Mental Models in Urban Stormwater Management

Ines Winz and Gary J. Brierley

School of Geography, Geology and Environmental Management, The University of Auckland
Private Bag 92019, Auckland 1142, New Zealand
Telephone 64 9 373 7599 ext. 88956, Facsimile 64 9 373 7434
i.winz@auckland.ac.nz, g.brierley@auckland.ac.nz

Abstract

Different mental models exist regarding environmental problems and solutions. To engender sustainable approaches to stormwater management, there needs to be understanding of, and engagement with, these different perspectives. This study used cognitive mapping to elicit and transparently capture perspectives of 31 stakeholders on problems, solutions and barriers to the implementation of urban stormwater management. Three core perspectives were discovered and synthesized as causal loop diagrams: conventional fixes, low impact solutions and community development.

Analysis confirms perspectives are diverse and conflicting. Each perspective has shortcomings in providing solutions that can address the perceived challenges. Therefore, the integration of solutions strategies is proposed. The implementation of low impact solutions may address environmental degradation and go some way to assist rehabilitation in the short term. In order to realise sustainable stormwater management, the long term focus must be on social learning, behaviour change and the creation of effective partnerships between communities and local authorities.

Keywords: systems thinking, cognitive mapping, soft system dynamics, urban stormwater management, New Zealand, Project Twin Streams, stream restoration, low impact development

1 Introduction

An inevitable time delay is evident between shifting perspectives regarding the most appropriate approach with which to manage environmental systems and the implementation of measures. While the sustainability agenda now presents a dominant mindset in terms of desired or even mandated practices, the ongoing deterioration of biophysical conditions is testimony to the limited effectiveness of transitional processes that promote sustainable practices. Technological solutions are a fundamental part of reformed approaches to environmental management. Critically however, they are only a part. Whole of systems thinking engages all stakeholders in reformation of practices implementing coherent plans of action that incorporate behavioral/attitudinal participatory approaches through genuine shifts in societal involvement in lifestyle choices, engagement with environmental repair and maintenance of benefits gained. Such transdisciplinary thinking provides the pivotal underpinning of sustainable practices.

Water is high on the sustainability agenda particularly in urban areas where huge investments are required to maintain increasing populations. Balancing the provision of these services, which import clean water, and export waste and excess rain water, relative to environmental, social and economic concerns is the primary objective on the journey towards sustainable urban water systems. We already live with the legacy of past perspectives and actions in solving stormwater issues, especially those associated with high-cost engineering infrastructure. As environmental planners and water managers are starting to realize that engineering infrastructure in itself will not engender sustainable outcomes (Higgs 2003), contemporary management focuses on providing 'more natural', environmentally sensitive and decentralized engineering solutions. In addition, active public engagement in environmental repair processes is proposed not only as a means to strengthen decision making arrangements and increase the likelihood of uptake and implementation of management activities, but from an understanding that a transition to systemic knowledge and environmentally friendly behavior can only occur when there are possibilities for exposure to and active engagement with local natural environments (Butler & Oluoch-Kosura 2006). However, acceptance of this shift from technological fixes to active public engagement is lacking among managers as well as the public (Folke 2007).

Pervasive degradation of urban streams and receiving environments is testimony to the fact that conventional engineering solutions are not working. This has resulted in conceptual shifts in thinking about environmental management whereby the stream ecosystem as subsystem of the larger stream network as well as surrounding watershed, are now perceived as complex adaptive socio-ecological systems for which expert-based approaches are no longer sufficient to provide effective management (Berkes 2004; Ravetz 2006; Pahl-Wostl 2007). Complex socio-ecological systems exhibit uncertainty, non-linearities and potentially chaos, a multitude of feedback processes that interact at different scales and create thresholds of ecosystem functionality and quality (Grinde & Khare 2008). The very existence of these characteristics implies a need for flexibility in the management of water resources. Any overly prescriptive solution lacks reference to stakeholder objectives and thus creates resistance for its implementation. As a result, solutions have to be developed as part of a long-term adaptive management strategy. While there are many unanswered questions about what adaptive management structures and methods are most effective, all build on underlying themes of commitment to experimentation, the use of iterative modeling processes as well as collective engagement and ownership.

It is now widely recognized that long-term sustained success in water resource management will only be achieved through adoption of participatory practices, promoting genuine societal engagement with the process of environmental repair (Higgs 1997; Gross 2002; Choi 2004; Naveh 2005; Turner 2005; 2007; Hobbs 2007). Critically, efforts to promote behavioral change with which to engender sustainable practice and outcomes must first appreciate and engage with the range of mind-sets that underpin contemporary approaches to environmental management.

Reported here is a synthesis of results from a case study that investigated key stakeholders' understanding of stormwater problems and solutions in the Project Twin Streams catchment, Waitakere City, New Zealand. Cognitive mapping was used to elucidate the different perspectives on stormwater problems and solutions of 31 research participants with different backgrounds as stormwater experts, local government officials/managers, scientists, real estate developers and residents living in the catchment.

2 Stormwater – Problems and Discourses in Management

Stormwater, the flow of water that results from rainfall events, is a disruptive natural force impacting on urban populations as well as local and regional environments. General problems caused by stormwater are the flow volume (low flows and high flows/flooding), deteriorating water quality, and infiltration of stormwater into the wastewater system which can lead to overflow events. These problems are exacerbated in an urban setting. Urban development results in an increase in impervious surface areas, e.g. roofs, roads and other paved areas, a change in vegetation cover, and the compaction of top soil. This greatly reduces infiltration of stormwater and increases run-off, substantially altering the natural water cycle (Wolman 1967; Arnold & Gibbons 1996). Urban pollutants that accumulate on impervious areas are then carried to urban receiving environments, i.e. streams, rivers, estuaries and harbors. Associated negative impacts include reductions in habitat quality and availability, amenity values, ecosystem services, among others (Paul & Meyer 2001; Bunn & Arthington 2002).

Traditionally, stormwater was piped with minimal treatment and disposed of in receiving environments as quickly as possible. Existing pipe infrastructure is inadequate in filtering the type and amount of pollutants that exist in urban areas, and insufficient given the current growth rate of the Auckland region. Overall, this strategy has lead to deteriorating receiving environments (Hauraki Gulf Forum 2008), a necessity to expensively upgrade existing infrastructure, and disconnection of citizens with their local streams and other receiving environments (Peters & Meybeck 2000; Hatt *et al.* 2004).

In a system with no or minimal anthropogenic influences, natural processes keep stormwater receiving environments intact by allowing for infiltration of rainwater into the soil, thereby slowing and detaining flows as well as improving water quality. Modern, water sensitive or low impact urban stormwater management[1] aims to mimic these processes. It has been defined as *"a design approach to site development that protects and incorporates natural site features into the stormwater management plan"* (Auckland Regional Council 2000, p. i-1).

By its very definition LID engineering solutions are decentralized, small-scale and require only minor if any built structures. LID solutions are shifted off-stream and focus on reducing imperviousness/drainage connection through the provision of permeable surfaces, e.g. vegetated swales, raingardens, roofgardens, vegetated buffer zones and house clustering (Hatt *et al.* 2004). Permeable areas keep contaminants on-site and prevent them from reaching the

[1] Common acronyms are LID - Low Impact Development (US), WSUD - Water Sensitive Urban Design (AUS), SUDS – Sustainable Urban Drainage Systems (UK), LIUDD - Low Impact Urban Design and Development (NZ). This manuscript uses LID.

stream. Local detention, e.g. in water tanks and small ponds, can reduce run-off volumes and peak flow. Source control is the reduction of contaminant input into the system. This can be achieved by, e.g. painting galvanized roofs. LID treatment techniques are associated with the use of permeable surfaces or small ponds, e.g. flocculation ponds (Auckland Regional Council 2004a, b; Roy *et al.* 2008).

In most instances, LID does not explicitly and actively promote behavior change. Note, that the label low impact design assumes a negative impact on the environment through the process of development albeit a smaller impact than in conventional development practices.

LID implementation is context driven. For example, water reuse features prominently as a technique in Australia mirroring water supply concerns, whereas in New Zealand, LID is mainly driven by stormwater quality objectives (Flynn *et al.* 2009). Urban areas in developing countries often lack basic stormwater management altogether. Here, LID is entirely absent from the management discourse (Silveira 2002; Biswas 2006; Kathuria 2006).

Recent emphasis on stakeholder involvement and social learning has promoted the establishment of local community stream restoration projects that prevent flooding and erosion on urban streams while improving environmental values (Kellert *et al.* 2000; Bernhardt & Palmer 2007; Rosenberg & Margerum 2008). These projects are often co-managed, where local authorities engage with communities and provide the support and fund activities such as clean-ups, re-vegetation, bank stabilization, channel reconfiguration to improve stream geomorphology and the acquisition of land critical for flood management. The community then drives most of the stream restoration work mainly focusing on riparian re-vegetation. Community engagement projects also attempt to raise awareness and facilitate behavior change. These projects are surrounded by much controversy because the costs are high and ecological effects in the streams are limited (Kellert *et al.* 2000; Palmer *et al.* 2005; Alexander & Allan 2007; Rumps *et al.* 2007). However, to date there are no long-term studies on their effectiveness when it comes to awareness raising and behavioral change. There are numerous assumptions when engaging in community development processes. For example, it is often assumed that reconnecting the public with their local environment results in behavior change or that this behavior change will form the basis for the development of long-term community ownership. While more research is clearly needed, evidence is emerging to substantiate claims on biological effectiveness and social change while highlighting numerous areas of opportunities for improvement (Kellert *et al.* 2000; Middleton 2001; Purcell *et al.* 2002; Pahl-Wostl 2006; Alexander & Allan 2007; Rumps *et al.* 2007).

3 Case Study – Project Twin Streams Catchment

Project Twin Streams (PTS) catchment in Waitakere City is situated between the Manukau and Waitemata harbours on the western side of the Auckland region, New Zealand. The Waitakere Ranges border the catchment in the southwest and most streams' headwaters originate there. Streams flow from the foothills of the ranges through the city's urban areas and into the Waitemata Harbour via Henderson Creek. The catchment area is 10,200 ha with rural to urban land use types. Population growth and associated urban development is predicted at o25-35% over the next 20 years (B Osborne 2008, pers. comm. 22 August). Present population size is 110,000.

Waitakere City stepped up to become New Zealand's first eco-city in 1993 with the objective of implementing Agenda 21 at the local level (Laituri 1996). As a result, programs in different areas have been implemented to provide environmentally friendly solutions (energy, building, environmental restoration, etc.). Over the years, Waitakere City Council has become a proactive local authority with numerous planning documents that actively promote and encourage LID. In 2003, Waitakere City Council was granted NZ$39.5 million (~US$25 million) in governmental funding for the Project Twin Streams (PTS) stream restoration program (Waitakere City Council 2008).

The goal of PTS is to create *"a sustainable catchment: healthy land, streams and harbours, and communities who are strong, happy, connected and responsive to the challenges that face us"* (Waitakere City Council 2008). Assumed outcomes included improved water quality and biodiversity as well as stronger communities through the involvement of local residents and community organisations in the project. The city council selects well-established and effective community organizations. Both negotiate a contract and form a partnership to restore the stream environment by re-vegetating 56km of stream banks (Waitakere City Council 2008).

The rationale for selecting PTS catchment as a case study was that the implementation of markedly different stormwater management strategies – from conventional to low impact to project aimed at environmental rehabilitation – created a substantial body of knowledge that I wanted to tap into. I was particularly interested in finding out about the underlying reasoning in engaging in different management strategies, their positive and negative outcomes as well as any problems that were experienced in their implementation. As such, PTS catchment in the context of stormwater management can be seen as an extreme case which can provide rich information and allows to *"clarify the deeper causes behind a given problem and its consequences"* (Flyvbjerg 2006, p. 229).

4 Methods

Data Collection

Non-probabilistic, purposive/expert sampling including snowballing was used to identify the 31 research participants. These are broadly grouped into stormwater experts (Exp) consisting of mainly engineers and experienced consultants, local government officials/managers (LG) that were either part of the stream restoration program Project Twin Streams (PTS) or in a management position, researcher-ecologists (RE) working in universities or research institutions, private and commercial real estate developers (D) and residents (Res) living in the catchment.

Semi-structured one-on-one interviews were held between June and September 2007. The interviews were structured around the following five questions:

- *What are the problems associated with stormwater?*
- *What are the causes and effects of these problems?*

- *What are the solutions to address these issues?*
- *What are the barriers to implementing these solutions?*
- *Can you identify the mindsets that are underlying a behavior/decision/solution?*
- *Can you identify any existing feedback situations?*

The interviewees were fully informed of the purpose of the interviews. Care was taken to minimize interviewer bias by refraining from asking leading questions other than the ones listed above, and by not introducing any ideas that may form part of the interviewee's subsequent answers, as well as being mindful of the interviewer's own verbal and non-verbal responses.

Answers were mapped out together with the participant utilizing cognitive mapping with software called Decision Explorer®[2]. Cognitive mapping captures a 'personal construct system', i.e. the elicitation of beliefs, values and expertise of decision makers relevant to the issue in hand in order to structure, analyze and make sense of written or verbal accounts of problems (Eden, 1988). The cognitive map is made up of concepts (constructs) that are interlinked to form chains or hierarchies of cause and effect/ explanations and consequences. All cognitive maps had a similar structure – from bottom to top: barriers to implementation of stormwater management techniques, solutions, problems, management goals (Figure 1).

Cognitive maps can provide a medium for problem solving but have been used here as the basis for structuring and understanding the beliefs of each participant. Maps are coded as action oriented representations of the participants' own frame of reference in order to reveal consequences or implications for all statements made. Arrows that link two concepts thus show causes or explanations, the implied action as well as its possible outcome(s). As a result, the map provides meaning not only through individual concepts but the consequences attributed to them as well as the explanatory concepts that support them.

Cognitive mapping in interviews took on average 40 minutes and resulted in cognitive maps containing an average of 60 concepts. After each interview, maps were cleaned up to improve readability and then presented to each participant as a final check. 17 cognitive maps were confirmed as extensive and correct representation of participants' own views and thinking processes. Data saturation occurred approximately after the first 15 interviews. 12 maps are unconfirmed where mapping could not be performed during the interview (mainly for time reasons). For these, cognitive mapping was performed based on the interview transcripts. To avoid bias, the unconfirmed maps were excluded from the quantitative map analysis. The remaining three interviews were too short to allow for mapping, although answers to the four questions above were noted. The exercise resulted in 28 cognitive maps consisting of a total of 1300 concepts.

[2] Banxia Software Ltd: http://www.banxia.com/dexplore

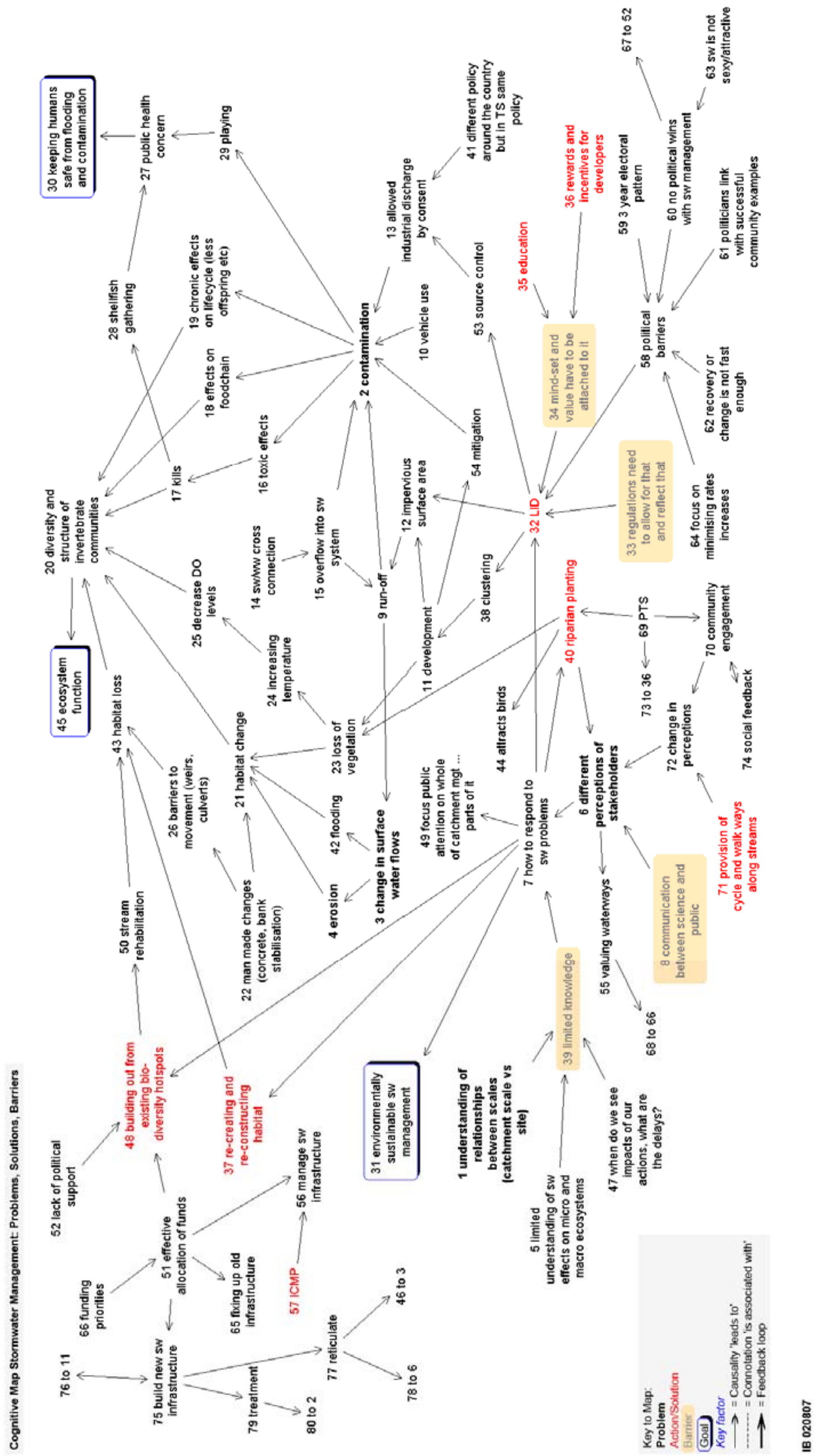

Figure 1 : Example Cognitive Map

Data Analysis

Individual cognitive maps were analyzed for their structure to determine richness of meaning for concepts, get a feel for the complexity of each map, and determine similarities between stakeholder groups. Simple analyses focused on the extent and density of maps with regards to the number of concepts and links and their relationship to each other to provide indications of the complexity of the issues (Eden 2004). Further analyses focused on the emergent properties of maps, i.e. domain analysis to detect central themes, cluster analysis to detect interconnectedness between themes, and the discovery of feedback loops (virtuous and vicious cycles), which may indicate dynamic behavior (Eden 2004).

Cognitive maps were combined using several stages of clustering and coded to reveal common patterns of reasoning. Concepts with identical meaning were combined in the first clustering stage, e.g. removal of forest and deforestation. In a second stage, concepts with similar meaning were combined and recoded, e.g. deforestation and removal of bank-side vegetation. This resulted in 150 clusters. The process was naturally selective and biased: *"Observation is also selective: The researcher is constantly making choices about what to register and what to leave out, without necessarily realizing that – or why – one exchange or incident is being noted but another one is not."* (Miles & Huberman 1994, Page 55f).

The 150 clusters were written on post it notes and mapped out on a white board. Links between the clusters were drawn to form causal loop diagrams reflecting common perspectives. Causal loop diagrams (CLD) are a key tool in system dynamics methodology for communicating the feedback structure of systems (Lane 2008). Feedback or the interactions between system components is the main cause for complex behavior exhibited by social-ecological systems (Sterman 2000). All dynamics arise from the interaction of self-reinforcing (positive) or self-correcting (negative) feedback loops.

5 Systems Thinking for Effective Stormwater Management

Structural Analysis of Individual Maps

Results of the structural analysis of the 17 confirmed maps are provided in Table 1. The average (±SD) number of concepts of all maps is 63.2 ±15, the average number of links in all maps is 87.6 ± 27, and the average ratio of links to concepts is 1.4 ± 0.2. No statistically significant similarities between stakeholder groups could be detected. While some participants had high scores in some of the tests, no group of participants dominated a particular structural component.

	D	Exp	LG	RE	Res
Maps	1	7	5	2	2
Number of concepts	53	59.7 ± 18.9	68.8 ± 12.9	68 ± 17	62 ± 11.3
Number of links	57	84.7 ± 32.6	99 ± 22.7	87 ± 5.7	58.5 ± 38.9
Links/Concepts	1.1	1.4 ± 0.2	1.4 ± 0.1	1.3 ± 0.4	0.9 ± 0.4

Table 1: Statistics of Structural Analysis of Individual Maps. Abbreviations for stakeholder groups: D – developer, Exp – stormwater experts/engineers, LG – local government officials, RE – researcher/ecologist, Res – resident.

Domain analysis argues that if a concept has many ingoing and outgoing links, the concept is cognitively central and hence dominates a person's thinking processes (Eden 2004). The domain analysis for all concepts with more than five links is presented in Table 2. Flooding was the main concern for about half of the participants followed by LID and Effective Management of stormwater in general. No one concept dominated the thinking of the majority of participants. This indicates that different stakeholders perceive different concepts to be important and provides a justification for including a diverse number of stakeholders in the research.

Cluster	Count	D	Exp	LG	RE	Res	Avg Links
Flooding	8		5	2		1	8.9
LID	7		5	1	1		10.9
Effective Management	7	1	1		3	2	8.4
Attitude/Ignorance	5		1	2		2	8
Pollution	5			3	1	1	7.8
PTS	4			3		1	11.5
Erosion	4		1	1		2	10.3
Community Education	3			2		1	8.7
Imperviousness	3		1	1		1	7.3
Development	2		2				9
Habitat	2		1		1		8
Species Diversity	2	1	1				7
Delays in consenting process	2			1	1		7
Behavior Change	2		1	1			6
Council acceptance	1			1			9
Community Buy-in	1		1				8

Table 2: Results of the domain analysis for concepts with more than five ingoing and outgoing links

It was assumed that statistical analysis would show strong similarities in perceptions of stakeholders within a group and marked differences between groups, for example that ecologists would be concerned with habitat and engineers with flooding. However, this was not the case; the similarities in perceptions were largely independent of stakeholder group. There were a few exceptions when considering domain analysis results for each stakeholder group. As Table 2 shows stormwater experts (engineers and consultants) are primarily concerned with LID and flooding. Local government officials thinking prioritized PTS and pollution. The developer is mainly concerned with delays in the consenting process and effective management. The highest number of links for a single concept was made by one expert (21 for LID). Habitat, on the other hand, was a concept that was not considered important for most stakeholders.

Other map analysis methods were not conclusive although a few feedback loops were identified. These loops informed the development of the causal loop diagrams introduced in the next section.

Perspectives in Stormwater Management

Causal loop diagrams were developed based on the saturation of participants' individual cognitive maps. Three distinct perspectives emerged: '*conventional fixes*', '*low impact* *solutions'* and *'community development'*. The maps are intended to capture the essence of these perspectives and include key concepts while avoiding detail. Arrows show causal relationships and are positive unless indicated otherwise. A negative sign implies a negative relationship (where an increase in one variable leads to a decrease in the other).

All maps show in black the causes and effects of the three main issues in stormwater management: flooding, pollution and erosion. Stories underpinning each map, along with underlying mental models, are supported by quotes.

'Conventional Fixes' Perspective

This causal loop diagram (Figure 2) encapsulates the traditional perspective on stormwater management. The primary management objective at the time was water quantity (flooding) which was addressed based on a technocratic paradigm by building large scale engineering infrastructure, particularly underground stormwater pipes. Brown (2005) suggests that this perspective was most prevalent form the beginning of the 20th century until 1985.

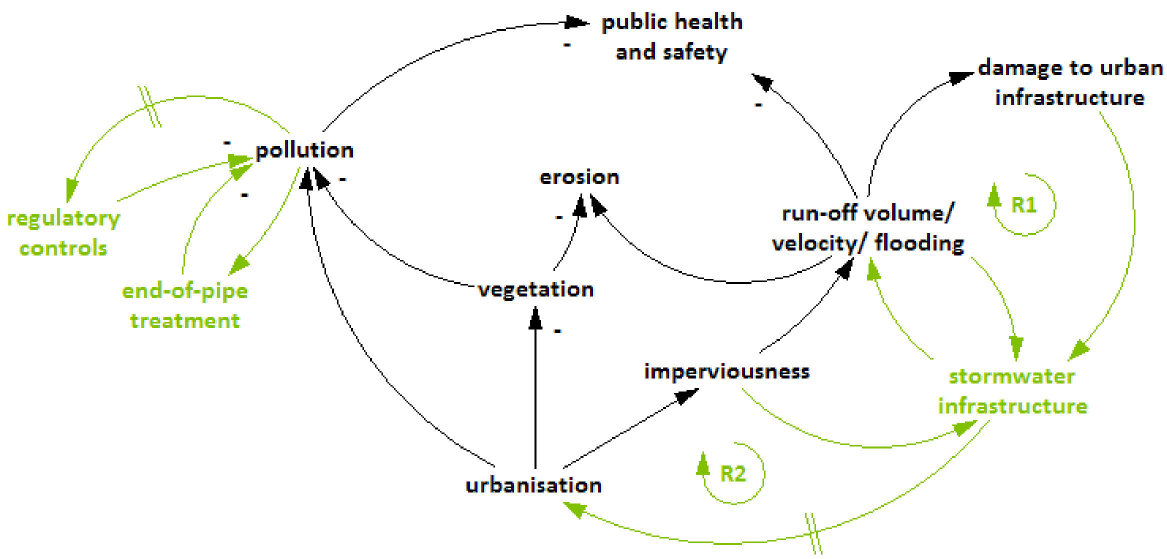

Figure 2: The 'conventional fixes' CLD

Urbanisation results in an increase in *impervious* surface and reduced *vegetation*. This allows less entrainment of stormwater into the soil. Water runs off the land and enters the stream system - often through the stormwater pipe network. The stream has to carry a higher *volume* of water at a higher *velocity*. This increases the likelihood of downstream *flooding*. Flooding can *damage urban infrastructure* including housing, as well as *public health and safety*.

The damage to urban infrastructure results in an increase in *stormwater pipes* to prevent future flooding. However, stormwater pipes increase velocity and volume of water in the network, which increases the likelihood of future flooding[3]. This is a self-reinforcing feedback cycle that may explain the dependence on the ongoing need for pipe solutions (**R1**). Whilst initial building costs are very high, maintenance costs for pipes are fairly low when spread over the working life of the built structure. As a result, urban areas become trapped in a situation of path dependence. Sunk costs of existing infrastructure are so substantial that a

[3] This is because artificial channel networks together with reduced natural drainage density and altered hydrological cycle contribute to the increase in flow volumes and velocities (Graf 1977; Paul & Meyer 2001).

changeover to other technologies seems prohibitive (Kahneman & Tversky 1979; Sterman 2000). However, where the pace of urban development is rapid, costs for extending infrastructure to newly developed areas are substantial and hit current and future rate payers, raising concerns of intergenerational fairness and equity.

Another feedback loop exists between stormwater infrastructure and urban development (**R2**). This is explained by the following statement:

Participant 19 (RE): *"Once you put in any kind of reticulation system then you'll only get more development. You want to encourage development. When you put a road in somewhere, people will build along it."*

High-velocity peak flows lead to erosion of the stream channel. Urban pollutants accumulate on impervious surfaces and are washed off carried to receiving environments by stormwater. Traditional approaches to solving pollution problems entail end-of-pipe treatments. Regulatory controls are expected to reduce pollution. However, stormwater largely carries small amounts of non-point source pollutants for which there is no clear point of origin. For these, regulatory controls are generally ineffective. This results in a long-term, slow, and often unnoticed degradation of water quality in receiving environments:

Participant 7 (Exp): *People accept creeping deterioration. People will say, "I remember when I was a kid, there was a little swimming hole at the beach in Brown's Bay. Well, it's all full of mud now, but that's progress." Or they might tell you that they don't like it, but they don't know how it could have been prevented.*

Pollution, particularly wastewater overflows also impact on public health and safety. This is where the boundary of this particular perspective was identified. While pollution, erosion and changes in the catchment's hydrodynamics greatly affect receiving environments (streams, estuaries, harbours), this was not a major concern of stormwater managers at the time.

An 'out of sight, out of mind' attitude and a lack of value attributed to the environment itself are underlying our engagement with stormwater in general.

Participant 31 (Exp): *In times past, they* [streams] *were an open drain to any type of rubbish, weeds, anything, pollution. People would put it into the streams and stormwater system and it would disappear.*

Participant 23 (Exp): *It* [stormwater] *was seen as something to get rid of as opposed to as a resource to be used. It was a nuisance to have water on your property.*

Participant 19 (RE): *The developer's view was a lot more reductionist and said well, let's look at this bit of waterway here and let's say it has got no value from an ecological perspective, so then let's develop it. And this bit here, we will develop that. So gradually you lose bits and bits of waterway to development.*

Removing flowing water from the public eye, e.g. by piping it underground, or creating open concreted channels for flow mitigation, have created a disconnection of the public with the stream environment:

Participant 16 (Res): *Most people don't understand the relationship between what they are doing on their section and what happens in the stream and how the stream relates to the sea and how all of that is interconnected.*

Participant 28 (LG): *You've got ignorance, pure and simple, with people. It's the "Ah yeah, bush heals itself, simple enough. You can throw your rubbish in every waterway. Amongst the cars and other rubbish it will rot away eventually." They don't see what damage they have done.*

'Low Impact Solutions' Perspective

Water quality concerns emerged as stormwater management objectives during the 1980's (Brown 2005) and are currently an important driver for public policy and scientific research.

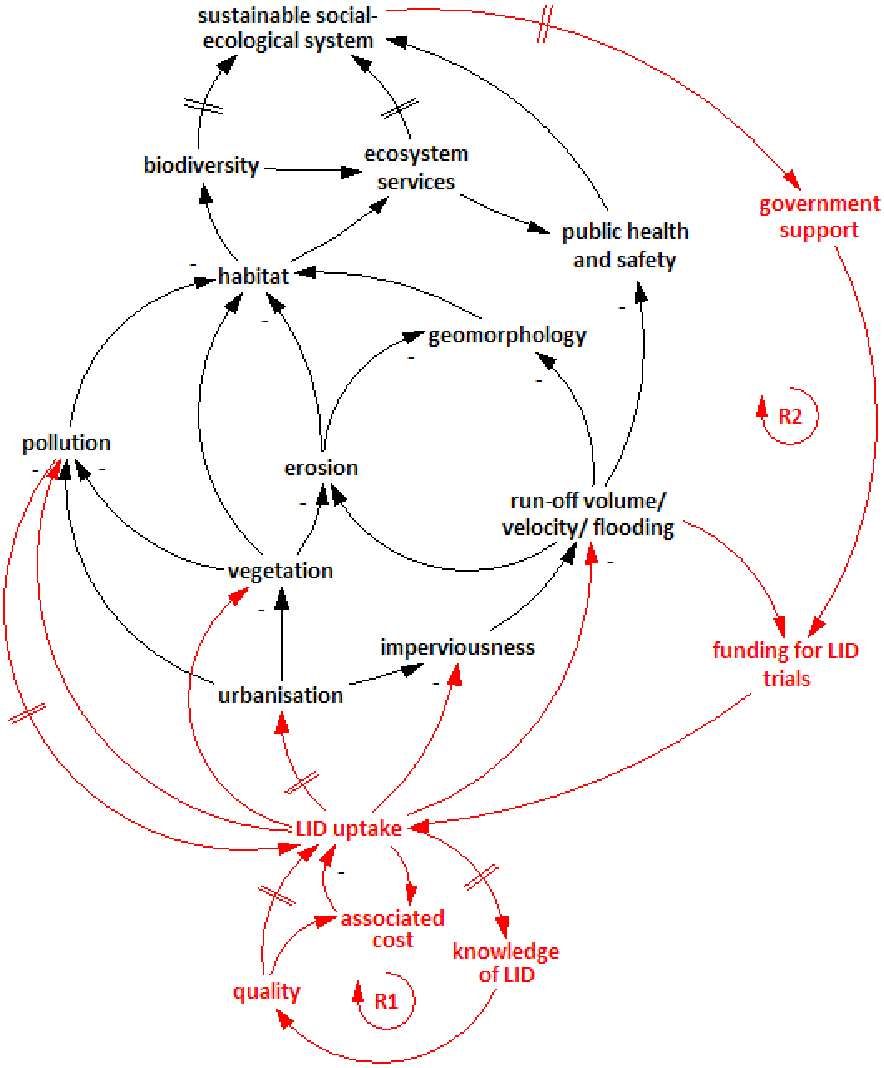

Figure 3: The 'low impact solutions' CLD

In the 'low impact solution' CLD (Figure 3), in-stream *erosion* and deposition of sediment adversely affects the *geomorphology* of waterways by creating homogenous, wide and flat stream channels (Reid *et al.* 2008). Pollution, vegetation loss, erosion and altered stream geomorphology reduces *habitat* quality. A broad range of *habitats* and healthy environments provide *biodiversity* and a multitude of *ecosystem services*. These include among others, cleaning and inactivating of harmful inputs into the ecosystem, providing harvesting from the land and water to humans, passive and active recreation including amenity, inspiration, artistic and spiritual engagement. Underlying the 'low impact solutions' perspective is an acknowledgement of the importance of the ecological health of waterways on our own health and well-being. Both are perceived as cornerstones of *sustainable social-ecological systems*.

In the context of Project Twin Streams catchment, substantial funds were provided to purchase and remove flood-prone properties. As a result, the feedback loop between stormwater infrastructure, flooding and urban infrastructure damage was broken.

All participants felt that maintaining a clean environment was important. However, for some participants it lost its importance when it came to actually implementing a stormwater solution and maintaining environmental values was not practicable.

Participant 8 (Exp): *I want my children to go to the park where there are watercourses and eels and fish etc. I am a kingfisherman, I want my harbour to be clean. I want to still be able to catch fish and my children to be able to catch fish.* (……) *Because as we found out through progressive development there is inherent value in keeping some watercourses and keeping riparian margins. That's what people want, they want a bit of nature.* (……) *The local council says 'We want it piped, it's pointless.' This is a residential area. The regional council is saying 'Ah, no, we might want to keep it.' And it's totally impractical.*

As an emerging technology the success of LID follows a diffusion/adoption process (Rogers 2003). Uptake of LID is dependent on the adoption rate, i.e. the probability that a person upon coming into contact with the technology in some way actually uses it. This probability is high if the contacts are plentiful, the technology displays significant and valuable results (by effectively and profitably solving the site's stormwater problem), the technology is compatible with existing technologies and there are no problems with training to use the technology. This is reflected in feedback loop **R2** in Figure 3. After deciding that a technology is good and worth pursuing, it is necessary to spend time and effort to train and become capable and experienced in its use. There will be a time delay from training and gaining experience in the field. The last point is represented in feedback loop R1 in Figure 3. This is the learning loop associated with uptake of LID. The use of LID leads to increased knowledge and increased quality of work.

Participant 4 (Exp): *We were out on Friday on an industrial site where they make concrete. And those sites are notoriously dirty because of all the concrete dust. We always had pH problems. So this company put in a wetland swale and it is gorgeous. We went out last Friday when it was raining and did a pH check at the inflow and outflow. The pH going into it was 9 and the pH coming out was 6.5. That is exactly what we want. So here is the case where the company paid the money, did this and by doing it came up with an environmental outcome and he still gets to make his concrete. We need more of those types of stories.*

Participant 2 (Exp): *Examples like that, if you could get them in front of developers, particularly for bottom end developers who wanted to put up a square box, you would say*

‘Well, actually if you do it this way, you’ll get a motivated buyer and you are making a similar amount of money.’

LID’s adoption rate appears to be slow, arguably due to perceptions of low profit and high cost (**R1**):

Participant 5 (D): *You don’t want to cause your business to become less profitable because you are the only maverick looking for LIDs. That doesn’t make any business sense.* (……) *Sometimes costs are a factor, sometimes they are not. Sometimes a more sensible environmentally friendly solution actually costs you a lot less and is easier to perform.* (……) *The relative cost comparisons for LID against standard designs is not an exploratory exercise that gets any money for a consultant. There is no commercial advantage, therefore why do it.*

Participant 8 (Exp): *To develop a section of land in a very conventional way with no view on retaining existing features or stormwater quality or extensive earthworks, your typical subdivision would be a lot cheaper than an environmentally friendly development.* (……) *It comes down to what is the cost of environmentally friendly and what is it that we can afford. I think that Auckland and New Zealand is going through that battle as our land and house prices skyrocket up. What is affordable to the general public to buy? This has to be balanced with what limits of environmental protection we are willing to put up with.*

Participant 2 (Exp): *There is certainly a real cost limitation to the whole package whether you use LID or some other method. Doing it properly for the Auckland region is all terribly expensive. That’s why we get into running battles with some of the city council people. Because they are trying to run budgets and work out what they can get.*

Participant 22 (Exp): *If you ask people whether they want to pay an extra $1000 on top of your rates for stormwater they may say no, unless they are being flooded.*

Hence, regulatory support and/or incentives for developers and/or consultants will be necessary in order to increase adoption of LID. Another reason for slow uptake is a lack of institutional support:

Participant 2 (Exp): *The TP10* [LID guideline] *is four years old. It’s probably taken 3 of those years for us to realise that people who read and even thought they wanted to implement those ideas on the local scale, we had to watch while they go to the council get frustrated and go back to a standard design with a stormwater treatment pond at the bottom.*

Participant 5 (D): *The only difficulty I have with the philosophical aspect of LID is that if the support network is not there from council or from the market place, intentional or unintentional is irrelevant. If you are trying to look for low impact solutions for no benefit to a business it just doesn’t make any sense.*

More critically, as another engineering strategy that relies mainly on devices (ponds, swales, etc.) LID does not raise the public awareness required for voluntary and widespread uptake. Public behaviour will still be guided by the device paradigm, i.e. the understanding that problems can be solved by installing devices (Higgs 2003). The widespread disconnection with the natural environment will still be in place and hence, behaviour change will not occur.

Participant 17 (Res): (…) *all those new funky technologies like swales, those Hynds sand filter things. And these are unnatural, there is absolutely nothing natural about them.*

Participant 16 (Res): *The greatest barrier I think is that people just don't care enough. It comes right down to not prioritising it sufficiently. Not seeing it as a real problem. Again, it's a cultural thing. It's like we are safe, we don't have to worry about the natural world.*

In some instances, LID may allow for more urbanisation to occur due to the off-set of stormwater impacts on the existing stormwater network. For example, in the upper parts of Project Twin Streams catchment, development is allowed if it maintains hydrological neutrality, i.e. the increased imperviousness does not result in an increase in stormwater run-off. The LID paradigm fits in with continued economic growth through increasing urbanisation. This suggests a similar infrastructure 'trap' as was identified in the 'conventional fixes' perspective.

'Community Development' Perspective

Community engagement projects like PTS aim to strengthen communities by changing behavior and reconnecting residents with their local environment.

Participant 31 (Exp): *The reason for the community to be involved so much is to make the project most effective really. Without the community being there, the contractors would be employed to do it. It would get done. It would get done possibly at the same cost, possibly for less. But once the project was finished it would have the potential to slowly go down. Because there would be no buy-in from community about changing the value of how they perceive streams.*

Participant 16 (Res): *People come; I think it's a combination of love of the native plants and the stream and wanting to be part of this neighbourhood. It's like a sense of identity.* (……) *It's a love of the natural world and it's a sense of neighbourhood, a sense of coming together and doing something permanent right there.* (……) *When people are down there working like that it's calm, peaceful, away from the busyness. People start to talk about things. So it's there is human development and a human growth - becoming part of something, of a bigger world*.

A focus on behaviour change is anticipated to have positive flow-on effects. Prospectively, it will not only increase the communities' willingness to reduce their impact on the streams and take care of their streams, it will also allow people to re-evaluate their consumption patterns and decisions regarding mode of travel and energy consumption from which economic benefits may result. Components and linkages of the community development CLD shown in Figure 4 promote manifold and intentional reinforcing feedback processes.

The 'community development' CLD also describes a diffusion process, in this case the diffusion of societal norms and behavioural change. Again, *government support* was perceived as a key to starting *community projects*. These projects are the vehicles for achieving *community buy-in* which in a favourable political climate would feed back to more government support (**R1**). There is a danger that a lack of community buy-in would result in a lack of governmental support. Hence, this relationship needs to be carefully managed. Community buy-in was a key variable in this CLD with many ingoing and outgoing links.

Community buy-in increases *project involvement*, in this case stream restoration, with positive effects on *vegetation* (**R2**) and people's *awareness*. Awareness is a necessary condition for *behaviour change* which will reduce *pollution* and may increase *uptake of LID*. Behaviour change was also perceived to lead to *economic benefits* which in turn feeds back to *community buy-in* and *socio-economic status* (**R3**).

PTS has been successful in the past years and this has enabled *follow-on projects* to be initiated (**R4**). These projects use the same model of community engagement and development to initiate behaviour change in other areas, notably waste reduction, travel mode and energy consumption (Waitakere City Council 2007). Uptake of these projects has also been strong (Trotman 2006). Economic benefits at the household as well as community level are envisaged, further strengthening communities and increasing their *socio-economic status*. This in turn will increase the support base for these projects.

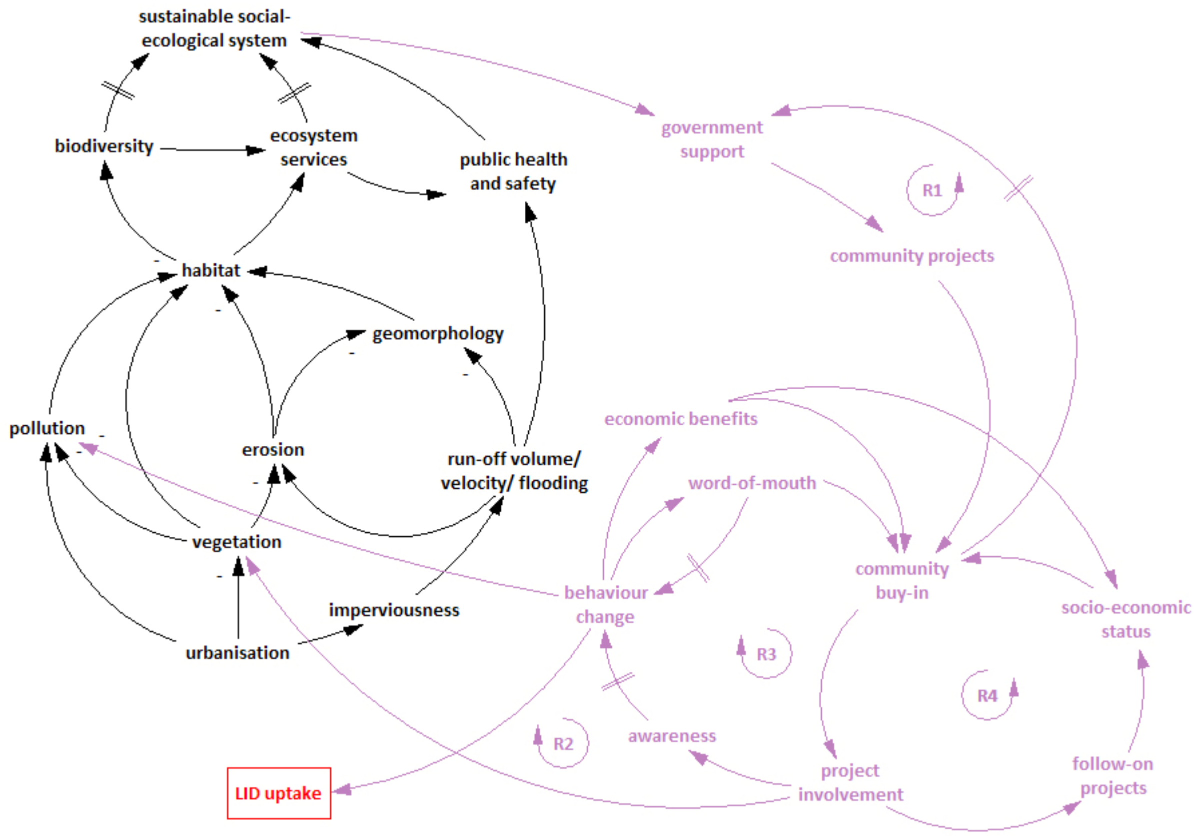

Figure 4: The 'community development' CLD

Overcoming initial inertia until a sufficient support base and uptake has been established takes time (Svendsen & Campbell 2008). Consequently, time delays and their effects are crucial to this perspective and community engagement in general. This stands contrary to existing and rapidly progressing environmental degradation.

Participant 28 (LG): *It's going to take another 30 years before people turn around respecting the streams, the evolution and life in the streams.*

Participant 16 (Res): *I mean people litter and most people don't really turn their heads. It's not culturally unacceptable yet.* (……) *When this area became inhabited by Europeans, people didn't really seem to respect these streams, because we find an enormous amount of junk down there. It's not been like that when it was Maori living here it was very different, careful.*

Participant 27 (LG): [It] t*akes away the interaction between people and the natural environment when you look at something and say "yuk". This becomes a bit of a cycle, if a stream is a rubbish dump people will dump more in there, because they can see it's a dumping ground.*

The 'community development' perspective was shared by half of the participants. While most of these participants did not come from an engineering background, all had an understanding of conventional and low impact stormwater solutions. Participants with an engineering background, on the other hand, showed a lack of understanding for the need of community development:

Participant 2 (Exp): *As I understand it* [PTS] *at the moment it's almost entirely riparian planting. Whether it's effective or not depends on what else happens in the catchment. It was always the wrong way around for us. To my mind it is the icing on the cake when you already taken out the contaminants and sorted out fish passage, and your water quantity problems. And then you got some streams where you might have a good habitat and then of course with riparian planting you can get that. So I tend to see it as a cart before the horse.* (…) *But I do think it will be good in 20 years time, but by goodness me it's expensive. It's very, very expensive.*

Mental Models in Stormwater Management

As part of the interviews participants were asked to identify mindsets (mental models) that are associated with stormwater management solutions. These are presented in Table 3 as either supporting or detracting from implementation. Mental models - our perceptions of reality - are the most powerful underlying driver of our actions. Effective behaviour change requires an uncovering and engagement with these underlying mindsets (Sterman 2000).

Most participants had a very good understanding of stormwater management strategies and solutions. However, there was little agreement on what solutions are preferential to address problems. Direct statements included:

Participant 20 (RE): *The system is not in a position where it can really help itself at this stage because it's such an impacted system to start with. So there's got to be a regulatory environment that says what is and what isn't permissible.*

Participant 26 (LG): *The overriding goal of PTS is to engage local residents in behaviour change and that is the most effective way of good stormwater management.*

Participant 17 (Res): *So it's process as well, it's not just about the streams; it's about the people who manage the streams. Until there is a forum or a project team where there is a* *reciprocal respect for the Maori culture and dimension to that, and the technical expertise, there isn't an effective management of that stream as far as I am concerned.*

	Supporting Mindsets	Preventing Mindsets
Conventional Fixes	Fear of uncertainty, of losing control Uncertainty about how to deal with new ways of thinking Control nature and people Acceptance of creeping deterioration Human predominance and superiority Low importance of stormwater compared to wastewater and water supply Right to develop and make own decision for private land Stormwater is a nuisance rather than a resource to be used Disconnection from environment in general Want council to take care of everything rather than share responsibility	Cost avoidance Changing perceptions
Low Impact Solutions	Acknowledging the value of water and waterways Outcomes encourage uptake Fear of uncertainty, of losing control Human predominance and superiority Engineering perspective with ecological objective	Frustration with bureaucracy Cost/Profit perception Disregard of maintenance Stormwater is not interesting politically Maximisation of the development area Profit maximisation Stuck in old ways, hard to change
Community Development	Caring attitude Changing perceptions Enjoy green areas and get upset by damage Desire to learn more Pride in achieving positive impact	Acceptance of environmentally damaging behaviour Perception/suspicion of policy and council Stuck in old ways, hard to change

Table 3: Supporting and preventing mindsets

Participants also expressed uncertainty as to how much management is required.

Participant 11 (Exp): *There is a lack of knowledge about the natural system, about how much we should manage the natural system. And how much we should let the system be natural, we haven't made that decision yet.*

Participant 19 (RE): *In a way we think we go and do a few actions and* [the stream] *then takes care of itself. We are not really seeing that.*

Conflict between the three different perspectives was apparent. This conflict may indicate uncertainty and possibly a lack of a common vision and well-defined objectives. Achieving agreement on the most effective solutions and measures of involvement requires careful collaboration, communication and deliberation strategies.

Analysis of the Differences in Perspectives

Results based on the analysis of participants' cognitive maps show that perspectives in stormwater management are diverse and potentially conflicting. Stakeholders conceive different solutions for stormwater management which are driven by substantially different mindsets. The main differences between perspectives are summarized in Table 3.

	Conventional Fixes Perspective	Low Impact Solutions Perspective	Community Development Perspective
Priorities of management goals	Public health and safety, safeguard built structures	Public health and safety, safeguard built structures, Provide ecosystem function	Behavior change, Community buy-in and development
Solution drivers	Capacity, reticulation infrastructure	Permeable surfaces, maintenance	Behavior change, public ownership of local waterways and their management
Spatial focus	Focus on the stream as well as all drainage connections to the streams, city scale	Off-stream, lot-scale with a catchment wide integration	Local stream environment, neighborhood scale
Timescale of implementation	Short term	Short term	Long term
Feedback	Minimal, linear thinking, short	Minimal predominantly linear thinking, short-medium as part of the diffusion process	Diverse and manifold, long
Inclusivity of stakeholders	Scientific and engineering, government officials, public (minimal)	Scientific and engineering, government officials, public (to a small extent)	Public (to a large extent), government officials
Use of available knowledge	Scientific knowledge (Hydrology, Civil Engineering, Public Health)	Scientific knowledge (Hydrology, Geomorphology, Ecology, Public Health)	Local and community knowledge, social marketing, social development
Ownership of the problem	Local authority	Local authority	Public (to a large extent) and local authority in a supporting role
Responsibility for implementing solutions	Regional and local authority	Local authority and public particularly with respect to maintenance	Public
Main shortcoming of this perspective	Disregard for stream ecosystem	Lack of behavior change and public ownership	Substantive delays and long-term implementation

Table 3: Overview of the main differences between the three perspectives in stormwater management

While balancing feedbacks are clearly present, we have concentrated our analysis on self-reinforcing feedback that serves to increase and perpetuate implementation. Most participants were not familiar with the concept of feedback and could not identify feedback situations on their cognitive map. This reflects the prevalence of linear thinking processes (Sterman 2000). Feedback in the conventional fixes perspective is nearly absent. The implementation of solutions is triggered by localised problem events. For example, a pollution event such as a spill will trigger a clean-up, and for recurring or non-point sources possibly the installation of a treatment device. Similarly, the low impact perspective shows few and predominantly short feedback cycles, even though the diffusion process for LID uptake follows a longer feedback cycle. Short feedback occurs when variables influence each other directly. For example in Figure 2, a localised flood event may lead to building of a pipe or a concrete channel, which in turn will prevent flooding to occur at this place in the catchment (but will increase possibilities for flooding downstream). The ‘community development’ perspective comprises a multitude of short and long feedback cycles. As such, the community development perspective starts to transition from our existing anthropocentric worldview by purposefully targeting and incorporating feedback processes.

Each perspective has shortcomings in providing solutions that can effectively address the challenges posed by stormwater. The conventional fixes perspective lacks an integration of ecosystem health in the management goals, and it can be argued that conventional solutions are inherently conflicting with environmental restoration goals. The main shortcoming of the low impact design perspective is the lack of public ownership of problems and solutions. In essence, low impact design provides a similar set of engineering solutions which may be more localised and environmentally friendly, but still maintain the status quo of a public that is inherently disconnected with their local environment. This disconnection causes a lack of understanding, a lack of care and environmentally damaging behaviour. It can be expected that with future population growth and existing development patterns, water quality problems in streams will continue to deteriorate. This will further increase the lack of respect of this resource to the point where they cannot be offset by low impact solutions:

Participant 11 (Exp): *There is the issue of impaired aesthetics of the streams from gross pollutants. There is a lack of ownership and the gross pollutants and littering causes a lack of respect in the stream. So, if I see lack of respect it enables me to have lack of respect. If I see that things are respected it enables me to respect things.*

The main drawbacks of the community development perspective are the long delays and resulting long-term implementation of solutions. Community development postulates social learning, behaviour change and the creation of public ownership, and as such has, in theory, manifold flow-on effects that can engender uptake of more sustainable technologies and strategies, e.g. co-housing, use of public transportation, reduced energy consumption. However, environmental degradation is a pressing concern and existing stormwater problems have to be addressed quickly and effectively while at the same time steps ensuring the restoration of impacted ecosystems. This however, is not identified as a priority in the community development perspective. As a result, none of the perspectives in themselves will lead to sustainable stormwater management outcomes.

6 Integration of Efforts: Transition Culture

The convergence of pervasive challenges, including environmental degradation and social discontent with prevalent political processes and outcomes, has brought us to a point where we are increasingly challenged to act. Thus, a concerted and integrated effort is required to address the multiple and pressing problems experienced in Project Twin Streams catchment. We need to enter a culture of transition among all facets of society. In order to realise a sustainable future, the long term focus must emphasize social learning, behaviour change, and the creation of effective partnerships with local authorities with a focus on increasing community resilience and capabilities for adaptation. Institutional learning and change must go in hand and support this long-term focus on behaviour change and community development. Low impact solutions can be implemented in the short term in new developments while retrofitting of old developments can occur over time as old infrastructure is phased out and more sustainable building practices are implemented. Figure 5 synthesises our argument by integrating the low impact development and community development perspectives. In addition, the deliberate use of regulatory controls should guide implementation of low impact development solutions and community development.

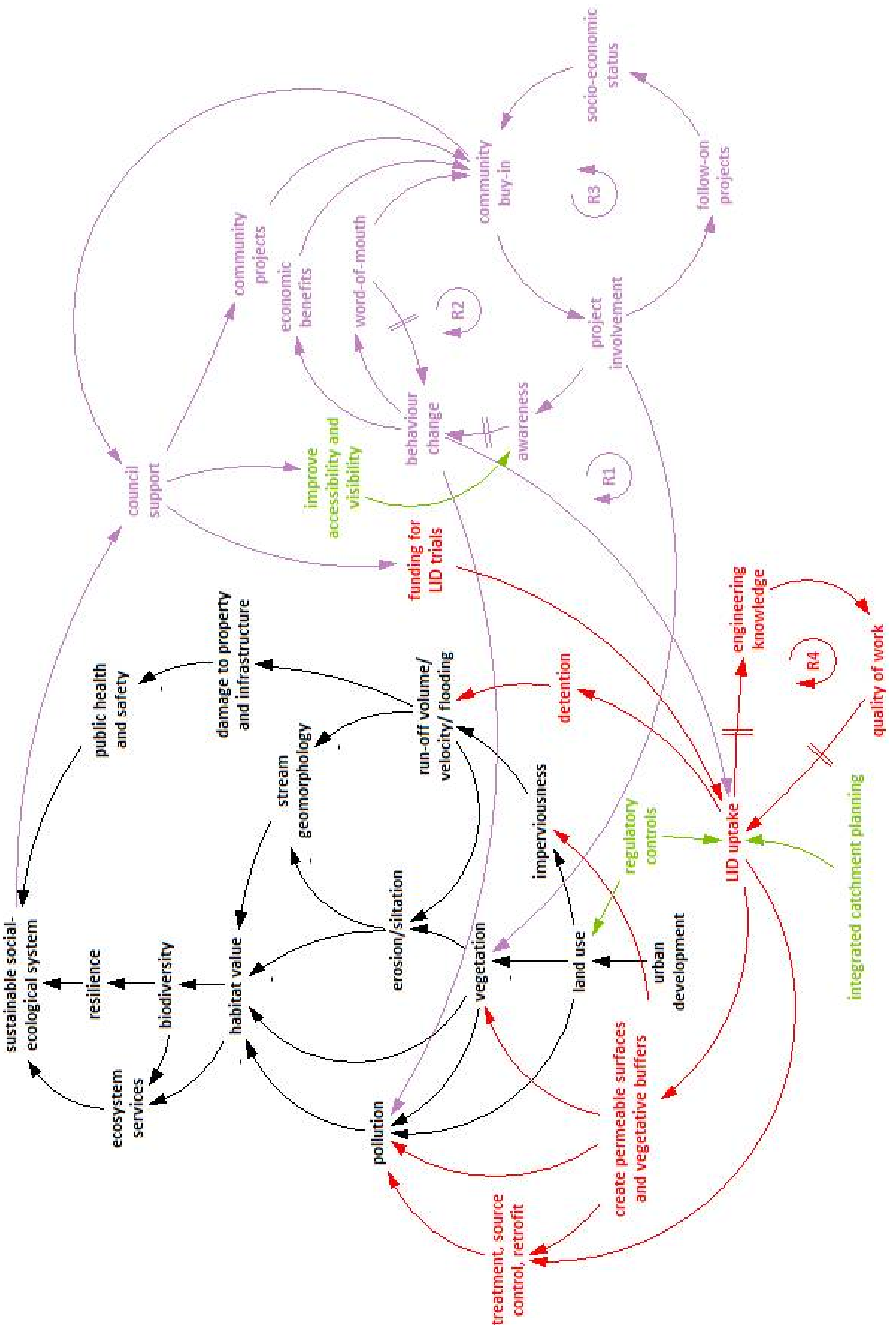

Figure 5: Integrating community engagement and LID serves multiple objectives and creates change at different levels and timescales.

This transition culture incorporates respect for diverse perspectives, personal responsibility and co-management. It requires understanding and acceptance of the need to live within the limits imposed by nature and each other by contributing to the common good. Genuine well-being and security arise from connections to people and place. The overarching goals of this culture must be the creation of sustainable mechanisms that can internalize anthropogenic environmental impacts.

This transition is hindered by the existence of manifold barriers which may be classified as social, institutional, educational, attitudinal, logistical, communication and internal barriers. These barriers can be understood as an indication or manifestation of underlying reductionist and risk-averse mental models among government officials and the public. We have purposefully steered away from a discussion barriers of implementation as this warrants a more in depth analysis. However, it must be clear that the existence of diverse perspectives on stormwater management is a contributing factor in our current failure to live and use our land without eroding its capacity for sustained provision of environmental services.

Understanding stormwater management as a complex social-ecological system is the pre-requisite for developing and implementing integrated solutions. Acknowledging and exploring the different perspectives on problems and solutions in stormwater management has far reaching implications for the relationships we build and the processes we put in place to manage stormwater. Under this new paradigm, stormwater is not considered to be purely a technical issue that requires a technological fix to deal with. Rather, there is a need to acknowledge that stormwater is multi-faceted: different stakeholders have different priorities for dealing with stormwater quantity, quality and erosion problems, and opinions on effective solutions range as far and wide so as to render the promotion of a single solution strategy such as low impact development ineffective. Social learning, stakeholder buy-in and ownership of any solution are paramount for successful implementation. Establishing buy-in calls for the development of new methods and processes focused on engagement and relationship building. Institutional structures need the capacity to adapt to this new focus, while our scientific research endeavors are challenged by different data needs and analytical practices. This presents considerable challenges for management and institutional structures, engagement with stakeholders, socio-cultural considerations that promote scientific/engineering agendas.

Recent moves towards LID which are now advocated by public institutions across the world, emphasize concerns for a technical focus, working from a premise that notionally healthy ‘solutions’ can be imposed through revised engineering applications. Implicit to these applications is the assumption that an engineered solution exists and that technology can be used to provide the answers. The premise is appealing to authorities given their desire to invest in measurable outcomes. As such, there has been a proliferation of design solutions that apply engineered infrastructure. Ultimately, however, it must be asked whether these measures address the key issues in stormwater management and are appropriate in the context of sustainability. Many pressing contemporary issues, including environmental degradation from urban stormwater run-off, can be traced back to a lack of understanding and adverse behavioral choices. A genuine commitment to sustainability requires that effective solutions extend beyond the device paradigm and place emphasis on socio-cultural transition.

At present, there is no wide-spread acceptance and ownership of low impact solutions and no understanding of what will be required to promote behavior change. There are inherent time delays in the process of behavior change. Given the scale and pace of change at which problems occur, windows for opportunities to address pollution problems are fast closing. There is an urgent need to develop and implement community oriented approaches to stormwater management that meet human needs while reducing harmful impacts and repairing stream environments.

7 Conclusions

Our perspectives of environmental issues frame the way we develop and implement solutions and actions to manage our natural environment. The most dominant perspectives in stormwater management have been based on a linear and technocratic worldview that often ignored perspectives of other stakeholders. In order to learn from past mistakes, understanding and engagement with diverse perspectives are required to develop more integrated and sustainable stormwater management practices.

Cognitive mapping and systems thinking were used successfully in this research to elucidate mental models and perspectives on stormwater management in Project Twin Streams catchment. Results show that problems and solutions regarding stormwater are conceptualized in substantially different ways. This provides evidence that there are multiple ways of knowing and that differing values are associated with stormwater management. The three different perspectives that were uncovered have profound influence on management goals, time scales and solutions for stormwater management. Critically, results show that none of the perspectives in themselves will lead to sustainable stormwater management outcomes.

Opportunities for future research include the application of cognitive mapping other areas to create a multiple case study which may provide a general theory. Furthermore, insights can be modeled quantitatively in a stock-and-flow or agent-based model in order to test some of the assumptions drawn from the CLD. Another interesting project would be a group modeling session which outcomes could be tested against this work. This could provide an understanding of the power relationships between stakeholder groups.

Our recommendations first and foremost are to create processes that serve to understand different perspectives of stakeholder groups as they pertain to council related business. This understanding is most effectively created in joint participatory action research projects. Second, we propose to better understand barriers of implementation of LID and community development projects, and to work to remove some of those barriers with the aim of better integrating different approaches. Community development projects rely on long-term funding and at present Project Twin Streams future is uncertain with funding streams to cease in 2012. While market-based instruments are a possible option for funding LID, their increased compliance and administrative costs as well as the total unfamiliarity with these approaches in city councils make their use unlikely. Development contributions are currently widely implemented to offset some of the cost associated with infrastructure provision. Clearly, providing incentives for LID might go a long way towards ensuring uptake, but numerous institutional barriers to implementation will have to be addressed first.

Understanding the diversity of perspectives and their wider impacts on research and management is only truly useful if it adds to mutual acknowledgement and respect of the different positions among stakeholders. This is a necessary step in reducing existing conflict and creating a common vision for a sustainable future. Different perspectives may lead to different solutions, but there are opportunities for these to complement each other. A transition towards this integration is crucial if we are to address present challenges in stormwater management and create sustainable solutions.

8 Acknowledgements

I would like to thank all research participants for their time, interest and encouragement. Helen Haslam, Clare Feeney and three anonymous reviewers thank you for helpful comments.

References

Alexander GG and Allan JD (2007) Ecological Success in Stream Restoration: Case Studies from the Midwestern United States. *Environmental Management*, **40**, 245-255.

Arnold CL and Gibbons CJ (1996) Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*, **64**, 243-258.

Auckland Regional Council (2000) Low Impact Design Manual for the Auckland Region. Auckland, New Zealand.

Auckland Regional Council (2004a) Auckland Regional Stormwater Project - an Action Plan to Deliver Improved Stormwater Outcomes - Final Report. Report prepared by the Boston Consulting Group, Auckland Regional Council, New Zealand.

Auckland Regional Council (2004b) Stormwater Treatment Devices: Design Guideline Manual. Auckland, New Zealand.

Berkes F (2004) Rethinking Community-Based Conservation. *Conservation Biology*, **18**, 621-630.

Bernhardt ES and Palmer MA (2007) Restoring Streams in an Urbanizing World. *Freshwater Biology*, **52**, 738 - 751.

Biswas AK (2006) Water Management for Major Urban Centres. *International Journal of Water Resources Development*, **22**, 183-197.

Brown RR (2005) Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform. *Environmental Management*, **36**, 455-468.

Bunn SE and Arthington AH (2002) Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management*, **30**, 492-507.

Butler CD and Oluoch-Kosura W (2006) Linking Future Ecosystem Services and Future Human Well-Being. *Ecology and Society*, **11**, 30.

Choi YD (2004) Theories for Ecological Restoration in Changing Environment: Towards "Futuristic" Restoration. *Ecological Research*, **19**, 75-81.

Choi YD (2007) Restoration Ecology to the Future: A Call for New Paradigm. *Restoration Ecology*, **15**, 351-353.

Eden C (2004) Analyzing Cognitive Maps to Help Structure Issues or Problems. *European Journal of Operational Research*, **159**, 673-686.

Flynn J, Beecham S, Shaver E, Kennedy P and Hodges P (2009) Panel Discussion. NZWWA Stormwater Conference, Auckland, New Zealand.

Flyvbjerg B (2006) Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, **12**, 219-245.

Folke C (2007) Social-Ecological Systems and Adaptive Governance of the Commons. *Ecological Research*, **22**, 14-15.

Graf WL (1977) Network Characteristics in Suburbanizing Streams. *Water Resources Research*, **13**, 459-463.

Grinde J and Khare A (2008) The Ant, the Grasshoper or Schroedinger's Cat: An Exploration of Concepts of Sustainability. *Journal of Environmental Assessment Policy and Management*, **10**, 115 - 141.

Gross M (2002) New Natures and Old Science: Hands-on Practice and Academic Research in Ecological Restoration. *Science Studies*, **15**, 17.

Hatt BE, Fletcher TD, Walsh CJ and Taylor SL (2004) The Influence of Urban Density and Drainage Infrastructure on the Concentrations and Loads of Pollutants in Small Streams. *Environmental Management*, **34**, 112-124.

Hauraki Gulf Forum (2008) Tikapa Moana - Hauraki Gulf State of the Environment Report.

Higgs E (2003) *Nature by Design: People, Natural Process and Ecological Restoration*. MIT Press, Cambridge, Massachusetts.

Higgs ES (1997) What Is Good Ecological Restoration? *Conservation Biology*, **11**, 338-348.

Hobbs RJ (2007) Setting Effective and Realistic Restoration Goals: Key Directions for Research. *Restoration Ecology*, **15**, 354-357.

Kahneman D and Tversky A (1979) Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, **47**, 263?291.

Kathuria V (2006) Controlling Water Pollution in Developing and Transition Countries - Lessons from Three Successful Cases. *Journal of Environmental Management*, **78**, 405-426.

Kellert SR, Mehta JN, Ebbin SA and Lichenfeld LL (2000) Community Natural Resource Management: Promise, Rhetoric and Reality. *Society & Natural Resources*, **13**, 705-715.

Laituri M (1996) Cross-Cultural Dynamics in the Ecocity: Waitakere City, New Zealand. *Cities and the Environment*, **13**, 329-337.

Lane DC (2008) The Emergence and Use of Diagramming in System Dynamics: A Critical Account. *Systems Research and Behavioral Science*, **25**, 3 - 23.

Middleton JV (2001) The Stream Doctor Project: Community-Driven Stream Restoration. *BioScience*, **51**, 293-296.

Miles MB and Huberman AM (1994) *Qualitative Data Analysis*. Sage, Thousand Oaks, CA.

Naveh Z (2005) Epilogue: Toward a Transdisciplinary Science of Ecological and Cultural Landscape Restoration. *Restoration Ecology*, **13**, 228-234.

Pahl-Wostl C (2006) The Importance of Social Learning in Restoring the Multifunctionality of Rivers and Floodplains. *Ecology and Society*, **11**, 10.

Pahl-Wostl C (2007) The Implications of Complexity for Integrated Resources Management. *Environmental Modelling & Software*, **22**, 561-569.

Palmer MA, Bernhardt ES, Allan JD, Lake PS, Alexander G, Brooks S, Carr J, Clayton S, Dahm CN, Follstad Shah J, Galat DL, Loss GS, Goodwin P, Hart DD, Hassett B, Jenskinson R, Kondolf GM, Lave R, Meyer JL, O'Donnell TKOD, Pagano L and Sudduth E (2005) Standards for Ecologically Successful River Restoration. *Journal of Applied Ecology*, **42**, 208-217.

Paul MJ and Meyer JL (2001) Streams in the Urban Landscape. *Annual Review of Ecology and Systematics*, **32**, 333-365.

Peters NE and Meybeck M (2000) Water Quality Degradation Effects on Freshwater Availability: Impacts of Human Activities. *Water International*, **25**, 185-193.

Purcell AH, Friedrich C and Resh VH (2002) An Assessment of a Small Urban Stream Restoration Project in Northern California. *Restoration Ecology*, **10**, 685-694.

Ravetz JR (2006) Post-Normal Science and the Complexity of Transitions Towards Sustainability. *Ecological Complexity*, **3**, 275-284.

Reid HE, Gregory CE and Brierley GJ (2008) Measures of Physical Heterogeneity in Appraisal of Geomorphic River Condition for Urban Streams: Twin Streams Catchment, Auckland New Zealand. *Physical Geography*, **29**, 247-274.

Rogers EM (2003) *Diffusion of Innovations*, 5th ed edn. Free Press, NY, USA.

Rosenberg S and Margerum RD (2008) Landowner Motivations for Watershed Restoration: Lessons from Five Watersheds. *Journal of Environmental Planning and Management*, **51**, 477 - 496.

Roy AH, Wenger SJ, Fletcher TD, Walsh CJ, Ladson AR, Shuster WD, Thurston HW and Brown RR (2008) Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States. *Environmental Management*, **42**, 344-359.

Rumps JM, Katz SL, Barnas K, Morehead MD, Jenkinson R, Clayton SR and Goodwin P (2007) Stream Restoration in the Pacific Northwest: Analysis of Interviews with Project Managers. *Restoration Ecology*, **15**, 506-515.

Silveira AL (2002) Problems of Modern Urban Drainage in Developing Countries. *Water Science & Technology*, **45**, 31-40.

Sterman JD (2000) *Business Dynamics: Systems Thinking and Modelling for a Complex World*. McGraw-Hill, Boston, MA.

Svendsen E and Campbell LK (2008) Urban Ecological Stewardship: Understanding the Structure, Function and Network of Community-Based Urban Land Management. *Cities and the Environment*, **1**, 4.

Trotman R (2006) Sustainable Communities - Sustainable Catchment (Sc2), Stage Two Evaluation, (July 2005 - June 2006). Sustainable Communities, Department of Internal Affairs, Auckland Regional Council.

Turner RE (2005) On the Cusp of Restoration: Science and Society. *Restoration Ecology*, **13**, 165-173.

Waitakere City Council (2007) Project Twin Streams Strategic Plan 2007. Waitakere City, New Zealand.

Waitakere City Council (2008) Project Twin Streams Strategic Plan Summary. Waitakere City.

Wolman MG (1967) A Cycle of Sedimentation and Erosion in Urban River Channels. *Geografiska Annaler*, **49A**, 385-395.