Ministry for Primary Industries
Manatū Ahu Matua

Urban Development and the NPS-FM: Lucas Creek Catchment Case Study

MPI Technical Paper No: 2016/66

Prepared for the Ministry for Primary Industries
by NIWA

ISBN No: 978-1-77665-388-1 (online)
ISSN No: 2253-3923 (online)

October 2016

New Zealand Government

Growing and Protecting New Zealand

Disclaimer

While every effort has been made to ensure the information is accurate, the Ministry for Primary Industries does not accept any responsibility or liability for error of fact, omission, interpretation or opinion that may be present, nor for the consequences of any decisions based on this information. Any view or opinion expressed does not necessarily represent the view of the Ministry for Primary Industries.

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries website at
http://www.mpi.govt.nz/news-and-resources/publications/

Foreword

Since 2009, the Government has been undertaking a comprehensive set of reforms to improve the way we manage fresh water in New Zealand. The reforms emphasise that local communities, through councils, are in the best position to make decisions about managing the fresh water in their region, taking local conditions, needs and aspirations into account.

In 2011, the Government implemented the National Policy Statement for Freshwater Management. The National Policy Statement provides national direction under the Resource Management Act 1991. It requires councils to set objectives and limits for fresh water quality and quantity in a way that is consistent around the country. The National Policy Statement also requires councils to ensure land use and water are managed in an integrated way, and that iwi/hapū are involved in freshwater management and their values are reflected in decisions about the management of fresh water.

Policy development is now focusing on the implementation of the National Policy Statement. This includes providing better information, tools and processes to support communities to make decisions with their councils about their local rivers and waterways. The aim is to increase the value from more efficient use of freshwater, improve freshwater quality and ecosystem health, and ensure economic growth is based on good environmental practice.

To assist with this, the Ministry for Primary Industries and Ministry for the Environment have undertaken several environmental economic studies to build a strong evidence base to support decisions by central government, local government and community stakeholders. These studies demonstrate the link between environmental investment decisions and impacts, help to identify the most appropriate solutions for catchments to achieve particular objectives, challenge assumptions about the likely benefits of different approaches, and help to better target policies.

This paper investigates the costs and effects of a range of future urban development scenarios on water quality in the Lucas Creek catchment, located on the northern fringe of Auckland.

Urban Development and the NPS-FM: Lucas Creek Catchment Case Study

Prepared for the Ministry for Primary Industries

March 2016

Prepared by:
Jonathan Moores[1]
Jennifer Gadd[1]
Sharleen Yalden[1]
Chris Batstone[2]

[1] NIWA
[2] Cawthron Institute

For any information regarding this report please contact:

Jonathan Moores
Group Manager
Urban Aquatic Environments
+64-9-375 2043
jonathan.moores@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 99940
Viaduct Harbour
Auckland 1010

Phone +64 9 375 2050

NIWA CLIENT REPORT No: AKL2015-028
Report date: March 2016
NIWA Project: MPI16101

Quality Assurance Statement		
	Reviewed and released by:	Ken Becker Regional Manager Auckland

Contents

Executive summary

The National Policy Statement for Freshwater Management (NPS-FM) requires councils to manage all freshwater for ecosystem health and human health for recreation. In terms of ecosystem health, councils' management approaches must aim to safeguard the life-supporting capacity, ecosystem processes and indigenous species, including their associated ecosystems. Another objective is that the "overall quality of fresh water within a region is maintained or improved" while protecting the significant values of wetlands and outstanding waterbodies, and improving significantly degraded waterbodies. This represents a significant challenge in catchments undergoing urban development. There is a wealth of historical evidence that contaminants such as sediments generated from earthworks activities and heavy metals conveyed in stormwater have compromised water quality in New Zealand catchments undergoing urban development. In view of this, there is a need for central and local government to understand how councils can manage the impacts of both historic and future urban development on water quality to achieve the objectives of the NPS-FM, while accommodating urban growth through the expansion or intensification of New Zealand towns and cities.

Reflecting this need, the Ministry for Primary Industries (MPI) commissioned this study to investigate the effects of a range of future urban development scenarios on water quality in the Lucas Creek catchment, located on the northern fringe of Auckland. While locating the assessment in a real catchment, however, it is important to note that the primary intent of the study was to investigate the outcomes of a largely hypothetical set of urban development scenarios to inform the NPS-FM implementation programme, rather than to make specific predictions for the study area catchment.

The Urban Planning that Sustains Waterbodies (UPSW) decision support system (DSS) was used to make predictions of: sediment and metal loads; a range of stream environmental indicator scores; the costs of mitigation; and indicators of estuarine environmental quality. The assessment considered five land use change scenarios over the period 2010-2060, with differences reflecting: the adoption of greenfield, brownfield and infill forms of development; the characteristics of historic development; and dwelling density. For each of these five land use change scenarios, a number of alternative contaminant and stream management interventions were considered. These included: differences in the level of earthworks controls and stormwater treatment; Water Sensitive Design (WSD) approaches; and extensive, high quality riparian planting.

The findings of the study are presented through illustrative results that address four key questions.

> *Question 1 - How can the overall quality of water be maintained or improved in an urban development context?*

The results of the study indicate that in order to maintain and improve water quality in an urban development context, a high level of contaminant control is likely to be required. This may involve measures over and above 'best practice' stormwater treatment and erosion and sediment control, including WSD development approaches and retrofitting stormwater treatment in areas of historic development. Recognising that the NPS-FM requires freshwater to be managed for ecosystem health, when ecological indicators of water quality are considered the study found that riparian planting is likely to provide significant additional benefits, over and above the water quality gains associated with better contaminant controls. In some scenarios involving relatively constrained urban footprints, higher sediment loads from undeveloped rural parts of the catchment were found to counteract the influence of lower urban metal loads on the water quality indicator score. This finding indicates the potential limitation of considering mitigation of urban development effects in isolation from the management of undeveloped, rural parts of a catchment. It may also be necessary to consider mitigation that targets rural land use effects on water quality, as part of the adoption of an integrated catchment management approach.

> *Question 2 - If stream water quality in some sub-catchments is not maintained and/or improved, is it still possible to maintain and improve water quality at the catchment scale? (on average)*

The study found that, while it may be possible to maintain or improve water quality in some 'average' sense, despite a decline in some locations, this outcome is dependent on: the relative contribution of flow and contaminants from different sub-catchments; the spatial distribution of development; and where any mitigation effort is focused.

> *Question 3 - What are the most cost-effective means of maintaining and/or improving stream water quality in an urban development context?*

The study found that high levels of contaminant management are the most cost effective form of mitigation when considering water quality based purely on its physical and chemical properties. However, when ecological indicators of water quality are considered, the results indicate that riparian planting, in combination with high levels of contaminant management, is generally the most cost effective mitigation. The results also suggest that, from the point of view of achieving an overall improvement in water quality, mitigation focused on the most influential sub-catchments may be more cost-effective than catchment-wide mitigation. In addition, further development of catchments which are already partly developed (and which already contain some level of mitigation) may be more cost-effective than attempting to mitigate the effects of development in greenfield catchments. It is also important to note that there may also be certain avoided costs[1] associated with WSD that have not been taken into account in this study, such that the cost-effectiveness of these scenarios may be under-represented.

> *Question 4 - While the NPS-FM only applies to freshwater, what are the impacts of different urban development scenarios and mitigation strategies on estuaries?*

The results of the study indicate a reduction in estuary environmental quality under all urban development scenarios. This reflects the depositional nature of the estuary, which acts as a sink in which contaminants delivered from its catchment accumulate. However, in scenarios employing the most effective contaminant management strategies, the rate of decline in estuary environmental quality was predicted to be much slower than in scenarios employing *status quo* controls.

[1] Such as a reduction in the area earthworked and converted to impervious covers and a reduction in network infrastructure (fewer or shorter pipes).

1 Introduction

1.1 Background

The National Policy Statement for Freshwater Management (NPS-FM: NZ Government, 2014) sets out objectives and policies for freshwater management under the Resource Management Act 1991. In broad terms, the NPS-FM directs local government to manage water in an integrated and sustainable way, while providing for economic growth within water quantity and quality limits.

The NPS-FM requires councils to manage all freshwater for ecosystem health and human health for recreation. In terms of ecosystem health, councils' management approaches must aim to safeguard the life-supporting capacity, ecosystem processes and indigenous species, including their associated ecosystems. Another objective is that the "overall quality of fresh water within a region is maintained or improved" while protecting the significant values of wetlands and outstanding waterbodies, and improving significantly degraded waterbodies (Objective A2). This represents a significant challenge in catchments undergoing urban development. There is a wealth of historical evidence that contaminants such as sediments generated from earthworks activities and heavy metals conveyed in stormwater have compromised water quality in New Zealand catchments undergoing urban development. In view of this, there is a need for central and local government to understand how councils can manage the impacts of both historic and future urban development on water quality to achieve the objectives of the NPS-FM, while accommodating urban growth through the expansion or intensification of New Zealand towns and cities.

Reflecting this need, NIWA, and our sub-contracted research partner Cawthron Institute, were commissioned by the Ministry for Primary Industries (MPI) to conduct a case study assessment of urban development impacts, and their mitigation, on stream water quality in the Lucas Creek catchment north of Auckland. The study involved modelling a number of land development and stormwater and stream mitigation scenarios using the "Urban Planning that Sustains Waterbodies" (UPSW) decision support system (DSS) currently under development as part of the MBIE-funded Resilient Urban Futures (RUF) research programme[2].

In addition to the focus on stream water quality, the case study also investigated the impacts of urban development and the performance of mitigation on estuarine environmental quality. While the NPS-FM does not apply to the management of coastal water bodies, central government is interested in how its implementation will influence estuarine environmental quality as part of taking an integrated approach to the management of connected freshwater and coastal water bodies. Because the UPSW DSS makes predictions of estuarine indicators, as well as stream indicators, and the selected case study area includes an estuary, the case study was able to accommodate this additional aspect.

1.2 Scope

The study brief specifies the primary objectives of the study as being to:

- *"Gather evidence about the impact of urban development on contaminant loads into freshwater bodies and estuaries; and*

[2] http://sustainablecities.org.nz/resilient-urban-futures/

- *Understand the implications of meeting the objectives of the NPS-FM in urban areas when assessed on average over the entire catchment and when assessed independently at multiple points. This will include an assessment of the costs and benefits of different management options and comparing the outcomes of Greenfields or and Brownfields development against baseline pre-development and historic development conditions."*

In order to provide a framework for reporting the findings of the study, these objectives were subsequently specified as the following set of four key questions.

1. How can the overall quality of water be maintained or improved in an urban development context?
2. If stream water quality in some sub-catchments is not maintained and/or improved, is it still possible to maintain and improve water quality at the catchment scale? (on average)
3. What are the most cost-effective means of maintaining and improving water quality in an urban development context?
4. While the NPS-FM only applies to freshwater, what are the impacts of different urban development scenarios and mitigation strategies on estuaries?

The study brief required these questions to be addressed in relation to a range of greenfield and brownfield urban development scenarios. The scenarios were to include: the *status quo* (no further development); greenfield development involving different levels of housing intensity; brownfield development converting areas of industrial land use to residential development; and intensification of existing residential areas. For each scenario, comparisons were to be made between employing traditional forms of urban development and using lower imperviousness Water Sensitive Design (WSD) approaches. Variants of each of the land use change scenarios were also to investigate the influence of a range of stormwater contaminant and stream mitigation options, including: varying levels of stormwater treatment and contaminant source control; varying levels of erosion and sediment control for retaining earthworks sediment during the development phase; and riparian management.

Scenarios were to accommodate a level of population growth and changes in commercial and industrial land uses consistent with projections for the study area, while accepting that variations in the form of development under most scenarios would deviate from that currently provided for in Auckland Council planning documents. The intent of the study was therefore to investigate the outcomes of a largely hypothetical set of urban development scenarios to inform the NPS-FM implementation programme, rather than to make specific predictions for the study area catchment.

In order to distinguish between scenarios, the study made a range of assumptions relating to the characteristics of development and mitigation. For instance, it was assumed that scenarios involving WSD would result in lower levels of imperviousness than equivalent non-WSD scenarios. Although consistent with the principles of WSD, such an assumption ignores the potential for individual property owners to modify properties post-development. While recognising the potential for deviations from the assumptions adopted by the study, it is important to note that an assessment of the feasibility (policy and/or practical) of implementing each of the scenarios modelled lay beyond the scope of the study.

1.3 Contents of this Report

Chapter 2 of this report describes the methods employed in the study, providing an overview of the UPSW DSS, a description of the case study catchment and receiving environment and a summary of the scenarios modelled. Chapter 3 presents the findings of the study. While 35 different scenarios were modelled as part of the assessment, the report focuses on presenting a limited sub-set of results which illustrate the key findings in relation to each of the four questions posed in Section 1.2. Chapter 4 summarises the key findings of the study, while two appendices provide information to support the commentary presented in the main body of the report.

2 Methods

2.1 Introduction

This chapter describes the methods employed in the study, starting with an overview of the UPSW DSS (Section 2.2) and a description of the case study catchment and receiving environment (Section 2.3). Section 2.4 then describes the implementation of the DSS including: the spatial representation of the study area; parameterisation; and source data. Finally, Section 2.5 describes the urban development and mitigation scenarios modelled.

2.2 UPSW Decision Support System

2.2.1 Overview of the DSS

The Urban Planning that Sustains Waterbodies (UPSW) research project involves the development of a decision-support system (DSS) that allows the impacts of urban development scenarios on attributes such as water and sediment quality; ecosystem health; and cultural, amenity and recreation values to be investigated and compared. This section provides a summary of the design and use of the pilot DSS. More detailed descriptions are provided in Moores et al. (2012 and 2014) and a series of supporting documents cited therein. Note that while the aspects of the DSS described below and employed in this study are fully functional, because other aspects remain under development the system has not yet been made available for use outside of the UPSW research team.

There are three important aspects of the design of the DSS. Firstly, the DSS incorporates a sustainability indexing system which integrates indicators of environmental, social, economic and cultural wellbeing[3] and allows impacts to be assessed holistically. Secondly, the DSS links a suite of models and data manipulation methods in order to make predictions of outcomes under alternative urban development and stormwater management scenarios. These methods include: deterministic models; a probabilistic model; look-up tables populated through expert elicitation techniques; and index construction. Thirdly, while a number of these models have been appropriated and modified from existing stand-alone applications, others have been developed specifically for incorporation in the DSS. These include models for estimating the lifecycle costs of catchment-scale mitigation, a stream ecosystem health model and a method for predicting social wellbeing indicators from precursor environmental attributes.

The pilot DSS operates as a single entity executed from an MS Excel platform, calling on each of several constituent models in a logical sequence. The inputs to the system are the characteristics of a given urban development scenario, specified for each of several 'planning units' (PLUs) within a study area. The outputs from the system are summary indicators of environmental, economic and social wellbeing, provided for each 'reporting unit' within the study area. Typically, each planning unit corresponds to a stream catchment and contains a single stream reporting unit (SRU). The estuarine environment to which these streams discharge is divided up into a number of estuary reporting units (ERUs), each of which is representative of relatively homogeneous bed-sediment characteristics and sediment dynamics.

[3] The cultural indicators are currently under development.

The first step in running the DSS is to implement it for a given study area. This involves defining:

- the number and size of planning units and reporting units that make up the study area;
- the baseline year and the year for which indicators are to be reported;
- baseline land use, stormwater management and other characteristics of the catchment;
- baseline characteristics of streams in the study area, such as slope, length and substrate;
- baseline characteristics of estuaries in the study area, such as size, bed-sediment particle size distribution and bed-sediment metal concentrations; and
- relationships between planning units and reporting units, for instance specifying how the contaminant load generated in a particular planning unit is distributed among several receiving estuaries.

Alternative urban development scenarios can then be run by specifying a range of inputs representing land use change, transport characteristics, earthworks controls, stormwater management and riparian management characteristics (see Table 2-1). Once inputs for all planning units in the study area have been entered, the pilot DSS runs by calling on the constituent models in sequence.

While the DSS calculates results in terms of numeric values (scores) of all indicators, it also assigns an indicator 'level,' in order to allow communication of predictions to technical and non-technical audiences, respectively. There are five levels, each of which corresponds with a quintile (20%) of the range of indicator scores. The system adopts a traffic light approach to representing the indicator levels, with the highest level coloured green and the lowest level coloured red (see Figure 2-1). The reporting of results also includes comparison of pre- and post-development indicator scores (see triangular score markers shown in see Figure 2-1).

Figure 2-1: Example of predicted environmental indicator levels for a stream reporting unit.

As well as presenting results in this form, the DSS also generates output files containing the results of running the individual component models. This is intended to allow a more in-depth investigation of the outcomes of alternative development scenarios, for instance by graphically superimposing the results of a number of model runs. It is this approach that has been adopted in the present study, focusing on indicators and other model outputs which are of most relevance for addressing the four questions posed in Section 1.2 (see Chapter 3). The following section provides a summary of those indicators and outputs and the models which generate them.

Table 2-1: Inputs to be specified as part of running an urban development scenario.

Characteristic	Input	Specified as:
Development phasing	Time to start of development (Ts)	Time in years in the range 0 to (Tr - 1) where Tr is the reporting time set at implementation
	Time to end of development (Td)	Time in years in the range (Ts + 1) to Tr
Land use and associated level of imperviousness	Proportion of land area in each land use class	0-100% of PLU in each of the following sub-categories: Rural: pasture, exotic forest, native forest, horticulture , custom Residential: low density, medium density, high density, CBD, residential WSD, custom Commercial: suburban, commercial CBD, commercial WSD, custom Industrial: traditional industrial, industrial WSD, custom Major roads: three categories based on traffic numbers, custom
	Roof contaminant source control	Yes or no (where "yes" results in selection of low zinc-yielding roof types) for a given land use class
Transport characteristics	Change in number of vehicles per day	% change over the study timeframe
	Direction of change	Increase or decrease
	Vehicle contaminant source control	Yes or no (where "yes" results in selection of low copper- and zinc-yielding vehicle components)
Earthworks erosion and sediment controls	Bulk earthworks target TSS[1] removal	0, 25, 75 or 90% (removal of earthworks-generated sediment associated with greenfield land development)
	Other earthworks target TSS[1] removal	0, 25, 75 or 90% (removal of earthworks-generated sediment associated with infill land development)
Stormwater treatment	Target TSS[1] removal	0, 25, 50, 75 or 90% (removal of total sediment)
	Target metals removal	Low, medium or high (removal of copper, lead and zinc) [2]
Stream management	Extent of managed riparian vegetation	0-100% of stream length
	Width	Wide or narrow
	Extent of unmanaged riparian vegetation	0-100% of stream length

[1] TSS = Total Suspended Solids.

[2] Metals removal is described in this narrative way because the DSS applies different removal rates to the dissolved and particulate fractions of each of copper, lead and zinc. In other words, 'medium' metals removal (for example) does not correspond with a single value for % removal.

2.2.2 Key Models and Outputs

The key constituent models and their respective outputs which are of relevance for this study are:

- A contaminant load model, providing estimates of catchment and sub-catchment loads of sediment, copper, lead and zinc;
- A stream ecosystem health model, providing estimates of a range of stream health indicators, of which this report places most emphasis on the water quality and macroinvertebrate indicators;
- An estuarine sediment quality model, providing estimates of sediment metal concentrations;
- An estuarine benthic health model, providing an indicator of benthic macroinvertebrate community health; and
- A set of mitigation costing models, providing estimates of the lifecycle costs of stormwater treatment, earthworks controls, stormwater quantity control and riparian management.

A summary of each of these models and the outputs which form the basis of the results and discussion presented in Chapter 3 of this report are presented below, while further details on each can be found in Moores et al. (2012).

Catchment Contaminant Annual Loads Model

The Catchment Contaminant Annual Loads Model (C-CALM) is a simple deterministic model that predicts annual levels of imperviousness and catchment loads of the stormwater contaminants sediment, copper, lead and zinc in each planning unit from inputs relating to land use, transport, earthworks controls and stormwater management characteristics. C-CALM was originally developed as a stand-alone model that extended Auckland Council's Contaminant Load Model (CLM, Timperley et al., 2010) into a GIS software environment (Semadeni-Davies and Wadwha, 2014). A number of enhancements, such as the ability to model land use change over time, have been made as part of integrating it within the DSS (Moores et al., 2012).

Stream Ecosystem Health Bayesian Belief Network

Environmental indicator scores for each stream reporting unit are calculated by a Bayesian Belief Network (BBN) based on three sets of inputs: riparian vegetation and stormwater management characteristics specified as part of the urban development scenario; percentage imperviousness and contaminant loads predicted by C-CALM; and a set of starting conditions defined as part of implementation of the DSS. The BBN is a probabilistic method developed specifically for incorporation in the DSS by building a conceptual model of logical relationships between variables and quantifying the strength of these relationships using conditional probabilities (Castelletti and Soncini-Sessa, 2007). These probabilities were derived from a range of sources, including literature review, observations and the expert judgment of specialist scientists (Moores et al., 2012).

The BBN predicts scores for seven stream environmental indicators: water quality; macroinvertebrates; riparian vegetation; habitat; hydrology; aquatic plants; and native fish. Definitions of these indicators are provided in Appendix A. These predictions are made in the form of probability distributions for the scores to fall into one of five classes ranging from 'low' health to 'high' health. The generation of the final score then involves manipulation of these distributions to generate a single expected value (or weighted average) score in the range 0 to 1, where a higher score indicates better stream health.

The findings of the current study are principally illustrated with reference to the water quality and macroinvertebrate scores (see Section 3.3), providing a physio-chemical and ecological indicator, respectively, of the outcomes of urban development scenarios. The presentation of results for the latter indicator reflect the fact that objective A1 of the NPS-FM includes, among other matters, to safeguard "the life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems, of fresh water." It is therefore relevant to consider metrics that not only reflect the physical and chemical qualities of fresh water bodies but also the health of the ecosystems that they support. While the results presented in Section 3.3 are illustrated with reference to the macroinvertebrate indicator, examples of the scores predicted for other stream ecological indicators are given in Appendix C.

Estuary Urban Stormwater Contaminants Model

The appropriated Urban Stormwater Contaminants (USC) model predicts the bed sediment accumulation rate, particle size distribution and concentrations of copper, lead and zinc in each estuary reporting unit from the sediment and metal loads calculated by C-CALM and a set of starting conditions defined as part of implementation. The full USC model has been progressively developed to model increasingly complex estuaries (Williamson et al., 1998; Green et al., 2004; Green, 2008), necessitating a degree of simplification, including its operation at an annual rather than daily time-step, in order to allow its integration within the DSS.

Estuary Benthic Health Model

The bed sediment concentrations of copper, lead and zinc predicted by the USC are used by the Benthic Health Model (BHM) to calculate an ecosystem health score for the benthic zone (which incorporates estuary bed sediments and lowest part of the overlying water column) in each estuary reporting unit. The BHM is an existing empirical model developed from benthic community and sediment chemistry data collected at sites throughout the Auckland region (Anderson et al., 2006).

Mitigation Costing Models

A set of models developed as part of the current research make predictions of the lifecycle costs of stormwater treatment, earthworks controls, stormwater quantity control and riparian management. The inputs to these models are land use characteristics, levels of stormwater management and earthworks controls and the extent and quality of riparian vegetation specified as part of the urban development scenario, along with the percentage imperviousness calculated by C-CALM. The development of the models involved application of a stormwater device-scale costing model, COSTnz (Ira et al., 2008) along with the collection and manipulation of data from councils and practitioners on the costs of stormwater management devices, erosion and sediment control and riparian planting to estimate representative catchment-scale costs under a range of catchment management scenarios (Ira, 2011; 2012; 2013; 2015a). Further comments on the costing models of particular relevance for the interpretation of the results of this study are made in Section 3.4.2.

2.3 Case Study Location

The case study investigated the effects of a range of future urban development scenarios in the Lucas Creek catchment, which straddles with current Metropolitan Urban Limit (MUL) on the northern fringe of Auckland (see Figure 2-2). The catchment covers an area of 3,774 ha, contains streams with a total length of 44km and drains to the 150ha Lucas Creek tidal inlet, an estuary of the Upper Waitemata Harbour.

Two principal factors favoured the choice of this catchment as the location for the study. Firstly, as part of the development of the DSS an earlier study had 'hindcasted' the effects of historic development in the Lucas Creek catchment over the period 1960 to 2010 and compared the results with observations in order to demonstrate the validation of the system (Moores et al., 2012; 2014). The catchment has undergone significant urban development since the 1980s (see Figure 2-2) and is relatively data rich as a result of various environmental monitoring and modelling studies (ARC, 2010; Green et al., 2004; North Shore City Council, NSCC, 2005a; NSCC, 2005b). Predictions of stream and estuarine indicators made by the DSS corresponded well with monitoring data, providing confidence in the capability of the system. The same study then ran a comparison of four illustrative future urban development scenarios, based on growth projections provided by Auckland Council (Moores et al., 2012). As a result of having previously demonstrated the performance of the DSS in Lucas Creek catchment and having the relevant environmental data and growth projections at hand, the choice of this catchment for the current study therefore ensured minimal set-up effort.

Secondly, the catchment contains sub-catchments which have undergone different forms of historic urban development. In particular, there is a marked contrast between the extent and characteristics of urban development in the sub-catchments of the Lucas Stream and Oteha Streams. The latter is more fully developed and contains virtually all of the industrial land use of the catchment as a whole. This contrast provided a basis for investigating the extent to which differences in historic forms of development influence the ability of mitigation to achieve the 'maintain or improve' intent of the NPS-FM.

The Lucas Creek tidal inlet is a relatively self-contained estuary, with most of the incoming contaminant load delivered from the immediate catchment (Green et al., 2004). This means that the impacts of development scenarios on estuarine environmental quality can be assessed without needing to have regard to contaminant sources in other catchments. The relative simplicity of the source-to-sink relationship in this location was one of the factors supporting its selection in the original 2012 study.

2.4 Implementation of the DSS

2.4.1 Spatial Representation

In the implementation of the DSS the catchment was represented by four PLUs (Table 2-2 and Figure 2-3). The PLUs were defined on the basis of land use and sub-catchment boundaries. PLU2 and PLU3 each contain an SRU, Lucas Stream and Oteha Stream[4], respectively. While the two remaining PLUs also contain a number of small streams, they do not form linked networks and SRUs were not defined in these sub-catchments. The Lucas Stream and Oteha Stream are by far the most significant parts of the stream network in the catchment as a whole and have sufficiently different catchment characteristics as to provide a basis for addressing the objectives of the study. The DSS makes its

[4] Including its tributary, the Alexandra Stream

predictions of the indicators for each of these two streams based solely on development in their corresponding sub-catchment (or PLU). In contrast, indicators for the sole ERU (the Lucas Creek tidal inlet) are influenced by development in all four PLUs.

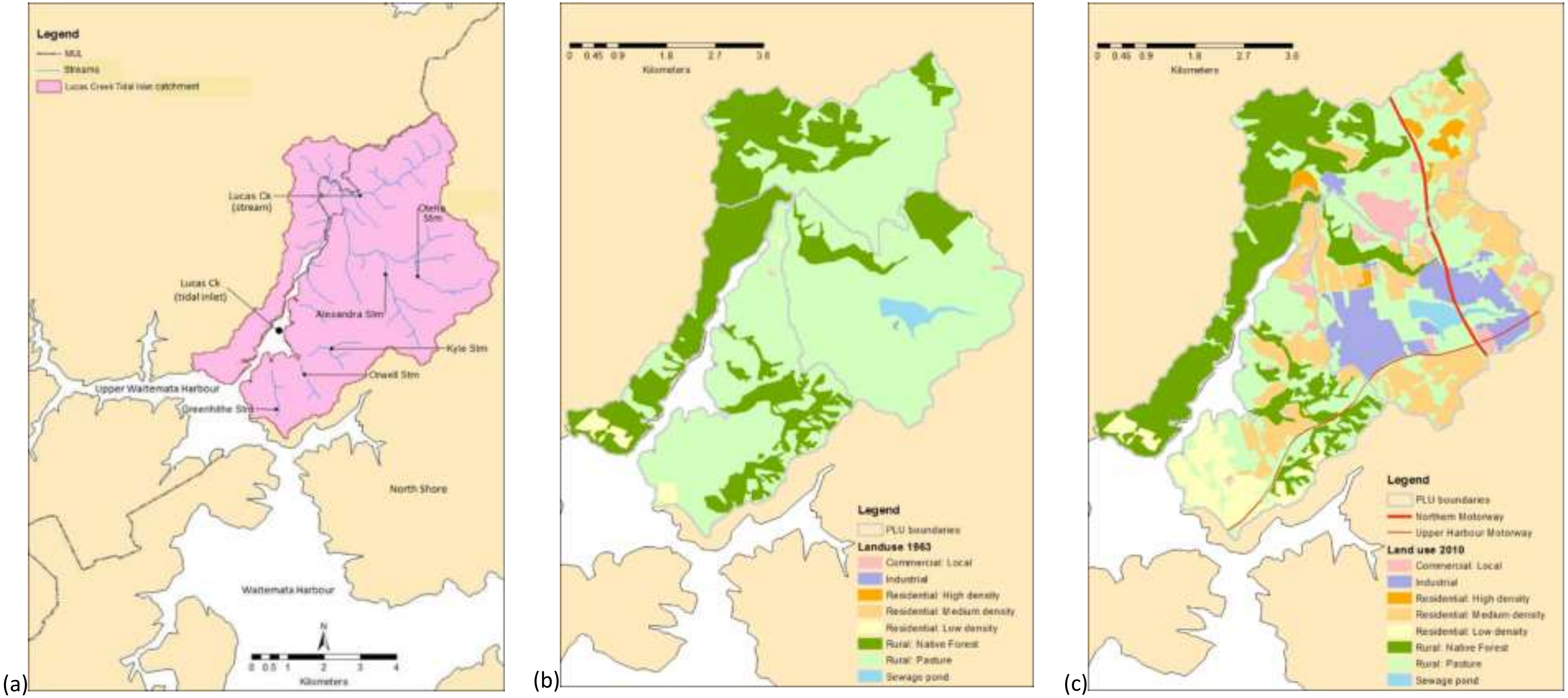


Figure 2-2: (a) Location of Lucas Creek tidal inlet and its catchment in relation to the Upper Waitemata Harbour and Auckland Metropolitan Urban Limits (MUL); (b) Land use in 1960; and (c) Land use in 2010.

Table 2-2: Spatial representation of the case study area in the DSS.

Unit	Name	Area (ha)	Length (km)	Contributing sub-catchment
PLU 1	Paremoremo	411	-	-
PLU 2	Lucas	957	-	-
PLU3	Oteha Valley	1258	-	-
PLU 4	Greenhithe	995	-	-
SRU 1	Lucas Stream	-	13.8	PLU 2
SRU 2	Oteha Stream	-	17.9	PLU 3
ERU 1	Lucas Creek tidal inlet	152	-	PLUs 1-4

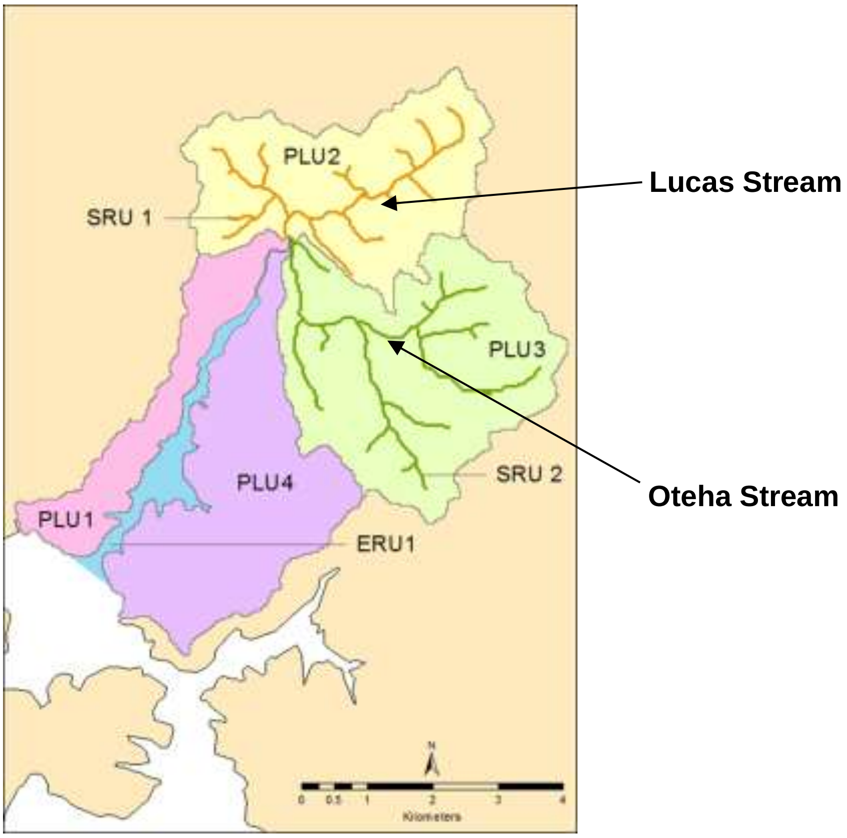


Figure 2-3: Spatial representation of the case study area in the DSS (PLU = planning unit; SRU = stream reporting unit; ERU = estuary reporting unit), emphasising the locations of Lucas Stream and Oteha Stream.

2.4.2 Data Sources

Implementation of the DSS also involved defining the value of various parameters that represent the characteristics of each PLU, SRU and ERU along with other parameters representing starting conditions in 1960. The DSS was then run, firstly, with inputs reflecting historic land use change over the period 1960-2010[5] and, secondly, assuming no land use change over the period 1960-2010. The outputs of these historic model runs were then adopted as a new set of implementation parameter values defining starting conditions in 2010 for the 'future' model runs representing the range of urban development scenarios assessed as part of the current study (see Section 2.5.1).

The data sources used to define implementation parameter values and to guide the historic model run included:

- Aerial photographs to map land-use change and to establish the timing and rate of urban development;
- Census population data (1976 to 2006) and housing stock counts (1960 to present) to establish the timing and rate of urban development;
- NZ Transport Agency publications and website (NZTA, 2008; 2012) to assess traffic numbers and trends;
- North Shore City Council (NSCC) stormwater asset management plan (2009) and asset consent data to estimate the degree of stormwater treatment in each of the PLUs;
- NSCC stream surveys (NSCC 2005a; 2005b; 2005c) to obtain implementation data relating to the streams;
- Various ARC documents including annual State of Environment reports for freshwater and coastal environments (e.g., Reed and Gadd, 2009; Neale, 2010a; and Neale, 2010b) to obtain implementation data relating to streams and the tidal inlet.

Further details of the manipulation of the data from these sources to implement the DSS are given in Moores et al. (2012).

2.4.3 Customisation

As described in Section 2.2.2, stormwater contaminant loads are estimated by the C-CALM model embedded within the DSS. C-CALM applies contaminant yields developed for Auckland Council's CLM. These yields were derived from analysis of stormwater monitoring results in areas of central Auckland, reflecting development at various times over the 1900s (Timperley et al., 2010). In contrast to central Auckland, most of the development in the Lucas Creek catchment has occurred since the 1980s, over which time trends in roofing materials have seen a reduction in the use of high zinc-yielding galvanised steel in favour of lower yielding materials such as unpainted zinc/aluminium (Zincalume) and coated zinc/aluminium (Colorsteel) (Timperley and Reed, 2008). Reflecting these trends, the split between different classes of roofing materials used in C-CALM's calculations was customised for the current study. The customised breakdown gives predominance to the use of

[5] Note that a 'historic' model run was performed as part of the current study rather than using the outputs of the 2012 study. This was because the DSS has undergone significant further development since that original study and it was important to have a 'seamless' set of predictions covering both the historic and future development periods.

unpainted zinc/aluminium in industrial areas and coated zinc/aluminium in residential and commercial areas (after Timperley and Reed, 2008).

2.5 Urban Development Scenarios

2.5.1 Land use change

The assessment considered variants of a set of five future land use change scenarios over the period 2010-2060. Differences in land use are important drivers of the predictions made by the DSS, because they determine the level of imperviousness and consequently, estimates of contaminant loads modelled under each scenario.

Three of the land use change scenarios take as their starting point the historic urban development that occurred in the Lucas Creek prior to 2010 (represented by the land use shown in Figure 2-2(c)). They are:

- Scenario 1 - Low density greenfield development;
- Scenario 2 - Higher density development involving a mix of greenfield development and infill development in existing residential areas; and
- Scenario 3 - Brownfield development, involving the replacement of areas of existing industrial development with high density residential development.

The two remaining land use change scenarios take as their starting point the hypothetical situation of there having been no urban development in the catchment over the 1960-2010 period. In other words, in these scenarios it was assumed that land use (and associated environmental conditions) in 2010 could be represented by the land use that existed in 1960 (Figure 2-2(b). These two scenarios are:

- Scenario 4 - Low density greenfield development; and
- Scenario 5 - Higher density greenfield development.

The rationale for the adoption of dual starting points was to allow the study to compare situations in which there may be legacy effects on water quality associated with historic urban development with those in which are no legacy effects. Had an alternative approach been adopted in which greenfield development scenarios in another catchment were compared with development scenarios in the historically-developed Lucas Creek, it is likely that the interpretation of results would have been complicated by the influence of variations in catchment characteristics. While recognising the completely hypothetical nature of Scenarios 4 and 5, by conducting this comparison in a single catchment area, the study was able to hold constant parameter values representing catchment characteristics.

All five land use change scenarios involve development over the first 25 years of the study timeframe, with development assumed to be complete by 2035. This is broadly consistent with Auckland Council growth projections, which project only limited growth after this date (see Figure 2-4). By the completion of development, all scenarios accommodate an identical number of dwellings, being the number consistent with full development of residential-zoned land at high densities added to the number resulting from historic development[6]. The distribution of dwellings among PLUs is also consistent between scenarios, with the exception of Scenario 3 (brownfield development). In this scenario, the majority of development occurs in PLU3 (Oteha Valley) due to that being the location of most of the existing industrial land use in the study area. Each scenario also accommodates the same extent of industrial and commercial land, again with the exception of Scenario 3 due to the replacement of existing industrial land with houses. It is assumed that this represents a situation in which redundant industrial land undergoes urban regeneration, such that there is no loss of industrial activity in the catchment. Accordingly, the study did not consider any effects of brownfield development associated with the relocation of industrial activity to other catchments. This would be an important consideration where such a situation exists. Note that Scenario 3 does allow for the development of the same area of new industrial and commercial land as the other scenarios. A 20% growth in vehicle numbers is assumed in all scenarios, consistent with the trend adopted in the earlier study (Moores et al., 2012).

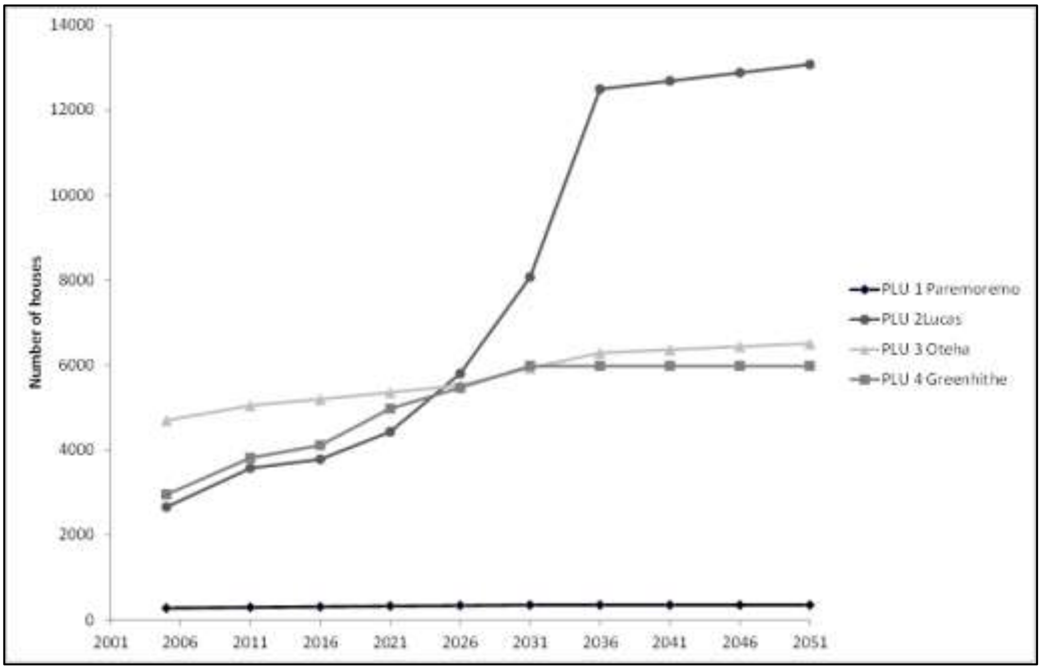


Figure 2-4: Projected number of dwellings by PLU. Data provided by Auckland Council.

Because each scenario accommodates the same number of dwellings but at differing densities, they each have a different 'urban footprint'. A greater proportion of the catchment is developed under scenarios involving low density forms of development than under those involving higher density forms (see Table A-2, Appendix B). It is important to note, however, that planning provisions are the main determinant of an urban footprint. In other words, dwelling density and numbers are a function of the allowed urban footprint (and related zoning rules), rather than the other way round.

Figure 2-5 shows the imperviousness (proportion of land under impermeable surfaces such as concrete, asphalt and roofs) in 2010 and predicted for 2060 under each of the five land use change scenarios for the catchment as a whole and for the focus sub-catchments of Lucas Stream and Oteha Stream. The study area imperviousness in 2010 under Scenarios 1, 2 and 3 is just under 30%, reflecting the historic development of the catchment. By 2060, the study area imperviousness

[6] Meaning that significantly more future development was assumed to occur in Scenarios 4 and 5 in order to reach the same 'end point' as Scenarios 1, 2 and 3.

increases to over 40% in Scenario 1 (low density) with less marked increases in Scenario 2 (higher density) and Scenario 3 (brownfields).

In contrast, in Scenarios 4 and 5 there is very little impervious cover in the study area at 2010 but under Scenario 4 (greenfields) this increases to nearly 50%, the highest level under any scenario. This reflects the low density nature of all development this scenario, in contrast with the other low density scenario (Scenario 1) in which some of the development occurring over the historic period was medium to high density.

Under all scenarios imperviousness in both 2010 and 2060 is higher in Oteha Stream sub-catchment than in Lucas Stream sub-catchment, reflecting the more extensive historic development in the Oteha Stream sub-catchment. However, the increase in imperviousness is actually greater in the Lucas Stream sub-catchment, reflecting the relative amount of projected future growth that each of the two sub-catchments will accommodate. Further details of the land use breakdown under each of Scenarios 1 to 5 is given in Appendix B.

Mitigation

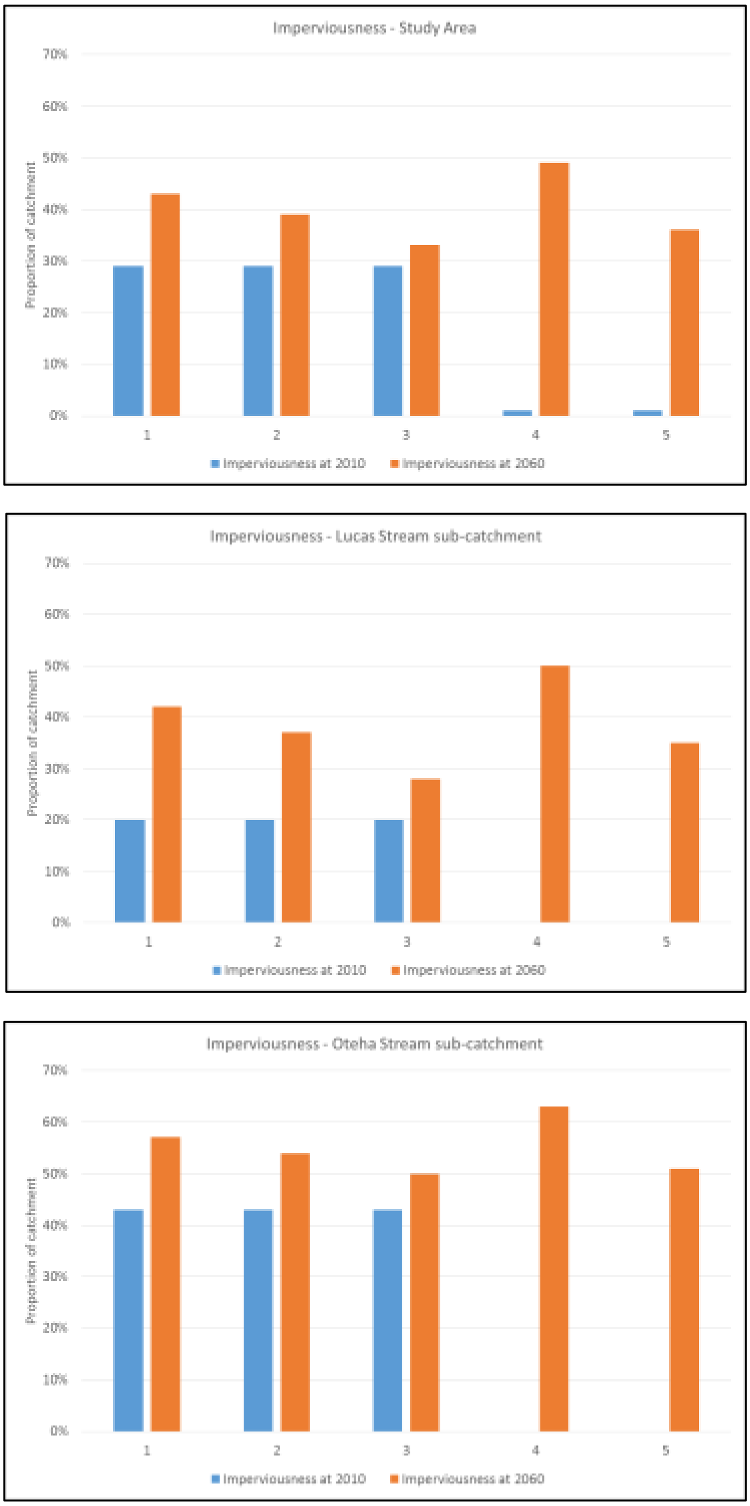
For each of the five land use change scenarios, a number of alternative contaminant and stream management interventions were considered. These included:

- *'Status quo'* levels of earthworks controls (75% removal of TSS) and stormwater treatment (either unchanged from the historic level of stormwater treatment or, in areas of new development, 75% removal of TSS and 'medium' metals removal[7]);
- 'Best practice' levels of earthworks controls (90% removal of TSS), stormwater treatment (90% removal of TSS and 'high' metals removal) and zinc source control of roofs (use of lowest zinc-yielding materials[8]) in areas of new development;
- Water Sensitive Design (WSD) development: projected additional dwelling numbers accommodated with a smaller impervious footprint[9] (see Figure 2-6 for a comparison of imperviousness under each scenario, with and without the adoption of WSD);
- Retrofitting 'best practice' stormwater controls to areas of existing development;
- Vehicle component source control: lower copper-yielding brake pads and lower-zinc yielding tyres; and
- Extensive and high quality riparian planting (90% of stream length, 20m buffer width, diverse species composition).

[7] As noted in Table 2-1, metal removal rates for each of 'high', 'medium' and 'low' vary between the dissolved and particulate fractions.

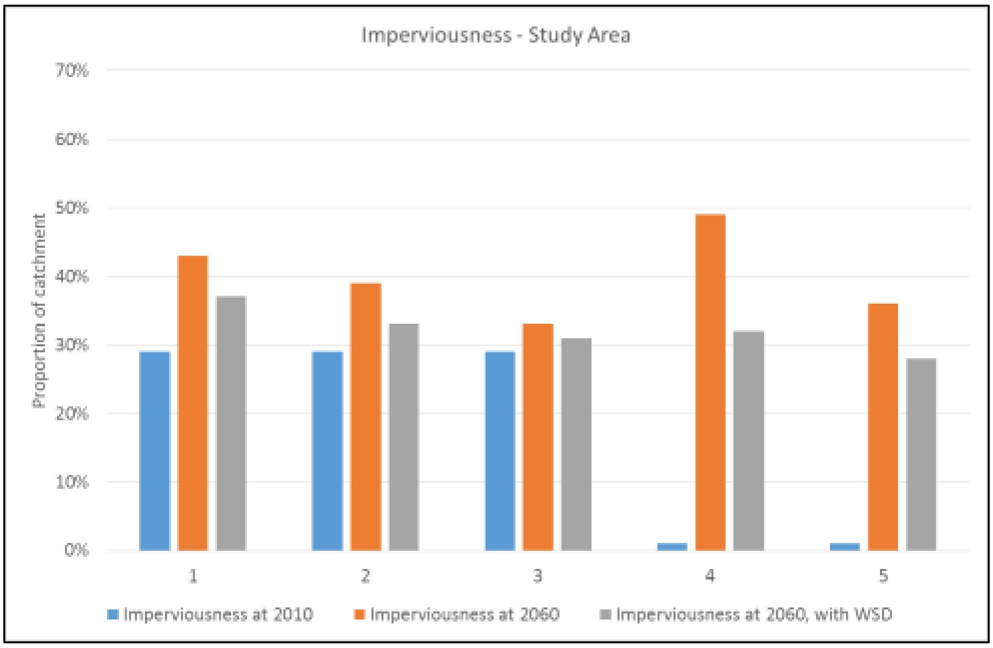
[8] As noted in Section 2.4.3, the customised breakdown of roofing materials gives predominance to the use of unpainted zinc/aluminium in industrial areas and coated zinc/aluminium in residential and commercial areas. While both are relatively low-zinc yielding materials, the former still has a zinc yield one order of magnitude (10 times) higher than the latter. In future development scenarios representing the application of roof contaminant source control, it was therefore assumed that coated zinc/aluminium would be used in the place of unpainted zinc/aluminium.

[9] The lower imperviousness associated with WSD reflects the assumption that, under this form of development, the areas of roofs, roads and paved impervious surfaces associated with a given number of dwellings will be smaller than under an equivalent non-WSD development, for instance as a result of clustering, the construction of narrower roads and the use of permeable paving.



Land development:	(1) Historic + low density	(4) Greenfield low density
	(2) Historic + high density	(5) Greenfield high density
	(3) Historic + brownfield	

Figure 2-5: Imperviousness in 2010 and 2060 for Scenarios 1 to 5, inclusive, for the study area (upper), Lucas Stream sub-catchment (middle) and Oteha Stream sub-catchment (lower). Note these plots show imperviousness in the absence of Water Sensitive Design (contrast with Figure 2-6)**.**



Land development:	(1) Historic + low density (2) Historic + high density (3) Historic + brownfield	(4) Greenfield low density (5) Greenfield high density

Figure 2-6: Imperviousness in 2010 and 2060 for Scenarios 1 to 5, inclusive, for the study area, showing influence of Water Sensitive Design.

These mitigation measures were applied in additive fashion to each land development scenario , with scenario variants involving status quo earthworks and stormwater controls given the label 'A' (see Figure 2 7). Scenarios involving increasing levels of contaminant controls were labelled as variants 'B' to 'E' of each Scenario. Scenario variants 'F' to 'H' then involved addition of riparian planting to the status quo scenario and to two of the contaminant management scenarios. This allowed comparisons to be made of the effectiveness of contaminant controls and riparian planting individually and in combination.

Appendix B provides a summary table of the variants of each scenario modelled.

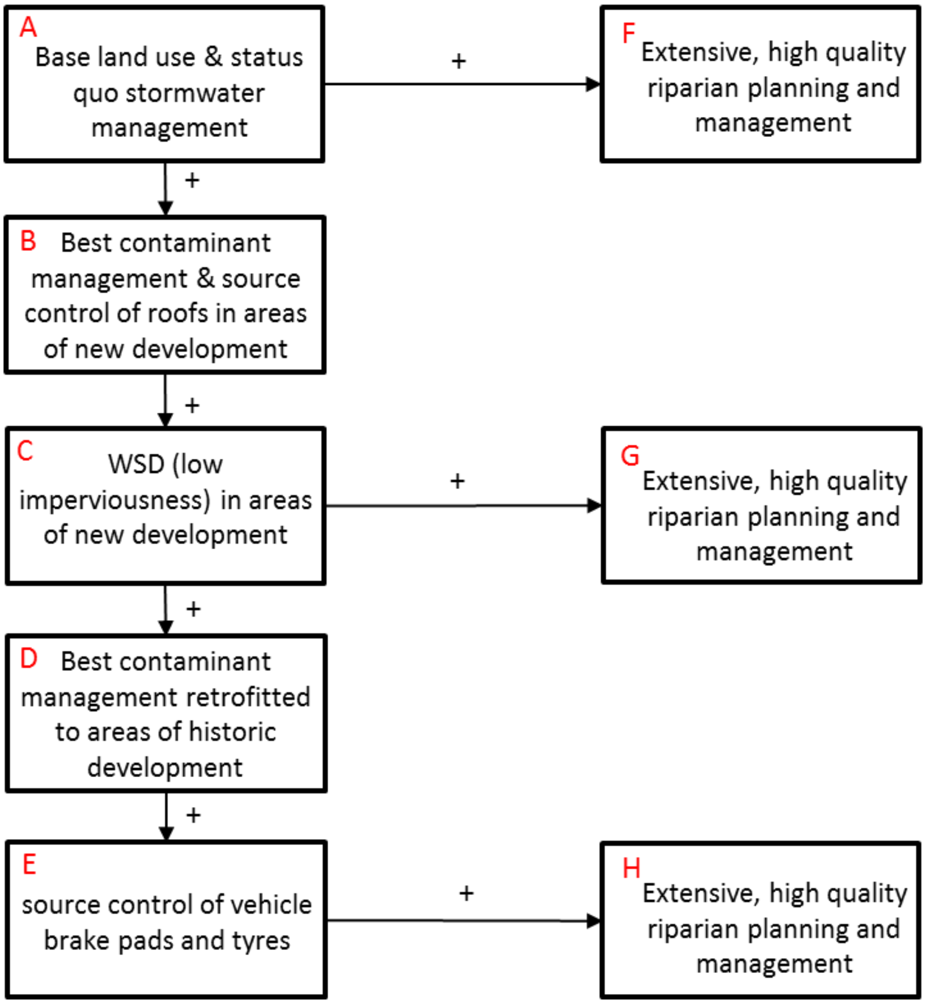


Figure 2-7: Mitigation applied in variants ‘A’ to ‘H’ of the five land use change scenarios.

3 Results and Discussion

3.1 Introduction

This chapter presents and discusses the results of the study. It provides, firstly, a comparison of the loads of sediment and metals predicted under alternative urban development scenarios before addressing each of the four key questions posed in Section 1.2.

While 35 different scenarios were modelled, with the DSS's full range of indicators predicted for each, the report focuses on presenting a limited sub-set of results which illustrate the key findings. Additional results that complement those presented in this Chapter are presented in Appendix C. While certain results are presented for the study area as a whole and others for the Lucas Creek estuary, emphasis is given to the results for the focus streams, Lucas Stream and Oteha Stream, and their sub-catchments.

3.2 Contaminant Loads

3.2.1 Introduction

As indicated in Section 1.2, the prediction and reporting of stormwater contaminant loads associated with urban development formed part of the objectives of this study. The contaminants modelled were sediment and the metals copper, lead and zinc.

In themselves, variations in loads of these contaminants are a useful indicator of the potential effects of urban development. In addition, having an understanding of variations in contaminant loads, and the reasons for those variations, provides context to understand some of the consequent findings relating to predictions of stream water quality.

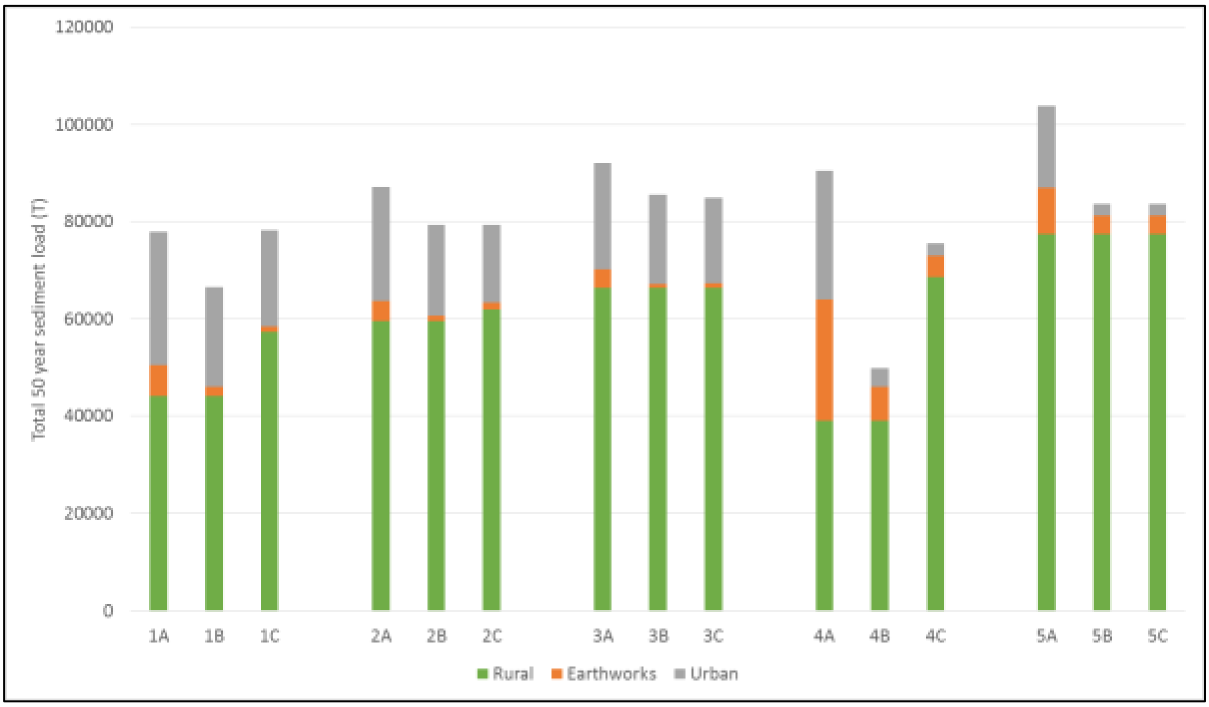
3.2.2 Sediment loads

Rural sediment

Figure 3-1 presents the predicted total sediment load over the 50 year study timeframe under variants A, B and C of each of Scenarios 1-5. Other than in Scenario 4A (greenfields low density development with *status quo* mitigation), around 70% or greater of the total catchment sediment load is associated with rural sources. This is because, despite a reduction in the area of rural land as urban development progresses, in the DSS sediment yields from rural land are higher than those from developed urban land. Differences between scenarios in the rural loads of sediment are a reflection of differences in the footprint of urban development, with Scenarios 4 and 1 (low density development) involving the conversion of the greatest area of rural land and, as a consequence, having the lowest rural sediment loads.

The same effect can be seen in relation to scenarios involving WSD. Figure 3-1 shows that rural sediment loads are predicted to be higher in scenarios 1C, 2C and 4C (which involve the use of lower imperviousness WSD) than in the corresponding A and B scenarios (which involve traditional, higher imperviousness, forms of development). This reflects the assumption that the use of WSD results in a smaller development footprint, leaving a larger area of undeveloped rural land.

These differences are important for the following reason. In the DSS, predictions of the stream water quality indicator take account of a range of factors which influence water quality, including both metal and sediment loads. In catchments featuring predominantly urban land use, the water quality indicator score tends to be relatively low as a reflection of high metal loads, despite the fact that sediment loads are relatively low. In contrast, in predominantly rural catchments the relatively high loads of sediment are the more influential factor in driving down the water quality score, because metal loads in these situations are relatively low (see Section 3.3.2). Understanding this influence of rural land is an important point, and not only so that certain potentially counter-intuitive results can be understood. It also indicates the potential limitation of considering mitigation of urban development effects in isolation from the management of undeveloped, rural parts of a catchment. It may also be necessary to consider mitigation that targets rural land use effects on water quality, as part of the adoption of an integrated catchment management approach.



Land development: (1) Historic + low density
(2) Historic + high density
(3) Historic + brownfield
(4) Greenfield low density
(5) Greenfield high density

Mitigation: (A) Status quo contaminant controls; (B) Best practice contaminant controls; (C) Best practice contaminant controls and Water Sensitive Design (lower imperviousness).

Figure 3-1: Total predicted sediment load by source for selected urban development scenarios, whole study area.

Urban sediment

Urban sediment loads are predicted to make up the next largest proportion of total sediment load under all Scenarios 1-3. In these scenarios, the application of best practice stormwater treatment (scenarios B) and WSD (scenarios C) results in only a slight reduction in the urban sediment load associated with *status quo* stormwater treatment (scenarios A). This is because the higher levels of treatment apply only to new areas of development, with treatment in areas of historic development remaining at the *status quo* levels.

Under Scenarios 4 and 5 there is a much greater contrast between urban sediment loads predicted for *status quo* levels of treatment (scenarios A) and those predicted for best practice stormwater treatment (scenarios B) and WSD (scenarios C). This reflects the fact that these scenarios assume that there has been no historic development and, as a result, the higher stormwater treatment levels apply to the entire area of urban development.

Earthworks sediment

Earthworks sediment loads are predicted to make up a relatively small proportion of the total load (less than 10%) in the majority of scenarios. It is worth noting that, in all of these scenarios, erosion and sediment controls are assumed to be in place, as represented by reductions of 75% and 90% of the generated load with the use of *status quo* and best practice controls, respectively. In the absence of these controls, or with less effective controls, the contribution of earthworks to the total sediment load and its influence on water quality indicators, could be expected to be much more significant.

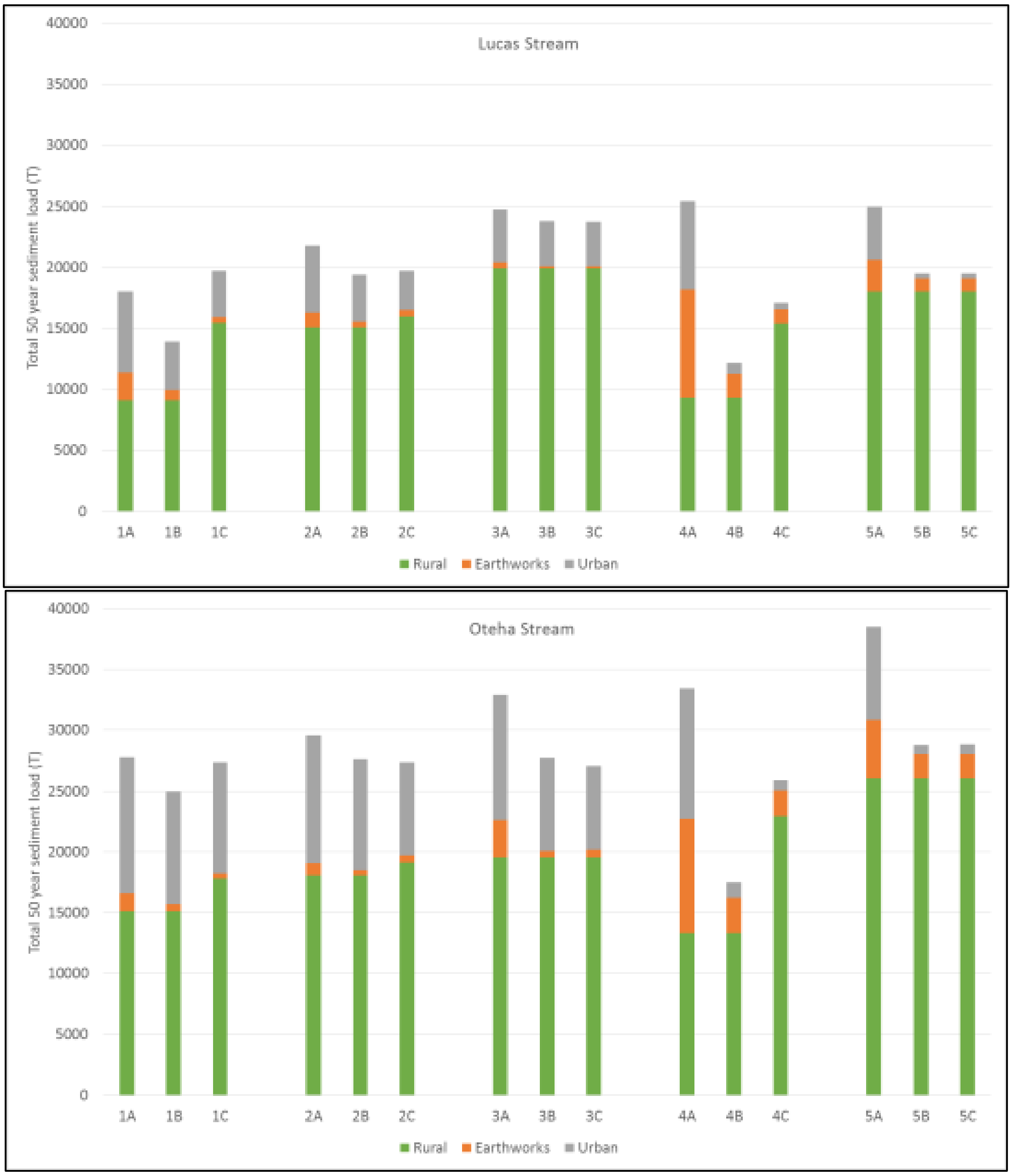
In Scenarios 1-3 the relative insignificance of the earthworks sediment loads also reflects the fact that a significant proportion of the urban development in the study area has already occurred over the historic development period. In contrast, higher earthworks loads are predicted under Scenarios 4 and 5, reflecting the much greater extent of new development under these scenarios. The contrasting performance of *status quo* (scenarios A) and best practice (scenarios B and C) earthworks controls is evident in relation to all five groups of scenarios but is most notable in the comparison of earthworks sediment loads predicted for Scenarios 4, reflecting the fact that this scenario involves the most extensive development footprint.

Sub-catchment variations

Figure 3-2 presents the predicted sediment loads for the same set of scenarios in Lucas Stream and Oteha Stream sub-catchments. While the relativity between loads predicted for each of the scenarios is similar to that for the study area as a whole, loads are predicted to be higher in the Oteha Stream sub-catchment than in the Lucas Stream sub-catchment, reflecting the larger size and more extensive development of the former. In addition, urban sources account for a greater proportion of the total sediment load in the Oteha Stream sub-catchment (mean of 24% in these scenarios) than in the Lucas Stream sub-catchment (mean of 17%). Conversely, rural sources account for a greater proportion of the total sediment load in the Lucas Stream sub-catchment (mean of 75% in these scenarios) than in the Oteha Stream sub-catchment (mean of 69%).

3.2.3 Metal loads

While soil contains background levels of copper, lead and zinc, the predominant source in catchments undergoing urban development is the wash-off of metals accumulated on impervious surfaces. These metals accumulate as a result of physical processes such as wear on vehicle components (tyres and brake linings) and chemical processes such as the dissolution of zinc from galvanised roofing materials. As development proceeds and the areas of roads, roofs and other impervious surfaces increase, so metal loads discharged to receiving water bodies can be expected to increase. This section illustrates the variations between scenarios using the example of annual zinc loads. However, much the same patterns as those described below are evident in the results predicted for the other metals.

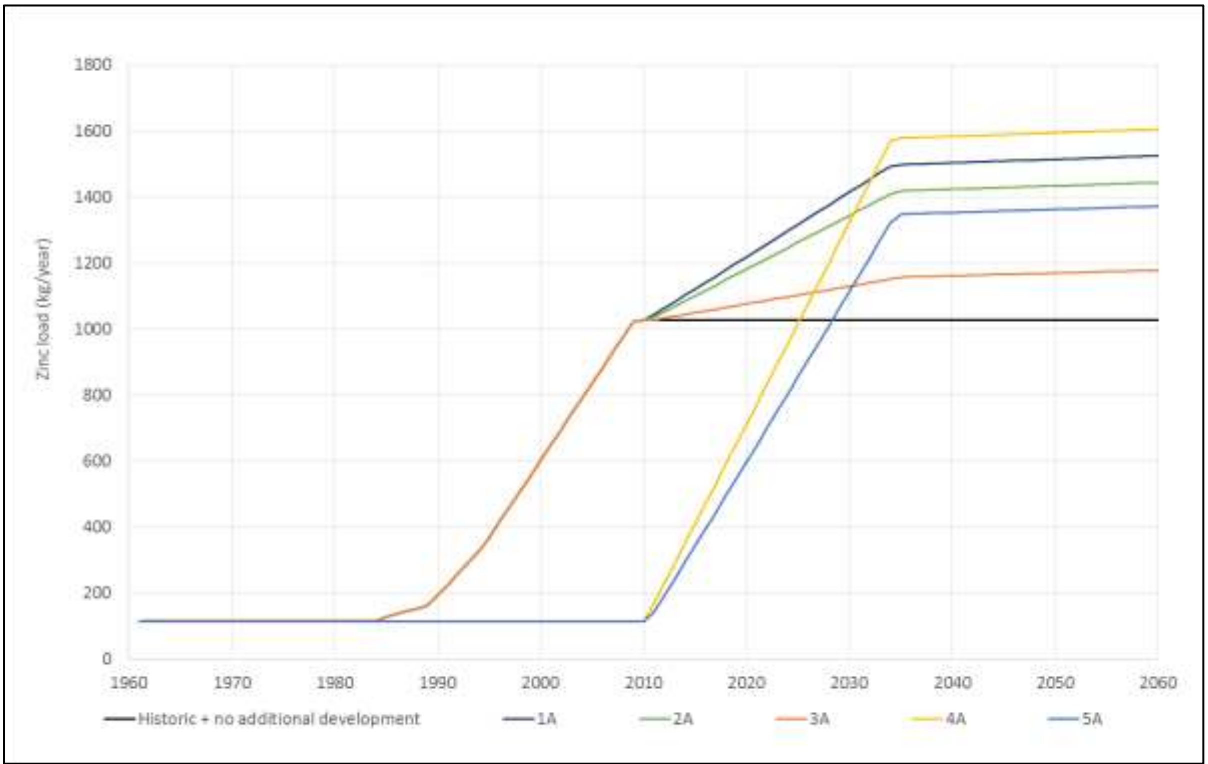


Land development:	(1) Historic + low density (2) Historic + high density (3) Historic + brownfield	(4) Greenfield low density (5) Greenfield high density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness)	

Figure 3-2: Total predicted sediment load for selected urban development scenarios, Lucas Stream sub-catchment (upper) and Oteha Stream sub-catchment (lower).

Influence of development type

Figure 3-3 shows modelled trends in annual loads of zinc over the study timeframe for the whole study area, including those associated with the historic period prior to 2010[10]. Trends are plotted for each of the land use change scenarios, assuming *status quo* levels of stormwater treatment (scenarios A).



Land development:	(1) Historic + low density	(4) Greenfield low density
	(2) Historic + high density	(5) Greenfield high density
	(3) Historic + brownfield	

Figure 3-3: Predicted annual zinc loads for urban development scenarios with *status quo* contaminant controls, whole study area.

Annual zinc loads under Scenarios 1-3 are modelled to be at around 1000 kg $year^{-1}$ by the end of the historic development, before diverging over the future development period. By the mid-2030s, following the completion of the future development, annual zinc loads under these Scenarios are predicted to be around 1500, 1400 and 1150 kg $year^{-1}$ under Scenarios 1A (low density), 2A (higher density) and 3A (brownfields), respectively. After this date, there is no further increase in the footprint of urban development and, accordingly, the rate of increase in the annual loads of zinc becomes much more gradual (note the flattening off of curves after 2035 in Figure 3-3). This more gradual rate of increase in annual zinc loads after 2035 reflects the assumption of a continuing increase in vehicle numbers over this period. The same trend can be seen in the results for other scenarios described below.

[10] In this, and subsequent figures, curves for two or more scenarios over the historic period (pre-2010) are often superimposed such that some curves are not visible. For instance, over the period 1985 and 2010, four of the scenarios (no additional development, 1A, 2A and 3A) are modelled to follow identical trends of increasing zinc loads, but only the curve for Scenario 3A is visible because it is the last of the four to be plotted. After 2010 the trends in zinc loads under each of the four scenarios differ such that the curves for each scenario are visible over this period.

Annual zinc loads under Scenarios 4 and 5 are around only 100 kg $year^{-1}$ in 2010, reflecting the relative absence of impervious surfaces. By the mid-2030s, following the completion of development, annual zinc loads under these Scenarios are predicted to be around 1600 and 1350 kg $year^{-1}$ under Scenarios 4A (low density) and 5A (higher density), respectively. These loads differ from the loads predicted under the comparable post-historic scenarios (1A and 2A, respectively) because they involve solely low density or higher density development, while the post-historic scenarios also include a mix of development that occurred over the historic period.

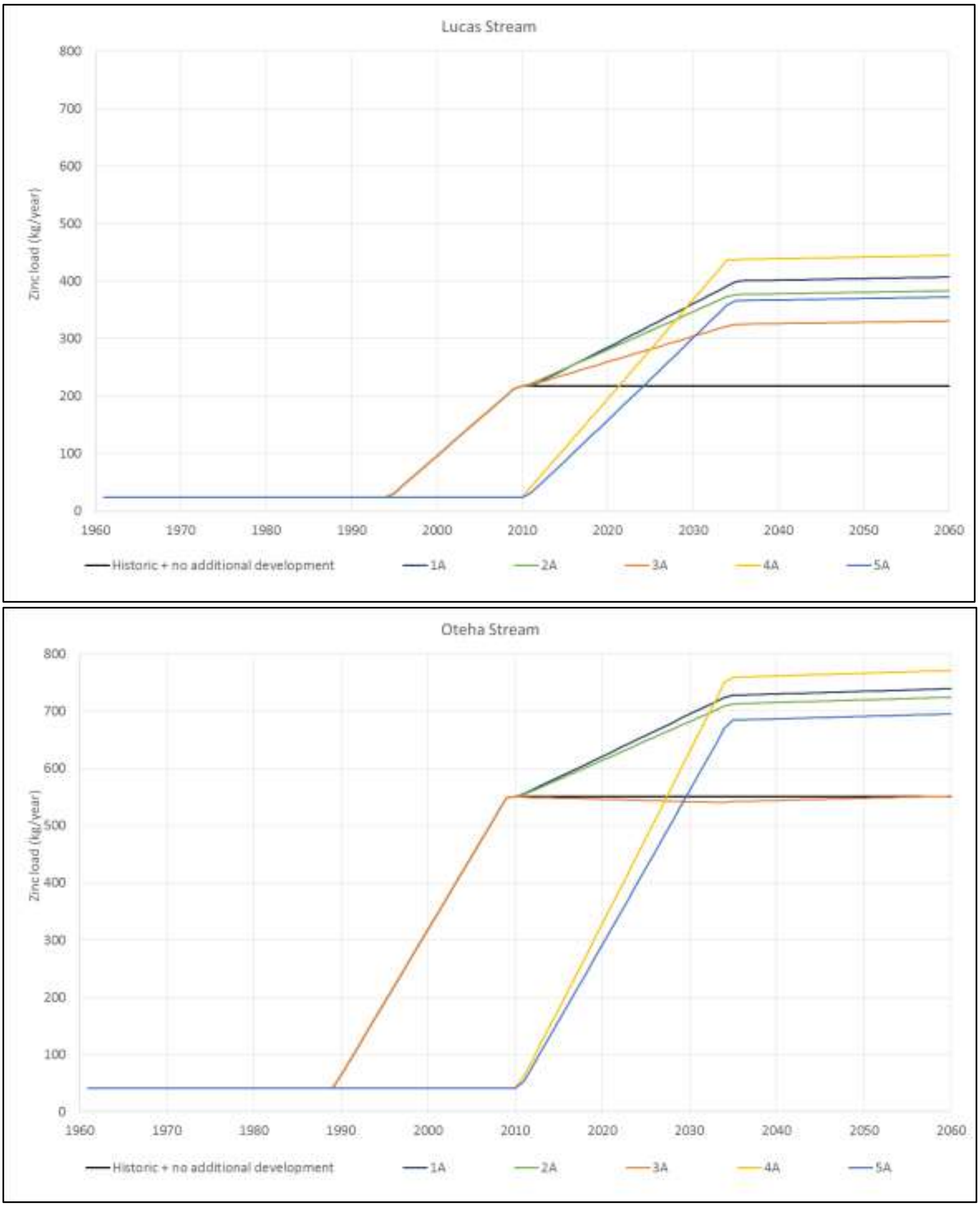
These differences between lower and higher density development scenarios are informative because they illustrate the beneficial effect on metal generation of constraining the development footprint through higher density and/or brownfields development. In the absence of the counteracting influence of higher sediment loads from rural land described in Section 3.2.2, these constrained forms of development could therefore be expected to deliver better water quality outcomes than more extensive, low density development. These results therefore provides a further illustration of the value of taking a whole-of-catchment approach that considers how best to manage both urban and rural effects on water quality.

Figure 3-4 presents the modelled zinc loads for the same set of scenarios in Lucas Stream and Oteha Stream sub-catchments. While the relativity between scenarios is similar to that for the study area as a whole, loads are predicted to be higher in the Oteha Stream sub-catchment than in the Lucas Stream sub-catchment, reflecting the larger size and more extensive development of the former.

An important feature of the results for the Oteha Stream that is not evident in the results for Lucas Stream or the study area as whole is the way in which the annual zinc loads predicted for Scenario 3A are slightly lower than those associated with the historic development. This reflects the fact that, under this Scenario, new residential development replaces areas of old industrial development in the Oteha Stream sub-catchment. This avoids an increase in the urban footprint so that, even with *status quo* stormwater treatment loads of zinc are held approximately at the existing levels. With improved levels of stormwater contaminant control, the brownfields scenario performs even better in this sub-catchment (see below).

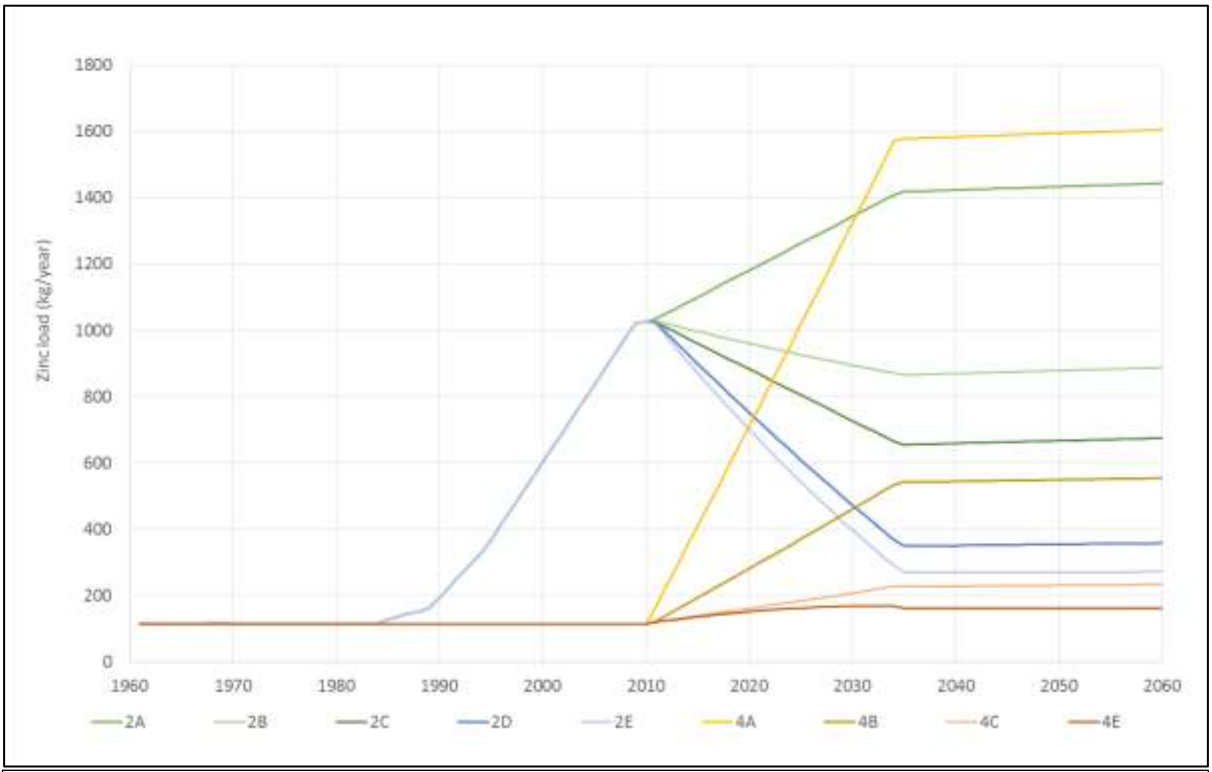
Influence of mitigation

Figure 3-5 shows the influence of alternative contaminant controls on predicted trends in annual loads of zinc for Scenario 2 (higher density, following historic development) and Scenario 4 (low density greenfields development). Loads are predicted to fall markedly with best practice levels of stormwater treatment (scenarios B). Post-development annual loads of zinc are predicted to be approximately 40% lower in Scenario 2B and 70% lower in Scenario 4B than in the corresponding scenarios involving *status quo* stormwater treatment (scenarios A). Further incremental reductions in annual zinc loads are predicted for scenarios which add in WSD (C), retrofitting of stormwater treatment to areas of historic development (D) and the use of low metal-yielding vehicle components (E). In this latter scenario, involving the full suite of contaminant control measures, post-development annual zinc loads are predicted to be 80% (2E) and 90% (4E) lower than under the respective *status quo* scenarios (A).



Land development:	(1) Historic + low density (2) Historic + high density (3) Historic + brownfield	(4) Greenfield low density (5) Greenfield high density

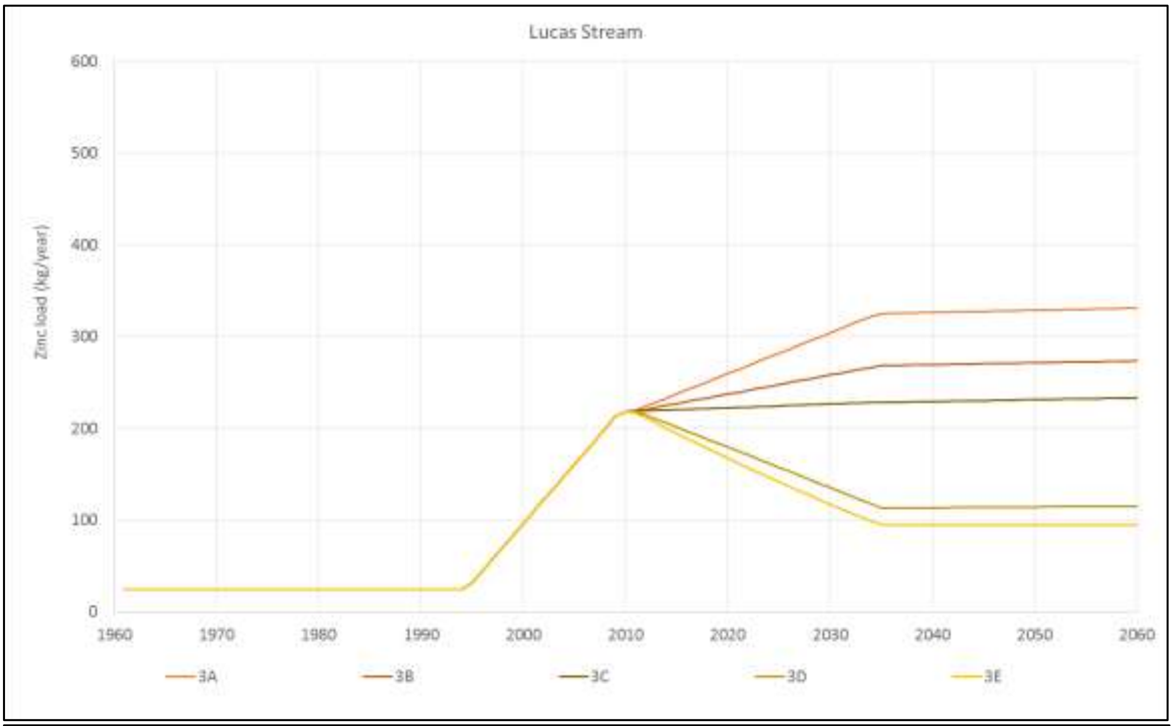
Figure 3-4: Predicted annual zinc loads for urban development scenarios with *status quo* contaminant controls, Lucas Stream sub-catchment (upper) and Oteha Stream sub-catchment (lower).

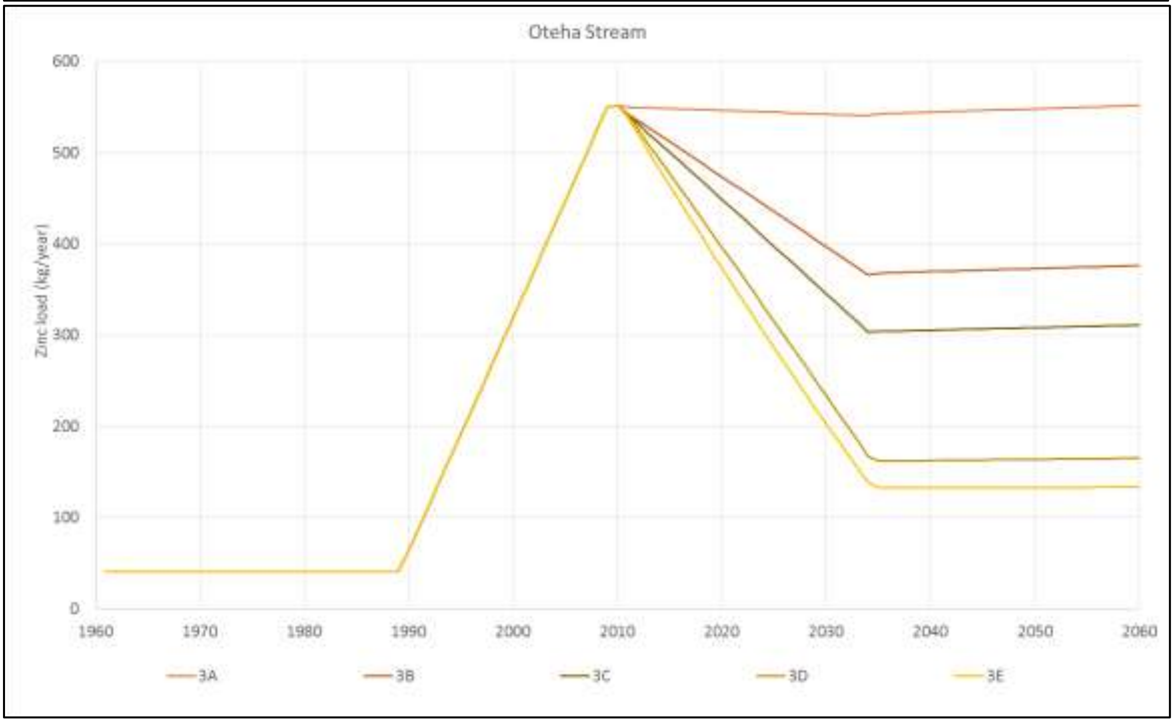


Land development:	(2) Historic + high density	(4) Greenfield low density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development (E) As (D) with vehicle source control	

Figure 3-5: Predicted annual zinc loads for selected urban development scenarios employing alternative stormwater contaminant control measures, whole study area.

Figure 3-6 shows the influence of alternative stormwater controls on predicted trends in annual loads of zinc in the Lucas Stream and Oteha Stream sub-catchments for Scenario 3 (brownfields development). While the relativity between predicted loads is the same in both sub-catchments, a significant difference is the way in which all forms of stormwater control are predicted to result in a reduction from historic zinc loads in the Oteha Sub-catchment. This reflects the influence of replacing existing industrial areas with new development, to which improved levels of stormwater control are applied.





Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development (E) As (D) with vehicle source control

Figure 3-6: Predicted annual zinc loads for brownfields development scenarios employing alternative stormwater contaminant control measures, Lucas Stream sub-catchment (upper) and Oteha Stream sub-catchment (lower).

3.3 Stream Water Quality

3.3.1 Introduction

This section presents and discusses illustrative results which address the first two of the four questions posed in Section 1.2. Those questions are:

> *How can the overall quality of water be maintained or improved in an urban development context?*
>
> *If stream water quality in some sub-catchments is not maintained and/or improved, is it still possible to maintain and improve water quality at the catchment scale? (on average)*

The findings are illustrated with reference to predictions of scores for the water quality and macroinvertebrate indicators, providing a physico-chemical and ecological indicator, respectively, of the outcomes of urban development scenarios. Scores for these indicators can take a value in the range 0-1, with a higher score indicating better stream health. As described in Section 2.2.2, the DSS also predicts five other stream environmental indicators. Examples of scores predicted for some of those other indicators are presented in Appendix C.

3.3.2 Influence of Development Type

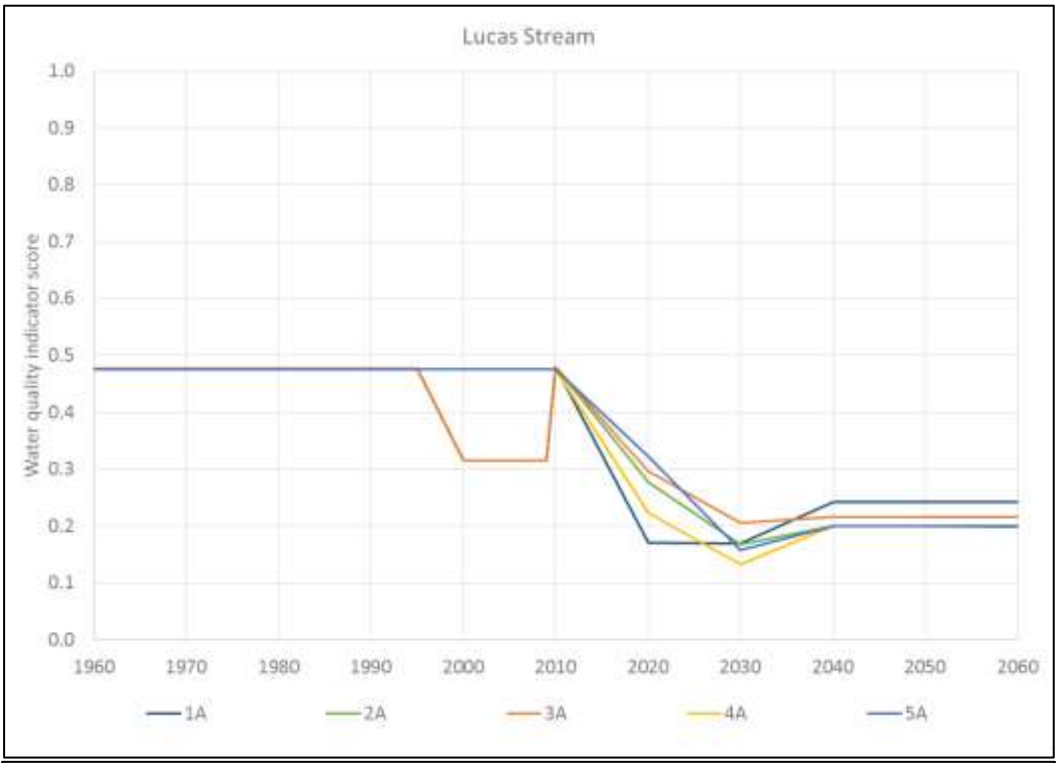
Figure 3-7 shows modelled trends in the water quality indicator score over the study timeframe for Lucas Stream and Oteha Stream, including those associated with the historic period prior to 2010. Trends are plotted for each of the land use change scenarios, assuming *status quo* levels of stormwater treatment (scenarios A).

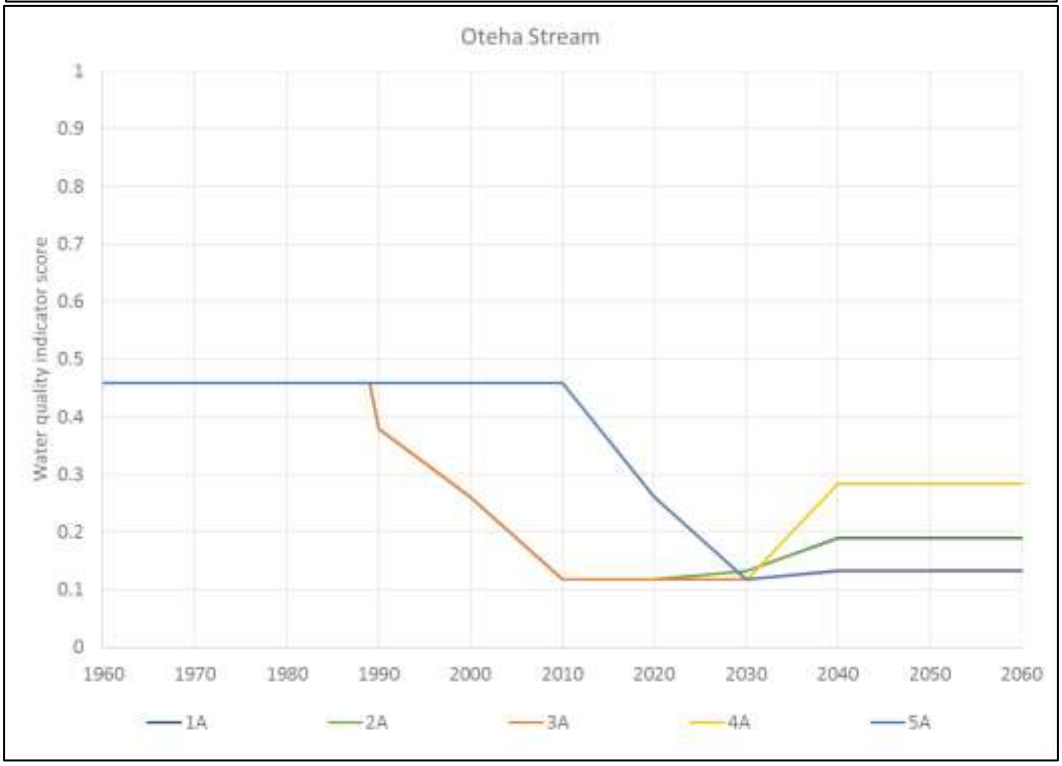
Under all scenarios, the water quality indicator score for the Lucas Stream is predicted to fall from a medium value of around 0.5 in 2010 to a low value of around 0.2[11] in 2060. There is relatively little difference between the results for each of the five scenarios.

There is greater variation in the predicted scores for Oteha Stream. Under Scenarios 1-3 the water quality indicator score is modelled to be very low (at around 0.1) in 2010, reflecting the impact of the more extensive historic development of this sub-catchment. With further development the predicted score remains low, although there is some improvement to a value of around 0.2 in Scenarios 1 and 2 as a result of the replacement of rural land and the consequent reduction in sediment load. Under Scenarios 4 and 5 the modelled water quality indicator score in 2010 is a medium values of around 0.45 reflecting the absence of historic development impacts. With development the score is predicted to fall to around 0.1. Notably, however, under Scenario 4 (low density greenfield) the large-scale consumption of rural land and consequent reduction in sediment load is predicted to lead to a partial recovery in the water quality score to a value of around 0.3.

When reflecting on the lower water quality scores for scenarios involving high density and brownfield development, it is therefore important to take account of the influence of rural-derived sediment, as discussed in Section 3.2.2. The higher rural sediment loads in these scenarios are countering the benefits of the lower metal loads achieved by constraining the development footprint (as described in Sections 3.2.3), again indicating a need to consider the management of rural impacts on water quality in catchments undergoing urban development.

[11] In the case of Scenarios 1-3, there is an earlier drop then recovery in the predicted water quality indicator score coinciding with the period of historic earthworks.





Land development:	(1) Historic + low density	(4) Greenfield low density
	(2) Historic + high density	(5) Greenfield high density
	(3) Historic + brownfield	

Figure 3-7: Predicted water quality indicator scores for urban development scenarios with *status quo* contaminant controls, Lucas Stream (upper) and Oteha Stream (lower).

3.3.3 Influence of Mitigation

Contaminant controls

Figure 3-8 shows the influence of alternative contaminant controls on predicted trends in the water quality indicator score for Scenario 2 (higher density, following historic development). The post-development water quality score is predicted to improve successively from a low score of around 0.2 for Scenario 2A (*status quo*) with the addition of an increasing number of stormwater controls.

In the case of Lucas Stream, the use of best practice contaminant controls (Scenario 2B) increases the predicted score to around 0.4, while remaining below the pre-development of score of around 0.5. In contrast, the addition of WSD (Scenario 2C) results in an improvement compared to the post-historic development score, increasing it to 0.6. Further improvements in the predicted score to a relatively high 0.7 are associated with the addition of retrofitted treatment of historic development (Scenario 2D) and use of low metal-yielding vehicle components (Scenario 2E).

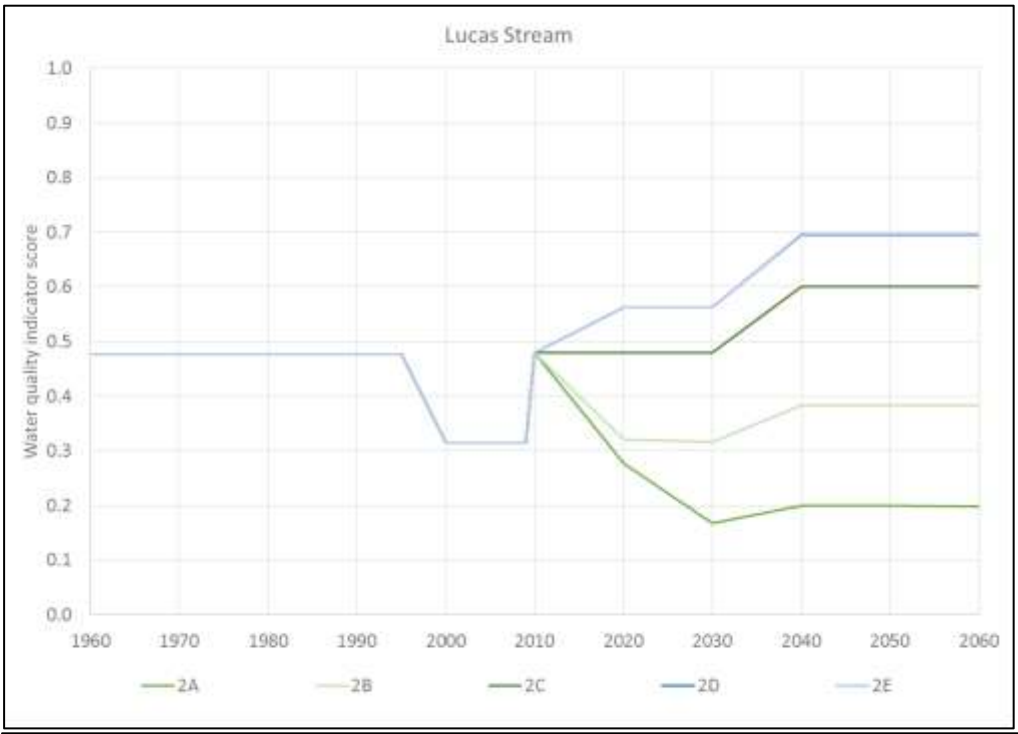
In the case of Oteha Stream, while scenarios involving best practice contaminant controls (Scenario 2B) and WSD (Scenario 2C) result in a small improvement in the predicted water quality score (around 0.25, compared to 0.2 for *status quo* controls), the score remains well below the pre-development score of around 0.45. However, with the addition of retrofitted stormwater treatment of historic development (Scenario 2D) and use of low metal-yielding vehicle components (Scenario 2E), the predicted score improves markedly to over 0.6. The more sluggish response of the water quality indicator score in the Oteha Stream compared with that in Lucas Stream reflects the greater difficulty of dealing with the legacy effects of the more extensive historic development in this sub-catchment.

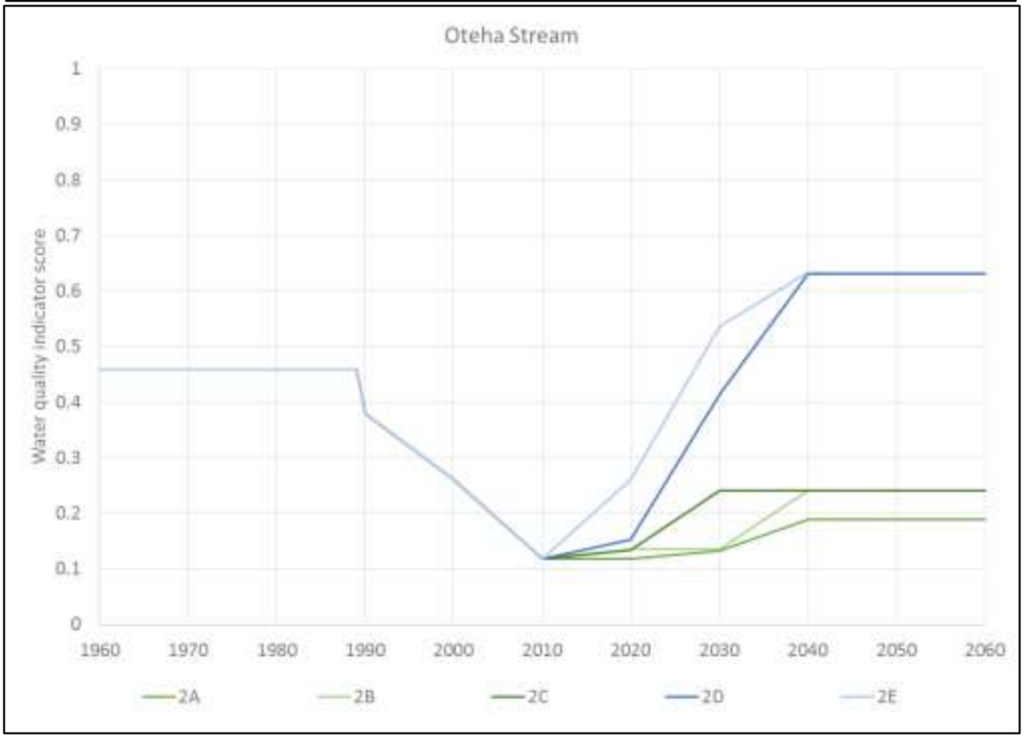
Riparian planting

Figure 3.9 shows the influence of extensive riparian planting, in combination with alternative levels of contaminant control, on predicted trends in the water quality indicator score for Scenario 2 (higher density, following historic development). Irrespective of the level of contaminant control involved, riparian planting is predicted to make only a marginal improvement in the water quality indicator score over and above the gains resulting from improved levels of contaminant control.

As noted in Section 3.2.2, the DSS's predictions of the stream water quality indicator take account of a range of factors which influence water quality. Riparian planting influences the indicator score through lower stream temperatures. However, planting has no influence on chemical aspects of the water quality indicator score (i.e. metal loads and concentrations) because stormwater pipe outlets are assumed to discharge urban runoff directly to streams, even where riparian planting has been undertaken. Riparian planting is therefore modelled in the DSS to play no role in the treatment of stormwater[12].

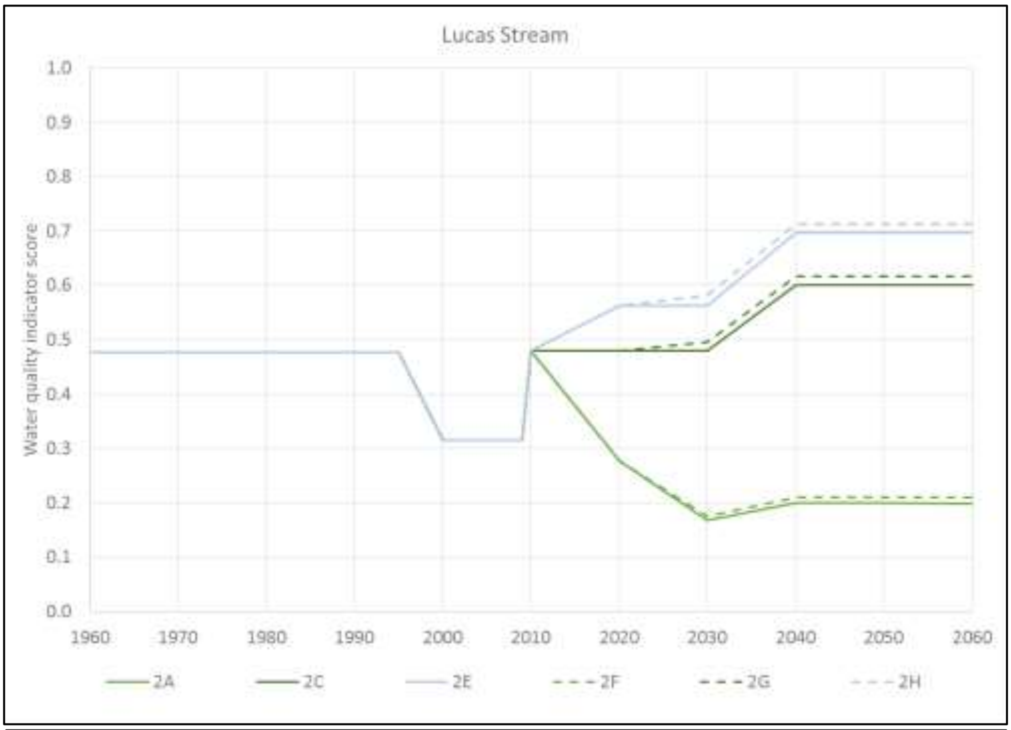
[12] However, a potential area for further development of the DSS is to allow it to take account of riparian planting in undeveloped rural areas of a catchment where diffuse runoff processes are likely to dominate. In these situations, riparian planting provides the potential to reduce loads of sediment delivered to rivers and streams.

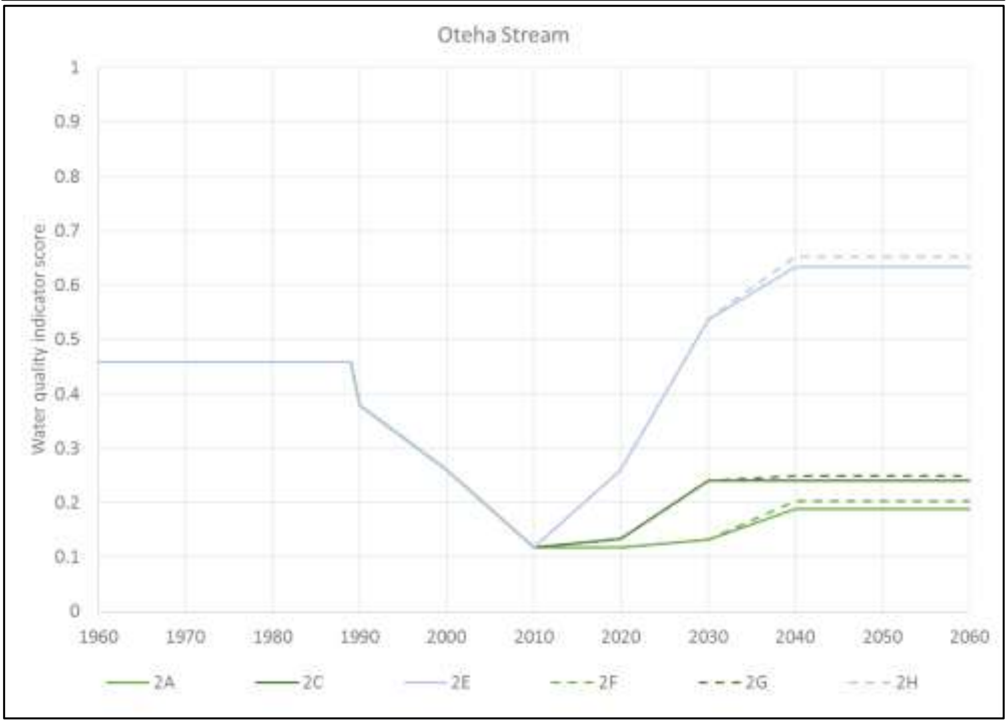




Mitigation: (A) Status quo contaminant controls
(B) Best practice contaminant controls
(C) As (B) with Water Sensitive Design (lower imperviousness)
(D) As (C) with retrofitted stormwater treatment of historic development
(E) As (D) with vehicle source control

Figure 3-8: Predicted water quality indicator scores for selected higher density urban development scenarios employing alternative stormwater contaminant control measures, Lucas Stream (upper) and Oteha Stream (lower). Note for Lucas Stream, the results for scenarios 2D and 2E are identical.





Mitigation:	(A) Status quo contaminant controls (C) Best practice contaminant controls with Water Sensitive Design (lower imperviousness) (E) As (C) with retrofitted stormwater treatment of historic development and vehicle source control (F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (E) with riparian planting

Figure 3-9: Predicted water quality indicator scores for selected higher density urban development scenarios employing alternative stormwater contaminant controls, with and without riparian planting.

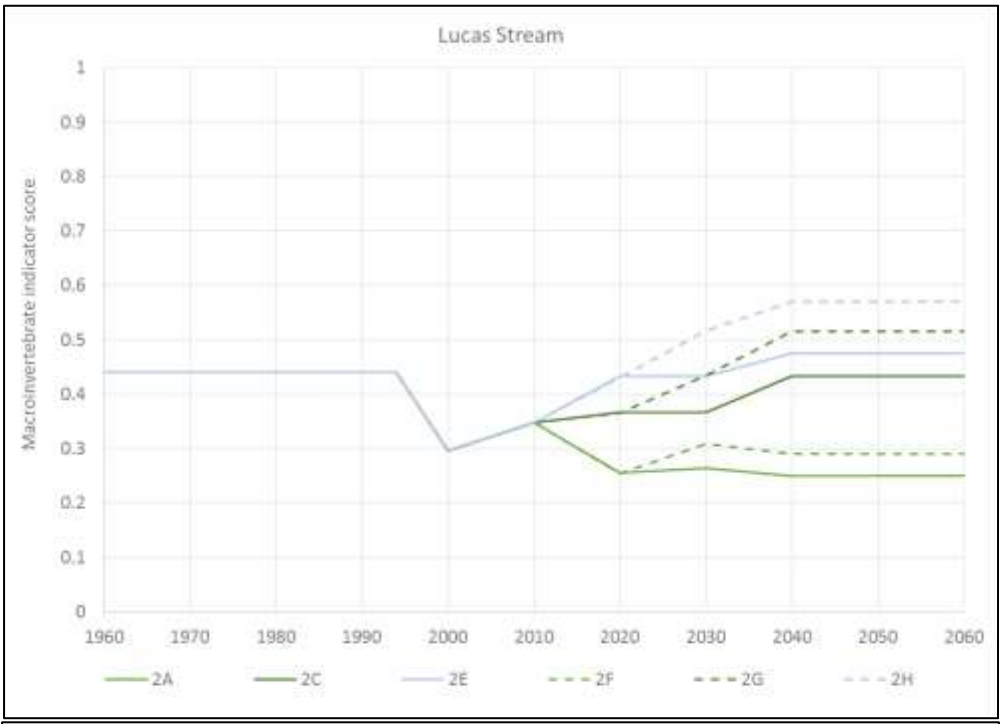
However, while riparian planting has only a minor influence on the water quality indicator score, in view of Objectives A1 of the NPS-FM (see Section 2.2.2) it is relevant to consider its influence on indicators of stream ecosystem health. For the purposes of illustration, the following discussion considers variations in the macroinvertebrate indicator score as a reflection of ecosystem health. However, examples of the scores predicted for other stream ecological indicators are given in Appendix C.

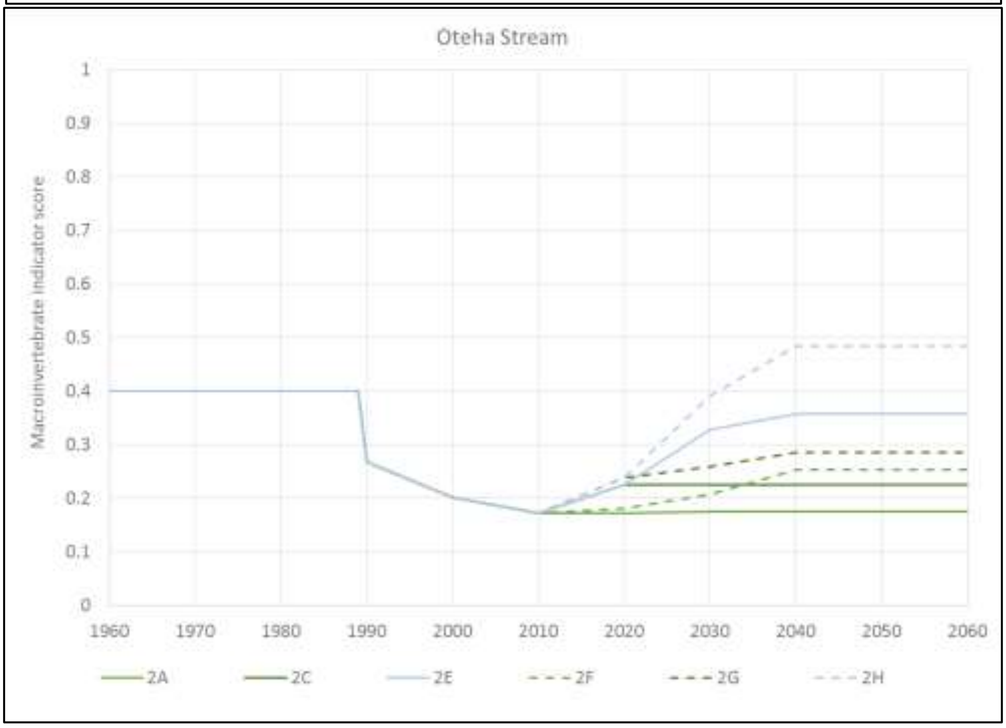
Figure 3-10 shows the influence of extensive riparian planting, in combination with alternative levels of contaminant controls, on predicted trends in the macroinvertebrate indicator score for Scenario 2 (higher density, following historic development). Compared with the water quality indicator score (Figure 3.9), riparian planting results in a more marked improvement in the macroinvertebrate indicator score over and above the gains associated with increasing levels of contaminant control.

In the case of Lucas Stream, development with *status quo* contaminant controls (Scenario 2A) is predicted to result in a decline in the macroinvertebrate indicator score from a medium pre-development value of around 0.45 to a low post-development value of around 0.25. Best practice contaminant controls and WSD (Scenario 2C) is predicted to almost return the macroinvertebrate indicator score to its original level, following a period of lower scores during the development phase, while the full suite of stormwater contaminant control measures (Scenario 2E) results in a slight improvement in the macroinvertebrate indicator score. The addition of riparian planting is predicted to result in an improvement in the post-development scores of around 0.05 when added to *status quo* stormwater treatment (Scenario 2F), increasing to around 0.1 when added to the full suite of stormwater contaminant control measures (Scenario 2H).

In the case of Oteha Stream, the macroinvertebrate indicator score is predicted to fall with all levels of contaminant control, including the full suite (Scenarios 2A, 2C and 2E). As with the water quality indicator, the less responsive nature of Oteha Stream compared with Lucas Stream reflects the greater difficulty of dealing with the legacy effects of the more extensive historic development in this sub-catchment. Similarly to the pattern evident in the results for Lucas Creek, however, the addition of riparian planting to successive levels of contaminant controls is predicted to result in increasingly large improvements to the macroinvertebrate indicator score. The addition of riparian planting is predicted to result in an improvement in the post-development scores of around 0.08 when added to *status quo* contaminant control (Scenario 2F), increasing to around 0.13 when added to the full suite of control measures (Scenario 2H). The addition of riparian planting in this latter scenario is predicted to result in an improvement in the post-development macroinvertebrate score of close to 0.5, compared with the pre-development 0.4.

The results for both Lucas Stream and Oteha Stream suggest a synergistic rather than additive relationship between the two forms of mitigation. That is, the relative benefits of riparian planting appear to increase as the level of contaminant control increases.





Mitigation:	(A) Status quo contaminant controls (C) Best practice contaminant controls with Water Sensitive Design (lower imperviousness) (E) As (C) with retrofitted stormwater treatment of historic development and vehicle source control (F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (E) with riparian planting

Figure 3-10: Predicted macroinvertebrate indicator scores for selected higher density urban development scenarios employing alternative stormwater contaminant controls, with and without riparian planting.

3.3.4 Maintaining or Improving Water Quality 'On Average'

This section addresses the question of whether or not water quality can be maintained or improved in some 'average' sense, despite a decline in some locations. In order to make this assessment, the Lucas Stream and Oteha Stream sub-catchments were treated as a single combined catchment. Scenarios for this combined catchment were developed by combining inputs to scenarios which resulted in a decrease in the water quality indicator score in one sub-catchment with inputs to scenarios which resulted in an increase in the water quality indicator score in the other sub-catchment. For example, the following results reflect the combination of model inputs for Scenario 5A (higher density greenfield development with *status quo* contaminant controls, decrease in the water quality indicator score) in the Lucas Stream sub-catchment with those for Scenario 5G (higher density greenfield development with high level of contaminant controls and extensive riparian planting, increase in the water quality indicator score) in the Oteha Stream sub-catchment, and *vice versa*.

Figure 3-11 compares the predicted water quality indicator scores for the combined catchment under these two scenarios with the scores predicted for the individual sub-catchments of the Lucas Stream and Oteha Stream. Scores are shown over the 'future' development period 2010-2060. In the case where there is a high level of mitigation effort in the Oteha Stream sub-catchment, but not in the Lucas Stream sub-catchment (upper plot), the water quality indicator score is predicted to improve from a pre-development value of around 0.45 to a post-development value of around 0.55. In contrast, where there is a high level of mitigation effort in the Lucas Stream sub-catchment, but not in the Oteha Stream sub-catchment (lower plot), the water quality indicator score is predicted to fall to a post-development value of around 0.15.

These differences reflect the relative influence of the two stream sub-catchments on the prediction of the score for the combined catchment. The Oteha Stream sub-catchment is larger and undergoes more development than the Lucas Stream in these scenarios. In any given combined scenario, model inputs to the combined catchment are therefore influenced more by the characteristics of the contributing scenario in Oteha Stream than by the contributing scenario in Lucas Stream. As a result, the predicted water quality score for the combined catchment is largely driven by the predicted score for the Oteha Stream (see Figure 3-11 for an illustration of the way in which the combined sub-catchment score generally tracks the score for Oteha Stream).

These results indicate that, while it may be possible to maintain or improve water quality in some 'average' sense, despite a decline in some locations, this outcome is dependent on: the relative contribution of flow and contaminants from different sub-catchments; the spatial distribution of development; and where any mitigation effort is focused. When assessing catchment water quality in an 'overall' or 'on average' sense in the real world, it will also be important to define what is meant by these terms and how and where they are measured.

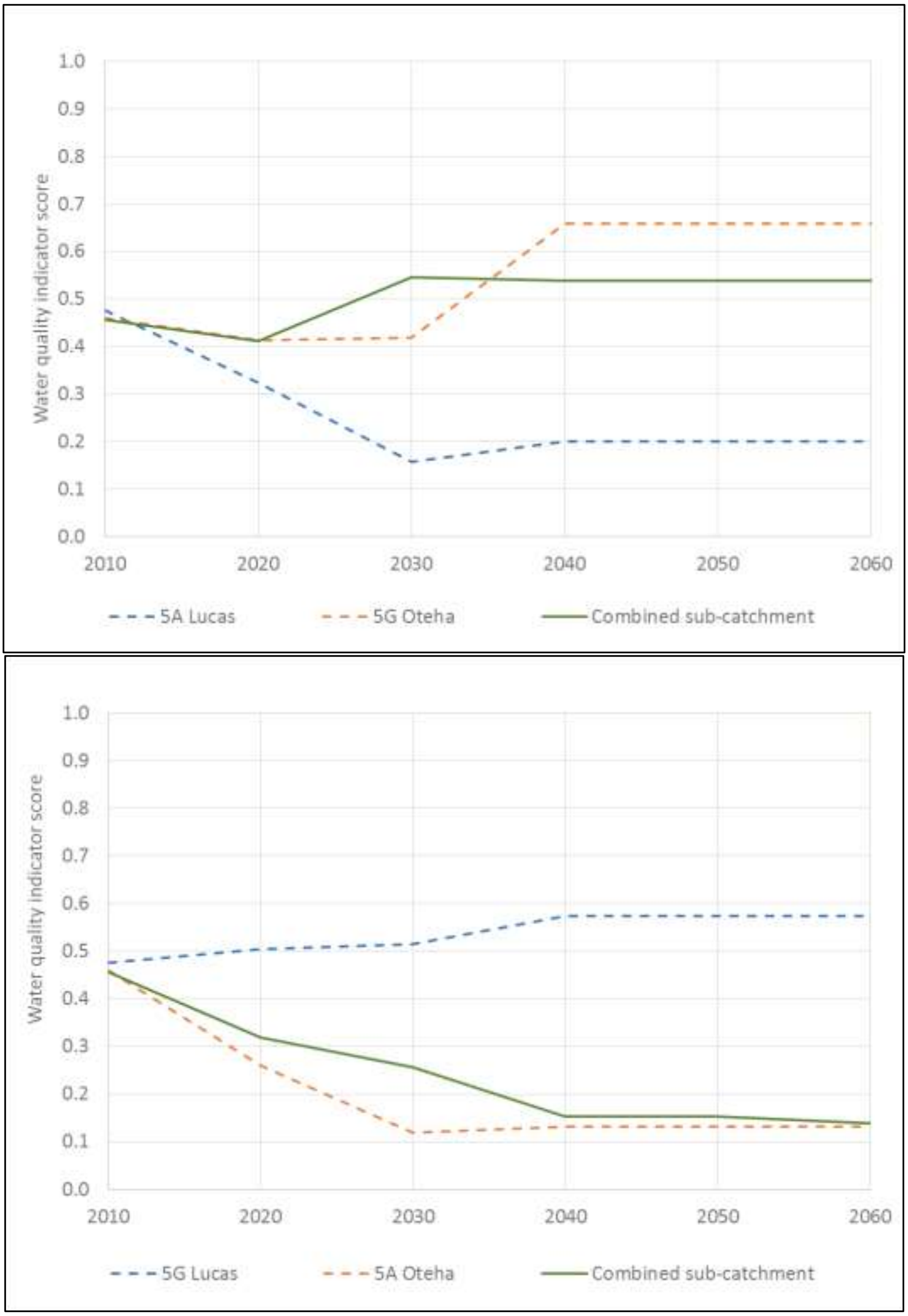


Figure 3-11: Predicted water quality indicator scores for selected higher density greenfield development scenarios: Lucas Stream, Oteha Stream and their combined sub-catchment. The scenario represented in the upper plot involves *status quo* contaminant controls in the Lucas Stream sub-catchment (5A) and a high level of contaminant controls with extensive riparian planting in the Oteha Stream (5G) . The scenario represented in the lower plot represents the reverse situation.

3.3.5 Summary

This section has addressed the following questions:

> *How can the overall quality of water be maintained or improved in an urban development context?*
>
> *If stream water quality in some sub-catchments is not maintained and/or improved, is it still possible to maintain and improve water quality at the catchment scale? (on average)*

The results of the case study assessment indicate that in order to maintain and improve water quality in an urban development context, a high level of stormwater contaminant control is likely to be required. This may involve measures over and above current 'best practice' stormwater treatment and erosion and sediment control, including WSD development approaches and retrofitting stormwater treatment in areas of historic development. In addition, in order to benefit from the potential gains associated with lower metal loads delivered from high density, infill and WSD forms of development, it may also be necessary to address water quality issues associated with undeveloped rural parts of catchments where these exert a significant influence over catchment water quality.

When the notion of water quality is extended beyond the physical and chemical properties of water to include ecosystem health, consistent with the objectives of the NPS-FM, the results indicate that riparian planting is likely to provide significant additional benefits, over and above the water quality gains associated with better contaminant controls.

The results also indicate that, while it may be possible to maintain or improve water quality in some 'average' sense, despite a decline in some locations, this outcome is dependent on: the relative contribution of flow and contaminants from different sub-catchments; the spatial distribution of development; and where any mitigation effort is focused.

3.4 Cost Effectiveness of Mitigation

3.4.1 Introduction

This section presents and discusses illustrative results which address the third of the four questions posed in Section 1.2. That question is:

> *What are the most cost-effective means of maintaining and/or improving stream water quality in an urban development context?*

Before considering cost effectiveness, it is important to understand certain aspects of the way in which the costing models operate, as this provide context for the interpretation of results (Section 3.4.2). The findings of the cost effectiveness analysis are then illustrated with reference to predictions of relationships between the costs of alternative forms of mitigation and scores for the water quality and macroinvertebrate indicators described above (Section 3.4.3).

3.4.2 Costs

The purpose of the development of the costing models described in Section 2.2.2 was to provide a basis for reporting a relative indicator of costs in the DSS that provides discrimination between alternative urban development scenarios. When comparing outcomes for alternative development scenarios, the emphasis is therefore on relativity between costs. Where the actual cost estimates are described below, it should be recognised that these are point estimates: the DSS does not provide any estimate of uncertainty (such as confidence limits).

While it is important to note these cautions, the cost models do provide a basis for estimating the lifecycle costs of a range of urban catchment management interventions. They were developed using relevant available costing data applied to plausible catchment management scenarios and include the costs of land acquisition, construction costs and maintenance costs. Costs are reported as discounted Net Present Value (NPV) lifecycle costs over the scenario timeframe (50 years in the current study). For the present study a discount rate of 8% per annum was used, consistent with the Treasury's default rate[13].

Costs are estimated separately for: stormwater treatment; stormwater quantity control, earthworks erosion and sediment control and riparian management. Detailed comments on the stormwater treatment costing models are given below, following a brief summary of each of the other models.

Stormwater quantity control involves the attenuation of elevated flows from impervious areas to avoid increased rates of stream erosion. In the DSS, rates of stream erosion influence the prediction of certain of the stream environmental indicators. In general, the greater the impervious area in a catchment the greater the need to attenuate flows and the higher the associated cost. Stormwater quantity control costs are estimated based on the costs of constructing and maintaining dry detention ponds and are a function of the area of urban development and level of imperviousness.

The costs of earthworks erosion and sediment control are those associated with the implementation of measures to prevent sediment runoff during the construction phase of development. Costs are estimated as a function of the area undergoing development and the desired level of performance (the sediment load reduction to be achieved).

The costs of riparian management are those associated with planting and maintaining (weeding and replanting) areas of vegetation adjacent to rivers and streams. Costs are estimated as a function of the stream length, proportion of the stream length planted, width of riparian zone and species mix.

The stormwater treatment costing models estimate cost as a function of imperviousness, desired performance (contaminant load reduction) and area treated. The models also distinguish between costs of 'traditional' forms of stormwater treatment (using 'end of pipe' devices such as ponds) and WSD forms of stormwater treatment (using 'at source' devices such as raingardens). As Figure 3-12 illustrates, the costs associated with WSD are predicted to be higher than those associated with traditional stormwater treatment, holding all other things equal. The analysis of cost data conducted as part of the development of these models indicates that while the lifecycle costs of devices such as ponds are dominated by acquisition costs, those of devices such as raingardens are dominated by the costs of ongoing maintenance (Ira, 2015a; 2015b). These higher maintenance costs are incurred throughout the lifespan of the devices, resulting in the lifecycle cost differential shown in Figure 3-12.

However, it is important to note that the scope of the costs included in the stormwater treatment costing models are limited to those directly associated with the treatment devices themselves. Estimates of avoided costs are not included in this scope. There are other aspects of WSD that may be expected to influence the cost differential with traditional forms of development. For instance, WSD may result in avoided costs associated with a reduction in the area earthworked and converted to impervious covers and a reduction in network infrastructure (fewer or shorter pipes). While there

[13] http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/currentdiscountrates

is currently insufficient information on these avoided costs to be able to take account of them in the costing models (Ira, 2015b), it is important to recognise that their absence generates uncertainty when considering the relative cost effectiveness of WSD and non-WSD scenarios based on the outputs generated by the DSS.

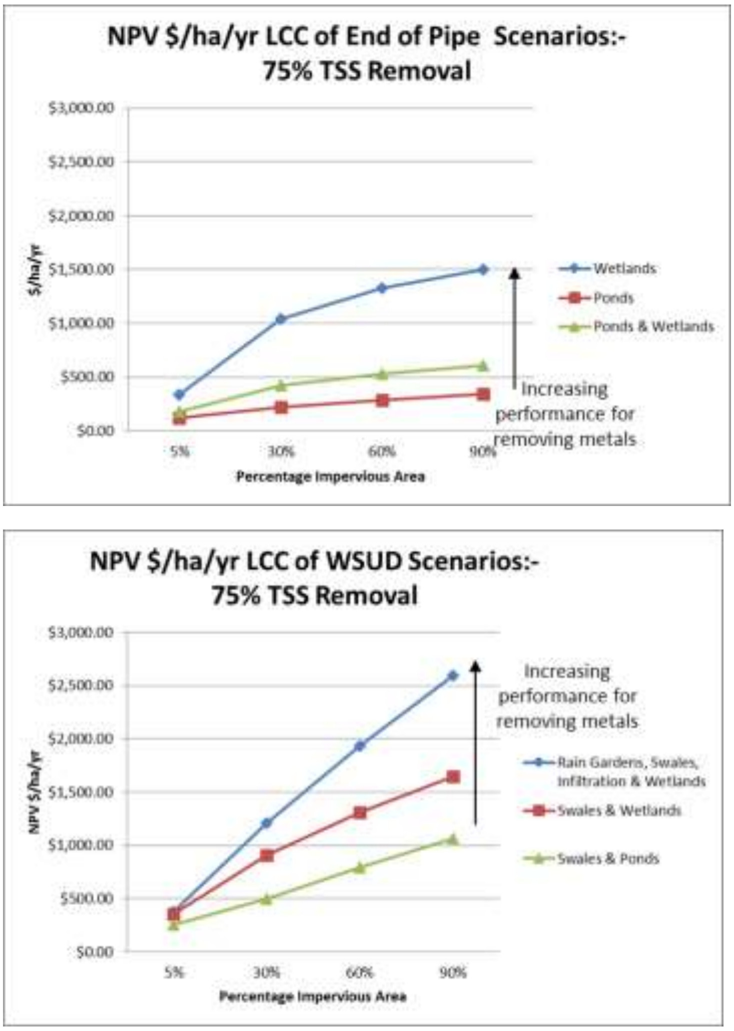


Figure 3-12: Examples of costing models developed for traditional (upper plot) and WSD (lower plot) forms of stormwater treatment. After Ira (2011; 2015a).

The application of low copper- and zinc-yielding vehicle components is also not costed, again due to an absence of information on the potential costs of this form of mitigation. In this, and the following section, results for scenarios involving source control of vehicle components are therefore not presented, since they deliver benefits (reductions in copper and zinc loads) that have not been costed.

Another important consideration that applies more generally to the suite of costing models is that they do not discriminate costs in terms of where they are borne. The cost estimates generated by the DSS are not solely a direct cost to the public purse: they reflect costs that are funded by public utility providers, councils, developers or private landowners. In terms of the likely split (S. Ira, pers. comm., 22 Sep 2015):

- earthworks controls and stormwater management devices are usually constructed by developers or private landowners;
- 'end of pipe' devices are usually maintained by councils or utility providers;
- 'at source' devices in the road reserve are usually maintained by councils or utility providers; and
- 'at source' devices on private property (e.g. house lots) are usually maintained by private landowners.

The potential funding split, and gaining a better understanding of who is responsible for the ongoing maintenance of WSD stormwater devices, are issues which still require further investigation. The point is, however, that while the cost estimates generated by the DSS partly represent public costs, they also include costs that will be privately incurred and passed on to consumers (house buyers) through market mechanisms.

Influence of land development type

Table 3-1, Table 3-2 and Figure 3-13 present the predicted total lifecycle costs of mitigation under selected urban development scenarios. The tables and figure also show, for each scenario, the breakdown of the total costs by stormwater treatment, earthworks erosion and sediment control (ESC), stormwater quantity control and riparian management.

Figure 3-14 presents this breakdown as a proportion (%) of the total costs. Under most scenarios costs are predicted to be higher in the Oteha Stream sub-catchment than in the Lucas Stream sub-catchment, reflecting the greater overall extent of development requiring mitigation in the former catchment. The exceptions are Scenarios 1A, 1B, 2A and 2B, in which mitigation is confined to stormwater and earthworks controls in areas of new development. Under these scenarios the area of new development is slightly greater in the Lucas Stream sub-catchment than in the Oteha Stream sub-catchment.

In the Lucas Stream sub-catchment, lifecycle costs are predicted to be lowest under variants of Scenario 3. This is the brownfields development scenario, involving the smallest development footprint in the Lucas Stream sub-catchment. In contrast, because it is the location for most of the brownfields development, the Oteha Stream sub-catchment is predicted to incur relatively high mitigation costs under Scenario 3. It incurs lower costs under variants of Scenario 1 (low density greenfield development, following historic development).

For any given mitigation scenario, lifecycle costs in both sub-catchments are predicted to be highest under Scenario 4 (compare, for instance, Scenarios 1C, 2C, 3C, 4C and 5C or Scenarios 1G, 2G, 3G, 4G and 5G in Figure3-13). This reflects the fact that under Scenarios 1, 2 and 3 the sub-catchments are already partially developed (and partially mitigated) as a result of the historic development. In contrast, Scenarios 4 and 5 solely involve greenfield development and any mitigation applies to the full extent of the development footprint. The costs associated with Scenario 4 are greater than those associated with Scenario 5 because the former involves lower density development and consequently has a larger development footprint.

Table 3-1: Predicted lifecycle costs ($ millions) of mitigation for selected urban development scenarios, Lucas Stream sub-catchment. Costs are estimated over 50-years using a discount rate of 8%.

Scenario	Stormwater Treatment	Earthworks ESC	Stormwater Quantity Control	Riparian Management	TOTAL
No development	0.4	0.0	0.4	0.0	0.8
1A	11.0	10.0	3.4	0.0	24.4
1B	30.7	10.2	3.4	0.0	44.3
1C	36.1	5.5	2.1	0.0	43.6
1F	11.0	10.0	3.3	7.8	32.1
1G	36.1	5.5	2.1	7.8	51.4
2A	7.2	5.6	2.3	0.0	15.0
2B	19.2	5.7	2.3	0.0	27.3
2C	32.8	6.9	1.9	0.0	41.6
2D	46.8	6.9	2.2	0.0	55.9
2F	7.2	5.6	2.3	7.8	22.8
2G	32.8	6.9	1.9	7.8	49.4
2H	46.8	6.9	2.2	7.8	63.7
3A	3.3	2.3	1.1	0.0	6.8
3B	8.4	2.3	1.2	0.0	11.9
3C	18.1	2.6	1.1	0.0	21.8
3D	35.8	2.6	1.4	0.0	39.8
3F	3.3	2.3	1.1	7.8	14.6
3G	18.1	2.6	1.1	7.8	29.6
3H	35.8	2.6	1.4	7.8	47.6
4A	24.2	22.8	6.9	0.0	53.9
4B	69.1	23.2	7.2	0.0	99.5
4C	83.6	14.0	4.3	0.0	101.9
4F	24.2	22.8	6.9	14.5	68.4
4G	83.6	14.0	4.3	14.5	116.4
4H	83.6	14.0	4.3	14.5	116.4
5A	14.2	11.9	4.1	0.0	30.2
5B	39.6	12.1	4.3	0.0	56.0
5C	72.4	12.1	3.8	0.0	88.3
5F	14.2	11.9	4.1	14.5	44.7
5G	72.4	12.1	3.8	14.5	102.8
5H	72.4	12.1	3.8	14.5	102.8

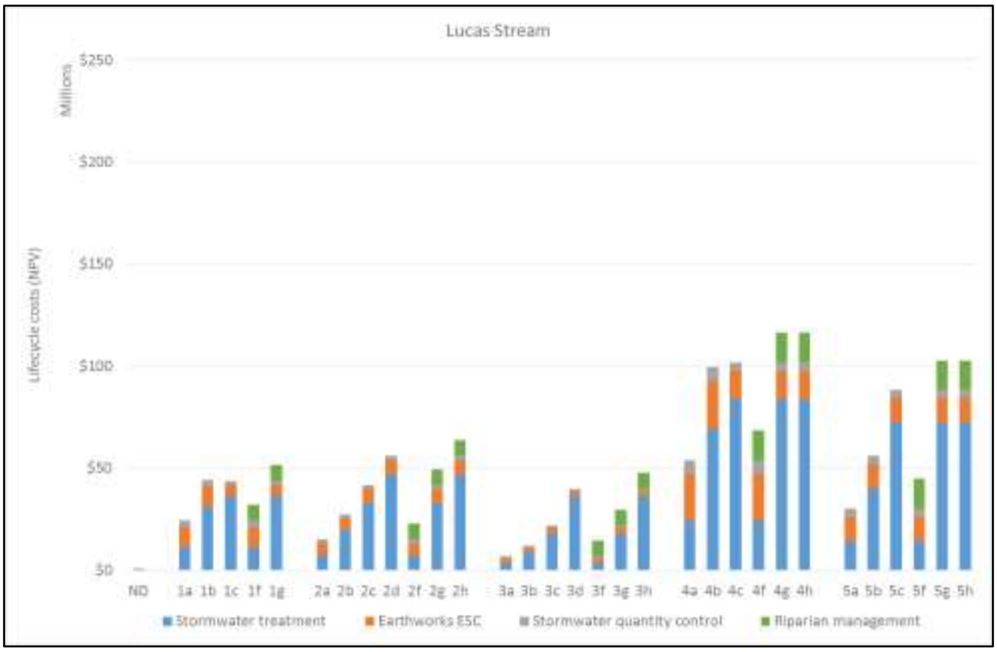
Land development:
(1) Historic + low density
(2) Historic + high density
(3) Historic + brownfield
(4) Greenfield low density
(5) Greenfield high density

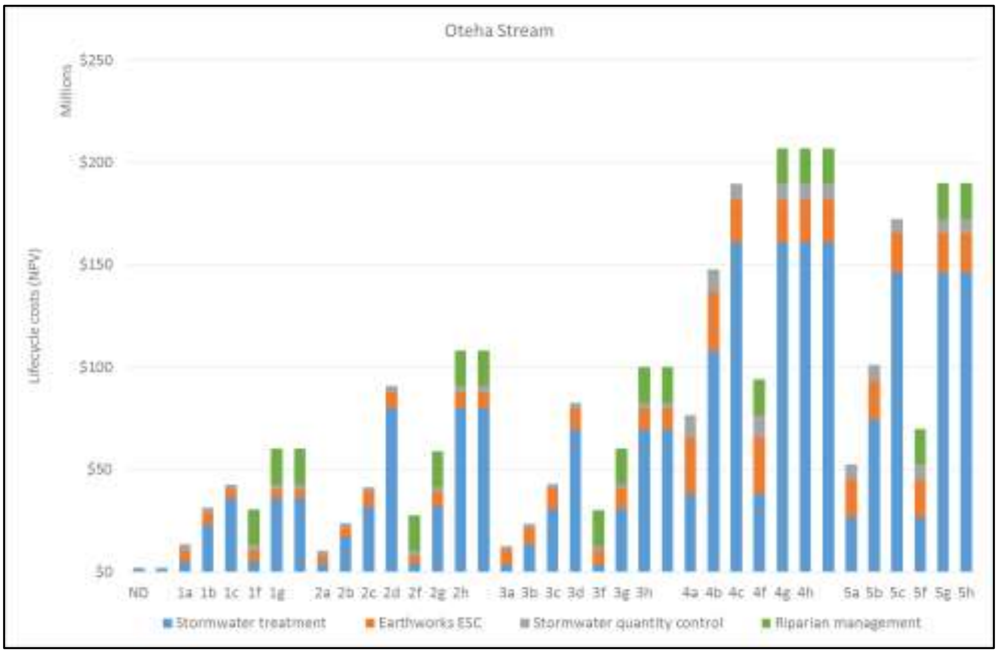
Mitigation:
(A) Status quo contaminant controls
(B) Best practice contaminant controls
(C) As (B) with Water Sensitive Design (lower imperviousness)
(D) As (C) with retrofitted stormwater treatment of historic development
(F) As (A) with riparian planting
(G) As (C) with riparian planting
(H) As (D) with riparian planting

Table 3-2: Predicted lifecycle costs ($ millions) of mitigation for selected urban development scenarios, Oteha Stream sub-catchment. Costs are estimated over 50-years using a discount rate of 8%.

Scenario	Stormwater Treatment	Earthworks ESC	Stormwater Quantity Control	Riparian Management	TOTAL
No development	1.1	0.0	1.0	0.0	2.1
1A	4.8	5.5	3.1	0.0	13.4
1B	22.7	5.7	3.1	0.0	31.5
1C	36.0	4.2	2.5	0.0	42.7
1F	4.8	5.5	3.0	17.3	30.6
1G	36.0	4.2	2.5	17.3	60.0
2A	4.0	3.8	2.5	0.0	10.3
2B	17.2	4.0	2.6	0.0	23.7
2C	31.8	7.4	2.3	0.0	41.4
2D	80.2	7.4	3.2	0.0	90.7
2F	4.0	3.8	2.5	17.3	27.7
2G	31.8	7.4	2.3	17.3	58.8
2H	80.2	7.4	3.2	17.3	108.1
3A	3.2	7.4	2.0	0.0	12.7
3B	13.3	7.7	2.4	0.0	23.4
3C	30.7	10.0	2.2	0.0	42.9
3D	69.6	10.0	3.1	0.0	82.7
3F	3.2	7.4	2.0	17.3	30.0
3G	30.7	10.0	2.2	17.3	60.3
3H	69.6	10.0	3.1	17.3	100.1
4A	38.1	27.5	11.0	0.0	76.6
4B	107.8	28.7	11.4	0.0	147.8
4C	160.8	20.8	8.0	0.0	189.6
4F	38.1	27.5	11.0	17.3	94.0
4G	160.8	20.8	8.0	17.3	207.0
4H	160.8	20.8	8.0	17.3	207.0
5A	26.6	18.1	7.7	0.0	52.5
5B	74.1	18.9	8.0	0.0	101.0
5C	146.3	18.9	7.3	0.0	172.5
5F	26.6	18.1	7.7	17.3	69.8
5G	146.3	18.9	7.3	17.3	189.9
5H	146.3	18.9	7.3	17.3	189.9

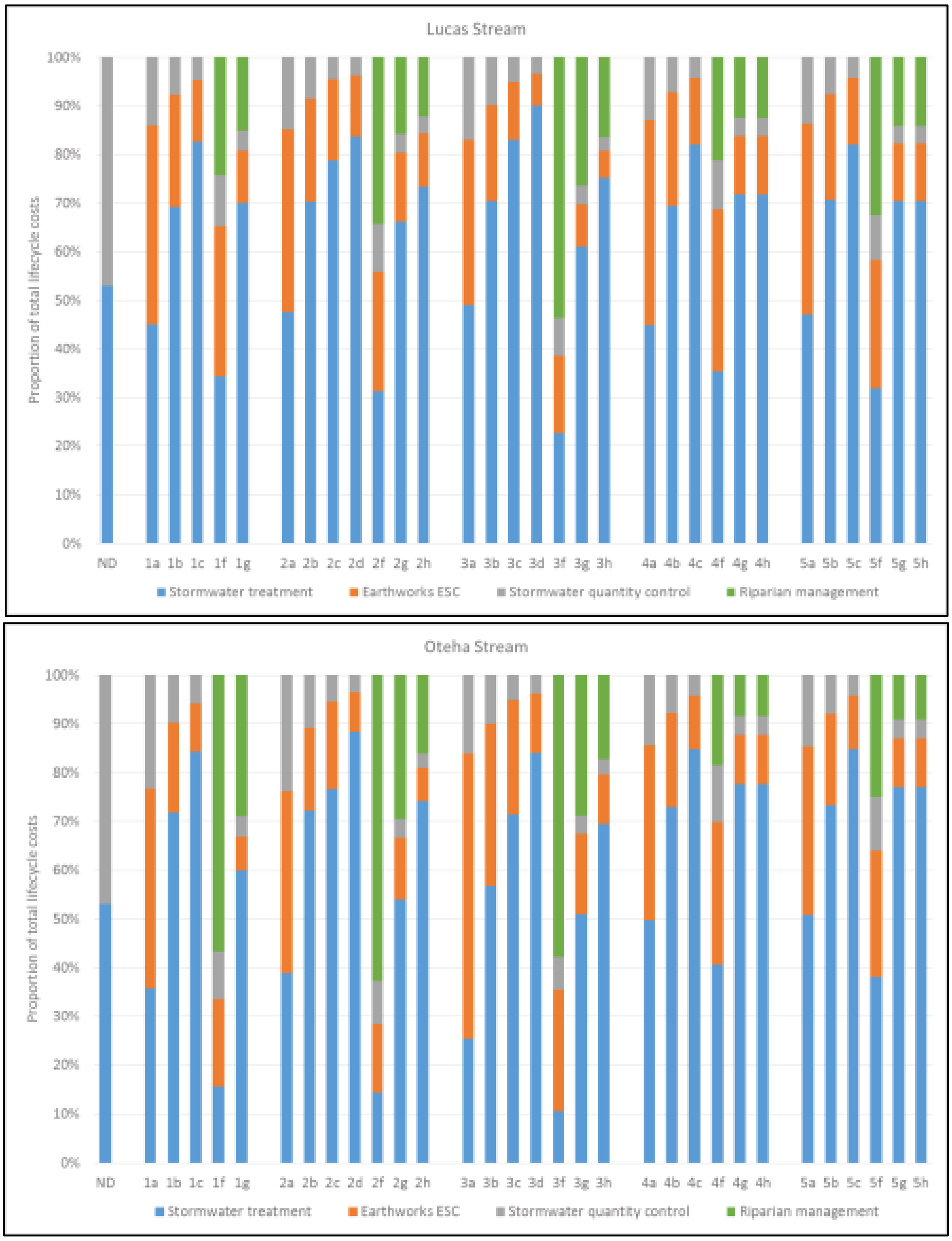
Land development:	(1) Historic + low density (2) Historic + high density (3) Historic + brownfield	(4) Greenfield low density (5) Greenfield high density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development	(F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (D) with riparian planting





Land development:	ND = no development (1) Historic + low density (2) Historic + high density	(3) Historic + brownfield (4) Greenfield low density (5) Greenfield high density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development	(F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (D) with riparian planting

Figure 3-13: Predicted lifecycle costs of stormwater treatment, earthworks erosion and sediment control (ESC), stormwater quantity control and riparian management under selected urban development scenarios, Lucas Stream sub-catchment (upper) and Oteha Stream sub-catchment (lower). Costs are estimated over 50-years using a discount rate of 8%. ND = no development.



Land development:	ND = no development (1) Historic + low density (2) Historic + high density	(3) Historic + brownfield (4) Greenfield low density (5) Greenfield high density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development	(F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (D) with riparian planting

Figure 3-14: Proportion of predicted total lifecycle costs incurred by stormwater treatment, earthworks erosion and sediment control (ESC), stormwater quantity control and riparian management under selected urban development scenarios, Lucas Stream sub-catchment (upper) and Oteha Stream sub-catchment (lower). ND = no development.

Influence of mitigation

For each land development scenario, costs increase with addition of increasing levels of contaminant control (compare, for instance, Scenarios 2A, 2B, 2C and 2D or Scenarios 5A, 5B and 5C in Figure3-13). In general costs associated with 'best practice contaminant controls and WSD development' (Scenarios C) are predicted to be markedly higher than those associated with 'best practice contaminant controls and non-WSD development' (Scenarios B), illustrating the points made above about the higher costs of WSD when considering stormwater treatment on its own.

In Scenarios involving *status quo* levels of stormwater and earthworks controls (Scenarios A), these two components each make up approximately a third to a half of the total lifecycle costs (see Figure 3-14). However, with the addition of increasing levels of contaminant controls, stormwater treatment costs are predicted to make up an increasingly significant part of the total costs. In scenarios involving best practice treatment, WSD and retrofitting of treatment to areas of historic development (Scenarios C and D), stormwater treatment is predicted to account for around 70-90% of the total lifecycle costs. The remaining approximate 10-30% of costs in these scenarios comprises the costs of earthworks erosion and sediment control and stormwater quantity control.

The same pattern of increasing costs can be seen in Scenarios involving riparian planting (compare, for instance, Scenarios 2F, 2G and 2H or Scenarios 5F, 5G and 5H in Figure3-13). These increases are driven purely by the differences in the contaminant management costs in these scenarios, with the extent of riparian planting (and hence costs) being held constant. However, while the costs of riparian planting are constant in these scenarios, the proportion of the total lifecycle costs accounted for by riparian planting varies (see Figure 3-14). Riparian planting costs make up a greater proportion of the total lifecycle costs in scenarios involving *status quo* levels of contaminant control than in scenarios involving higher levels of contaminant control. Under the brownfields development scenario (Scenario 3), for instance, riparian planting makes up over 50% of total lifecycle costs in both sub-catchments with *status quo* levels of contaminant control (3F), compared with less than 20% of total lifecycle costs with higher levels of contaminant control (3H).

3.4.3 Cost Effectiveness

Figure 3-15 and Figure 3-16 show the relationships between the costs of mitigation and the change in the water quality and macroinvertebrate indicator scores, respectively, for scenarios which result in an improvement relative to the pre-development scores (in 2010). In these figures, scenarios are grouped into:

- those employing 'higher levels' of contaminant mitigation, meaning better than *status quo* levels, in the absence of riparian planting;
- those employing riparian planting, in the absence of higher levels of contaminant management; and
- those employing both higher levels of contaminant mitigation and riparian planting.

Results for Scenarios 1, 2 and 3 are also distinguished from those for Scenarios 4 and 5. It is worth noting that the 2010 indicator scores against which changes in water quality are assessed differ for Scenarios 1, 2 and 3 compared with Scenarios 4 and 5, reflecting the legacy effects of historic development in the former group of scenarios.

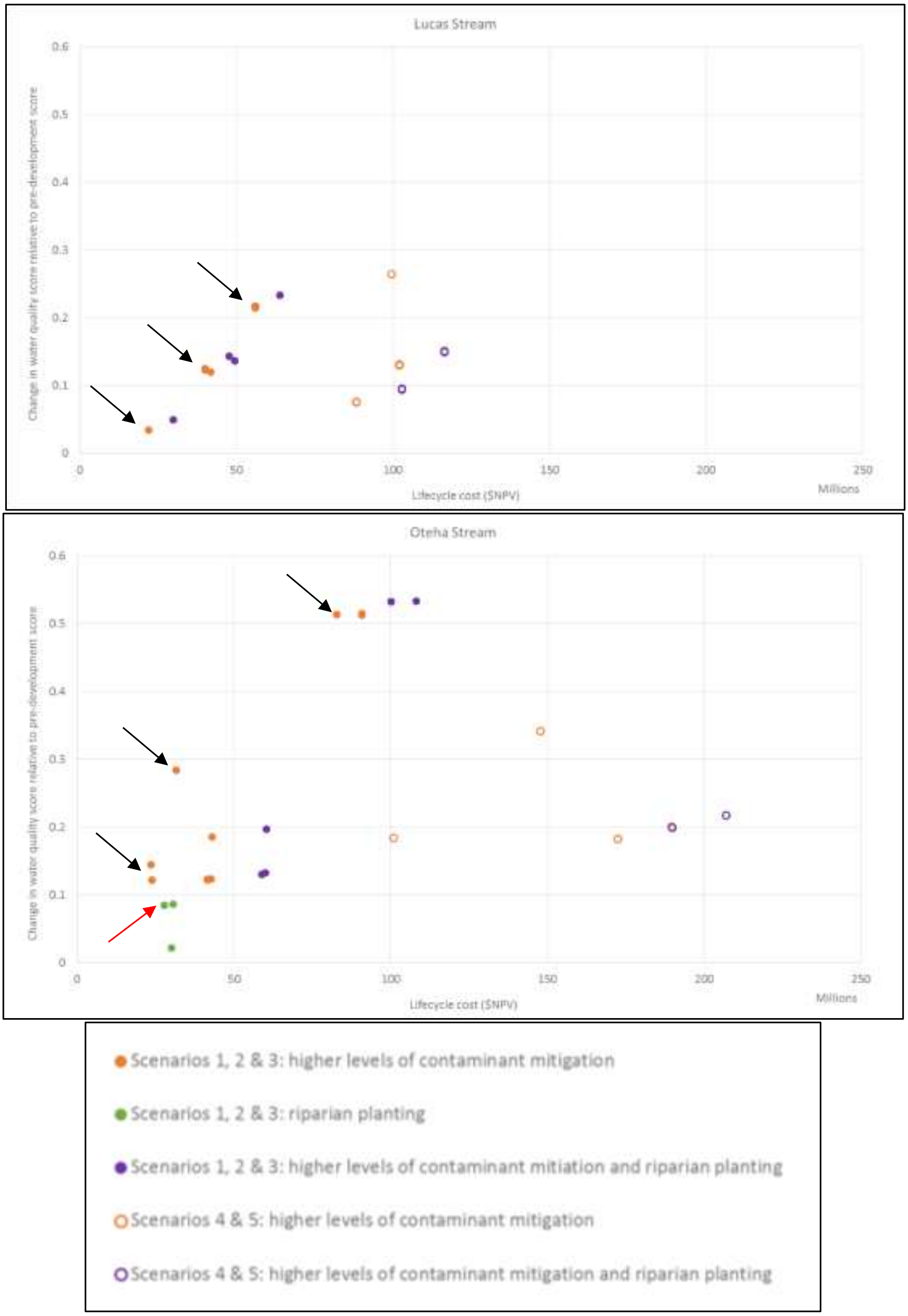


Figure 3-15: Relationship between the costs of mitigation and the change in the water quality indicator score for scenarios which result in an improvement relative to the pre-development score, Lucas Stream (upper) and Oteha Stream (lower). Costs are estimated over 50-years using a discount rate of 8%. Arrows indicate examples referred to in the text.

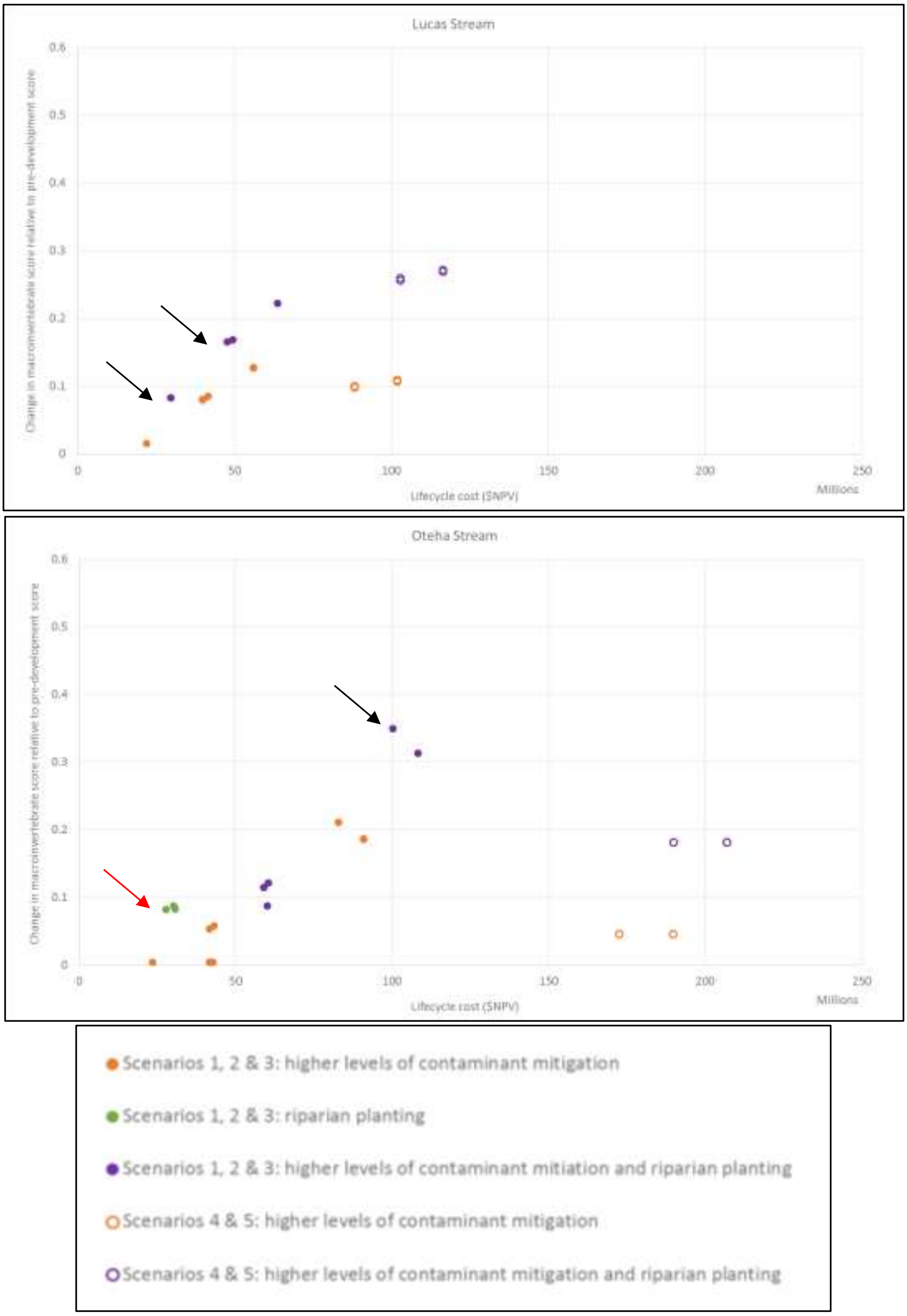


Figure 3-16: Relationship between the costs of mitigation and the change in the macroinvertebrate quality indicator score for scenarios which result in an improvement relative to the pre-development score, Lucas Stream (upper) and Oteha Stream (lower). Costs are estimated over 50-years using a discount rate of 8%. Arrows indicate examples referred to in the text.

Range of Costs

The total lifecycle costs of scenarios that deliver improvements in the water quality and macroinvertebrate indicator scores in both the Lucas Stream and Oteha Stream sub-catchments vary between $45.2M[14] and $323.4M[15], when estimated over 50 years using an 8% discount rate. These figures are equivalent to costs of $3,885[16] and $19,687[17], respectively, per new dwelling. The costs at the lower end of the range are associated with partial brownfields redevelopment while those at the upper end are associated with full, low-density greenfield development (i.e. assuming no historic development).

Water Quality Indicator Score – Cost Effectiveness of Mitigation

Based on the water quality indicator score, scenarios employing solely high levels of contaminant mitigation measures are generally predicted to be the most cost effective, delivering a given improvement in the score for the lowest lifecycle cost (Figure 3-15, examples indicated by black arrows). Noting (from Section 3.4.2) that there may also be certain avoided costs in scenarios involving WSD that are not taken into account here, the cost-effectiveness of some of these contaminant mitigation scenarios may be under-represented.

While scenarios involving both high levels of contaminant mitigation and riparian planting also deliver improvements in the water quality indicator score, these generally have higher associated costs for a given change in score. For example, in the Lucas Stream sub-catchment an improvement in the water quality score of just over 0.1 is delivered by contaminant mitigation scenarios with costs in the range $40-42M, compared with scenarios employing contaminant mitigation and riparian planting at a cost of $48-49M. In the case of Lucas Stream, scenarios that solely involving riparian planting are not cost effective because they fail to deliver on the objective of maintaining or improving water quality (hence, they do not appear in Figure 3-15).

In contrast, some scenarios involving riparian planting do result in an improvement in the predicted water quality indicator score in the Oteha Stream (Figure 3-15, examples indicated by red arrows). However, while these scenarios are relatively low-cost ($28-31M), there are even lower-cost scenarios (costing in the range $23-24M) involving contaminant mitigation that deliver greater improvements in the water quality indicator score.

Macroinvertebrate Indicator Score – Cost Effectiveness of Mitigation

The cost effectiveness results based on the macroinvertebrate indicator score provide a number of contrasts with the results described above, although it is again important to recognise that the costs of some of the contaminant mitigation scenarios do not reflect potential avoided costs associated with WSD. In the case of Lucas Stream, scenarios employing both high levels of contaminant mitigation and riparian planting are predicted to be the most cost effective, delivering a given improvement in the score for the lowest lifecycle cost (Figure 3-16, examples indicated by black arrows). While scenarios involving solely higher levels of contaminant mitigation also deliver an

[14] This is the combined cost of the least costly scenarios that deliver improvements in the water quality and macroinvertebrate index scores in Lucas Stream sub-catchment (3C: $21.8M) and Oteha Stream sub-catchment (3B: $23.4M), respectively.

[15] This is the combined cost of the most costly scenarios that deliver improvements in the water quality and macroinvertebrate index scores in Lucas Stream sub-catchment (4G/4H: $116.4M) and Oteha Stream sub-catchment (4G/4H: $207.0M), respectively.

[16] Under Scenario 3, the total number of new dwellings modelled was 11,634, made up of 1,921 in Lucas Stream sub-catchment and 9,713 in Oteha Stream sub-catchment.

[17] Under Scenarios 4 and 5 the total number of new dwellings modelled was 16,427, made up of 7,455 in Lucas Stream sub-catchment and 8,972 in Oteha Stream sub-catchment.

improved macroinvertebrate indicator score, these have higher associated costs for a given change in score. For example, an improvement in the macroinvertebrate score of over 0.1 is delivered by a scenario employing contaminant mitigation and riparian planting at a cost of $48M, compared with a cost of $56M for a contaminant mitigation scenario. Scenarios that solely involve riparian planting are not cost effective because they fail to deliver on the objective of maintaining or improving water quality (hence, they do not appear in Figure 3-16).

In contrast, in the case of Oteha Stream, some scenarios that solely involve riparian planting are cost-effective but only for the delivery of a very modest improvement in the macroinvertebrate indicator score (improvement of around 0.1 for costs of $28-31M: Figure 3-15, examples indicated by red arrows). Some scenarios involving solely contaminant mitigation result in moderate improvements in the macroinvertebrate score of around 0.2, but these have relatively high associated costs of $82-90M. The most marked improvements in the macroinvertebrate score (of over 0.3: Figure 3-15, examples indicated by black arrows) are delivered by scenarios employing both high levels of contaminant mitigation and riparian planting. These top scoring scenarios have costs in the range $100-108M, of which $18M are the costs associated with the riparian management that drives the added improvement in the score.

Influence of Pre-Development Conditions

Figure 3-15 and Figure 3-16 also provide for a comparison of the cost-effectiveness of mitigation in relation to differences in the pre-development conditions. In both figures, points representing variants of Scenarios 4 and 5 (open circles) tend to plot to the right of points representing variants of Scenarios 1, 2 and 3 (solid circles). This reflects the fact that it is generally more costly to mitigate the effects of the more extensive development involved in Scenarios 4 and 5 than to mitigate the effects of partial development involved in Scenarios 1, 2 and 3. For example, mitigation costs in the Oteha Stream sub-catchment are estimated to be up to $207 million under full greenfield development scenarios, compared with a maximum of $108 million under partial development scenarios. This suggests that, from the point of view of achieving the objectives of the NPS-FM, further development of catchments which are already partly developed (and which already contain some level of mitigation) may be more cost-effective than attempting to mitigate the effects of development in greenfield catchments.

Cost Effectiveness in Relation to an 'Overall' Improvement in Water Quality

A final point on the cost effectiveness results is that they should not be used to assess which sub-catchment is likely to represent the best 'bang for buck' in the absence of considering the respective contribution of each sub-catchment to 'overall' water quality in the catchment as a whole. While mitigation in Lucas Stream is on average lower cost than that in Oteha Stream[18], the results presented in Section 3.3.4 indicate that mitigation would need to occur in the latter sub-catchment in order to deliver on the objectives of the NPS-FM at the catchment scale. Using the scenarios presented in Section 3.3.4 as an example, Table 3-3 shows the costs of different combinations of mitigation in the two sub-catchments along with the water quality outcomes achieved. It can be seen that a high level of mitigation (Scenario 5G) is required in the Oteha Stream sub-catchment in order to improve the overall water quality score for the combined catchment. The most cost-effective way of achieving this overall improvement is to adopt *status quo* levels of mitigation in the Lucas Stream

[18] Mean mitigation costs in scenarios which maintain or improve the water quality indicator score are $71 million and $90 million for Lucas Stream and Oteha Stream, respectively. Mean mitigation costs for scenarios which maintain or improve the macroinvertebrate indicator score are $70 million and $95 million in Lucas Stream and Oteha Stream, respectively.

sub-catchment, while recognising that this results in a localised deterioration in water quality in that sub-catchment.

Table 3-3: Predicted lifecycle costs of mitigation and change in water quality under combinations of Scenarios 5A and 5G in Lucas Stream and Oteha sub-catchments and their combined catchment. Costs are estimated over 50-years using a discount rate of 8%.

Scenario	Lifecycle Cost ($ millions)			Change in WQ score		
	Lucas Stream	Oteha Stream	Combined catchment	Lucas Stream	Oteha Stream	Combined catchment
Lucas 5G + Oteha 5A (High density greenfield with high level of mitigation in Lucas and *status quo* mitigation in Oteha)	102.8	52.5	155.3	+ve	-ve	-ve
Lucas 5A + Oteha 5G (High density greenfield with high level of mitigation in Oteha and *status quo* mitigation in Lucas)	30.2	189.9	220.1	-ve	+ve	+ve
Lucas 5G + Oteha 5G (High density greenfield with high level of mitigation in both)	102.8	189.9	292.7	+ve	+ve	+ve

The lowest cost associated with achieving an overall catchment water quality improvement is the same as the lowest cost for achieving an improvement in both Lucas Stream and Oteha Stream, being the $45.2M associated with brownfields partial development scenarios[13]. The highest cost for achieving an overall catchment water quality improvement, while accepting a water quality decline and minimising costs in Lucas Stream sub-catchment, is $237.3M[19]. This compares with the maximum cost associated with delivering an improvement in <u>both</u> sub-catchments of $323.4M[14].

3.4.4 Summary

This section has addressed the following question:

> *What are the most cost-effective means of maintaining and/or improving stream water quality in an urban development context?*

The results of the case study assessment indicate that high levels of contaminant management are the most cost effective mitigation when considering water quality based purely on its physical and chemical properties. However, when the notion of water quality is extended to include ecosystem health, the results indicate that riparian planting, in combination with high levels of contaminant management, is generally the most cost effective form of mitigation. It is also important to note that there may also be certain avoided costs associated with WSD that have not been taken into account in this study, such that the cost-effectiveness of these scenarios may be under-represented.

The results also suggest that, from the point of view of achieving an overall improvement in water quality, mitigation focused on the most influential sub-catchments may be more cost-effective than catchment-wide mitigation. In addition, further development of catchments which are already partly

[19] This is the combined cost of the most costly full development scenario in Oteha Stream sub-catchment that delivers an overall improvement in the water quality index score (4G/H: $207.1M) and the least costly full development scenario in Lucas Stream sub-catchment (5A: $30.2M).

developed (and which already contain some level of mitigation) may be more cost-effective than attempting to mitigate the effects of development in greenfield catchments.

3.5 Estuarine Environmental Quality

3.5.1 Introduction

This section presents and discusses illustrative results which address the final of the four questions posed in Section 1.2. That question is:

> *While the NPS-FM only applies to freshwater, what are the impacts of different urban development scenarios and mitigation strategies on estuaries?*

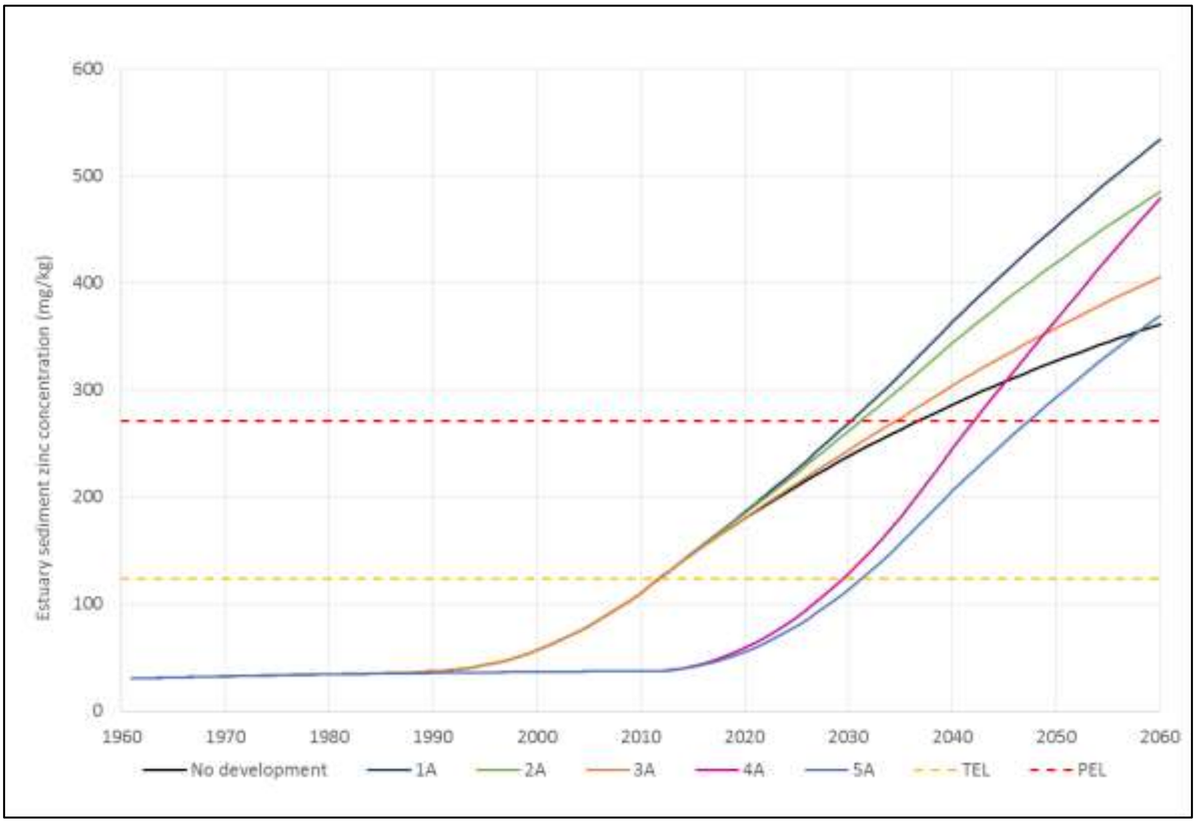
The findings are illustrated with reference to predictions of sediment concentrations of zinc and the Benthic Health Index (BHI), a measure of the ecological health of benthic macroinvertebrate communities.

3.5.2 Influence of Development Type

Figure 3-17 shows modelled trends in concentrations of zinc in the bed sediments of the Lucas Creek estuary over the study timeframe, including those associated with the historic period prior to 2010. Trends are plotted for each of the land use change scenarios, assuming *status quo* levels of contaminant controls (Scenarios A). The figure also shows the Threshold Effects Level (TEL; 124 mg kg^{-1}) and Probable Effects Level (PEL; 271 mg kg^{-1}) concentrations of zinc (MacDonald, 1996). These are widely used sediment quality guideline values derived from eco-toxicological studies which indicate concentrations above which effects are considered possible (the TEL) and likely (the PEL).

Observed zinc concentrations following the historic development of the catchment are already around the TEL (Green et al., 2004) and, even without any further urban development, the PEL is predicted to be exceeded before 2040. This represents a ‘sliding baseline’ against which further changes in sediment quality modelled under the various development scenarios should be assessed.

Under Scenarios 1, 2 and 3 zinc concentrations are predicted to rise more steeply than with no development, exceeding the PEL between 2030 and 2035, and reaching concentrations of approximately 400-530 mg $kg^{-1}$by 2060. Under Scenarios 4 and 5, sediment zinc concentrations at 2010 are predicted to be well below the TEL, reflecting the lack of historic development in these Scenarios. However, with the subsequent development of the catchment concentrations are predicted to rise relatively steeply, exceeding the PEL by around 2050, and reaching concentrations of approximately 370-480 mg $kg^{-1}$by 2060.



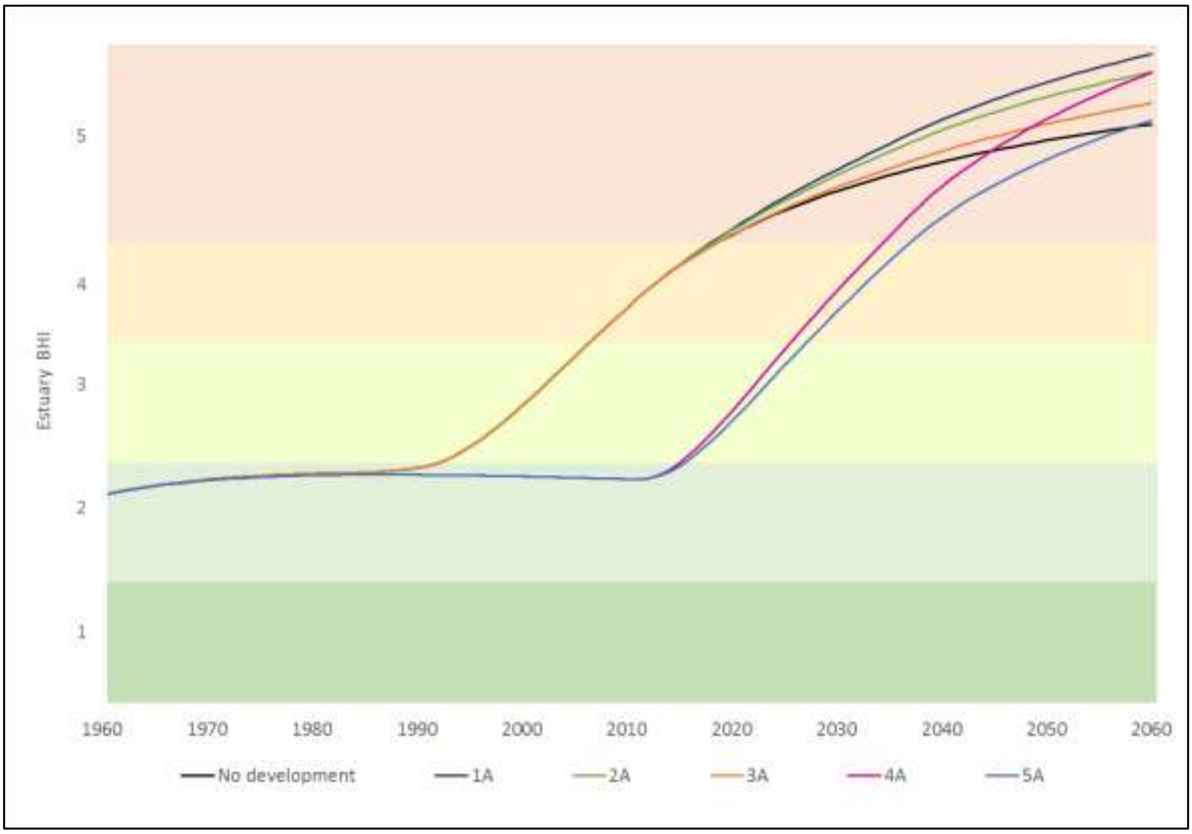
Land development:	(1) Historic + low density (2) Historic + high density (3) Historic + brownfield	(4) Greenfield low density (5) Greenfield high density

Figure 3-17: Predicted sediment zinc concentrations under selected urban development scenarios with *status quo* contaminant controls, Lucas Creek estuary.

In each of the two groups of Scenarios (1, 2 and 3; and 4 and 5), higher sediment zinc concentrations are associated with low density forms of development than high density forms. This reflects the fact that the former scenarios are predicted to result in the highest metal loads, because of their relatively large urban footprint, and the lowest sediment loads, because of their relatively small rural footprint.

The lowest sediment zinc concentrations in scenarios following on from the historic development of the catchment are associated with brownfields development. These differences reflect the relative size of the development footprint in each scenario and, in the case of the brownfields scenario, the replacement of higher zinc-yielding industrial land use with lower zinc-yielding residential land use.

Figure 3-18 shows corresponding trends in the predicted BHI score. The BHI is reported on a scale of 1 (healthy) to 5 (severely degraded). Reflecting the predicted elevation of sediment zinc (and copper) concentrations to levels well in excess of the PEL, the BHI score is predicted to change from a reasonably healthy '2' to a severely degraded '5' under all land use change scenarios (as well as with no further development).

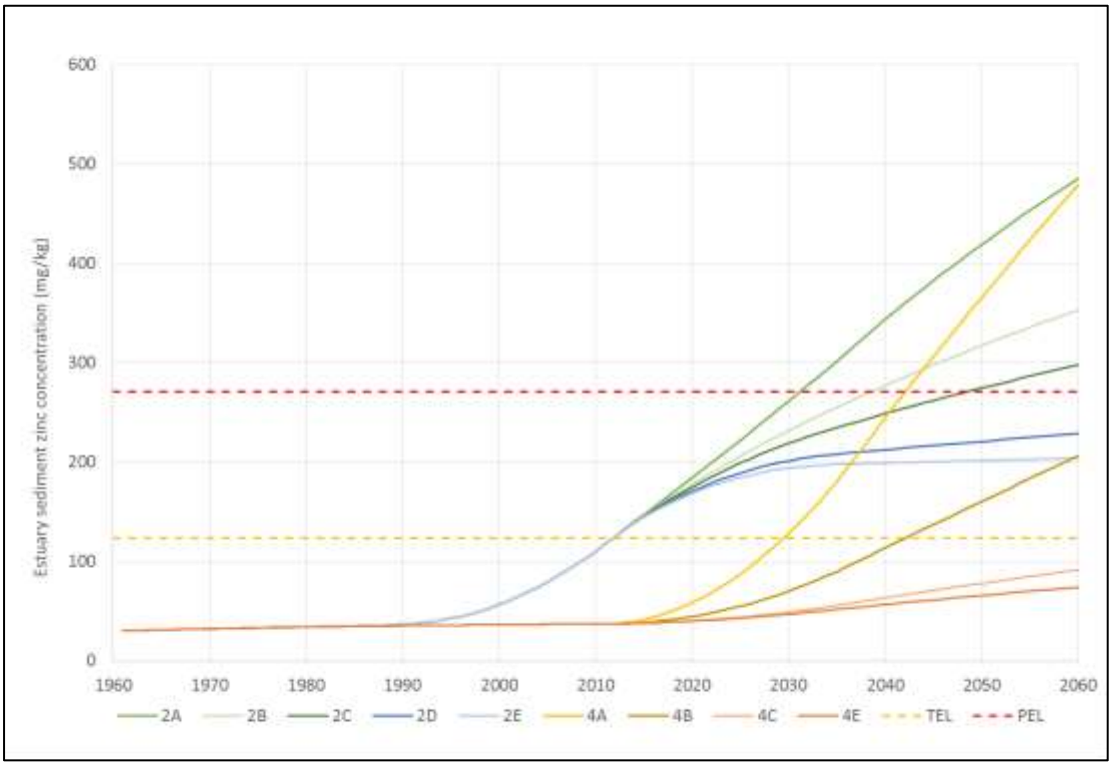


Land development:	(1) Historic + low density (2) Historic + high density (3) Historic + brownfield	(4) Greenfield low density (5) Greenfield high density

Figure 3-18: Predicted BHI scores under selected urban development scenarios with *status quo* contaminant controls, Lucas Creek estuary.

3.5.3 Influence of Mitigation

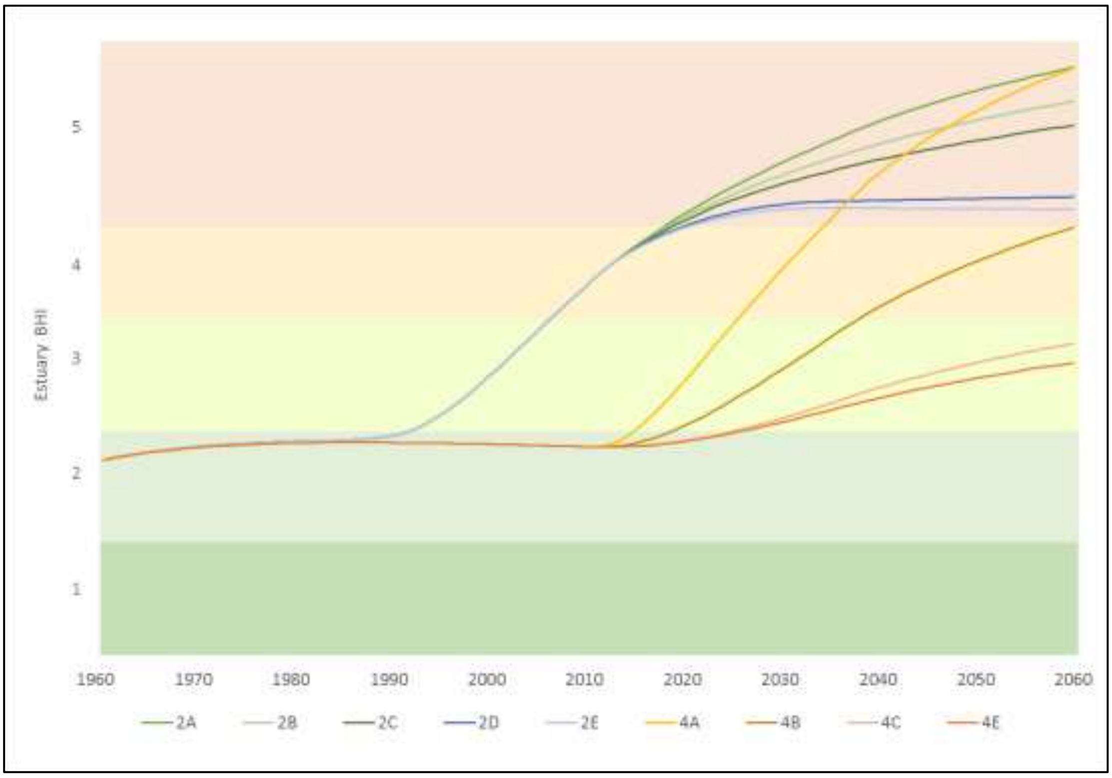
Figure 3-19 shows the influence of alternative contaminant controls on predicted trends in sediment zinc concentrations for Scenario 2 (higher density, following historic development) and Scenario 4 (low density greenfields development). The rate of increase in zinc concentrations is predicted to fall markedly with best practice levels of stormwater treatment (Scenarios B). Sediment zinc concentrations in 2060 are predicted to be approximately 25% lower in Scenario 2B and nearly 60% lower in Scenario 4B than in the corresponding scenarios involving *status quo* contaminant controls (Scenarios A). Further incremental reductions in the rate of increase are predicted for scenarios which add in WSD (C), retrofitting of stormwater treatment to areas of historic development (D) and the use of low metal-yielding vehicle components (E). In the case of Scenario 2, these additional contaminant controls are predicted to result in zinc concentrations remaining below the PEL (Scenarios 2D and 2E). In the case of Scenario 4, in which sediment zinc concentrations are not affected by historic development, zinc concentrations are predicted to remain below the TEL (Scenarios 4C and 4E).



Land development:	(2) Historic + high density	(4) Greenfield low density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development (E) As (D) with vehicle source control	

Figure 3-19: Predicted sediment zinc concentrations under selected urban development scenarios employing alternative stormwater contaminant control measures, Lucas Creek estuary.

Figure 3-20 shows corresponding trends in the predicted BHI score. In the case of Scenario 2, contaminant controls are unable to prevent the BHI reaching a score of 5, indicating severely degraded conditions. In contrast, under Scenario 4, development scenarios involving WSD, with and without the addition of low metal-yielding vehicle components (4E and 4C, respectively) are predicted to result in a moderate BHI score of 3. However, this still represents a decline in ecological condition, given a pre-development score of 2.



Land development:	(2) Historic + high density	(4) Greenfield low density
Mitigation:	(A) Status quo contaminant controls (B) Best practice contaminant controls (C) As (B) with Water Sensitive Design (lower imperviousness) (D) As (C) with retrofitted stormwater treatment of historic development (E) As (D) with vehicle source control	

Figure 3-20: Predicted BHI scores under selected urban development scenarios employing alternative stormwater contaminant control measures, Lucas Creek estuary.

The predicted degradation of environmental quality in the estuary, irrespective of mitigation aimed at reducing contaminant loads, reflects its depositional characteristics. It is modelled to act as a 'sink' in which contaminants delivered from its catchment accumulate. As a result of urban development, metal concentrations in sediments delivered from the catchment markedly exceed pre-development background concentrations. Over time, metal concentrations in the estuary bed sediments increase as a result of the deposition and accumulation of these urban-sourced sediments. Even with contaminant controls in place, metal concentrations in urban-sourced sediments are relatively high compared with concentrations in the bed sediments. This means that even in those scenarios involving contaminant controls, sediment metal concentrations follow an upwards trend. The point at which this trend flattens out indicates that the sediment metal concentrations in estuary bed sediments and in sediments delivered from the catchment are approaching an equilibrium.

3.5.4 Summary

This section has addressed the question:

> *While the NPS-FM only applies to freshwater, what are the impacts of different urban development scenarios and mitigation strategies on estuaries?*

The results of the study indicate a reduction in estuary environmental quality under all urban development scenarios, reflecting the depositional nature of the receiving environment. However, in scenarios employing the most effective contaminant management strategies, the rate of decline in environment quality is predicted to be markedly reduced when compared to scenarios involving *status quo* or partial contaminant management strategies.

4 Summary

A key objective of the National Policy Statement for Freshwater Management (NPS-FM) is that the "overall quality of fresh water within a region is maintained or improved". This represents a significant challenge in catchments undergoing urban development. There is a wealth of historical evidence that contaminants such as sediments generated from earthworks activities and heavy metals conveyed in stormwater have compromised water quality in New Zealand catchments undergoing urban development. In view of this, there is a need for central and local government to understand how councils can manage the impacts of both historic and future urban development on water quality to achieve the objectives of the NPS-FM, while accommodating urban growth through the expansion or intensification of New Zealand towns and cities.

This study investigated the effects of a range of future urban development scenarios on water quality in the Lucas Creek catchment, located on the northern fringe of Auckland. This catchment was chosen because a validated methodology, relevant environmental data and future growth projections were available from a previous study. The study area also contains sub-catchments with varying levels and forms of historic urban development, the less-developed Lucas Stream and more-developed Oteha Stream sub-catchments. This contrast provided for an assessment of the way in which differences in historic forms of development may influence the implementation of the NPS-FM. While locating the assessment in a real catchment, however, it is important to note that the primary intent of the study was to investigate the outcomes of a largely hypothetical set of urban development scenarios to inform the NPS-FM implementation programme, rather than to make specific predictions for the study area catchment

The Urban Planning that Sustains Waterbodies (UPSW) decision support system (DSS) was used to make predictions of: sediment and metal loads; a range of stream environmental indicator scores; the costs of mitigation; and indicators of estuarine environmental quality. The assessment considered variants of a set of five future land use change scenarios over the period 2010-2060. Three of the land use change scenarios take as their starting point the historic urban development that occurred in the Lucas Creek prior to 2010: (1) low density greenfield development; (2) higher density greenfield and infill development; and (3) brownfield development, involving the replacement of areas of existing industrial development with high density residential development. The two remaining land use change scenarios take as their starting point the hypothetical situation of there having been no urban development in the catchment over the 1960-2010 period: (4) low density greenfield development; and (5) higher density greenfield development. The rationale for the adoption of dual starting points was to allow the study to compare situations in which there may be legacy effects on water quality associated with historic urban development with those in which are no legacy effects.

For each of the five land use change scenarios, a number of alternative contaminant and stream management interventions were considered. These included: '*status quo*' levels of earthworks controls and stormwater treatment; 'best practice' levels of earthworks controls and stormwater treatment and zinc source control of roofs; Water Sensitive Design (WSD) development adopting a smaller impervious footprint; retrofitting 'best practice' stormwater controls to areas of existing development; vehicle component source control of copper and zinc; and extensive, high quality riparian planting.

The findings of the study are presented through illustrative results that address four key questions.

Question 1 - How can the overall quality of water be maintained or improved in an urban development context?

The results of the study indicate that in order to maintain and improve water quality in an urban development context, a high level of contaminant control is likely to be required. This may involve measures over and above 'best practice' stormwater treatment and erosion and sediment control, including WSD development approaches and retrofitting stormwater treatment in areas of historic development. This finding applies irrespective of the extent of prior development, with high levels of contaminant control required to maintain or improve the water quality indicator score in all five scenarios.

While lower metal loads were predicted for scenarios involving high density, infill, brownfields and WSD forms of development than for low density scenarios, the reverse finding applied to sediment loads. Relatively high sediment loads were predicted for high density forms of development, because of the greater extent of undeveloped rural land in these scenarios. In some scenarios, these higher sediment loads were found to counteract the influence of lower metal loads on the water quality indicator score. This finding indicates the potential limitation of considering mitigation of urban development effects in isolation from the management of undeveloped, rural parts of a catchment. It may also be necessary to address water quality issues associated with undeveloped rural parts of catchments, as well as the effects of urban development, where rural land exerts a significant influence on catchment water quality.

The study predicted marked improvements in the macroinvertebrate indicator score in scenarios involving the use of riparian planting, in contrast to a relatively minor improvement in the water quality indicator score. This indicates that when the notion of water quality is extended beyond the physical and chemical properties of water to include ecosystem health, consistent with the objectives of the NPS-FM, riparian planting is likely to provide significant additional benefits, over and above the water quality gains associated with better contaminant controls.

Question 2 - If stream water quality in some sub-catchments is not maintained and/or improved, is it still possible to maintain and improve water quality at the catchment scale? (on average)

The study assessed the water quality indicator score for the combined sub-catchments of the Lucas Stream and Oteha Stream under scenarios involving an improvement in water quality in one sub-catchment and a decline in the other. The indicator score for the combined sub-catchment was found to track the individual score for the Oteha Stream, because of its larger sub-catchment area and development footprint. These results indicate that, while it may be possible to maintain or improve water quality in some 'average' sense, despite a decline in some locations, this outcome is dependent on: the relative contribution of flow and contaminants from different sub-catchments; the spatial distribution of development; and where any mitigation effort is focused.

Question 3 - What are the most cost-effective means of maintaining and/or improving stream water quality in an urban development context?

As might be expected, the study found that the costs of mitigation increase as more and more controls are employed. However, in comparing cost estimates of WSD scenarios with non-WSD scenarios, it is important to note that certain avoided costs associated with WSD were not modelled. This results in uncertainty over the cost differential between these scenarios. In addition, while the lifecycle costing models employed in the study were developed using the best currently available data applied to plausible catchment management scenarios, it is important to recognise that they were primarily developed to provide for a relative, rather than absolute, assessment of mitigation costs under different scenarios. When interpreting the cost estimates it is also important to note that they include both public and private costs.

The assessment found that high levels of contaminant management are the most cost effective mitigation when considering water quality based purely on its physical and chemical properties. For a given water quality indicator score, mitigation costs associated with scenarios involving high levels of contaminant management were predicted to have lower costs than those involving both contaminant management and riparian planting. However, when ecological indicators of water quality are considered, the results indicate that riparian planting, in combination with high levels of contaminant management, is generally the most cost effective form of mitigation.

The results also suggest that, from the point of view of achieving an overall improvement in water quality, mitigation focused on the most influential sub-catchments may be more cost-effective than catchment-wide mitigation. In addition, further development of catchments which are already partly developed (and which already contain some level of mitigation) may be more cost-effective than attempting to mitigate the effects of development in greenfield catchments. For a given water quality indicator score, costs associated with greenfield development scenarios were generally higher than those associated with scenarios incorporating the historic urban development of the catchment.

> *Question 4 - While the NPS-FM only applies to freshwater, what are the impacts of different urban development scenarios and mitigation strategies on estuaries?*

Based on predictions of sediment metal concentrations and the Benthic Health Index, the results of the study indicate a reduction in estuary environmental quality under all urban development scenarios. This reflects the depositional nature of the estuary, which acts as a sink in which contaminants delivered from its catchment accumulate. However, in scenarios employing the most effective contaminant management strategies, the rate of decline in sediment metal concentrations and the Benthic Health Index was predicted to be much slower than in scenarios employing *status quo* controls.

5 Acknowledgements

The authors wish to thank Sue Ira for her helpful comments on the interpretation of the mitigation cost and cost effectiveness results of this study.

6 Glossary of abbreviations and terms

BBN	Bayesian Belief Network, a type of probabilistic model
BHI	Benthic Health Index
BHM	Benthic Health Model
Best practice contaminant controls	Combination of earthworks and stormwater controls that achieve 90% removal of TSS and high levels of metal removal
Brownfields	Urban development involving the replacement of an existing urban land use with another
C-CALM	Catchment Contaminant Annual Loads Model
DSS	Decision Support System
ERU	Estuary reporting unit
ESC	Erosion and Sediment Control measures for earthworks activities
Greenfields	Urban development involving the replacement of undeveloped rural land with urban land uses
Imperviousness	Proportion of an area occupied by impermeable surfaces such as roads, roofs and paved areas
Infill	Urban development involving an increase in the density of dwellings in areas of existing residential development
MUL	Metropolitan Urban Limit
NPS-FM	National Policy Statement for Freshwater Management
PLU	Planning Unit, generally corresponding with a sub-catchment
RUF	Resilient Urban Futures research programme
SRU	Stream Reporting Unit
Status quo contaminant controls	Combination of earthworks and stormwater controls implemented as part of historic development, or that achieve 75% removal of TSS and medium levels of metal removal in areas of new development
TSS	Total Suspended Solids, used as a measure of sediment loads or concentrations
UPSW	Urban Planning that Sustains Waterbodies research project
USC	Urban Stormwater Contaminants estuary sediment quality model
Vehicle source control	Use of low-copper yielding brake pads and low zinc-yielding tyres
WSD	Water Sensitive Design
zinc source control of roofs	Use of lowest zinc-yielding roofing materials in the place of higher yielding materials

7 References

Anderson, M.; Hewitt, J.E.; Ford, R.; Thrush, S.F. (2006). Regional models of benthic ecosystem health: prediction pollution gradients from biological data. Technical Publication 317. Auckland Regional Council.

Auckland Regional Council (ARC). (2010). State of the Auckland Region 2009. Auckland Regional Council, Auckland, New Zealand.

Castelletti, Andrea, and Rodolfo Soncini-Sessa. (2007). "Bayesian Networks and participatory modelling in water resource management." Environmental Modelling & Software 22: 1075-1088.

Green, M. (2008). Central Waitemata Harbour Study. USC-3 Model Description, Implementation and Calibration. Prepared by NIWA Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2008/042.

Green, M., Williamson, R., Timperley, M., Collins, R., Senior, A., Adams, A., Swales, A. and Mills, G. (2004). Prediction of Contaminant Accumulation in the Upper Waitemata Harbour – Methods. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Publication No. 261.

Ira S. (2011). The Development Of Catchment Scale Life Cycle Costing Methods For Stormwater Management. Report commissioned by Cawthron Institute. Cawthron Report No. 2082. 35 p. plus appendices

Ira, S. (2012). Development of a life cycle cost model for urban lowland stream riparian planting and stormwater quantity management, Addendum to Cawthron Report 2082.

Ira, S. (2013). Costs of Erosion and Sediment Control. Koru Environmental Ltd report prepared for Cawthron Institute.

Ira, S. (2015a). Addendum to Report No. 2082 by the Cawthron Institute entitled: "The Development of Catchment Scale Life Cycle Costing Methods for Stormwater Management".

Ira, S. (2015b). Quantifying the Cost differential Between Conventional and Water Sensitive Design Developments – a Literature Review. Koru Environmental Ltd report prepared for Cawthron Institute.

Ira, S., Vesely, E-T. and Krausse, M. (2008). Life cycle costing of stormwater treatment devices: a practical approach for New Zealand. 11th International Conference on Urban Drainage. Edinburgh, Scotland.

MacDonald, D. D., Carr, R. S., Calder, F. D., Long, E. R. and Ingersoll, C. G. (1996). Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology, 5: 253-278.

Moores, J., Batstone, C., Gadd, J., Green, M., Harper, S., Semadeni-Davies, A. and Storey, R. (2014). Evaluating the Sustainability of Urban Development in New Zealand in Relation to Effects on Water Bodies. The International Journal of Environmental Sustainability, 9(4): 31-47.

Moores, J.; Harper, S.; Batstone, C.; Semadeni-Davies, A.; Gadd, J; Green, M. (2012). Development of a Spatial Decision Support System for Evaluating the Impacts of Urban Development on Waterbodies: Building and Testing the Pilot System. NIWA report AKL-2012-038 prepared under contract C01X0908 funded by the Ministry of Business, Innovation and Employment.

Neale, M. W. (2010a). State of the Environment Monitoring: River Water Quality Annual Report 2008. Auckland Regional Council Technical Report 2010/16

Neale, M. W. (2010b). State of the Environment Monitoring: River Water Quality Annual Report 2009. Auckland Regional Council Technical Report 2010/30

New Zealand Government (2014). National Policy Statement for Freshwater Management 2014.

New Zealand Transport Agency (2012). State Highway Traffic Data Booklet 2007-2011. http://www.nzta.govt.nz/resources/state-highway-traffic-volumes/

New Zealand Transport Agency (NZTA, 2008). Regional Summary – Auckland. Downloaded from http://www.nzta.govt.nz/resources/regional-summaries/auckland/docs/auckland-regional-summary.pdf

North Shore City Council (2005a). The Kokopu Connection: Lucas Creek Stream Assessment. Report No. KC17

North Shore City Council (2005b). The Kokopu Connection: Oteha Valley Stream Assessment. Report No. KC22

North Shore City Council (2005c). The Kokopu Connection: Alexandra Stream Assessment. Report No. KC3

North Shore City Council (2009). Stormwater asset management plan 2009.

Reed, J. Gadd, J. (2009). Marine sediment monitoring programme 2007 results. Prepared by National Institute of Water & Atmospheric Research Ltd (NIWA) for Auckland Regional Council. Auckland Regional Council Technical Report 2009/098.

Semadeni-Davies, A.; Wadwha, S. (2014). C-CALM 2.0 User Manual - Catchment Contaminant Annual Load Model. NIWA report number AKL2014-026.

Timperley, M.; Reed, J, (2008). Central Waitemata Harbour Contaminant Study. Development of the Contaminant Load Model. Prepared by NIWA Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2008/038.

Timperley, M., Skeen, M. and Jayaratne, J. (2010). Development of the Contaminant Load Model. Auckland Regional Council Technical Report 2010/004.

Williamson, R., Morrisey, D., Swales, A. and Mills. G. (1998). Distributions of contaminants in urbanised estuaries: Predictions and Observations. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Publication No. 139.

Appendix A – Bayesian Belief Network Indicator Descriptions

Indicator	Description
Aquatic Plants	An indicator of the potential extent of stream bed cover occupied by either periphyton (hard bottomed streams) or macrophytes (soft bottomed streams) based on flow, shade and nutrient characteristics.
Habitat	An indicator of stream habitat quality based on characteristics which include deposition of fine sediment, overhead cover, in-stream channel heterogeneity and channel modifications such as stream straightening.
Hydrology	An indicator of the extent to which the natural stream flow regime occurs, based on the frequency and magnitude of low and high flows associated with levels of catchment imperviousness.
Macroinvertebrates	An indicator of the potential abundance and diversity of macroinvertebrate species, based on water quality, physical habitat, and riparian condition.
Native Fish	An indicator of the potential abundance and diversity of native fish species, based on water quality, physical habitat, spawning habitat and the presence of pest fish.
Riparian Vegetation	An indicator of the quality of ecological functions provided by stream margins, based on the vegetation type and ground surface cover of the riparian zone and the connectivity between the riparian zone and the stream.
Water Quality	An integrated indicator of water quality based on the comparison of a range of attributes, including clarity, dissolved oxygen, nutrients and toxicants, against guideline values.

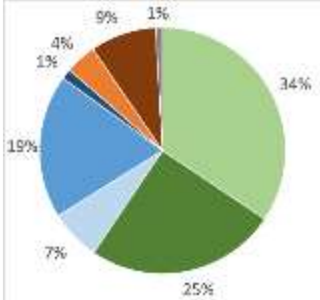
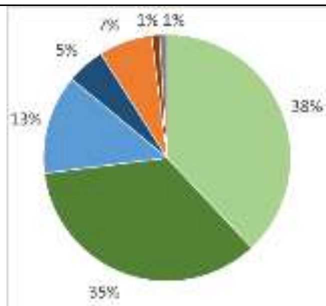
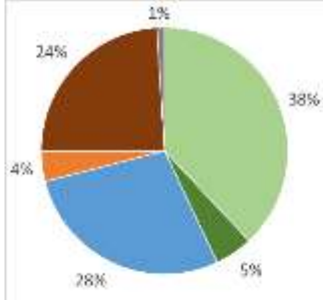
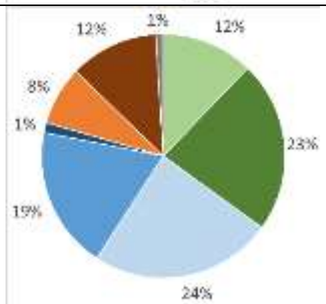
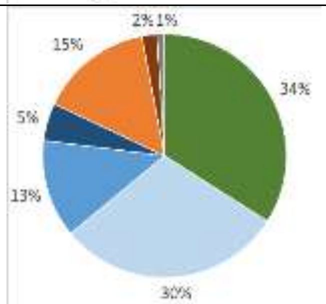
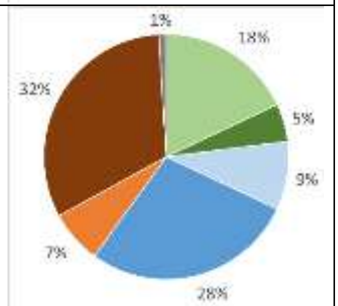
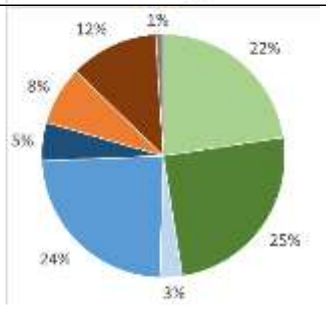
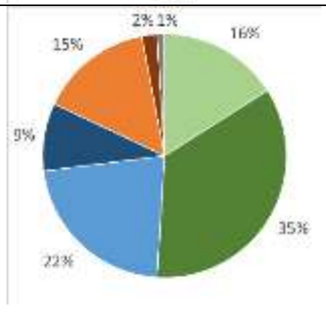
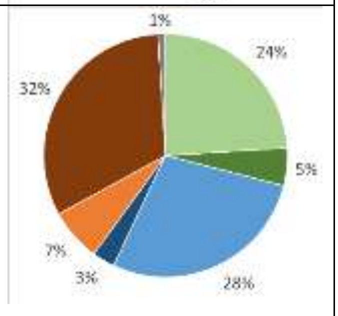
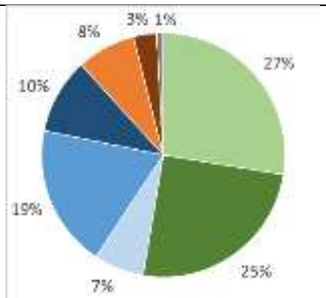
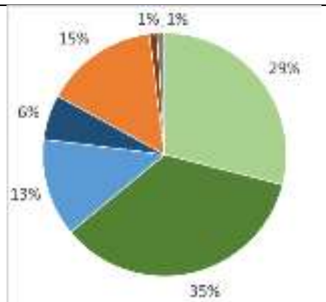
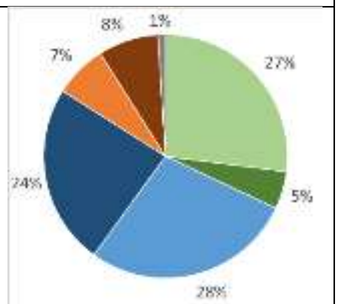
Appendix B - Supporting Information on Urban Development Scenarios

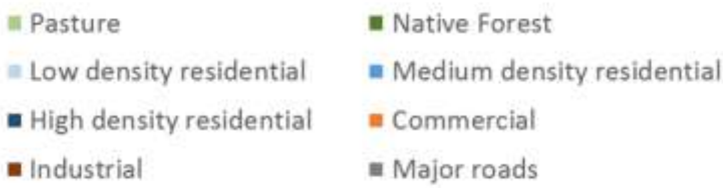
Table 0-1: Summary of land use change and mitigation in each of the urban development scenarios assessed. (ESC = erosion and sediment control)

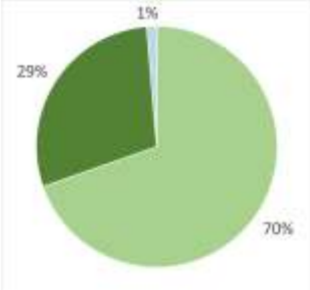
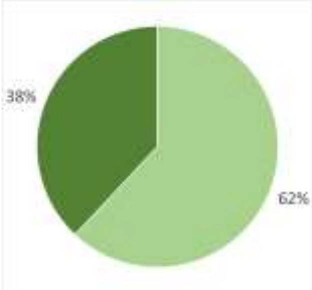
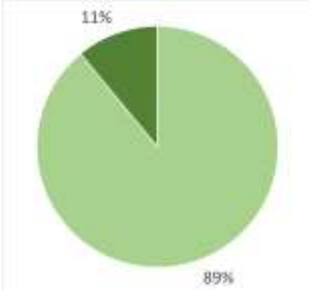
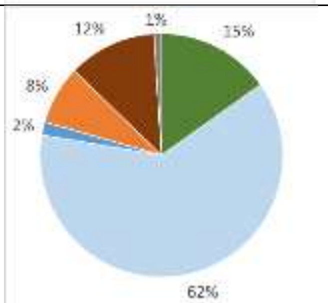
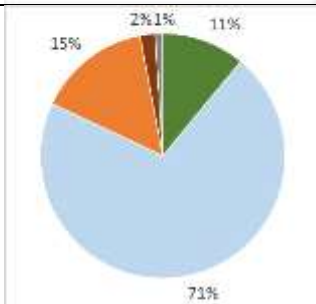
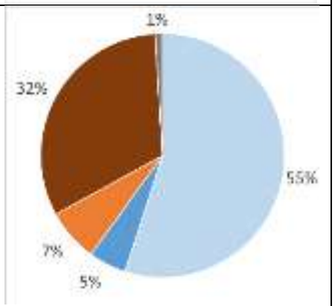
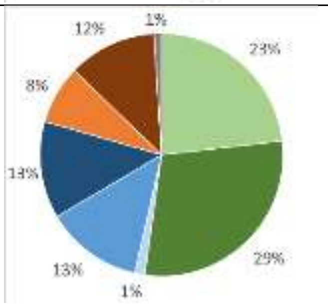
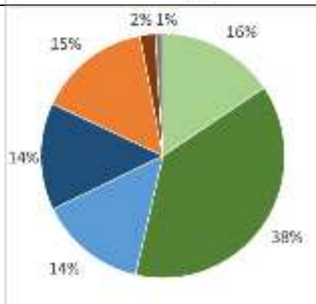
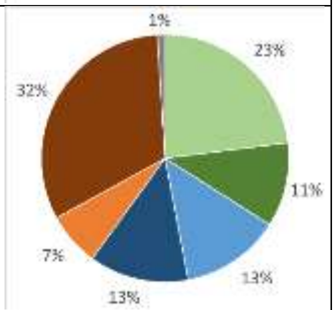
Scenario	Number of Dwellings: Start	Number of Dwellings: End	Land Use at Start	Form of Development	Scenario Variant	Mitigation: *Status quo* stormwater treatment and ESC	Mitigation: Best practice treatment, ESC & roof source control	Mitigation: WSD development (lower imperviousness)	Mitigation: Retrofitted best practice stormwater treatment of historic development	Mitigation: Source control of brakes and tyres	Mitigation: Extensive and high quality riparian planting
1	As of 2010	AC projected for 2051	Actual as of 2010	Low density greenfield development: all new housing at low densities on undeveloped land.	A	X					
					B		X				
					C		X	X			
					F	X					X
					G		X	X			X
2	As of 2010	AC projected for 2051	Actual as of 2010	Higher density development: mix of greenfield land and infill in existing residential areas.	A	X					
					B		X				
					C		X	X			
					D		X	X	X		
					E		X	X	X	X	
					F	X					X
					G		X	X			X
					H		X	X	X	X	X
3	As of 2010	AC projected for 2051	Actual as of 2010	Brownfield development: higher density residential development replacing areas of existing industrial development	A	X					
					B		X				
					C		X	X			
					D		X	X	X		
					E		X	X	X	X	
					F	X					X
					G		X	X			X
					H		X	X	X	X	X

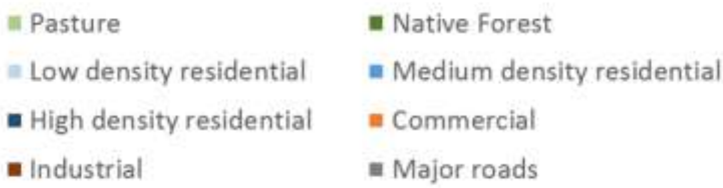
Scenario	Number of Dwellings		Land Use at Start	Form of Development	Scenario Variant	Mitigation					
	Start	End				*Status quo* stormwater treatment and ESC	Best practice treatment, ESC & roof source control	WSD development (lower imperviousness)	Retrofitted best practice stormwater treatment of historic development	Source control of brakes and tyres	Extensive and high quality riparian planting
4	As of 1960	AC projected for 2051	Undeveloped rural (based on 1963 land cover)	Low density greenfield development: projected dwelling numbers accommodated by low density forms of development.	A	X					
					B		X				
					C		X	X			
					E		X	X	X	X	
					F	X					X
					G		X	X			X
					H		X	X	X	X	X
5	As of 1960	AC projected for 2051	Undeveloped rural (based on 1963 land cover)	Higher density greenfield development: projected dwelling numbers accommodated by higher density forms of development.	A	X					
					B		X				
					C		X	X			
					E		X	X	X	X	
					F	X					X
					G		X	X			X
					H		X	X	X	X	X

Table 0-2: Land use breakdown for each scenario, pre- and post-development. (continued on next page)

Scenario(s) (and Year)	Study Area	Lucas Stream sub-catchment	Oteha Stream sub-catchment
1, 2 and 3 pre-development (2010)			
1 post-development (2060)			
2 post-development (2060)			
3 post-development (2060)			



Scenario(s) (and Year)	Study Area	Lucas Stream sub-catchment	Oteha Stream sub-catchment
4 and 5 pre-development (2010)			
4 post-development (2060)			
5 post-development (2060)			



Appendix C - Other Stream Environmental Indicators

This section provides additional illustrative examples of results for contrasting urban development scenarios, based on scores predicted for the stream hydrology, habitat, fish and aquatic plants indicators.

Influence of Water Sensitive Design on Hydrology Indicator

As well as reducing loads of contaminants (Section 3.2.3), another aim of WSD is to maintain (or restore) stream hydrological regimes closer to their natural characteristics. This involves maintaining base flows and minimising any increase in flood peak flows, volumes, and frequency so as to limit any increase in stream erosion. The stream hydrology indicator score provides a measure of the extent to which the hydrological regime is predicted to deviate from its natural characteristics, with a lower score indicating a greater deviation.

Figure 0-1 shows the influence of WSD on the stream hydrology indicator score (Scenarios 2C and 4C), when compared with scores for scenarios that do not involve WSD (Scenarios 2A and 4A). Under Scenario 4C, which involves application of WSD to the full development area, the hydrology indicator score is predicted to remain at a relatively high level while still declining from the pre-development score. In contrast, the predicted score under Scenario 2C is only slightly higher than the score under Scenario 2A, because WSD does not apply to areas of historical development in these scenarios.

Influence of Mitigation on Habitat, Fish and Aquatic Plants Indicators

Section 3.3.3 describes the influence of contaminant mitigation and riparian planting on scores for the water quality indicator and macroinvertebrate indicators. Contaminant management is shown to have a marked influence on the stream water quality indicator score, while the addition of riparian planting provides only marginal additional benefit. However, riparian management is shown to exert a greater influence on stream ecological health, through more significant improvements to the macroinvertebrate scores when compared with scores associated with contaminant management alone.

These same patterns are evident in the results for other indicators of ecosystem health: those relating to stream habitat, native fish and aquatic plants. A higher score for these respective indicators is indicative of better instream habitat conditions, conditions which favour diversity and abundance of native fish (and fewer pest species) and lower likelihood of proliferations of aquatic macrophytes or periphyton.

Habitat

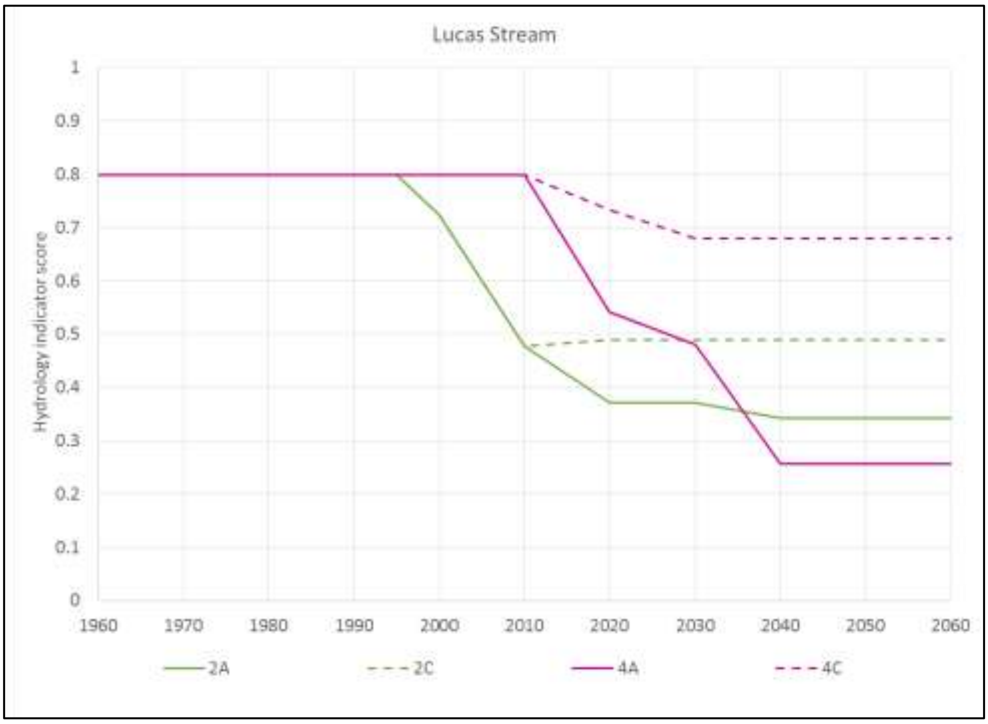
In the case of the Lucas Stream, different levels of contaminant management are predicted to have virtually no influence on the habitat indicator score (Figure 0-2: Scenarios 2A, 2C and 2E). However, in the Oteha Stream, the habitat score is higher under Scenarios 2C and 2E than 2A. This is because these scenarios include WSD. The DSS adopts the assumption there will be less stream modification (for instance, channelization and lining) where development follows WSD principles. In the case of the Oteha Stream, the lesser extent of stream modification under Scenarios 2C and 2E results in an improved habitat score. This is because in non-WSD scenarios a much greater proportion of the stream network is assumed to be modified than is the case for the Lucas Stream. In both sub-catchments the addition of riparian planting is predicted to result in an improvement in the habitat indicator score, irrespective of the contaminant management employed (Scenarios 2F, 2G and 2H).

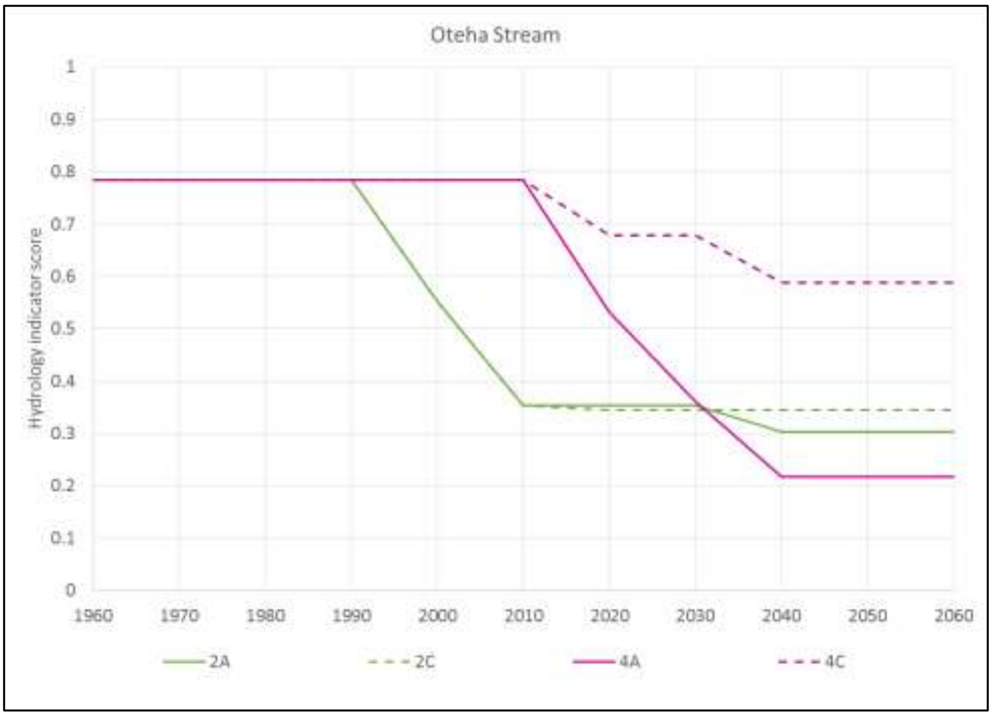
Native Fish

In general, increasing levels of contaminant management are predicted to result in successive improvements in the native fish indicator score (Figure 0-3: Scenarios 2A, 2C and 2E). The addition of riparian planting is predicted to result in further improvements in the native fish indicator score, over and above those associated with contaminant management (Scenarios 2F, 2G and 2H).

Aquatic Plants

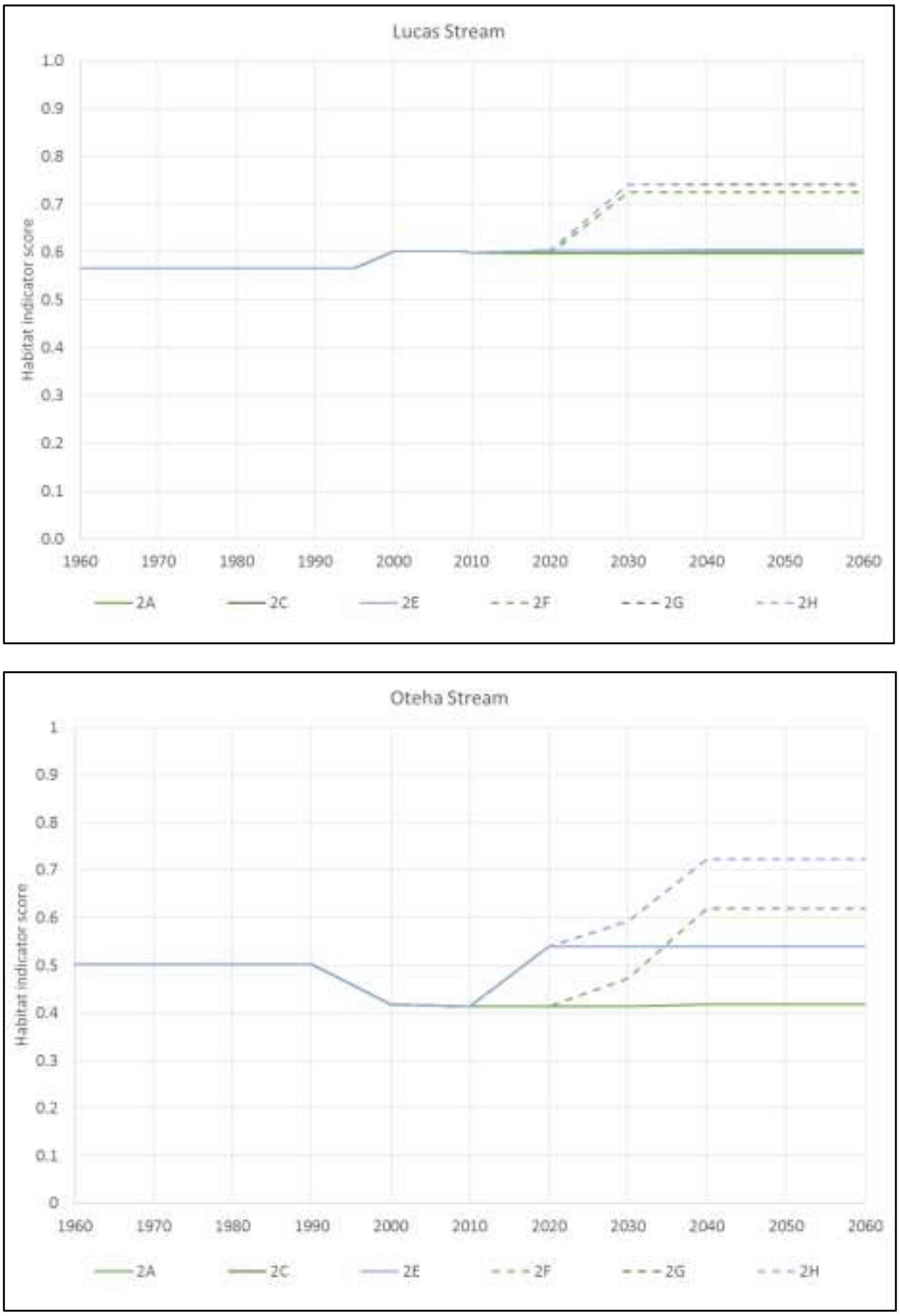
Increasing levels of contaminant management are predicted to have no influence on the aquatic plants indicator score. Figure 0-4 therefore only compares the predicted scores for a scenario involving *status quo* contaminant controls (2A) with the scores for the same level of contaminant management but with the addition of riparian planting (2F). There are two points at which the score improves. Firstly, the scores improve during the period of historic development, reflecting a reduction in the area of pasture and a predicted reduction in the associated nutrient inputs. Secondly, under Scenario 2F the addition of riparian planting makes a further improvement to the score, reflecting the effect of stream shading.





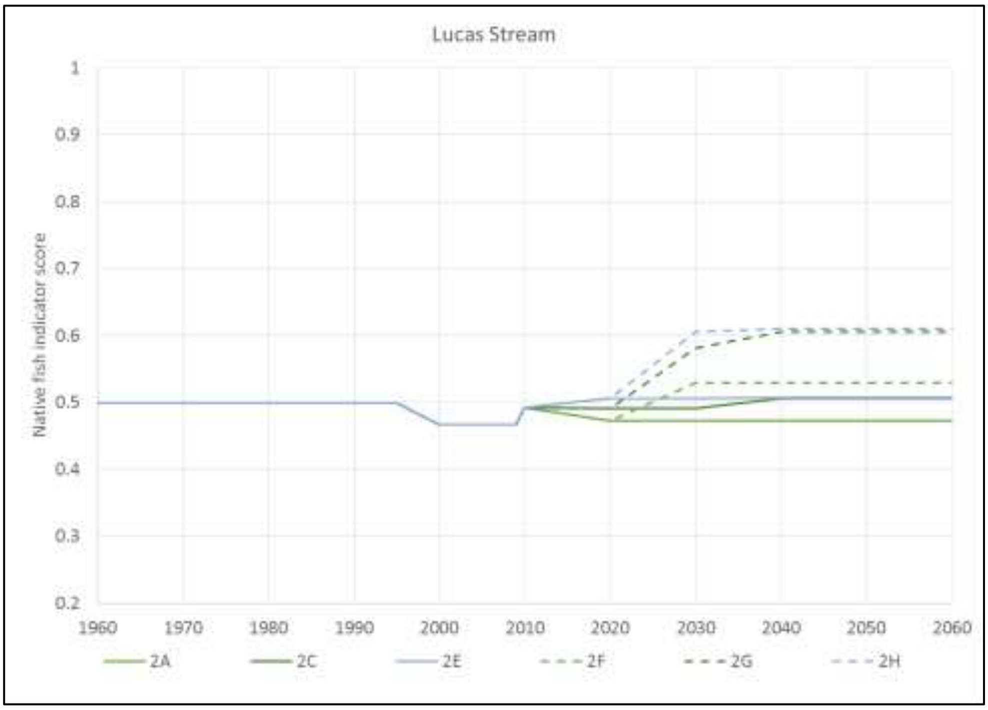
Land development:	(2) Historic + high density	(4) Greenfield low density
Mitigation:	(A) Status quo contaminant controls (C) Best practice contaminant controls with Water Sensitive Design (lower imperviousness)	

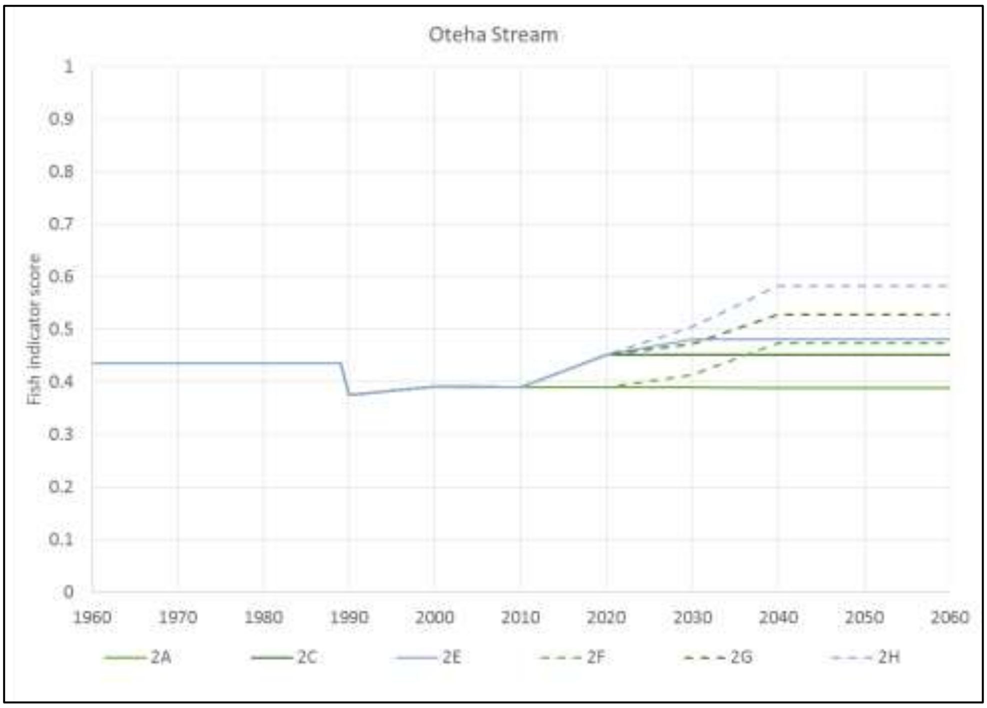
Figure 0-1: Predicted hydrology indicator scores for selected urban development scenarios with and without WSD, Lucas Stream (upper) and Oteha Stream (lower).



Mitigation:	(A) Status quo contaminant controls (C) Best practice contaminant controls with Water Sensitive Design (lower imperviousness) (E) As (C) with retrofitted stormwater treatment of historic development and vehicle source control (F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (E) with riparian planting

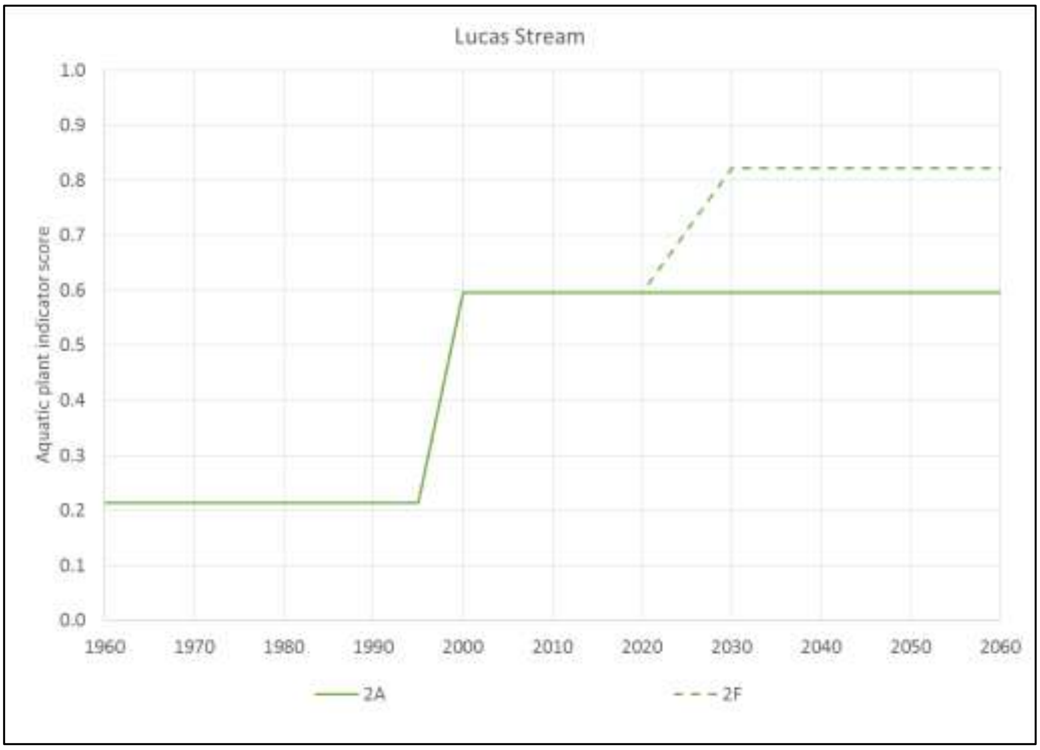
Figure 0-2: Predicted habitat indicator scores for selected urban development scenarios employing alternative stormwater contaminant controls, Lucas Stream (upper) and Oteha Stream (lower).





Mitigation:	(A) Status quo contaminant controls (C) Best practice contaminant controls with Water Sensitive Design (lower imperviousness) (E) As (C) with retrofitted stormwater treatment of historic development and vehicle source control (F) As (A) with riparian planting (G) As (C) with riparian planting (H) As (E) with riparian planting

Figure 0-3: Predicted native fish indicator scores for selected urban development scenarios employing alternative stormwater contaminant controls, Lucas Stream (upper) and Oteha Stream (lower).



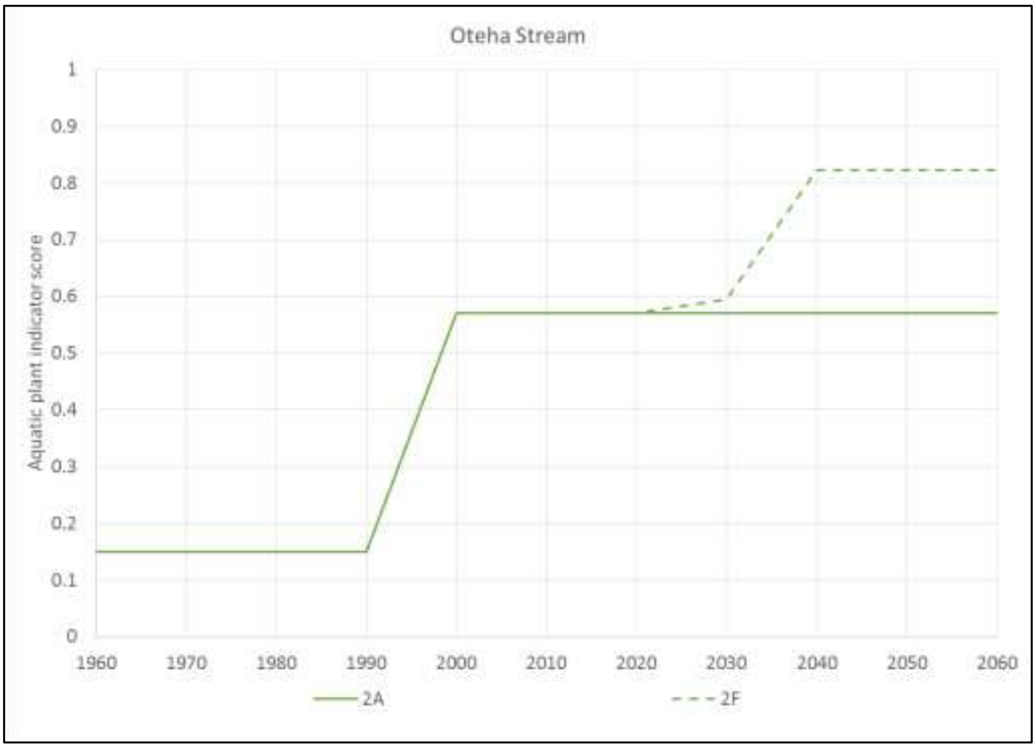


Figure 0-4: Predicted aquatic plants indicator scores for urban development Scenario 2, with *status quo* contaminant controls and with (2A) and without (2F) riparian planting, Lucas Stream (upper) and Oteha Stream (lower).