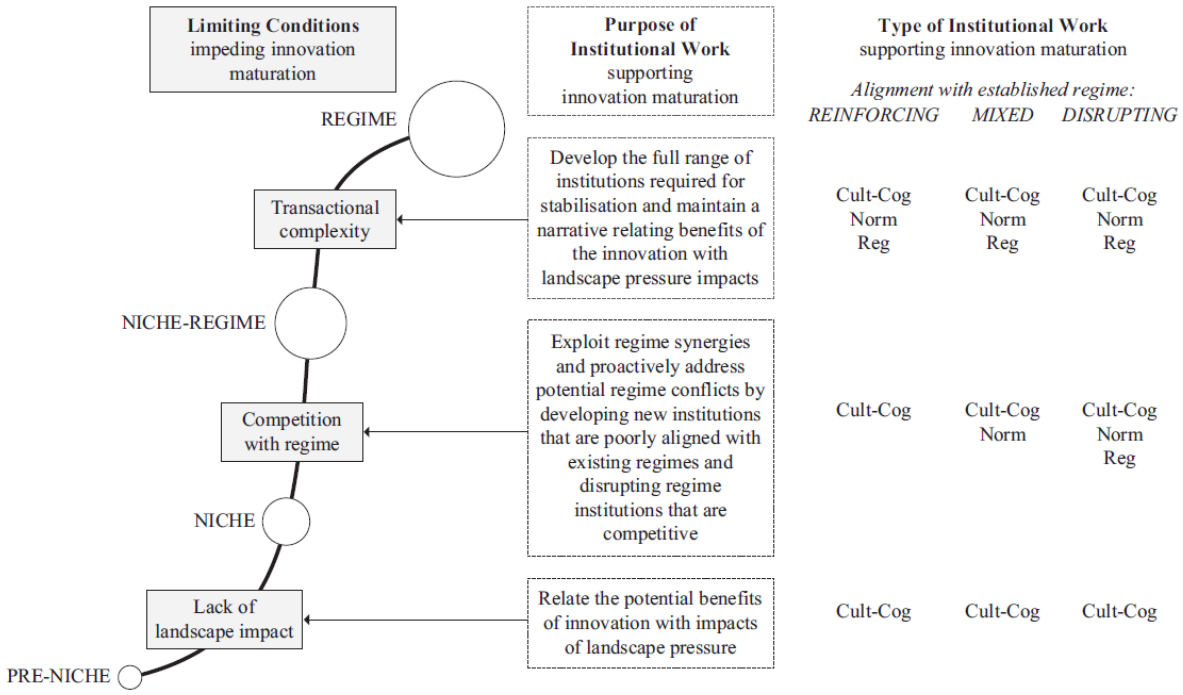


Figure 2-14: Roger et al. (2015, Fig. 4)'s hypothetical model denoting the purpose and type of institutional work required for successful sustainability transitions (cult-cog: 'cultural-cognitive', norm: 'normative' and reg: 'regulative' – as defined in Table 2-1).

The model considers the transition of the sustainability innovation from the perspective of its transformation from one constellation to the next, where power shifts as a function of landscape pressures. At the *predevelopment* phase, the innovation exists within a *Pre-niche*[8] constellation and, while the innovation(s) have the same system function, they exert no influence over the societal system. At this point in the transition, institutional work should be primarily cultural-cognitive (Table 2-1); i.e., work that facilitates the shifting of shared conceptions on how the societal service (e.g. water supply) is acquired and delivered (Scott 2008). At this phase of the transition, this work is mostly developing 'technical knowledge' such as scientific, theories, empirical data, technology development and testing (Rogers *et al.* 2015a). As cultural-cognitive work continues to build knowledge, and assuming the landscape pressure is maintained, a 'critical mass' is reached, pushing the transition into *take-off* (Rotmans *et al.* 2001, Rogers *et al.* 2015a). The innovation sub-system evolves into a Niche constellation, where the technology or practice is introduced, exhibiting only a small amount of influence over the societal system (de Haan *et al.* 2011). Cultural-cognitive work remains the primary type of institutional work. However if transition momentum is to continue to build, the cultural-cognitive work needs to expand to include building experimental and cultural knowledge, such as the implementation of pilot and demonstration projects to raise awareness and start to build practical operational knowledge (Rogers *et al.* 2015a).

[8] It is noted that de Hann and Rotmans (2011) do not articulate a *Pre-niche* constellation. This appears to be a novel contribution by Rogers et al. 2015a to accommodate the *predevelopment* phase of Rotmans et al.'s (2001a) four phases of transition.

Table 2-1: Types of institutions for Melbourne's water system (reproduced from Rogers *et al.* 2015a, Table 1, p.45)

Institutional types	Indicators	Examples
Cultural-cognitive	Cultural knowledge	Awareness, beliefs, meanings, language, narratives, symbols
	Technical knowledge	Scientific knowledge, theories, empirical data, technology development, technology testing, technical designs
	Experiential knowledge	Tacit knowledge, practical experience, skills in operating and maintaining technologies
	Implementation tools	Procedures, templates, guidelines, routines, manuals, models, frameworks
Normative	Public expectations	Values, concerns, perceptions, visions
	Communities of practice	Formal networks, informal networks, loose affiliations, coalitions, alliances, project teams, organisational departments, partnerships
	Roles and responsibilities	Allocation of stakeholder responsibilities, advisory network for decision-makers, formal obligations, informal obligations
	Goals and commitments	Formal policy, strategic documents, strategic programmes, official announcements, media statements, organisational commitments
	Standards	Accreditation, benchmarking, product labelling, best practice guidelines, design standards, case studies, codes of practice, industry awards
Regulative	Governance arrangements	Service delivery and revenue collection by Government agencies, private companies, communities, households
	Resource mobilisation	Taxpayer funding, public grants, public-private partnerships, private investment, household investment
	Regulatory mechanisms	Laws, bans, limits, targets, restrictions, performance indicators, contractual clauses, audits, sanctions, licences

In order to *accelerate* the evolution of the innovation constellation through *Niche-regime*, new institutions will need to be developed to disrupt the path-dependencies that give conventional regimes a competitive advantage (de Haan *et al.* 2011, Loorbach *et al.* 2017). To facilitate this disruption, Rogers *et al.* (2015a)'s model indicates that normative work and regulative work (Table 2-1) will now be needed. Regulative work, in its broadest sense, refers to mechanisms instituted to overtly constrain and dictate behaviour (Scott 2008). Therefore, while they include formal legal mechanisms, they may also include governance arrangements and how resources are mobilised (Scott 2008, Rogers *et al.* 2015a). In contrast, normative work refers to altering the formal institutions that inform behaviour and practice, such as defining roles and responsibilities, formalising goals and commitments, the establishment of 'communities of practice'[9] and the development of standards (Wenger 1999, Scott 2008, van de meene 2010, Rogers *et al.* 2015a). While not necessarily legally binding, normative work provides the foundation upon which things are done. Finally, to see the innovation constellation achieve regime status and *stabilise* accordingly (i.e., become a dominant power in the societal system), all three types of institutional work will need to be engaged to continue to disrupt the conventional regime and re-enforce the innovation constellation (Rotmans *et al.* 2001, de Haan *et al.* 2011, Rogers *et al.* 2015a).

2.7 Literature Review Summary

Stormwater Control Measures (SCMs) are, in public infrastructure terms, still a relatively new form of innovation, and the completeness of their transition towards business-as-usual practice is both patchy and a matter of debate. As with any form of public infrastructure, SCMs require effective maintenance programs to ensure that they see out their operational life cycle and, as they do so, provide their intended levels of services. While there have been multiple papers published on the transition of SCMs from divergent innovation towards adoption, none of these

[9] Groups of individuals and entities with similar passions and goals that come together to facilitate collective learning and advancement of ideas and practices (Wenger, 1999)

papers have considered evidence pertaining to how well they are maintained and how integrated they have become into 'business-as-usual' practices. A review of published literature instead reveals a general paucity of research concerning the maintenance of SCMs, with the limited number of studies focusing predominantly on the effectiveness of a specific types of maintenance treatments for specific types of SCM. Only a few explore empirical evidence for on-ground maintenance outcomes, and none appear to specifically explore the challenges and barriers organisations face in maintaining these systems.

The management of SCMs, including their maintenance, within the local government context is a function of the practice of *asset management*. The practice of asset management within the Victorian local government context can be described as sociotechnical, being dependent on the interaction between people, technology and administrative systems within councils consisting of multiple departments and teams. It is also subject to exogenic influences beyond the bureaucratic structures of local government, including community expectations, influences of higher tiers of government and broader national economic circumstances. Consequently, the problem of SCM under-maintenance is likely to be affected by the complexities associated with the sociotechnical nature of asset management. Due to the sociotechnical nature of asset management, it is likely that investigating SCM under-maintenance in local government would benefit from a sociotechnical system thinking approach. While the application of sociotechnical systems thinking has focus predominately on innovation adoption, this is more a limitation of its application rather than the approach (Davis *et al.* 2014).

Finally, in the course of undertaking the literature review, no studies were found to have investigated the underlying reasons behind the under-maintenance of SCMs, though several did identify it as an issue (Lloyd 2001, Schlüter *et al.* 2005, Drake *et al.* 2008, Goonetilleke *et al.* 2011, Burns *et al.* 2015). Due to this paucity in research, and because of the potentially complex, multi-causal nature of the problem of SCM maintenance (Section 2.4), a deductive approach is considered unlikely to be effective. This is because sociotechnical systems and problems that arise within them are not just potentially multi-cause, but inter-dependently so (Kim *et al.* 2006, Van der Brugge *et al.* 2007, Davis *et al.* 2014), and, therefore, may be a function of other problems or an underlying issue not overtly apparent. Consequently, attempting to predict variables to facilitate a deductive approach runs a high risk of errors of omission. Hence, an explorative, inductive approach is considered more appropriate to investigate the phenomenon of SCM under-maintenance in Victorian local government.

3 Methodology

3.1 Introduction

Two important factors define the nature of this research topic and have implications for research design. The first is that the under-maintenance of SCMs in Victorian local government is potentially a multi-causal problem affected by complex path-dependent relationships. The second is the relative paucity of research conducted thus far in relation to the topic, leaving little evidenced based information upon which to deduce why this might be the case. While the consequences of ineffective SCM maintenance manifest physically, the causes are likely to lie in a comprehensive array of interdependent and diverse issues that cross socio-technical and socio-institutional boundaries. This is because SCM maintenance in local government is a function of infrastructure asset management, and the practice of asset management in local government is consistent with general features of a sociotechnical system (Section 2.4). Therefore, the complexities associated with the manifestation of SCM under-maintenance in local government are potentially equally complex. This situation combined with the paucity of research investigating the causes of SCM under-maintenance, renders a deductive approach at risk of being too narrow in scope (Stebbins 2001). Consequently, the research takes a predominately explorative, inductive approach that does not seek to confirm a predetermined idea on what the underlying causes might be, but instead uses data as a means of seeking them out.

This chapter describes how a predominately explorative and inductive approach was formulated and executed to answer the research questions (Table 3-1). In the interests of transparency and to highlight potential biases, the chapter begins with a description of the philosophical paradigm or 'worldview' adopted by the researcher in designing the methodology, followed by an overview of the design itself. Again, in the interests of transparency and rigour, the researcher's background, relative to the research topic, is provided, followed by a description of the ethical considerations associated with this research. The Chapter then turns its attention to the collection of data, defining the study area, how participants ('respondents') were identified and recruited, and how the survey program was designed. The chapter then concludes by describes the different analyses adopted and developed to address each research question and why these methods were chosen, along with discussions on their limitations.

Table 3-1: Research Questions

Research Question 1	How well are SCM being maintained by municipal governments?
Research Question 2	What barriers and challenges effect SCM maintenance within Victorian local government?
Research Question 3	What intervention pathways might see long-term improvement to SCM maintenance outcomes in Victorian local government?

3.2 Worldview

The research paradigm or 'worldview' is fundamental to the execution of research because it inevitably colours research findings, influencing the entire research processes, including how data is collected, what data is collected, and how it is analysed and interpreted (Kuhn 1970, Creswell 2014). Thus, the research paradigm, whether a function of conscious choice by the researcher or trends in science at the time, can significantly affect research findings (Kuhn 1970, Ritzer 1975). The term 'worldview' is often used to describe the philosophical foundation upon which research is undertaken (Creswell 2014), providing "a basic set of beliefs that guide action" (Guba 1990, p. 17). The importance of identifying the underlying philosophy or paradigm taken by the researchers lies in the practical implications it has on the conduct of inquiry and interpretation of findings (Guba *et al.* 1994). Worldviews also help to describe a researcher's potential biases, so clearly stating it has important implications in relation to transparency and rigour. Recognising and articulating the worldview is particularly pertinent in the context of this study given the potentially complex nature of the problem. This is because the potentially highly complex and amorphous nature problem means that findings associated with its study could be influenced by the methods applied and the perspective of the researcher.

Four commonly cited research philosophies or paradigms discussed in the literature are *postpositivism*; *constructivism*; *pragmatism* and, *transformative*, the major elements for which are provided in Table 3-2 (Christ 2013, Creswell 2014). While all of the worldviews have merit (Habibis 2006, Canales 2013), pragmatism has been adopted for this research as it meshes well with the potentially complex nature of research problem and the paucity of research on the topic. Unlike postpositivism, constructivism and transformative world views, pragmatism does not take a specific ontological stance, instead taking a "Deweyan 'what works'" perspective (Christ 2013, p. 112). It views reality as being indeterminate and fluid, and open to multiple interpretations (Bryant *et al.* 2007a, Christ 2013). Therefore, pragmatism is problem focused, allowing the researcher to adapt their perspectives and, therefore, their research design accordingly. Its philosophy makes it helpful for guiding research design in light of the topic's physical and human-constructed realms, and its potentially complex nature, allowing the researcher to choose methods, techniques and procedures to match (Creswell *et al.* 2007, Morgan 2007, Denscombe 2008, Greene 2008, Venkatesh *et al.* 2013, Creswell 2014, Shannon-Baker 2015).

Pragmatism's alignment with mixed methods and openness to inductive research facilitates the explorative research deemed necessary due to the relative paucity of published research on the topic (Star 2007, Venkatesh *et al.* 2013). Its 'what works' (Christ 2013, p. 112) philosophy also accommodates multiple contexts, including social, historical, political, and institutional; all of which could have a bearing on the research topic given the local government context. Importantly, pragmatism takes the view that while people's perceptions may not necessarily reflect reality, they still form an important mix of variables which provide insight into the nature of the problem (Star 2007, Bryant *et al.* 2007a, Denscombe 2008, Brinkmann 2018). This inherent respect for respondent experiences, knowledge and perspectives was particularly pertinent to the adoption of pragmatism for this study.

Table 3-2: Elements of four commonly cited Worldviews (Christ 2013, Creswell 2014)

	Postpositivism	Constructivism	Pragmatism	Transformative
Ontology (nature of reality)	Etic view. A singular reality exists, though imperfectly represented.	Emic view. No absolute truths. Individuals experience different realities.	Multiple forms of reality. 'What works' action-oriented view of reality.	Inequalities exist in power structures.
Epistemology	Objectivity. Researcher distances themselves from subjects to improve reliability of representation.	Knowledge is co-constructed as a result of closeness: researchers work together with participants to create knowledge.	Etic and emic (objective and subjective). Different strands provide knowledge than can be compared and combined to increase confidence in findings.	Knowledge is collaborative. Giving voice to oppressed to expose inequalities. Participants are not study subjects, but rather collaborators.
Axiology (values in research)	Researcher tries to remove their biases when collecting and analysing data.	Researcher and participants acknowledge bias and use them to negotiate their shared interpretations.	Pluralistic. Values are openly acknowledged and recognised as influencing the research process.	Oppression exists, and the role of the researcher should be to facilitate social justice.
Methodology	Deductive. Test and verification of theory. Focus is on determining significant differences between groups or strength of relationships between variables.	Inductive. Constructivist grounded data analysis to building patterns, themes and general concepts.	Mixed. Qualitative and quantitative data blended to create a representative model.	Researchers actively participate in change. Research is action oriented, designed to facilitate individual, social and societal change.

3.3 Reflexivity Statement

The researcher's interest in the topic is based on their background in environmental science and four years working in local government in stormwater management and waterway protection. During those four years, the researcher completed a research Master's Degree investigating the performance of a constructed wetland. They also developed a council's first stormwater asset management plan. This experience provided the researcher with certain advantages in the method development and execution. This included a general understanding of how local governments function and how they manage their assets, as well as the culture of local government and the language used. This background was particularly useful when developing the research survey and relating to respondents. However, the researcher needed to be mindful of their own preconceived notions and to be constantly vigilant not to read their own perspectives into the responses of the study's participants. This was, in part, the purpose of the follow-up interviews, where the researcher could ensure their interpretation of the questionnaire responses were consistent with the intention of the respective respondent.

3.4 Research Design

Consistent with the pragmatic worldview, the research design was developed using different methods to accommodate the potentially complex nature of the problem, the paucity of the research concerning the maintenance of SCMs and the purpose and practicalities associated with each research questions (Table 3-1). Importantly, the research design included two objectives to account for the sociotechnical and potentially complex nature of the problem:

- To cast as wide a net as possible to account for the potentially wide range of barriers and challenges to the maintenance of SCMs.
- Recruit a sufficiently diverse range of respondents to approach *saturation* (Glaser *et al.* 2006) concerning the identification of those barriers and challenges.

To facilitate these objectives, the selection of councils to participate in this study was deliberately biased towards councils more likely to be performing better than most in the area of SCM maintenance. The logic being that such councils would provide access to respondents that have direct and ongoing experience with SCMs and their maintenance. Further, and particularly pertinent to Research Question 1, selecting such councils also allowed findings derived from this study to be considered 'best case'. Consequently, it could be assumed that, on the balance of probabilities, the results in relation to Research Question 1 are likely better than that for most other Victorian councils.

In line with the "what works" (Christ 2013, p. 112) ontology of pragmatism, different methods were chosen for each research question based on the purpose of each question and the practical limitations of the study's resources (Figure 3-1). A quantitative approach was taken for Research Question 1 using data from three different sources. Due to its purpose, i.e., to test the veracity of concerns about the under-maintenance of SCMs, Research Question 1 was the only question to use qualitative data. The three different sources were chosen to (1) provide a means of cross checking observed SCM condition relative to perspectives on the condition of SCMs held by participants and (2) enable comparison with jurisdictions beyond Victoria to ascertain the relative uniqueness of the Victorian experience. Research Question 2 and Research Question 3 relied on the collection and analysis of qualitative data. Research Question 2 was addressed first, involving the *abstraction* (Glaser 2002) of the barriers and challenges using inductive methods informed by Grounded Theory (Glaser 2001, Glaser *et al.* 2006). Research Question 3 was then addressed by subjecting the results of Research Question 2 to a set of sequential analyses based predominately on sociotechnical systems thinking and theory. These sequential analyses were based on theory associated with the Multi-level Perspective of sociotechnical systems and the ideas underpinning the research area of Sustainability Transitions (Geels 2002, Geels 2004, Markard *et al.* 2012, Loorbach *et al.* 2017).

The research design summarised here and detailed in the proceeding sections, has been developed to maximise the identification of barriers and challenges to the maintenance of SCM maintenance in Victorian local government. It has also been designed to identify a strategic basis upon which policy makers, in consultation with communities of practice, can focus their attention towards lasting improvement to SCM maintenance outcomes. It is important to note that by taking an explorative, inductive approach, the findings produced by this study are a matter of considered judgement. That is, they are not findings that are *verified by* data, but rather, they are postulations that are "grounded in data" (Glaser and Straus 2006, P.33).

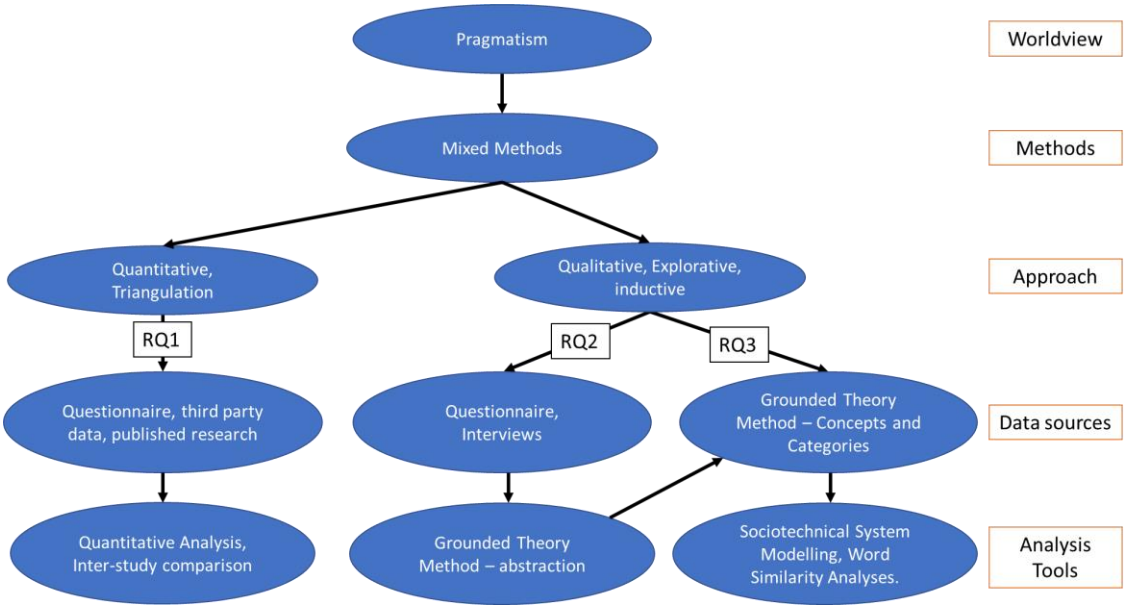


Figure 3-1: Research Design (RQ: 'Research Question').

3.5 Ethical Considerations

In Australia, ethics in research is now governed by the *National Statement on Ethical Conduct in Human Research 2007* (NHMRC *et al.* 2018). Research that does not abide by ethical considerations not only runs the risk of legal challenge, it also runs the risk of appearing to lack integrity and, thereby, undermining confidence in its findings, damaging the reputation of the researchers and their institutions (Bryman 2001a, Habibis 2009, Walliman 2018). The research conducted for this study included engagement with local councils and their staff in the form of questionnaires, interviews and request for documentation and data. While this target population acted to exclude vulnerable persons (NHMRC *et al.* 2018), it did introduce issues pertaining to the privacy and confidentiality of individuals and organisations. To uphold and protect these groups, an application for approval was developed in accordance with the *Australian Code of the Responsible Conduct of Research*, the *National Statement on Ethical Conduct in Human Research* and the *Code of Conduct for Research of the University of Melbourne* (Statute 17.1, Regulation 17.1.R8) and submitted to the University of Melbourne's Human Research Ethics Committee (HREC). Approval was granted accordingly (Ethics ID: 1545197.1).

3.6 Study Area

Data collection occurred between March 2016 and January 2017 within the Australian state of Victoria (Vic), primarily from within the greater metropolitan area of Melbourne (Figure 3-2). Victoria has highly diverse councils, from rural agricultural councils with large areas and low population through to highly urbanised metropolitan councils with dense populations. The Melbourne metropolitan area includes 32 of the 79 Victorian councils covering a wide variety in terms of area, development, population density, socio economics and environmental assets. The management of stormwater in Melbourne has grown in research and practice to a point where Water Sensitive Urban Design (WSUD), including SCM adoption, is now commonplace (Brown *et al.* 2007, Morison *et al.* 2012). This diversity in local councils and historical association with the development and adoption of SCM makes the Melbourne metropolitan area ideal for conducting research into the barriers and challenges faced by local councils regarding the long-term operation and maintenance of SCMs.

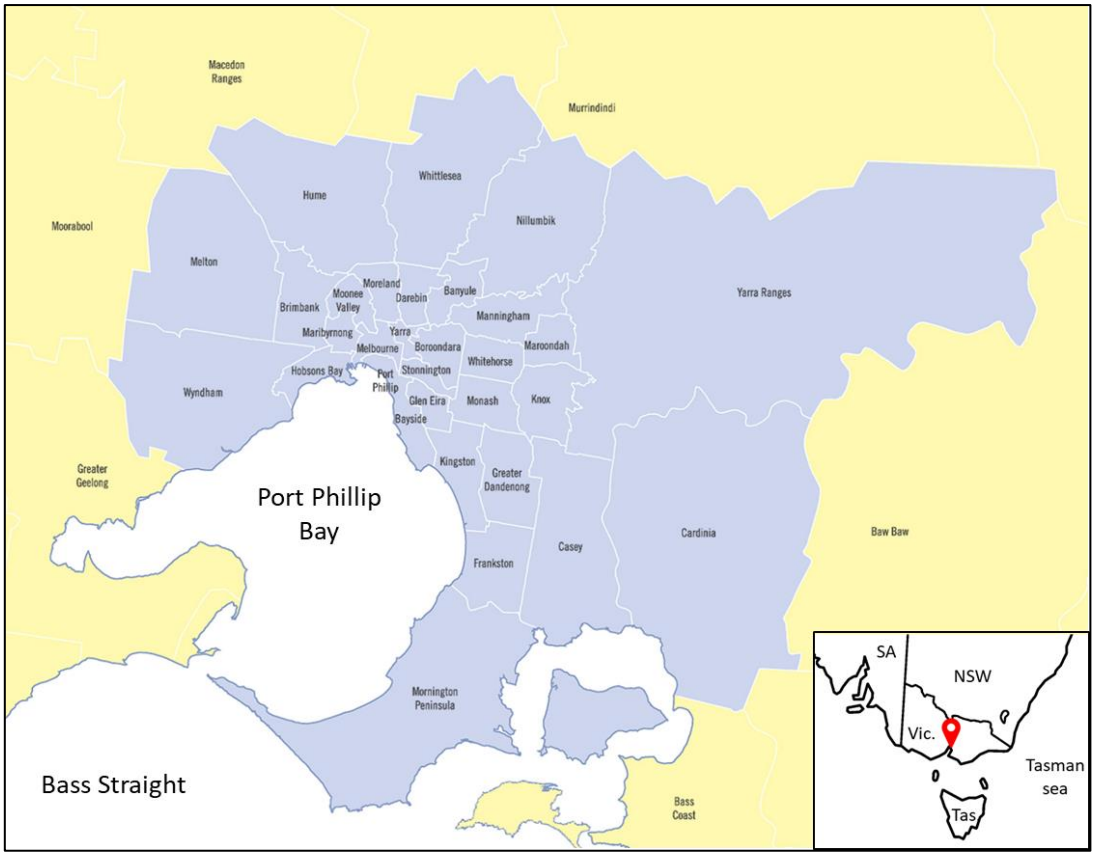


Figure 3-2: Local Councils within the Greater Melbourne Metropolitan Area (light blue area)

3.7 Sampling strategy and participant Selection

3.7.1 Overview

The ideal sample group for this study needed to be (1) *willing and able* to participate in the study and (b) be sufficiently diverse to comprehensively capture the barriers and challenges facing local councils regarding the maintenance of SCMs. As found by Morison *et al.* (2010), not all councils are equal concerning their commitment to and experience with SCM maintenance. Further, only certain personnel, such as drainage maintenance and management staff, drainage engineers, urban water planners, environmental personnel and asset managers are likely to have the required experience with SCMs and their maintenance within a given council. Hence, targeting councils and specific personnel therein that are likely to have experience with SCM maintenance and management was considered paramount to the success of this study.

To this end, respondent recruitment followed a 'clustering' (multistage) procedure (Creswell 2014, p. 158), executed using nonprobability purposive sampling (Battaglia 2008) in three stages:

- Stage 1: Recruitment of 'participating councils'
- Stage 2: Recruitment of individual respondents: questionnaire
- Stage 3 Recruitment of individual respondents: follow-up interview.

This process is given detailed description below.

3.7.2 Stage 1: Selection of Participating Councils

The process used to select councils for this study had two key objectives:

- Objective 1: Identify councils that would be both willing and able to participate
- Objective 2: Maximise diversity between councils that meet Objective 1.

Screening councils against Objective 1 was achieved using the characteristics for municipal commitment to Water Sensitive Urban Design (WSUD) matrix developed by Morison and Brown (2011). This 'commitment matrix' (Table 3-3), developed from research conducted within the Melbourne metropolitan area (Figure 3-2), provides a range of characteristics that can be used to place a given council into one of three commitment categories: *limited commitment*, *partial commitment* and *high commitment*. As the name suggests, those councils with characteristics aligned with *high commitment* are likely to be highly committed to WSUD (including SCMs) and are generally proactive in their disposition towards sustainability. In contrast, "WSUD tends to be ignored or misconstrued" (Morison and Brown 2011, page 90) by councils exhibiting *limited commitment* characteristics, whereas those exhibiting *partial commitment* characteristics tend to shift their commitment in line with intergovernmental funding and mandates.

Purposive sampling focused on councils whose profiles fell within either the *high commitment* or *partial commitment* categories. *High commitment* councils were considered likely to be both *willing and able* to participate in the study, potentially providing data for both developer 'gifted'[10] assets and assets delivered under the council's own capital works program. *Partial commitment* councils were also targeted to widen the diversity of the sample group. *Limited commitment* councils were excluded as considered less willing to participate and, even if willing, unlikely to have sufficient experience to provide meaningful data to the study.

Applying the matrix developed by Morison *et al.* (2011) incurred some challenges and limitations. While instructive, it had only limited metrics to precisely define when a given characteristic shifts from one commitment level to the next. Determining commitment levels for *environmental values* and *demographic and socio-economic state* was relatively straightforward, being achieved through the review of publicly available information such as government websites (e.g., Australian Bureau of Statistics website and council websites), public documents, aerial imagery and maps. Similarly, *municipal environmental messages* could be ascertained relatively quickly by reviewing a candidate council's website and its publicly available documents. However, *localised organised environmentalism* was more difficult to establish as the listing of environment groups is not undertaken uniformly by local governments and, when listed, it was not always practically possible to gauge their relative degree of activism. A potential candidate council's *intergovernmental disposition* was also difficult to gauge, hence the researcher needed to rely on the advice of professionals and academics who had experience with councils within the study area to gauge this particularly characteristic.

[10] A colloquialism used to describe assets delivered by developers under the Victorian Planning Provisions that are then handed over to council under the Victorian Subdivision Act 1988.

Table 3-3: Characteristics for the municipal types of limited commitment, partial commitment and high commitment (summarised from Morrison and Brown 2011, Table 4)

Characteristic	Limited Commitment	Partial Commitment	High Commitment
Environmental Values	Environmental assets are concealed or disassociated.	A blend of apparent and unapparent environmental assets, depending on the municipality.	Obvious environmental assets.
Demographic and socio-economic state	Relatively small municipal populations, generally lower levels of constituent wealth and municipal revenue.	Intermediate municipal populations; mediocre levels of constituent wealth and municipal revenue, sometimes varying across the municipality.	Relatively high municipal populations; higher levels of constituent wealth and municipal revenue.
Local organised environmentalism	Unknown or negligible values; where present, are not lobbying for WSUD.	Some long-term environmental groups with varying degrees of political success.	Influential municipal environmental coalitions, catchment committees, and/or "Friends" groups.
Municipal environmental messages	WSUD not used or related to messages; environmental messages are token.	Some informal linkage of WSUD with other messages' reactive to current policy issues.	WSUD is formally integrated with broader environmental messages.
Intergovernmental disposition	Minimalist, services to property focus; inert or obstinate with state mandates.	Variable service foci' dependence on intergovernmental grants and regulation.	Maximalist, services to people focus; civic pride, obstreperous with state mandates.

Table notes
Environmental Assets – natural assets such as rivers, watercourses, coastal features and native habitat.
Municipal environmental message – the nature and frequency of environmental messages emanating from a council.

Due to the subjective nature of the commitment matrix, candidate councils were triangulated (Patton 2002, page 247-248) against two independent objective classification systems, i.e., the *Australian Classification of Local Governments* system and the median household income to gauge the diversity of the sample population (Table 3-4). The purpose of the *Australian Classification of Local Governments* is to assist the Australian federal government to assess the effectiveness of grant funding distribution by providing a systematic means of differentiating councils (ACLGSC 1994). The system is based primarily on population and geographical determinants, providing 22 separate categories, where councils of the same category are considered to be similar in nature and, therefore, have similar issues and challenges (ACLGSC 1994). As a final check on diversity in council candidate selection, and to compensate for the lack of socio-economic indicators in the ACLG system, the median income for candidate councils were also compared. This triangulation process resulted in the shortlisting of 12 candidate councils that were then approached to participate in the study via a letter addressed to each shortlisted council's Chief Executive Officer (Appendix A). Of these 12 councils, eight agreed to participate in full ('participating councils') whereas one agreed only to provide SCM condition audit data (Table 3-4).

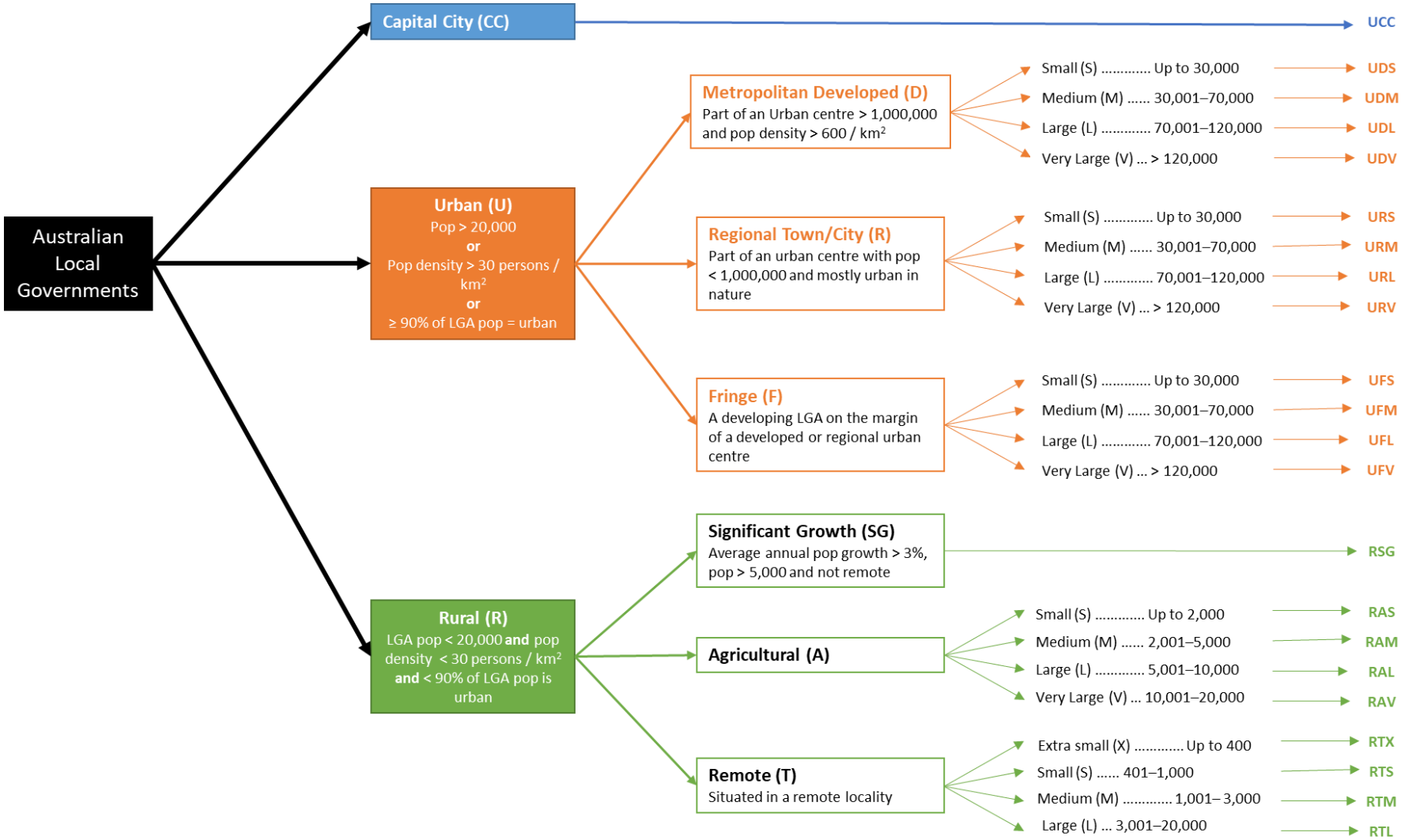


Figure 3-3: Australian Classification of Local Governments (DIRG 2015)

Consistent with the objectives of the nonprobable purposive sampling, these eight participating councils represented a relatively diverse sample population (Table 3-4). While seven were located in the Melbourne metro area, two were from outside this area (but still within the state of Victoria). Three of the six within the metropolitan area were identified as *highly committed* and three were identified as *partially committed*. Both councils outside the metropolitan area were identified as *partially committed*. Regarding the ACLG (Figure 3-3), three were classed as UDV ('urban metro-developed very large'), two were classified as UFV ('urban fringe very large'), one as UDL ('urban metro developed large'), one as URV ('urban regional city, very large') and one was classified as URL ('urban regional city large'). ACLG classifications have not been listed in Table 3-4 in order to protect participating councils' privacy and confidentiality. Median household income was similarly diverse, with five being above the median household income, and four being below. Likewise, exact figures for median household income have not been reported in Table 3-4 to protect the identities of the participating councils.

Table 3-4: Participating Council profiles

Council Code	Commitment Matrix characteristics (Morison *et al.* 2011)						Above / below Victorian median household income †^	Dominant development
	Environmental Values	Demographic and socio-economic state	Local organised Environmentalism	Municipal Environmental Messages	Intergovernmental disposition	Overall commitment to WSUD		
A*	Limited	Partial	Partial	Partial	Partial	Partial	below	Greenfield (affordable)
B	High	High	High	High	High	High	above	Mostly infill
C	Partial	Partial	Partial	Partial	High	Partial	above	Mostly infill
D	High	High	High	High	High	High	below	Infill
E*	High	Partial	High	High	Partial	High	above	Mixed
F	Partial	Partial	Low	High	Partial	Partial	below	Greenfield (affordable)
G	Low	Partial	Partial	High	Partial	Partial	above	Infill
H	Partial	Partial	Low	Partial	Partial	Partial	below	Greenfield (affordable)
I*,α	High	High	High	High	High	High	above	Infill

Table notes

^ - Relative to median household income for Victoria as a whole = $1,419 (ABS 2016). Actual median household income not shown to protect the identity of participating councils

† - Local Government Area

* - Was able to provide SCM condition audit data

α - only participated by providing condition audit data for SCM. Did not participate in questionnaire and interview process.

3.7.3 Stage 2: Selection and Recruitment of Respondents – Questionnaire and Interviews

Recruitment of respondents required individual candidates to be identified from within participating council who could most likely provide meaningful information and data for the study. These included personnel whose roles contributed to the planning, design, construction, operation or maintenance of SCMs. To identify such candidates, *expert knowledge* was needed to undertake nonprobability purposive sampling of each participating council's employee population (Battaglia 2008). However, such *expert knowledge* was outside the purview of the researcher. This issue was overcome by requesting from each participating councils' Chief Executive Officer, a contact person who could help with the recruitment of candidates from within their council (see *first contact* correspondence, Appendix A). Once allocated, this contact person was briefed on the purpose of the research, the types of candidates being sought from their council, and the importance of maintaining the privacy and confidentiality of those identified. They were then asked to provide a suitable list of candidates.

The researcher then contacted each nominated candidate separately and confidentially. This initial contact correspondence included a formal request to participate in the study; a concise 'plain language' *Information for Participants* (Appendix B) document and access to the questionnaire (Appendix C) should they decide to participate. Access to the questionnaire was provided via three options: Link to an online form (Google Forms), an electronic form (PDF), or hardcopy sent via post. Recruitment for follow-up interviews was conducted using the questionnaire. Included at the end of the questionnaire was an *Expression of Interest* request to participate in an interview. Those respondents who expressed an interest were sent a pre-interview package that included an *Information for Participants – Interviews* (Appendix D) document outlining their rights and the researcher's responsibilities consistent with the research's ethical approval requirements (Section 3.5).

Initial attempts to recruit respondents failed to attract executive representation from any of the participating councils. To address this shortfall in perspectives, council contacts were explicitly asked to provide contact details for executives. Further, working on the assumption that executives had limited time, the questionnaire and hour follow-up interview process was abandoned and replaced with a half-hour interview format only (Appendix E). Interview questions were altered to accommodate this reduced contact time, which included changes to questions to focus on executive level concerns, particularly around organisational risk presented by SCM and their maintenance issues. Executive candidates were sent a formal request to participate in the study via their work email address. This formal request included an abridged *Information for Participants* document to include the aforementioned changes to the engagement process and renamed (Appendix F). Those executives that agreed to participate were then asked to provide a location and time of their choosing to conduct the interview.

3.7.4 Assessment of Recruitment Process

Nine of the twelve councils shortlisted as candidates for the study agreed to participate. Only one of the councils that declined offered a reason, citing that it did not consider the participation of staff members in such studies as a worthwhile use of employee time. The average response time from first contact to councils formally agreeing to participate was 27 Calendar days ($\sigma = 5$, range = 5 to 34). In all instances, follow up correspondence (phone calls and emails) was required to achieve this response rate. While the turnaround from councils was a little longer than anticipated, the high (75%) recruitment rate (Baruch *et al.* 2008) and apparent diversity of councils (Table 3-4) demonstrate that the recruitment strategy applied was effective.

Respondent recruitment rates are summarised in Table 3-5. Overall, 73% (54) of the candidates that were sent formal requests to participate in this study agreed to participate and returned completed questionnaires accordingly. Of these ('respondents'), 72% (39) also

agreed to and participated in follow up interviews. Such response rates are considered relatively high for voluntary questionnaires collected from organisations (Baruch *et al.* 2008) and the total number of respondents is generally considered sufficient for the application of Grounded Theory (Creswell 2014, page 189). Hence the recruitment strategy employed was considered to be a success from a recruitment perspective.

Given that the objective of the study was to comprehensively draw out the barriers and challenges facing local government in relation to the maintenance of SCM, maximising the diversity of respondents from within the target population was important. The voluntary nature of respondent participation and the need to involve a third party (council contact persons) reduced the level of control the researchers had as to exactly who participated in this study. To test respondent diversity, the respondent population was analysed against four categories: Hierarchy; Qualifications; Years of Service and Department (Figure 3-4). Hierarchy refers to where in the organisational structure a given respondent sits within an organisation. Qualifications were included because a respondent's qualification(s) may influence their perspective (Brunson 1992, Ash 1997, Brown 2005). Years of Service measures both length of time in current position and years in council, and was used as a means of reflecting the likely age and experience mix. The Department category refers to the administrative segments Victorian councils are typically divided into, and the demarcation of responsibilities of each. While there are no set rules governing precisely how individual councils divide their organisations into departments, similarities between councils are generally evident given their shared history, similar services provisions and their constitution under the same state government legislation. Hence, this category was included to gauge the degree to which different departments were represented in the study.

Table 3-5: Summary of recruitment process outcome for questionnaire and interview process

Council Code	Commitment to WSUD	Number of candidates identified	Number of respondents* (% of candidates identified)	Number of interviews completed (% of respondents)	Number of executive interviews completed^
A	Partial commitment	7	6 (86%)	5 (83%)	1
B	High commitment	21	11 (52%)	9 (82%)	1
C	Partial commitment	8	8 (100%)	4 (50%)	2
D	High commitment	6	6 (100%)	6 (100%)	2
E	High commitment	12	9 (75%)	7 (78%)	1
F	Partial commitment	5	2 (40%)	2 (100%)	0
G	Partial commitment	8	6 (75%)	4 (67%)	0
H	Partial commitment	6	5 (83%)	2 (40%)	1
?	Unknown†	1	1	0	0
Totals for study =		74	54 (73%)	39 (72%)	8

Table Notes

* - Defined as the number of questionnaires submitted relative to the number of candidates approached

^ - Executives were approached separately using different methods of engagement to other respondents, hence these figures are independent of other figures reported in this table.

†- Respondent did not provided organisational details

Figure 3-4 reveals that despite the voluntary nature of the respondent recruitment process and the need to involve a third party in candidate selection, respondent diversity was sufficient to give confidence that a wide range of views and perspectives have been incorporated into the study. The hierarchy graph reveals that while many respondents were technical professionals involved in the planning, designing and long-term operation of SCMs (44%), a relatively large proportion were also working in roles responsible for day to day maintenance activities (field

operatives and frontline managers, 32%). Low representation from management levels reflects the triangular shape of council organisational structures and the relative contribution of middle and upper management to SCM maintenance. Figure 3-4 also reveals a wide array of qualifications represented within the respondent population. While core civil engineering qualifications are well represented, other related qualifications such as management, environmental sciences and natural resource management are also well represented. Years of Service reveal a good distribution of respondents, indicating that age and experience bias do not apply to this study (e.g. the over-delegation of questionnaires to junior staff members). Finally, the spread of respondents across departments is appropriately uniform. While respondents are concentrated within departments focused on infrastructure management, this is neither excessive or surprising given the focus on asset maintenance. Yet, other relevant departments including environmental, parks and open spaces, and development and planning are all well represented.

3.8 Survey Program Design

3.8.1 General

The collection of qualitative data from practitioners working in local government formed the primary source of data collection for this study. This data was collected via a cross-sectional survey program (Trobia 2008, p. 655) designed to maximise data richness and minimise satisficing. The purpose of this survey program was to collect descriptions of the lived experiences of professionals working in local government concerning SCM and the barriers and challenges to their ongoing maintenance. In particular, to sample a sufficient number of such professionals within local government in order to make interpretations of this topic area that will likely be representative of local government generally within Victoria (Kvale 2007c, Creswell 2014).

The survey design consisted of two sequential elements, i.e. a respondent self-administered questionnaire (Appendix C), followed by a semi-structured interview based on the respondent's answers to their questionnaire. The survey program was structured in this way to maximise data richness by reducing the disadvantages associated with using each method on their own. Most notably the satisficing and motivational issues associated with questionnaires and the lack of time offered during interviews for respondents to provide thought out answers (Krosnick *et al.* 2002, Anand 2008, Dialsingh 2008). The dissemination of the self-administered questionnaire also had the advantage of providing a basis upon which to construct and delimit in advance the follow-up semi-structured interviews (Patton 2002). Follow-up interviews were included, as they have been shown to be a powerful means of casting light on human experience, rather than relying on questionnaires alone (Kvale 2007c).

Satisficing is a function of task difficulty as off-set by respondent ability and their motivation to complete the task, where the risk of satisficing increases proportionally with task difficulty and inversely relative to respondent ability and motivation (Simon 1956, Anand 2008, Krosnick *et al.* 2018). In order to minimize satisficing for this study, the interdependent factors of task difficulty, respondent ability, and respondent motivation were given priority consideration in survey program design. Survey modes of delivery were also considered from the perspective of the respondents, being chosen based on compromise between ease of use by the respondent, minimising risk to respondent anonymity and ease of data handling and management for the researcher (Trobia 2008).

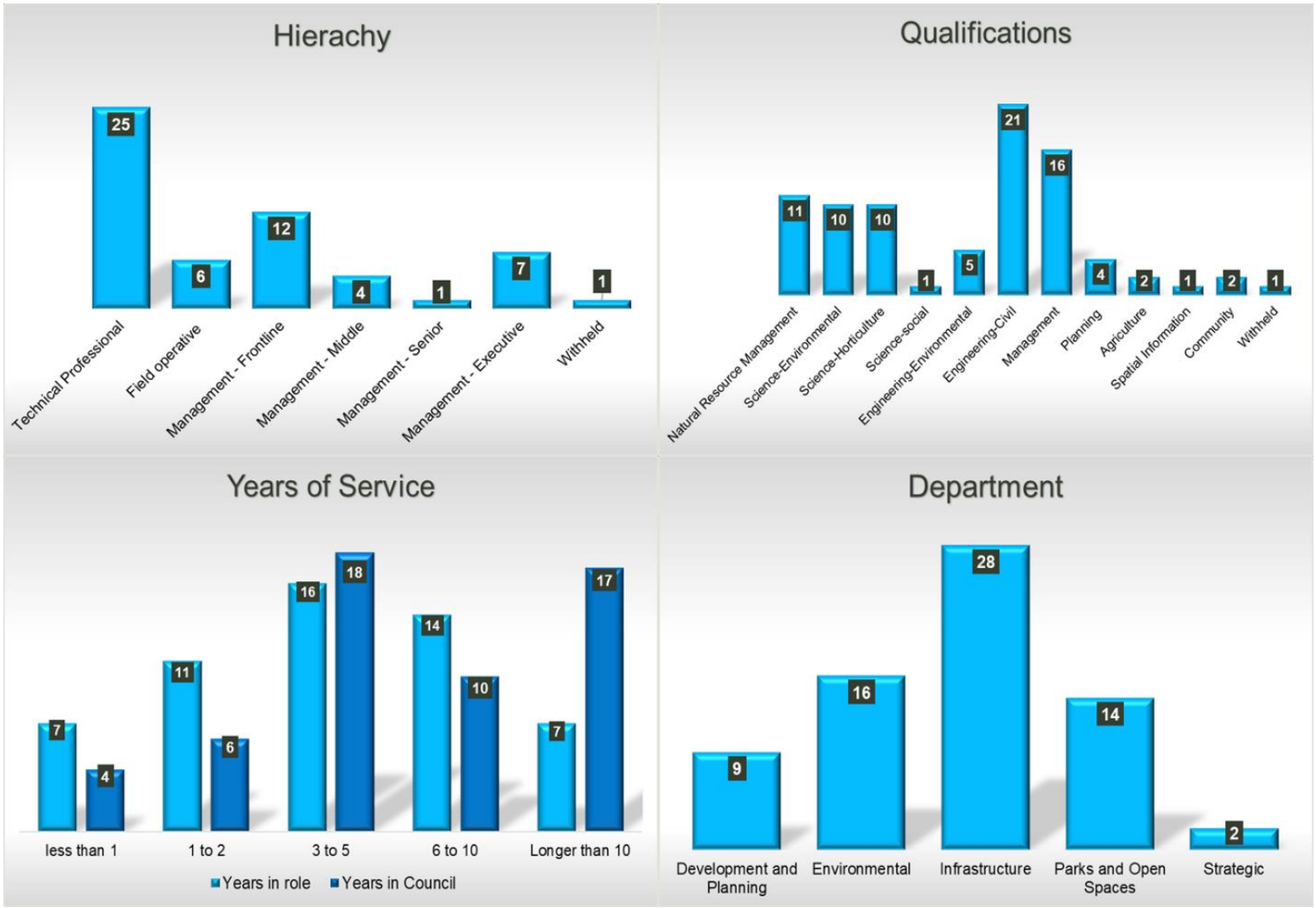


Figure 3-4: Respondent diversity

3.8.2 Questionnaire

The survey program was initiated via the distribution of a self-administered questionnaire (Appendix D) to respondent candidates (Section 3.7.3). Its key objectives were to:

- Introduce respondents to the nature and importance of the research and, in-so-doing, motivate respondent participation
- Gather meta-data about the respondents
- Elicit their views, perspectives and experiences in relation to various aspects of SCM maintenance and their council's asset management practices
- Recruit for follow-up interviews.

A mix of closed-ended and open-ended questions were used, the latter being relied upon for the vast majority of data collected for the research program. Despite the increased risk of respondent satisficing and the significant analysis burden qualitative data entails (Harrison 2007, Trobia 2008, Krosnick *et al.* 2018), the use of open-ended questions was considered necessary given the explorative requirements of the research program (Section 3.1). To mitigate satisficing, the following principles and practices were applied to improve both response rate and the quality of those responses (Harrison 2007, Trobia 2008, Harvard University 2018, Krosnick *et al.* 2018).

Questions were divided into six distinct sections to facilitate subsequent collation and analysis and to break up the questionnaire into manageable chunks for the respondent. The first, Section 1, comprised questions concerning the respondent's background and role ('respondent meta-data'). Section 2 introduced the respondent to questions directly related to the research. Semantic differential questions were employed in this section to get respondents thinking about the topic without burdening them with the need to provide long, open-ended responses. Options to add additional text to explain choices were also provided to boost the richness of this data (Krosnick *et al.* 2018). Sections 3 and 4 consisted entirely of open questions designed to engage the respondent at a deeper and more thoughtful level. These were deliberately left to the latter half of the questionnaire with the expectation that by this point, most respondents would be both motivated and sufficiently across the purpose of the questionnaire to provide relevant and detailed answers. To facilitate data richness and depth the questions in sections 3 and 4, while essentially asking the same question, were worded differently to capture the nuances within the perspectives (Trochim 2006c, Kvale 2007c). Section 5 consisted of a single open-ended, 'catch-all' question, included to allow respondents to add anything they thought relevant. Section 6 acted as a recruitment tool for the follow-up interview component of the survey. This section was included to maximise recruitment efficiency and uptake by engaging with the respondent while they were still engaged with the survey process. Consistent with convention, it was deliberately left to last due to its singularly open ended and deliberative nature (Harrison 2007).

The appearance and structure of questionnaires are known to be important factors in improving response rates (Harrison 2007, Holyk 2008, Trobia 2008). To align the questionnaire with professionals working in local government, careful attention was given to both these aspects in order to convey the significance of the research and its value to their (respondents) industry. Effort was also put into the general look of the questionnaire, maintaining a neat and structured appearance, ensuring consistency in formatting and syntax, and the inclusion of an image related to the study on the first page. Some technical terms were deliberately included in the questionnaire for two important reasons. The first was to establish a rapport with respondents by demonstrating a level of competence of the researcher through the use of appropriate terminology. The second was to promote precision in language (Harrison 2007) through the

use of industry specific terminology supported in part by the provision of definitions at the start of the questionnaire.

Before formal administration of the questionnaire, pre-testing was carried out to ensure its design met the above design objectives and was generally 'respondent friendly' (Trobia 2008). This involved sending out the initial draft of the questionnaire to four individuals ('testers') with specific instructions to answer the questionnaire and critique according to the design objectives described above. The 'testers' selected for this purpose were persons known to the researcher who fitted the criteria of the target sample population (Section 3.7.1). They were also people who possessed the necessary professional and academic background to understand the intent and importance of the pre-testing process. Once alterations had been made according to the advice of the testers, the questionnaire was then distributed to respondent candidates (Section 3.7.3).

To minimize extraneous variables, the questionnaires were distributed via the same mode, i.e., each candidate's work email address (a small number were distributed by post to those candidates who did not have a personal email address). To improve response rate and ensure respondents were appropriately informed of their rights, a cover letter (Appendix C) was included with each questionnaire distributed (Trobia 2008). The cover letter also included additional instructions on how to access and fill out the questionnaire. In particular, attention was paid to minimizing the effort to access the questionnaire so as to avoid non-response due to cumbersome access procedures. Initially, respondents had two options: to fill out an online version or print out a PDF version of the questionnaire. Shortly into the survey program, an electronically PDF form option was offered due to issues with some councils' internet security settings and accessing the online option.

3.8.3 Follow-up Interviews

Interviews can be a powerful means of qualitative data collection, allowing the interviewer to improve *Specificity* and explore nuance via the use of probing questions formed and executed during the interview (Kvale 2007b, Kvale 2007c). Consequently, individual (face-to-face) semi-structured interviews were conducted as a follow-up mechanism to questionnaires. The purpose of these interviews were twofold: (1) ensure the responses in questionnaires were correctly interpreted according to the respondent's intention; and (2) to facilitate *specificity* (Kvale 2007c), i.e., enhance data richness by providing the researcher with the opportunity to ask probing questions and follow specific lines of inquiry as they arose during the interview. While individual interviews can be more time consuming than group interviews, they were chosen because they considered more amenable to facilitating candid and unfettered responses from interviewees. Potential for response bias was also considered to be lowered by excluding potential for bias towards dominant extroverted personalities or the withholding of views by participants when a power imbalance exists within the group.

The interviewing styles *interview guide approach* and *informal conversation interviewing* (Patton 2002) were used in each follow-up interview. *Interview guides* were created prior to each interview. These guides were customized to each respondent based on their responses to their questionnaire and findings from previous interviews. Consideration of previous interviews was undertaken within the context of Grounded Theory's principle of *constant comparison*, where lines of inquiry favoured the identification of new concepts as indicated by the given respondent's questionnaire answers (Holton 2007). With the exception of three interviews, all interviews were audio-recorded and transcribed post-interview (two for technical reasons, and one request not to be recorded). Audio recording was used to improve data richness and quality by freeing up the interviewer from excessive note taking. The rights of interviewees and responsibilities of researchers concerning the collection of audio data were included in the

information for participants – interviews plain language statements sent out to participants prior to the interview (Appendix D) and again verbally at the start of each interview.

A small number of interviews were not supported by pre-interview questionnaires. All of these interviews were associated with executive level respondents for reasons detailed in Section 3.7.3. Executive level interview guides also followed a different format than the bulk of the interviews and were aimed at completing within half the time assigned to the bulk of the interviews (half-an-hour) to account for the perceived time-poor schedules of executive staff. Regarding format, questions were focused primarily around risk to organisation and establishing to what extent SCM maintenance was visible and important towards the top of a council's hierarchy. The design of these interviews was guided by an executive from outside of the participating councils' group (Table 3-4) and pilot-tested by an executive from within this group.

3.9 Research Question 1: How well are SCM being Maintained by Municipal Governments?

3.9.1 Overview

The purpose of Research Question 1 was to provide empirical evidence to concerns of under-maintenance and to gain insights into the effectiveness of SCM maintenance under the management off municipal government. Asset management guidelines identify asset inspection condition assessments as a means of assessing the effectiveness of existing maintenance programs (IPWEA 2011, LGV *et al.* 2015). Ideally, for the purposes of this study, this would have involved selecting a representative sample of SCMs and undertaking a thorough condition assessment. However, given the sheer number of SCMs within Victoria alone and their geographical distribution, such an approach was considered well beyond the practical limitations of this study. As an alternative, multiple data sources were drawn upon to gauge the potential status of SCM maintenance:

- Analysis of audit data collected by local councils in Victoria
- Review of published studies that specifically investigated the condition of SCM.
- The questionnaire distributed as part of this study.

While the use of third-party data brings with it disadvantages, such as a lack of control over method and quality control, it also brings advantages. By gaining access to condition assessment data collected by councils, it is possible to compare methods used and what basis councils are using to collect their data (guideline, standard or other). The inclusion of results published by others from locations beyond Victoria's borders significantly increase geographical range, enabling the Victorian situation to be compared with other jurisdictions across the globe. The questionnaire data was included to facilitate the comparison between observed asset condition and that perceived by participants from those same councils.

3.9.2 Victorian Council SCM condition audit data

Participating councils were asked to provide SCM condition audit data collected for the purposes of maintenance planning, along with any supporting documentation describing how this data was collected, analysed and interpreted. The evaluation methods used by each council were compared to determine the degree of consistency between councils concerning asset evaluation and to develop a means to compare results between councils. By collecting such data from each council and comparing and contrasting asset evaluation methods, it became possible to (1) test compliance with good asset management practice by ascertaining how many participating councils were able to provide a data set on the condition of their SCMs;

(2) ascertain how systematic this process was, and (3) using these data, determine to what extent maintenance issues were contributing to SCM condition outcomes.

3.9.3 Survey Data

Two closed-ended questions were incorporated into the questionnaire (Appendix C) sent to each respondent (Section 3.7.3). The first question (Q2.1) sought to gauge respondent perspectives on the general condition of SCMs at their council, whereas the second (Q2.2) sought to do gauge respondent perspectives on the sophistication of SCM asset management[11] at their council. The survey questionnaire also collected data on each respondent's role and in which council they were employed. The collection of this survey data enabled the perspectives of council employees concerning SCM maintenance to be gauged, and how these perspectives are influenced according to role and council. Importantly, the survey data also provided a means of triangulating with condition audit data, enriching interpretation and bolstering the robustness of overall findings.

3.9.4 Beyond Victoria

A wide-ranging data base search for published studies that focused on the maintenance of SCMs was undertaken using the National Library of Australia and the University of Melbourne Library database search engines. This provided access to a wide range of academic and professional journals and report databases. A specific set of search strings incorporating commonly used terms for SCMs (Fletcher *et al.* 2014) were used (Table 4-6). Each search setting was set to "relevance" such that strongest matches were displayed first. All articles from each search or the first 250 (whichever came first) were assessed for relevance, and those found to have collected and analysed empirical evidence pertaining to operational SCM condition and / or maintenance sophistication were retained for review[12]. These articles were then examined for relevance to Research Question 1. That is, the reporting on the effectiveness of SCM maintenance programs by municipal organisations.

3.10 Research Question 2: What barriers and challenges effect SCM maintenance within Victorian local government?

The purpose of Research Question 2 was to identify, as comprehensively as possible, the barriers and challenges to the maintenance of SCMs within Victorian local government. In line with the pragmatist worldview of the importance of individual experience of a phenomena (Star 2007, Bryant *et al.* 2007a, Denscombe 2008, Brinkmann 2018), data collected to address Research Question 2 was acquired through a survey program targeting professionals in local government whose roles, in some way, included the undertaking or planning of SCM maintenance (Section 3.8). Therefore, the qualitative data set used to answer Research Question 2 was based on the experiences and perspectives of 54 respondents working across eight councils in the greater Melbourne Metropolitan area of Victoria (Table 3-5). Analysis of the qualitative data was undertaken inductively according to the principles of Grounded Theory (Figure 3-5).

[11] Questionnaire responses exclude executive-level respondents as, for reasons discussed in Section 3.7.3, executives did not participate in the questionnaire phase of the survey process.

[12] Because search settings were set to "relevance", search strings that returned a large number of hits tended to see a relatively quick drop-off in relevance. Hence, an upper limit of the first 250 articles was set to strike a balance between relevant article capture and useful effort.

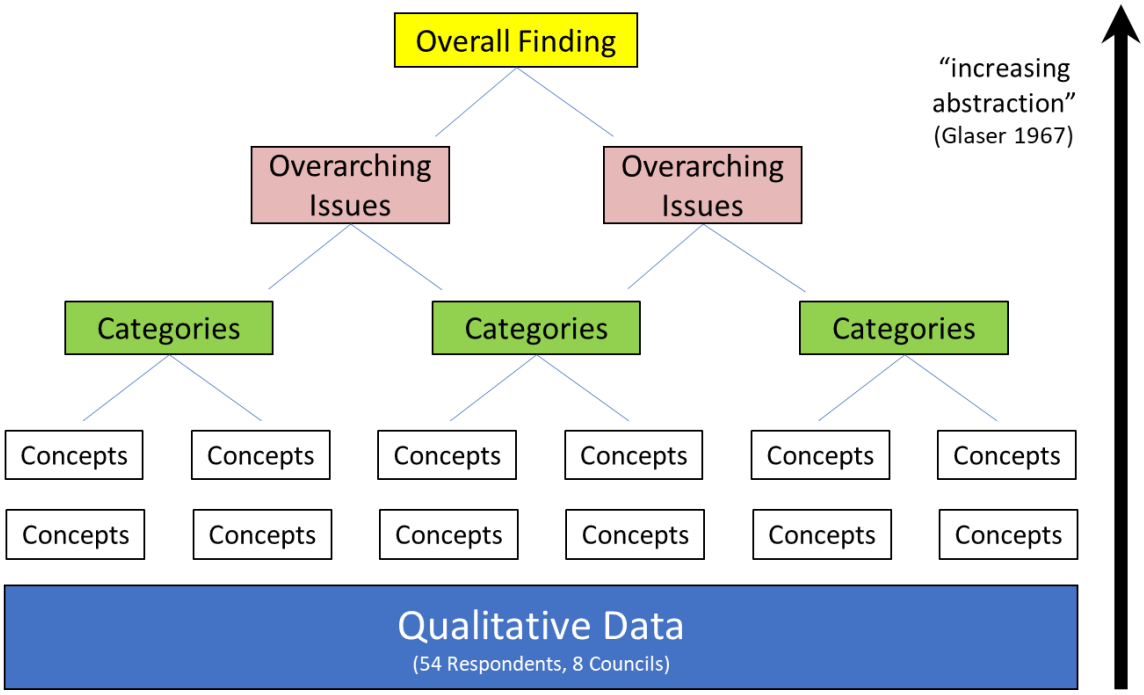


Figure 3-5: Grounded Theory Method informed analysis as applied to Research Question 2 (Glaser *et al.* 2006, Moerman *et al.* 2016)

Questionnaire responses and, where applicable, their follow up interview responses, were first transcribed onto individual transcripts (one for each respondent). These transcripts were then uploaded into NVivo Pro 12 (Bazeley *et al.* 2013, Woods *et al.* 2016). The inductive analysis was then performed in the NVivo environment, beginning with the coding of text from each transcript according to topics and issues raised by respondents (Holton 2007). These codes were systematically evolved and refined into concepts via the principle of *constant comparison* based on the content of additional respondents transcripts as the analysis progressed (Glaser *et al.* 2006, Bryant *et al.* 2007a). As this process proceeded and common themes began to emerge, these themes were used to develop categories into which concepts were organised accordingly. On completion of the coding of all 54 transcripts, it was apparent that *saturation* had been achieved, with concepts and associated categories appearing settled (Glaser *et al.* 2006, Bryant *et al.* 2007a). These concepts and their associated categories were then used to further abstract 'over-arching' issues, i.e., central factors considered to be contributing to the under-maintenance of SCMs which, in turn, were used to abstract the overall finding representing the underlying cause of SCM under-maintenance in local government. Accordingly, this process culminated in the postulation of central factors and ultimate causation of SCM under-maintenance in Victorian local government that are "ground in data" (Glaser and Strauss 2006, p. 33).

3.11 Research Question 3: What intervention pathways might see long-term improvement to SCM maintenance outcomes in Victorian local government?

3.11.1 Overview

The purpose of Research Question 3 is to illuminate intervention pathways which are considered likely to lead to lasting improvement in SCM maintenance outcomes. These intervention pathways are postulations of key path-dependencies that link together SCM maintenance sociotechnical system mis-alignments. That is, the linking of key concepts derived from the analysis of qualitative data collected for this study as per Research Question 2. These intervention pathways were determined via a three-step sequential process developed specifically for this study. The first, termed *sociotechnical system mapping*, involved the 'mapping' of concepts and their categories derived from Research Question 2 onto a heuristic model of SCM Maintenance in Victorian local government. The second, termed *Concept Causation Test*, involved classifying each concept such that those concepts representing mis-alignments in the SCM maintenance sociotechnical system could be differentiated from those concepts that were not. The third, termed *Concept Connections*, involved assessing how the respondents, as a group, tended to group concepts together. The results from these stepwise analyses were then used in conjunction with the findings of a review of literature concerning the management of public infrastructure by councils (Section 2.3) and the researcher's full comprehension of the qualitative dataset to postulate intervention pathways. In so-doing, consistent with the principles of Grounded Theory, the intervention pathways postulated by this study are, therefore, "grounded in data" (Glaser and Strauss, 2006, P.33).

3.11.2 Sociotechnical System Mapping

The purpose of this step was to give form and function to the problem of SCM Maintenance within Victorian local government by providing a means of placing the concepts and categories determined for Research Question 2 onto a model of the SCM maintenance sociotechnical system. To this end, a heuristic sociotechnical model of SCM maintenance in local government was developed for this study (Figure 3-6). The purpose of heuristic models is to provide a basis for locating, framing and analysing a phenomenon, particularly where they occur in complex systems (Brown *et al.* 2013). Ideally, such a model should be sensitive to both the research subject and the context within which it occurs, and be sufficiently descriptive to be useful, but not so prescriptive as to risk errors of omission. Given the sociotechnical perspective taken for this study, it also needed to not only be sensitive to 'objective facts', but also the subjective opinions and attitudes of actors within the sociotechnical system.

To meet these requirements, the model for SCM maintenance in local government (Figure 3-6) was developed by merging the generic model for sociotechnical systems developed by Davis *et al.* (2014) (Section 2.4) with the Multi-Level Perspective underpinning Sociotechnical Transitions Theory (Section 2.5.4). The dashed lines delineating boundaries between levels acknowledge that these boundaries are, in reality, not sharp. Rather, they are fuzzy, accounting for the complex and highly interactive processes between levels within sociotechnical systems (Geels 2011). The Niche scale is shown to occur in both the Regime space and Landscape space to avoid suggesting that Landscape factors do not directly influence Niche outcomes or vise-versa. An important difference between the model developed for this study and that developed to illustrate the dynamic nature of transitions conceptualised by Sociotechnical Transition Theory (Figure 2-10, Section 2.5.4) is the absence of time. This is because the model created for this study has been developed to analyse a systemic problem within a sociotechnical system at a particularly point in time rather than the transition of an innovation over time.

Each level incorporates *elements* based on the elements identified by Davis *et al.* (2014) (Figure 2-4) to assist with locating categories and concepts abstracted from the qualitative data as per Research Question 2. For the purposes of this study, the Regime level is given highly specifically definition, being the social, institutional and technical manifestations of asset management within local government, with a focus on stormwater management given the research topic[13]. While there has been debate concerning the definition of regime in the scholarship (Geels 2011), Geels points out that his definition for regime has been deliberately left open so that it can be adapted to different innovations, contexts and research objectives (Geels 2011). Accordingly, the regime definition for this study is appropriate because the research is explicitly concerned with the management of SCMs within local government. Most of the elements identified within the Regime are carried directly over from Davis *et al.* (2014)'s generic model for sociotechnical systems (Figure 2-4). However, given the research topic focuses on a specific type of infrastructure (SCMs), the *infrastructure* element has been removed, appearing instead as the element *niche-innovation* at the Niche scale. The inclusion of the Niche scale, and the incorporation of SCM within it, provides a framework for differentiating causal factors associated with the 'newness' of SCMs, their unique nature (Section 1.2), and their protected space from factors intrinsic to the Regime and Landscape. The element *technology* within the Regime refers not to SCMs, but rather the range of digital and software technology used by local governments to collect, collate and analyse the wide array of data necessary to manage their infrastructure. *Financial Constraints* has also been added to the Regime scale to account for the current financial status of local government in Australia, as discussed in Section 2.3.2.

Industrial orientation and *stakeholders* have been placed in juxtaposition to the Regime and Landscape to signify their respective dual existence in both spaces. Industry orientation refers to the culture and professional biases of the stormwater industry. While many of the professions involved in stormwater management and their representative bodies exist beyond of local government (e.g. *Stormwater Australia*, *Institute for Public Works Australasia*, *Asset Management Council*, and *Engineers Australia*), many of their members are directly employed by, or otherwise provide services to, local government. Hence, the culture and professional biases of these professions are likely to both affect and be affected by local government. Regarding stakeholders, given the constitutional intent of local government, the major stakeholder is each council's local community. Influence over the local council occurs primarily through each local council's sitting councillors and their interests in being re-elected. Hence, while the community may sit outside the regime, the body that represents the community, the councillors, is part of the regime. For this reason, *Political Agenda* is also shown in a juxtaposition. Political agenda encapsulates "the set of issues that are subject to decision making and debate within a given political system at any one time" (Baumgartner 2015, p. 362). In relation to this study, this is intended to cover political agendas at the local, state and federal levels within the Australian context.

[13] The Multi-level Perspective scales are written in proper noun format (capitalised first letter) when using the terms specific to the SCM Maintenance in Victorian Local Government sociotechnical model developed for this study.

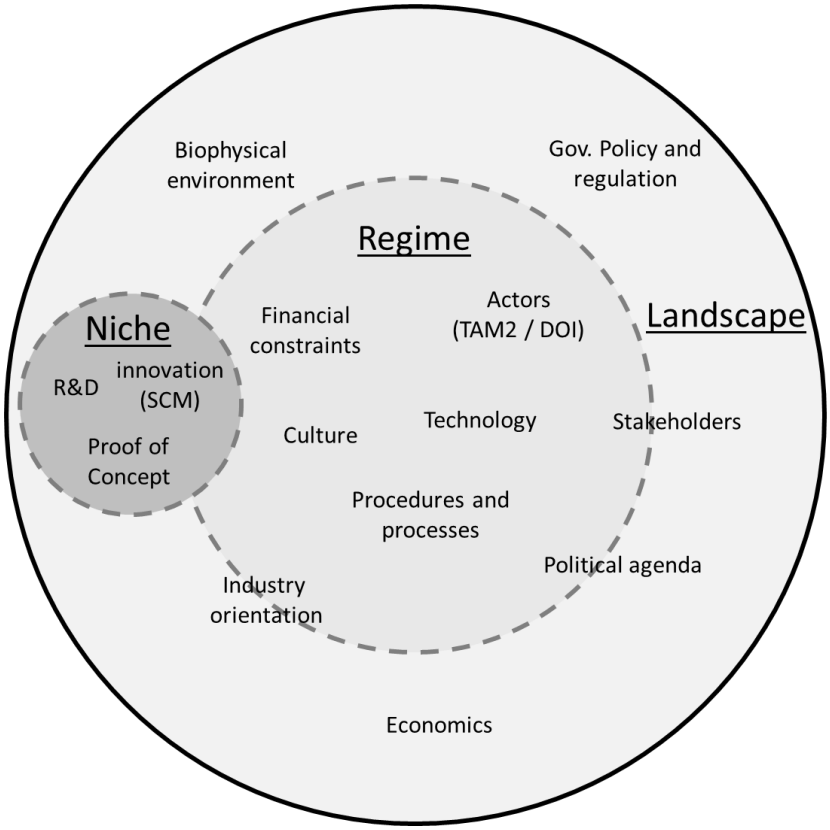


Figure 3-6: Heuristic model for exploring and investigating SCM maintenance in local government

Another elemental change in the heuristic model is the replacement of *people* with *actors.* This small but important change recognises that 'people' within the defined SCM maintenance sociotechnical system are active participants. While some may have more power than others, most are likely to have the capacity to, in some way, affect maintenance outcomes. For example, while a field operative may not be able to refuse to maintain particular assets, they will likely have control over the quality of maintenance work undertaken and the accuracy of condition assessments. Similarly, while maintenance planners may not have the power to decide if SCMs are built in the first instance, they are likely to have influence over how much attention and funding different asset classes receive. Given that human beings make decisions based on a mix of objective and subjective factors (Fink *et al.* 1971, Lazarus 1991, Sabatier 2007, Siriwardhane *et al.* 2014), actor variables from DOI theory and TAM are drawn on to account for this (Sections 2.6.2 and 2.6.3 respectively).

Sitting wholly outside the Regime at the Landscape level are *Government Policy and Regulation*, the *Biophysical Environment* and *Economics.* In Australia, local government comes under the direct jurisdiction of state government, along with its policies and regulations. Further, while the federal government has fewer such powers, they have been able to influence local government decisions through various policy mechanisms, particularly those that appeal to local residents and have funding attached (Kelly *et al.* 2009). Consistent with Sociotechnical Transition Theory, the *biophysical environment* has also been incorporated as a specific element because of the biophysical design of SCMs, and the rise of SCMs being linked to climatic events (particularly the millennium drought) and as a policy solution to climate change (Brown *et al.* 2013, Rijke *et al.* 2013, Farrelly *et al.* 2014). Lastly, while inevitably linked to the Regime element *financial constraints*, landscape economics is differentiated by referring to the economic circumstance exogenic to a council. This may be local economic factors, such as the socio-economic realities of a given local government area, as well as the respective economic status of state, federal and global economies.

3.11.3 Concept Causation Test

To help identify potential intervention pathways, the *Concept Causation Test* was developed to differentiate concepts abstracted from the qualitative data analysis for Research Question 2. Its purpose is to provide a means of locating mis-alignment within the SCM maintenance sociotechnical system that reflects where sociotechnical system reconfiguration has either failed to occur, or is struggling to occur (Geels 2004, Kim *et al.* 2006, Van der Brugge *et al.* 2007, Davis *et al.* 2014). The test facilitated the differentiation of concepts by assigning each concept to one of the following classifications:

1. *Intrinsic*: The concept is considered to be primarily a function of the intrinsic nature of the innovation's engineering or operational philosophy (Section 1.2). Hence, concepts that refer to barriers and challenges that are a function of the defining nature SCMs are classified as *intrinsic*. To change these is to essentially change the innovation itself, rendering such concepts effectively 'unchangeable' within the scope of this study.
2. *Mis-alignment*: The issues captured by the concept are considered to be primarily a consequence of the introduction of the innovation. If the innovation was removed, these issues would likewise disappear from the broader sociotechnical system. Hence, the concept represents issues that will need to be ameliorated to see sustaining path-dependencies established that support the innovation, culminating in the successful transition of the innovation.
3. *Independent*: Issues captured by the concept are considered to be primarily a function of pre-existing conditions within the broader sociotechnical system that act upon the innovation, but are not a function of the innovation (i.e., neither *intrinsic* nor *mis-alignments*). Accordingly, they are not a function of the introduction SCMs or its constitution, but rather problems associated with public infrastructure and local government more broadly. While *Independent* concepts may still be very important to SCM maintenance outcomes, they are problems that do not just effect SCMs, existing before SCMs were introduced into local government (Section 2.3.2). The ability to differentiate between *Independent* concepts and *Mis-alignment* concepts requires a detailed understanding of the broader sociotechnical system. This has been accommodated for in this study via the literature review (Chapter 2), particularly sections 2.2 through 2.4 inclusive.

The basis for the Concept Causation Test is drawn directly from Sociotechnical Transitions Theory and the notions of path-dependencies and system mis-alignments (Section 2.5.4). As Figure 3-7 is intended to illustrate, when an innovation begins to compete with the conventional practice, path-dependencies (blue straight arrows) that sustain the regime are disrupted, and the dynamic equilibrium of the regime is destabilised (Geels 2004, Van der Brugge *et al.* 2007). This disruption results in the generation of system mis-alignments between the existing sociotechnical system and the innovation (smaller, multi-directional blue arrows). If the transition of the innovation is to be successful (i.e., the establishment of a new regime), then these system mis-alignments will need to be addressed in order to establish new sustaining path-dependencies. Therefore, concepts that are classified as 'mis-alignments' indicate key challenges and barriers that are preventing the systematic management of SCMs as a stormwater management solution and, if ameliorated, should see lasting improvement to SCM maintenance outcomes. Differentiating concepts in this way, then revising the heuristic model produced as per Section 3.11.2 by colour coding the concepts accordingly, provided extra dimension to the model produced, improving its analytical power.

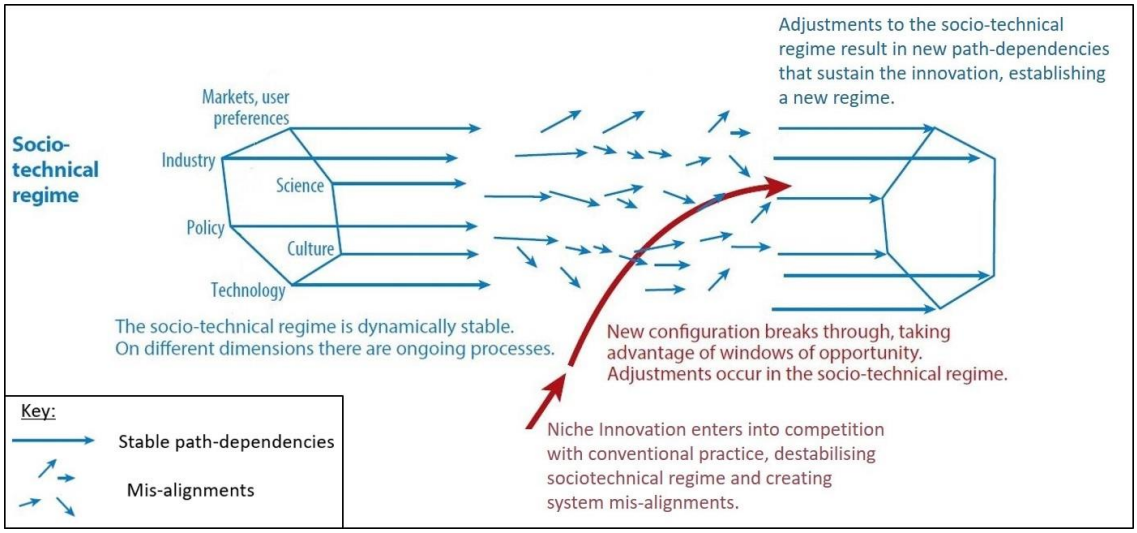


Figure 3-7: Zoom-in of Geels's Multi-level Perspective of system innovations, focusing on the disruption and reconfiguration of the regime, resulting in sociotechnical system mis-alignments then reconfiguration respectively. Assuming transition is successful, this results in the creation of new path-dependencies and, *ipso-facto*, a new regime (modified from Loorbach et al. 2017, p. 606, fig. 1)

3.11.4 Respondent Perspectives on Concept Connections

To give further indication of potential intervention pathways, the *concept connection* analysis was developed to reflect the general tendencies of the respondents to link concepts together in cause and effect relationships. This analysis combined a specific coding protocol and the word similarity analysis tool available in NVivo 12 Plus. The process of coding described in Section 3.10 was performed such that when a respondent linked two or more concepts together in a cause and effect relationship, precisely the same section of text denoting that relationship was coded to the respective concept nodes. Inclusion of this in the coding protocol ensured that those concepts that respondents tended to link together in cause and effect relationships likewise built up a similarity in the numbers and types of words. On completion of the coding process, a word similarity analysis was performed incorporating all concept coding nodes using NVivo's word similarity analysis tool (Pearson correlation coefficient similarity metric). This process produced a dendrogram designed to infer the tendency of respondents, as a group, to link concepts together. This, together with the model process described previously, were used to help inform the identification of intervention pathways for improving long-term SCM maintenance outcomes.

The decision to test for respondent concept cause and effect associations in this way was taken due to the high number of respondents (54) and the large qualitative data set that resulted (Appendix G). It is important to emphasise that the word similarity test applied does not directly measure respondent perspectives, but simply the similarity of word contents between concept nodes using a mathematical algorithm based on the Pearson correlation coefficient. Consequently, it will always show some level of correlation between concepts, and its sensitivity is reduced where concepts nodes only attract a small number of respondent references. Further, given the potential complex sociotechnical nature of the problem, it was also important to be mindful that important path-dependent relationships may not be obvious to respondents in their day to day experience of the problem. Hence, those relationships most often mentioned by respondents may not necessarily identify all potentially important relationships. Therefore, the output generated by this analysis was used as one of four sources of information to assist with intervention pathway postulation. The other three being the findings of the Grounded Theory analysis of the qualitative data (Research Question 2, Section 3.10), the findings of the

literature review (Chapter 2) and the researcher's full comprehension of the respondent commentary.

4 Evidence for Stormwater Control Measure Under-maintenance

4.1 Introduction

Anecdotal evidence suggests that SCMs under local government management in Victoria are not being effectively maintained. This being so, SCMs under the remit of local government may not be achieving their intended service levels (Section 1.2). Consequently, the investments made towards developing SCMs as an innovation and establishing their presence in the urban landscape may not be fully realised. Many international studies raise similar concerns in relation to other jurisdictions, though very few provide empirical evidence (Bergman *et al.* 2011, Hunt *et al.* 2011, Al-Rubaei *et al.* 2013, Drake *et al.* 2013, Merriman *et al.* 2014, Al-Rubaei *et al.* 2016, Korkealaakso *et al.* 2016, Winston *et al.* 2016, Blecken *et al.* 2017, McDonald 2018). In this chapter, Research Question 1 (Table 1-1) is addressed by examining empirical evidence of the under-maintenance of SCMs within Melbourne and jurisdictions beyond Victoria as described in Section 3.9. In so-doing, this chapter provides empirical evidence to these concerns.

To this end, the Chapter is split into two parts. Part 1 provides empirical evidence concerning the maintenance of SCMs in Victoria. Results of the examination of council condition audit data are presented first, followed by the results of the two closed ended questions included in the study's questionnaire (Q2.1 and Q2.2, Appendix C). Part 1 then concludes with a brief discussion of the results, their limitations and potential implications. Part 2 provides the results of the review of published studies beyond Victoria that provide similar evidence, reporting on the number of studies available, the regions they cover, methods used and their findings. Part 2 then concludes with a brief discussion of the findings, consistencies between studies and the implications of the research. The Chapter then concludes with a comparison between the findings for each part, and what this suggests about the general effectiveness of SCM maintenance in Victoria and beyond.

4.2 Part 1: Victorian Local Government.

4.2.1 SCM Condition Assessment Data

Each of the nine councils recruited to participate in this study (Table 3-4) was asked to provide records of the most recent condition audit results for their SCMs. Only three councils were able to provide formalised data sets: Council A; Council E and Council I. Council A provided condition assessment data for 76 of their SCMs, collected by a contractor on their behalf during 2014. These SCMs were described as 23 gross pollutant traps[14] ; 16 treatment wetland systems (with pre-wetland sediment basins); 16 treatment swale systems; 4 retarding basins with informal wetland forming in base; and three ponds. Council E provided condition assessment data collected during 2015 for 83 of their SCMs. They described these assets as 13 infiltration systems, 64 raingardens, 5 wetlands and a single wetland. Unlike Council A, Council E used internal resources to gather their data. Council I engaged a contractor to collect condition data on 18 of their SCM during 2013, describing them as 16 bioretention systems, one tree pit system and one constructed wetland. Unlike Council A, neither Council I or Council E

[14] Gross pollutants Traps are civil engineered structures that enable the physical separation of litter and course sediment from stormwater, typically via an arrangement of mesh or screens, incorporating some sort of 'trap' to capture filtered gross pollutants. Such systems need to be subject to routine cleaning of traps to keep them operational.

provided data for GPTs. The reasons for this are not known; however, it is highly unlikely these councils do not own and operate such SCMs.

Of the remaining six councils, three indicated that they were in the process of setting up a systematic auditing processes, but were yet to undertake their first condition assessment, whereas the remaining three had not yet formally identified condition auditing of SCMs as a required process. It is also noted that while Councils A, E and I were able to provide useful data, none of these datasets had been collected as part of an ongoing, established program as good practice requires (AAMCoG 2012, LGV *et al.* 2015). Rather, they represent the first attempts by each of these councils to collect such data in order to address a recognised gap in their asset information.

Councils' A, E and I used different scoring systems for assessing the condition of their SCMs, none of which were consistent with the 1-5 scale system recommended by the Victorian *Local Government Asset Management Better Practice Guide* (LGV *et al.* 2015). Council A's scoring system utilised seven assessment categories scored between 0 and 10, where higher scores meant better condition (Table 4-1). Of the seven assessment categories used by council A, four were focused on maintenance, i.e.: 'litter', 'sediment build-up', 'functional vegetation' and 'weeds'. The remaining categories were 'planning and design', 'civil condition' and 'water quality objectives' and, while they may affect maintenance outcomes, none are a consequence of maintenance.

Table 4-1: Condition assessment category definitions for Council A.

Assessment Category	Assessment focus
Litter Build-up†	Presence / absence of gross pollutants on, in and around each asset, and their impact on the subject assets function (e.g. blocking of pipes, weirs, inlets, outlets and, if applicable, storage capacity)
Sediment Build-up†	Presence / absence of sediment build-up on, in and around each asset, and their impact on the subject assets function (e.g. blocking of pipes, weirs, inlets, outlets and, if applicable, storage capacity)
Functional Vegetation†	Condition, health and density of functional vegetation*, where "functional" referred to both water quality and / or landscaping aesthetics
Weeds†	Degree to which weeds had encroached into the asset, and the extent they had become established
Planning and Design	Whether or not due process was followed during the planning stage in accordance with council protocols; if the assets were appropriately located; whether the asset conflicts with other land uses; and whether or not other objectives were met such as landscape and ecology
Civil Condition	Match between the as-built asset and its respective design drawings; and whether the design sufficiently matriculated into an asset that was resilient to operational issues such as scouring, sediment deposition, unintended gross pollutant entrapment and unintended human interaction (e.g. trampling, being used as a parking space, etc.)
Water Quality Objectives	Based on a range of indirect measures ("surrogates"), such as the extent to which gross pollutants, sediments deposition and vegetation growth had reduced the treatment area; whether or not the system was bypassing appropriately; and that functional vegetation was healthy, appropriately located and of the right density

Councils E and I used very similar assessment categories to assess the condition of their SCMs (Table 4-2). In contrast to the seven categories used by Council A, Councils E and I only used four, one of which was devoted to maintenance. The other three categories were devoted to the degree of compliance with the council's planning process, the appropriateness of the design in terms of location and purpose, and how well the system had been constructed in terms of quality and compliance with its design.

Table 4-2: Condition assessment category definitions for Council E and Council I

Assessment Category	Assessment focus
Planning	The degree to which a given SCM complied with council's planning process
Design	Appropriateness of each's asset design in the context of its intended purpose and location. This included if the asset was appropriately sized and located, if it included effective upstream pre-treatment (e.g. sediment forebays and GPTs), if it was sensitive to surrounding land uses and did not interfere with foot and vehicular traffic.
Construction	Consistency with design and quality of works
Maintenance	General condition of the SCM on the day of inspection as the health of functional vegetation; structural integrity of engineered and landscaped components, and general aesthetics.

Some similarity was also evident between the scoring used by Council E and Council I, with both reporting their final scores as discrete rankings, i.e., 'good', 'average' and 'poor'. 'Good' referred to assets requiring little or no rectification to restore them to optimal condition, 'average' referred to minor to moderate rectification required, whereas 'poor' denoted an asset requiring major rectification or, alternatively, decommissioning and replacement. However, where Council E relied solely on this discrete ranking system, Council I first scored their assets between 0 and 10 for each category before converting the results using the rules presented in Table 4-3.

Collating Council A's condition inspection data to facilitate comparisons between councils produced an additional challenge. As discussed earlier, Council A's data included seven different categories, of which four were attributed directly to issues pertaining to maintenance: *Litter Build-up*, *Sediment Build-up*, *Functional Vegetation*, and *Weeds* (Table 4-1). While Council A also used a scoring system between 0 and 10, it was applied in the reverse order to Council I (Table 4-3). Further, where Council A's scoring system appears to be an in-house system developed by their contractor, Council I's contractor identified their scoring system as being adapted from the *Moloney Model* method (MAMS 2015)[15]. To facilitate comparison with the other two councils, a two-step process was used. The first was assigning an overall maintenance condition inspection rating to each of Council A's assets by assigning it the score for the lowest maintenance category. For example, if an asset achieved a 'good' ranking for Litter Build-up and Functional Vegetation, an 'average' ranking for Weeds and a 'poor' ranking for 'sediment build-up', then it was assigned an overall maintenance condition of 'poor'. The logic behind this process is that these sub-categories simply define the reason for a condition rating, i.e., the asset is rated 'poor' because of sediment build-up. This score was then used to assign each of Council A's assets to discrete rating of "Good", "Average" or "Poor" in similar fashion to that used by Council E (Table 4-3).

[15] It is noted that while the *Moloney Score* model included guidelines for stormwater assets at the time of the assessment, these guidelines focus only on 'grey' infrastructure (pits and pipes) with no mention of SCM.

Table 4-3: Conversion of Council A's scoring system for the purposes of this study.

Scoring – Council I	Scoring – Council A	Definition (Council A / Council I)	Derived Discrete Ranking
0-1.9	10	No problems identified / a new or recently rehabilitated asset with no visible signs of deterioration.	Good
2-3.9	9	Some minor problems / an asset with very slight condition decline or early stages of deterioration, but still minor in nature and causing no serviceability problems.	
4 to 5.9	7 to 8	Problems identified but can be addressed by minor maintenance activities / some obvious deterioration and some serviceability loss.	Average
6 to 6.9	4 to 6	Problems identified but can be addressed by moderate or ongoing maintenance activities / Condition deterioration is quite obvious, asset serviceability clearly affected, maintenance costs rising.	
7 to 7.9	2 to 3	Problems identified can only be addressed by major or ongoing intensive maintenance activities / deterioration is quite severe and would be starting to limit the serviceability of the asset, maintenance costs high.	Poor
8 to 9.9	1	Problems identified can only be addressed by asset reconstruction or retrofitting / asset in very poor to extremely poor condition, at point of need of rehabilitation with serviceability heavily impacted and maintenance cost very high.	
10	0	Problems identified cannot be adequately addressed / asset has failed, is no longer serviceable and should not remain in service.	

Table notes:

† - For Council I the discrete ranking is as per contractor's system whereas Council A was derived based on definitions as Council A's contractor made no such conversion.

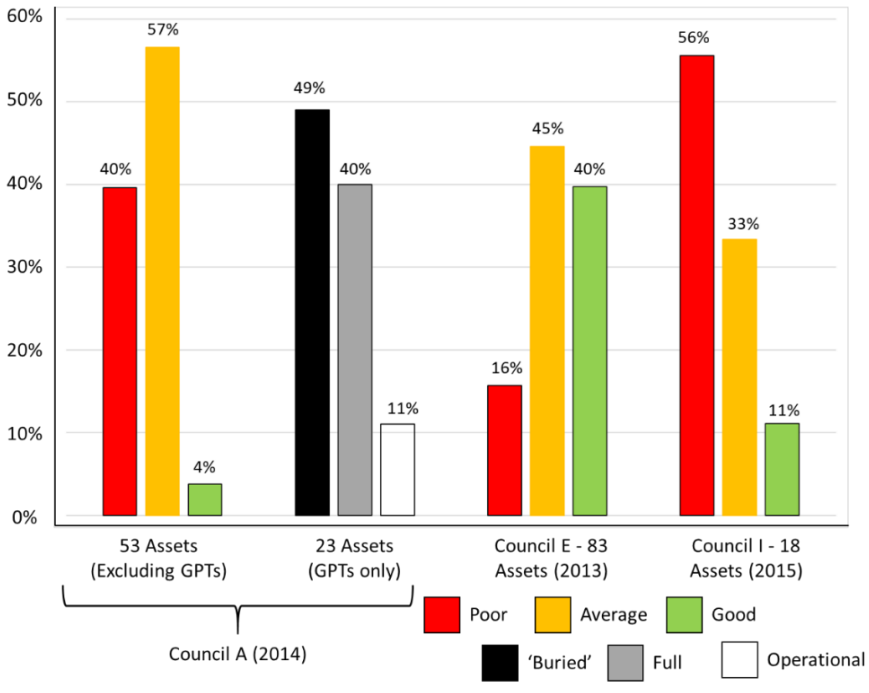


Figure 4-1: Collated SCM maintenance inspection condition results for Council I, A and E.

The collated maintenance related condition inspection results for councils A, E and I are summarised in Figure 4-1, along with gross pollutant trap condition inspection results for Council A. Council A was the only council to provide condition inspection data for their gross pollutant traps. It is important to note that the data supplied by Council A for its gross pollutant traps refers only to their need for cleaning relative to their operational status at the time of inspection (i.e., how full of gross pollutants they were). Specifically, if the traps had sufficient room to be considered able to capture gross pollutants during the next rain event (or more)[16]. Therefore, gross pollutant traps were assigned to one of three classes: 'operational', meaning able to capture gross pollutants; 'full', meaning not able to capture any more gross pollutants; and 'buried', denoting that the condition of the trap suggested that the device had never been cleaned out since its construction[17].

Because of the different methods used to assess the condition of SCMs at each council, the results presented in Figure 4-1 can be considered as indicative only in a comparative sense. However, they still provide a useful means of gauging the general condition of SCMs at each council. These results reveal relatively low proportions of assets being in 'good' condition. This is particularly so for Councils' A and I, where the proportion of assets considered to be in good condition are much lower than those considered to be in poor condition. Council E fared somewhat better[18], though it is noted that less than half of their SCMs were observed to be in good condition. Gross pollutant traps (Council A only) likewise reveal concerning results, with only 11% (3 of 20) being operational at the time of inspections, and almost half observed as being in such a poor state that they appeared to have never been serviced (cleaned).

4.2.2 Survey data

Question Q2.1 of the survey questionnaire asked respondents to equate operational performance relative to maintenance, plus the option to opt out of the question if they felt they were not able to answer it (Table 4-4 and Appendix C). The intent of this question was to provide a means of comparing respondent perspectives from each council relative to condition data provided by these same councils (Figure 4-1). Given that only three councils were able to provide condition data, this data set now also serves as an indicator for those councils that were not able to provide such data. Note that Council I does not appear in Table 4-4 as it chose not to participate in the qualitative part of this research.

Respondents were given five options (Table 4-4), the last of which was to opt out of answering the question if they felt they were not able to adequately answer it. The remaining four options asked the respondent to estimate, based on their experience, the relative proportion of assets operating optimally as a function of their maintenance needs. Only one (2%) of the 44 respondents who answer this question believed that most of their assets were operating at an optimal level, compared to 5 (11%) who believed most of their council's SCMs required significant amounts of assets. Another 6 respondents (15%) indicated that they were unsure. The remaining majority of the respondents 32 (73%) were split between 'many' and 'some'. Excluding those who chose 'I am unsure', a slight skewing towards the lower end of the scale is evident. Table 4-4 also reveals no overt differences between councils, with the possible exception Council E, which reveals a higher proportion of 'Few' responses relative to other councils. However, such quantitative assessments are indicative only, given the number of respondents relative to number of councils.

[16] The precise measure for this was not articulated in the information provided.

[17] While not the same council, Figure 2-1 (Chapter 2) provides an example of what a gross pollutant can look like after an extended period of not being cleaned (years).

[18] There are extenuating circumstances that are likely to have contributed to Council E's better condition results, however describing these would reveal the Council's identity, breaching the ethical considerations associated with this study (Section 3.5).

Figure 4-2 provides a graph that distributes the responses to survey question Q2.1 relative to role. Roles are split into two role categories 'Frontline" and "Administrative". This delineation separates responses based on how often respondents would likely have direct contact with operational SCMs, where Frontline personnel (field technicians and coordinators) are likely to have higher contact given their direct role in executing maintenance. This distribution suggests that administrative staff perspectives concerning the condition of SCMs to be slightly more negative that their frontline colleagues.

Table 4-4: Summary of results for questionnaire closed-ended question Q2.1

	Councils								**All Councils**
Q2.1: Generally Speaking, which statement reflects the condition YOU consider your council's SCMs to be in?	A	B	C	D	E	F	G	H	**Number (Percent)**
Most (90% or more) of council's SCMs can be expected to be operation at, or close to, optimal, requiring only minor maintenance to maintain this standard.	-	-	-	-	-	-	1	-	**1 (2%)**
Many (70-90%) of council's SCMs can be expected to be operating at, or close to, optimal, requiring only minor maintenance to maintain this standard. However, some assets required major cleaning, maintenance or rebuild to restore their optimal operational performance.	1	5	3	2	2	-	2	1	**16 (36%)**
Some (40-79%) of council's SCMs can be expected to be operating at, or close to, optimal, requiring only minor maintenance to maintain this standard. However, many assets required major cleaning, maintenance or rebuild to restore their optimal operational performance.	3	3	1	2	2	2	3	-	**16 (36%)**
Few (less than 40%) of council's SCMs can be expected to be operating at, or close to, optimal, requiring only minor maintenance to maintain this standard. However, most assets required major cleaning, maintenance or rebuild to restore their optimal operational performance.	-	1	1	-	3	-	-	-	**5 (11%)**
I am unsure, as I don't have a sense of their performance or am not directly involved assessing or observing their performance.	-	1	1	-	1	-	-	3	**6 (15%)**
Total number of responses per council.	4	10	6	4	8	2	6	4	100% 44

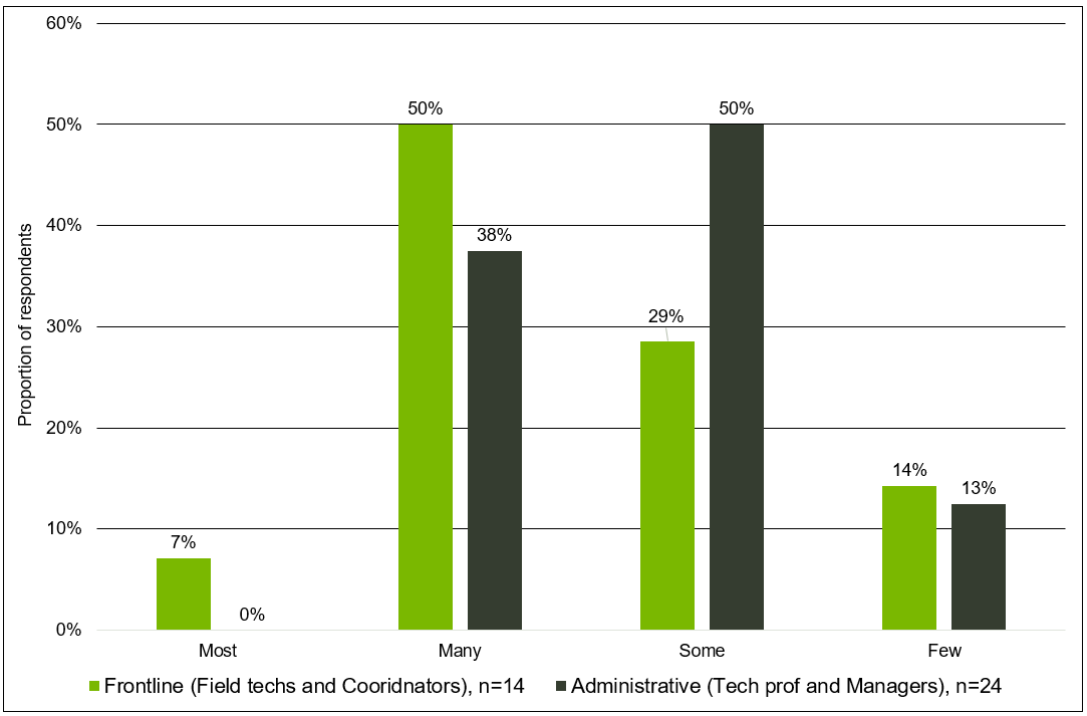


Figure 4-2: Respondent perspectives on condition of SCMs by role, all participating councils.

Question 2.2 of the survey questionnaire asked respondents to indicate how sophisticated they thought their council was regarding SCM asset management (Table 4-5 and Appendix C). As discussed in Section 2.3.1, good practice asset management dictates that infrastructure should be managed in a systematic way, being integrated into the organisational structure and systems. Assets should be registered and subject to condition assessment, with maintenance plans and budgets in place. Communication between teams and departments should be sufficient to ensure SCM service levels are achieved, within adequate human resources available to do the work. Therefore, a response of "EXCELLENT" indicates SCM related asset management meets good practice, and anything below indicates increasing levels of deficiencies. Note that Council I does not appear in Table 4-4 as it chose not to participate in the qualitative part of this research.

Table 4-5 reveals that responses are, overall, skewed towards under-performance in SCM asset management by the councils that participated in this study. Only 2 (5%) respondents indicating a perception that their council's practices were at a standard that fit the definition of 'EXCELENT'. This compares to 12 (27%) of respondents who perceived their council's performance fit the definition of 'POOR' and 25 (57%) who perceived it to fit the definition of 'O.K.'. No overt differences between councils is evident in the results. When these results are distributed based on role, administrative personnel appear to tend towards a more negative outlook regarding asset management sophistication Figure 4-3.

Table 4-5: Summary of results for questionnaire closed-ended question Q2.2

	Councils								All Councils
Q2.2: Generally Speaking, which statement reflects the level of sophistication YOU consider your council exhibits regarding SCM operation and maintenance (O&M)?	A	B	C	D	E	F	G	H	**Number (Percent)**
EXCELLENT: The O&M of SCM is integrated into council's existing asset management system with periodic and / or predetermined maintenance triggers that adequately reflect on-ground needs of each system. O&M planning is effectively communicated to relevant staff. Council has access to a sufficient number of appropriately trained personnel to undertake SCM O&M	-	1	-	1	-	-	-	-	**2 (5%)**
O.K.: The O&M of SCM is being undertaken by council, however deficiencies in the application of council's asset management system, O&M planning procedures, communication and / or access to sufficient numbers of capable personnel is resulting in a moderate reduction in the effectiveness of SCM O&M	3	7	3	3	3	-	3	3	**25 (57%)**
POOR: The O&M of SCM at your council is *ad-hoc* and / or seriously deficient, creating the potential for some assets to receive no maintenance (getting "lost" in the system), whilst many others are receiving insufficient and / or adequate maintenance	-	1	3	-	4	2	2	1	**12 (27%)**
I am unsure, as I don't have a sense on their performance or am not directly involved assessing or observing their performance.	1	1	-	-	1	-	1	-	**5 (11%)**
Total number of responses per council.	4	10	6	4	8	2	6	4	100% 44

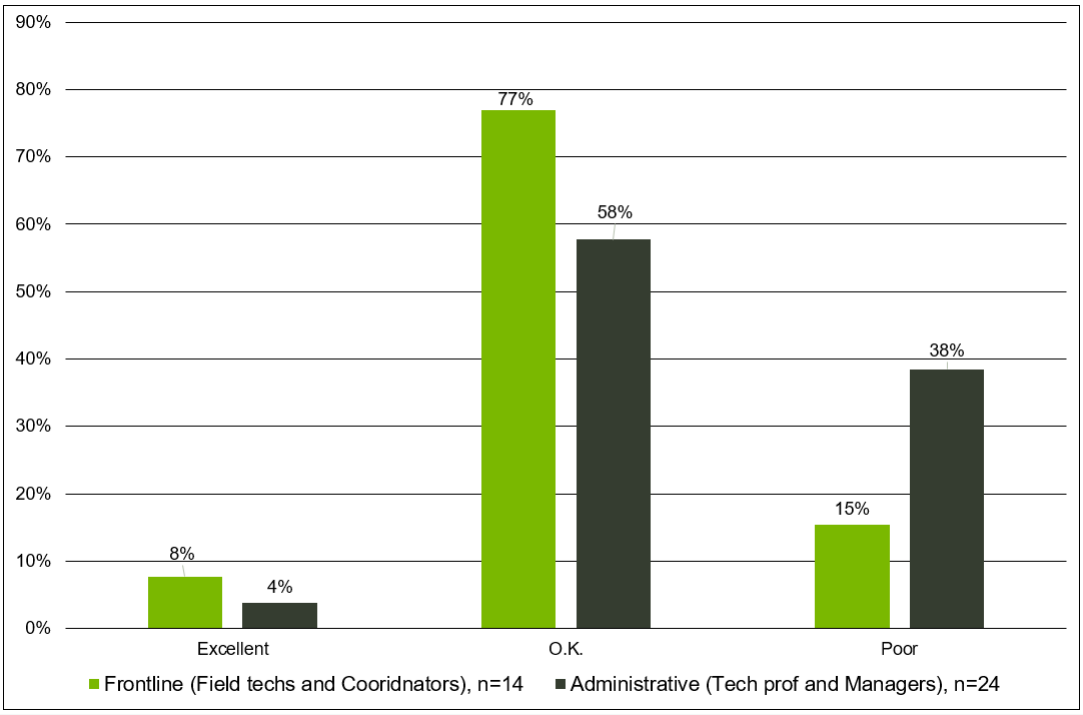


Figure 4-3: Respondent perspectives on SCM asset management sophistication by role, all participating councils.

4.2.3 Discussion.

Councils selected to participate in this study were chosen based on the likelihood that they would be performing better than most councils in Victoria concerning SCM maintenance and management (Section 3.7.2). This sampling strategy was employed to bias the results towards higher performing councils such that the results presented here could be considered as above average. Despite this bias, analysis of the SCM condition inspection data and survey questionnaire results points to a general lack of maturity in the management of SCMs by participating councils (Sections 2.3.1 and 2.3.2). Most councils were not able to provide condition assessment data (six of nine councils) as they were yet to conduct a systematic assessment of their SCMs. Of three councils that were able to provide such data, all revealed low proportions of SCMs found to be in 'good' condition. Further, these three councils all used different methods, all of which were inconsistent with the IPWEA NAMS[19] '1 to 5 scale system' (IPWEA 2012) recommended by the Victorian *Local Government Asset Management Better Practice Guide* (LGV *et al.* 2015). Given the positive bias in the sample group, it is therefore probable that most Victorian councils are exhibiting similar SCM asset management and maintenance outcomes, if not worse. Therefore, the evidence presented here supports concerns that SCMs are not being effectively maintained by Victorian local government (Eggleton *et al.* 2012, Burns *et al.* 2015, Beardshaw 2019)

Specific benchmarks for acceptable proportions of 'good', 'average' and 'poor' condition for SCMs do not yet appear to exist. There are currently no guidelines or policies that provide such a benchmark. Further, despite the Victorian *Local Government Asset Management Better Practice Guide* (LGV *et al.* 2015) recommending service levels be set for all assets, none of the participating councils had done so for SCMs. To compensate for a lack of a more suitable benchmark, Victorian state roads condition data is used as a substitute, as published in the Victorian *Maintaining State-Controlled Roadways* report (VAGO 2017). While it is recognised

[19] The Institute of Public Works Engineering Australia (IPWEA) and its National Asset Management Strategy (NAMS) council.

that these are very different asset classes, in lieu of an alternative, roadways offer the most reliable and readily-available comparison given the regulatory environment that governs the tracking of roadways in Victoria[20].

The *Maintaining State-Controlled Roadways* report found that 62% of roads were considered to be 'good to fair', 23% were in 'poor' condition and 15% were 'very poor'. VAGO (2017) concluded that such condition results were an indication that road maintenance was "not adequate to sustain functional road condition" (VAGO 2017, page 15). Even if a conservative approach is taken and it is assumed that 'poor' and 'very poor' applied in VAGO (2017) are roughly equivalent to 'poor' as applied in this study, then the SCMs of Council A and Council I are faring worse than Victoria's roads. Council E fairs only slightly better than Victoria's roadways, despite the special circumstances concerning the maintenance of SCMs at this council[21]. Further, while Council E appears to be faring better, closer examination of Council E's data reveals that most of their assets were only recently constructed prior to condition inspection[22]. When condition results are graphed according to their construction date (Figure 4-4), a clear pattern emerges showing that older assets are more likely to be in average or poor condition. This finding introduces the possibility that the relatively young age of Council E's SCMs is a contributing factor to its results, rather than better maintenance practices alone.

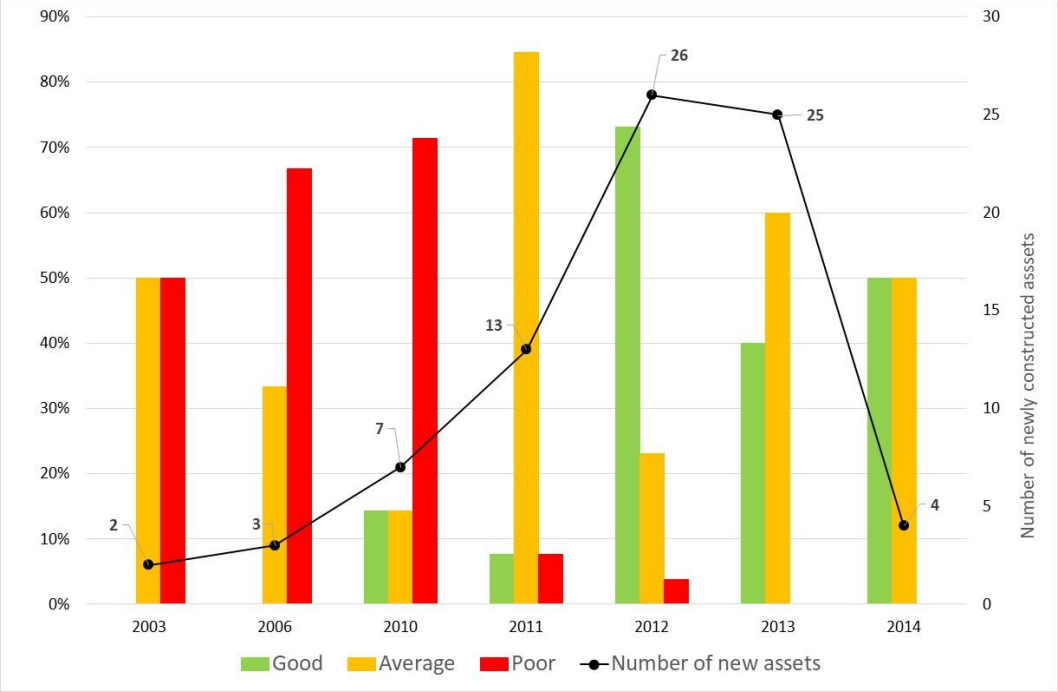


Figure 4-4: Asset condition distributed by year of construction – Council E (audit year = 2015)

The finding that only three of the nine councils were able to provide SCM condition audit data also has important implications for the maintenance of SCMs by Victorian local government. Asset management standards and guidelines state that the routine collection of such data is an essential component of asset management, providing critical information for determining maintenance schedules and budgets (IPWEA 2011, IPWEA 2012, LGV *et al.* 2015). Yet despite biasing the sample group towards councils likely to be performing better than most other Victorian councils, only three had collected such data. Further, those three councils that did

[20] Victorian *Road Management Act 2004*.

[21] There are extenuating circumstances that are likely to have contributed to Council E's better condition results, however describing these would reveal the Council's identity, breaching the ethical considerations associated with this study (Section 3.5).

[22] Council A and I did not supply construction dates with their condition data.

had done so not as part of a routine condition inspection program, but rather as a first-off attempt in recognition that their SCM asset knowledge was poor. This finding points to a deeper, more systemic problem concerning the management of SCMs by local government, introducing the possibility that SCMs are being managed in an *ad-hoc* fashion across Victoria.

Survey responses to Q2.1. (Table 4-4) are also generally consistent with findings of the condition audit data, indicating that council staff that participated in this study (respondents) do perceive SCM performance to be affected by maintenance related issues. Due to the low number of councils that provided both condition audit data and survey data, it is not possible to confirm this, but, on balance, the survey data suggests similar SCM conditions across all nine councils to those presented in Figure 4-1. Survey responses to Q2.2 (Table 4-5) indicate that this outcome is, at least in part, a function of systemic issues associated with the way in which participating councils are managing their SCMs. Most responses (84%) indicated shortcomings in SCM asset management at all eight councils, with only two respondents (5%) indicating that their council was meeting good practice. Therefore, the agreement between these two different data sources provides consistent evidence for short-comings in asset management practices that are likely to be, at least in part, contributing to the apparent low proportions of SCMs in good operational condition. Further, the consistency between the SCM audit data and the survey data indicates that a lack of practitioner awareness is not a contributing factor. In summary, the lack of available condition assessment data, the low proportions of assets found in good condition where this data was available, and the survey responses all support anecdotal evidence that SCMs are not being effectively maintained by local government in Victoria.

These findings have important environmental, financial and legal implications. While SCMs provide a range of other ancillary services to communities, such as aesthetics, habitat and urban cooling, their primary purpose is to protect local waterways. In the probable event that these findings are similar or worse across all Victorian councils, there is a discernible risk that a large proportion of SCMs are not performing optimally. Consequently, waterways may not be receiving the level of protection current adoption rates of SCMs would suggest, particularly over the long-term. This situation brings into question the return on the significant investments made by research bodies, the public sector (including local councils), and the private sectors into developing, promoting and establishing this new asset class over the past two to three decades. Further, it may also see many local councils at risk of being inconsistent with their environmental, social and economic responsibilities as stipulated in the Victorian *Local Government Act 1989*.

4.3 Part 2: Beyond Victoria

4.3.1 Results

As summarized in Table 4-6, the search strings used to find studies that included empirical evidence for SCM maintenance returned over 2,000 individual hits, of which 738 were considered relevant[23]. Of these 738 articles, only 11 studies provided empirical evidence for SCM maintenance (Table 4-7). They did so by via the collection and analysis of asset condition data and the adequacy of maintenance systems and processes of the asset owner. A much larger proportion of these 738 articles focused on other aspects of SCM maintenance or included maintenance only as a cursory issue. This included a large proportion of articles that focused on the effectiveness of various types of maintenance treatments for various types of operational SCM of varying ages. Other studies included advice or commentary on how to maintain different SCMs, while others included maintenance in the cost-benefit analysis of various types of SCMs. The literature search also found that those search strings that resulted

[23] Where searches exceeded 250 hits, only the first 250 articles were reviewed due to a significant decline in the number of relevant articles.

in high numbers of hits tended to show a significant decline in relevance after approximately 100 articles; hence, in such cases, only the first 250 articles were reviewed.

Published studies found to provide empirical evidence relating to SCM maintenance are listed in Table 4-7 along with their locale, methods and key findings. Five studies focused on a single public entity or city (Goonetilleke *et al.* 2011, Donnelly 2014, Al-Rubaei *et al.* 2015, Burns *et al.* 2015, Li 2015), whereas the others incorporated multiple locations and organisations within a given region (Schlüter *et al.* 2005, Drake *et al.* 2008, Erickson *et al.* 2009, Vandiver *et al.* 2009, Al-Rubaei *et al.* 2017, McDonald 2018). Data collection methods also varied between studies, some of which applied mixed methods to determine their findings. Six deployed various types of surveys targeting practitioners, typically within asset owner organisations (Drake *et al.* 2008, Erickson *et al.* 2009, Vandiver *et al.* 2009, Goonetilleke *et al.* 2011, Burns *et al.* 2015, McDonald 2018). Five collated and analysed asset condition data that they collected themselves or acquired from third parties (Schlüter *et al.* 2005, Goonetilleke *et al.* 2011, Donnelly 2014, Li 2015, Al-Rubaei *et al.* 2017). Three studies also incorporated the review of organisational documentation in their data set (Schlüter *et al.* 2005, Goonetilleke *et al.* 2011, Al-Rubaei *et al.* 2017). Only two studies employed in-situ monitoring of SCM performance parameters, one of which relied on the measurement of infiltration rates (Al-Rubaei *et al.* 2015) and the other incorporated some flow monitoring, but did not rely solely upon it (Schlüter *et al.* 2005).

Table 4-6: Search results by search strings as executed in order of appearance in the table (2004-2018)

Search String	Number of hits	Articles assessed†	Relevant articles found	New articlesΩ
Anywhere in article: "stormwater control measures" and "maintenance"	1,430	250	5	5
Title search: "stormwater" and "maintenance"	98	98	3	1
Title search: "SUDS" and "maintenance"	6	6	1	1
Title search: "LID" and "maintenance"	8	8	0	0
Title search: "Green infrastructure" and "maintenance"	11	11	0	0
Title search: "Best Management Practice" and "maintenance"	6	6	0	0
Title search: "WSUD" and "maintenance"	4	4	0	0
Title search: "Alternative Techniques" and "maintenance"	0	0	0	0
Title Search: "stormwater" and "asset management"	23	23	1	1
Anywhere in article: "Stormwater Control Measures" and "asset management"	15	15	1	0
Anywhere in article: "Stormwater Control Measures" and "maintenance considerations"	52	52	0	0
title search: "stormwater control measures" and "management"	5	5	0	0
title search: "stormwater control measures" and "operation"	2	2	0	0
Anywhere in article: "stormwater control measures" and "inadequate maintenance"	8	8	0	0
Anywhere in article: "Stormwater" and "Inadequate maintenance"	403	250	3	3

Table notes:
† - Where hits exceeded 250 articles, only the first 250 were assessed as relevance diminished because search settings were prioritised according to relevance.
Ω - This column excludes articles already identified by early searches.

4.3.2 Discussion

Despite the relatively low number of studies identified (Table 4-7), all came to similar conclusions to that found for Victoria by this study (Section 4.2). Further, these studies are not isolated to a given part of the world, but represent multiple jurisdictions, taking in parts of North America (Canada and the US), Europe, and Australia. They concluded that the SCMs within their study areas were either suffering from high proportions of assets in poor condition or were at risk of such a scenario, due to a lack of adequate maintenance. Studies that examined asset condition data found such results irrespective of their locale. This included high proportions of assets that showed clear signs of inadequate maintenance regimes, some of which were either significantly underperforming or had failed as a consequence (Goonetilleke *et al.* 2005, Schlüter *et al.* 2005, Donnelly 2014, Al-Rubaei *et al.* 2015, Li 2015).

In Sweden, for example, Al-Rubaei *et al.* (2015) identified that a "complete lack of adequate maintenance" was a key contributing factor to poor infiltration rates of SCMs. Similar sentiments have been raised in studies conducted in Australia (Goonetilleke *et al.* 2011, Burns *et al.* 2015), Scotland (Schlüter *et al.* 2005), the USA (Vandiver *et al.* 2009) and Canada (Drake *et al.* 2008). The only exception was a study conducted by Al-Rubaei *et al.* (2017), who inspected 25 ponds scattered across five cities in Sweden. However, while they found that most ponds required only minor maintenance, this was attributed to the age of the ponds rather than good maintenance practice, noting that "not all ponds surveyed were regularly inspected in a way that would contribute to ensuring their proper function" (Al-Rubaei *et al.* 2017, p. 05017001-9).

Many of the studies also found that most public entities exhibited significant shortcomings in SCM asset management that had either compromised existing SCM performance, or were putting their long-term function at risk (Schlüter *et al.* 2005, Drake *et al.* 2008, Erickson *et al.* 2009, Vandiver *et al.* 2009, Goonetilleke *et al.* 2011, Al-Rubaei *et al.* 2017, McDonald 2018). This included *ad-hoc* or non-existent asset condition auditing, a lack of asset registration, and poor asset information management and record keeping. The lack of regular condition auditing is particularly concerning, as it essentially renders organisations blind to their assets' needs, severely undermining their capacity to set up effective maintenance regimes (Section 2.3.1). Poor information management and record keeping is also a concerning factor as it often means maintenance managers do not have access to pertinent maintenance planning information such as design specifications, technical manuals, as-built drawings and bathymetric surveys. For example, McDonald (2018) concluded that in Scotland "improvements are needed for storing of information and all local authorities would benefit from moving to a digital record system" (p.13). Similar sentiments were echoed in Sweden by Al-Rubaei *et al.* (2017) who noted that due to missing information on basic pond characteristics and detailed design specifications, maintenance planning for activities such as sediment removal intervals had been compromised.

Table 4-7: Results of published literature search

Citation	Title	Methods	Locale	Relevant findings
Al-Rubaei et al. 2015	Long-term hydraulic performance of stormwater infiltration systems.	Field monitoring (infiltration rates).	Växjö, southern Sweden.	Significant risk to the function of existing infiltration systems in Växjö, Sweden due, in part, to a "complete lack of adequate maintenance." (page 670).
Al-Rubaei et al. 2017	Survey of the Operational Status of 25 Swedish Municipal Stormwater Management Ponds.	Asset condition inspection. Review of organisational records (maintenance).	Cities of Malmö, Örebro, Växjö, Umeå and Östersund, Sweden.	Nine ponds suffered from access issues that would prevent effective maintenance (five of which were excluded from the study as they could not be accessed on foot for inspection). Just over half required cleaning to remove sediment and litter. Several municipalities could not provide maintenance related information such as design specifications or as-built drawings.
Burns et al. 2015	Building capacity in low-impact drainage management through research collaboration.	Survey (workshop).	Melbourne, Australia.	Neglect of ongoing maintenance was found to be a key issue due to a lack of recognition of maintenance requirements and needs at the planning stage.
Schluter and Jefferies 2005	The real issue with in-ground SUDS in Scotland.	Asset condition inspection (directly collected and third party). Review of organisational records (maintenance procedures).	East Scotland.	Of the 46 systems included, no evidence of maintenance could be found for 39, with almost half being found in an unsatisfactory condition and half of those rated as having failed. Only 16% were found to be in good operational order. No routine maintenance programs were found to be in place, with maintenance being carried out *ad-hoc*, typically incident based.
Vandiver and Hernandez 2009	Assessment of stormwater management in coastal South Carolina: A focus on stormwater ponds and low impact development (LID) practices.	Survey (interviews and workshop).	South Carolina, USA.	Ponds were often neglected, with maintenance being cited most as a cause of operational issues (33%), in part due to pond failure not being immediately apparent, leading to maintenance being overlooked.
Li 2015	Green Infrastructure for Highway Stormwater Management: Field Investigation for Future Design, Maintenance, and Management Needs.	Asset condition inspection.	Maryland, USA.	51% of the systems inspected were found to require extensive maintenance due to inadequate maintenance. Of these systems, 17% were identified as poor (essentially no longer functioning).
Donnelly 2014	An investigation into the Stormwater Quality Treatment Practices.	Asset condition inspection.	Mackay Qld, Australia.	Of the seven systems inspected, six achieved a poor rating for at least one maintenance related criteria (of seven) and, of these, four were rated poor for more than three. No systems achieved a good rating.

Citation	Title	Methods	Locale	Relevant findings
Drake and Guo 2008	Maintenance of Wet Stormwater Ponds in Ontario.	Interviews (practitioners).	Ontario, Canada.	Many municipalities are not maintaining their ponds effectively, largely due to municipalities being uninformed as to the condition of their ponds due to a lack of monitoring programs. Overall, there was little uniformity between municipalities regarding pond management and most were unprepared for the maintenance needs of their aging ponds.
Erickson et al 2009	Survey of Stormwater BMP Maintenance Practices.	Survey (questionnaire).	Minnesota, USA.	Most (89%) of cities were performing inspection and maintenance activities at a frequency of once per year or less.
McDonald 2018	Sustainable Urban Drainage Systems (SUDS) in Scotland: Assessment of Monitoring and Maintenance within Local Authorities and Scottish Water.	Survey (questionnaire, telephone interview & email correspondence).	Scotland.	Maintenance of SCM was found to occur mostly on a reactive basis. SCM asset management practices were limited, with poor asset record keeping reducing potential for effective maintenance planning. Condition inspections were *ad-hoc* and generally inconsistent with the national guidelines†.
Goonetilleke et al 2011	Water Sensitive Urban Design (WSUD) application auditing.	Survey (questionnaire). Literature review. Asset condition inspection. Review of organisational records.	Gold Coast, Australia.	A lack of SCM condition auditing and maintenance emerged as a common theme among respondents. This was supported by the asset condition inspection as well as an earlier condition audit conducted by the subject council (Gold Coast City Council).

Table notes:

† - *The SuDS Manual*, Version 2 (Woods-Ballard *et al.* 2015)

4.4 Conclusions

The empirical evidence presented in this Chapter supports concerns that SCMs under the management of Victorian local government are not being effectively maintained. Despite being selected based on the likelihood of representing better practice than most Victorian councils, only three of the nine councils that participated in this part of the study were able to provide condition assessment data for their SCMs. Further, those three councils that were able to provide condition data had collected that data as a discrete project when it became apparent to internal staff that their council had not properly registered their growing SCM asset base. Therefore, none of the councils that participated in this study had yet established a formal asset inspection and condition auditing system for their SCMs; an essential component for effective maintenance planning (IPWEA 2011, AAMCoG 2012, LGV *et al.* 2015).

Responses to the closed-ended questions in the questionnaire mirror these findings (Section 4.2.2), indicating that council staff are aware that SCMs were not receiving sufficient maintenance and asset management processes were generally not well instituted for this purpose. Given the consistency between observed (condition assessment) and perceived (survey responses) SCM asset maintenance outcomes, a lack of awareness by council personnel is unlikely to be a causal factor in the under-maintenance of SCMs. Rather, the evidence suggests that immature asset management practices are, at least in part, responsible for these findings. Nonetheless, given the complexities associated with asset management in local government and the potential complex nature of the problem of SCM maintenance accordingly (Section 2.4), further investigation of causal factors is required to properly understand why SCMs are at risk of inadequate maintenance.

While limited in number, the consistency and geographical distribution of similar investigations in other parts of the world suggest that the problem of SCM under-maintenance is not limited to Victoria. Accordingly, it is therefore possible that at least some of the causal factors are not a function of the Victorian context, but rather, related to the technology itself and its status as a relatively new sustainability innovation. Reasons as to why so few studies exist that examine empirical evidence for SCM maintenance effectiveness by the organisations responsible for them is uncertain. Given that such assets are now becoming established in increasing numbers around the world (Madsen *et al.* 2017, Radcliffe 2019), this is somewhat surprising as maintenance management is known to be a key component of effective physical asset management, irrespective of type (Section 2.3.1). Given the importance that effective maintenance has regarding the long-term viability of any asset, prudence dictates that further studies are needed to understand why SCM owners and operators appear to be struggling with their maintenance. Otherwise, there remains a risk that the benefits intended by their implementation and the investments made accordingly will not be fully realised.

5 Barriers, Challenges and Intervention Pathways

5.1 Introduction

The findings detailed in Chapter 4 suggest SCMs are being under-maintained in Victoria. The purpose of this chapter is to explore why SCMs are vulnerable to under-maintenance and, based on these findings, postulate 'intervention-pathways' likely to ameliorate this situation. Importantly, given the explorative and inductive underpinnings of the research program, the findings presented herein are not claims of verification or 'truth' *per-se*. Rather, consistent with the Grounded Theory, they are propositions that are grounded in the survey data collected for this study and the analyses undertaken to address the research questions. Therefore, they provide an understanding of the problem of SCM maintenance that is based on the perspectives and experiences of local government professionals who are, in different ways, involved with the planning and execution of SCM maintenance in Victorian local government.

The Chapter begins by addressing Research Question 2 by providing an overview of the main findings of the Grounded Theory informed analysis of the survey data collected for this study (Section 3.10). It then delves into the specific barriers and challenges that led to the formulation of these findings. The Chapter then addresses Research Question 3 by first giving form and function to the problem of SCM under-maintenance by locating ('mapping') each barrier and challenge elicited onto a heuristic sociotechnical model developed specifically for this purpose (Section 3.11.2). The chapter then differentiates these barriers and challenges based on their relation to the innovation (SCMs) and Victorian local government SCM maintenance sociotechnical system ('the system') to give the sociotechnical model additional dimension (Section 3.11.3). As a final analysis, the chapter then presents the results of a word similarity analysis designed to reflect the tendency of respondents to identify cause and effect relationships between barriers and challenges (Section 3.11.4). The chapter then concludes by drawing together and reflecting upon the findings of each analysis to propose pathways likely to see the long-term improvement to SCM outcomes. Accordingly, and consistent with Grounded Theory, the findings presented herein are not claims of verification or 'truth' *per-se*, but rather postulations that are "grounded in data" (Glaser and Strauss 2006, P.33).

5.2 Barriers and Challenges to SCM Maintenance in Victorian Local Government (Research Question 2)

5.2.1 Overview

The analysis of interview transcripts and questionnaire responses ('the qualitative data set') produced 55 barriers and challenges ('concepts') across nine sociotechnical categories. Representing the collective experience and perspectives of the 54 respondents, such a wide range of barriers and challenges is consistent with SCM under-maintenance being a complex sociotechnical problem as postulated in Section 2.4. From these concepts and their categories, three over-arching issues contributing to the under-maintenance of SCMs in Victorian local government were abstracted. These are *Under-developed Industry*; *Policy Inertia*; and *Invisibility*. The abstraction of these over-arching issues resulted in the further abstraction of a final, over-all finding concerning the underlying cause of SCM maintenance. That is, the postulation that the problem of SCM maintenance is symptomatic of what has been conceived as '*Failure to Thrive'* scenario. The phrase '*Failure to Thrive*' postulates that the under-maintenance of SCMs is a result of SCMs falling short of achieving mainstream adoption as a stormwater management technology. Figure 5-1 summaries these findings, in the order of their abstraction from the qualitative data set.

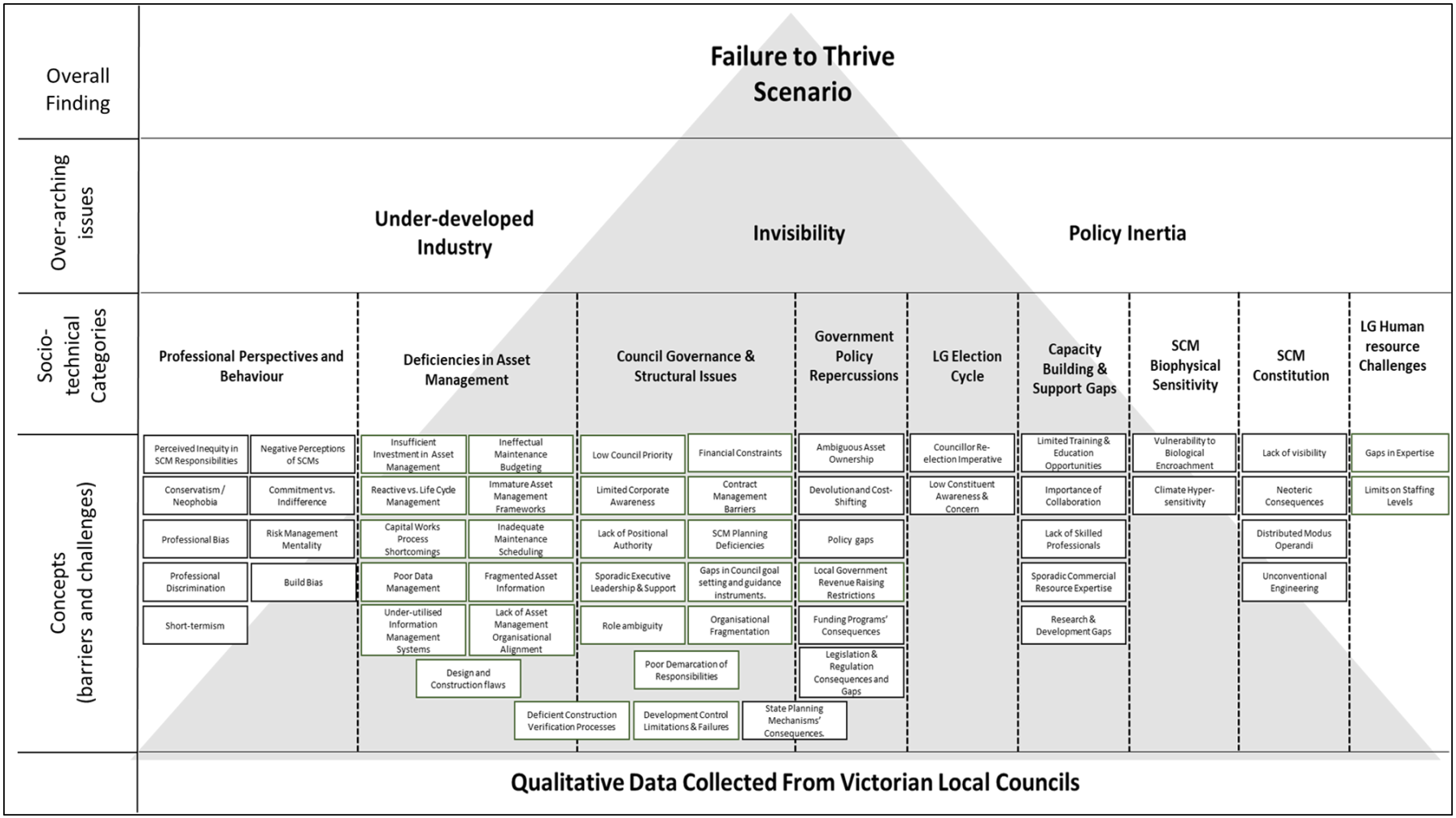


Figure 5-1: Grounded Theory Method analysis results of the qualitative data collected from local government in greater Melbourne, Victoria (LG = Local Government)

5.2.2 Concepts and Categories

5.2.2.1 Professional Perspectives and Behaviours

A key feature of sociotechnical systems thinking is the importance it affords the role subjectivity plays in human motivation and decision-making (Rogers 1962, Lazarus 1991, Venkatesh *et al.* 2000, Sabatier 2007). Accordingly, the category *Professional Perspectives and Behaviours* evolved from those concepts that reflect the subjective views and behaviours exhibited by respondents, or identified by respondents as being present within their organisation. Chief amongst these is the *Perceived Inequity in SCM Responsibilities*, which takes two distinct forms. The first captures concerns about who pays and who benefits. The current source for funding of SCM maintenance is via a council's general revenue (as is the case for most local government infrastructure). However, several respondents questioned whether or not local ratepayers should be solely contributing to the upkeep of SCMs given the benefits are often felt downstream.

> "Why should this community be paying for the water quality treatments for the rest of Melbourne downstream?" Particularly when its ability to pay is probably less than most other parts of Melbourne." (Respondent A1)

This was more pronounced in respondent commentary from councils where the average household income is below the Victorian median household income (Table 3-4). The second, and most persistent, was a belief that responsibility for waterway protection was the domain of state government.

> *"it is Melbourne Water's responsibility for water quality*." (Respondent E9)

Hence, some respondents felt that the inclusion of the 60 hectare convention in the Victorian Planning Provisions is legally questionable and an example of deliberate attempt at cost-shifting on behalf of the Victorian Government[24] (see also *Devolution and Cost Shifting*, section 5.2.2.4).

The concepts *Professional Bias* and *Conservatism / Neophobia* are concepts that have been identified by others in the sustainable technology transition scholarship (Rygaard *et al.* 2011, Marlow *et al.* 2013). The former refers to the tendency for people to favour solutions and practices that they are most familiar with and typically associate with their chosen profession.

> "*My understanding was some of these water sensitive design solutions in theory were supposed to be more cost effective. Certainly my experience in … and … that was the case. … Whereas, I hear the opposite here from our engineers that there's been a resistance... that traditionally the engineers have felt that, no, they've been more expensive. And especially long-term maintenance. … and you wonder sometimes .., whether it's just because there's a different way now that you have to maintain these things, and they haven't built that into their thinking or their work practices*." (Respondent C4-E)

The latter (*Conservatism / Neophobia*) refers to the tendency for some to resist new ideas due to concerns about how effective the new idea really is, how well the downsides of the new idea are really understood, or just because the new idea is contrary to the way things have always been done.

> *"… they're trying to change it [maintenance] from being a reactive to being proactive. And I think that's the hardest challenge with the old-school mentality."* (Respondent B9)

> *"… Old fashioned ideas about what infrastructure is for [is a barrier to council's effective management of their SCM operation and maintenance]".* (Respondent E4)

[24] The 60 hectare convention is now part of a broader review of urban stormwater institutional arrangements in Victoria (DELWP 2020).

It is noted, however, that not all respondents felt that *Professional Bias* and *Conservatism / Neophobia* was still a significant factor affecting SCM maintenance outcomes at their council. Rather, in some instances, respondents downplayed the relevance of such attitudes, often noting that while such issues had been a problem concerning the operation and maintenance of their SCMs at their council in the past, they were less of an issue now.

Risk Management Mentality refers to the adoption of a management style that consciously focuses on managing risks in order to avoid organisational liability, particularly in the areas of public safety, finance and reputation. Some respondents noted that because SCMs, when they fail, do so in a manner that is rarely perceptible (see *Lack of Visibility,* Section 5.2.2.8), reducing SCM maintenance is tempting when balancing financial constraints with public safety and reputational damage.

> "*So, if you talk to the people who do that asset management, they'll say that that's a soft area of Council if you're looking for savings. You can always take a few dollars out of the Asset Management System, or the operational side of things. If you're building more stuff and you're taking that stuff away, at some point you are going to hit a crisis, and it depends on what the nature of the crisis is as to whether anything is done about it. So if it's a biofilter that's clogged up and full of a bit of water, is that an issue really? As opposed to a pothole in the road, and someone hits it and wraps themselves around a tree?*" [Respondent C1]

Short-termism, referring to the favouring of short-term gains irrespective of long-term consequences, was also raised by some respondents.

> *So we look it and, say, we spend $20 million on your asset. But in reality that asset is going to have $40 million dollars' worth of maintenance and operating costs over ten years. But we are applying all the knowledge and effort to this first, front end and not worrying about the rest of it [operation, maintenance and renewal]. It's the short-termism."* (Respondent A2)

Emphasis was placed on the respective councils tending to focus on immediate concerns, such as completing projects and dealing with acute matters highly visible to the public (or at least their councillors), yet failing to consider long-term issues, particularly in terms of budget for ongoing maintenance and renewal.

Build Bias refers to respondent commentary concerning their council's excessive focus on building new infrastructure relative to maintaining existing infrastructure.

> "*There is some knowledge of it [insufficient maintenance] higher up, but it's not a particularly attractive / gratifying thing to resolve, so people don't do it. It is not like ribbon cutting!*" (Respondent D5)

> "*Look, maintenance is always going to struggle no matter - you've got councillors - everyone wants to be elected. People like doing new. To be quite honest I was a construction supervisor, designer and survey officer and I always said I'd never go to maintenance. I couldn't bear doing maintenance, just holding things together, just trying to find - it's just one of those jobs that you need a different mindset. You'd need to know you're not going to get the big thankyous. You're not there opening up new buildings. You're not doing any of that sort of stuff.*" (Respondent E6)

While bearing some similarity to *Short-termism*, it also brings into play elements of politics and self-interest. Respondents identified three possible reasons driving this bias within their council: (1) the desire of councillors to be seen delivering for the community, thereby increasing one's chances of re-election; (2) the desire to leave behind a legacy; and (3) the desire to increase council revenue by drawing on external funding. Also, bearing some resemblance to *Short-termism*, but relating specifically to attitudes to work, the concept *Commitment vs Indifference* refers to the mindset of those directly responsible for SCM maintenance. That is, the degree to which individuals and teams balance what they understand should be done against what is expected of them, where the latter shifts the balance towards indifference.

> *"It's variable. They [maintenance staff] do what they have got to do and don't think any more of it. But others get into it, so it is quite variable depending on the individuals."* (Respondent A4)

Due to the price-sensitive, competitive nature of contract tendering, this may be particularly problematic for councils that outsource SCM maintenance and lack the necessary expertise to effectively set up and manage SCM maintenance contracts.

> "*And also no one gives a shit internally because it's not our asset [responsibility of contractor]. The contractor - the guy will just mow up to the edge of it and then off they go. But I mean our staff are going to be, like, "Oh no, I'm not taking any weeds out of there.*" (Respondent F1)

The concept *Negative Perceptions of SCMs* speaks to two distinct issues raised by respondents. The first is negative perceptions about the effectiveness of SCMs to delivery on their intended services, with their ability to improve waterway health being most commonly mentioned.

> "*Because we did have one councillor that sort of said 'why are we even bothering for? I have been around and seen some of these things. They look horrible. They can't be doing anything. Let's just stop doing any of it'.*" (Respondent E2)

Such perceptions have been previously identified as barriers to adoption (Brown *et al.* 2009b, Winz *et al.* 2014, Madsen *et al.* 2017), though in this study it relates to motivation to undertake a task rather than deciding to adopt an innovation in the first instance. The second issue relates to perceptions on how amenable SCMs are to maintenance in terms of logistics, and their fit with existing expertise and equipment.

> "*I've got to put my hand on my heart and say I'm the one who stopped that [small roadside raingardens] because they're a maintenance nightmare and we were starting to get too many of them and we just weren't going to be able to manage them.*" (Respondent C2-E)

> "*So, having the skillset to identify the nature of the aquatic species, that they've been planted right, et cetera ... to actually assess the asset as fit for purpose at the front end, we have limited skills there. And then, managing that asset after the event, like taking it on under our control, putting in a regime that manages it to a point where you don't have to rebuild it. There's been plenty of examples in other areas in Victoria that I'm aware of where they had to rip it out and redo it because of siltation and the like, because it wasn't managed. That's our risk.*" (Respondent H1-E)

Respondents also noted other issues that contribute to the negative perceptions of SCMs and their maintenance. Some are attributed to issues with shortcomings in the design. That is, a failure to consider maintenance in design, such as forgetting to ensure future access to the assets (e.g. no easements) and the failure to consider issues such as allowing enough space to manoeuvre equipment (e.g. loaders or excavators) and facilitate access to personnel (e.g. walkways, access lids and confined spaces). Others relate to the inherent engineering of the various types of SCMs, such as the delicate nature of maintaining raingarden beds or specialised equipment for different types of proprietary gross pollutant traps. The distributed nature of the placement of SCMs at various locations within a catchment was also mentioned as creating logistical challenges for maintenance crews who had to access large numbers of small systems, particularly those located on roadways where traffic controls were necessary to ensure safe work. Several respondents further noted that negative perceptions towards maintenance are, to a large degree, a legacy of older designs that failed to adequately consider maintenance. However, other respondents noted that poor 'maintenance-in-design' and planning was still an issue with recently constructed systems.

Professional Discrimination refers to a tendency for a person's level of education, attitude and general intellectual capability to be assumed based on their position within the hierarchy and whether they were an 'office worker' or member of the 'outdoor staff'.

> *"Yes. I've read them[25]. I've used the information out of them in constructive emails to the Stormwater Team, to tell them that things aren't functioning like they should, according to these guidelines – to make it sound a little bit more official, and get them to understand I'm not as dumb as I am in fluoro [laughing]."* (Respondent B9)

Raised exclusively by respondents who held roles directly responsible for on-ground SCM maintenance work (i.e., outdoor staff occupying positions at the bottom of the hierarchy), this form of discrimination appears to manifest in two main ways. The first is the tendency of superiors to ignore, or at least fail to seek out, the experience of on-ground staff responsible for maintaining SCMs. The second is the tendency to exclude on-ground staff from vocational development opportunities, such as attending SCM related training courses, seminars and conferences.

> "*But we are not going to get funded to go. … Because part of the organisation probably sees that it is more important for the [team name removed in line with ethics approval] to attend [external training]. To justify paying us to go would be... [shrugs].*" (Respondent B5 – outside staff member)

As a result, respondents noted that their practical experience was not informing organisational or industry knowledge, and that a lack of training opportunities offered was affecting their capacity to keep up with industry advancements.

5.2.2.2 Deficiencies in Asset Management

The management of public infrastructure is a key function of local government and, as such, the practice of asset management is a major activity for local councils (Section 2.3). The category *Deficiencies in Asset Management* captures 11 concepts relating to shortcomings in local government asset management practices that are reducing SCM maintenance outcomes. Many of these concepts are not specifically associated with SCMs, but are systemic and ongoing issues with asset management within local government (Section 2.3.2). This situation is particularly evident by the concepts *Immature Asset Management Frameworks, Lack of Asset Management Organisational Alignment*, and *Under-utilised Information Management Systems*, all of which appear in reports and published articles concerning shortcomings in local government asset management practices (Section 2.3.2). These deeply systemic issues relate to *Insufficient Investment in Asset Management* mentioned by many respondents, influencing many of the concepts listed in Figure 5-1.

> *"… we do not have a comprehensive asset management system at Council and 16/17 is the first time we have received any money specifically to assist with maintenance. These funds do not cover the need for redesign and clean up, nor do they cover the full cost of litter collection and drainage/ hydrology and pump repairs [Stormwater Harvesting]."* (Respondent G1)

Inadequate Maintenance Scheduling was persistently raised by respondents as a key factor contributing to poor SCM maintenance outcomes at their council. Several of the other concepts captured under the category *Deficiencies in Asset Management* were raised as contributing to this problem. Chief amongst these was *Fragmented Asset Information* and the closely associated *Poor Data Management*.

> "*The experts … argue that a council should have one asset register that - but I would say our council, and most councils, do not have one asset register. What I mean by that is the maintenance team might have an asset register and the financial people might have an asset register. That causes difficulty*." (Respondent E9)

> "*That's the issue [with poor data management]. It's up to the council officer to store all that data there and put it in place. Whether they do or they don't … it comes down to the individual. There's not an*

[25] Melbourne Water's WSUD Maintenance Guidelines – A Guide for Asset Managers (MWC 2013)

automated process where it will happen. It still comes down to an individual making sure that occurs." (Respondent B2)

These two concepts suggest councils experience difficulty in managing the large volumes of data necessary to effectively manage their asset base, particularly regarding the collection, collation and storage of critical asset information. Respondents regularly stated that asset information, such as design and maintenance manuals, as-constructed drawings and even asset location (geospatial data) were often missing, and operational data such as maintenance activities and condition assessment rarely collected. Further, information that was collected was often not stored on centralised asset management information management systems, but rather *ad-hoc* on shared drives, personal computers and, in some cases, in hard copy (an example of *Organisational Fragmentation*, Section 5.2.2.3). Because of these deficiencies in asset knowledge and data management, *Ineffectual Maintenance Budgeting* is commonplace.

"*There are probably six wetlands. Probably two of them are covered by some sort of agreement. The other ones… So, let's say 60% [are not]. That's not because they are functioning properly or anything. We just don't have any formal process to recognise where they are and what's required. They've never been factored in the budget.*" (Respondent C1)

SCM *Design and Construction Flaws* were consistently noted as contributing to poor maintenance outcomes for SCMs, with a lack of access for people and equipment, and a general lack of consideration of 'maintenance-in-design' commonly cited by respondents.

"[Council A] has quite a lot of GPTs [Gross Pollutant Traps] that are not performing well. These were mostly installed by developers, and a recent audit of SCM performance identified that many of them were undersized or poorly designed for the catchment/location they were in. There were also issues with maintenance." (Respondent A1).

"*More consideration needs to be given at the design & construction phase of [SCM] systems as how maintenance can be achieved. Improved access for large plant, safer work zones ….*" (Respondent C8)

While a lack of expertise (both in-house and external) was often cited as a reason for poor design, so too were each council's *Capital Works Process Shortcomings* and *Deficiencies in Construction Verification Processes.* These two concepts speak to a failure to properly review designs from a maintenance perspective and the lack of inspections during construction works. The result of these two deficiencies is SCMs that are difficult to maintain or exhibit the need for high maintenance visitation rates. They also capture ineffective asset handover processes, where maintenance teams are simply told that there is a new asset with no further details, or are simply not advised at all.

"*… what I talked to you before about the lack of ability to correctly assess the plans – that also applies to the lack of ability to correctly assess the construction and the maintenance. So there's … no clear handover. It would be very similar to other councils. We don't really do it. …sometimes they [the SCMs] appear and we're like, "Oh, where'd that come from?" and no one really knows."* (Respondent E4)

Deficiencies in Construction Verification Processes are located aside the categories *Deficiencies in Asset Management* and *Council Governance & Structural Issues* in Figure 5-1 because deficiencies in the local government construction and verification processes also contribute to *Development Control Limitations & Failures.* Consequently, *Deficiencies in Construction and Verification Processes* may also be contributing to instances where councils are inheriting SCMs with similarly poor maintenance from developers.

5.2.2.3 Council Governance and Structural Issues

The category *Council Governance and Structural Issues* was evolved from 11 concepts that referred to issues concerning the centralised command, control and decision-making frameworks that underpin contemporary councils in Victoria (Figure 5-1). The concept *Low Council Priority* refers to consistent respondent commentary that SCMs were not considered a high priority within the councils.

> "*They [management] get it, to a level, yes. Certainly they're supportive and understand. They're not really pushing it. It's not particularly high on their agenda.*" (Respondent F2)

> "*The Council, if they had all of the drainage issues in front of them, they would be saying 'look after those people that are suffering hardship as a consequence of insufficient drainage infrastructure [rather] than doing the value-adding of what WSUD provides.*" (Respondent E3-E)

Multiple reasons for how this affects maintenance outcomes for SCMs were raised by respondents. Of those that come under the category *Council Governance and Structural Issues*, *Financial Constraints* was the most commonly noted. As discussed in Section 2.3.2, local government suffers from a persistent shortage of funding, with many councils at risk of being financially unsustainable (see also *Devolution and Cost Shifting* and *Local Government Revenue Raising Restrictions*, Section 5.2.2.4). As a consequence of being a *Low Council Priority*, SCMs are often one of the first areas to suffer cuts to maintenance funding to compensate for these *Financial Constraints*.

> "*So, by requiring that maintenance, there is finances involved and so if there were pressures on us financially, how this function would measure up or survive against others that would have to be reduced or scaled back, that would present a fairly significant risk to the [SCM] treatments."* (Respondent E3-3)

> "*We're now in a rate capped environment. So something's got to give. We've been given all these [SCM] assets that we need to maintain, but we're not necessarily given the rate base to be able to maintain those assets.*" (Respondent A5-E).

Limited Council Awareness, which refers to a general lack of awareness of SCMs and their purpose by those at the executive and councillor levels, was cited by respondents as contributing to the low prioritisation of SCMs by their council.

> "*Because the way it works here is – management above me isn't 100 percent aware of what goes on out there. They don't know enough. They need to know a lot more of what's going on [SCMs and stormwater drainage generally]. And if they did, I think things would be vastly different.*" (Respondent B2)

This concept was also attributed, in part, to *Sporadic Executive Leadership & Support*, referring to the reliance of SCM maintenance on informed and engaged executive level personnel. Respondents noted that such pro-active executive level leadership and support was relatively rare, leaving SCM maintenance to the mercy of individual executives within their council.

> "*Varying degrees of managerial support (& linked to this turnover of staff) that slows progress [improvements to SCM maintenance].*" (Respondent C1)

While the SCM scholarship points to a rise in SCM related expertise within local government (Eggleton *et al.* 2012), respondents also noted that personnel within council with SCM-related knowledge and expertise suffered from a *Lack of Positional Authority*. They typically occupied lower levels in organisational hierarchies, rarely above the status of team leader. Hence, such personnel had little direct power to influence organisational policy settings in favour of SCM maintenance.

"*… the sort of people that we had that are involved in water sensitive urban design here are at not even a coordinator level, they're … team leader levels and below. So it's never going to have the same profile that … water management issues would have in, say, a water authority.*" (Respondent A5-E)

The *Sporadic Executive Leadership & Support* and *Lack of Positional Authority* of SCM specialists appears to have resulted in *Gaps in Council Goal Setting and Guidance Instruments* (e.g. policy, plans and work procedures). Hence, SCM maintenance is often *ad-hoc* in both planning and execution.

"*I am actually talking about a bit more of the strategy type stuff as well. It is a bit more of, o.k., what is the intention of council? Are we going to have 10,000 of these [SCMs] assets in six years' time or are we going to have 5,000? Is Council strategy going to … include this [SCMs] in every single design that we do, or are we going to be more strategic about when we do it as part of designs. That is the sort of stuff we haven't finalised yet to say yep, we've got an asset management plan, we've done an audit, what is the plan for the future?*" (Respondent E2).

The concepts *Role Ambiguity* and *Poor Demarcation of Responsibilities* characterise how the structures of councils have not adapted well to the introduction of SCMs. The former captures consistent respondent commentary about positions not specifically allocated to the execution or planning of SCM maintenance tasks. Often such tasks were either taken up by personnel through their own volition, or allocated by front line managers, who noticed SCMs were not being maintained.

"*… clear roles/personnel need to be identified for maintenance of WSUD assets and then appropriate hands-on training provided, supported by inspection checklists linking back to the Asset Management System.*" (Respondent G4-P)

"As a development liaison, I'm supposed to be facilitating development and the interaction between council and developers and what have you. So WSUD – there's no mention of WSUD in my position description, however, I got involved in it and two or three years ago. We raised the issue." (Respondent F2)

Role Ambiguity was also identified as contributing to the failure of councils to recruit personnel with SCM-related maintenance skills and experience. Without clearly defined position descriptions, human resource departments did not develop the necessary selection criteria for specialist staff.

"*Operational staff Position Descriptions should include selection criteria that relates to knowledge, exposure, experience in WSUD maintenance.*" (Respondent B3)

Poor Demarcation of Responsibilities refers to confusion as to which department and teams were responsible for the ongoing management and maintenance of SCMs. Some respondents noted that due to the mix of green and grey infrastructure typically incorporated into SCMs, individual assets were often split between departments (e.g. Infrastructure and Parks & Gardens) or, in some cases, not assigned at all. Also, where SCMs were assigned to different departments, communication issues arising from *Organisational Fragmentation* mean that coordination of maintenance activities are severely hampered.

"*I think they're [SCMs] suffering because they're a bit more specialised and there's the cross in departments. I think the key to it is crossing multiple departments. There's that lack of clear line of responsibility.*" (Respondent A1)

Respondents from most councils also identified *SCM Planning Deficiencies* and *Development Control Limitations & Failures* as indirectly contributing to poor maintenance outcomes. The former refers to the planning of SCM systems delivered through local government capital works

programs. Respondents cited a lack of catchment-scale planning and consideration of surrounding land uses that resulted in the *ad-hoc* selection and placement of treatment types, creating logistical challenges for maintenance teams and leaving some systems exposed to incompatible land uses (e.g. sunken raingardens in carparks).

> "*Council's GPTs are generally performing poorly. Many are unsuited to their catchment e.g. undersized or are unsuitable for the particular site (e.g. on a gradient) or both. Some are completely inaccessible for any machinery. Some are adversely affected by downstream wetlands e.g. do not function due to backwater.*" (Respondent A6)

> "*So the road's no wider than this desk and when you get two cars trying to cross, one moves over and then lands in the actual WSUDs. So the community themselves ended up putting rocks in this WSUD*[26] *to try and keep people [safe] – if you did veer off into it you'd be caught because there's been that many tow trucks had to come and tow cars out.*" (Respondent G3)

The latter refers to the oversight of SCMs designed and constructed by developers that then become the responsibility of local government. Because councils are delegated consent authorities under state government planning powers, a council will often be the consent authorities for approving developer designed and built SCMs that they will eventually inherit. However, a lack of resources and oversight (e.g. construction inspections) by local government when performing this role appears to be resulting in councils inheriting SCMs that require excessive maintenance visitation rates, or are not conducive to easy and efficient maintenance.

> "*Developer-constructed assets are the 'unknowns' by and large – poor design and/or construction – no internal expertise in the past to assess drainage designs from developers for WQ [water quality] systems; compounded by these assets being inherited by Council at [the] end of [the] defects liability period with little knowledge of system status …*" (Respondent B3)

> "*Resources [are lacking] - not having adequate resources to afford the time to thoroughly assess SCM's and provide in-depth input.*" (Respondent C3)

Also captured by the concept of *Development Control Limitations & Failures* is the limits on the powers afforded to local government in their role as consent authorities, and the power that the state government has in overriding their decisions (see also *State Planning Mechanisms' Consequences*, Section 5.2.2.4). Therefore, despite being the consent authority, councils are not necessarily in a position to dictate what developers install and, as a consequence, what they (the council) will inherit when the asset is handed over to council.

> *"We can't actually force people to do a specific type of WSUD [Water Sensitive Urban Design] because they could just say no and take it to VCAT [Victorian Civil & Administrative Tribunal], unless we change the planning scheme, which no-one is going to want to do. … this is a huge problem.*" (Respondent E4)

Respondents also noted that, due to poor handover procedures, SCMs acquired by their council from developers were often passed onto council maintenance teams with no supporting information, or were simply not passed on at all. Respondents put this issue primarily down to systemic communication failure within their council, associated with *Organisational Fragmentation,* which is known to manifest in multi-departmental and geographically-distributed organisations (Tett 2015).

> "*A lot of them [SCMs] came online in the early days and the maintenance side of the world didn't actually know they existed, didn't know they were getting developed, so when it came to handover it*

[26] WSUD – Water Sensitive Urban Design, a term often used to refer to SCMs in Australia (Fletcher *et al*., 2014)

didn't happen or it happened pretty poorly and had to be absorbed within the current resources of the area, which still happens to a degree now." (Respondent G2)

Organisational Fragmentation was also identified as contributing to internal issues around the ongoing asset management and maintenance of infrastructure, including SCMs.

"*Everyone is just looking after their little patch, and sometimes there just isn't that communication between the various departments … There's also the issue specific to our council, where we've got the engineering section remotely located from the main building. So, that communication is, again, hindered in part …*" (Respondent C3)

The concept *Contract Management Barriers* concerns councils that outsource their infrastructure maintenance to contractors. Respondents noted that while SCMs tended to be more vulnerable, a lack of oversight of maintenance contractors applied generally across all asset classes. This lack of oversight is attributed to shortcomings in council contractor management protocols and restrictions on staff recruitment that have resulted in over-stretched council contract managers.

"*We do exception reporting rather than reporting on what is actually happening. Our maintenance contracts are set up so the service provider provides us with an annual service plan telling us how they are going to deliver their contract outcomes for that particular contract year. … All that is in the annual service plan. And through their reporting to us, we'll just say, "have you undertaken stormwater maintenance activities in accordance with the annual service plan" and that's it. Yes / no. And it's then an exception report. So if they say "no, we haven't undertaken", they're made to list what they haven't done. Now they always say, "yes they have". Now, are we 100% confident that that is the case? There is a lot of trust. So we are trusting them, and we do a lot of spot checking.*" (Respondent D6)

The particular vulnerability of SCMs is attributed to the highly variable quality of contractor SCM expertise and the difficulty recruiting contractor managers who are familiar with SCMs. Respondents also noted that where primary contractors were engaged to manage large parts of, or all of, a council's infrastructure maintenance, the practice of managing costs via subcontracting risked SCM maintenance being undertaken by contractors that were not properly checked for expertise.

"*Whereas with the contractor, and particularly sub-contractors, you might have the opportunity to talk to that sub-contractor, but there is not a guarantee that he or she will be doing that work again in a month's time because they might engage someone else. So, that's the big downside of it. I am guessing the benefit (of contracting maintenance out) should be that there's reduced costs and liabilities for Council. But, from a maintenance point of view, often there is more downsides than upsides and I hear that from lots of different parts of Council in terms of contracting stuff out. There is less checks and balances and less communication.*" (Respondent D5)

5.2.2.4 Government Policy Repercussions

Abstracted from seven concepts (Figure 5-1), *Government Policy Repercussions* captures a range of ways that, according to respondents, mostly State government policy impacts on SCM maintenance outcomes. The concept *State Planning Mechanisms' Consequences* is shown as sitting across the categories *Government Policy Repercussions* and *Council Governance & Structural Issues*) because of the role local government plays in acting on behalf of state government to oversee new land developments (see also *Development Control Limitations & Failures*, Section 5.2.2.3). Many respondents noted that due to changes to Clause 56 of the Victorian Planning Provisions (Section 2.3.3), state government planning policy was forcing local government's hand in taking up SCMs. Several respondents, irrespective of position, argued that this requirement was putting an unfair imposition on local councils due to limited

state government policy support in the areas of capacity building and revenue raising for the ongoing management and maintenance of SCMs.

> "*It is great that Clause 56 came about [Victorian Planning Provisions]. … Clause 56 [specifically, 56.07 Integrated Water Management] was a gift and it came out but the whole processes and how that mechanism works was not thought through. So state policy came out, threw it into the VPPs [Victorian Planning Provisions], planning schemes in every local council picked it up, made it real: 'o.k., no worries, we'll start implementing what you ask us to'. No training for the staff, they don't know what they are asking for. They are looking at design drawings and they don't even know if the design drawing is right.*" (Respondent B3)

The concept *Devolution and Cost Shifting* refers to the democratic and political machinations in state government that see state government shift their responsibilities and costs onto local government (Section 2.3.2). Some respondents suggested that the inclusion of Clause 56.07 in the Victorian Planning Provisions is an attempt by state government to shift their responsibilities and costs for waterway protection onto local government. Irrespective of the veracity of such claims, commentary suggests that changes to the Victorian Planning Provisions have created some discontent towards SCM within local councils (see *Perceived Inequity in SCM Responsibilities*, Section 5.2.2).

> "*The other thing, too, is I think creating these treatments is more a Melbourne Water objective than a Council objective, but the council is then left with the ongoing maintenance responsibility, so rate payers are then having to pick up that cost.*" (Respondent E3-E)

> "*… State & Federal Government cost shifting. No funding for management or maintenance - just design, construction (for some WSUD projects) & education.*" (Respondent G1)

The concept *Local Government Revenue Raising Restrictions* refers to both the general restrictions placed on councils to raise revenue and the specific avenues for raising revenue for stormwater management. Regarding the former, many respondents raised concerns about the passing of Victorian legislation in 2015 that capped council rates (ESC 2018, LGV 2018). Some respondents noted that this legislation was a function of the delivery of an election promise made by the Labor party leading up to the 2014 Victorian state election, which it subsequently won. This claim by respondents can be verified based on media releases by the Labor government since its introduction (Hutchins MP 2015, Kairouz MP 2017).

> "*Because it's popular. It's interesting; we've got an ALP government – state government – they took rate capping to the state government election as a mandate. I think local government's a good kicking – you know. I think it's easy to believe the hoo-ha*[27] *about local government, you know – 3AW* [28] *– all resting on our shovels*[29]*. I don't think people appreciate the complexity of local government, and the level of infrastructure they actually have to manage.*" (Respondent G1)

Respondent commentary consistently noted that Victorian local governments have no means of raising additional revenue to cover costs associated with SCMs inherited under the Victorian Planning Provisions. This commentary also indicated that this situation is contributing to negative perceptions towards existing planning mechanisms that require councils to acquire developer built SCMs (see also *Perceived Inequity in SCM Responsibilities*, Section 5.2.2).

> "*State government are the ones saying, "Oh councils can't increase rates." But they are putting stuff in the planning scheme and telling us we're not allowed to ask for money to cover it. Gee, it's pretty dumb, I mean, if you really think about it.*" (Respondent F1)

[27] An Australian Colloquialism for a commotion or fuss
[28] Talk back radio station in Melbourne, Victoria.
[29] An Australian Colloquialism for laziness, particular when used in relation to the workplace.

It is noted that unlike New South Wales (NSW)[30], the Victorian state government provides no specific mechanism through which they can raise additional revenue for stormwater management. But The Victorian *Local Government Act 1989* may allow additional revenue for SCM maintenance to be raised via the *Service rate and service charge* (s162) or the *Special rate and special charge* (s163). However, no examples of a council using these clauses could be found and, therefore, the legality of doing so could not be verified.

Somewhat paradoxically, the concept *Funding Program Consequences* was also identified by respondents as being responsible for contributing to poor SCM maintenance outcomes. A commonly-cited example was the sole focus of state government SCM-related funding programs on capital works projects (i.e., the design and construction of new SCMs), without having the ability to contribute to the costs of ongoing maintenance of these assets. Therefore, some respondents perceived such funding to be another example of state government engaging in *Devolution and Cost Shifting*.

> "*Someone will go to the Victorian government and they'll say we want this little project happening. They'll give them some money. The project will take place. Then all of a sudden it will be devolved down to council to continue to run without any funding. It was never a council priority. It was never a council function but of course the state government gave it money for one year or two years and now Council's got to adopt it and this happens time and time and time again. This is where a lot of money gets lost in councils.*" (Respondent G3)

It was also noted by some respondents that state government funding programs sometimes come with short submission and project completion times. These tight schedules were, in part, blamed for poorly designed and constructed SCMs that hampered maintenance activities or required excessive visitation rates.

> "*We've got a couple of examples where, because of the relationships that particularly my previous director had with the people at Melbourne Water, when they were trying to get funding out the door, they were struggling. So, [Council C] can do something. That was top level, but it was rushed out. "Here's some money. Build, build, build.*"" (Respondent C1)

The concept *Policy Gaps* refers to a general absence of policy that specifically recognises the role of SCMs in improving urban aesthetics and protecting waterway health. As a consequence, there are currently few policy instruments that local councils and their employees can draw on to promote the effective upkeep of SCMs and justify the diversion of funding accordingly. Reasons stated for this centre around an absence of awareness of SCMs within state government, made more acute by constant changes in state government departments and cut backs in relevant departments.

> "*We don't get anything from State Government. We just get more requests for assistance to comment on policy documents and whatever else documents they have got. But we don't get anything from them, we just get more work requirements and more advocacy opportunities to state the case yet again. But we don't get anything from them as such. …. Not support in terms of doing, achieving. Just support in terms of they see where the momentum and the campaign has come from and is going, and going to achieve. They hear what the practitioners are saying and it is almost like policy is now trying to catch up with reality, but it is more us servicing them because there's no knowledge, serious lack of knowledge at a state level.*" (Respondent B3)

[30] NSW has a 'Stormwater Management Service Charge' that councils, if they wish, may charge residents in addition to their general rates.

Related to *Policy Gaps*, the concept *Legislation and Regulation Gaps* refers to respondent commentary concerning gaps in, and the disjointed nature of, stormwater legislation that governs stormwater management in Victoria[31].

> "*Lack of state government policy, I would say you could put in there. Clear state government policy around stormwater control. I mean, it's – they have – like I've said before, they have these principles but there's no enforceable guidelines or rules.*" (Respondent E4)

Unlike roads, stormwater drainage infrastructure has no legislation that requires councils to develop asset management strategies and plans, and there are currently no state or federal regulatory bodies that pro-actively monitor council performance concerning waterway protection. Respondents note that there are few levers available to council staff interested in improving their performance regarding the maintenance of SCMs.

> "*… we've got to get that as well, but we actually have, because the road management plan and road management act[32], you've got requirements to do inspect, etcetera…. Inspect, maintain, and repair are requirements of the Road Management Act. So, because there is an Act for that, that has forced council to spend the time and effort to do it. There is no Act for stuff that is under the ground [referring to stormwater]. The drains and that sort of thing is not covered by that.*" (Respondent E2)

Some respondents noted that ambiguity in relation to subdivision legislative[33] was also creating SCM maintenance problems. Ambiguity concerning handover periods and responsibilities of developers was cited as reasons for SCMs being acquired by councils that had not been properly maintained, were poorly constructed or were not designed well for maintenance. Some respondents also note that this problem was being aggravated by their own council due to a lack of oversight during planning, design and construction phases (see also *Deficient Construction Verification Processes*, Section 5.2.2.2, and *Development Control Limitations & Failures*, Section 5.2.2.3)

Finally, the concept *Ambiguous Asset Ownership* is less an issue of policy or politics, and more one of collaboration and information sharing between state government agencies (e.g. Melbourne Water) and local government. It refers to the difficulty respondents noted at identifying where their local government's responsibilities ended, and Melbourne Water's started. This ambiguity was put down to the 60-hectare convention (Section 2.3.3) and the difficulty accessing precise geospatial information from Melbourne Water delineating responsibilities between the organisations.

> "*We had situations where demarcation was unclear. This asset here looked, for all intents and purposes, the same as that asset over there, but this one would be ours and the other theirs [Melbourne Water's]. And if maintenance isn't done on this one, if affects that one; and if maintenance isn't done on that one, it affects this one.*" (Respondent A2)

5.2.2.5 Local Government Election Cycle

In Victoria, the policy direction of a given council is set by its councillors, who are elected by residents located within the respective Local Government Area (Victorian Government 2020). The category *Local Government Election Cycle*, and its two concepts: *Councillor Re-election Imperative* and *Low Constituent Awareness & Concern*, illuminate an important link between a council's policy priorities, those issues that constituents consider most important, and the desire of politicians to be re-elected.

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[31] A discussion on stormwater legislation is provided in Chapter 2, Section 2.3.3.
[32] Victoria *Road Management Act 2004*
[33] Victorian *Subdivision Act 1988*.

> "*I was meaning if the community was expressing any interest, … it's not something that's really at the forefront here [stormwater quality]. Like I said, that may change with a change of council. If you have a councillor who is more willing to stand up and talk about this as an important issue and … tie it in a bit more with environmental issues, that it might get some more traction. Where … the council plan is full of actions that the council has identified where they think the priorities are. If it doesn't get a mention there, it's kind of hard to get extra funding for it.*" (Respondent A1).

Where SCMs are concerned, respondents consistently noted their local community was generally unaware of SCMs and what purpose they served (see also *Lack of Visibility*, Section 5.2.2.8). Moreover, respondents noted that while their local community may be generally in favour of protecting the environment, other issues such as affordable housing, community services, well maintained roads and local employment tended to take precedence. This was particularly so for councils identified as *Partially Committed* to Water Sensitive Urban Design (Table 3-3), which also tend to be councils where SCMs are rapidly established via greenfield residential development.

> "*[Stormwater is] probably much higher [in priority] than in other municipalities I've worked at because of the lake and the desire to use every skerrick of water efficiently to maintain those sorts of assets. It probably has a higher rating than some municipalities, but it's still lower than the visible road, building, et cetera. …*" (Respondent H1-E)

In essence, respondents noted that unless constituents made it known to the council that something mattered to them, it simply did not receive attention from councillors and, consequently, did not receive attention in the council's planning and policy instruments.

5.2.2.6 Capacity Building and Support Gaps

Key to ensuring the effective adoption of new innovations is putting the necessary support mechanisms in place. The concepts that evolved the category *Capacity Building and Support Gaps* indicate that the stormwater industry is yet to effectively develop such mechanisms. The concept *Limited Training & Education Opportunities* was generated from commentary that external opportunities for developing staff knowledge and skills were very limited. While respondents noted that courses were available (e.g., Melbourne Water's Clearwater program), they were considered to be mostly rudimentary in nature, to run for no more than a few days, and to tend to focus on introductory level functionality and design, with very few offering maintenance based training. A small number of respondents noted that they had attended or knew of courses offered by private companies that did include SCM maintenance, but these were also short courses and tended to be prohibitively expensive. When respondents were asked if they knew of any tertiary level courses that incorporated detailed SCM programs, all answered that they did not know of any such courses.

> "*I've had a look through the reputable TAFEs[34] and haven't found a great deal. … and haven't really come up with something that I feel would satisfy me and then would satisfy the requirements. I just don't want to do a horticultural course. You want to do something that's designed around WSUD [SCM] management.*" (Respondent B1).

> "*We did do the Clearwater Maintenance course that they offer. …we had them come out here and talk to … our gardeners and drainage maintenance staff that we do have. That helped a little bit, but it was just a half day."* (Respondent E1)

This perspective of a lack of capacity development is also reflected in the concepts *Lack of Skilled Professionals* and *Sporadic Commercial Resource Expertise.* The former refers to the difficulty councils appear to face when trying to recruit people with skills that relate to the

[34] TAFE - Technical and Further Education institutions

management of SCMs from the external job market. Respondents noted that this difficulty often resulted in the recruitment of personnel with indirectly relatable skills and qualifications (e.g. horticulture). The latter refers to a high variability in quality between companies offering SCM-related services (e.g. design and maintenance). Several respondents noted that they or their council had resorted to training contractor staff themselves in order to redress this gap.

> "*I think it's difficult [to recruit skilled people]. Yes, I'd still think the knowledge externally isn't great with them either unless it's something that is a focus of yours. I don't think the knowledge is great within the sector. The whole philosophy of what the purpose of them are and what they do …*" (Respondent G2)

> "*Yeah, knowledge and experience, and having done it before [is the main issue with contractors]. So, I guess even more so than being the contractor, it is often then sub-contracted within that contract. So, we'll have a head contractor, rarely will they have … But for SCM maintenance there is not a bunch of companies to go to, to do it. … there is not a bunch of small ones like there would be if you wanted to replace bluestone kerb, you've probably got half a dozen companies to go to. To pave a road, you've probably got twenty or thirty companies to go to. For this [SCM maintenance] you've barely got one company to go to.*" (Respondent D5)

Contributing to this outcome is the concept of *Research & Development Gaps*. This concept refers to a lack of research into the long-term performance of SCMs and the identification and frequency of their maintenance. Consequently, guidelines and standards on the long-term management of SCMs, where they exist, tend to be high level in nature and lack the detail respondents indicate as necessary to adequately plan, budget for, and undertake maintenance with confidence.

> "*I am worried that long-term performance of these assets with regard to their ability to treat stormwater is not well understood, and that Councils may have large liabilities in the future for maintenance/renewal etc.*" (Respondent F1)

> "*[In reference to "Melbourne Water's WSUD Maintenance Guidelines – A Guide for Asset Managers"] Again it's that detail that I was talking about that's still lacking from my perspective and it's about really delving into what maintenance is required, at what level, scheduling costs and that side of it. Whilst it covers it from a higher level perspective, we really need to delve into that more I think to understand it so we can better manage them in the future.*" (Respondent G2)

The final concept captured by the category *Capacity Building and Support Gaps* acknowledges respondents consistently noting the positive impact that collaboration with other entities (e.g. universities, government agencies, industry bodies and commercial entities) had on attitudes towards, and integration of, SCMs at their council. Given the label *Communities of Practice*, respondents also noted that such collaboration was pivotal in helping to raise awareness and transforming attitudes of executive management and councillors.

> "*The partnership we have with Melbourne Water and the universities has been exceptionally good. We would not be where we are at if it was not for that partnership and support. So, if that was to be diminished or stopped, then that could be a threat to the ongoing longevity of these treatments.*" (Respondent E3-E)

The term *Communities of Practice* is an established term, referring to groups of people or organisations who, sharing a common interest or goal, come together collaboratively to learn and problem solve together (Wenger 1999). The elicitation of this concept from the survey data reflects relatively recent work by Brodnik *et al.* (2018), which found that communities of practice played an important role in transforming capacity in stormwater management in Melbourne, particularly in the areas of experimentation, training and skill development, and vision and narrative setting.

5.2.2.7 SCM Biophysical Sensitivity

While all physical infrastructure is, to some degree, affected by its biophysical surroundings, SCMs are appreciably so due to the incorporation of green engineering (i.e. functional vegetation, filter media and water columns). *Vulnerability to Biological Encroachment* refers to invasion from undesirable living organisms, in particular fast-growing flora species within the functional green components. Such invasions can lead to increased maintenance needs as, without control, they can lead to loss of functional vegetation, reduced water retention capacity and draw negative attention from residents (e.g. unsightliness and the presence of vermin).

> "*The natives and weeds flourish in these systems [SCMs], which is great for habitat, but it is more challenging to manage the weeds, as the water flows are constantly changing. In those systems some of the weeds are impossible to control and much money could be wasted trying. As they are surrounded by weedy degraded sites, it is not possible to eradicate weeds, as they are constantly coming in from birds, floods or by the wind.*" (Respondent B5)

In contrast, *Climate Hyper-sensitivity* refers to the sensitivity of functional vegetation and filtration media to changes in weather patterns. For example, periods of dry weather can lead to the drying out of wet areas and functional plant loss, while periods of intense rain can erode filter media and quickly fill smaller systems with detritus. Therefore, the effective management of SCMs may not solely rest with routine inspection and maintenance programs, but will also likely require inspection and maintenance programs that are adaptive to prevailing weather conditions. This not only presents logistical challenges, but also requires appropriately skilled personnel who are able to implement adaptive maintenance strategies.

> "*… for example, this side of town will be very different to the western side of town, in the way we manage [SCM] assets because of different rain patterns.*" (Respondent B1)

5.2.2.8 SCM Constitution

SCM Constitution refers to the characteristics specific to the technology itself, i.e., their physical engineering, the philosophy behind their development, how they manifest in their operational environment, and their status as a 'new thing'. The concepts captured under this category speak to how these intrinsic factors impact on their maintenance outcomes. Of these five concepts, *Lack of Visibility* was raised most often by respondents as being a barrier to effective SCM maintenance outcomes.

> "*I don't think things are always visible. The [SCM] problems aren't always visible. You don't necessarily notice that a GPT [gross pollutant trap] isn't functioning at all. You certainly notice a road full of potholes. And so does a councillor. So you get way more complaints in that instance [potholes in roads].*" (Respondent A6)

The use of green engineering techniques makes SCMs particularly amenable to blending into the urban landscape, and they are often designed to appear as something else (e.g. a garden or water feature) for reasons of improving urban aesthetics and biodiversity (Wong *et al.* 2009, de Haan *et al.* 2014, Baptiste *et al.* 2015). Even gross pollutant traps, which don't incorporate green engineering, are increasingly being constructed underground to enhance public safety and to hide the unsightly build-up of gross pollutants. To protect delicate SCM components (e.g. macrophyte zones) and to avoid becoming a public nuisance or hazard, SCMs are also designed to 'by-pass' when they reach maximum treatment capacity or when they fail (Healthy Waterways 2006, Landcom 2009b, MWC 2017a). While the intent of this invisibility has merit, respondents consistently indicated that this design philosophy plays a significant role in poor maintenance outcomes for SCM by contributing to *Low Constituent Awareness* (Section 5.2.2.5). Unlike other public infrastructure, such as roads and drainage, which produce highly

visible and often inconvenient consequences when they fail, the outward appearance of SCMs rarely look any different to the casual observer irrespective of their operational status.

The concept *Unconventional Engineering* relates to how the unique mix of green and grey engineering of SCMs impacts on maintenance outcomes. Respondents consistently noted that due to a combination of civil and environmental engineering, SCMs struggle to find a natural fit within conventional local government organisational structures. Therefore, the respective grey and green components are sometimes allocated to different departments, bringing into play issues associated with *Organisational Fragmentation* (Section 5.2.2.3), or are simply passed from one department to another without formal recognition of ownership (see also *Poor Demarcation of Responsibilities*, Section 5.2.2.3).

For reasons such as limited space in existing developments, maximising lot yield in new developments, and to protect tributaries higher up in catchments, SCMs are generally distributed throughout a catchment rather than relying on a small number of large 'end-of-pipe' solutions. However, respondents note that this distributed operational approach brings with it certain maintenance-related challenges for a council. Captured by the concept *Distributed Modus Operandi*, these issues include increased maintenance frequencies, due to smaller size and higher number of systems, and the logistical challenges associated with the proliferation of small systems across large areas.

> "*That's all based on water sensitive urban design principles. We have, like some councils, we did start doing on some of our road upgrades, the localised little mini treatment areas associated with site intricates [kerb guttering, and nature strips]. I've got to put my hand on my heart and say I'm the one who stopped that because they're a maintenance nightmare. And we were starting to get too many of them, and we just weren't going to be able to manage them.*" (Respondent C2-E)

Finally, the concept *Neoteric Consequences* captures maintenance barriers that some respondents noted were attributable to the relative 'newness' of SCMs as a technology. For example, the tendency of people to resist new ideas because they are new and, therefore, an unknown quantity (Juma 2016). Also noted was the time lag between innovation take-off and the establishment of the required industry and professional knowledge to effectively operate and maintain the technology (Borrás *et al.* 2015). The tendency for people to resist new ideas finds commonality with concepts *Conservatism / Neophobia*; *Professional Bias* and *Negative Perceptions of SCMs* (Section 5.2.2). The time lag between innovation take off and the establishment of industry and professional knowledge finds commonality with the concepts *Research & Development Gaps* and *Lack of Skilled Personnel* (Section 5.2.2.6).

> "*Resourcing and finances is definitely a risk because if they are not maintained then they will go into decline. They will silt up and they will stop functioning. And so there'll be tens, hundreds of thousands of dollars invested into these treatments that, if they stop working, then we have got no ongoing outcome, have we. Because they are also a relatively new type of treatment, the maintenance framework is still evolving.*" (Respondent E3-E).

5.2.2.9 Local Government Human Resource Challenges

The concepts *Gaps in Expertise* and *Limits on Staffing Levels* that make up this category attracted more commentary from respondents than any other concept. *Gaps in Expertise* refers to consistent respondent statements concerning the existing of large gaps between the skills needed to ensure SCMs are effectively maintained and what currently exists at their council.

> "*But it's then understanding the whole maintenance requirements behind it and we're not there yet. We don't understand it.*" (Respondent G2)

Respondents noted that their councils lacked the skills required to plan maintenance, execute maintenance, or manage contractors to do the same. It was also noted that councils often

lacked the necessary skills to oversee the design, construction and handover of maintenance-friendly SCMs assets (see also *Deficient Construction Verification Processes*, Section 5.2.2.2), affecting their SCM related capital works programs and their council's capacity to oversee the delivery of SCMs by developers.

> "*I'd say it is a really a big problem. Our list of things is not very clear. And that stuff – what I talked to you before about the lack of ability to correctly assess the plans – that also applies to the lack of ability to correctly assess the construction and the maintenance so there's not really a – there's no clear handover.*" (Respondent E4)

Some respondents noted that even where such skills and experience did exist, they were often not in positions where those skills could be fully realised (see also *Role Ambiguity* and *Lack of Positional Authority*, Section 5.2.2.3).

Limits on Staffing Levels refers to the consistent statements from respondents concerning the general stretched nature of personnel at their council, and that this is leading to the under-allocation of staff to SCM maintenance relative to other tasks deemed more important. Therefore, this concept finds commonality with *Low Council Priority* (Section 5.2.2.3) and *Risk Management Mentality* (5.2.2).

> "*I mean, we used to do a bit of the other stormwater management systems, but we've really backed off on that, just due to resourcing, probably over the past two years. We've had a few people off and away – long term employees are no longer here, so we've lost a few resources that haven't been backfilled yet – so that [SCM maintenance] was one thing that I've want to let slip. There's usually two of us working this department; we've probably had 1.3 for two years. So, a few things had to get let slip.*" (Respondent B2)

Even in cases where such caps were circumvented by outsourcing infrastructure maintenance activities, they still impacted on the number of personnel available to effectively manage contracts (SCMs or otherwise). This lack of contract managers and limited expertise mean SCMs are particularly vulnerable to under-maintenance, even where outsourcing is applied.

> "*Again, it is an added extra. I do them [SCM condition inspections] when I can, but it is quite patchy. But no-one else does, so, again, it's a missing thing within Council. Even if we contracted out to our various contractors, you still need someone [to follow up] because it is fairly new technology, you still want someone to check and our contract managers don't have time. It is really only me in my very long list of in my PD [position description] tasks to date*." (Respondent D4)

Some respondents further noted that even where opportunities arise to recruit personnel specifically for SCM management and maintenance activities, finding appropriately qualified and experienced personnel was also a challenge (see *Capacity Building and Support Gaps*, Section 5.2.2.6).

5.2.3 Over-arching Issues

By encapsulating the essence of all 55 concepts, the three over-arching issues describe the key areas causing under-maintenance of SCMs in Victorian Local Government, based on the collective perspectives of the respondents. The first over-arching, *Under-developed Industry*, refers to the current state of the stormwater industry. It implies that the industry that supports stormwater management within Victoria has not yet sufficiently developed, lacking the capacity to support SCM asset management, including maintenance and renewal. The category *Capacity Building and Support Gaps* played a key role in the derivation of this over-arching issue. For example, the concept *Limited Training & Education Opportunities*, suggests a lack of SCM maintenance related vocational courses and an apparent absence of sustainable stormwater management in tertiary education programs is contributing to a *Lack of Skilled Professionals* and *Sporadic Commercial Resource Expertise.* Adding to these issues are *Research & Development Gaps*, such as a lack of long-term SCM performance studies and the

development of guidelines and standards in collaboration with communities of practice. *Under-developed Industry* is also reflected in the category *Government Policy Repercussions*, where respondents point to a range of policy and regulation issues that act to confound SCM maintenance outcomes.

The second over-arching issue refers to the *Invisibility* of SCMs both in the physical landscape and the collective consciousness of the voting public. This is a function of the design goals of most SCMs. Most SCMs are designed to by-pass stormwater, returning stormwater flows back into the drainage network when their treatment capacity is exceeded or when their hydraulic performance is reduced due to lack of maintenance or system failure. Consequently, unlike other forms of public infrastructure, such as roads, most SCMs may not always show overt signs when their performance drops away. Further, because SCMs are also often designed to improve urban amenity, they may appear as gardens or natural waterbodies to the untrained eye, or may be primarily hidden below ground level. While these design goals are justifiable, they also appear to have the unintended effect of rendering them invisible to the voting public, significantly reducing the visibility to democratic institutions, including local and state government. Therefore, the use of the word "invisibility" refers not only to how SCMs manifest in the physical environment, but also how this results in them remaining largely invisible to the body politic.

The third, *Policy Inertia*, is derived from concepts spread across multiple categories, particularly *Government Policy Repercussions* and *Council Governance & Structural Issues*, but also reflected in categories such as *Capacity Building & Support Gaps*. This over-arching issue proposes that state government policy has not kept pace with the changing needs of SCMs as they transition from niche innovation to mainstream practice. While not necessarily important for all types of transitions, the emerging field of Sustainability Transitions suggests that the role of government is of particular importance to changing practices at the societal level (Markard *et al.* 2012, Loorbach *et al.* 2017). Hence, *Policy Inertia* is likely to be important for SCMs delivered as an alternative to conventional stormwater management practices via local government. This is particularly so given that local government has very little control over state government policy, but is heavily affected by it due to the constitutional authority state governments hold over local governments in Australia.

5.2.4 Overall Finding

The overall finding '*Failure to Thrive*' was abstracted from the three over-arching issues and an understanding of the history of SCMs as a recently introduced sustainability innovation (Section 1.3). It infers that the problem of SCM under-maintenance is symptomatic of another, deeper problem concerning SCMs in Victorian local government, i.e., a potential loss of momentum in the transition of SCMs from novel solution, to an accepted mainstream practice in urban stormwater management and waterway protection. The abstraction of 55 concepts and associated nine sociotechnical categories from the qualitative dataset collected for this study (Figure 5-1) illustrates that complex sociotechnical interactions underpin this situation, consistent with the complexities associated with Sustainability Transitions (Section 2.5.5). Such a loss of transition momentum is considered to be a relatively common occurrence for sustainability innovations (Section 2.5.5), and may indicate a failed transition such as Lock-in, backlash or system breakdown (Figure 2-12). Therefore, the *Failure to Thrive* scenario and the concepts and categories underpinning it support the postulation that the problem of SCM under-maintenance in Victorian local government is likely to exhibit complex, sociotechnical characteristics (Section 2.4). Hence, to establish a basis upon which to ameliorate SCM maintenance outcomes, these findings suggest viewing the problem from a Sustainability Transitions perspective has merit. Importantly, given the opaqueness and uncertainties associated with Sustainability Transitions, this suggests that attempting to come up with 'the solution' or set of specific solutions risks wasted effort and unintended consequences (Rotmans

et al. 2009, Loorbach *et al.* 2017). Rather, an understanding of the key path-dependent relationships that have resulted in this *Failure to Thrive* scenario is called for that can be used as a basis for policy makers and communities of practice to coordinate and focus their efforts towards long-term lasting improvement to SCM maintenance and management. Such is the intention of Research Question 3, as described in the proceeding section.

5.3 Intervention Pathways (Research Question 3)

5.3.1 Sociotechnical System Form and Function

This section describes how the findings from Research Question 2 were subsequently collated and analysed to postulate three 'intervention pathways' that are considered likely to assist in producing lasting improvement to SCM maintenance outcomes. Each subsection is set out in the same order that the analyses were carried out, starting with the mapping of each of the 55 concepts elicited from the qualitative data set, along with their associated sociotechnical categories, onto a heuristic model derived specifically for this study. This is followed by the classification of each of the concepts into one of three classes, depending on their relationship with the innovation (SCMs) and the SCM maintenance in Victorian local government sociotechnical system ('the system'). The next sub-section then presents the results of a word similarity analysis of the qualitative data according to the allocation of text to concepts coding nodes. These analyses are then used to postulate 'intervention pathways' based on the identification of key path-dependencies considered to be contributing to the *Failure to Thrive* scenario and, *ipso-facto*, SCM under-maintenance.

5.3.1.1 Sociotechnical System Mapping

The 'sociotechnical system mapping' processes (Section 3.11.2) was undertaken by locating each concept onto the 'SCM Maintenance Sociotechnical Model' according to its point of origin within the SCM maintenance sociotechnical system and then using these concepts as waypoints for establishing category boundaries. The resultant model (Figure 5-2), gives illustration to the sociotechnical nature of SCM under-maintenance in local government based on respondents' experience and perspective. Importantly, it reveals that not all the of the challenges and barriers concerning SCM maintenance in local government are a function of local government. Rather, a significant proportion are a function of external 'Landscape' and 'Niche' factors, over which local councils have little direct control. The multiple examples of categories and concepts crossing sociotechnical boundaries illustrates the complexity of the system, where decisions, actions and conditions beyond local government directly and indirectly impact on SCM maintenance outcomes within local government. These findings support the proposition that the problem of SCM maintenance is sociotechnical in nature, being characterised by multicausality (Section 2.4). Therefore, simple, binary solutions are unlikely to see long-term improvement to SCM maintenance outcomes, and risk creating unexpected and potentially unfavourable consequences if implemented (Rotmans *et al.* 2009). Crucially, the occurrence of concepts and categories beyond local government indicates that focusing purely on local government to improve SCM maintenance outcomes risks wasted effort through sub-optimal or even failed outcomes.

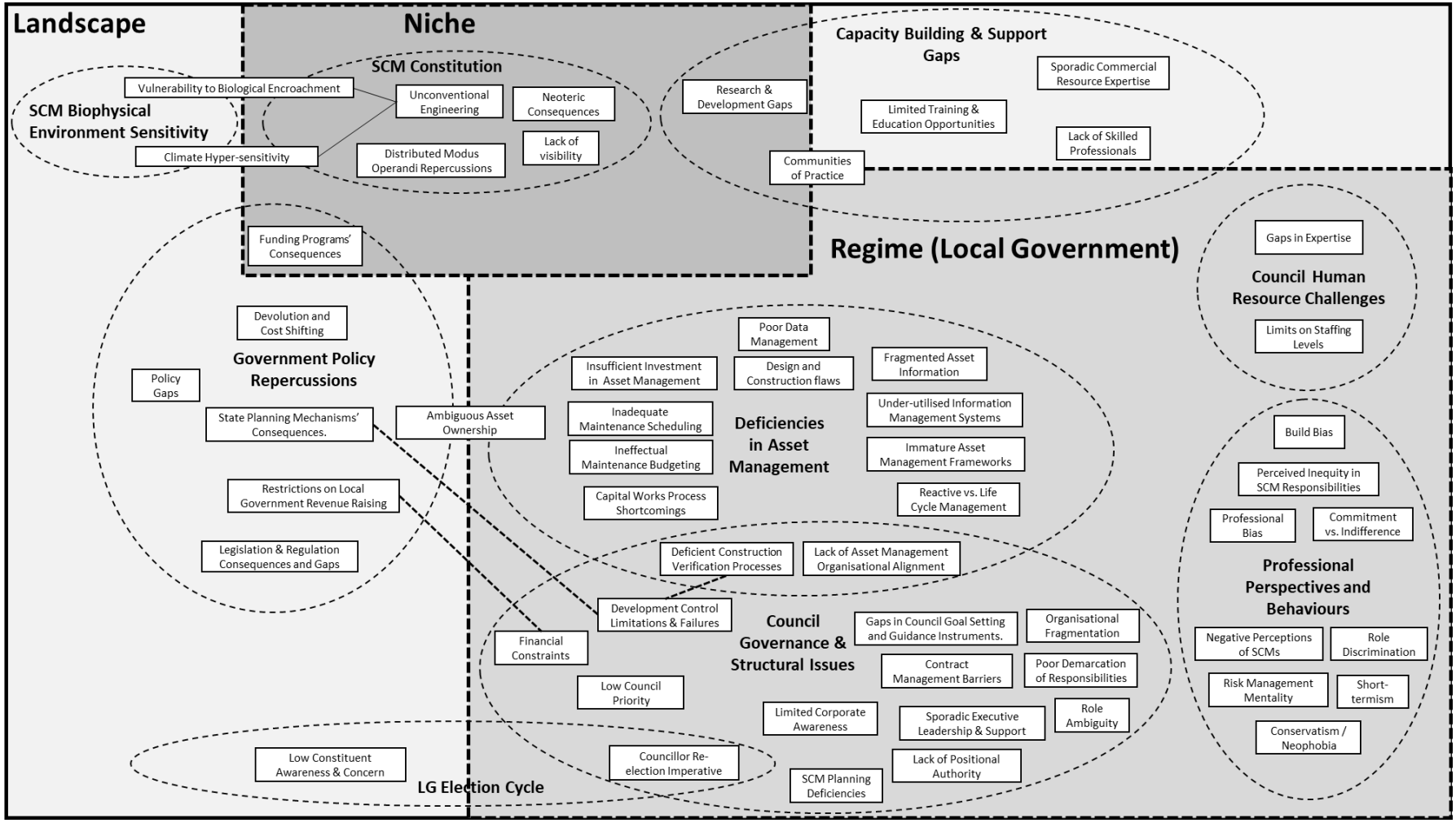


Figure 5-2: Victorian local government SCM Maintenance Sociotechnical Model following mapping of concepts and categories (dotted lines denote existing regulative links).

5.3.1.2 Concept Causation Test

The Concept Causation Test is a novel test developed specifically for this study. It draws on the idea of mis-alignments within the sociotechnical systems as barriers to the transition of sustainability innovations (Section 3.11.3). Its purpose is to provide a means of differentiating concepts to draw out which concepts are more likely to result in improved maintenance outcomes if addressed as a priority. That is, concepts that represent mis-alignments with the Victorian local government SCM maintenance sociotechnical system. As detailed in section 3.11.3, the Concept Causation Test differentiated concepts by allocating each to one of following three classifications:

1 *Intrinsic*: The concept is primarily a function of the intrinsic nature of the innovation's design, engineering or operational philosophy.

2 *Mis-alignment*: The concept is primarily a consequence of the introduction of the innovation. That is, if the innovation was removed, the issues characterised by the concept would likewise disappear.

3 *Independent*: The concept is primarily a function of pre-existing conditions within the broader sociotechnical system that act upon the innovation but are not a function of the innovation.

Concepts identified as *Mis-alignments* represent mis-alignments in the Victorian local government SCM maintenance sociotechnical system (Van der Brugge *et al.* 2007). Accordingly, they act to locate where within the SCM maintenance sociotechnical system reconfiguration is likely required to return SCMs to a successful transition trajectory and, *ipso-facto*, see lasting improvement to SCM maintenance outcomes. In contrast, *Intrinsic* concepts are a function of the nature or 'constitution' of the technology and can only be addressed by removing or exchanging SCMs with another stormwater management solution. While addressing *Independent* concepts are also likely to see improved SCM maintenance outcomes, they are a function of the broader "macro socio-environmental conditions" (Van der Brugge and Rotmans 2007, p. 254) within which the SCM maintenance sociotechnical system exists. As discussed in Section 2.3.2, government reports and academic publications dating back over two decades indicate that these broader conditions have thus far proved to be intrenched and intractable. However, by focusing on *Mis-alignment c*oncepts, it is likely that the impact of at least some of these *Independent* concepts will be softened.

Incorporating the *Concept Causation Test* into the SCM Maintenance Sociotechnical Model (Figure 5-3) adds a third dimension to the model (the first being the analysis results for Research Question 2 and the second being the multi-layer perspective). This updated model distinguishes 27 concepts as *Mis-alignments*, i.e., 27 mis-alignments within the Victorian local government SCM maintenance sociotechnical system that need to be 're-aligned' in order to address the *Failure to Thrive* scenario and, in so-doing, see long lasting improvement to SCM maintenance outcomes. The scattering of these *Mis-alignment* concepts across all three sociotechnical levels (Niche, Landscape & Regime) gives further credence to the proposition of the complex, sociotechnical nature of the problem of SCM under-maintenance (Section 2.4). The SCM Maintenance Sociotechnical Model also confirms that all *intrinsic concepts* are associated with the Niche regime (i.e., the nature of the innovation itself) and are therefore non-systemic. The only way to mitigate their impact is to swap out or remove the innovation from the system.

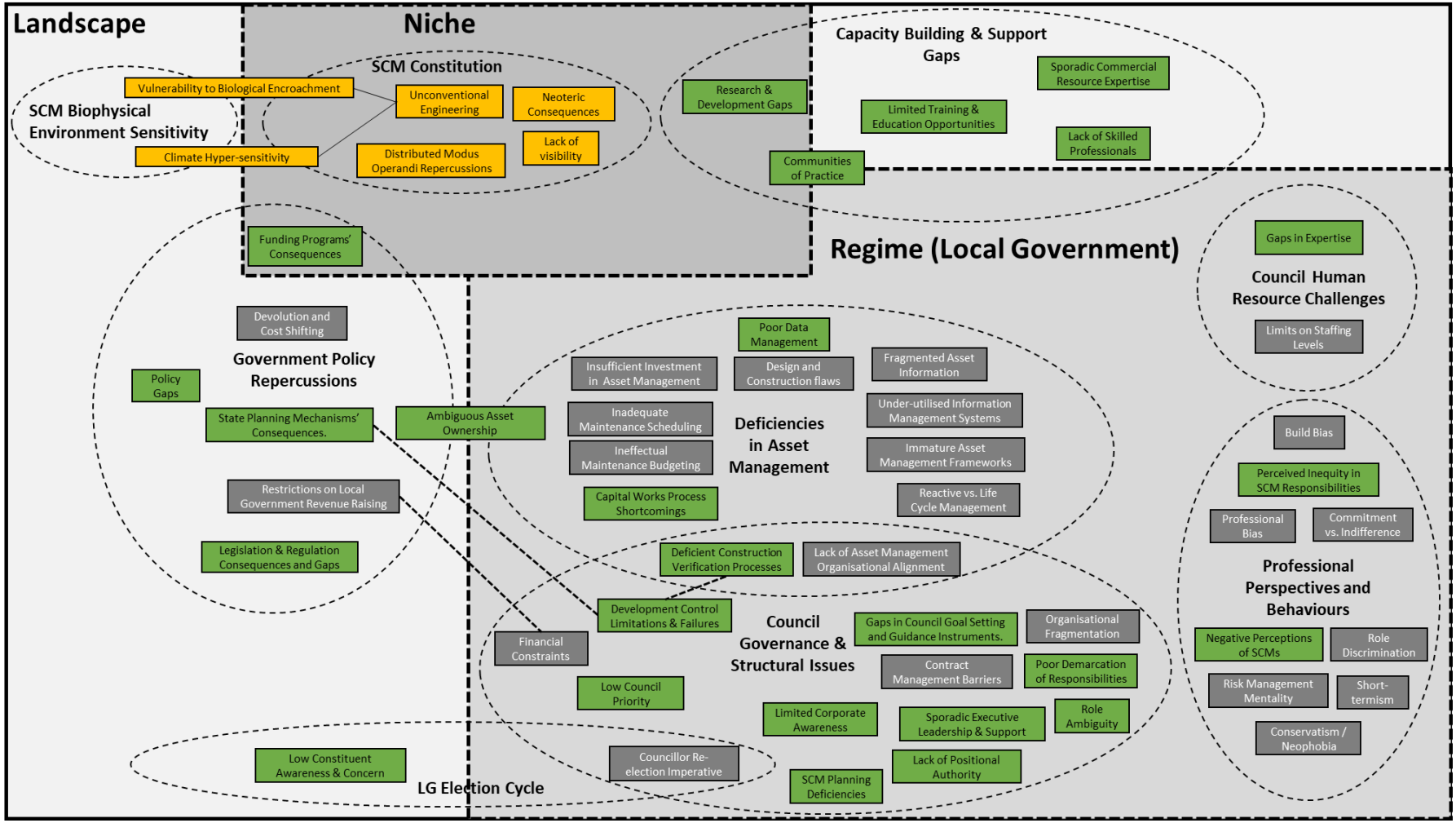


Figure 5-3: Victorian local government SCM maintenance sociotechnical model incorporating Concept Causation Test results (dotted lines denote existing regulative links) (orange = Intrinsic concepts, green = Mis-alignment concepts and grey = Independent concepts)

5.3.1.3 Respondent Concept Interrelationships

This subsection presents the results of the word similarity analyses conducted using NVivo's word similarity analysis tool (Section 3.11.4). The purpose of the use of this tool was to elicit the tendencies of respondents to link together different barriers and challenges in cause and effect relationships, and to use the results to assist with the postulation of intervention pathways. In this regard, it is important to note that the word similarity analysis comes with two important limitations. The first, is that its algorithm is relatively unsophisticated, being based on individual words only. For example, it does not consider where within sentences words occur. To minimise the effects of this limitation, specific coding protocols were used during the coding of the qualitative data set (Section 3.11.4). The second limitation is the assumption that the cause and effect relationships between concepts most often mentioned by respondents are the most important relationships. However, where complex sociotechnical problems are concerned, not all cause and effect relationships may be overtly obvious (Rotmans *et al.* 2009). Hence, the interpretation of the word similarity analysis outputs provided below, and its use in assisting with the postulation of intervention pathways (Section 5.3.2), have been undertaken with these limitations in mind.

The results of the word similarity analysis are provided in dendrogram format as Figure 5-4, where strong associations are shown as closely clustered groups sharing the same cluster number. Cluster 17 shows the grouping of multiple shortcomings in asset management, reflecting the findings of the inquiry into the sustainability of local government in Victoria (VAGO 2014). Similarly, Cluster 13 links higher tier government funding programs with a perception among respondents that such funding programs are, at least in part, an attempt to shift state government responsibilities onto local government (in the case of SCM, waterway protection). Cluster 18 reflects the role of local government as the State government's deputised development authority, capturing a range of shortcomings in state government legislation and processes within local government that result in SCMs that require excessive maintenance or are poorly designed for maintenance.

The word similarity analysis reveals some potentially important relationships that specifically relate to the *Failure to Thrive* Scenario (Section 5.2.1). For example, Cluster 16 brings together concepts from different sociotechnical categories and scales that supports the proposition that the inconspicuous presence of SCMs in the urban environment results in them being considered a low council priority. Because local constituents are not aware of SCMs, they do not reflect concerns about their fate through the democratic avenues afforded them through local government. Therefore, councillors likewise do not value them as a mechanism for ensuring re-election. Because councillors sit atop the governance structure in local government, this lack of value attributed to SCMs permeates down hierarchical structures of local councils. Consequently, SCMs and their maintenance become reliant on the presence of individual 'champions', working in organisations that hold SCMs as a low priority deliverable (Brown 2005, Taylor 2009).

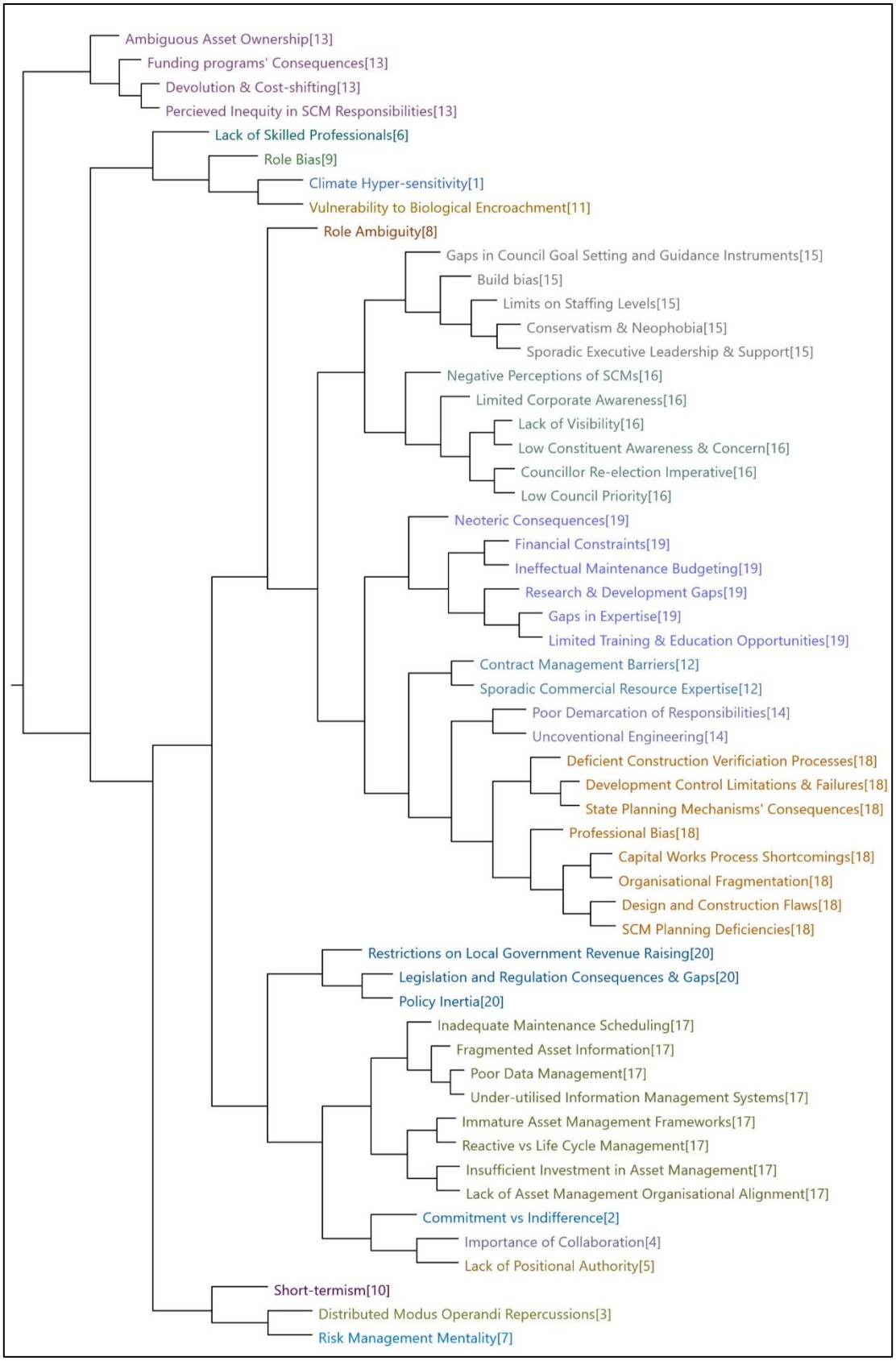


Figure 5-4: Dendrogram reflecting the tendencies for respondents to associate causality between concepts (produced in NVivo using word similarity function)

Another potentially important set of concept relationships is that represented by Cluster 19, which reveals a tight clustering between the concepts *Research & Development Gaps*, *Gaps in Expertise* and *Limited Training & Education Opportunities.* The linking of these concepts reflects respondents noting that insufficient research and development concerning the long-term performance of SCMs is contributing gaps in expertise. This is because knowledge dissemination cannot occur until the necessary research into the long-term performance of SCMs and maintenance treatments has been undertaken. Without such research, councils will not be able to access the required expertise to effectively manage and maintain their SCMs irrespective of the mechanisms through which training and education is delivered. The inclusion of the concepts *Financial Constraints* and *Ineffectual Maintenance Budgeting* reflects respondent perspectives that poor maintenance budgeting is not just a function of a lack of funding, but also a function of a lack of research and development. Specifically, a lack of well-developed and evidenced based standards and guidelines for long-term SCM maintenance and renewal planning.

5.3.2 Postulation of Intervention Pathways

The purpose of 'intervention pathways' is to provide policy makers and communities of practice with a strategic basis upon which to focus attention and effort towards the formulation of various interventions to improve SCM maintenance outcomes. This section presents three intervention pathways based on the three over-arching issues derived from the Grounded Theory Method analysis (Figure 5-1). The basis upon which these intervention pathways are postulated is the ides of 'path-dependencies' of conventional practices (e.g. sunken investments, benefits of scale and cultural behaviours) and their role in confound the transition of sustainability innovations (Section 2.5.5). This basis has been used because the Grounded Theory Method analysis identified SCM maintenance as being symptomatic of another problem, i.e., a loss of moment in the transition of SCMs towards an accepted, mainstream urban stormwater management practice (the *Failure to Thrive* scenario). Accordingly, the postulation of the three intervention pathways draws on the three over-arching issues, the analyses presented in Section 5.3.1 and the review of literature concerning the management of public infrastructure by local government (Section 2.3).

The *Industry Capacity Building* pathway links all of the concepts within the *Capacity Building & Support Gaps* sociotechnical category, before terminating in the *Council Human Resource Challenges* category (Figure 5-5). The pathway moves through all three sociotechnical scales, being anchored in the Niche scale via the concept *Research & Development Gaps* and terminating in Regime scale (local government) at the concept *Gaps in Expertise*. As captured by word similarity analysis Cluster 19 (Figure 5-4), this path-dependent relationship between *Research & Development Gaps* and *Gaps in Expertise* illustrates how gaps in SCM research at the Niche scale effects the capacity of councils to effectively manage and maintain their SCMs at the Regime scale. The lack of research into the long-term performance of SCMs leaves scant evidenced based knowledge to build effective education and training programs (*Limited Training & Education Opportunities*). Likewise, it limits information available for communities of practice to develop industry guidelines, standards and codes that support effective maintenance outcomes. These issues combine to create a *Lack of Skilled Professionals* within the workforce, creating a deficit of personnel available to council who have the skills to effectively management and maintain SCMs (*Sporadic Commercial Resource Expertise* and *Gaps in Expertise*).

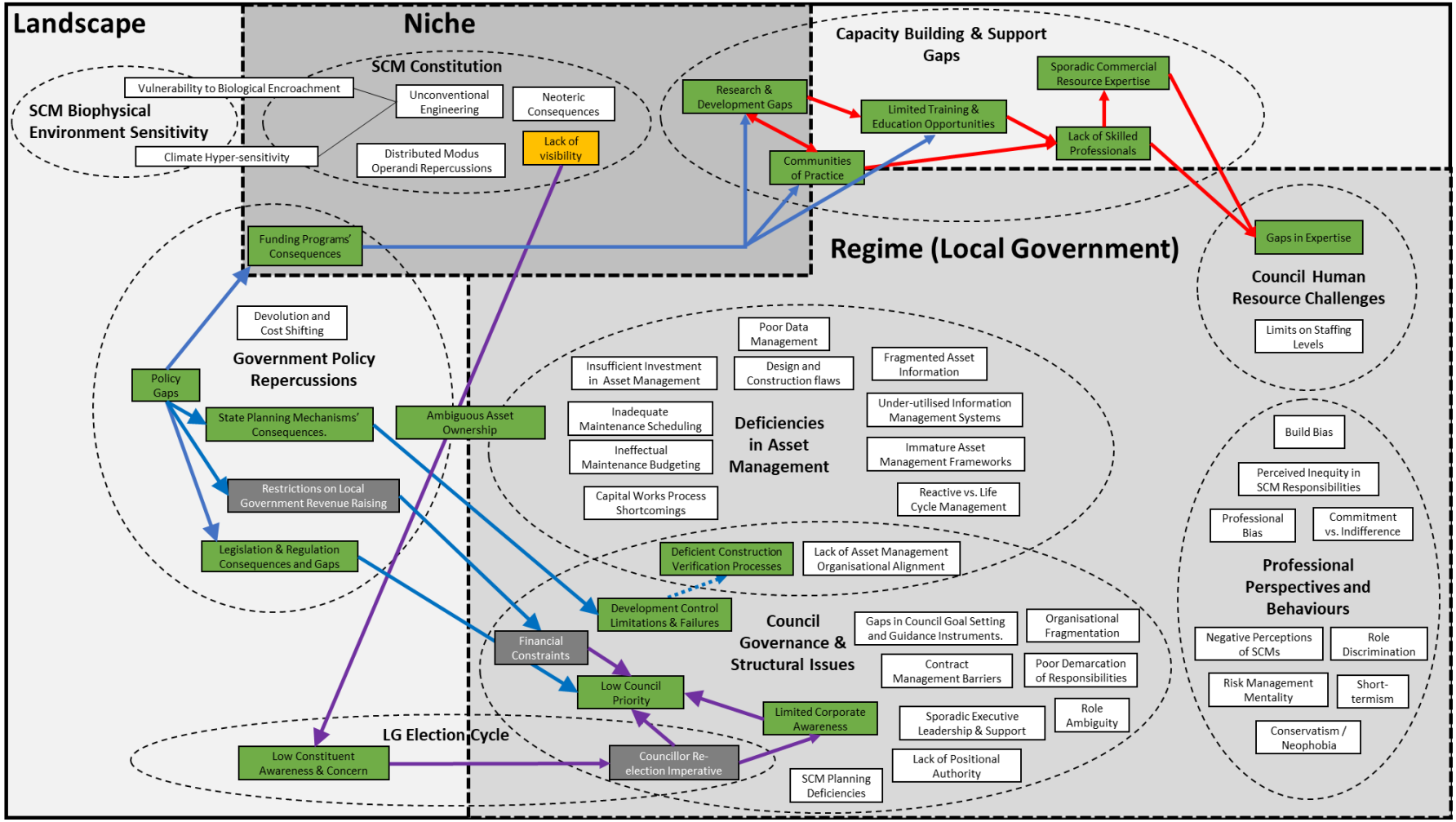


Figure 5-5: Victorian local government SCM maintenance sociotechnical model showing intervention pathways (Red = *Industry Capacity Building*; Purple = *Increasing Visibility*; Blue = *Policy Realignment*).

The intervention pathway *Increasing SCM Visibility* illuminates the path-dependent relationship that appears to have contributed to SCMs achieving a low priority status in local government. Reflected in word similarity analysis Cluster 16 (Figure 5-4), this pathway is anchored in the Niche by the concept *Lack of Visibility*, passing into the Landscape via the concept *Low Constituent Awareness & Concern* and entering the Regime scale via the concept *Councillor Re-election Imperative.* This relationship is considered to render SCMs to a low priority in local councils because councillors tend to set their council's priorities based on those matters that concern their constituents the most. Therefore, SCMs are not given high priority (*Low Council Priority*) and, therefore, rarely gain the attention of council executive (*Limited Corporate Awareness*). The anchoring of this pathway in the concept *Lack of Visibility* reflects two important design goals of most SCMs. The first is the inclusion of stormwater by-pass systems that divert stormwater back into the drainage system to prevent SCMs from becoming a public nuisance or hazard. The second is to enhance urban aesthetics by designing SCMs to appear as gardens or natural waterbodies to the casual observer, or by constructing most of the asset underground (typically gross pollutant traps). However, as the intervention pathway *Increasing Visibility* reveals, these design goals appear to have had an unintended consequence, i.e., contributing to the insufficient maintenance of SCMs by lowering their importance within local councils.

Intervention pathway *Policy Realignment* reflects the importance of top-down intervention in changing societal level practice (de Haan *et al.* 2011). Reflected in word similarity analysis clusters 13, 18 and 20 (Figure 5-4), this multi-pronged pathway illuminates the various ways that the actions and inactions of particularly state government appear to be contributing to poor SCM maintenance outcomes and, accordingly, the *Failure to Thrive* scenario. The path-dependent link between *Restrictions on Local Government Revenue Raising* and *Financial Constraints* reflects consistent respondent perspectives concerning the lack of a mechanism for raising revenue for SCM maintenance independent of rate capping[35]. Another example is the path-dependent link between the concepts *State Planning Mechanisms' Consequences* and *Deficient Construction Verification Processes.* While many respondents noted that deficiencies in their council's verification process were a function of internal issues, they also noted that the development consent powers afforded to their council through state government planning regulation are insensitive to the green components incorporated into most SCMs. Accordingly, existing planning regulation was noted as being unclear as to what constituted 'practical completion' for vegetative and aquatic components.

The *Policy Realignment* pathway also illustrates the path-dependencies between the intervention pathways themselves. For example, the connections between *Policy Realignment* and *Industry Capacity Building* via the concept *Funding Program Consequences* to the concepts *Research & Development Gaps*, *Communities of Practice* and *Limited Training & Education Opportunities*. This linkage reflects the focus of state government SCM related funding, which has thus far concentrated on the establishment of new assets in partnership with local councils. Research funding has been far more opportunistic, relying on a range of different programs over the past three decades from state and federal government sources. Further, while some state government funding has been allocated to capacity building, this has focused predominately on niche programs such as *Clearwater*, with little integration into tertiary education programs. Therefore, the connection between *Policy Realignment* and *Industry Capacity Building* reflects opportunities to refocus funding programs towards different goals. Examples include funding research programs that focus on SCM long-term performance and the effects of different maintenance treatments, and funding programs that encourage tertiary education institutions to incorporate SCMs and Integrated Water Management into existing under-graduate programs. Another example is the diversion of funding towards initiatives that

[35] As discussed in Section 5.2.2.4, this may not be technically true as the Victorian Local Government Act 1989 does include mechanism that might be applicable to such a purpose.

encourage collaboration between communities of practice in the development of standards, guidelines and codes that encourage and promote effective SCM maintenance outcomes.

The *Policy Realignment* intervention pathway also connects to the *Increasing SCM Visibility* pathway via the concept *Legislative & Regulation Consequences and Gaps* (Figure 5-5). This meeting of intervention pathways reflects how gaps in existing state government regulation and the engineering goals of SCMs have inadvertently come together to contribute to the 'invisibility' of SCMs within local government. Based on respondent perspectives, a key contributing factor to the low priority of SCMs at their respective councils is the ambiguity concerning responsibilities and accountabilities regarding the protection of natural waterways (Section 2.3.3). This lack of clarity appears to leave councils ambivalent about their responsibilities concerning SCM maintenance relative to other more clearly defined areas within their broad mandate. For example, respondents noted the stark difference between the attention paid to local roads relative to SCMs. Due to their high visibility and the existence of specific state government regulative controls[36], roads are a central priority, with SCMs receiving far less attention. Therefore, the linking up of the *Policy Realignment* intervention pathway with the *Increasing Visibility* pathway illustrates the potentially important role regulative interventions could contribute to raising the importance of SCMs within local government.

It is important to note that systemic mis-alignments and path-dependencies that arise in Sustainability Transitions systems are typically highly complicated and collectively unknowable (Rotmans *et al.* 2009, Loorbach *et al.* 2017). Hence, the pathways proposed here should not be considered as an attempt to identify all possible path-dependencies (that would likely be impossible), but rather strategic intervention pathways likely to maximise positive outcomes by creating ripple effects that permeate throughout the system. Just as importantly, these three pathways should not be seen as three isolated options, but instead three interdependent pathways that need to be addressed in tandem if lasting improvements are to be seen. Further, the complexity of the SCM Maintenance socio-technical system means that specific interventions should be subject to ongoing monitoring for effect such that unintended consequences can be corrected, and new opportunities can be identified and exploited (Rotmans *et al.* 2009, Furlong *et al.* 2019).

5.4 Summary of Major Findings

The *Failure to Thrive* scenario derived from Research Question 2 analysis (Section 5.2.1) indicates that the under-maintenance of SCMs by Victorian local government is symptomatic of complications with its transition towards mainstream adoption, indicating it may be at risk of a partial or total failed transition (Figure 2-12). This overall finding is despite a proliferation of new SCMs since the turn of the century, largely due to changes to the Victorian Planning Provisions in 2006 (Clause 56.07-4) and state government grant funding targeting the construction of SCMs through local government. Therefore, while existing state government policy has helped to launch SCMs beyond 'Take-off' (Brown *et al.* 2007, Rogers *et al.* 2015a), the findings to Research Question 2 indicate that pro-active interventions may be required to remove impediments to the mainstream adoption of SCMs within Victorian local government.

The *Failure to Thrive* of SCMs is postulated as being a function of three 'over-arching issues'. The first is an *Under-developed Industry* that is yet to achieve the sophistication required to effectively manage SCMs. The second is the inherent *Invisibility* of SCMs in the physical landscape and the community, a factor that works against their presence within a democratically governed environment. And the third is *Policy Inertia*, particularly at the state government level, which appears to have not kept pace with the changing needs of SCMs as they transition from niche innovation to mainstream adoption. The identification of nine separate categories

[36] Notably, the Victorian *Road Management Act 2004* and associated regulations and codes.

abstracted from 55 concepts and their subsequent ‘mapping’ onto the heuristic model developed for this study confirms the complex sociotechnical nature of the problem of SCM under-maintenance in Victorian local councils (Section 2.4). Consequently, effective amelioration of the problem of SCM maintenance is unlikely to be conducive to a single, simple solution (Rotmans *et al.* 2009, Norman *et al.* 2015). Rather, it is likely to see improvement through careful and considered selection of strategic interventions that optimise effort and avoid unintentional consequences (Rotmans *et al.* 2009, Norman *et al.* 2015, Furlong *et al.* 2019).

To ameliorate the *Failure to Thrive* scenario and, therefore, see lasting improvement to SCM maintenance outcomes, three ‘intervention pathways’ have been postulated, i.e., *Industry Capacity Building*, *Increasing SCM Visibility* and *Policy Realignment*. *Industry Capacity Building* identifies the key concept relationships that appear to work together to create a situation where local government is unable to access the expertise it needs to effectively manage their SCMs. *Increasing SCM Visibility* identifies the key concept relationships that reveal how seemingly unrelated fields of endeavour, engineering and politics, act together to de-prioritise SCMs with local councils. And *Policy Realignment* reveals not only how state government policy appears to have not kept up with the needs of SCMs as they make their transition journey from niche innovation to mainstream practice, but also how all three intervention pathways are themselves inter-related. Consequently, these intervention pathways are not individual options, but a set of inter-related strategic pathways that need to be addressed in an integrated way. Importantly, these three pathways were postulated based on the analysis of quantitative data collected from 54 employees across eight councils involved in the management, planning and maintenance of SCMs in Victorian local government. Hence, while these pathways are presented as postulations, they are postulations that are demonstrably “grounded in data” (Glaser and Strauss 2006, p. 33).

6 Discussion

6.1 Introduction

The analyses presented in Chapter 4 suggest that, consistent with anecdotal concerns, SCMs are being under-maintained in Victoria. Findings presented in Chapter 4 also indicated that this situation may not be unique to Victoria, with a limited number of studies finding similar scenarios from jurisdictions across the globe. While it is known that local government in Victoria struggles with the management of their public infrastructure generally (Section 2.3.2), analysis of SCM condition data (Chapter 4) and survey data (Chapter 5) indicates that SCMs may be particularly vulnerable to insufficient maintenance. The *Failure to Thrive* scenario determined from the Grounded Theory informed analysis (Section 5.2.4) suggests that the under-maintenance of SCMs is symptomatic of underlying issues with the transition of SCMs as an urban stormwater management solution. Chapter 5 reveals that the reasons for this are complex, wide ranging and highly nuanced, verifying the problem of SCM maintenance as being a complex sociotechnical problem. Therefore, seeking to address the *Failure to Thrive* scenario and see lasting improvement to SCM maintenance is unlikely to be amenable to a simple, binary solution (Rotmans *et al.* 2009, Norman *et al.* 2015). Rather, it will require a strategic and multifaceted approach that address the many sociotechnical path-dependencies that are currently working against the effective management of SCMs in Victorian local government (Rotmans *et al.* 2009, Furlong *et al.* 2019).

Accordingly, this chapter begins by exploring the relationships between SCM under-maintenance and the transition of SCMs as a sustainability innovation. It does so by viewing the *Failure to Thrive* scenario through the lens of Sustainability Transitions (Van der Brugge *et al.* 2007, Markard *et al.* 2012, Loorbach *et al.* 2017) and what this finding might mean for the current transition trajectory for SCMs. The chapter then reverses this focus, postulating an alternative Sustainability Transition pathway that considers the possibility that the *Failure to Thrive* scenario does not necessarily indicate a failed transition. Rather, it may represent an unavoidable consequence of the complexities of Sustainability Transitions that, through incremental and iterative system reconfiguration, can be overcome (Rotmans *et al.* 2009, Furlong *et al.* 2019). This chapter then returns its focus to SCMs, first considering how its status as a sustainability innovation and its unique features are contributing to the apparent *Failure to Thrive* scenario elicited from the survey data collected for this study. It then looks at how the intervention pathways (Section 5.3.2) might be utilised to address the *Failure to Thrive* scenario and, *ipso-facto*, result in long lasting improvement to SCM maintenance outcomes in Melbourne. The Chapter then concludes by discussing what the *Failure to Thrive* scenario observed for SCMs tells us about what successful transition might look for SCMs in Victorian local government and for Sustainability Transitions more generally.

6.2 SCM Under-maintenance – A Symptom of Transition in Trouble

The introduction of SCMs through local government represents a response to societal concerns about the degradation of freshwater and marine environments that challenges conventional stormwater management practices. Therefore, it fits within the general meaning of the term ‘Sustainability Transitions’ (Markard *et al.* 2012, Loorbach *et al.* 2017). The *Failure to Thrive* scenario indicates that SCM under-maintenance in Victorian local government may be a symptom of a loss of momentum in the transition of SCMs towards mainstream adoption. While the precise nature of this loss of momentum is not readily discernible, the emerging field of Sustainability Transitions research offers some insights into what the *Failure to Thrive* scenario might be foreshadowing. Accordingly, seminal concepts underpinning this relatively new field of

transitions science are applied in this section to help understand what the *Failure to Thrive* scenario might mean for the transition of SCMs in Victorian local government.

As discussed in Section 2.5.5, Rotmans *et al.* (2001) and Van der Brugge *et al.* (2007) offer four pathways Sustainability Transitions may take (Figure 6-1): *Stabilization*, *Lock-in*, *Backlash* and *System Breakdown*. Of the four pathways, only the *stabilization* pathway represents a successful transition path. The predevelopment phase represents a build-up of pressure upon the existing, conventional regime due to changing sociotechnical conditions, typically in the form of exogenic pressure from the landscape (e.g. growing concerns about waterway degradation) combined with the availability of alternative approaches from the niche (Geels 2002, Van der Brugge *et al.* 2007). Eventually, this pressure exceeds a critical point, allowing alternative practices ('innovations') to compete with the conventional practice (*take-off*) (Rotmans *et al.* 2001, Markard *et al.* 2012, Loorbach *et al.* 2017).

The path towards *stabilization* continues providing *Take-off* is followed by *acceleration*, where the cascading changes to the sociotechnical system are maintained by continued exogenic pressures and the presence of an innovation that is congenial to the institutional nuances of the sociotechnical system. This being so, *stabilization* is achieved following the necessary system "reconfigurations" (Geels 2002, p. 1272), resulting in a regime dynamic where the new practice becomes accepted as a mainstream practice (Rotmans *et al.* 2001, Van der Brugge *et al.* 2007, Loorbach *et al.* 2017). Specifically, the necessary changes within the societal sociotechnical system have taken place such that a new system equilibrium is reached, signifying the establishment of a new paradigm where the new practice is no longer 'new', but rather part of the established way of doing things (Rotmans *et al.* 2001, Loorbach *et al.* 2017).

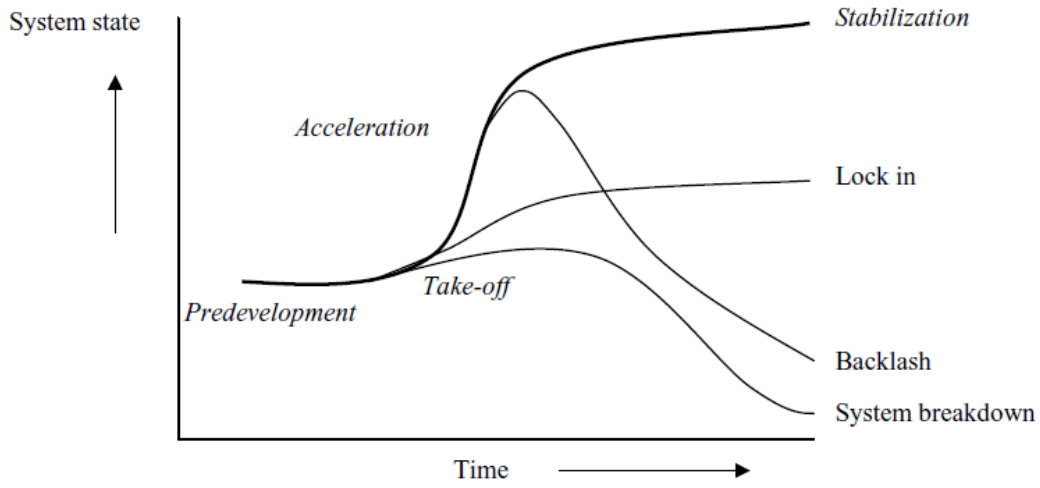


Figure 6-1: Pathways for Sustainability Transitions (Van der Brugge and Rotmans 2007, Fig. 3)

The *Failure to Thrive* scenario suggests that the current trajectory of the transition of SCMs may not be consistent with a *stabilization* pathway, leaving *lock-in*, *backlash* and *system breakdown* as possible alternatives. *System Breakdown* occurs when pressures on the existing regime are not sufficient to see it destabilised sufficiently to facilitate *take-off* (de Haan *et al.* 2011). Such a fate for SCMs in Melbourne is considered not applicable given the numerous studies and reports demonstrating that SCMs have passed beyond the *take-off* phase (Brown *et al.* 2013, Rogers *et al.* 2015a, Brodnik *et al.* 2017). A *Lock-in* fate for SCMs, however, remains a possibility. *Lock-in* occurs when the innovation is only partially compatible with the regime, or where it is only partially able to meet demands and, as a consequence, while gaining influence, it fails to completely replace conventional practices (Van der Brugge *et al.* 2007, de Haan *et al.* 2011). Evidence provided by earlier studies does not exclude this possibility, particularly that

provided by Morison *et al.* (2010) which revealed wide variability in the embracement of SCM technologies across local government in Melbourne.

Likewise, this evidence does not exclude a *backlash* pathway as an eventuality for the *Failure to Thrive* scenario. *Backlash* describes a rapid uptake of an innovation that initially appears to be on-track for complete system reconfiguration, but part way through the reconfiguration processes, suffers a rapid and un-recoverable loss of transition momentum (Rotmans *et al.* 2009, de Haan *et al.* 2011). Consequently, *Backlash* results in a return to the original system state (Figure 6-1). This is particularly evident from the concepts that led to the abstraction of the sociotechnical category *Professional Perspectives and Behaviour* (Section 5.2.2). Specifically, *Negative Perceptions of SCMs*, *Perceived Inequity in SCM responsibilities*, *Conservatism / Neophobia*, *Short-termism* and *Risk Management Mentality* all reveal resistance to SCMs as a stormwater management infrastructure solution. Such perspectives were evident in all councils that participated in this study irrespective of the professional's position in the hierarchy. Other concepts, such as *Poor Demarcation of Responsibilities*, *Limited Corporate Awareness*, and *Lack of Positional Authority* also support a *backlash* fate for SCMs, revealing that, despite at least three decades of external and niche pressures (Brown *et al.* 2007), councils are yet to integrate SCM management effectively into their organisational structure.

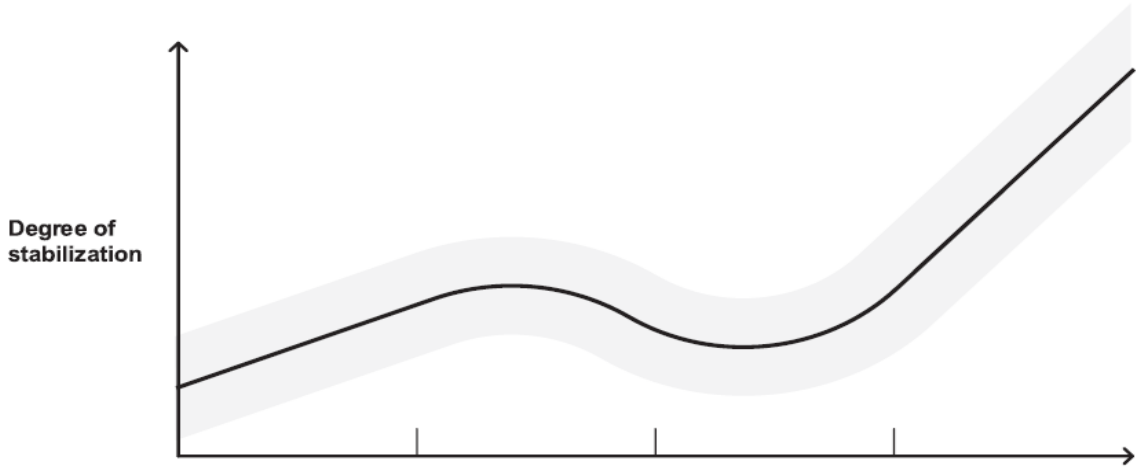
Seeming to contradict the *Failure to Thrive* scenario, Madsen *et al.* (2017) concluded that the Melbourne SCM "innovation system has stabilised" (p. 208). To facilitate data analysis, the authors developed a technology stabilisation framework based on the Social Construction of Technology and Transition Science (Figure 6-2). This framework was then used to interpret primary and secondary sources of qualitative data. The primary data was collected from eight urban water practitioners ('actors') from Melbourne[37] via semi-structured interviews and the secondary data was collected from a range of grey and white literature. The eight actors were drawn from different areas associated with SCMs, described as 'Public Management' (2), 'Industry' (2), 'Research' (2), 'Citizen' (1) and 'Politician' (1). Madsen *et al.* (2017) drew their conclusions based on meanings associated with SCMs as elicited from their primary and secondary data, finding, in the case of Melbourne, low levels of interpretive flexibility. Accordingly, they concluded that Melbourne had achieved the 'Agreement' stage concerning what SCMs are, and what it is that they do.

The reason for these apparent contradictions between the *Failure to Thrive* scenario proposed by this study and that conducted by Madsen *et al.* (2017) is the fundamentally different theoretical perspectives taken. This study takes a systems-based perspective, drawing on complex adaptive systems theory where concepts of path-dependencies and co-evolution determine the fate of an innovation (Rotmans *et al.* 2009). Therefore, the innovation both effects and is effected by 'the systems' where the system is a complex mix of social, cultural, political, economic and institutional subsystems (de Haan *et al.* 2011). In contrast, Madsen *et al.* (2017) takes a social constructivist perspective, drawing on Social Construction of Technology theory that holds that the fate of technology is ultimately a function of human action as defined by the meanings held by different groups in relation to the technology and the degree of interpretive flexibility between those groups.

The contradiction between Madsen *et al.* (2017) and the *Failure to Thrive* scenario reveals a limitation of Social Construction of Technology, giving excessive focus to design and immediate use, but obscuring issues associated with long-term adoption (Sovacool *et al.* 2017). This is particularly important where SCMs in local government are concerned, given their long-term performance is dependent on their effective integration into the governance and structural frameworks of the councils responsible for them. Further, because of the structural power

[37] Madsen *et al.* 2017 also collected data from practitioners in Copenhagen, comparing results for Melbourne and Copenhagen in the final analysis.

imbalance between local and state governments[38], equating innovation system stabilisation with low levels of interpretive flexibility between actor groups is likely to obscure this power imbalances (Worthington *et al.* 2001, Klein *et al.* 2002). For example, the required uptake of SCMs by local councils via the 2006 changes to Victorian Planning Provisions irrespective of their ability and commitment to do so (Morison *et al.* 2011).



	New technology	Testing	Opportunity	Agreement
Description	The technology emerges as a result of an issue with the current system.	Test cases are used. Only few actors involved.	New actors are involved because there is dissatisfaction. Leads to new confrontations that need to be settled.	Confrontations are settled over time, agreement arises.
Technologies in play	Few emerging technologies	Few more complex technologies	More complex technologies	Complex technologies
Main actors in play	Researchers Industry frontrunners Government Citizen	Researchers Industry frontrunners	Researchers Industry Government Citizens	Government Industry Citizens
Meanings in play	New technology is needed. Improvements of new technology are needed.	Improvements are needed. Benefits and risks are weighed.	Dissatisfaction with current system. LAR/WSUD are the solution.	LAR/ WSUD are a significant supplement to the original system and integrate several values.

Figure 6-2: Conceptual framework developed and applied by Madsen *et al.* (2017)

In fairness to Madsen *et al.* (2017), they did note that low levels of interpretive flexibility did not necessarily mean the technology itself had, *ipso-facto*, achieved mainstream adoption. However, the different findings between their study and this study provide a useful contrast, highlighting the importance of broader socio-technical and socio-institutional factors and their role in determining the fate of sustainability type innovations (Markard *et al.* 2012, Loorbach *et al.* 2017). This includes the role of institutional dynamics and the inherent routines, powers, interests and discourse are affecting the acceptance and adoption of SCMs within Victorian local government (Geels *et al.* 2007, de Haan *et al.* 2011, Rogers *et al.* 2015a, Loorbach *et al.* 2017). Therefore, While this study did not find any evidence to dispute Madsen *et al.* (2017)'s findings, the elicitation of concepts such as *Ineffectual Maintenance Budgeting*, *Inadequate Maintenance Scheduling*, *Low Council Priority*, *Policy Inertia*, *Poor Demarcation of Responsibilities*, and *Gaps in Expertise* present an alternative perspective that demonstrate that

[38] In Australia, state governments have constitutional authority over local governments, and have the power to directly regulate local government through their respective local government acts and other regulative instruments.

interpretive flexibility is but one factor contributing to the mainstream adoption of sustainability innovations, including SCMs.

6.3 An Alternative Transition Path for Sustainability Transitions

The transition pathways discussed previously (Section 6.2) offer explanations for the *Failure to Thrive* scenario that end in partial or total failed transition. Yet the *Failure to Thrive* scenario does not necessarily mean that full transition is implausible. Rather, it may be a natural and inevitable part of Sustainability Transitions, borne of the systemic complexities associated with transitions that occur at the societal level (de Haan *et al.* 2011, Loorbach *et al.* 2017). It may also be a scenario that does not mean that a sustainability innovation is somehow unfit for purpose, but rather a sign that the societal system is now at a point where it is now 'primed' (ready) for pro-active reconfiguration. To give substance to this idea, an alternative pathway is offered to give accent to these complexities and to highlight the need for considered and pro-active interventions to see benefits realised (Figure 6-3). Inspired by the Garner Hype Cycle (Geels 2005b), but heavily modified for Sustainability Transitions, this alternate pathway draws on existing transition scholarship (Section 2.5) and the findings of this study (Chapters 4 and 5). To give emphasise to, and guidance on, the need for pro-active interventions, Rogers *et al.* (2015a)'s hypothetical model denoting the purpose and types of institutional work required to progress sustainability transitions (Figure 2-14) has been transposed onto this alternative pathway.

As Figure 6-3 illustrates, the *Iterative Reconfiguration Pathway* to transition begins in the same way as that described for the four-phase transition pathway described in the previous section, incorporating the *predevelopment* and *take-off* phases (Section 2.5.5). These phases coincide with Rogers *et al.* (2015a)'s *Pre-niche*, where the innovation exists only as a plan or undeveloped technology, exhibiting no influence over the sociotechnical system. Institutional work at this stage is predominately cultural-cognitive (Scott 2008), with relevant actors focusing on technology development and building scientific and technical knowledge. For SCMs in Melbourne, this *Pre-niche* period stretches from as early as the mid-1960s to the mid-1990s (Brown *et al.* 2007, Madsen *et al.* 2017). To facilitate and prepare for *take-off*, cultural-cognitive activities should be expanded to include experimental knowledge and cultural knowledge (Table 2-1). For example, the implementation of pilot programs and demonstration projects to raise awareness and start to build practical operational knowledge (Geels *et al.* 2007).

As momentum builds, normative work and regulative work should begin to kick-in (Scott 2008, Rogers *et al.* 2015a). Normative work should including facilitating a sharp rise in advocacy by key actors (e.g. industry champions, special interest groups, industry peak bodies and industry frontrunners) and the production of initial standards and guidelines (Rip *et al.* 1998, Brown 2008a, Geels 2011, Bankins *et al.* 2016). To kick-start the destabilisation of the established regime and initiate *take-off*, regulative and normative work should be used to encourage the uptake of the new practice (Rogers *et al.* 2015a). In the case of SCMs in Melbourne, such institutional works included changes to the Victorian Planning Provisions, the introduction of Melbourne Water's Living Rivers Program and the launching of the *Clearwater* niche capacity building program (Brown *et al.* 2007, Madsen *et al.* 2017). Assuming these institutional works are successful, a *rapid acceleration* phase occurs and the innovation constellation evolves to the Niche stage (de Haan *et al.* 2011, Rogers *et al.* 2015a).

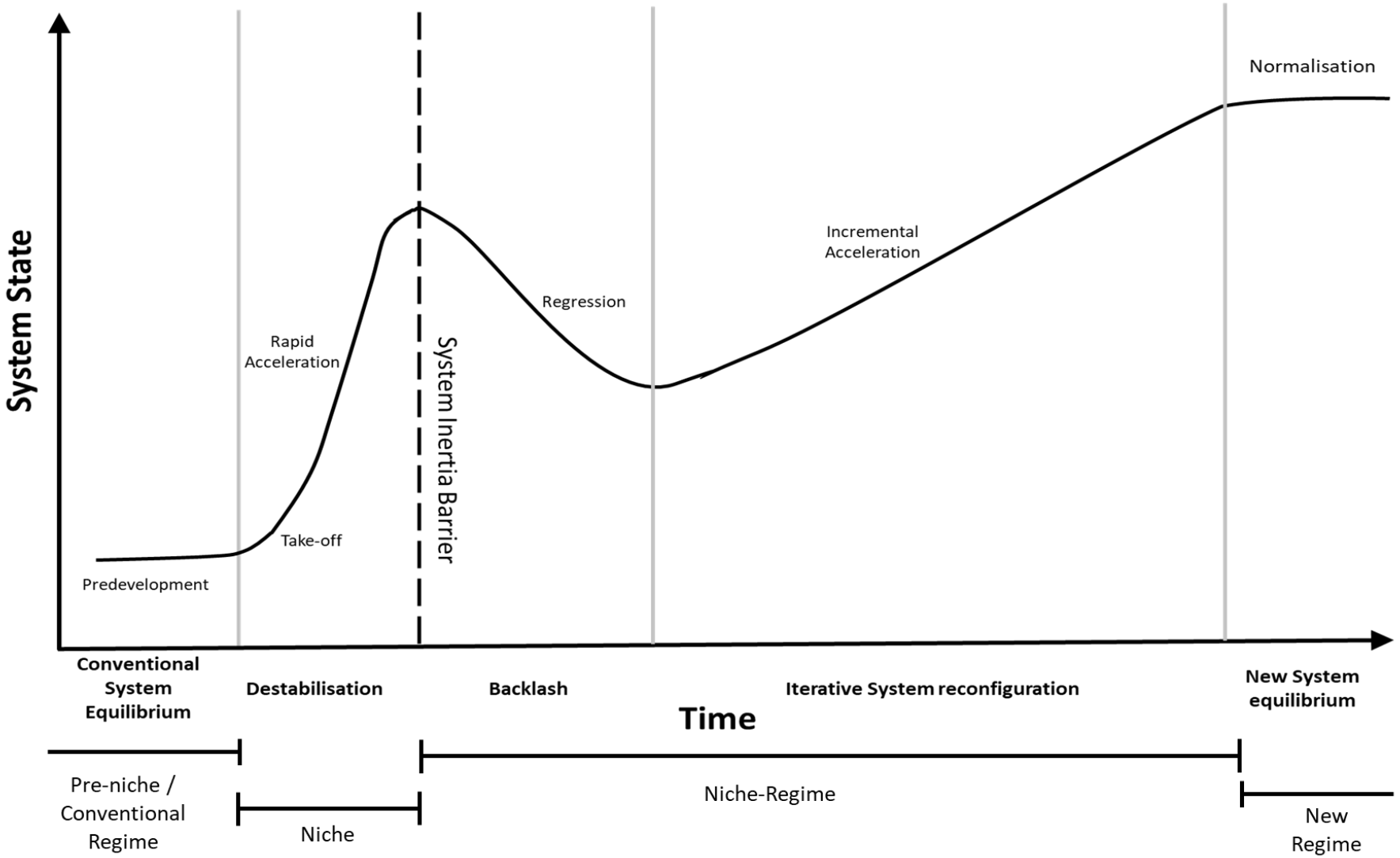


Figure 6-3: The *Iterative Reconfiguration Pathway* to transition: an alternative pathway for Sustainability Transitions incorporating Rogers et al. 2015's innovation constellation stages.

The *rapid acceleration* phase is where the alternative sustainability transition pathway begins to differ from Rotmans *et al.* (2001)'s four phase transition pathway. It denotes a phase where the rapid uptake of the innovation triggers a strong push-back from the established regime, where the firmly imbedded, well established and highly inter-dependent path-dependencies of the establish regime act to push-back against the destabilising effects of the *Niche* activities (Geels 2002, Geels 2005a, de Haan *et al.* 2011). The *System Inertia Barrier* and subsequent *regression* phase depicted in Figure 6-3 symbolises this societal system push-back and associate loss of transition momentum. Informed by this study via the *Failure to Thrive* scenario (Section 5.2.1) and *Mis-alignment* concepts (Section 5.3.1.2), the *System Inertia Barrier* postulates that sustainable transitions experience an initial build-up of resistance shortly after an initial period of rapid accelerated. This effect is considered to be a likely if not inevitable consequence of the *Niche* institutional work and the highly complex sociotechnical nature of Sustainability Transitions (Van der Brugge *et al.* 2007, Rogers *et al.* 2015a, Loorbach *et al.* 2017). Therefore, the institutional work undertaken during the *Niche* stage, while essential, cannot hope to address the complexities facing the innovation as it begins its transition journey. Rather, most mis-alignments ('barriers and challenges') will only become apparent when the innovation is launched into competition with the conventional regime, bringing the path-dependencies of the conventional regime to the fore. At this point, the societal system is now 'primed' in the sense that these path-dependency mis-alignments are discoverable using techniques like those applied in this study (Section 3.10 and 3.11).

As discussed earlier in this chapter, if left unchecked, the *regression* phase depicted in Figure 6-3 could lead to a *lock-in* or *backlash* fate for the innovation. However, strategic interventions designed to disrupt the path-dependency advantages afforded to the established regime could see the early stages of *regression* turned around. Rogers *et al.* (2015a) suggest that a mix of cultural cognitive, normative and regulative institutional work (Scott 2008) could achieve the full range of institutions required to facilitate the evolution of the innovation constellation to *Regime* status. The *Iterative Reconfiguration Pathway* to transition depicted in Figure 6-3 concurs with this proposition. But as the *Incremental Acceleration* phase is meant to emphasise, given the dynamic, unpredictable and complex nature of Sustainability Transitions, successful transition is likely to be best served by an adaptive and iterative change process, potentially spanning decades (Rotmans *et al.* 2009, Norman *et al.* 2015, Furlong *et al.* 2019).

Consequently, *system reconfiguration* is considered to truly begin only when this iterative process begins, where institutional work undertaken by government policy makers[39] and communities of practice work collaboratively to identify and ameliorate system mis-alignments that are preventing the transition of the sustainability innovation. Informed by the *radical change in incremental steps* paradox (Rotmans *et al.* 2009), incremental acceleration allows the system to continually adjust and be adjusted while providing the necessary time to detect and correct unintended consequences. Ideally, this pro-active, incremental approach to reconstellation will eventually see the innovation constellation evolve from Niche-regime to Regime status where system mis-alignments are ameliorated and new path-dependencies are established that sustain the sustainability innovation. Unlike the four-phase of transitions model (Rotmans *et al.* 2001), the achievement of Regime status is not defined as "stabilisation", but rather referred to as 'normalisation'. This is because *stabilisation* is defined as the "phase where the speed of social change decreases and a new dynamic equilibrium is reached" (Rotmans *et al.* 2001, P. 017). However, this definition could equally apply to the *lock-in* pathway later defined in Van der Brugge *et al.* (2007) which refers to a partial failed transition. Hence, the term 'normalisation' has been used to differentiate the end point of the *Iterative Reconfiguration Pathway* as being one of successful transition, where success is defined as the establishment of the innovation as the new regime. Ideas about exactly what constitutes

[39] Because Sustainability Transitions are a response to societal pressures rather than demand (Section 2.5.5), market forces and consumer behaviour are unlikely to be sufficient to see successful transition.

successful transition, particularly where SCMs are concerned, is given further consideration in Section 6.6.

In summary, the successful transition of sustainability innovations like SCMs from Pre-niche to Regime constellations will require long-term commitment from stakeholders and will be heavily reliant on government driven structural change (de Haan *et al.* 2011). Sustainability Transitions are as unpredictable as they are complex and, therefore, will require constant monitoring to identify intervention opportunities and correct for unintended consequences (Rotmans *et al.* 2009, Loorbach *et al.* 2017, Edmondson *et al.* 2019). Consequently, as the innovation constellation evolves from *Niche* to Niche-regime, research and development work will itself need to transition, from being primarily focused on technical development, to one that increasingly incorporates the monitoring and evaluation of the transition itself. Such a monitoring and evaluation program will need to be able to detect conventional regime path-dependency and system mis-alignments across sociotechnical scales (Geels 2004, Loorbach *et al.* 2017) in order to determine where interventions might best be focused. Given the sociotechnical complexities of such transitions, this presents a considerable challenge. However, the methods applied in this study to address research questions 2 and 3 (Chapter 3) provide an example of how such a program might be established.

6.4 Invisibility – An Achille's Heel for Stormwater Control Measures

The analysis of survey data collected for this study identified three over-arching issues contributing to the under-maintenance of SCMs: *Under-developed Industry*, *Invisibility* and *Policy Inertia*. While all three are considered important, *Invisibility* has been singled out for two reasons. The first is that it appears to be a unique feature of SCM technology not typically exhibited by most other forms of public infrastructure, potentially explaining its particularly slow pace of transition (Rogers *et al.* 2015a). The second and related reason is that this 'invisibility' may explain why SCMs are, as a form of public infrastructure, particularly vulnerable to under-maintenance. Importantly, the term *Invisibility*, as applied in this context, is meant both figuratively and literally, manifesting both in the physical landscape and intangibly within the societal system in multiple, interdependent ways. In accordance with the apparent criticality of this feature to the *Failure to Thrive* scenario, it is given specific consideration in this section.

The invisibility of SCMs as a barrier to the maintenance of SCMs featured strongly in the survey data, being linked to a range of concepts across the sociotechnical categories featured in Figure 5-5. For example, it was cited by several respondents as being a factor in insufficient budgeting for SCM maintenance[40], the failure to assign SCMs to teams and departments[41], and the failure to properly account for these assets in asset management plans[42]. Crucially, it was regularly cited as being the primary reason why SCMs were consigned to a low priority within councils, as demonstrated by intervention pathways *Increasing Visibility* and *Policy Realignment* both having termination points at the concept *Low Council Priority* (Figure 5-5). A key reason for this appears to be the democratic governance structures underpinning both State and Local governments and that, according to respondents[43], the community generally having no awareness of what SCMs are, nor understanding of what their purpose is.

In democratic societies, politicians who wish to seek re-election will tend to focus on issues that will get them elected, irrespective of the broader and long-term societal implications (Niskanen 1971, Canovan 1999, Kollmann *et al.* 2010). Consistent with this tendency, respondents noted that the lack of awareness of SCMs held by the community, combined with their tendency to prioritise more acute issues over the protection of local waterways (e.g. services, rates,

[40] *Ineffectual Maintenance Budgeting*, Section 5.2.2.2,
[41] *Poor Demarcation of Responsibilities*, Section 5.2.2.3
[42] *Immature Asset Management frameworks*, Section 5.2.2.2
[43] Awareness of SCMs in the community was not tested by this study

employment and transport), was generally understood by councillors. Consequently, respondents noted that councillors did not prioritise the maintenance and management of SCMs when setting the strategic direction of their council. Concepts elicited from the qualitative data, also suggest similar democratic and political implications at the state government level. Some are overt, such as the transference of waterway protection onto local government without specific mechanisms in place to cover the costs associated with the delivery of the new service[44]. Some are subtler, seeing SCMs inadvertently falling victim to machinations where their fate is likely not even considered. Politically-motivated rate-capping is one such example[45]. Another may be the tendency of senior administrators of state government departments to prioritise their department's status over the interests of the community (Niskanen 1971, Chang *et al.* 2002, Kollmann *et al.* 2010). Hence, the effects of SCM *Invisibility* play out at the local government and state government level, with implications for SCMs being both direct and indirect (Brown 2005).

While not suggesting SCMs or other sustainability innovations alone exhibit varying degrees of invisibility, it is argued that they tend to be more common where sustainability innovations are concerned. This is, in part, because, sustainability innovations are generally not offering a new type of service. Rather, they are merely replacing or augmenting one to ameliorate a perceived societal issue (e.g. environmental damage), but otherwise perform the same societal function (Markard *et al.* 2012, Loorbach *et al.* 2017). Therefore, Sustainability Transitions are not being driven by 'positive' demand for a new service or function, but rather 'negative' pressure to correct a side-effect of an otherwise established and highly integrated societal service (e.g. electricity, water supply, reticulated sewerage and flood prevention). Further, these side-effects are often perceived as distant in terms of time or geographical distance, bringing into play the effects of psychological distancing[46] (Liberman *et al.* 2008, Spence *et al.* 2012).

This 'invisibility' is particularly acute where SCMs are concerned given the various and additional ways their invisibility manifests. First, they are, by design, benign and often disguised in the urban landscape[47]. They are benign because SCMs often do not exhibit any acute symptoms when their performance reduces, or when they fail; typically being designed to bypass stormwater back into the stormwater drainage system under such circumstances. Hence, unlike conventional stormwater infrastructure, they generally do not result in acute flooding incidents when they fail. Many are also disguised to look like something else, such as a garden or natural waterbody or, as is particularly the case for many types of gross pollutant traps, are mostly hidden underground. This is partly a function of their engineering function and partly as a means of improving urban aesthetics (Section 1.2). Consequently, the local community are rarely directly impacted by SCMs if their performance wanes or they fail, and their true intention is rarely visible to the casual observer.

Unlike many types of public infrastructure, SCMs also have no direct user, i.e., no individuals that directly interact with SCMs in relation to their primary purpose (Figure 6-4). For example, roads have drivers, footpaths have pedestrians, buildings have occupants, and parks have active and passive recreators. While some SCMs are designed for passive and, very occasionally, active use, such uses are not tied directly to their primary and original purpose: the amelioration of stormwater runoff impacts on local waterways (Fletcher *et al.* 2014, Radcliffe 2019). This is considered to be problematic for SCM maintenance outcomes within the local government context, as such users act as 'natural advocates' for these technologies (Davis 1989, Venkatesh *et al.* 2000, Rogers 2010). As Figure 6-4 is intended to illustrate, public

[44] *Devolution and Cost Shifting* and *Restrictions on Local Government Revenue Raising*, Section 5.2.2.4
[45] *Restrictions on Local Government Revenue Raising*, Section 5.2.2.4
[46] The tendency of people to prioritise the importance of issues, in part, based on their temporal, social and geographical distance, and the level of uncertainty (Liberman and Trope 2008; Spence et al. 2012)
[47] *Lack of Visibility*, Section 5.2.2.8

infrastructure users and beneficiaries serve to provide important feedback loops to providers, helping to ensure such infrastructure is effectively managed and maintained.

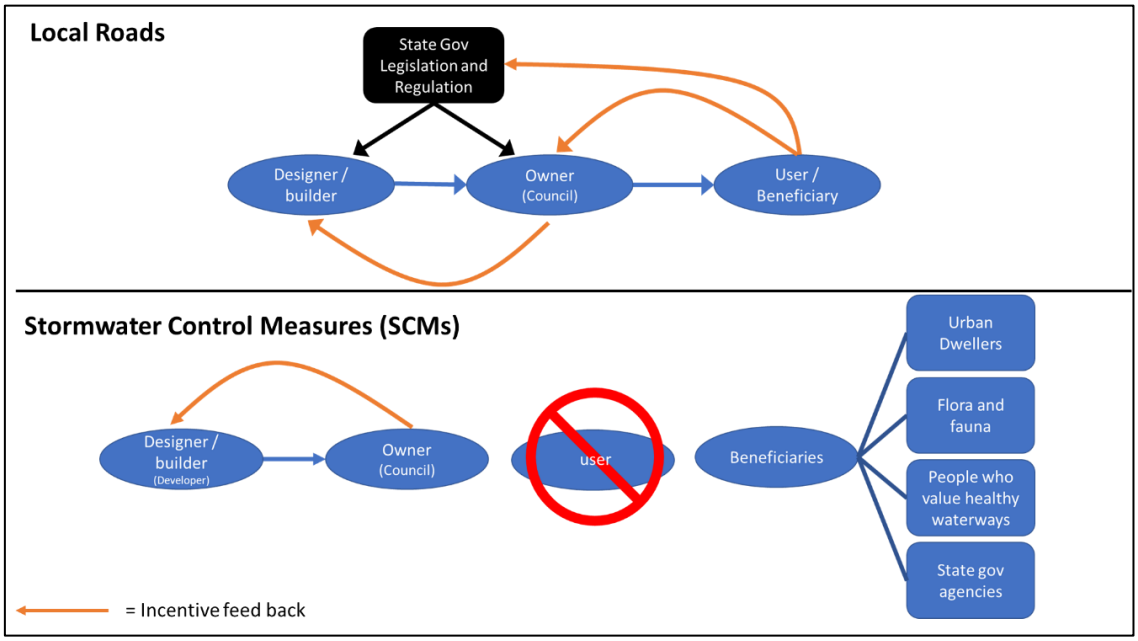


Figure 6-4: Incentive feedback loops – contrasting local roads with SCMs in local government

Further, beneficiaries (Figure 6-4), who might also act as natural advocates, are unlikely to be aware that they a receiving benefit from SCMs for two reasons. The first is that the technology is new and appears to be poorly understood by the community[48], having little time to become part of the collective societal consciousness. For example, conventional urban stormwater infrastructure (e.g. pipes, pits and channels) can be traced back between 3000 and 5000 BC (Chocat *et al.* 2001, Burian *et al.* 2002), giving ample time for their basic function and purpose to permeate into the consciousness of the public. SCMs, on the other hand, can only account, for at best, one generation (Brown *et al.* 2007, Radcliffe 2019). Second, due to the distributed nature SCMs, they are often separated from the waterbodies they protect. Therefore, beneficiaries may not even be aware of the role SCMs are playing in their benefit, nor be afforded the democratic avenues even if they were if the benefit is experienced beyond the local government area where the SCMs are located. Consequently, SCMs do not have clearly discernible group of 'natural advocates' and, as illustrated by Figure 6-4, feedback loops to councils that would otherwise encourage them to maintain and renew infrastructure are highly disrupted.

In summary, SCMs status as a sustainability innovation, their 'by-design' benign presence in the urban landscape, lack of direct user, and their disconnection with beneficiaries; renders SCMs effectively 'invisible' to the decision-making structures required to ensure their effective long-term management. While other public infrastructure technologies may share some of these factors, very few share them all. For example, while stormwater detention basins may be invisible to the casual observer, the consequences of their malfunction (i.e., flooding) are not. Similarly, while few people may not immediately recognise a freeway sound barrier, those living nearby certainly notice their absence. Therefore, the acute invisibility of SCMs represent a severe handicap within the democratic governance systems associated with local and state governments. Given the important role assigned to social aspects of transitions dating back to the seminal works of Rogers (1962), this situation has critical and potentially fatal implications for the successful transition of SCMs as a sustainability transition (Venkatesh *et al.* 2008, Loorbach *et al.* 2017, Sovacool *et al.* 2017). Therefore, if the *Failure to Thrive* scenario is to be

[48] See *Lack of Community Awareness and Support*, Section 5.2.2.5

reversed, pro-active, 'top-down' reconstellation (government led structural changes) will likely be needed to address the consequences of SCM *Invisibility* on maintenance outcomes and its transition to mainstream practice.

6.5 Intervention Pathways – Guiding Improvement to SCM Maintenance Outcomes

The final outcome of the sequential analysis process applied to answering Research Question 3 was the postulation of the three 'intervention pathways', i.e., *Industry Capacity Building*, *Enhancing SCM Visibility* and *Policy Realignment* (Figure 5-5). Informed by the three over-arching issues abstracted from the inductive analysis of the survey data (Figure 5-1), intervention pathways propose key path-dependencies that are contributing to the under-maintenance of SCMs in Victorian local government. They do so by linking together *Mis-alignment* concepts within the Victorian local government SCM maintenance sociotechnical system and, in so-doing, illuminate where various types of institutional work should be focused and coordinated to see lasting improvement to SCM maintenance outcomes. Because the *Failure to Thrive* scenario indicates that SCM maintenance is a symptom of a loss of momentum in the transition of SCMs towards mainstream adoption, it is further proposed that focusing on these intervention pathways will also aid the transition of SCMs towards mainstream adoption. Together, these three intervention pathways represent a strategic basis for policy makers, working collaboratively with communities of practice, to focus their attention to formulate and implement interventions towards improving SCM Maintenance outcomes. The intent of this section is to give description and example to how these pathways help policy makers and communities of practice in this endeavour.

The intervention pathway *Industry Capacity Building* (Figure 5-5) illuminates how mis-alignments in the Victorian Local Government SCM Maintenance Sociotechnical System are culminating to create a shortage in SCM operational knowledge in Victorian local councils (*Gaps in Expertise*). As the arrows indicate, the path-dependencies that are contributing to this shortage in SCM operational knowledge trace back to *Research and Development Gaps*, linking a range of issues associated with collaboration (*Communities of Practice*) and professional training (*Limited Training & Education Opportunities*). This pathway is largely concerned with cultural-cognitive type institutional work (Scott 2008), focusing on the building of experiential knowledge and the development and refinement of implementation tools (Table 2-1). The survey data indicates that experiential knowledge should focus more on developing knowledge in SCM operation and maintenance. This suggests a need for longitudinal studies that establish long-term performance of different systems and how different maintenance treatments effects performance over time.

The survey data also indicates that implementation tools (e.g. guidelines, manuals, procedures, etc.) need continued development, involving the refinement of those that exist and the development of those that are still required. As the two-way arrow between *Research & Development Gaps* and *Communities of Practice* is intended to illustrate, the development and refinement of implementation tools should be done collaboratively between research institutions and communities of practice (Brodnik *et al.* 2018). Finally, to advance cultural knowledge, the survey data suggests that there is a need to expand capacity building programs beyond niche-type programs such as Melbourne Water's *Clearwater* program by transitioning knowledge into mainstream vocational and tertiary education programs. It is proposed that this will not only help to address issues such as *Lack of Skilled Professionals* and *Sporadic Commercial Resource Expertise*, but also act to support inter-generational change, encouraging professional perspectives that see SCMs and the stormwater management philosophies that underpin them as 'business-as-usual' practice.

The intervention pathway *Enhancing SCM Visibility* reveals the relationships between specific concepts (barriers and challenges) that, together, appear to be relegating SCMs within local councils to a low priority issue. As the arrows for this pathway are intended to indicate (Figure 5-5), this issue is, in part, a function of their design (*Lack of Visibility*) intended to protect public safety and enhance urban aesthetics (Section 1.2). Further, as discussed in Section 6.4, it is also a function of more subtle effects associated with the status of SCMs as a sustainable innovation, the lack of a direct user and degrees of separation between the technology and its beneficiaries. Given the democratic governance systems underpinning local and state government in Victoria, community engagement and education programs might seem an obvious means of *Enhancing SCM Visibility*. Indeed, such initiatives have been suggested (Sharma *et al.* 2016, Choi *et al.* 2017, Erickson *et al.* 2018). However, challenges discussed in Section 6.4, particularly psychological distancing and the lack of direct user, suggest that such programs are unlikely to be effective on their own. Further, such education programs would need to be implemented at a societal (state-wide) level, presenting significant logistical challenges and incorporating a wide range of demographic and socio-economic groups. While some communities may be amenable to such programs, such as those located within local government areas of high commitment, it is probable that most communities would prove difficult to reach (Morison *et al.* 2011, Leonard *et al.* 2014). Hence, even if these logistical challenges proved surmountable, there is no guarantee that even a well-educated community would prioritise SCMs over other local government services (e.g. safe roads, rubbish collection, tidy streetscapes, rate charges, etc). Consequently, addressing the invisibility of SCMs and its role in the relegation of SCMs to a *Low Council Priority* (Section 5.2.2.3) is likely to require normative and, in particular, regulative institutional work.

The connection of the Intervention pathway *Policy Realignment* with Intervention Pathway *Enhancing SCM Visibility* via the Mis-alignment concept *Low Council Priority* highlights the likely important role of particularly state government in addressing the consequences of the low visibility of SCMs (Figure 5-5). For example, normative work might include addressing ambiguity regarding state government agency and local government responsibilities concerning waterway protection[49] (Section 2.3.3). Further, existing and future strategic planning and policy documents for state and local government should include specific mention of the link between public expectations around waterway protection and effective management of SCMs. Regulative work might mean looking further afield and addressing current gaps in state government legislation concerning local government asset management practices (Section 2.3.2). Such an approach has precedent in the form of the Victorian *Road Management Act*, brought into law to ensure local and state roads were managed in a systematic way. Regulative work could also involve modifications to 'resource mobilisation' mechanisms (Table 2-1) to address consequences associated with *Restrictions on Local Government Revenue Raising* and *Financial Constraints*. For example, the introduction of a stormwater service charge like that available in NSW, or similar means of stormwater management / waterway protection specific revenue raising (DLG 2006).

Further highlighting the inter-connectedness between the intervention pathways, Figure 5-5 also shows important connectivity between *Policy Realignment* and the previously discussed *Industry Capacity Building* pathways. This connectedness is illustrated via the concept *Funding Programs' Consequences*, connecting with *Research & Development Gaps*, *Limited Training Opportunities* and *Communities of Practice.* The relationship between *Policy Realignment* and *Industry Capacity Building* is primarily about shifting the way in which state government supports different types of institutional works to facilitate better maintenance outcomes and, *ipso-facto*, helps to transition SCMs towards mainstream adoption. For example, an issue noted by several respondents was a perceived excessive emphasis of state government

[49] Since this study was initiated, the Victorian Government has initiated such a review; the Melbourne Urban Stormwater Institutional Arrangements Review (MUSIA) (DELWP 2020).

funding programs on the design and construction of new assets relative to capacity building. Hence, a solution might be to alter state government policy concerning funding distribution to focus on long-term SCM performance monitoring and maintenance interventions, and to fund projects that use the resultant knowledge to develop guidelines and standards in collaboration with communities of practice. Another example is the re-directing of state and federal government funding towards transitioning current capacity building programs from niche-type programs (e.g. Melbourne Water's Clearwater program) into mainstream tertiary institutional programs (e.g. civil engineering, town planning and natural resource management undergraduate degrees).

Importantly, the three intervention pathways for improving SCM maintenance outcomes are not intended to detract from the importance of other concepts and their associated categories. Rather, they are considered to represent critical path-dependencies that, if addressed, should see maximum benefit through varying degrees of improvement in other areas. For example, the *Mis-alignment* concepts *Perceived Inequality in SCM Responsibilities* and *Negative Perceptions of SCMs* remain important barriers given the influence such perspectives have over decision making (Fink *et al.* 1971, Lazarus 1991, Rogers *et al.* 2015a). However, they are not included in an intervention pathway as they will likely see redress through interventions that address concepts elsewhere within the SCM maintenance sociotechnical system. For example, enabling councils to raise revenue to fund this additional service (*Restrictions on Local Government Revenue Raising*) and clearing up ambiguity surrounding state and local government responsibilities (*Policy Inertia)* will likely see amelioration of *Perceived Inequity in SCM Responsibilities*. Likewise, a shift in focus of funding towards long-term performance of SCMs and the inclusion of integrated stormwater management into mainstream education institutions will likely see a shift in *Negative Perceptions of SCMs*.

In summary, the intent of the three 'intervention pathways' is to guide policy makers and communities of practice as to where their efforts should be focused to facilitate lasting improvement to SCM maintenance outcomes. They do so by linking up *Mis-alignment* concepts in likely key path-dependent relations within the Victorian Local Government SCM Maintenance Sociotechnical System that are, based on this study, considered to be working against the effective maintenance of SCMs. Therefore, the goal of policy makers and communities of practice should be to work collaboratively to identify potential interventions, guided by these intervention pathways. The example interventions offered above are offered to illustrate how these intervention pathways might be used. Crucially, however, actual interventions will need to be derived by policy makers in close collaboration with stormwater management and waterway protection communities of practice such that those who best understand the issues are able to influence action. Further, even under such collaborative arrangements, given the complex sociotechnical nature of the problem of SCM maintenance, close monitoring of the impacts of solutions implemented will be necessary to avoid unintended consequences and to identify new opportunities (Rotmans *et al.* 2009, Norman *et al.* 2015).

6.6 Failure to Thrive and Insights About what Constitutes a Successful Transition.

Transitions science is concerned with the social, technical and organisational processes behind the technology adoption (Section 2.4). But what exactly is adoption, and what does it look like? How do we know that the technology has successfully transitioned, and a new regime equilibrium has been established? For the most part, a successful transition tends to be measured in the uptake of a technology in terms of the number of units taken up (e.g. sold or built), or how much a technology gets used (Venkatesh *et al.* 2007, Rogers 2010). When market systems are involved and where there are clear and direct relationships between technology and user, such measures have merit. However, despite the accelerated uptake of

SCMs by local government since 2006 in Victoria, the findings of this study and others suggest the mainstream adoption of SCMs is still some way off (Rogers *et al.* 2015a, Choi *et al.* 2017, Furlong *et al.* 2019). Hence, correlating increasing rates of SCM uptake by local government with the acceptance of SCMs as a mainstream stormwater management solution risks drawing false conclusions (Onori *et al.* 2018).

The reasons for this go to the heart of SCMs as a sustainability innovation. Where transition of technology is typically driven by demand, Sustainability Transitions are instead driven by external societal pressure acting on a conventional regime (Geels 2004, Markard *et al.* 2012, Loorbach *et al.* 2017). Typically, that pressure manifests in the form of dissatisfaction with a side effect of a service delivered at the societal level that is otherwise considered essential to the function of the society. For example, fossil fuel power generation and climate change or, in the case of urban stormwater management, flood protection and waterway degradation (Geels 2004, Radcliffe 2019). Victorian local government experiences this pressure to change their stormwater management practices predominately in the form of regulative directives (e.g. changes to the Victorian Planning Provisions) and political pressure, particularly in councils where environmental leaning councillors and community groups are present (Morison *et al.* 2011). Consequently, while these pressures may lead to the uptake of SCM technology by a given council, it does not necessarily mean the council, as a bureaucratic entity, is committed to them (Morison *et al.* 2011). Nor does it necessarily mean that the stormwater industry, as a whole, considers SCMs as a mainstream stormwater management solution (Madsen *et al.* 2017).

Consequently, a different means of indicating when mainstream adoption of SCMs is needed that can detect when the societal system has changed sufficiently such that a new system equilibrium that systematically sustains SCMs has been reached (Figure 6-3). By drawing on the *Mis-alignment* concepts elicited from the survey data for this study (Section 5.3.1.2, Figure 5-5), institutional conditions that might reflect the mainstream adoption of SCMs in Melbourne are proposed in Table 6-1. These are provided in terms of Scott's (2008) three pillars of institutions and their interpretation within the context of the Melbourne's urban water system (Rogers *et al.* 2015a). Because SCM maintenance was found to be a likely consequence of issues with the transition of SCMs as a sustainability innovation, Table 6-1 gives exemplification to the idea of 'normalisation' introduced in Section 6.3. As discussed above, where Sustainability Transitions are concerned, successful transitions cannot necessarily be considered to have been achieved based purely on technology uptake, particularly when viewed over the long-term[50]. As the *Iterative Reconfiguration Pathway* (Figure 6-3) is intended to articulate, the up-take of technology is a necessary part of the beginning of transition process, not its end point. Rather, a successful transition for sustainability innovations is proposed as being a function of the *iterative system reconfiguration* stage, where institutional work is undertaken to correct systemic mis-alignments and establish new path-dependencies that sustain the innovation. Table 6-1 gives exemplification to this from the perspective of SCMs, i.e., the amelioration of the *Mis-alignment* concepts identified in Section 5.3.1.2.

In concluding, it is important to note that where Sociotechnical Transitions are concerned, successful transition does not necessarily mean the creation of a perfect system. Rather, successful transition may simply mean that the manner in which the sustainability innovation is managed and perceived merely reflects the general nature of the broader societal sociotechnical system. The *Independent* concepts (Section 5.3.1.2, Figure 5-3) developed in relation to SCM maintenance by this study give illustration to this idea. These concepts capture barriers and challenges to the maintenance of SCMs that are considered to be primarily a function of pre-existing conditions within the broader Victorian local government public

[50] Figure 4-4, Section 4.2.1 illustrated this, revealing a correlation between asset age and declining condition, suggesting that while the council is increasingly constructing new SCMs, they may not yet have been 'normalised' into the councils collective consciousness and systems.

infrastructure management sociotechnical system. While they do effect maintenance outcomes for SCMs, they do so in a way that effects all forms of public infrastructure delivered through Victorian local government. Consequently, they are a function of issues associated with the broader sociotechnical system associated with the management of public infrastructure by local government, not the transition of SCMs *per-se* (Section 3.11.3). Hence, where SCMs are concerned, the successful transition of SCMs, at least from a management and maintenance perspective, is reflected by the amelioration of the *Mis-alignment* concepts, i.e., their 'normalisation' relative to the broader local government public infrastructure sociotechnical system.

Table 6-1: Institutional conditions reflecting mainstream adoption of SCMs in Melbourne from a maintenance perspective (proposed).

Type	Condition	*Mis-alignment Concepts*† ameliorated	Example indicators
Cultural-cognitive	Meanings, language, narratives and symbols associated with SCMs are settled across CoPs. Issues captured by concepts *Limited Training & Education Opportunities.*	*Limited Training & Education Opportunities* *Lack of Skilled Professionals* *Gaps in Expertise* *Sporadic Commercial Resource Expertise.* *Poor demarcation of Responsibilities* *Negative Perceptions of SCMs*	Low levels of interpretive flexibility between Individuals, irrespective of department, organisational, sector and professional background. Professional development delivered through mainstream educational institutions (universities, TAFE and other RTOs).
	Technology development is now in an advanced state. Scientific knowledge and empirical data are now focused on long-term performance optimisation (including maintenance interventions) and sociotechnical integration.	*Research & Development Gaps* *Lack of Skilled Professionals* *Gaps in Expertise* *Negative Perceptions of SCMs*	SCMs are generally accepted as delivering improved service outcomes relative to conventional approaches. Scientific research is now about optimisation and refinement, with a focus on longitudinal studies.
	Tacit knowledge, practical experience, skills in operating and maintaining technologies are now a primary focus of research and development activities.	*Research & Development Gaps* *Lack of Skilled Professionals* *Gaps in Expertise* *Sporadic Commercial Resource Expertise.* *Poor demarcation of Responsibilities* *SCM Planning Deficiencies*	CoP are now predominately concerned with the optimisation of SCM operation, maintenance and integration within the broader institutional context, with issues concerning technology development and adoption now mostly settled. Existing implementation tools are being refined and gaps in such tools are being filled.
	The bulk of relevant procedures, templates, guidelines, routines, manuals, models and frameworks now considered to exist.	*Research & Development Gaps* *Communities of Practice*. *Design and Construction flaws* *SCM Planning Deficiencies*	CoP are now focused on the optimisation of implementation tools rather than addressing gaps in their existence. Implementation tools are now largely standardised and available through entities such as Standards Australia and the ISO, as well as IPWEA and other peak body publications.
Normative	Existing state and local government policy, strategies and plans reflecting public expectations concerning urban planning and waterway protection, making a direct link to SCMs role in achieving these. These are reflected in similar local government strategy and planning instruments.	*Policy Gaps* *Low Council Priority* *Gaps in Council Goal Setting and Guidance instruments.* *Limited Corporate Awareness*	Consistency between councils and state government policies, strategies and plans is high. Importantly, public expectations are reflected in the service levels articulated in council asset management strategies and plans.
	Lines of collaboration between policy makers and CoP are formally established. CoP include bodies associated with urban planning and waterway protection, as well as stormwater management.	*Policy gaps* *Legislation & Regulation Consequences and gaps* *Funding Programs' Consequences* *Communities of Practice* *Research and Development Gaps*	CoP work closely with state government to set agendas and develop policy directions and implementation tools accordingly (standards, guidelines, manuals, models, etc). State government policy and associated funding programs are guided by CoP.

Type	Condition	*Mis-alignment Concepts*† ameliorated	Example indicators
	Roles and responsibilities concerning the establishment, maintenance and renewal of SCMs are clearly articulated in state government policy documents and, where appropriate, regulative instruments.	*Low Council Priority* *Perceived Inequity in SCM responsibilities* *Development Control Limitations & Failures* *Ambiguous Asset Ownership* *Lack of Positional Authority*	Low levels of interpretive flexibility within CoP. Formal obligations are uniformly captured in legislative instruments and articulated in official state agency and peak body publications. SCM maintenance outcomes are comparable to other types of public infrastructure delivered through local government. Technology has been integrated into the governance structures of local government, with roles and responsibilities of departments and positions established. Hence, SCMs within individual councils are no longer reliant on the presence of champions (Taylor 2009).
	Uniformly articulated in state government policy documents and regulative instruments. Reflected in local government commitments.	*Policy gaps* *Gaps in Council Goal Setting and Guidance Instruments* *Poor demarcation of Responsibilities*	Low levels of interpretive flexibility within CoP and associated publications. Goals and commitments reflected in publicly available council urban development, environmental and asset management policies and strategies.
	The development of accreditation, benchmarking, best practice guidelines, design standards, codes of practice and industry recognition is driven by CoPs and supported by state government.	*Sporadic Commercial Resource Expertise* *Research and Development Gaps*	Design standards and best practice guidelines are available through entities such as Standards Australia and the ISO, as well as IPWEA and other peak body publications. Local government SCM asset management practices comply with current asset management practices (e.g. *Local Government Asset Management Better Practice Guide*). Industry recognition occurs beyond the stormwater industry, e.g. Municipal Association of Victoria.
Regulative	Service delivery and revenue collection between governments, private sector and general community are established and understood. Focus is now on ironing out revenue streams and equity issues.	*Policy Gaps* *Perceived Inequity in SCM Responsibilities*	Due to involvement of CoPs, there are low levels of interpretive flexibility concerning the delivery of SCM related services between state government agencies, developers and local government. Service delivery and financial reporting mechanisms at local and state government levels are aligned accordingly.
	Roles and responsibilities, of state government, local government and the private sector (particularly developers) are adequately reflected in relevant legislations, regulations and codes. Hence, issues Contributing to SCM *Invisibility* have been largely addressed.	*Legislation & Regulation Consequences and Gaps* *Low Council Priority* *Limited Corporate Awareness* *Lack of Positional Authority* *State Planning Mechanisms' Consequences*	Improved maintenance outcomes (reflected in asset condition audit data). Senior management awareness of SCMs within councils is measurably higher (reflecting same low levels of interpretive flexibility as CoP). Key asset management performance indicators include SCMs. Methods for the collection of operational data is uniform across councils.

Table Notes: TAFE – Technical and Further Education institutions; RTO – Registered training organisations; ISO – International Organisation for Standards; IPWEA – Institute of Public Works Australasia; CoP – Communities of Practice; † – *Mis-alignment* concepts: As described in Section 5.3.1.3, these concepts represent mis-alignments with the Victorian local government SCM maintenance sociotechnical system.

7 Conclusions

7.1 Introduction

The impetus for this study was concerns that stormwater control measures (SCMs) managed by local government in Victoria, Australia were not being effectively maintained. SCMs, a form of sustainability innovation, are a relatively recent infrastructure solution to urban stormwater management that has seen sporadic introduction throughout various parts of the world in the late 20th and early 21st Century (Radcliffe 2019). While SCMs provide additional services such as improving urban aesthetics and biodiversity, their primary purpose is to mitigate the environmental impacts of convention pit, pipe and channel approaches to stormwater management on receiving waters (Fletcher *et al.* 2014). Using a mix of civil ('grey') and environmental ('green') engineering, they do so by reducing stormwater flow energies to urban waterways and improving stormwater quality. In Victoria, the uptake of SCMs by local government accelerated in the mid-2000s (Rogers *et al.* 2015a). This uptake was driven primarily by changes to state planning provisions that required residential developments to meet specific stormwater environmental targets along with state government grant funding programs designed to encourage councils to retrofit systems in existing developments. However, since this period of accelerated uptake, concerns have continued to grow that SCMs are not being effectively managed and maintained. Accordingly, this raised concerns that the intended benefits of these new type of stormwater management infrastructure may not be delivering the environmental benefits intended, raising concerns not only about waterway protection, but also the significant investments made in research and development, implementation and stormwater industry transformation.

Table 7-1: Restatement of research questions

Research Question 1	How well are SCMs being maintained by municipal government?
Research Question 2	What barriers and challenges effect SCM maintenance within Victorian local government?
Research Question 3	What intervention pathways might see long-term improvement to SCM maintenance outcomes in Victorian local government?

To address these concerns, this study set out to answer three research questions, restated here in Table 7-1. The purpose of Research Question 1 was to first ascertain the veracity of the concerns regarding the under-maintenance of SCMs. The purpose of Research Question 2 was to understand why SCMs under the remit of Victorian local councils might be at risk of under-maintenance, the findings for which were used as a basis to address Research Question 3. A mix of quantitative and qualitative data was used to address these Research Questions. This data was collected primarily from nine councils within the Australian state of Victoria, chosen for their likelihood to have had direct experience managing SCMs (Figure 7-1).

The Quantitative data was used to address Research Question 1. It took the form of SCM condition inspection data provided by the councils that participated in this study and closed ended questions included in the questionnaire sent out to respondents. To compare findings to that found for these Victorian councils, similar studies from jurisdictions beyond Victoria were also used as a data source. Qualitative data used to address Research Question 2 was collected from 54 personnel working across eight of the councils that participated in this study using a mostly open-ended questionnaire and semi-structured interviews. Analysis of the qualitative data was via abstraction based on the Grounded Theory Method. The results of this analysis were subsequently used to address Research Question 3 using a heuristic model developed specifically for this study. This model and the stepwise processes that were used to

postulate the intervention pathways drew on sociotechnical systems thinking and theory, as well as a word similarity analysis of the qualitative data set and findings from the literature review (Chapter 2).

Method = Nonprobability Purposive Sampling → experience with SCM management + Diversity of council type

Stage 1 = Recruitment of Councils: 12 approached → 9 participated ('participating councils')

Stage 2 = Recruitment of council employees from participating councils to complete questionnaire: 74 approached → 54 participated ('respondents')

Stage 3 = Recruitment of individual respondents to undertake follow-up Interviews: 54 approached → 39 participated

Figure 7-1: Sampling method process and resultant recruitment outcome for this study. Note that while nine councils provided condition data for Research Question 1, only eight participated in questionnaire and follow-up interview stages (Research Question 2).

This concluding chapter begins by directly responding to each of the research questions. This includes a summary of what was found, how the answers were arrived at, and what their implications and / or applications are. The chapter then looks to the bigger picture, detailing how this research adds to the scholarship in terms of its contribution to Sustainability Transitions research and theory, the investigation of complex, sociotechnical problems and its contribution to the practice of stormwater management. It then concludes with a discussion of the key limitations of the study and how these limitations inform opportunities for further research.

7.2 Answering the Research Questions

As discussed in the previous section, three research questions were proposed to investigate concerns regarding the maintenance of SCMs by local government in Victoria. Answers to each question produced by this study are summarised below:

> *Research Question 1: How well are SCMs being maintained by municipal government?*

The purpose of Research Question 1 was to test the veracity of concerns that SCMs on Victorian local government were not being affectively maintained. The approach taken was quantitative, drawing on and comparing three sources of data: (1) SCM asset condition audit data collected by participating councils; (2) closed-ended questionnaires included in the survey questionnaire sent out to respondents; and (3) similar studies undertaken in other jurisdictions beyond Victoria's borders. This third data source was utilised to ascertain whether the findings for Victoria bore resemblance to other jurisdictions, or if the problem is unique to Victoria.

While only three of the nine councils that participated in Research Question 1 were able to provide consolidated SCM condition inspection data sets, all three revealed low proportions of SCMs being in a good working order at the time of inspection. Results for Council A and Council I were particularly low at only 4% and 11% respectively, with over half of Council I's assets identified as being in need of significant maintenance interventions, retrofit or rebuild to return them to acceptable working order (Figure 4-1). While Council E appeared to have

performed somewhat better, cross referencing against SCM construction dates indicated that this was, at least in part, a function of the relatively young age of Council E's SCMs rather than effective maintenance practices (Figure 4-4). Questionnaire data results were generally consistent with asset condition data findings, with only 2% of respondents indicating that most of their SCMs were in good working in order. Similarly, when asked about how sophisticated their councils were in managing their SCMs, only 5% indicated that their councils did so in accordance with good asset management practice (IPWEA 2011, LGV *et al.* 2015).

The review of published studies that looked specifically at the question of SCM management and maintenance outcomes in jurisdictions beyond Victoria found similar results. While the number of articles available were quite low despite an extensive search of journal databases, the geographical spread of these articles was reasonably wide, taking in parts of North America, Europe and other Australian states. All studies concluded that SCMs were either suffering from insufficient maintenance or were at risk of being so due to sub-standard asset management practices. Several of these studies also found that relevant public entities exhibited shortcomings in SCM asset management, including *ad-hoc* or non-existent condition auditing, lack of asset registration, and poor record keeping (Drake *et al.* 2008, Erickson *et al.* 2009, Goonetilleke *et al.* 2011). Hence, the under-maintenance of SCMs by Victorian local government does not appear to be a problem unique to Victorian.

In summary, the empirical evidence collected and analysed to address Research Question 1 supports concerns that SCMs are being under-maintained by Victorian councils. This finding is particularly pertinent given that the nonprobability purposive sampling method employed, targeted councils more likely to be performing above average relative to other Victorian councils. Accordingly, these results indicate that other councils within Victoria are likely to be managing and maintaining their SCMs at similar levels, if not worse. The characteristics of the data collected to answer Research Question 1 also give insight into the shortcomings concerning the maintenance of SCMs by Victorian councils. Notably, only three councils were able to produce datasets, none of which used data collation and scoring methods consistent with recommend practice (IPWEA 2012, LGV *et al.* 2015). Further, none of these three councils collected their SCM condition data based on an established, condition inspection program. Rather, they did so as a first-off due to internal concerns that assets were not properly registered on the respective councils' asset registers. Hence, the evidence collected for this study indicates that SCM asset management practices within Victorian councils is likely well below recommended standards (IPWEA 2011, LGV *et al.* 2015)

> *Research Question 2: What barriers and challenges affect SCM maintenance* within Victorian local government*?*

The purpose of Research Question 2 was to understand why SCMs are vulnerable to under-maintenance. Given the paucity of research on this topic, an explorative and inductive approach was taken using qualitative data collected from participating council employees who, in some way, were involved in the management and maintenance of SCMs (Figure 7-1). The method chosen was based on the Grounded Theory Method (Charmaz 2006, Glaser *et al.* 2006, Bryant *et al.* 2007b), where concepts, categories and issues were abstracted from the qualitative dataset (Figure 3-5). This data collection and analysis process elicited 55 separate barriers and challenges ('concepts') to the maintenance of SCMs in Victorian local government. Nine 'sociotechnical categories' were subsequently abstracted from these 55 concepts:

- Professional Perspectives and Behaviours
- Deficiencies in asset management
- Council Governance & Structural Issues
- Government Policy Repercussions

- Local Government Election Cycle
- Capacity Building and Support Gaps
- SCM Biophysical Sensitivity
- SCM Constitution
- Local Government Human Resources Challenges.

Three over-arching issues were identified from the abstraction of these concepts and categories that are considered to capture the key issues contributing to the problem of SCM under-maintenance (Figure 5-1). These are: (1) an *Under-developed Industry* that is not yet able to provide the knowledge, expertise and skilled professionals necessary to effectively manage SCMs throughout their operational life cycle; (2) government *Policy Inertia*, particularly at the state government level that has not kept pace with the uptake of SCMs by local government; and (3) the *Invisibility* of SCMs in terms of their presence in the urban landscape and, *ipso-facto*, the consciousness of the body politic. The over-arching issue *Invisibility* appears to be a uniquely acute feature of SCMs, playing a key role in SCM under-maintenance, relegating the management and maintenance of SCMs to a low priority within Victorian local government. This 'invisibility' appears to be associated with the constitution of SCMs themselves, where their engineering, service provision and operational philosophy work against community awareness of their existence. Given the democratic nature of local and state governments in Australia, it appears that this invisibility likewise renders SCMs 'invisible' to the democratic process, making SCM management and maintenance vulnerable to short-term cost saving measures in favour of higher profile projects and issues.

The Grounded Theory informed abstraction processes culminated in an overall finding that the problem of SCM maintenance is a symptom of another, underlying issue. Given the term *Failure to Thrive*, this overall finding suggests that the under-maintenance of SCM is symptomatic of a loss in momentum in the transition of SCMs from novel stormwater management solution to an accepted, mainstream practice for managing urban stormwater runoff. The high number of concepts abstracted, their distribution across nine sociotechnical categories and the overall *Failure to Thrive* scenario identifies the problem of SCM under-maintenance as a complex sociotechnical problem, and one associated with the transition of SCMs as a sustainability innovation.

> *Research Question 3: What intervention Pathways might see long-term improvement to SCM Maintenance outcomes?*

The complex, sociotechnical nature of the problem of SCM under-maintenance in Victorian local government indicated it would not be amenable to simple, binary solutions as attempting to do so would risk wasted effort and unintended consequences (Rotmans *et al.* 2009, Norman *et al.* 2015). Consequently, Research Question 3 was framed towards developing 'intervention pathways' that identified relationships between key concepts identified in response to Research Question 2. In order to propose such intervention pathways, the concepts and categories identified in Research Question 2 first needed to be given 'form and function' in terms of their relevance and relationships within the 'Victorian local government SCM maintenance sociotechnical system'. This was achieved via a three-step process developed specifically for this study that drew on sociotechnical systems thinking and theory.

The first step involved 'mapping' the concepts and their categories onto a heuristic model of the Victorian local government SCM Maintenance sociotechnical system (Figure 3-6). This heuristic model was developed by merging the Multi-layer Perspective underpinning Geels's Sociotechnical Transitions Theory (Geels 2002, Geels 2004) with the generic model for sociotechnical systems published in Davis *et al.* (2014). Concepts and their associated categories were then mapped onto this model based on their point of origin within the Victorian

local government SCM maintenance sociotechnical system (Figure 5-2). The mapping process illustrated that while many concepts and categories occurred within local government ('the Regime'), many others did not. Some were associated with the technology's constitution and its development ('the Niche'), whereas others were associated with factors beyond local government ('the Landscape'), such as state government, the community and the stormwater industry. Accordingly, this first step illustrated that the problem of SCM under-maintenance was not wholly attributed to local government, but also a range of issues beyond local government.

The second step gave the heuristic model further dimension by differentiating the concepts based on their relationship with the Victorian local government SCM maintenance sociotechnical system (Figure 5-3). Termed the "Concept Causation Test", this test allocated each of the 55 concepts to one of three classifications. The first was *Intrinsic* concepts, being concepts that were a primarily function of the engineering and operational philosophies of that define SCMs[51]. The second classification, *Independent* concepts, referred to those concepts known to pre-date the introduction of SCMs into Victorian local government, being a function of issues with the broader Victorian local government and public infrastructure management system (Sections 2.3). The third classification identified those concepts that were primarily a result of the introduction of SCMs into Victorian local government. Concepts allocated to this third classification are considered key concepts as they represent "'mis-alignments' and instability" (Geels 2004, p. 914) within the Victorian local government SCM maintenance sociotechnical system. Given the term *Mis-alignment* concepts accordingly, these concepts are considered priority issues as, through their amelioration, they are likely to directly address the *Failure to Thrive* scenario and, *ipso-facto*, see lasting improvement to SCM maintenance outcomes[52]. The resultant revised heuristic model revealed 26 *Mis-alignment*. While many fell within the Regime (local government), others also fell beyond local government into the Landscape and Niche sociotechnical scales, further illustrating that the problem of SCM maintenance in Victorian local government is not solely an issue with local government (Figure 5-3).

The third and final step involved testing the degree to which respondents tended to link together different concepts in cause and effect relationships. Due to the high number of individual references within the qualitative data set (3,095, Appendix G), this test was undertaken by applying a word similarity analysis between all 55 concepts using NVivo 12's word similarity analysis tool (Pearson correlation coefficient). This test produced a dendrogram revealing how closely respondents, as a group, associated different concepts together (Figure 5-4). Guided by the three over-arching issues derived in relation to Research Question 2, the results of the word similarity analysis and the three steps were used in conjunction with the researchers comprehensive understanding of the qualitative dataset to postulate three 'intervention pathways' (Figure 5-4): namely *Industry Capacity Building*, *Increasing SCM Visibility* and *Policy Realignment*. Deriving their names conversely from the over-arching issues from which they are based, these 'intervention pathways' show key relationships between *Mis-alignment* concepts, providing a strategic basis upon which policy makers working collaboratively with communities of practice should focus their efforts towards improving SCM maintenance outcomes.

[51] The only way to address these concepts is to remove SCMs from Victorian local government.

[52] This does not suggest *Independent* concepts are not important. This is certainly not the case. Rather, *Mis-alignment* concepts specifically relate to the introduction of SCMs, which is the focus of this study. Further, as Section 2.3.2 describes, many of the issues captured by the *Independent* concepts have proven intractable despite decades of academic and government inquiry.

7.3 Contributions of the Research

7.3.1 Contributions to Sustainability Transitions

Sustainability Transitions is a relatively new and evolving field within the broader Transitions Sciences (Markard *et al.* 2012, Loorbach *et al.* 2017). It is concerned with the complexities of innovation transitions that are intended to correct the long-term consequences of conventional practices adopted at a societal level (Rotmans *et al.* 2001, Elzen *et al.* 2004, Brown *et al.* 2008, Markard *et al.* 2012). Sustainability Transitions emphasises the broader societal factors that lead to the disruption of conventional practices and, conversely, also act against the innovation (Van der Brugge *et al.* 2007, de Haan *et al.* 2014, Loorbach *et al.* 2017). Analysis undertaken in relation to Research Question 2 identified the problem of SCM maintenance as exhibiting sociotechnical complexity and likely symptomatic of the transition of SCMs as a sustainability innovation. Consequently, theories and ideas associated Sustainability Transitions were utilised to develop tools and methods for addressing Research Question 3 (Section 3.11) and to interpret the possible implications of the *Failure to Thrive* scenario (Section 6.2). Successful transitions are typically expressed using various forms of the s-curve, such as the Multi-Layer Perspective (Geels 2002, p. 1263, fig. 5) and the Four Phases of Transitions proposed by Rotmans *et al.* (2001). Deviations from this s-curve, signify failed transitions, such as those variants offered by Van der Brugge *et al.* (2007) that were utilised in this study to discuss the potential implications of the *Failure to Thrive* scenario (Figure 6-1).

During the process of applying and using these theories, it became apparent that a loss of transition momentum (i.e. deviation from the S curve) did not necessarily have to herald a failed or partially failed transition. Accordingly, this study offers an alternative pathway to successful transitions for sustainability innovations (Section 6.3). It accommodates and seeks to explain that slowdowns and regressions in transition momentum may be an inevitable part of the Sustainability Transitions journey. It postulates that such losses in transition momentum are an inevitable consequence of the complexities of societal level transitions and, providing action is taken, points at which the system is 'primed' (ready) for intervention and reconfiguration. Informed by the *Failure to Thrive* scenario and reflecting the *radical change in incremental steps* paradox derived from complexity theory (Rotmans *et al.* 2009), this alternative pathway introduces new concepts, stages and phases to illustrate the *Iterative Reconfiguration Pathway* to successful Sustainability Transitions (Figure 6-3).

The *Iterative Reconfiguration Pathway* postulates that due to the complexities associated with Sustainability Transitions, pre-niche and niche preparation work are unlikely to pre-empt most of the issues that are likely to arise as the innovation begins to compete with the established regime. Rather many, if not most, will only become apparent once the innovation comes into play and the conventional societal system is allowed to push-back against it. To do so, the conventional system needs to be stimulated into a response, likely through regulative and normative institutional stimulus. The intent of this stimulus is to trigger a rapid uptake or influx of the innovation such that the sociotechnical system experiences a rapid change in system state. Accordingly, this *rapid acceleration* results in the *destabilisation* of conventional sociotechnical system, bring system mis-alignments to the fore (Geels 2002, Geels 2004). Due to system complexity, this rapid acceleration results in a push-back against the influx of the innovation as the innovation comes up against the path-dependency relationships that sustain the conventional practice. Given representation as the *System Inertia Barrier* in *Iterative Reconfiguration Pathway* (Figure 6-3), this barrier represents the limits of the sociotechnical system to change of its own accord, causing the transition to lose momentum. At this point, if left unchecked, it is likely that transition system will result in partial or total failed transition (Van der Brugge *et al.* 2007, Rotmans *et al.* 2009).

However, the *Iterative Reconfiguration Pathway* developed by this study proposes that this loss of momentum also signals that the sociotechnical system is now 'primed', ready to be investigated. This is because the influx of the innovation has destabilised the system and, in doing-so, stimulated system mis-alignments. These mis-alignments signal where reconfigurations are needed to create counter path-dependencies that favour the conventional practice and create new path-dependencies that favour the innovation (de Haan *et al.* 2011, Rogers *et al.* 2015a, Loorbach *et al.* 2017). Accordingly, the sociotechnical system is now ready to be explored and system mis-alignments teased out using explorative and inductive techniques such as those applied to Research Question 2 (Section 3.10). Using techniques such as those applied to Research Question 3 (Section 3.11), these system mis-alignments can then be used to develop a strategic basis upon which interventions can be formulated and instituted in order to begin the process of *iterative system reconfiguration* (Figure 6-3). The goal of this pro-active, institutional work driven reconfiguration process is to facilitate the steady alteration of the sociotechnical system such that the innovation achieves *normalisation* through the creation of a new regime (Scott 2008, Rogers *et al.* 2015a). The term *normalisation* has been used as the end point of a successful transition to acknowledge that successful transition does not necessarily mean the establishment of a perfect system. Rather, successful transition means that the manner in which the sustainability innovation is managed and perceived merely reflects the general nature of the broader societal sociotechnical system (Section 6.6).

Importantly, the *Iterative Reconfiguration Pathway* proposes that pro-active institutional work is a fundamental requirement for societal type Sustainability Transitions. This is because of their high complexity, the difficulties associated with reconfiguring path-dependencies that may have developed over thousands of years[53], and that sustainability innovations are a response to societal pressure, not a direct demand for a service or technology. The importance of the differentiation between societal pressure driven change and demand driven change is well illustrated by the Melbourne SCM experience. SCMs are not being driven by a demand for SCMs *per-se*, but rather a response to community pressures related to waterway protection. Hence, while these societal pressures appear to have been enough to see SCMs proceed past the *take-off* phase, the findings of this study indicate that such pressures may not be enough to sustain them. Informed by the *Failure to Thrive* scenario, the *Iterative Reconfiguration Pathway* therefore proposes that incremental, pro-active institutional work will be required if transition is to proceed successfully beyond *take*-off. This will not only require the development of an effective intervention strategy, but also ongoing investigation and monitoring of the transition system itself to manage uncertainty and identify new intervention opportunities as the transition system moves towards *normalisation* (Rotmans *et al.* 2009, Norman *et al.* 2015, Edmondson *et al.* 2019).

7.3.2 Contributions to Tackling Complex Sociotechnical Problems.

Policy makers are increasingly facing societal level problems that exhibit complex sociotechnical characteristics and are proving notoriously difficult to solve (Norman *et al.* 2015, Edmondson *et al.* 2019). Such complex sociotechnical problems are as wide ranging and numerous as they are unique, and each must be addressed according to its own unique circumstances (Rotmans *et al.* 2009, Davis *et al.* 2014). While theories and models have been developed to help analysts conceptualise complex societal problems, the search continues to find methods for deciphering the complex path-dependencies and managing their inherent uncertainties (Norman *et al.* 2015, Edmondson *et al.* 2019). By addressing the problem of SCM under-maintenance in local government, this study provides a novel example of how explorative,

[53] For example, conventional approaches to urban stormwater management can be traced back to between 3000 and 5000 BC (Section 1.2).

inductive research can be combined with sociotechnical systems thinking to decipher their underlying causes and develop evidenced-based strategies for their amelioration.

By applying Grounded Theory Method techniques to qualitative data collected from those closest to the problem, this study was able to identify 55 separate challenges and barriers ('concepts') spread across nine sociotechnical categories (Figure 5-1). Accordingly, this finding demonstrated the complex sociotechnical nature of the problem, which in turn informed the manner and expectations of the approach taken to improving the SCM maintenance outcomes. Importantly, through the abstraction of the 'over-arching issues' and 'overall finding' (Figure 5-1), the method used was able to illuminate the underlying nature of the problem, i.e., the *Failure to Thrive* scenario (Section 5.2.4). This scenario indicated that the problem of SCM under-maintenance was likely a function of problems with the transition of SCMs as a sustainability innovation. The importance of these findings lies in how they steered this study towards sociotechnical systems thinking and Sustainability Transitions to develop a systematic process for proposing systematic intervention pathways to improve SCM maintenance outcomes.

To facilitate an understanding of the problem of SCM maintenance and its manifestation, a model of the Victorian local government SCM maintenance sociotechnical system was created. This model was created by merging the Multi-layer Perspective underpinning Geels (2004)'s Sociotechnical Transitions Theory and Davis *et al.* (2014) generic model for sociotechnical systems. This model was then used to produce a 'map' of the concepts and their categories according to where within the Victorian local government SCM maintenance sociotechnical system. By combining inductive methods with sociotechnical systems thinking in this way, a model was produced that enabled the complex sociotechnical problem of SCM maintenance to be visualised, providing a heuristic means of postulating strategic approaches to ameliorate the problem. While it is acknowledged that such problems are, by nature, always subject to uncertainty (Norman *et al.* 2015), the combination of methods applied in this study provide a demonstrable means of formulating amelioration strategies that are based on rigorous investigation. Hence, they provide an evidenced-based platform to inform the amelioration of a complex sociotechnical problem (SCM under-maintenance in local government) that, given the nature of complex sociotechnical problems, is a necessary step towards their amelioration (Rotmans *et al.* 2009, Norman *et al.* 2015).

7.3.3 Contributions to Practice – Urban Stormwater Management

The initial impetus for undertaking this research was growing concerns that SCMs in Victoria were not being effectively maintained. By setting out to address these concerns, this research contributes to the stormwater management industry in three important ways. One, it provides the first consolidated empirical evidence for the under-maintenance of operational SCMs in Victoria. Hence, it provides evidence that the concerns are justified and, in so doing, adds to growing evidence published in other jurisdictions across the world that there may be a problem with the adoption of SCMs as a stormwater management solution. Secondly, this study appears to be the first to approach the question of SCM transition from the perspective of their management as a form of public infrastructure and, in-so-doing, has provided a unique perspective on the transition of SCMs. Third, it provides an evidenced-based strategic basis upon which to focus efforts towards improving the management and maintenance of SCMs that should also help progress the transition of SCMs towards 'normalisation' as a stormwater management infrastructure solution in Victoria.

A possible reason why no academic or government reports have been published concerning the condition of operational SCMs in Victoria is the logistical challenges associated with collecting SCM asset condition data from a large enough sample size. To undertake such a task directly would require the mobilisation of considerable resources to inspection multiple SCM assets

across multiple local government areas, made more challenging by the variety of skills required (e.g. hydrology, civil engineering, water quality, and plant identification and health). This study overcame this hurdle by requesting and analysing recent SCM asset condition data collected by the councils that agreed to participate in this study. The collection and analysis of third party was not without compromise, most notably the lack of control over the methods used to collect, collate and score the assets. However, it also meant that this study was able to make inferences about the sophistication of asset management practices by comparing the methods used relative to those recommended by current industry standards (IPWEA 2011, IPWEA 2012, LGV *et al.* 2015)

Importantly, this research provides what appears to be the first study that attempts to understand why SCMs appear to be at risk of under-maintenance. While there have been studies that investigate the maintenance and management of SCMs, these studies have been oriented towards demonstrating insufficient maintenance, not understanding why it is happening (Section 4.3). Further, while there have been several studies concerning SCMs in the state of Victoria, their focus has been oriented towards their adoption, with routine maintenance and management only given cursory mention, if at all (Rogers *et al.* 2015a, Brodnik *et al.* 2017, Madsen *et al.* 2017). Most only report on how far SCMs have progressed in terms of their transition and how this informs and fits with sociotechnical and transitions theory. Very little practical guidance is offered to policy makers, communities of practice and local government towards *normalising* these assets such that they are managed and maintained systematically like any other established form of public infrastructure. Given the findings for Research Question 1 and Research Question 2, it is apparent that the effective maintenance of SCMs is a problem of SCMs and one that appears to be a function of problems with their transition. By changing the orientation of the research questions towards the question of SCM maintenance rather than their transition *per-se*, this research not only offers a basis upon which to focus efforts towards improving SCM maintenance outcomes, but also valuable insights into how to prevent a potential lock-in or backlash fate for SCMs as a sustainability innovation. In doing-so, this study demonstrates that by understanding how a sustainability innovation is managed and operated by the organisations and entities that are charged with its implementation, valuable insights into its transition can be extracted and used to facilitate its transition towards successful regime change.

7.4 Limitations and Opportunities for Further Research

Perhaps the most pertinent limitation of this study is the restriction of the qualitative data set to the perspectives of those employed in local government. As the findings to Research Question 2 and Research Question 3 illustrate, the many issues contributing to the problem of SCM under-maintenance in Victorian local government are not solely a function of local government. Hence, the perspectives of representatives within stormwater management communities of practice beyond local government, including state government agencies, consultants and contractors, would likely add important value to this research topic. This is particularly so given the complex sociotechnical nature of the problem, where different perspectives are likely to yield different insights and understandings (Rotmans *et al.* 2009, Norman *et al.* 2015). Accordingly, it is recommended that future studies incorporate such perspectives. However, it is noted that given the research focus, the views of those in local government remain central to the problem. Hence, future research could greatly benefit by using the findings of this study as a basis to expand inquiry through workshops as well as quantitative studies that utilise the findings to design quantitative questionnaires.

It is also important to note that the *Iterative Reconfiguration Pathway* proposed in this study is very much theoretical. While its proposal is based on the findings of this study and the work of others as described in Section 6.3, it is a theory that still needs further supporting evidence to refine and verify. Ongoing study of the SCM transition process in Melbourne, particularly

involving the implementation of the intervention pathways proposed by this study, offers an ideal situation to do this. Further, it is necessary to investigate the ideas and concepts underpinning the *Iterative Reconfiguration Pathway* with the transitions of other types of sustainability innovations to ascertain the degree to which its generalisations translate across various types of Sustainability Transitions. Likewise, it would also likely be beneficial to compare Sustainability Transitions under different types of government systems to see how these different systems facilitate and impede societal level change towards more sustainable practices.

By virtue of the decision to take an explorative and inductive approach, the findings associated with Research Question 2 and, therefore, Research Question 3 must be understood as postulations rather than tested and verified 'truths'. The decision to take such an approach was based on the lack of published research on the topic and concerns that the potential complex sociotechnical nature of the problem would render quantitative methods at high risk of errors of omission due to their reductive parsimony (Lucas *et al.* 2007, Schwarz *et al.* 2007). Given the high number of concepts spread across multiple sociotechnical categories abstracted from the qualitative data set, the decision to take an explorative, inductive approach has been justified. Irrespective of the merits of this decision, the limitation concerning the level of uncertainty attributable to the findings for Research Question 2 and Research Question 3 still holds. However, while the findings may not be verified and tested 'truths' in the quantitative sense, confidence in their estimation of the true nature of the problem of SCM maintenance is founded in that they are demonstrably "grounded in data" (Glaser and Strauss 2006, P.33). Accordingly, given the complex sociotechnical systemic issues involved, the methods chosen, and the findings determined thereof can be considered as a reliable interpretation of the problem and its amelioration.

To conclude, it is also noted that sometimes limitations can themselves provide unexpected insights. For example, a key limitation identified in relation to Research Question 1 was the limited number of councils able to provide condition audit data for their SCMs. Compounding this limitation were the different methods used by the three councils who did provide consolidated data sets, raising concerns about comparability of the condition ratings between these three councils. Yet had it been feasible to collect this data specifically for this study using a standardised method, important information derived from these third-party datasets may have been missed. For example, the fact that six of the nine councils could not provide appropriately consolidated datasets provided insight into the *ad-hoc* nature of SCM asset management, particularly given that the sample group selection process was biased towards better performing councils. Also, the fact that the three councils that were able to provide useable datasets had collected their data inconsistent with recommended practice shed further light on the inconsistent and *ad-hoc* nature of SCM asset management. Hence, while the use of third-party data may be messy and introduces uncertainty, it can also bring with it interesting and important insights. As Barney G. Glaser himself puts it: "All is data" (Glaser 2001, p.147), where even the quality, nature and shortcomings of the data itself can provide important insights into the nature of phenomenon being studied.

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Appendix A – Council Request to Participate Letter

Professor Tim Fletcher
Professor of Urban Ecohydrology

xxx April 2016

xxx xxx, CEO
xxx xxx Council
xxx
xxx. VIC xxx

Dear xxx,

The University of Melbourne (UoM), in collaboration with Melbourne Water, is currently conducting research into the long term-performance of stormwater assets that are designed to reduce environmental impacts on local waterways. These assets, termed Stormwater Control Measures (SCMs) include raingardens, constructed wetlands, porous pavements, swales and gross pollutant traps.

Like any physical asset, SCMs require appropriate operation and maintenance regimes to sustain service levels over their operational life. Evidence to date suggests that the operation and maintenance of SCMs may not be occurring at levels required to ensure optimal performance and operational life expectancy due to a range of economic, institutional and resourcing issues. Research is urgently needed to help provide guidance to asset managers, particularly those within local government where many of these assets are held.

The research being conducted by the UoM and Melbourne Water aims to address this information gap by collecting, collating and analysing information from asset owners and operators.

The success of this research is dependent on effective key stakeholder engagement, i.e. gathering information from a range of professionals working for local councils and related industries. It also offers your organisation the opportunity to influence policy and potentially funding for SCM maintenance. To facilitate this high level of stakeholder engagement we are seeking xxx Council's agreement in participating in our research in the following ways:

- Allowing our researchers to engage with your staff involved in various aspects of SCM operation and maintenance through a questionnaire and follow up interview process (refer to Attachment 1 and Attachment 2).
- Access to reports and / or data directly related to SCM condition assessment completed in the last three years (if available).
- Access to policy documents related to urban water management and asset management.

Ethics approval has been granted for this research (Ethics Application ID 1545197.1) as detailed in Item 5 of Attachment 1. To gain this approval, the researchers were required to demonstrate the establishment of strict protocols to protect participating organisations' and individuals' privacy and confidentially.

If xxx Council is willing to participate in this research, could you please advise me by way of responding to this letter (email is preferable) and by identifying an appropriate contact within your organisation to liaise with our research team? When responding via email, please send to tim.fletcher@unimelb.edu.au and CC in Andrew Thomas (thomasa2@student.unimelb.edu.au).

If you have any questions, please do not hesitate to contact me. Also, If you have any concerns about this proposal and seek independent verification of its content, you are welcome to contact the Executive Officer, Human Research Ethics, The University of Melbourne by phoning 03 8344 2073 or fax 03 9347 6739 and quoting the ethics application ID number: 1545197.1.

Yours sincerely

Tim Fletcher
Professor of Urban Ecohydrology

Faculty of Science
The University of Melbourne, 500 Yarra Boulevard, Burnley Victoria 3121
T: 03 9035 6854 M: 0407 517 662 E: tim.fletcher@unimelb.edu.au

Appendix B – Information for Respondents (Questionnaire)

INFORMATION FOR PARTICIPANTS

Research Title

Long-term Performance and the Barriers to Maintaining Distributed Stormwater Control Measures.

1. **Background**

Over the last two decades, there has been an increasing awareness of the value and role that stormwater control measures (biofiltration systems, constructed wetlands, gross pollutant traps, swales, etc.) can play in improving the storm flow and water quality regimes of local waterways. Cities around the world have been installing them in public spaces as part of urban renewal and "greenfield" (new) developments. A large proportion of these assets fall to government agencies to manage (mostly local governments). However anecdotal information suggests that many agencies are facing barriers that limit their capacity to maintain and operate this relatively new asset class.

2. **Overall Project Aim**

This research aims to understand how well stormwater control measures (SCM) are currently being operated and maintained by local governments and to ascertain what barriers are reducing their capacity to do so.

It is intended that the knowledge derived from this project will be used to develop better targeted strategies, policies, plans and programs to help improve the operation and maintenance outcomes for SCM (including rectification works).

3. **What we (the researchers) need from you.**

Initially, we are asking you to fill out a questionnaire designed to get an understanding of your professional views based on your lived experience as a professional involved in aspects of SCM operation and maintenance. If you are willing, we would also like to follow up with an interview to make sure we understand the meaning and intent of your responses.

The information extracted from your responses (questionnaire and interview), along with a small group of others, will be used to develop a tick-box survey that will be distributed "en-masse" at a national scale. Consequently, the information you provide will be critical to the quality of the tick-box survey and, therefore, the overall quality of information that will be gathered for use by policy makers.

For these reasons, what we need most from you is your professional and candid responses to the questions in the questionnaire provided.

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

WATERWAY ECOSYSTEM RESEARCH GROUP

4. How do you participate?

To participate, please take the time to fill out the questionnaire. This questionnaire should take roughly 20 minutes to complete (depending on how much detail you wish to provide). At the end of the questionnaire you'll be asked to give an expression of interest to participate in a face to face interview with Andrew, one of the researchers listed at the end of this document (Item 8).

You may fill out the questionnaire by following either one of the following two options:

- Completing the questionnaire on-line (web-based) by clicking here. If this link does not work, copy and paste the following URL into the web address field of your web browser (make sure the whole address is copied). Note that, depending on your Council's internet protocols, access to the web-based questionnaire may be blocked. In such circumstances, you can contact your IT department to get access, or simply print out and fill in the PDF version (see next bullet point).

https://docs.google.com/forms/d/1U1fACdlxj-BE5Od0H557vh0799lzi3bMNtFNGcQywRo/viewform?usp=send_form

- Printing out the PDF version of the questionnaire provided with this information document, filling it in by hand, and sending it to us using the envelope provided marked "confidential".

If you have any technical questions about accessing, filling in and / or submitting responses, please contact Andrew Thomas (contact details as per Item 8 of this document).

5. How will we protect your confidentiality?

Your confidentiality in participating in this questionnaire and follow up interview is protected by law. In accordance with the *Australian Code of the Responsible Conduct of Research*, the *National Statement on Ethical Conduct in Human Research* and Statute 17.1, Regulation 17.1.R8 *Code of Conduct for Research of the University of Melbourne*, the identities of those responding ("respondents") to this questionnaire must, by law, be strictly protected. In order to ensure that both you and your organisation's identities are protected, the researchers have successfully applied for ethics approval (Ethics Application ID 1545197.1), which includes the following protocols that must be followed by the researchers to protect respondents' identities:

- All responses, whether they be hardcopies or electronic, go directly to the authorised researchers (i.e., they will not pass through a third party, including your employer).
- Your responses will not be made available to any individuals or organisations other than the four researchers approved to view your responses (as listed in Item 8 herein).
- Hardcopy responses are sent directly to the authorised researchers in a sealed envelope marked "confidential" and will be kept in a single location known only to the researchers under lock and key.
- Email (electronic) responses will be kept on a stand-alone, password protected storage device kept at a location known only to the researchers, under lock and key. Once stored, emails will be immediately and systematically deleted from the designated email address inbox.
- On completion of the research project, your responses will be destroyed (maximum storage period is 5 years).
- Respondent names will not be used in any publications, reports, presentations or other forms of information distribution.
- A coding system will be used to ensure specific organisations and their employees cannot be identified in any publications, reports, presentations or other forms of information distribution that include data captured in this questionnaire.

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

6. **Do I have a right to withdraw at any time?**

Yes. Participation in this study is entirely voluntary. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so.

7. **Where can I get further information?**

If you require any further information or have concerns, please do not hesitate to contact any member of the research team as per the Contact Details below (item 8). Should you have any concerns about the conduct of the project and do not feel comfortable contacting the research team, you are welcome to contact the Executive Officer, Human Research Ethics, The University of Melbourne, on phone: (03) 8344 2073, or fax: (03) 9347 6739.

8. **Researchers and funding**

This project is funded primarily by an Australian Post Graduate Award scholarship and Melbourne Water. It is being undertaken as part of a PhD candidature with Melbourne University's School of Ecosystem and Forest Science. The researchers and their organisations are provided in the table below. This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1).

Student Researcher and Primary Contact:	
Andrew Thomas PhD Candidate **M:** 0400 539 011 **E:** thomasa2@student.unimelb.edu.au	Student No. 717175 The Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
Lead Researcher:	
Dr Darren Bos **P:** 03 8344 9248 **E:** dbos@unimelb.edu.au	Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
Co-Researcher:	
Prof Tim Fletcher **P:** 03 9035 6854 **E:** timf@unimelb.edu.au	Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
Co-Researcher:	
Dr Peter Morison **P:** 03 9679 6808 **E:** Peter.Morison@melbournewater.com.au	Manager Land, Liveability & Stewardship Melbourne Water

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

WATERWAY ECOSYSTEM RESEARCH GROUP

Appendix C – Questionnaire

THE UNIVERSITY OF MELBOURNE

WATERWAY ECOSYSTEM RESEARCH GROUP

Questionnaire: Barriers to Maintaining Stormwater Control Measures

Welcome to the Waterway Ecology Research Group's questionnaire for professionals involved in the operation and maintenance of stormwater control measures. This questionnaire should take you roughly 20 minutes (more or less), depending on how much detail you wish to provide.

Before beginning, please note the following definitions:

Stormwater Control Measures (SCM): infrastructure designed to protect the flow regimes and / or water quality of local waterways. Typical SCMs include constructed wetlands, biofiltration systems (e.g. raingardens), vegetated swales and gross pollutant traps (GPT).

Operation and Maintenance (O&M): activities associated with maintaining the performance of existing assets over time, including inspection, cleaning, repairs, modifications and re-builds.

Barriers: For the purpose of this questionnaire, a barrier is any impediment preventing you / your council from effectively operating and maintaining SCM, whether these be related to ineffective policy (internal or external), technical barriers, skill and resourcing barriers, issues with organisation structure, organisation culture, funding allocation, expenditure tracking, etc.

IMPORTANT NOTE: Space has been allocated to allow for hand written responses to each question. However, there is no restriction on how much (or how little) you can chose to provide in your responses. Should you find that the space allocated to a question is not sufficient, please feel free to continue your answer using A4 size paper and attach them to the back of this questionnaire. If / when you decide this is necessary, please begin each extended answer with the question number to which it is related.

1. About you

An individual's technical background and role within an organisation affects their perceptions and experiences. Consequently, the following questions may provide important insights into how to better targeted policy and programs.

However, we (the researchers) acknowledge that there may be some concerns that this information could be used to identify individuals. To protect you, we have established protocols that ensure that the details you provide cannot be used to trace your identity as described by item 5 of the Information for Participants sheet that should have accompanied this questionnaire. These protocols have been vetted and approved by the University's Human Ethics Board (Ethics Approval ID: 1545197.1), hence the researchers, by law, must adhere to these protocols.

Q1.1. Which council do you work for?

Q1.2. What qualifications / certifications do you hold?

Q1.3. What is the title of your current role?

Q1.4. How long have you been in your current role?

Please tick only one box.

- ○ less than 1 year
- ○ 1 to 2 years
- ○ 3 to 5 years
- ◉ 5 to 10 years
- ○ Longer than 10 years

Q1.5. How long have you been employed by the council you currently work for?

[This question assumes that you've held more than one role with the council that you currently work for. If you haven't, just put the same answer as you did for the previous question.]

Please tick only one box.

- ○ Less than 1 year
- ○ 1 to 2 years
- ○ 3 to 5 years
- ○ 6 to 10 years
- ○ Longer than 10 years

Q1.6. Which department do you work for and what SCM related functions is it responsible for?

[This may include things like forward planning; budgeting; supervising or physically doing on groundworks, cleaning GPTs; landscaping; inspection; structural maintenance; etc.]

Q1.7. In your own words, what functions and responsibilities are you actually responsible for regarding SCM O&M in your current role?

[The researchers recognise that official position descriptions (PDs) do not always reflect what a person actually does in their work roles. What the researchers need here is what you actually do, not necessarily what your official PD states.]

2. Current practices at your council

The following questions are designed to obtain your views on how well SCMs are being managed at your council. We would like to understand what you think is the case based on your existing knowledge and experience.

Q2.1. Generally speaking, which statement best reflects the condition YOU consider your council's SCMs to be in?
Please tick only one box.

(●) MOST (90% or more) of council's SCM can be expected to be operating at, or close to, optimal, requiring only minor maintenance to maintain this standard.

( ) MANY (70-90%) of council's SCM can be expected to be operating at, or close to, optimal, requiring only minor maintenance to maintain this standard. However, some assets require major cleaning, maintenance or rebuild to restore their optimal operational performance.

( ) SOME (40-70%) of council's SCM can be expected to be operating at, or close to optimal, requiring only minor maintenance to maintain this standard. However, many assets require major cleaning, maintenance or rebuild to restore their optimal operational performance.

( ) FEW (less than 40%) of council's SCM can be expected to be operating at, or close to, optimal, requiring only minor maintenance to maintain this standard. However, most assets require major cleaning, maintenance or rebuild to restore their optimal operational performance.

( ) I am unsure, as I don't have a sense on their performance or am not directly involved in assessing or observing their performance.

If you'd like to add an explanation to further clarify or explain your answer, please do so here:

Q2.2. Generally speaking, which statement best reflects the level of sophistication YOU consider your council exhibits regarding SCM operation and maintenance (O&M)
Please tick only one box.

◯ EXCELLENT: The O&M of SCM is integrated into council's existing asset management system, with periodic and / or predetermined maintenance triggers that adequately reflect on-ground needs of each system. O&M planning is effectively communicated to relevant staff. Council has access to a sufficient number of appropriately trained personnel to undertake SCM O&M.

◯ O.K.: The O&M of SCM is being undertaken by Council, however deficiencies in the application of council's asset management system, O&M planning procedures, communication and / or access to sufficient numbers of capable personnel is resulting in a moderate reduction in the effectiveness of SCM O&M.

◯ POOR: The O&M of SCM at your council is ad-hoc and / or seriously deficient, creating the potential for some assets to receive no maintenance (getting "lost" in the system), whilst many others are receiving insufficient and / or inadequate maintenance.

◯ I am unsure, as I don't have a sense of council's asset management system or am not directly involved in using such systems.

If you'd like to add an explanation to further clarify or explain your answer, please do so here:

Q2.3. Are there any types of SCM that in particularly receive less O&M attention at your Council? If so, which types and why do you think this is the case?

3. SCM operation and maintenance barriers

We are interested in your views on the barriers that are currently hindering your ability to undertake your SCM related O&M functions, and those that are hindering your council as an organisation.

Q3.1. Thinking about your role, what barriers are currently reducing your capacity to affectively execute your functions and responsibilities concerning SCM O&M (if any)?

Q3.2. Thinking about your Council as an organisation, what barriers are reducing its capacity to effectively manage SCM O&M (if any)?
[When thinking about this question, consider internal factors (e.g. Systems, culture, governance, expertise, knowledge, funding and resources) and external factors (e.g. community expectations and perceptions, politics and state government policy.]

Q3.3. In contrast to the previous two questions, are there any specific tools, programs or policy that currently facilitate (help) you and / or your council to pro- actively operate and maintain their SCM?

4. Opportunities for improving SCM O&M

The following two questions seek to understand your views on what solutions might help improve SCM operation and maintenance outcomes. The first is specific to you / your role, and the second is broader, relating to your council as a whole.

Q4.1. Thinking about your role, what would help you more effectively carry out your responsibilities for SCM O&M (if any)?

Q4.2. Thinking about your Council, what do you see as potential solutions to improving your Council's capacity to better manage SCM O&M (if any)?

[When thinking about this question, consider internal factors (e.g. systems, culture, governance, expertise, knowledge, and resources) and external factors (e.g. community expectations and perceptions, politics and state government policy).]

5. Other?

Q5.1. Is there anything else you would like to add regarding the management of SCMs that was not covered by the previous questions?

6. Expression of Interest in participating in a follow-up interview.

Follow-up interviews provide the researchers with the means to ensure they understand the meaning and intent of your answers (a type of quality control). Should you agree to an interview, you'll be contacted by one of our researchers to establish a time and location for the interview at your convenience. You will also be provided with an information sheet describing the interview process, including protocols established to protect your privacy and confidentiality, as well as relevant contact details should you, at any time during this process, have any concerns. Note that as per the protocols established under the Ethics Application for this research (Ethics ID: 1545197.1), you are within your rights to retract your expression of interest in participating in the follow up process at any time during this process.

Q6.1. Would you be interested in participating in a follow-up interview?
Please tick only one box.

- (●) Yes – Continue to the next page
- (●) No - Go to last page (page 12).

Your details for follow up Interview

[You may fill in one or more of the contact details requested below. As per earlier statements and the Information for Participants document provided with this questionnaire, the researchers cannot, by law, provide your contact details to anyone other than the four researchers listed under item 8 of the Information for Participants brochure. However, if you're still not comfortable with adding your name and contact details here, you can elect to contact Andrew Thomas directly on 0400 539 011 or email at thomasa2@student.unimelb.edu.au.]

Q6.2. Your name

Q6.3. Mobile phone number

Q6.4. Landline

Q6.5. Email address

Finished!

On behalf of the researchers, I thank you for your time.

Please send your completed questionnaire to Andrew Thomas via email (thomasa2@student.unimelb.edu.au). If this is not possible, please call Andrew on 0400 539 011 to arrange an alternative means of providing your completed questionnaire to the research team.

If you're interested in keeping up with this research and its findings, please feel free to contact me (Andrew) using the contact details provided below

Kind regards,

Andrew Thomas

Email: thomasa2@student.unimelb.edu.au

Mobile: 0400 539 011

Appendix D – Information for Respondents (Semi-structured Interviews)

INFORMATION FOR PARTICIPANTS - INTERVIEWS

THE UNIVERSITY OF MELBOURNE

Research Title

Long-term Performance and the Barriers to Maintaining Distributed Stormwater Control Measures.

1. **Background**

This document has been provided to you because you have expressed an interest in participating in a follow up interview based on your response to Q6.1 of the *Barriers to Maintaining Stormwater Control Measures* Questionnaire (if this is not the case, please advise Andrew Thomas of the mistake as per contact details provided in Item 9 below).

2. **What we (the researchers) need from you during the interview.**

The interview process provides the researchers with the opportunity to make sure they have understood your responses correctly (a form of quality control), and to ask additional questions to further clarify your responses in the context of the research questions. As was the case for the Questionnaire, what we need most from you is your professional and candid responses to the interview questions.

3. **How long will the interview take?**

The length of time for completing the interview is roughly half an hour, however this timeline is really just a guide. In reality, the interview can go as long as you want it to (shorter or longer), depending on ow much you wish to share and what time constraints are acting upon you when the interview takes place. To facilitate your needs, the interviewer will confirm how much time you have to complete the interview process at the start of the interview, and will keep to that timeline accordingly.

4. **Voice Recording the Interview**

At the start of the interview, the interviewer (Andrew Thomas) will ask you a number of preliminary questions to make sure you understand your rights and the purpose of the interview process. This will include asking you if it is o.k. to voice-record your interview.

Voice- recording the interview is another form of quality control to ensure accuracy of the study. Any and all such recordings will not be published or provided to anyone that is not designated as a "researcher" in Item 9 (consistent with ethics approval for this study). Further, all recordings will be stored on a pass-word protected stand-alone storage device that will be erased and re-formatted on completion of the study. Irrespective, the interviewer cannot, by law, record you without your permission. If you do not wish to have your interview voice-recorded, advise the interviewer when asked.

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

WATERWAY ECOSYSTEM RESEARCH GROUP

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5. **How do you participate?**

Simply respond to the request for interview email with your preferred time and location. Because your council has endorsed this research and your participation, this may be anytime during business hours. However, if this is not convenient for you, times can be arranged outside of these hours. The location is also entirely up to you, and may include your council desk, meeting room or your preferred coffee shop, or wherever you feel most comfortable to answer questions in an unfettered manner. The only criteria we would ask you to consider is that the location is relatively quiet so as to facilitate effective communication.

Once you've provided the above information, a meeting request will be sent by the interviewer (Andrew Thomas). Then all you need to do is accept the meeting request and turn up for the interview.

6. **How will we (University of Melbourne) protect your confidentiality?**

The protection of your confidentiality as described in Item 5 of the "Information for Participants" document provided with the questionnaire remains intact regarding any and all information you provide during the interview. Put simply, the researchers are not allowed, by law and Melbourne University research policy, to divulge any information you provide during the interview that directly links you to your responses.

If, for whatever reason, you would like another copy of the "Information for Participants" document provided with the questionnaire, advise Andrew when responding to the email requesting an interview and he will send one in reply.

7. **Do I have a right to withdraw at any time?**

Yes. Participation in this study, including the interview process, is entirely voluntary. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so at your discretion. Simply advise Andrew or any of the other researchers using the contact details listed under Item 9.

8. **Where can I get further information?**

If you require any further information or have concerns, please do not hesitate to contact any member of the research team as per the contact details provided in Item 9. Should you have any concerns about the conduct of the project and do not feel comfortable contacting the research team, you are welcome to contact the Executive Officer, Human Research Ethics, The University of Melbourne, on phone: (03) 8344 2073, or fax: (03) 9347 6739.

9. **Researchers Contact Information**

The researchers and their contact information are provided in the table on the next page.

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

THE UNIVERSITY OF MELBOURNE

WATERWAY ECOSYSTEM RESEARCH GROUP

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Student Researcher and Primary Contact:	
Andrew Thomas PhD Candidate **M:** 0400 539 011 **E:** thomasa2@student.unimelb.edu.au	Student No. 717175 The Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
Lead Researcher:	
Dr Darren Bos **P:** 03 8344 9248 **E:** dbos@unimelb.edu.au	Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
Co-Researcher:	
Prof Tim Fletcher **P:** 03 9035 6854 **E:** timf@unimelb.edu.au	Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
Co-Researcher:	
Dr Peter Morison **P:** 03 9679 6808 **E:** Peter.Morison@melbournewater.com.au	Manager Land, Liveability & Stewardship Melbourne Water
Co-Researcher: Dr Stephanie Lavau P: 03 8344 0393 E: Stephanie.lavau@unimelb.edu.au	Office for Environmental Programs School of Ecosystem and Forest Science Faculty of Science Melbourne University

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

WATERWAY ECOSYSTEM RESEARCH GROUP

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Appendix E – Interviewer Guide for Executive Interviews

Interview Form

Pre-start Questions

The Purpose of this interview is to understand the challenges of operating and maintaining SCM assets within the broader context of running a Council. Questions are aimed to understand the strategic challenges rather than specific operational matters.

Do you understand that with the exception of my fellow researchers, any information provided by you must be presented in a manner that does not allow you or your council to be identified?

Do you understand that you may terminate this interview at any time and ask that information provided by you be removed from the research and destroyed accordingly?

Are you o.k. with this interview being recorded?

Interview Details

Interviewee:	
Date of Interview:	
Council:	
Location:	
Qualifications:	
Position Title:	
Department:	
Years in role:	
Years with council:	
Voice Recording file:	
Post interview review complete?:	

1. Which department do you manage and what functions is it responsible for?

2. Can you give a brief description of your council? It's socio-economic character and rate of development (e.g. is it a Growth Council).

3. From your perspective, what are the major issues facing your Council at the moment?

4. **What do you understand to be the purpose of SCM?**

5. **Do you think your community values their purpose and how often is it an issue for the Council and councillors?**

Explore the community understanding of the connection between their purpose and the assets themselves, i.e., do they understand what these assets are and how they are connected with improving waterway health.

Explore this question relative to other issues such as roads, libraries, parks, and other council services.

Explore how often issues raised at the Council / councillor levels translate to the assets themselves.

6. **From Council's perspective, what do you consider to be the risks associated with the management of these assets?**

Financial

Legal

Community perceptions

Values

7. **What systems do you have in place to ensure that these assets and their risks are properly managed? Do you think they are adequate?**

8. **Regarding SCM assets built under Clause 56 of the Victorian Planning Provisions, what are the key issues / risks currently facing Council in terms of inheriting these assets?**

9. **O.k. that is pretty much it. The last thing I need you to do is to reflect on, what do you think the major challenges for your council are regarding the ongoing maintenance of SCM?**

Deep breath, chill out and reflect

Appendix F – Information for Executive Respondents

INFORMATION FOR EXECUTIVE PARTICIPANTS

Research Title

Long-term Performance and the Barriers to Maintaining Distributed Stormwater Control Measures.

1. **Background**

Over the last two decades, there has been an increasing awareness of the value and role that stormwater control measures (biofiltration systems, constructed wetlands, gross pollutant traps, swales, etc.) can play in improving the storm flow and water quality regimes of local waterways whilst adding to the liveability of urban and suburban areas. Cities around the world have been installing them in public spaces as part of urban renewal and "greenfield" (new) developments. A large proportion of these assets fall to government agencies to manage (mostly local governments). However anecdotal information suggests that many agencies are facing barriers that limit their capacity to maintain and operate this relatively new asset class.

2. **Overall Project Aim**

This research aims to understand how well stormwater control measures (SCM) are currently being operated and maintained by local governments and to ascertain what barriers are reducing their capacity to do so. It is intended that the knowledge derived from this project will be used to develop better targeted strategies, policies, plans and programs to help improve the operation and maintenance outcomes for SCM.

3. **What we (the researchers) need from you.**

We ask for no more than half an hour of your time between now and the end of January 2017 in order to meet with Andrew Thomas (see Item 7 for details) in order to discuss your knowledge and perspectives on urban water management within the context of your role.

Note that for the purposes of accuracy and research quality assurance, Andrew will request that the meeting be recorded using a voice recording device. As per Item 4, these recordings will only be made available to the Research Team (as listed under Item 7), and will be destroyed when the research is complete. You can agree or decline this request at your discretion (it is entirely up to you).

4. **How will we (University of Melbourne) protect your and your Council's confidentiality?**

Your confidentiality in participating in the interview is protected by law. In accordance with the *Australian Code of the Responsible Conduct of Research*, the *National Statement on Ethical Conduct in Human Research* and Statute 17.1, Regulation 17.1.R8 *Code of Conduct for Research of the University of Melbourne*, the identities of those participating in this research must, by law, be strictly protected. In order to ensure that both you and your organisation's identities are protected, the researchers have successfully applied for ethics approval (Ethics Application ID 1545197.1), which

includes the following protocols that must be followed by the researchers to protect respondents' identities:

- All responses, whether they be hardcopies or electronic, go directly to the authorised researchers (i.e., they will not pass through a third party, including your employer).
- Your responses will not be made available to any individuals or organisations other than the five researchers approved to view your responses (as listed in Item xxx herein).
- On completion of the research project, all records of your responses will be destroyed (maximum storage period is 5 years).
- Participant names will not be used in any publications, reports, presentations or other forms of information distribution.
- A coding system will be used to ensure specific organisations and their employees cannot be identified in any publications, reports, presentations or other forms of information distribution that include data captured as part of this research.

5. Do I have a right to withdraw at any time?

Yes. Participation in this study is entirely voluntary. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so.

6. Where can I get further information?

If you require any further information or have concerns, please do not hesitate to contact any member of the research team as per the Contact Details below (item 8). Should you have any concerns about the conduct of the project and do not feel comfortable contacting the research team, you are welcome to contact the Executive Officer, Human Research Ethics, The University of Melbourne, on phone: (03) 8344 2073, or fax: (03) 9347 6739.

7. Researchers and funding

This project is funded primarily by an Australian Post Graduate Award scholarship and Melbourne Water. It is being undertaken as part of a PhD candidature with Melbourne University's School of Ecosystem and Forest Science. The researchers and their organisations are provided in the table over page. This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1).

This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

WATERWAY ECOSYSTEM RESEARCH GROUP

Student Researcher and Primary Contact:	
Andrew Thomas PhD Candidate **M:** 0400 539 011 **E:** thomasa2@student.unimelb.edu.au	Student No. 717175 The Waterway Ecosystem Research Group School of Ecosystem and Forest Science Faculty of Science Melbourne University
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Co-Researcher:	
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This project has received clearance by the Human Research Ethics Committee (HREC No. 1545197.1)

WATERWAY ECOSYSTEM RESEARCH GROUP

Appendix G – Coding Meta-data

Note: the ethical approval for this research required that the names of councils and respondents who participated in this study would not be released in reports, publications, presentations or any other medium. Consequently, transcripts could not be provided with this thesis.

Nodes

Files = individual respondent transcripts
References = discrete coded text

Name	Files	References
Challenges and barriers	52	3095
Asset Management	50	923
Immature Asset Management Frameworks	35	140
Ineffectual Maintenance Budgeting	37	137
Inadequate Maintenance Scheduling	34	125
Under-utilised Information Management Systems	36	121
Fragmented Asset Information	35	115
Design and Construction Flaws	30	110
Poor Data Management	30	74
Capital Works Process Shortcomings	19	48
Reactive vs Life Cycle Management	27	46
Insufficient Investment in Asset Management	6	7
Council Governance and Structural Issues	50	855
Organisational Fragmentation	35	150
Financial Constraints	36	87
Sporadic Executive Leadership & Support	31	86
Development Control Limitations & Failures	24	78
Low Council Priority	30	75
SCM Planning Deficiencies	24	67
Limited Corporate Awareness	30	64
Lack of Asset Management Organisational Alignment	18	44
Deficient Construction Verification Processes	19	42
Gaps in Council Goal Setting and Guidance Instruments	22	40
Poor Demarcation of Responsibilities	23	38
Role Ambiguity	26	37
Contract Management Barriers	13	33
Lack of Positional Authority	10	14
Council Human Resource Challenges	43	353
Gaps in Expertise	38	201
Limits on Staffing Levels	35	152
Professional Perspectives and Behaviours	39	244
Conservatism & Neophobia	24	51
Negative Perceptions of SCMs	24	36
Professional Bias	21	36
Build bias	19	35

Nodes

Name	Files	References
Percieved Inequity in SCM Responsibilities	19	31
Risk Management Mentality	14	17
Commitment vs Indifference	12	16
Role Discrimination	7	15
Short-termism	5	7
Capacity Building and Support Gaps	39	217
Limited Training & Education Opportunities	35	101
Sporadic Commercial Resource Expertise	22	50
Research & Development Gaps	26	40
Communities of Practice	11	19
Lack of Skilled Professionals	6	7
SCM Constitution	41	174
Lack of Visibility	30	69
Uncoventional Engineering	25	67
Neoteric Consequences	14	24
Distributed Modus Operandi Repercussions	12	14
Government Policy Repercussions	34	156
State Planning Mechanisms' Consequences	13	36
Funding programs' Consequences	16	28
Devolution & Cost-shifting	15	25
Legislation and Regulation Consequences & Gaps	14	24
Restrictions on Local Government Revenue Raising	16	23
Policy Inertia	8	14
Ambiguous Asset Ownership	4	6
Local Government Election Cycle	37	139
Low Constituent Awareness & Concern	34	84
Councillor Re-election Imperative	26	55
SCM Biophysical Environment Sensitivity	12	34
Vulnerability to Biological Encroachment	6	20
Climate Hyper-sensitivity	9	14