Auckland Unitary Plan stormwater management provisions: Technical basis of contaminant and volume management requirements

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Executive Summary

The Auckland Council has developed the Auckland Unitary Plan (the Unitary Plan) to help shape the way Auckland grows. The Unitary Plan will replace the Auckland Regional Policy Statement (ARPS) and the 12 existing district and regional plans (legacy plans), many of which are already more than 10 years old.

It has long been recognised that stormwater runoff is a predominant contributor to water quality and stream and coastal ecosystem health in Auckland. As a result, stormwater management has been a significant component of the approach to managing fresh and marine waters in the operative ARPS and the Auckland Regional Plan: Air, Land and Water (ALW Plan) and Auckland Regional Plan: Coastal (Coastal Plan).

The Unitary Plan continues to develop and refine this approach to improve environmental and community outcomes and address gaps in the current approach to stormwater management. In particular the Unitary Plan seeks to better integrate the management of land use and development and associated adverse effects, with a greater focus on the generation and management stormwater at or near-source. This is consistent with the direction provided by the National Policy Statement for Freshwater Management 2011 (NPSFM), the New Zealand Coastal Policy Statement 2010 (NZCPS) and the Auckland Plan.

As part of development of this broader approach, Auckland Council has also reconsidered the performance requirements for the management of stormwater contaminant and flows that is currently required by the legacy plans and current practice. The reconsideration of stormwater contaminant management has stemmed from concerns that the current performance requirement for stormwater quality, generally 75 % removal of total suspended solids (TSS), does not adequately address the contaminants of concern (which may not be sediment) from an activity. Also the specification of a removal percentage does not guarantee the effluent quality from a device (as this is dependent on influent quality).

The assessment identifies the main stormwater contaminants and the extent to which they are of concern in Auckland in terms of their effects on water quality and their accumulation in receiving environments. The contaminant yields from a variety of land use activities are identified, based on stormwater sampling and modelling that has been undertaken in Auckland. Those that have relatively high yields have been identified as High Contaminant Generating Activities (HCGAs). These yields are then compared to the results of an assessment of the performance of a range of best management practices (BMPs), using both local and international information, to derive the land use activities to which stormwater treatment BMPs should be applied to reduce contaminant concentrations and loads.

Design effluent quality requirements (DEQRs) have been derived based on the performance that can reliably be expected from the suite of BMPs that are currently regarded as best practice. That is, the design performance has been established on the basis of properly sized and designed devices. The assessment has also identified those devices that are able to achieve "enhanced treatment", which is an effluent quality that is better than the DEQR. While adopting enhanced treatment is not a requirement of the Unitary Plan there may be circumstances, particularly in greenfield development draining to sensitive receiving environments, where a higher level of stormwater quality management is warranted.

In respect of flow management, the current practice of managing stormwater flows through peak flow control (typically 2, 10, and 100 year events) and extended detention does not reduce stormwater volumes. Instead, the flatter runoff hydrographs resulting from this approach extend the duration at which "erosive" flows occur and this may result in increased erosion of sensitive streams.

There are two aspects of flow management that are considered in the report. The first assesses the requirements for hydrology mitigation having regard to the aims and benefits of mitigation and the restoration of more natural hydrologic processes, the current approach of managing peak flows, an extensive review of international approaches to flow management and an assessment of rainfall and runoff characteristics in Auckland.

This leads to the derivation of hydrology mitigation requirements that incorporate both detention (peak flow attenuation) for the 95th percentile, 24 hr storm event runoff volume and retention (reduced volume) of 10 mm of the design event. The report concludes that this approach will mitigate the adverse hydrologic effects of development such as reduced infiltration and increased surface runoff more successfully than the current approach to peak flow management.

An assessment of the implementation of the retention and detention requirements concludes that the required performance can be met using standard TP10 designs with some minor modification, although some commonly used devices such as ponds and wetlands are unable to meet retention (volume loss) requirements. Importantly, volume loss can be achieved for a single site redevelopment and enable small developments to mitigate the effects of their development where previously mitigation was not possible. Volume reduction is a good fit for intensification expected through implementation of the Unitary Plan. Large greenfield development will go through more extensive structure planning processes to derive a comprehensive and integrated approach to stormwater management.

The second aspect of hydrology management is the identification of streams and their associated sub-catchments that are particularly susceptible to the adverse effects of increased stormwater runoff, in which hydrology mitigation requirements are necessary to prevent further degradation of the stream and its values.

This involved the application of three primary criteria for determining stream sensitivity to increased stormwater flows (slope, catchment imperviousness and Macroinvertebate Community Index score), which were then applied to the catchments within the Rural Urban Boundary (RUB) to derive a consolidated numerical score along the stream and its contributing sub-catchments. The initial score was then "moderated" using a combination of factors and knowledge of the catchments to identify those sub-catchments where hydrology mitigation of impervious surfaces would be beneficial to minimise the adverse effects of further development on the streams.

These areas have been identified in the Unitary Plan in the Stormwater Management Area: Flow (SMAF) Overlay – which is a spatially applied set of requirements for the development and redevelopment of impervious areas. Two classes of SMAF are identified. SMAF1 are those sub-catchments that discharge to streams with high current or potential value that are sensitive to increased stormwater flows and which have relatively low levels of existing impervious area. SMAF2 are those sub-catchments which discharge to streams with moderate to high current and potential values and sensitivity to stormwater flow and with generally higher levels of existing impervious area within the sub-catchment. Different mitigation requirements apply in each of these areas, with more stringent requirements applying in a SMAF1.

The SMAF Overlay has then been mapped and included in the Unitary Plan using a Geographical Information System (GIS).

As a result of this technical review, the following contaminant and flow management requirements are proposed in the Unitary Plan:

1. The application of stormwater contaminant treatment to High Contaminant Generating Activities (HCGAs), which are those land use activities that generate and discharge contaminants at a level where treatment will result in a substantial reduction in contaminant concentration and load. HCGAs are identified as:

    - parking areas, and associated accessways that are exposed to rainfall and carry more than 50 vehicles per day;
    - building roofing, spouting, and external walls cladding and architectural features using materials with an:
        - exposed surface or surface coating of metallic zinc or any alloy containing greater than 10% zinc;
        - exposed surface or surface coating of metallic copper or any alloy containing greater than 10% copper; or
        - exposed treated timber surface or any roof material with a copper-containing or zinc-containing algaecide.
    - high use roads being:
        - A motorway, state highway, regional primary arterial and or district secondary arterial road; or
        - A road that carries more than 10,000 vehicles per day

    But excludes ancillary areas that do not receive stormwater runoff from the high use road.

2. A change in the measure of performance of stormwater treatment devices from percentage removal to a Design Effluent Quality Requirement (DEQR).

3. Broadening the range of indicator contaminants to TSS, metals (copper and zinc) and temperature, for which DEQR must be met depending on the nature of the receiving environment into which they discharge.

    Contaminants of Concern and their DEQRs are as follows:

Receiving Environment	Land Use Activity		
	Road, carpark	Roofing	Industrial Sites Activity Area
River or Stream	S, M, T	M, T	Appropriate to nature of activities, contaminants and receiving environments
All others	S, M	M	

S = sediment, M = metals, T = temperature

Symbol	Name	Design Effluent Quality Requirement
S	Sediment	TSS < 20 mg/L
M	Metals	T Cu < 10 µg/L, T Zn < 30 µg/L
T	Temperature	Temperature < 25°C

4. A requirement for the mitigation of runoff that requires both retention (volume reduction) and detention (peak flow reduction) for discharge in SMAF areas as follows:

Area	Stormwater mitigation	Flow/volume mitigation requirement
SMAF 1	Level 1 hydrology mitigation	• provide detention (temporary storage) with a volume equal to the runoff volume from the 95th percentile, 24 hr rainfall event for the impervious area for which hydrology mitigation is required; and • provide retention (volume reduction) of a 10mm, 24 hr rainfall event for the impervious area for which hydrology mitigation is required
SMAF 2	Level 2 hydrology mitigation	• provide detention (temporary storage) with a volume equal to the runoff volume from the 90th percentile, 24 hr rainfall event for the impervious area for which hydrology mitigation is required; and • provide retention (volume reduction) of a 8mm, 24 hr rainfall event for the impervious area for which hydrology mitigation is required

5. The application of hydrology mitigation to sub-catchments of streams that have been identified as being sensitive to increases in stormwater flows. These areas have been mapped and applied in the Unitary Plan as the Stormwater Management Area: Flow (SMAF) Overlay.

It is emphasised that the controls derived in this report are only a part of a wider suite of stormwater management measures. As highlighted in the report, integrated approaches such as Water Sensitive Design are also important to minimise the effects of growth and development of freshwater systems and coastal waters.

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1.0 Background

1.1 Introduction

The Auckland Council has developed the Auckland Unitary Plan (the Unitary Plan) to help shape the way Auckland grows to accommodate the predicted growth of 1 million people over the next 30 years and associated commercial activity. The Unitary Plan sets out what can be built and where, seeking to create a higher quality and more compact Auckland while providing for rural activities and maintaining the marine environment. With proper planning and quality development, that growth can be used to make the region stronger, prouder and more vibrant and even better.

The Unitary Plan will replace the Auckland Regional Policy Statement (ARPS) and the 12 existing district and regional plans (legacy plans), many of which are already more than 10 years old. Currently these are primary tools for managing land use activities and development and associated stormwater discharges to ensure that adverse effects are appropriately avoided, remedied or mitigated within the legislative framework of the Resource Management Act 1991 (RMA).

It has long been recognised that stormwater runoff is the predominant contributor to water quality and stream structure and health in urban areas. Given the nature and value of Auckland's aquatic environment, stormwater management has been a significant component of the approach to managing fresh and marine waters in the operative ARPS and regional plans: Auckland Regional Plan: Air, Land and Water (ALW Plan) and Auckland Regional Plan: Coastal (Coastal Plan)).

The Unitary Plan continues to develop and refine this approach to improve environmental and community outcomes and address existing gaps in the stormwater management approach, particularly in respect of integrating and aligning land use and the generation of stormwater and its subsequent discharge. The Unitary Plan provides both the opportunity and the need to review the land use and discharge provisions to develop a consistent approach across the region and therefore includes a suite of provisions that seek to provide a comprehensive approach to land development and stormwater management.

1.2 Purpose of this report

The purpose of this report is to outline the key aspects of the stormwater management approach in the Unitary Plan and to provide the technical and scientific evidence base and requirements to support the provisions that have been developed in relation to land use controls that manage stormwater contaminants and stormwater volume/flow. These land use controls are a part of a broader suite of stormwater management provisions within the Unitary Plan. However, they are the specific focus of this report as:

1. They are new requirements that change the approach to managing stormwater contaminants and flows and the report provides the reasons and technical basis for this change;
2. They require some technical explanation to assist in their implementation.

This report is not an assessment prepared in accordance with s32 of the RMA – it is focussed on the technical aspects of the stormwater contaminant and volume/flow requirements and their derivation. However, it should be read in conjunction with the Unitary Plan s32 assessment, which summarises the planning process, assessment of options and provides and analysis of objectives, policies and rules and an assessment of the costs and benefits of the proposed statutory approach.

1.3 Report structure

This report is structured as follows:

Section 1:	This introduction.
Section 2:	Provides an overview of the freshwater and stormwater management approach in the Unitary Plan and presents a more detailed summary of the provisions in respect of stormwater contaminant and flow/volume management.
Section 3:	Outlines the key stormwater issues in relation to the adverse effects of land use development and stormwater discharges on the natural environment, with an emphasis on contaminants and flow effects.
Section 4:	Outlines the basis and technical requirement for contaminant management in the Stormwater Management - Quality rules in the Unitary Plan.
Section 5:	Outlines the basis and technical requirements for volume/flow management in the Stormwater Management - Flow rules in the Unitary Plan.
Section 6:	Provides the methodology for determining the location and spatial extent of the Stormwater Management Areas: Flow (SMAF) overlay in the Unitary Plan.

2.0 Overview of Unitary Plan provisions

2.1 Introduction

The Unitary Plan contains a suite of provisions that have relevance to stormwater management – ranging from high level objectives and policies relating to freshwater systems and water quality to specific rules relating to stormwater contaminant and volume/flow management.

The purpose of this section is to outline the overarching framework for freshwater and stormwater management in the Unitary Plan and to detail the specific requirements for the stormwater contaminant and volume/flow rules. The following sections of this report provide the technical basis for, and explanation of, the contaminant and volume/flow requirements.

2.1.1 Legislative and strategic guidance

The Unitary Plan approach to stormwater management has been guided by both legislation and national and regional policy/strategy documents, including the:

- RMA and documents prepared under it:
    - National Policy Statement – Freshwater Management 2011;
    - New Zealand Coastal Policy Statement 2010;
- Hauraki Gulf Marine Park Act 2000; and
- Auckland Plan.

The direction and guidance provided by these, and other documents, is discussed in more detail in the Unitary Plan Section 32 Assessment: Urban Stormwater section. In achieving the sustainable management purpose of the RMA, the key themes directing stormwater management are:

- Protecting water quality and ecosystems where they good or have high values;
- Enhancing water quality where it is degraded or is having significant adverse effects on ecosystems or other values;
- Sustaining/safeguarding the life-supporting capacity of ecosystems;
- Integrated management of natural and physical resources through the management of land use activities; and
- Providing for future growth in a way that achieves both community and natural environment objectives, with a transformational shift to green growth and the implementation of water sensitive design on new and redevelopment.

2.2 Unitary Plan structure

The Unitary Plan has several tiers of provisions including:

1. Regional Policy Statement objectives and policies;
2. Region-wide objectives, policies and rules. These include district and regional plan provisions that apply across the region;

3. Zone objectives, policies and rules. These include district and regional plan provisions that apply to land use types/activities in the relevant zones across the region;
4. Overlay objectives and policies. These are district and regional provisions that apply to specific spatial (mapped) areas.
5. Precinct objectives, policies and rules. These provisions apply to local areas, typically structure plan and legacy plan change growth areas.
6. Special Areas objectives policies and rules. These apply to special land use areas.

The sections below present a summary of the RPS and region-wide objectives and policies that are relevant to stormwater management, followed by a more detailed discussion of the stormwater contaminant and volume management rules.   It is not a full discussion or description of the provisions. Appendix A indicates where the provisons that are most relevant for stormwater quality and flow can be found in the Unitary Plan. These provisions are also likely to be subject to change as the Unitary Plan advances through the statutory process following notification.

2.3 Overarching provisions

The stormwater contaminant and volume/flow management rules are components of a broader stormwater, freshwater and coastal management framework established in the Unitary Plan RPS and Auckland-wide policies.

2.3.1 Regional Policy Statement (RPS)

The key RPS and Region wide objectives and policies that relate to stormwater management are referenced in Appendix A.

The RPS objectives of most relevance to stormwater management seek to:

1. Safeguard natural, social, economic and cultural values when land and freshwater are used and developed;
2. Maintain freshwater quality and the values of freshwater systems, and enhance them where they are degraded;
3. Minimise the adverse effects of stormwater runoff and progressively reduce existing adverse effects; and
4. Recognise Mana Whenua values, mātauranga and tikanga associated with freshwater.

This is achieved through a range of policies including:

Integrated management of land use and freshwater: Integrate the management of land use development, including redevelopment, and freshwater systems by:

- ensuring stormwater (and other) infrastructure is adequately provided for in areas of new growth or intensification;
- requiring comprehensive and integrated land use and water management planning processes and the adoption of water sensitive design in greenfield and major redevelopment; and
- controlling the use of land to minimise the adverse effects of stormwater runoff.

Freshwater systems: Manage land use, development and subdivision to:

- avoid the permanent loss of freshwater systems;
- protect and enhance remaining rivers and streams;
- manage stormwater flows to minimise effects on streams and other values; and
- use the opportunities provided by change to restore freshwater values.

Freshwater quality: Manage land use and development, discharges and other activities to:

- avoid adverse effects of land use development on the water quality or biodiversity values in identified natural areas;
- avoid adverse effects on Mana Whenua values;
- prevent or minimise the adverse effects of discharges; and
- use opportunities provided by land use change and development to reduce existing effects.

Urban stormwater: Manage the adverse effects of land use and development, and the discharge of contaminants from stormwater and networks in urban areas by:

- using land use change and redevelopment opportunities to reduce existing adverse effects;
- controlling the extent of impervious surfaces to minimise adverse effects;
- controlling stormwater volumes and runoff from land use development in areas that discharge to rivers and streams that are identified as being susceptible to the adverse effects of increased stormwater flows (SMAFs);
- minimising the generation and discharge of stormwater and contaminants;
- adopting the best practicable option to manage discharges from public stormwater networks.

2.3.2 Auckland-wide

Auckland-wide objectives and policies apply across the region and incorporate both high level objectives and policies for freshwater, together with specific policies for stormwater contaminant and volume/flow management. The coastal zones also provide objectives and policies that relate to stormwater management.

Generally the region-wide provisions provide more specific guidance for the implementation of the RPS objectives and policies. Water quality objectives include:

- Protect areas of high quality and values from degradation and enhance degraded areas (freshwater and coastal);
- Minimise the adverse effects of development on marine and freshwater systems;
- Recognise and provide for the mauri of freshwater and the relationship of Mana Whenua with freshwater and reflect this in management processes and decision making.

In achieving these objectives, the Unitary Plan adopts the Macroinvertebrate Community Index (MCI) as an interim guideline for managing water quality and ecosystem health in freshwater systems. In the coastal marine area, marine sediment quality indicators for common stormwater contaminants have also been adopted.

The relevant polices provide guidance on how adverse effects will be prevented or minimised, in particular:

- Matters to consider when deriving the best practicable option (BPO) for stormwater network (and significant infrastructure) discharges;
- Adopting water sensitive design in new and major redevelopment;
- The circumstances in which stormwater volume and flow will be required to be managed including:
    - within a stormwater management area flow (SMAF);
    - where development exceeds the maximum impervious area for the relevant zone;
    - from areas of impervious surface where discharges may give rise to flooding or adversely affect rivers and streams;
    - in areas that discharge to the combined sewer network.
- The circumstances in which stormwater contaminant management will be required, being:
    - high contaminant generating activities;
    - at the time of development/redevelopment;
    - consideration of measures to limit the generation and discharge of gross pollutants including litter;
- Specific matters to be considered when assessing the extent to which adverse effects from stormwater discharges should be prevented or mitigated;
- Requiring contaminant and volume/flow management to be undertaken on-site, unless there is a communal management device that can meet the same or better level of stormwater management performance.

2.4 Stormwater contaminant management requirements

Stormwater runoff is the most significant contributor to urban water quality and contaminant management has been a primary component of stormwater management in the Auckland region for the past 20 years or more. Over this time, the approach to contaminant management has evolved from an initial focus on end of pipe treatment via ponds to a more holistic approach that incorporates reduction at source (source control), at-source/on-site management and communal ponds, wetlands and other bioretention devices.

The Unitary Plan continues this holistic approach and

- Emphasises the reduction and management of contaminants at source to:
    - Focus management at the primary source of contaminants;
    - Minimise the need to manage large volumes of stormwater at a sub-catchment scale, particularly in existing urban areas where space is limited for large treatment devices;
    - Achieve benefits to streams and other elements of freshwater systems that may not be provided by sub-catchment scale treatment.
- Seeks to reduce existing adverse effects from contaminant discharges, consistent with national guidance and Auckland Plan expectations while reducing costs as far as possible by requiring contaminant reductions/ treatment to be applied *at the time of redevelopment*.

2.4.1 Overview of approach

In accordance with the objective and policy framework described above, stormwater contaminants are managed at three levels:

1. Greenfield development and major redevelopment: with a focus on water sensitive design and green infrastructure and the management of contaminants on site;
2. The management of high contaminant generating land use activities: rules are applied to specific land use activities at the time of development or redevelopment of the impervious/contaminant generating area; and
3. Management of stormwater discharges through discharge rules including those that apply to stormwater network discharges.

This technical document provides the basis for managing contaminants from High Contaminant Generating Areas (HCGAs) and the requirements of the Stormwater Management – Quality rules. The specific requirements of the rules are presented below.

2.4.2 Land use rules: Stormwater quality

The land use rules for stormwater quality apply to activities that are identified as being HCGAs as follows:

- parking areas, and associated accessways that are exposed to rainfall and carry more than 50 vehicles per day;
- building roofing, spouting, and external walls cladding and architectural features using materials with an:
    - exposed surface or surface coating of metallic zinc or any alloy containing greater than 10% zinc;
    - exposed surface or surface coating of metallic copper or any alloy containing greater than 10% copper; or
    - exposed treated timber surface or any roof material with a copper or zinc containing algaecide.
- high use roads being:
    - A motorway, state highway, regional primary arterial and or district secondary arterial road; or
    - A road that carries more than 10,000 vehicles per day

  But excludes ancillary areas that do not receive stormwater runoff from the high use road carriage way.

Industrial sites are also identified as HCGAs. However, these are controlled by the Industrial and Trade Activity provisions of the Unitary Plan.

For the first two categories, the rules follow a similar construct:

1. The use of land for the purpose of a HCGA is permitted up to a threshold area;
2. Above this threshold, the land use is a controlled activity subject to the implementation of measures/devices that are designed to meet contaminant management requirements;
3. Where these requirements are not met for parking areas, the activity becomes a restricted discretionary activity and is assessed against the relevant assessment criteria and objectives and policies of the Unitary Plan;
4. Where these requirements are not met for roofing/cladding, the activity becomes a discretionary activity and is assessed against the relevant objectives and policies of the Unitary Plan.

Due to the management issues and scale associated with high use roads, a different rule construct is used as follows:

1. Land use associated with the development/redevelopment of high use roads (where undertaken by a road controlling authority) is permitted up to a threshold of 5,000 m^2 subject to the provision of stormwater treatment in accordance with the contaminant management requirements;
2. The development/redevelopment of high use roads above 5,000 m^2 is a controlled activity (where undertaken by a road controlling authority) subject to the provision of stormwater treatment in accordance with contaminant management requirements;
3. Where requirements are not met, the activity defaults to a restricted discretionary activity and is assessed against the relevant assessment criteria and objectives and policies of the Unitary Plan.

For all HCGAs, the requirements to treat stormwater contaminants apply to new areas (where the threshold is exceeded) and any existing areas as follows:

1. For parking areas stormwater treatment is applied to the entire site where the development /redevelopment covers more than 50% of the car park area;
2. For roofing/cladding when the total (new and existing) area of HCGA exceeds the threshold;
3. For high use roads, treatment is required for any new areas plus any existing area that is directed to the same discharge point.

2.4.3 Treatment requirements

The provisions in the Unitary Plan propose a different approach to that of the ALW Plan in two key areas:

- Treatment performance expressed as Design Effluent Quality Requirements (DEQR) for several key contaminants; and
- Targeting treatment requirements based on contaminants of concern and receiving environment sensitivity.

This approach replaces the use of the single 75% Total Suspended Solids (TSS) removal required by the ALW Plan and enables contaminant management to be better aligned to contaminants of concern and the receiving environment. This change in approach to treatment device performance, together with the basis for the DEQRs, is discussed in Section 4.

Additional guidance is being prepared that identifies the type of devices that are suitable for achieving the effluent standards. As indicated in Section 4, most existing stormwater treatment devices meet the DEQRs in most circumstances.

Proposed DEQRs in the Unitary Plan are provided in Table 1 and Table 2:

Table 1. Stormwater device Design Effluent Quality Requirements

Symbol	Name	Design Effluent Quality Requirement
S	Sediment	TSS < 20 mg/L
M	Metals	T Cu < 10 µg/L, T Zn < 30 µg/L
T	Temperature	Temperature < 25°C

S = sediment, M = metals, T = temperature

Table 2. Stormwater contaminants of concern

<table>
<tr><th rowspan="2">Receiving environment</th><th colspan="3">Land use activity</th></tr>
<tr><th>Road, carpark</th><th>Roofing</th><th>Industrial sites activity area</th></tr>
<tr><td>River or stream</td><td>S, M, T</td><td>M, T</td><td rowspan="2">Appropriate to nature of activities, contaminants and receiving environments</td></tr>
<tr><td>All others</td><td>S, M</td><td>M</td></tr>
</table>

S = sediment, M = metals, T = temperature

2.5 Stormwater hydrology management

The loss of natural water systems and the degradation of their values, particularly streams, are highlighted in the Unitary Plan as significant issues. The introduction of impervious surfaces into a catchment, unless mitigated, significantly increases stormwater volumes and flows and can have a profound effect on the physical structure, ecosystem health and functioning of freshwater systems.

Past development has resulted in both the physical loss (infilling/piping) and significant modification (such as straightening, channelising, introduction of structures, loss of riparian vegetation) of streams in the urban area. This significantly reduces the ability of a stream to support healthy, diverse aquatic ecosystems. In these circumstances, stream management is often focussed on minimising erosion and enhancing community and amenity values of watercourses.

However in areas where stream values and functioning have not been significantly compromised by past development there is an opportunity to manage streams to support multiple values, including healthy in-stream ecosystems and community and Mana Whenua values. This will primarily be achieved by managing land use (particularly impervious areas) and stormwater runoff to reduce hydrological effects.

Management of imperviousness is also required to ensure the efficient functioning of the reticulated stormwater network, to minimise flood risks and, in some older parts of Auckland, to avoid increasing combined sewer overflows.

2.5.1 Application of hydrology management

Stormwater volumes/flows from land use development are managed in five primary ways in the Unitary Plan:

- Water sensitive design applied to greenfield development and major redevelopment;
- Hydrology mitigation in areas identified as high sensitivity/value (SMAF overlays);
- Impervious area/flow management in areas draining to the combined sewer system;
- The control of impervious surfaces and runoff volumes in areas outside of the SMAFs/ combined sewer areas (through maximum impervious areas in zones); and
- The control of discharges from large impervious areas direct to receiving environments or from the public stormwater network.

In order to provide an overview of the range of stormwater volume/flow requirements, these approaches are discussed below. However the focus of this discussion, and the technical information in Sections 5 and 6, is on the development of the hydrology mitigation requirements for SMAF areas.

2.5.1.1 Greenfield areas / major redevelopment

The primary stormwater management focus for new (and re-) development is the adoption of water sensitive design and the retention of natural hydrology and the elements of natural water systems, in accordance with the regional objectives and policies.

It is anticipated that these requirements will be applied through integrated land use/stormwater management planning during structure planning, framework planning and subsequent plan changes and land use, subdivision and stormwater discharge resource consents.

Importantly, stormwater management policy sets an expectation that stormwater runoff in greenfields areas draining to streams will be managed to achieve hydrological mitigation equivalent to that required in a SMAF1; applying both on-site and communal solutions appropriate for the area and development anticipated.

2.5.1.2 SMAF areas

Stormwater Management Area: Flow (SMAF) areas are those (sub) catchments, within the RUB (i.e. urban), draining to streams that have been identified as being sensitive to increases in stormwater flows and which have values (or potential values) that can be protected or enhanced through the management of stormwater volumes. Rural land uses are managed through maximum impervious area rules for rural zones.

The SMAF areas have been mapped and are applied as spatial overlays in the Unitary Plan. Specific hydrology controls apply within the SMAF overlay area.

Section 6 details the methodology used to determine and classify the SMAF1 and 2 areas. However, in general, SMAF1 areas are those catchments which discharge to sensitive or high value streams that have relatively low levels of existing impervious area, while SMAF2 areas typically discharge to streams with moderate to high values and sensitivity to stormwater, but generally with higher levels of existing impervious area within the catchment.

The hydrology controls are applied through land use rules that are triggered with the development or redevelopment of impervious surfaces within the SMAF areas. The approach of the rules is summarised as follows:

- The development or redevelopment of minor impervious areas (up to 25 m^2) is allowed as a permitted activity without any requirement to mitigate stormwater runoff.
- Development or redevelopment of impervious areas in excess of this threshold is required to manage runoff from the impervious surface to meet the following:

Table 3. SMAF hydrology requirements

Area	Stormwater mitigation	Flow/volume mitigation requirement
SMAF 1	Level 1 hydrology mitigation	• provide detention (temporary storage) with a volume equal to the runoff volume from the 95th percentile, 24 hr rainfall event for the impervious area for which hydrology mitigation is required; and • provide retention (volume reduction) of a 10 mm, 24 hr rainfall event for the impervious area for which hydrology mitigation is required
SMAF 2	Level 2 hydrology mitigation	• provide detention (temporary storage) with a volume equal to the runoff volume from the 90th percentile, 24 hr rainfall event for the impervious area for which hydrology mitigation is required; and • provide retention (volume reduction) of a 8 mm, 24 hr rainfall event for the impervious area for which hydrology mitigation is required

Section 5 outlines the basis for managing stormwater volume in preference to flow rate and the hydrology mitigation requirements.

- If the required level of hydrology mitigation is met then the development is assessed as a controlled activity under the Unitary Plan.
- The SMAF rules establish a threshold of 50% development / redevelopment. Below this threshold (that is, if less than 50% of the site is developed / redeveloped) the hydrology mitigation requirements only apply to the new/redeveloped impervious areas. If more than 50% of the site is developed / redeveloped, then the hydrology mitigation is applied to the entire impervious area to progressively reduce existing flows/volumes and associated adverse effects.
- Where the required hydrology mitigation is not met the development / redevelopment of the impervious area defaults to a restricted discretionary activity and is assessed against the relevant assessment criteria and objectives and policies of the Unitary Plan

The SMAF controls also apply to roads operated by a road controlling authority. However, a different rule regime applies:

- Development / redevelopment of an impervious area of up to 1,000 m^2 is allowed as a permitted activity, subject to meeting the hydrology mitigation requirement.
- Development / redevelopment of an impervious area of between 1,000 and 5,000 m^2 is allowed as a controlled activity, subject to meeting the hydrology mitigation requirement.
- The land use defaults to a restricted discretionary activity where hydrology mitigation requirement is not met and is assessed against the relevant assessment criteria and objectives and policies of the Unitary Plan.

The SMAF controls apply irrespective of zone maximum impervious area limits and apply to all activities within the SMAF.

2.5.1.3 Combined sewer areas

The addition of impervious area in those parts of the city that are serviced by a combined sewer network directly contributes to increased overflows from this network. Accordingly, the Unitary Plan imposes controls on the development of new impervious areas that drain to the combined sewer network.

Due to the complexity of the combined sewer system and the difficulty in specifically identifying what areas drain to it, these controls are not applied by way of a map spatial overlay. Instead, a non-statutory, indicative map of the combined sewer area will be used to identify sites that have the potential to drain to the combined sewer network and sites will be assessed on a case by case basis. Development (or redevelopment) of sites what drain to the combined sewer network is a permitted activity if they achieve the same runoff characteristics to that which existed prior to development (or redevelopment). A discretionary activity resource consent is required if the permitted activity requirements cannot be met.

The Unitary Plan does not include any “clawback” provisions for stormwater flows draining to the combined system as Watercare Services Limited has indicated that it is satisfied that its existing controls and processes are sufficient.

This approach is included for completeness and is not discussed in the following sections.

2.5.1.4 Maximum impervious area requirements for zones

Stormwater controls are applied to development by way of a maximum impervious area for some zones.

The rule framework is as follows:

- Some zones (for example residential and most rural zones) include maximum impervious areas as part of the zone development controls;
- Where this maximum is not exceeded, sites are not required to implement measures to reduce stormwater volumes/flows (although large areas of impervious surface may be subject to controls in accordance to discharge provisions);
- Where the maximum impervious area is exceeded, then the development of the additional impervious areas is assessed as a restricted discretionary activity against the relevant assessment criteria and the objectives and policies of the Unitary Plan (including consideration of the capacity of the stormwater network, flooding and effects on rivers and streams).

- Rural and open space zones have a low maximum impervious area (10% or 5,000 m^2), which provides mitigation of volumes and flows from impervious areas.

Where sites do not have a connection to the public stormwater network, a maximum of 10% site coverage is permitted. Coverage in excess of this is a controlled or discretionary activity to ensure that a suitable stormwater solution is applied.

2.5.1.5 Stormwater Diversion and Discharge

As currently is the case under the ALW Plan, stormwater diversion and discharge consents are also required for large impervious areas (greater than 1,000 m^2 in urban areas and greater than 5,000 m^2 in rural areas) where these areas do not discharge to a public stormwater network. Resource consents are also required for the diversion and discharge of stormwater from a public stormwater network.

2.6 Summary

In summary, the Unitary Plan contains a significant range of provisions in respect of freshwater and stormwater management, consistent with the importance of stormwater management in Auckland.

The key approaches that are proposed in the Plan are as follows:

- Water sensitive design in new and major redevelopment;
- A focus of stormwater treatment on areas of HCGAs rather than all areas;
- Treatment device performance expressed in terms of indicator contaminants (TSS, Metals and Temperature) instead of a single parameter (TSS);
- The aligning of treatment devices and performance requirements to land use activities, contaminants of concern and receiving environments;
- Hydrology mitigation requiring both retention and detention in preference to peak flow management and extended detention;
- The requirement to apply hydrology mitigation in catchments with sensitive stream environments (SMAFs);
- Controls on maximum impervious area allowed in some zones, with a requirement to mitigate stormwater flows where impervious areas exceed the maximum allowable; and
- The application of contaminant and flow/volume requirements to existing developed areas/entire sites at the time of re-development, subject to more than 50% change/ re-development or other thresholds.

The following sections focus on the stormwater management issues, the technical basis and derivation of the controls and levels of performance for contaminant management and hydrology mitigation.

3.0 Regional stormwater management issues

This section provides a summary of stormwater management issues, within the Auckland context.

3.1 Contaminants

In a natural, forested catchment, a significant proportion of the rainfall is ultimately lost through either evapotranspiration into the atmosphere or infiltration into the soil, and only larger events give rise to surface runoff. The low volumes of runoff that are generated tend to flow at relatively low velocities over surfaces with high roughness. In doing so, they entrain a small amount of predominantly organic and soil-derived sediment and this is transported by natural watercourses to freshwater and marine receiving environments where it contributes to benthic sediments. Relatively low loads of nutrients and very low loads of metals are transported with this sediment.

When a forested catchment is converted to pasture, runoff volumes and velocities can be expected to increase, and this results in an increased sediment load. Nutrient discharges will also increase somewhat, but loads of metals typically remain low.

When land use is converted to urban, the increase in imperviousness gives rise to a significant change in the quantity and quality of the runoff. Increased volumes of stormwater and increased velocities tend to entrain more contaminants in the water column. In addition, human activities tend to change the nature of the contaminants.

3.1.1 Sediment

Stormwater typically carries with it a range of solids. They range from micrometre diameter soil particles through to gravel, twigs and leaves, litter etc. The finer particles comprise the suspended solids and are discussed further here. Larger particles, and other solids such as plant detritus, are described as settleable solids and gross solids, respectively. The latter are discussed separately, below. The point at which a solid is considered to be sediment or a gross pollutant is dependent on size, a working definition for the Auckland region is that sediment includes all solids less than 5 mm diameter (Davis & Moores, 2013).

Sediment can be further divided according to its size. Solids that will pass through a 2 µm sieve are classified as dissolved, and include fine clays, colloids, and bacteria and viruses. Fine solids comprise the size range of 2 to 250 µm, and include coarser clays, silt, fine sand and organic fines. Coarse solids are those between 250 µm and 5 mm, and include coarse sand and gravel (Davis & Moores, 2013) (Roesner, Pruden, & Kidner, 2007). These particle size distribution (PSD) ranges are summarized in Figure 1.

The size of the sediment has several implications for stormwater management. Firstly, the most effective removal mechanism differs for each size range – coarser particles can be removed through settling and screening, finer particles require other means of removal, such as filtration, adhesion or coagulation. Secondly, whilst all sediment may have other contaminants associated with them, finer solids have a higher proportion of other contaminants as their small size and high surface area offers greater physico-chemical properties such as cation exchange capacity, which can bind other contaminants. Thirdly, the size and density of the particles affects their location in the water column, and this and other factors makes representative sampling of storm water sediment somewhat challenging (Davis & Moores, 2013).

Both rural and urban stormwater contains sediment. A major factor that distinguishes urban sediment is the range and concentration of other contaminants that are associated with it. Urban sediments include soil, drain sediments, and eroding roading material, and include contaminants washed off buildings and roads, including the products of vehicle wear (Griffiths & Timperley, 2005) (Williamson B. , 1993).

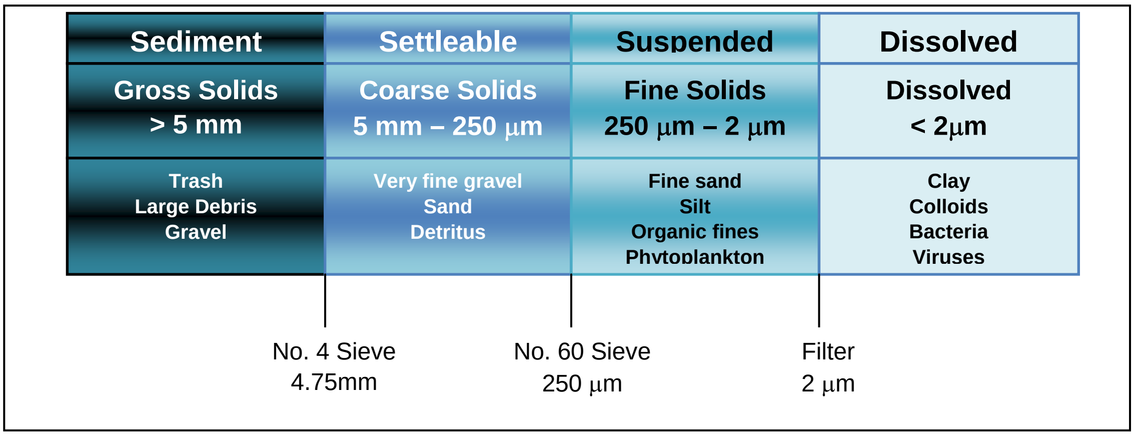


Figure 1. Particle size distribution ranges. Modified from solids size classification diagram (Roesner, Pruden, & Kidner, 2007).

One of the greatest impacts of urbanisation on receiving waters is sediment eroded from soils during construction. The typical greenfield development practice of stripping vegetation and topsoil, and recontouring the land increases the potential for erosion and sediment deposition into waterways. The main factors influencing sediment yield under these conditions is catchment size and rainfall (Williamson B. , 1993). Large scale earthworks pose a risk of major sediment deposition events, and require effective erosion and sediment management to reduce risk. However, evidence is increasing that the development (or brownfield re-development) of individual small lots (small site development) can cumulatively cause significant sediment discharge also.

The yield of sediment from development decreases as the catchment becomes more fully developed with increasing percentage of impervious area. However, in mature urban areas, sediment continues to be generated from pervious areas (lawns, gardens and parks), and from vehicle and road surface wear.

Inorganic material makes up a substantial portion of road dust (up to 60%). Most of this is fairly coarse, 80 -90% is >1mm. The low proportion of fines in road dust compared to storm water (up to 70% is >63 μm diameter) suggests much of the road dust is not transported through the storm water system into streams (Mills & Williamson, 2008).

Another major source of sediment is stream bank and bed erosion. The changes in hydrology that occur with urbanisation increase runoff frequency, velocity and volume cause erodible material in the stream to be mobilised, enlarging the stream channel (Williamson B. , 1993). In fact, sediment from stream channel erosion in urban areas can be the single greatest source of catchment sediment yield (Huang, 2012).

The discussion below relates to the effects of sediment as a contaminant in its own right. In addition to these effects, there are additional effects of contaminants that adsorb onto sediment, including metals, nutrients, hydrocarbons, and other toxic chemicals.

Sediment loads in fresh and marine waters can cause adverse effects. In fresh water, the accumulation of fine sediment on stream beds may reduce the abundance and diversity of invertebrates. Many New Zealand fish species appear superficially unaffected by sublethal turbidity levels, however evidence is increasing that some species show reduced feeding levels or avoidance behaviour at relatively low turbidity levels of >25 Nephelometric Turbidity Units (NTU) (Kelly, 2010). Auckland urban streams (and many rural streams) demonstrate high turbidity and suspended solids concentrations, and low visual clarity, affecting both the aesthetic appeal and ecological function of these streams (Williamson & Mills, 2009). Sediment that deposits in stream beds, fills interstitial spaces, which reduces the opportunity for fish and invertebrates to find refuge from high temperatures and predation during low flows. Recent NZ studies using radio tagged fish have demonstrated the importance of interstitial microhabitats to native New Zealand fish species (McEwan & Joy, 2011) (McEwan & Joy, 2013)

Sediment is a major marine contaminant that degrades coastal habitat and is toxic to many marine organisms. In the Auckland region, the most obvious long term impact is the infilling and “muddying” of estuaries, and the associated expansion of mangroves. The expansion of mangroves leads to loss of other habitats and ecological function, including the loss of open sand and mud flat habitat, and changes in benthic community; the loss of roosting habitat for birds that require open sand and mudflats; a potential reduction in the overall quality of fish habitat, as the species diversity is low in a mangrove forest; and provision of habitat for a number of terrestrial invertebrates and reptiles (Kelly, 2010).

Deforestation in the last 150 years and rapid urbanisation in the last 50 years has caused sedimentation in Auckland’s estuaries up to an order of magnitude higher than they were under forest cover. Changes in sediment grain size have consequential effects on porosity, stability, biogeochemical fluxes, rates of faunal movement, and bioturbation. Most benthic organisms prefer a particular sediment texture, so a change in sediment texture causes a shift towards communities that are adapted to that texture (Kelly, 2010).

Thick, catastrophic deposits of sediment (>20 mm) usually kill almost all bottom-dwelling organisms within a few days. Recovery is slow after catastrophic events, with the recovery of macrofauna lagging behind recovery of chemical and geotechnical properties (Kelly, 2010). Thin sediment deposits (1 – 7 mm) also reduce diversity and abundance of benthic organisms. The number of taxa and individuals has been observed to decline by around 50% within a number of days of sediment deposition (Kelly, 2010).

Sediment can also affect reef communities, preventing larvae and propagules setline, smothering and/or scouring adult and juvenile stages, interfering with foraging and feeding activities, and affecting the growth, fertility, and/or morphology of reef species (Kelly, 2010).

On the basis of the above issues, TSS is identified as a significant contaminant of concern, and the Unitary Plan addresses this by setting a Design Effluent Quality Requirement (DEQR), as outlined in Section 4.

3.1.2 Metals

Metallic solids, containing neutral atoms, are characterized by thermal and electrical conductivity; however, few common metals are stable in this form. Most oxidize (corrode) to form stable positively charged ions (cations). In general, we utilise metals as metallic solids, but ultimately, due to corrosion and wear, they become transported in runoff as particulate or in the dissolved state. Dissolved metals are very often bound to sediments, due to electrostatic attraction with the negative surface charges of clay and soil particles in particular.

The toxicity of heavy metals is linked to the chemical form in which they occur. Metals can be present in a soluble form, or combine with other elements and organic matter to form a range of compounds of varying solubility, bioavailability, and toxicity. In determining environmental effects of metals, it is common to measure a total concentration of a metal, and also a bioavailable form, which is typically taken to be the fraction that is soluble or able to be extracted by a weak acid. Metals in water are distributed between dissolved and particulate phases. The particulate phase comprises metals attached to solids, and particulate metal concentrations relate to suspended sediment concentrations (Griffiths & Timperley, 2005).

Zinc (Zn), copper (Cu) and lead (Pb) have been measured in Auckland stormwater and sediment. These metals have been found to be present in elevated concentrations (discussed further below) and are toxic in their own right. However, they also act as surrogates for elevated concentrations of other metals that are not routinely analysed for and may be present in lower concentrations. Cadmium (Cd), mercury (Hg) antimony (Sb) and tin (Sn) have also been measured in Auckland sediment, and have been found to be strongly correlated to Zn, Cu and Pb concentrations (Mills G. , Williamson, Cameron, & Vaughan, 2012). Arsenic (As) has also been measured in Auckland sediments, but has not demonstrated a correlation with other metals. On this basis it is suggested that it is not primarily derived from stormwater (Mills G. , Williamson, Cameron, & Vaughan, 2012).

Initial work on determining sources of metals in Auckland involved measuring the concentration of Zn, Cu and Pb in stormwater in a residential, commercial and industrial catchment in Auckland, and comparing the measured concentrations to modelled amounts predicted from land uses (Timperley, Williamson, Mills, Horne, & Hasan, 2005). The measured and modelled concentrations did not align well, but provided a starting point for stormwater management and further work. Metal sources and budgets were revisited in an effort to further identify sources of metals and reduce uncertainty (Kennedy & Sutherland, 2008).

Zinc, copper and lead are common metals used in a wide range of materials and products within the urban environment. Through monitoring, it is recognised that the metals content in stormwater varies significantly across urban areas due to a variety of factors, including land use. From literature and observation, the major sources of metals have been identified as atmospheric deposition, vehicles, soil (including contaminated soil), buildings, garden products, road surfaces, water supply loss, and unknown. Residential, commercial and industrial areas have been surveyed for potential sources of metals, and metal budgets revisited. Uncertainties in the metals budgets were redefined, and the proportions of metals from each source recalculated. The results for three Auckland catchments are presented graphically in Figure 2 (zinc) and Figure 3 (copper). The primary sources of zinc are building roofs, vehicle tyre wear and atmospheric deposition (Kennedy & Sutherland, 2008). Primary sources of copper are atmospheric deposition, building material and vehicle brake pads. Primary sources of lead are atmospheric and garden soil – the latter, where soils had been contaminated by vehicle fumes prior to removal of lead from petrol in 1996.

The metals found in Auckland harbour sediments do not all necessarily derive from stormwater. Recently (Gadd & Cameron, 2012), antifouling paint has been revealed as a potential source of copper in Auckland's harbours. Leachate from landfills may also contribute significant quantities of various metals.

Metals sourced from roof runoff are almost 100% dissolved form. Zinc from road runoff is around 50% dissolved form. As dissolved metals move through the stormwater network, they may adhere to suspended sediment and behave more like particulates, with lower bioavailability. The appropriate management for metals in stormwater needs to have regard to the solubility of metals, which can be influenced by the proximity to the source of metals.

Concentrations of Zn, Cu and Pb in urban runoff often exceed receiving water quality criteria designed to protect aquatic life (Williamson B. , 1993). Water quality criteria, e.g. ANZECC guidelines, have a series of concentrations indicating increased potential for adverse effects. Toxicity is usually assessed indirectly by comparing contaminants in water and sediments to guidelines. It is very difficult to provide unequivocal evidence that heavy metals are causing toxic effects in the receiving water (Williamson B. , 1993) (Mills & Williamson, 2008). In part this is due to the co-occurrence of other factors that affect ecological health (Griffiths & Timperley, 2005).

Analysis of suspended solids in the water column and bed sediments of Auckland streams have shown elevated concentrations of Zn and Cu in the water column, such that both short-term acute effects and long-term chronic effects probably occur. Very high concentrations of Zn, Cu and Pb have been found in streambed sediments, suspended sediments and biofilms, at concentrations that are almost certainly toxic to aquatic animals that ingest this material while feeding (Williamson & Mills, 2009).

Marine water quality monitoring undertaken by Council shows general marine water quality is poorest in inner harbour and estuary sites, whereas coastal water quality is relatively good. This monitoring has not specifically targeted the water quality of stormwater discharges, but does assist in determining effects. Monitoring of Zn in the water column in the Whau estuary has been relatively high during low flow conditions. This was not expected, and suggests Zn can desorb from particulate matter in the saline – freshwater zone. Zn concentrations can exceed water quality guidelines in pore water (Williamson & Mills, 2009).

Metal contaminants in marine sediment follow a well-described spatial pattern, with highest concentrations found in the muddy upper reaches of estuaries receiving runoff from older, intensively urbanised catchments, particularly in the Tamaki Estuary and Central Waitemata Harbour. Lowest concentrations are found in rural/forested catchments and open coastal boundaries. Regionally, 41% of sites were in Environmental Response Criteria (ERC) green, 45% amber, and 16% red. Zinc was the metal that most often reached the ERC red concentrations, whilst copper was most frequently in the amber range (Mills G. , Williamson, Cameron, & Vaughan, 2012). Very few sites adjacent to urban areas in the Waitemata harbour achieved green status.

On the basis of the above issues, copper and zinc are identified as significant contaminants of concern, and the Unitary Plan addresses this by setting a DEQR, as outlined in Section 4.

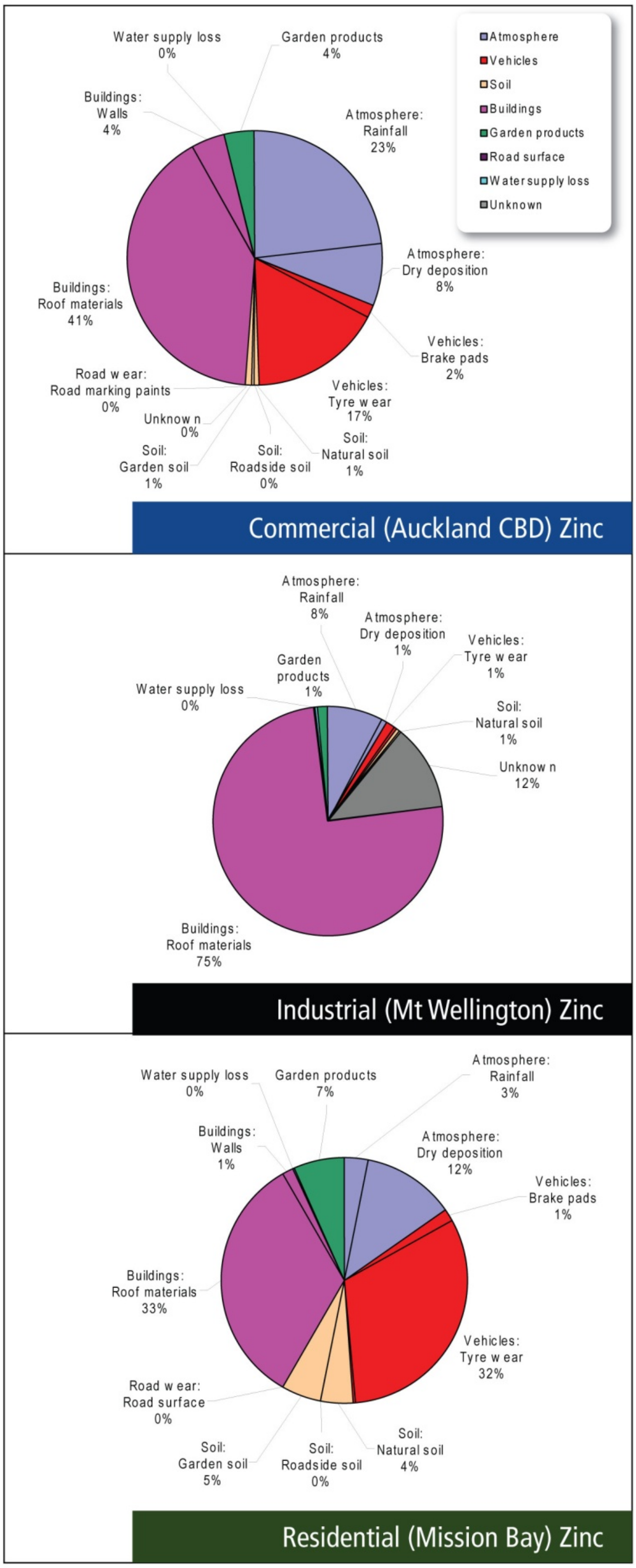


Figure 2. Assessed proportions of sources contributing zinc to stormwater (Kennedy & Sutherland, 2008)

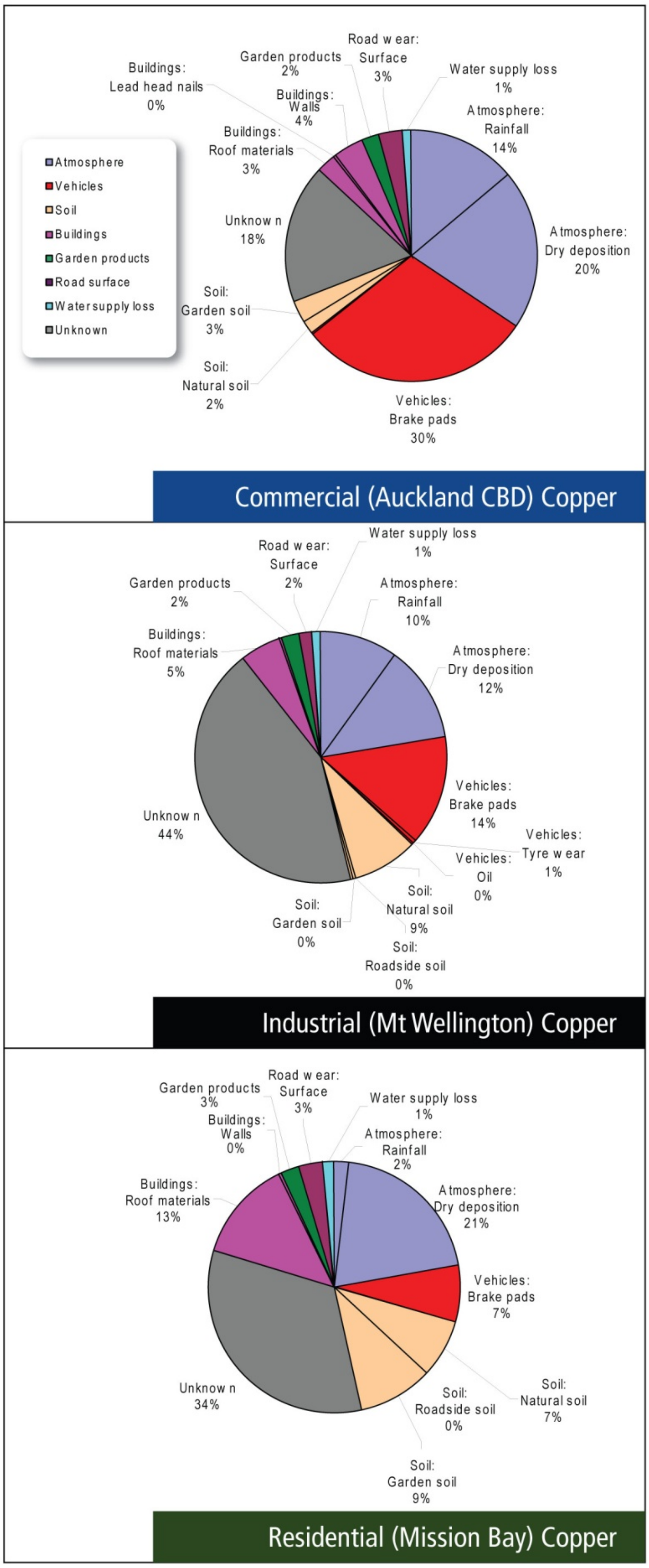


Figure 3. Assessed proportions of sources contributing copper to stormwater (Kennedy & Sutherland, 2008).

3.1.3 Nutrients

The major plant nutrients that are frequently found in stormwater are nitrogen (N) and phosphorus (P).

Nitrogen is found in many forms in the environment, and cycles between different forms. Some plants can take up atmospheric N_2. Once in the terrestrial cycle, N can be found in oxidized (nitrate NO_3^-, nitrite NO_2^-) and reduced (ammonia NH_3 and ammonium NH_4^+), and incorporated into organic material. N moves through different forms as a consequence of biological activity, aerobic state of environment, and pH (ammonia to ammonium in water).

Phosphorus is a highly reactive metal element. Due to its reactivity, it quickly forms phosphate oxides in the environment. These oxides vary in solubility and bioavailability, and P may undergo further reactions with soil particles to become increasingly insoluble. The behaviour of P in the environment is more similar to heavy metals than to N.

Nutrients in the water column are delivered to freshwater bodies in short pulses, and have less effect due to limited time they are present. However, in the urban environment, most of the nutrient load is associated with particulate material, and is only partly or slowly available for plant growth. This particulate material can be deposited in beds of streams, ponds and lakes, and the associated nutrients are then metabolised for plant growth (Griffiths & Timperley, 2005) (Williamson B. , 1993).

Occasional high ammonia concentrations have been recorded in streams, most often associated with wastewater overflows or leakage (Williamson & Mills, 2009).

The major sources of nutrients in the urban environment are fertiliser run-off, sewage overflows, and soil loss. Plant nutrients are present in moderate amounts in storm water. Concentrations are much higher in sewage, and therefore stormwater contaminated by wastewater overflows have considerably higher nutrient concentrations (Mills & Williamson, 2008).

Natural healthy water bodies have a very limited supply of nutrients, this limitation restricts plant and algal growth in the water body. With additional nutrients and other favourable conditions, such as elevated temperature, algae and aquatic weeds may proliferate. This in turn can cause low dissolved oxygen (DO), large diurnal DO changes, benthic anoxia, fish kills, reduced water clarity and reduced aesthetics in the water body (Kelly, 2010) (Williamson B. , 1993).

Urban streams in New Zealand have few reported incidents of eutrophication, however in rural catchments there is increasing concern that eutrophication is occurring (Kelly, 2010). Regional scale trends have shown decreasing nutrient concentrations, although nitrogen still regularly exceeds ANZECC guidelines (Williamson & Mills, 2009). Ponds and lakes present a different scenario. Stormwater ponds and wetlands have been found to produce poor water quality in relation to temperature and dissolved oxygen. Lake Pupuke and Western Springs Lake are the most significant natural freshwater lakes in the Auckland urban region. Monitoring data for Lake Pupuke has indicates that the water quality in the lake has been stable with regard to nutrients since nutrient sources were diverted with the removal of domestic sewage and agricultural discharges to the lake (Mills & Williamson, 2008). Western Springs is a natural wetland fed from the basalt aquifer that lies beneath the Meola catchment, and was modified to form a lake in 1875. Poor water quality in this lake is probably due to a combination of stormwater inputs and wastewater exfiltration into the aquifer, as well as waterfowl in the lake itself.

In extreme situations, anoxia has occurred in the marine area in sheltered inlets e.g. Cox's Creek, due to eutrophication (Kelly, 2010).

In many parts of the world nutrients in stormwater are prime contaminants of concern. In Australia, in particular, the total nitrogen load in stormwater is implicated in marine algal blooms. Many freshwater bodies are prone to algal blooms as a consequence of stormwater-borne phosphorus. Whilst nutrients have been identified as contaminants of concern in certain Auckland water bodies, in general this has been linked to wastewater, rather than stormwater contamination. As such, the Unitary Plan does not set a Design Effluent Quality Requirement (DEQR) for either nitrogen or phosphorus.

3.1.4 Hydrocarbons

Hydrocarbons in this document are intended to address the full range of compounds produced by the petro-chemical industry. Hydrocarbons are commonly divided into groups depending on their molecular weight and use. The lightest non-volatile hydrocarbons are the BTEX group – benzene, toluene, ethylene and xylene. Another common grouping is total petroleum hydrocarbons or TPH – as the name suggests, this is the range found in vehicle fuels. Heavier compounds include lubricating oils and poly-cyclic aromatic hydrocarbons (PAH).

Vehicle exhaust emissions and lubricating oil leaks are considered to be the major sources of TPH in Auckland's urban areas, although point source pollution, including spills, can be a problem in some urban areas. Traffic accidents may result in petrol and oil spills. Some industrial yards may have inadequate treatment to deal with oil-rich storm water from spills and on-site activities (Williamson B. , 1993).

PAHs occur naturally in crude oil and its products, and are also produced by combustion processes eg internal combustion engines (motor vehicles) and fire (Griffiths & Timperley, 2005).

The total amount of hydrocarbons washed off roads is quite large, but is still usually too small to cause acute toxic effects. However, some PAHs which occur in oils are known to be highly toxic to animals, and some are known carcinogens (Griffiths & Timperley, 2005). Lighter hydrocarbons, such as the BTEX and TPH group, frequently volatilize and do not enter storm water, although this is affected by weather conditions at the time of any spill.

As discussed with metals, toxicity in fresh and marine waster and sediments is assessed by comparison to guideline values, and identifying one single contaminant as causing an effect is difficult because of the co-occurrence with other contaminants. As vehicle exhausts are a major source of PAH, it can be inferred that roading runoff will include PAH and other hydrocarbons, as well as metals, that will contribute to toxicity in the receiving environments (Mills & Williamson, 2008).

PAH concentrations in marine sediments are generally below the ERC amber threshold, and are therefore considered unlikely in cause adverse effects on benthic ecology in their own right. However, it is possible that they contribute to cumulative effects associated with the presence of multiple contaminants (Mills G. , Williamson, Cameron, & Vaughan, 2012). Some specific sites do show elevated levels of PAHs. Most of these sites are adjacent to historic landfills, and it is unclear whether these act as point sources for these contaminants.

Hydrocarbons are predominantly found associated with vehicle use, and thus are a contaminant of concern on highly trafficked roads. It is found, however, that hydrocarbons tend to bind to sediment, and that BMPs that are effective at removing TSS, are also generally effective at removing TPH

(Geosyntec and Wright Water Engineers, 2012). For this reason the Unitary Plan does not specify a DEQR for TPH.

3.1.5 Micro-organisms (pathogens)

Micro-organisms in general are ubiquitous, and in many cases necessary to ecological function. A subset of organisms that are pathogens (micro-organisms capable of producing infection or disease) are of concern. In the context of stormwater and receiving water quality, it is the pathogens that are transmitted via faeces that are of the most concern. As pathogens are not always present, depending on the health of the population, it is common to use indicator organisms to detect potential pathogen presence.

Pathogens that are transmitted in water need to enter the body either through the mouth (enteric pathogens), or via another route e.g. a wound (non-enteric pathogens). Human pathogens that may be present in storm water can include enteric viruses such as Polio, Coxsackie, Echoviruses, Hepatitis A, Rotavirus, Adenovirus, and Norwalk Agent. Pathogenic bacteria including E.coli, Salmonella spp., Shingella spp., Campylobacter Jejuni, Yersinia enterocolitica, and protozoa Giardia lamblia, Cryptosporidium spp. and Entamobea histolytica may also occur (Griffiths & Timperley, 2005).

Birds, rodents, cats and dogs are the main source of micro-organisms in stormwater, as their wastes wash into stormwater with every rain event. However, waste water overflows (WWOF) from the municipal sewage network can provide an intermittent, but significant potential source of human pathogens. Poorly operating septic tank systems are another source of pathogens in storm water run-off (Williamson B. , 1993).

A pathogen can only cause a disease in the host if a sufficient number enters the host (the infective dose). Concentrations in storm water are low compared to sewage. Wastewater overflows into streams can increase numbers of pathogens. Urban stormwater represents a moderate risk to human health because of the potential presence of pathogens (Griffiths & Timperley, 2005).

The risk of infection from ingestion of water is relatively low, however food gathered from sewage-contaminated waterways can provide an infection route. Infection from skin contact can also occur, this is a low risk in streams as they are not widely used for contact recreation, but is a definite risk where swimming beaches are contaminated with micro-organisms. This risk is most severe during and immediately after rainfall events, most micro-organisms die off relatively quickly in salt water, but in some storm water systems sewer overflows occur with most rainfall events (Griffiths & Timperley, 2005).As micro-organisms are primarily associated with wastewater, the Unitary Plan does not specify a DEQR.

3.1.6 Temperature

In a natural catchment, the heating effect of solar radiation on the surface is significantly mitigated by the shading and evapotranspiration provided by vegetation. Shading intercepts radiant energy, whilst evapotranspiration removes heat due to the energy required to change the phase of water from a liquid to a gas. As a consequence of these effects, the surfaces of natural catchments are relatively cool. When rain falls, most infiltrates into the soil, where it quickly equilibrates with the groundwater temperatures. The small amount of surface runoff that occurs does not have a significantly elevated temperature. Streams in these catchments have low temperatures because they have high baseflow from low temperature groundwater stores. Typical stream temperatures are in the range of 15 to 20 °C, depending upon degree of shading (Neale, 2012).

In an impervious catchment, the lack of shading and evapotranspiration causes the surface to become significantly hotter. Impervious surfaces, such as asphalt or concrete, may reach temperatures in excess of 45 °C. When rain falls, there is no infiltration and most gives rise to runoff. The temperature of this runoff is elevated due to energy transfer from the hot surface, and the result is a pulse of high temperature stormwater entering streams. During summer the temperature of stormwater from impervious catchments is typically in the range of 20 to 25 °C, even in temperate climates. Where these catchments have stormwater ponds and wetlands for water quality and flow control purposes, stormwater temperatures may become even further elevated. Water temperatures in the range of 25 to 35 °C are routinely recorded downstream of stormwater ponds.

Water temperature is an important factor influencing the health and survival of all aquatic organisms, including native fish, amphibians, and invertebrates, and influences the physicochemistry of streams and other water bodies. Most fish, insects, zooplankton, phytoplankton, and other aquatic organisms that operate in only narrow ranges of temperature can be killed by sudden temperature changes. High water temperatures lower the dissolved oxygen content and this is stressor to most aquatic organisms. Consistently higher stream temperatures can adversely affect growth, reproduction, species competition, and disease progression within aquatic communities. High temperature water may also act as a fish barrier.

On the basis of the above issues, temperature is identified as a significant contaminant of concern, and the Unitary Plan addresses this by setting a DEQR, as outlined in Section 4.0.

3.1.7 Gross pollutants

As discussed above, stormwater solids cover a very wide range of particle sizes and types, and a proposed working definition of gross pollutants is particles greater than 5 mm diameter.

Any particle with a diameter greater than 5 mm is considered to be a gross pollutant. This includes coarse sediment, defined as inorganic particulates, such as sand, fine gravel, and road aggregate. It also includes plant detritus, including leaves, twigs and grass clippings. In the urban environment, the range is significantly expanded with litter or rubbish, defined as human-derived material including paper, plastics, metals, glass and cloth, cigarette butts, and so on. Any material that lands on the road and enters the storm water system, or is blown off the streets or rubbish bins and into receiving waters, can constitute gross pollutants. While all gross pollutants are not 100% human derived, human activities are likely responsible for an exponential increase in pollutants over pre-development conditions (Fitzgerald & Bird, 2010).

Gross pollutants that are sediment-type material (i.e. sand, gravel, and products of road wear) are usually relatively easily captured in catchpits, storm water pipes and ponds. They do carry some other contaminants through adsorption, but the amount is proportionally less than other sediments. Where they enter the receiving environment, they contribute to the effects of urban sediment.

Organic material can represent a biological oxygen demand (BOD), therefore deposition of large quantities (e.g. grass clippings) have the potential to reduce dissolved oxygen as the material decomposes).

Artificial litter or rubbish is prevalent in urban storm water. It presents a major adverse aesthetic effect, and an economic and social cost in reduced aesthetics of streams and beaches and the costs of cleanup. However, in addition to aesthetic effects, litter has significant environmental effects.

Figure 4 and Figure 5 show the composition of gross pollutants and urban litter by mass. Of all litter, plastics are estimated to comprise 60-80% of all marine litter and contribute up to 90–95% of litter in some areas. The ubiquity and volume of plastics, and their persistence in the marine environment makes them particularly problematic. The following issues related to plastics in the marine environment have been identified (Kelly, 2010):

1. Plastic trash fouls beaches, reducing aesthetic values and creating a public health hazard;
2. Plastic entangles marine life and kills by drowning, strangulation, creating drag and reducing feeding efficiency;
3. Plastics that resemble natural food items are often ingested;
4. Plastic pellets and fragments are sources and sinks for xenoestrogens and persistent organic pollutants (POPs) in marine and aquatic environments;
5. Plastics provide an effective vector for the dispersal of invasive species;
6. Plastics that sink to the sea floor have the potential to inhibit gas exchange and interfere with, or smother, the inhabitants of the sediments;
7. Plastic litter can degrade nursery habitats; and.
8. Plastic litter fouls vessel intake ports, keels and propellers, putting crews at risk.

While gross pollutants are an environmental issue of concern, their variable nature and sources are such that the Unitary Plan does not set a DQER for gross pollutants in stormwater.

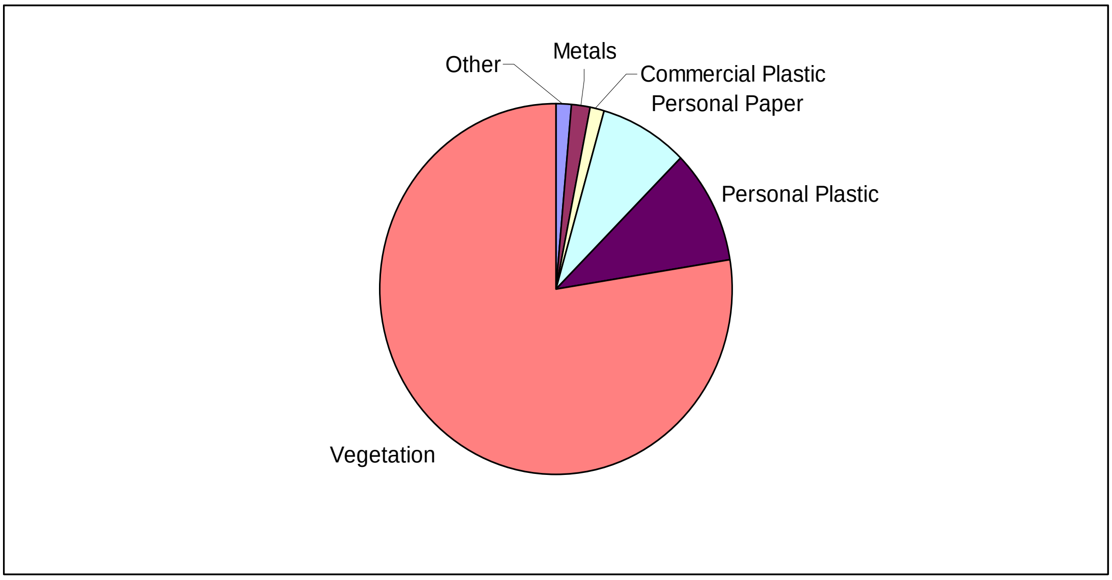


Figure 4. Composition of urban gross pollutants by mass (Fitzgerald & Bird, 2010).

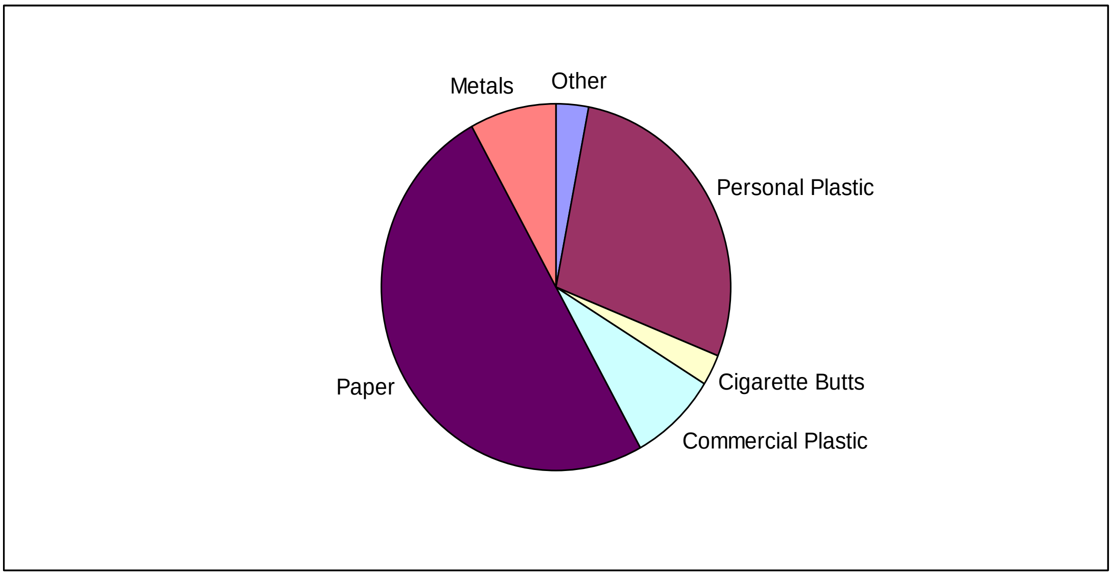


Figure 5. Composition of urban litter by mass (Fitzgerald & Bird, 2010)

3.1.8 Emerging chemicals of concern

Emerging chemicals of concern (ECC) is a name given to a large group of organic chemicals in products that are in day-to-day use that are manufactured or consumed in high volumes. The environmental hazard of these chemicals is emerging over time as more becomes known about their behaviour in the environment (Ahrens, 2008).

ECCs includes classes of products such as plastics, resins and plastic additives (plasticisers, flame retardants), pharmaceuticals and personal care products (e.g. disinfectants, antibiotics, fragrances, sunscreens, drugs, natural and synthetic hormones), detergents and other cleaning agents, various petroleum products, pesticides and biocides (e.g. weed killers, fumigants, wood preservatives, antifouling agents), and compounds derived from wastewater and drinking water treatment, landfills, and incineration (Ahrens, 2008).

The most likely routes of entry of ECCs into the aquatic environment are during use and upon disposal, for example from park and agricultural run-off, sewage treatment plant effluent and sludge, and landfill leachates. Marinas, areas receiving agricultural and residential runoff, water bodies below decommissioned landfill sites, and urban streams downstream of combined wastewater and overflows, are the areas with the greatest likelihood of receiving ECCs (Ahrens, 2008).

Many ECCs have a lower environmental hazard than priority organic pollutants, the latter of which have high environmental persistence, high bioaccumulation, and high acute toxicity. However, ECCs have the potential to cause chronic adverse effects by being neuroactive or acting as hormone mimics, thus disrupting normal endocrine behaviour. In some cases, the compounds the original chemical degrades to in the environment may also be toxic (Ahrens, 2008).

Marine sediments were samples at 13 sites in Auckland and analysed for some major classes of ECCs and included surfactants, flame retardants, plasticisers, oestrogens, antifoulants and pesticides. Sites were selected in both Manukau and Waitemata Harbours, based on likelihood of contamination, and included sites potentially influenced by sewage outfalls, urban storm water runoff, closed landfills, marinas, agricultural runoff, and background.

The list of ECCs was reduced to 35, based on the ability of commercial laboratories to undertake analyses (Stewart, Ahrens, & Olsen, 2009). Finding laboratories with analytical capabilities down to very low detection limits required remains an impediment to ECC monitoring. Several ECCs were detectable in Auckland estuarine sediments, including flame retardants (PBDEs), fungicides and herbicides (dithiocarbamates and glyphosate), plasticisers (phthalates), surfactants (alkylphenols) and estrogens (Stewart, Ahrens, & Olsen, 2009).

It is recommended that monitoring is repeated at intervals (every five or so years) to determine if there are trends in ECC accumulation. Future monitoring should be focused on a smaller subset of ECCs, for which meaningful analytical or biochemical data can be obtained.

At this stage, the Unitary Plan does not set a DQER for ECCs.

3.2 Hydrology

This section discusses the effects of changes to the hydrologic cycle resulting from development on the environment. Measures to mitigate these effects on stream health and the application of these targets to SMAF areas are discussed in section 5.0 and 6.0.

3.2.1 The hydrologic cycle

The need for stormwater management arises primarily from anthropogenic changes to the hydrologic cycle.

The hydrologic cycle is the movement of a finite amount of water around the earth, powered by solar radiation (Figure 6). The physical processes of precipitation, interception, evapotranspiration, infiltration, runoff and groundwater flow transport water in a solid, liquid or gas phase and supports life on earth. The hydrologic cycle maintains the cool surface of the earth through the process of evaporation and is one of the driving forces behind atmospheric circulation.

At the local scale, the hydrologic cycle provides many functions including providing drinking water, cooling urban areas and supporting ecosystems. The water transport processes that relate to stormwater management are shown in Figure 7.

Evapotranspiration includes all process that result in stormwater moving “up” back into the atmosphere. Evapotranspiration processes include evaporation and plant transpiration.

Surface runoff is the movement of water above the ground or in man-made underground conduits. Surface runoff includes all overland flow processes as well as flow in piped systems.

Infiltration is the soakage of water from the surface or man-made underground structures into the unsaturated layer of the ground. Infiltration includes soakage from the ground surface into topsoil layers, soakage out of the base of stormwater Best Management Practices (BMPs) and stormwater disposal direct to base layers via soakpits. Infiltration can happen in reverse when water exits the unsaturated layer and moves above ground, commonly referred to as seepage.

Percolation is the movement of water from the unsaturated layer above the water table into the saturated layer below. The example of stormwater disposal via a soakpit can be considered an infiltration and percolation process if the soakpit extends below the water table. Percolation can happen in reverse when groundwater is drawn above the water table via capillary action or through extraction for drinking water and irrigation.

Interflow occurs when water infiltrates into the ground, travels through the unsaturated layer and then seeps directly into a body of water.

Groundwater flow is the movement of water through the saturated zone below the water table. Groundwater flow encompasses the flow of water underground or the flow of water from saturated zones into a body of water.

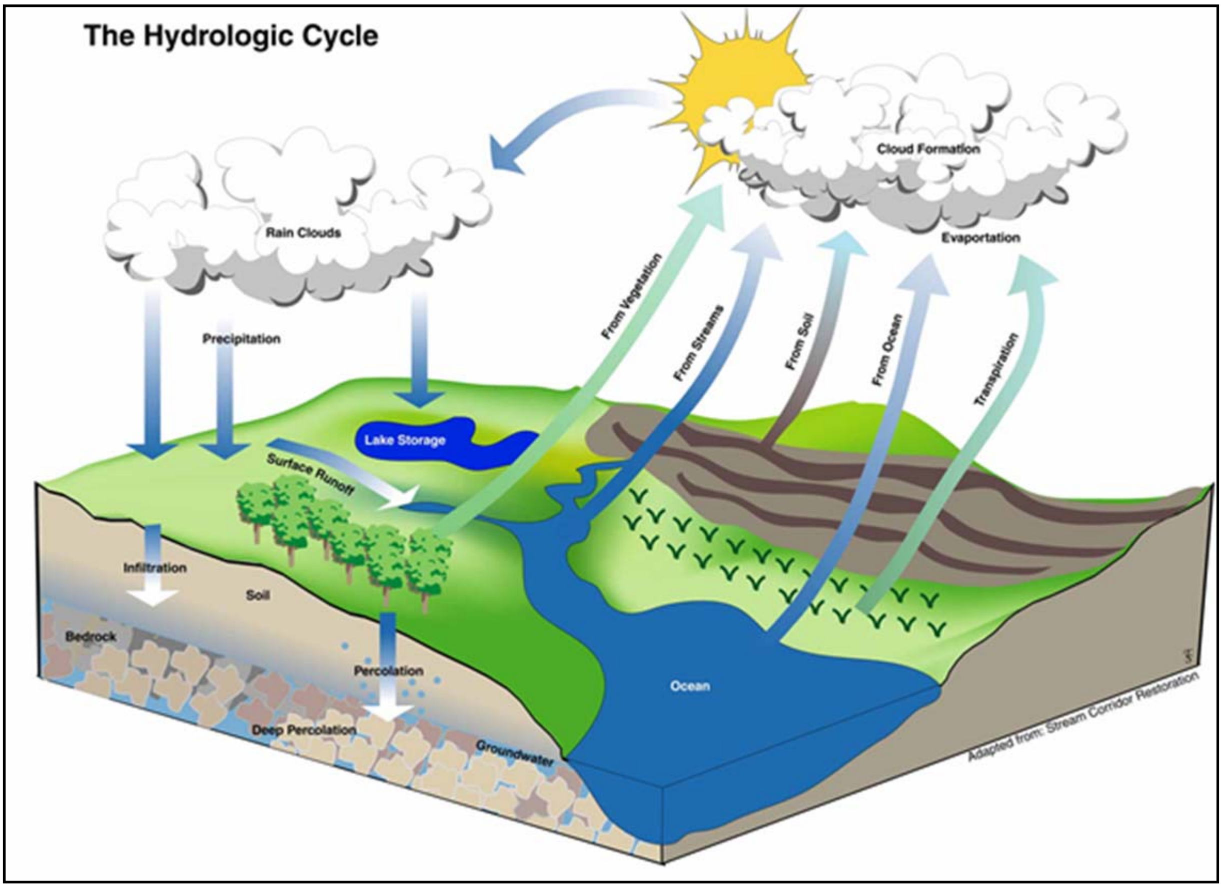


Figure 6. The hydrologic cycle (reproduced from http://www.cet.nau.edu)

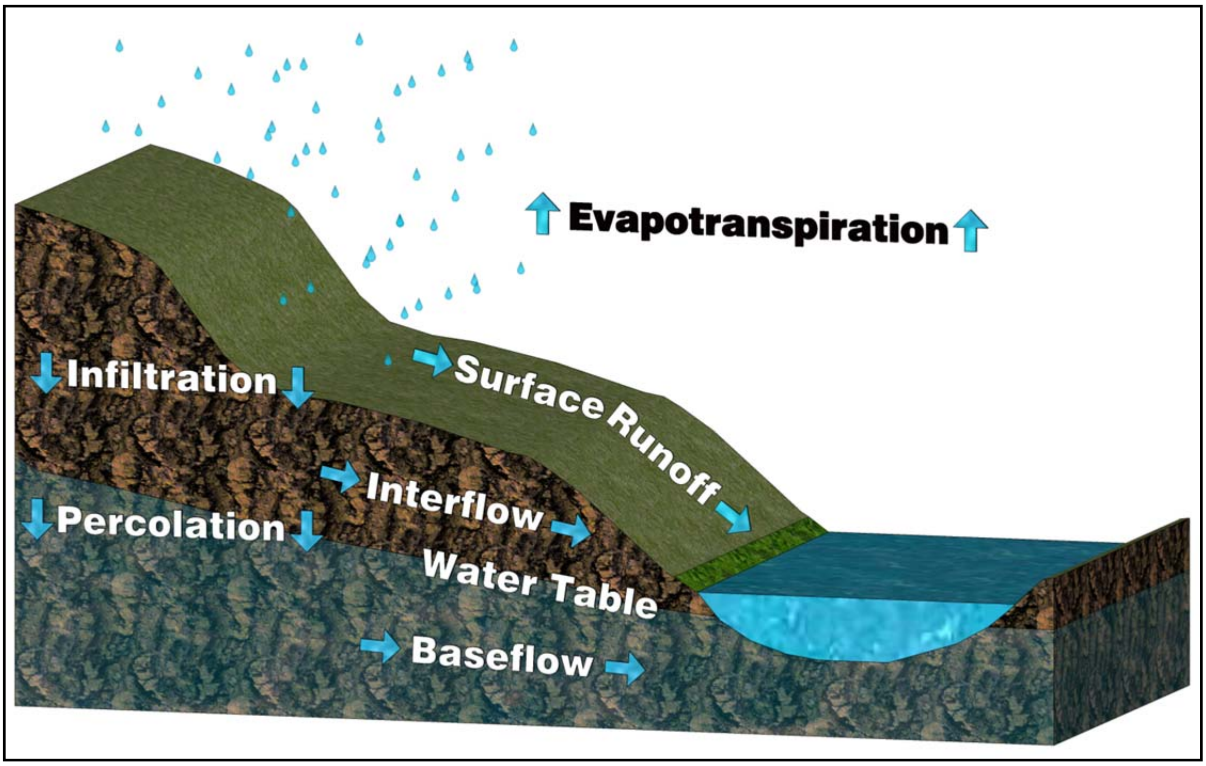


Figure 7. Water transport processes relating to stormwater

3.2.2 Hydrologic effects of development

At its simplest level, development involves the installation of impervious areas in the form of buildings and transportation networks (Prince Georges County Department of Environmental Resources, 1999). Impervious areas provide minimal water storage due to flat, smooth surfaces, and prevent infiltration. Evapotranspiration likewise reduces with reduced surface storage and vegetation, and interception decreases due to the absence of vegetation. When infiltration and evapotranspiration decrease, runoff volumes increase. Figure 8 shows how the proportion of water in the hydrologic cycle processes changes with development. The numbers shown were estimated for non-volcanic soils in the Auckland region in TP10 (Auckland Regional Council, 2003).

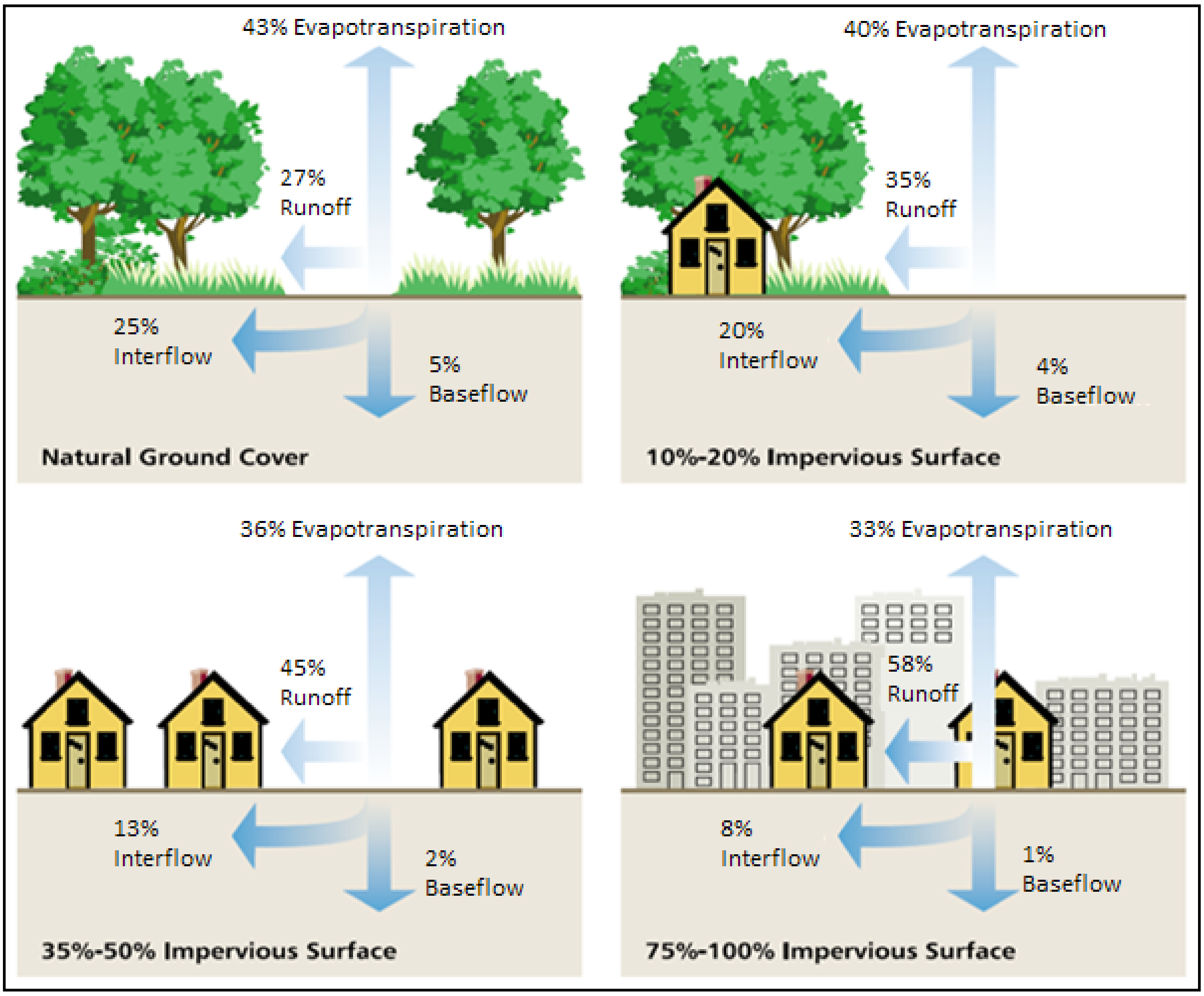


Figure 8. The effects of development on the hydrologic cycle, adapted from (Prince Georges County Department of Environmental Resources, 1999) & (Auckland Regional Council, 2003).

Impervious surfaces also increase the velocity of runoff, which entrains more sediment and sediment bound contaminants in the water column.

Increased runoff volumes increase the erosion of receiving streams and rivers. Frequent, increased flow velocities accelerate the erosion of stream banks, destroying habitat and causing slips. The degradation of aquatic habitats resulting from erosion has been shown to have a strong negative effect on the condition of biological communities in receiving waters (Prince Georges County Department of Environmental Resources, 1999).

Stream geomorphology changes significantly as development takes place. Significant increases in runoff volumes and suspended sediment yields have been measured in the Auckland Region in fully developed catchments and catchments undergoing development. Stream channel cross sections for totally urban catchments were found to be three times larger than pastoral catchments due to the high volume and peak flow of surface runoff (Herald, 1989). These large channel cross-sections develop as incised channels, removing connectivity with the floodplain and increasing the risk of bank instability (Gregory, Reid, & Brierley, 2008).

Furthermore, the concurrent lack of infiltration reduces interflow and groundwater flow. This has the effect of:

- Removing the natural filtering of water as it slowly moves to the ground, increasing contaminant loads to the stream;
- Water temperatures increase as water no longer is cooled as it moves through the ground and/or absorbs the heat as it runs over impervious surfaces; and.
- Stream flows in dry periods are reduced as interflow and groundwater flow are the main source of water for the stream during dry periods.

These changes have the effect of reducing biodiversity in the stream. As little as 10% impervious cover has been shown to adversely affect the biodiversity of receiving waters, with hydrologic factors having a greater effect than pollutants until impervious cover is greater than 40% (Auckland Regional Council, 2003). Few species can survive the combination of higher levels of contaminants, warmer water temperatures and reduced flows during dry periods.

3.2.3 Variation of effects by storm depth

The environmental effects of development vary with the depth of storm events. Figure 9 shows the distribution of rainfall events divided into four classes by recurrence interval. The first two classes are the most frequent rainfall events, which are targeted for water quality control, ground water recharge and channel erosion control. Storms in zones three and four are water quantity storms, for which the control objectives are channel erosion and flood control (Claytor & Schueler, 1996).

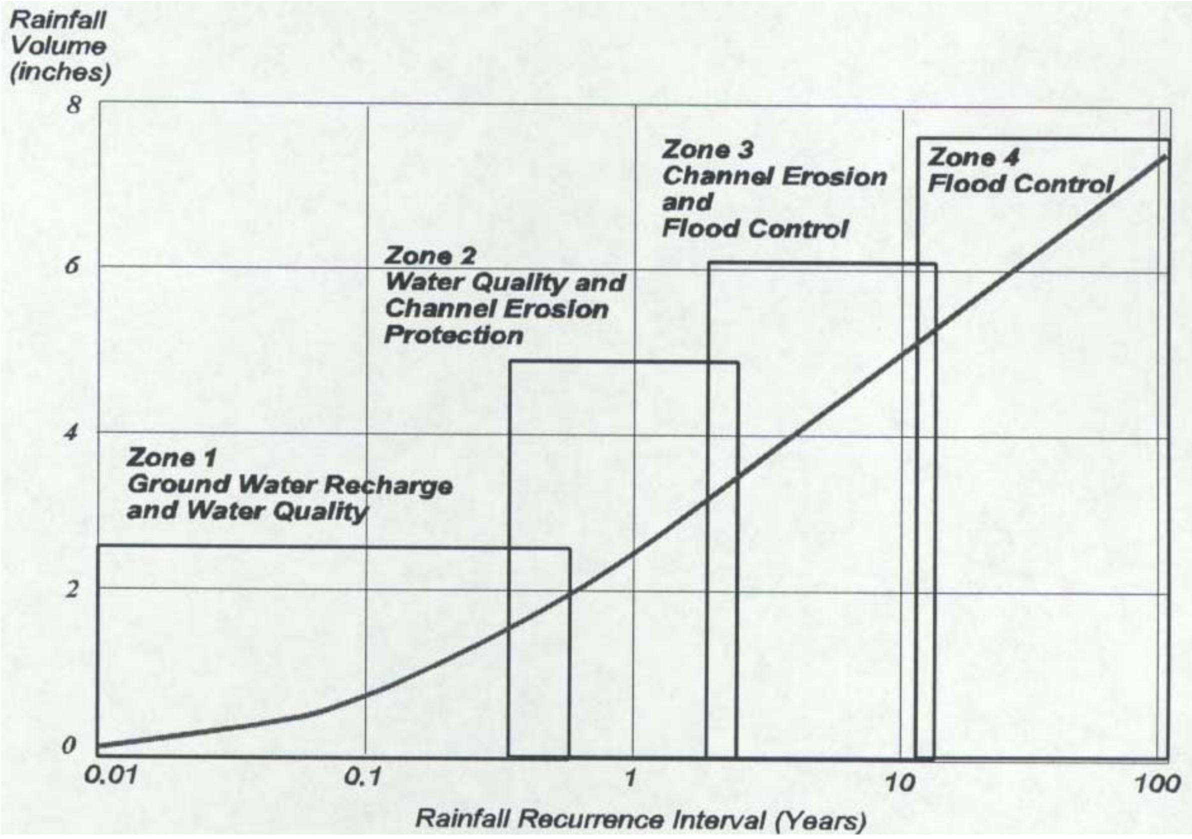


Figure 9. Stormwater control points along the rainfall frequency spectrum (Claytor & Schueler, 1996).

Figure 9 suggests that channel erosion is a result of storms greater than approximately 0.35 yr (4 mo) annual recurrence interval (ARI). Some stormwater management references suggest that medium storms with the recurrence interval of 6 mo to 2 yr are the critical storms that determine the size and shape of the receiving streams (McCuen, 2004) (Clar, Barfield, & O'Connor, 2004). Storms up to the 6 month event are important for restoring groundwater recharge through infiltration.

Similar to Figure 9, the jurisdiction of the Vermont Agency of Natural Resources identifies that effective stormwater management must include both water quality and water quantity controls, and Figure 10 provides rainfall event ranges to demonstrate the proportion of rainfall contributing to each parameter of concern (groundwater recharge, water quality, channel protection, and flood protection). The intended approach is to manage the entire frequency of rainfall events anticipated over the life of the stormwater management system, ranging from the smallest, most frequent events that produce little runoff, but make up the majority of individual storm events and are responsible for the majority of groundwater recharge, up to the largest, very infrequent events that can cause catastrophic damage (Vermont Agency of Natural Resources, 2002).

Note that both Figure 9 and Figure 10 identify that the more frequent events (ARI <1 yr and 50^{th} percentile event, respectively) are important for groundwater recharge. Groundwater recharge is one of the key hydrologic functions provided by a natural landscape that is often significantly compromised by urbanisation and the installation of impervious surfaces.

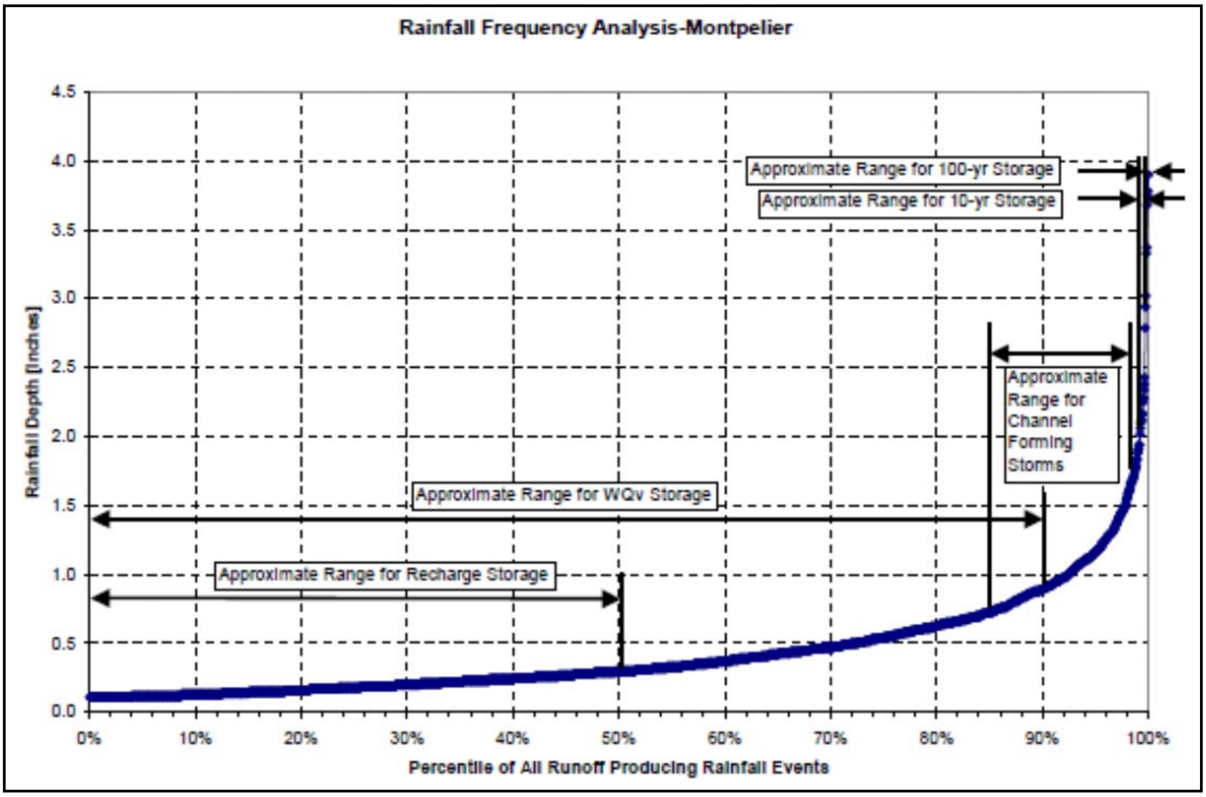


Figure 10. Rainfall event ranges for sizing stormwater treatment practices to meet treatment standards for water quality, channel protection, groundwater recharge, overbank flood protection and extreme flood control (Vermont Agency of Natural Resources, 2002).

Figure 11 shows the increase in runoff volume resulting from urbanisation. For large storm events in zone 4 of Figure 9 (>10 yr ARI event), the runoff volume for an urbanized catchment is up to two times the runoff volume for a natural catchment. In zone 3 (2 to 10 yr ARI event), volumetric increases are up to three times the natural rate. For zone 1 and 2 (up to the 2 yr ARI event), volumetric increases are up to 20 times the natural rate, significantly higher than the 2-3 times increase for larger events.

This large proportional increase is during small, frequently occurring rainfall events. Streams are frequently subjected to high surface runoff volumes during and immediately after rainfall, and groundwater flow between events is lower due to reduced infiltration. The frequency of this variation in flow rates causes many issues in zone 1 and 2 for water quality control, ground water recharge, channel erosion control and stream health. Strategies to mitigate these adverse effects of development, stormwater management efforts should target these small events.

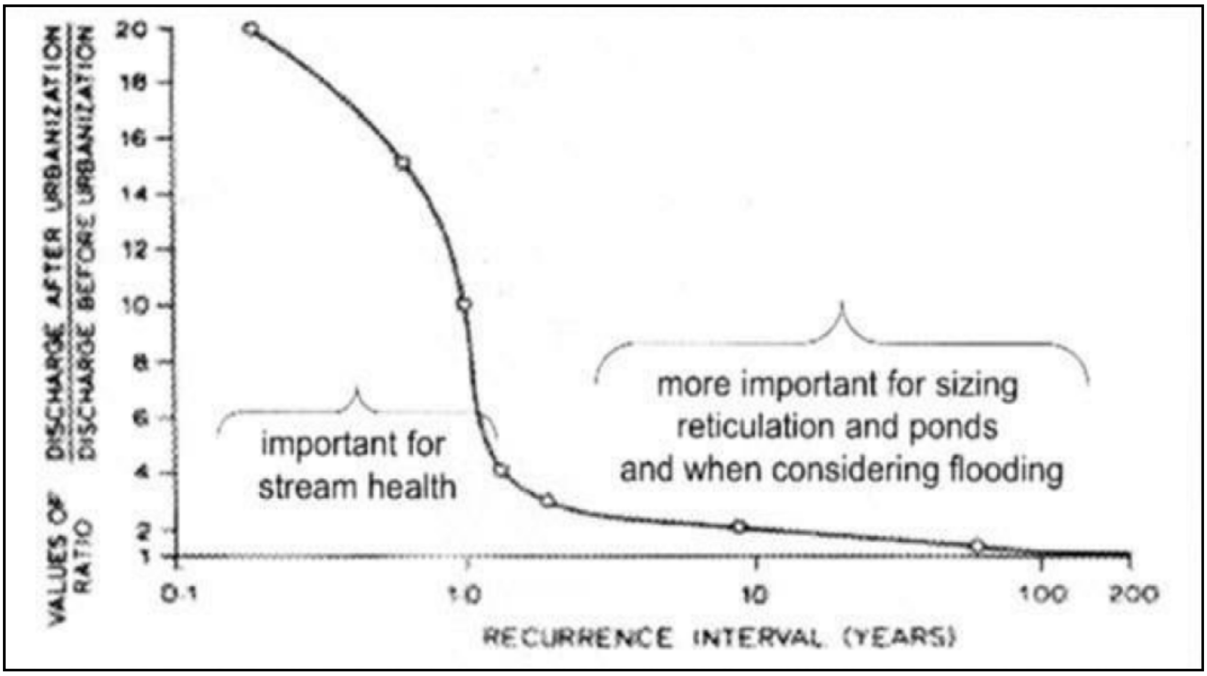


Figure 11. Ratio of stormwater discharges before and after urbanisation (Centre for Watershed Protection, 2003).

3.2.4 Stream health impacts

Stream health impacts arise from changes to channel erosion processes as well as the effects of reduced interflow and baseflow. Both of these processes are discussed in the following sections.

3.2.4.1 Channel erosion processes

The increase in stormwater volumes and peak flows that accompanies development (i.e. imperviousness), alters channel erosion processes; increasing the frequency and duration of flow. Key characteristics driving stream channel erosion which are affected by hydrology changes are *bankfull flow* and *effective discharge*. Changes in the frequency and duration of bankfull flow have been observed following extensive urbanisation (Booth & Jackson, 1997) (Hammer, 1972), with implied resultant channel instability and changes in bankside vegetation (Hey, 2006). The discussion herein applies to natural stream channels subject to fluvial processes. Constructed channels, ditches, or other artificial drainage systems are excluded.

The following key terms are commonly used in literature:

- *Bankfull discharge* is a range of flows that are most important in forming a channel, floodplains (benches), and banks (Ward, D'Ambrosio, & Witter, 2008). It is often related to the amount of water flowing in a stream that fills the main channel and begins to spill onto the active floodplain (zone 2 and 3 of Figure 9). Measurements of stream channel geometry are usually needed to determine the bankfull geometry and associated discharge capacity according to Manning's equation and the continuity equation. Actual measurement is difficult in unstable streams (Hey, 2006) (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003).

- *Effective discharge* is the amount of water that transports the most sediment over the long term (Ward, D'Ambrosio, & Witter, 2008). It is usually determined by plotting the sediment discharge against various flow rates over the long term. The maximum value in the plot is the effective discharge. The Wolman-Miller model for geomorphic work is usually used to determine sediment movement. Stream discharge data is also needed or must be estimated to determine a frequency histogram. Seasonal effects may be important in determining effective discharge, recognising that small, frequent flows may be capable of transporting large sediment masses, this concept links sediment load with channel geometry.

Often, the terms *bankfull flow* and *effective discharge* are considered to be synonymous (Hey, 2006) (Leopold, 1964). Either, or both, may be considered a "channel-forming discharge". However, the channel-forming discharge more generally as a single discharge that given enough time, would produce the width, depth, and slope equivalent to those produced by the natural hydrograph for a given alluvial channel geometry (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003). This concept is claimed valid for streams in humid regions and perennial streams in semi-arid regions (Auckland's climate is temperate) (Biedenharn, Thorne, Soar, Hey, & Watson, 2001) (Soar & Thorne, 2000). The notion of bankfull or effective discharge underpins the well-known stream restoration scheme called the Rosgen Method, but is not the only variable design option (Hey, 2006) (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003) (Rosgen, 1994).

Current stormwater management design largely originates from work by Leopold, which empirically determined that the bankfull discharge for most streams has a 1–2 yr ARI (Leopold, 1964). Subsequent studies have shown that the relationship between channel-forming discharges and return periods for storm events is not well-defined (Ward, D'Ambrosio, & Witter, 2008) (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003), and may have significant error for urbanising watersheds where land use change forces changes in hydrology and geomorphology (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003). For various streams in Ohio (USA), bankfull discharges were found to be associated with less than 1-yr to 5-yr ARI. In terms of effective discharges for the same streams, the ARI was found to be *ca.* 0.45–1.3 yrs. It has been demonstrated that the greatest increase in erosion potential was associated with moderate flow events with less than 1.5 yr ARI (MacRae, 1991), and further demonstrated that under urban conditions the maximum effective work in a stream increased in magnitude and shifted to flows of 0.5–1.5 yr ARI (MacRae & Rowney, 1992). Another study found that events that shape in-channel features occurred 14–30 times per year, and did not equate with bankfull conditions (Gippel, 2001). Bankfull or overbank flood occurs every 1.7 to 21.1 months across the Rouge River Watershed, Michigan (Alliance of Rouge Communities, 2012). There is evidence to suggest that bankfull flows occur more frequently as basin area decreases and slope increases (Gippel, 2001).

These results give rise to caution in using a return period as a stand-alone metric in determining bankfull characteristics (Ward, D'Ambrosio, & Witter, 2008). It is clear, however, that channel forming discharges generally may occur or be exceeded several times a year for humid or semi-humid regions (Ward, D'Ambrosio, & Witter, 2008). Shields has warned that any estimate of a channel forming flow which exceeds a 1-3 yr ARI should be questioned, and that more than one metric out of bankfull discharge, effective discharge, and ARI flows, should be considered with respect to determining channel-forming flows (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003). Ultimately, in order to address erosion problems in receiving waters, it is important to understand the frequency of the erosive small storm events and take actions to reduce the frequency of these events (Alliance of Rouge Communities, 2012).

Regional curves for bankfull discharge have been determined in areas of the USA and UK. Shields indicates that regional relationships are best applied to channel networks with large data sets that include stable sites (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003). An underlying assumption is that future hydrology will be similar to past, as it is a purely empirical method, and thus may result in error in watersheds undergoing development. Significant variation from regional values has been observed for site-specific data (Hey, 2006) (Ward, D'Ambrosio, & Witter, 2008). Hey suggests development of curves based on stream type and bank vegetation density, rather than by regional clustering. These observations were confirmed locally by ARC studies, which documented challenges associated with measuring shear stress in local streams, and defining regionally-appropriate rules (Hey, 2006).

In streams, the shear stress that causes scour and erosion is related to the depth of flow and the slope of the channel bed (Ward, D'Ambrosio, & Witter, 2008). To maintain stability, a river needs to transmit the incoming sediment load without net erosion or deposition (Hey, 2006) (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003). In the Rosgen method, calculations are made to ensure that the river can transport the largest stone represented in the bed material at bankfull flow, implying that the river will just transmit the incoming bed load material up to and including this critical size. This idea implies defining a critical shear stress for the particle size of interest. To estimate erosion potential in a specific stream, therefore, site specific bed-load characterisation is useful (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003).

Flows greater than the effective discharge do not significantly increase erosive forces where floodplains are broad and well preserved. Flow, velocity, and shear stress in the main channel are maintained at or near effective discharge conditions when streams are allowed to overtop and spread across the floodplain when flow exceeds the effective discharge (Ward, D'Ambrosio, & Witter, 2008). In terms of designing for stormwater management, investigation of shear stress duration curves with respect to flow-duration relationships for a particular stream suggest that as long as the critical portion of the shear stress duration curve can be matched between pre- and post-development, no net increase in erosion potential takes place (Rohrer & Roesner, 2005).

In summary, the literature indicates:

- Erosion in natural streams is driven by channel-forming flows, which are often defined as either *bankfull flow* or *effective discharge*;
- Regional values for channel forming flows are unlikely to accurately reflect conditions at a particular site;
- Channel-forming flows are not related to a single ARI discharge, control of a range of runoff events is required;
- Site-specific analysis would be required to accurately estimate erosion potential in a stream, and thus design measures to mitigate effects; and
- Flows in excess of the channel forming flows do not significantly increase erosive forces within the channel.

3.2.4.2 Effects of reduced interflow and baseflow

As shown in Figure 12 development leads to higher flows and runoff volumes during a rainfall event. As a consequence of this there is reduced infiltration and percolation, which decreases interflow and groundwater flow, causing the stream baseflow to be reduced in between events. The negative relationship between imperviousness and stream baseflows, reflecting the reduced infiltration of rain water into the ground, has been reported in a number of studies (Simmons & Reynolds, 1982) (Ferguson & Suckling, 1990) (Spinello & Simmons, 1992) (Rose & Peters, 2001), although changes to baseflow are inconsistent (Evett, 1994) (Walsh, Roy, Feminella, Cottingham, Groffman, & Morgan II, 2005). Inconsistencies are attributed to the complexity of factors affecting stream baseflows, difficulties in monitoring stream baseflows, and timing. However, the relationship of stream baseflow to urbanisation is generally described as in Figure 12 (Elliott, Jowett, Suren, & Richardson, 2004).

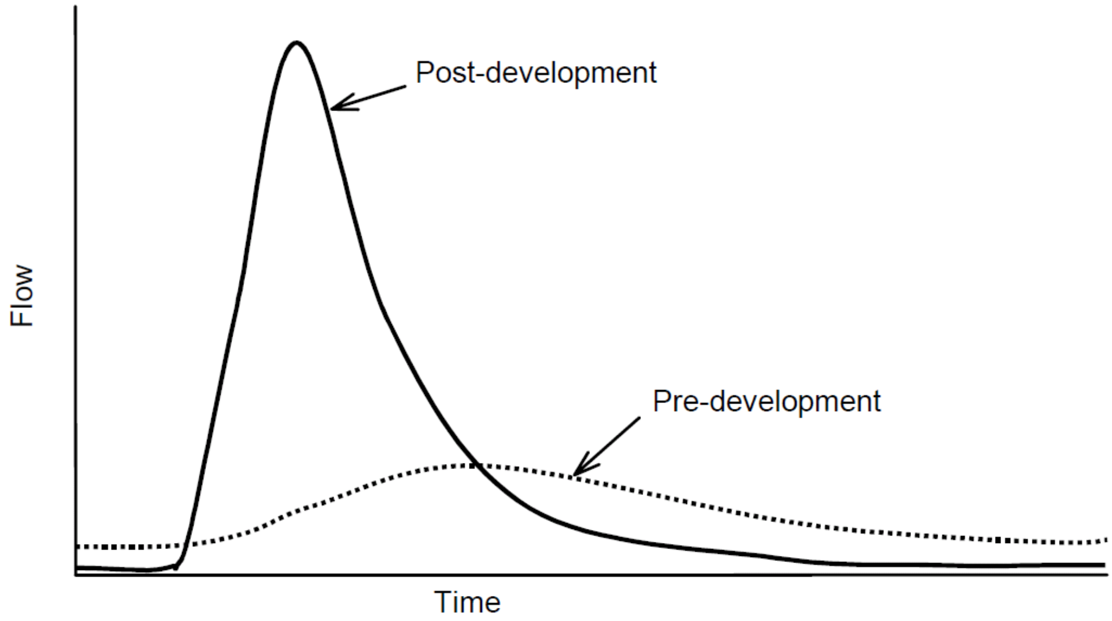


Figure 12. Schematic diagram of a typical storm hydrograph before and after a high degree of urbanisation showing the higher, sharper peak and reduced baseflow (Elliott, Jowett, Suren, & Richardson, 2004).

Whilst overland flow reaches a stream within a matter of minutes and hours, interflow and groundwater flow takes much longer and is dependent on topography, geology, soils and distance to the stream. Residency times of subsurface flows contributing to stream baseflow have been modelled as 8 to 9 months (Vitvar, Burns, Lawrence, McDonnell, & Wolock, 2002), 11 months (Burns, Murdoch, Lawrence, & Michel, 1998), 2 to 5 years (Morgenstern, 2008), greater than 3 months for interflow, and between 5 to 10 months for groundwater flow (Dunn, McDonnell, & Vache, 2007). Long retention times promote contaminant removal processes, cooling of infiltrated stormwater, and provide a consistent release of water into the stream. Groundwater flow and interflow play a critical role in the hydrological cycle, especially in summer, when these are the main sources of water for the stream and determine the extent and quality of freshwater habitat.

Stream flows distribute nutrients and food down streams, detritus for invertebrates and drifting insects for fish, and aids species dispersal (Jowett, Hayes, & Duncan, 2008). These processes decrease during low flow periods, when in-stream biota is subject to high levels of stress, which can reach untenable levels under unnaturally low stream baseflows. Small low volume streams with limited buffering capacity, characteristic of the majority of Auckland streams, are particularly vulnerable.

In small to medium sized streams, low flows generally set the lower limit of suitable habitat available for native fish, and the duration of low flows is also relevant. Permanent streams may become intermittent and intermittent streams may disappear altogether, whilst habitat complexity diminishes. Because water depth and velocity generally increase with flow, there tends to be an optimum flow that provides a maximum amount of habitat for a particular fish species and life stage (Beca, 2008). The minimum flow requirement for a stream is usually set at the minimum flow requirement of the most sensitive fish species in a stream; some fish species in Auckland streams have relatively high stream baseflow requirements. Low stream baseflow during summer was identified as a potential limiting factor for riffle dwelling fish and invertebrate species in Auckland (Allibone, Horrox, & Parkyn, 2001), which has the potential to impact on regionally rare species such as koaro and torrentfish.

Research in the Waipara River, where native fish habitat is limited at low flow, showed the detrimental effect on fish numbers increased with lower levels and longer durations of low flows (Jowett, Richardson, & Bonnett, 2005). Research on the Onekaka River displayed the same results (Richardson & Jowett, 2006) . Most Auckland fish species require a series of connected pools and channels of sufficient depth to survive and reproduce. Such habitats become fragmented and inadequate during unnaturally low stream baseflows.

Almost half of New Zealand's native fish species are diadromous and rely on connected waterways to complete their life cycles, and many of these species migrate during summer and autumn (Stevenson & Baker, 2009). Shallow water depth can become a fish barrier during periods of low flows, especially for larger fish species. Whilst shallow water is not necessarily a physical impediment to smaller fish species, shallow water is more prone to thermal effects, which can pose a barrier fish to migration. Complete drying out of a watercourse affects all species. Shallow waters furthermore expose fish to an increased risk of predation, as reported for juvenile eels (Boubee, Reynolds, & Roper, 1998) .

The transitional zone between surface and groundwater forms an ecotone called the hyporheic zone. Stream baseflow is generated by groundwater entering the stream channel from the hyporheic zone below the stream bed and adjacent saturated zones. Whilst performing an important contaminant removal function (Smith, 2005), in many systems the hyporheic zone contains a unique invertebrate fauna with a mix of surface and subsurface species (Boulton, Scarsbrook, Quinn, & Burrell, 1997) (Collier & Scarsbrook, 2000) (Hancock, 2002). Groundwater recharge and hyporheic flow can provide the only refuge for fish and invertebrates during dry spells and are essential to sustain isolated aquatic refugia in intermittent streams (Arthington, Naiman, McClain, & Nilsson, 2010) (Larned, Datry, Arscott, & Tockner, 2010).

Decreased low flows have less available water to dilute contaminant loadings, resulting in higher in-stream concentrations of pollutants (e.g. zinc, copper, lead, and nutrients), which negatively affects aquatic life. Algal blooms and aquatic macrophyte weeds proliferate in summer in response to high temperatures and increased nutrient availability; in such conditions the food chain can shift to one dominated by snails, worms and midges (Biggs, 2000) (Suren, Biggs, Kilroy, & Bergey, 2003), and such environments are also usually less diverse (Clausen & Biggs, 1997). Aquatic weeds also clog waterways, which exacerbate heating of streams and further reduce dissolved oxygen minima.

Water temperature influences virtually every biotic component of stream ecosystems. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred, often narrow, temperature range. Residence by any fish species will be limited by temperature tolerance during summer base flows (Allibone, Horrox, & Parkyn, 2001). If temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are none. The importance of groundwater flows and interflow in mitigating stream temperature effects is often understated.

Stream baseflow tends to have a cooling effect on stream temperature because groundwater is usually maintained at a relatively constant temperature, despite fluctuations in ambient temperatures. Runoff committed to soakage is cooled as it moves through the ground. Any activity that compromises stream base flows can affect water temperature (LeBlanc, Brown, & FitzGibbon, 1997). As stream baseflow decreases, its cooling effect decreases as well. Shallow streams, receiving diminished groundwater inputs, are also more susceptible to temperature exchanges; they heat up faster than deep streams with the same mean velocity, and cool more quickly, attaining higher daily maximum and minimum temperatures (Rutherford, Marsh, Davies, & Bunn, 2004). Groundwater exchange provides stable temperature habitats and localised areas of high groundwater discharge in streams provide thermal refugia for fish (Hayashi & Rosenberry, 2002). Sustained stream baseflows therefore play a critical role in controlling stream temperatures and maintaining stream ecosystems.

One especially important aspect of water temperature is its inverse relationship with oxygen solubility. Fish and other aquatic life require dissolved oxygen to breathe. Oxygen depletion is common at high stream temperatures, causing stress and mortality in aquatic life. Low energy, water-stressed streams also generally have lower dissolved oxygen levels than free-flowing, turbulent waters. Dissolved oxygen levels are therefore generally most limiting in the driest, hottest part of the year. Aquatic species, such as banded kokopu (Allibone, Horrox, & Parkyn, 2001), will at these times actively seek oxygen rich areas, emphasising the need to sustain stream baseflows during the summer low flow period.

Physical habitat conditions, average stream temperatures, contaminant concentrations, and low dissolved oxygen concentrations are all negatively affected by decreased base flow. Consequently, less tolerant fish and invertebrate populations disappear under unnaturally low stream baseflows, resulting in streams with severely compromised diversity and biomass of species, and alterations to the natural distribution of aquatic life along stream gradients.

3.2.4.3 Mitigation of effects

The current extended detention approach to aquatic habitat protection, detaining stormwater and slowly releasing it over a 24 hour period, does not mitigate the long term effect of reduced baseflow in streams. Reduced baseflows are most relevant during dry periods when there is little rainfall to detain and release, and controlled release of stored stormwater directly into the stream over a relatively short period does not mimic the sustained long term provision of stream baseflow from groundwater flow and interflow. The latter takes place over weeks and months, as opposed to hours or days. Provision of extended detention is furthermore primarily concerned with preventing erosion, rather than ensuring sustained stream baseflows.

The extended detention approach does not mimic the natural filtering processes of soils, which serve to mitigate elevated runoff temperatures and remove contaminants entrained in stormwater. Extended detention can have the added negative effect of increasing water temperatures when heated stormwater is discharged from ponds, which have been shown to increase downstream temperatures. In thermally sensitive areas, where extended detention cannot be avoided, it has been recommended that detention times be reduced to 6 – 12 hours, to minimise thermal enrichment (Galli, 1991). Extended detention does, however, partially mitigate the decreased time of concentration in surface runoff, which also requires control. Natural infiltration rates themselves are low on Auckland clay soils, limiting what can be achieved with infiltration on any development site.

The stormwater management requirements proposed in the Unitary Plan partially restore interflow and groundwater flow through promoting infiltration, which mitigates potential decreases in stream baseflow. In terms of contaminant removal, the proposed approach restores some of the natural soil filtering processes, and as mitigation techniques often are media-based, also provides filtering capacity within stormwater treatment devices. Temperature effects are also mitigated by most volume reduction techniques through infiltration and shaded storage areas.

For the above reasons, the proposed practice of infiltrating stormwater, supported by extended detention, is considered a preferable approach for stream habitat protection.

4.0 Contaminant management

The approach to contaminant management in the Unitary Plan differs in a number of ways from the existing ALW Plan. This chapter provides:

- a description of the approach;
- guidance on how to comply with the provisions; and
- analysis of the implications of the changes.

Many of the changes may seem substantial, and in particular the adoption of DEQRs is a significant departure. However, it is important to understand that the DEQRs have been developed based on the effluent water quality that can reliably be expected from the suite of stormwater Best Management practices (BMPs) that are currently regarded as 'best practice'. As such, in most cases there is little or no change to achieving compliance with the new provisions although there may be some devices that cannot be used in some circumstances. In general, the design guidance in ARC Technical Publication 10 (Auckland Regional Council, 2003) (TP10) is a means to achieving the DEQRs in the Unitary Plan, just as it was a means of achieving compliance with the ALW Plan's 75% TSS removal objective. Section 4.4 provides specific guidance regarding how to demonstrate compliance with the Unitary Plan's provisions.

4.1 Current contaminant management approach

4.1.1 Current approach

The requirement for contaminant management in the ALW Plan is primarily the adoption of the 'best practicable option' (BPO), both at a network and individual scale, to prevent or minimise the adverse effects of stormwater discharges. In some instances, this is translated into permitted and controlled activity rules that include the requirement for stormwater treatment devices that are designed to remove at least 75% TSS on a long term average basis.

Where stormwater discharges are not covered by permitted or controlled activity rules, and restricted / discretionary resource consents are required, the 75% TSS removal requirement does not specifically apply. However consent processing practice is such that, where stormwater treatment is deemed necessary, it is generally required that 75% TSS removal be achieved. In essence, the 75% TSS removal requirement has become the *de facto* BPO for all stormwater treatment. In many circumstances, it is unlikely to be the BPO as a level of performance based simply on the removal of TSS does not take into account the contaminants that are present or the sensitivity of the receiving environment to those contaminants.

Implementation of this treatment requirement has generally relied upon the guidance provided by TP10 (Auckland Regional Council, 2003). TP10 contains an inventory of most currently accepted stormwater contaminant BMPs, together with design guidance. It is generally implicitly accepted that, when designed in accordance with TP10, any of these BMPs meet the performance requirement of 75% TSS removal.

4.1.2 Limitations to the current approach

The current contaminant management approach is considered to have limitations, as follows:

- The current approach fails to take account of other contaminants. TSS is the only contaminant considered by the ALW Plan and associated plan implementation practice, although it is made clear in TP10 that "removal of sediment will remove many of the contaminants of concern, including; particulate trace metals, particulate nutrients, oil and grease on sediments and bacteria on sediments". This approach has significant limitations where sediment is not the major contaminant of concern or where a contaminant is not well correlated with the presence of TSS. In particular this is relevant to high contaminant yielding roofing and cladding materials, which generate significant loads of metals, but very little sediment. Thermal pollution also has no correlation with TSS loads.

- The current approach fails to take account of the fact that stormwater BMPs exhibit a range of performance for TSS and a (potentially different) range of performance for other contaminants. Thus a device that may be effective at removing sediment may be ineffective of removing other contaminants of concern – hence not achieving an appropriate environmental outcome.

- A percentage removal metric is not a reliable measure of device performance as it is influenced by influent load. On a site with high TSS load, 75% removal may be easy to achieve, whilst on low load sites it is possibly unachievable. This does not encourage reduction at source as the requirement is still to remove 75% of what is left. In addition, 75% removal of TSS from a high load site may have still have unacceptably high effluent TSS (and other contaminants), whilst a very low load site may have acceptable water quality with little or no additional removal of TSS.

- In the sense that a percentage removal metric provides no indication of effluent water quality, it is considered that the current approach does not support implementation of the National Policy Statement on Freshwater Management or the New Zealand Coastal Policy Statement. Both of these propose numerical objectives for water bodies. It is considered that an effluent water quality metric provides a better means of complying with water body objectives in the national guidance.

4.2 Unitary Plan contaminant management framework

In order to address the above issues, the contaminant management approach in the Unitary Plan has been changed, as follows:

- The metric for the performance of stormwater BMPs is changed from percentage removal to a Design Effluent Quality Requirement (DEQR). The DEQRs represent the expected discharge concentration from *most* of the currently accepted suite of stormwater BMPs.

There is consideration of a range of contaminants, rather than solely TSS. DEQRs have been developed for the following contaminants:

- Total Suspended Solids (TSS)
- Metals
    - Total Copper (TCu)

- Total Zinc (TZn)

- Temperature

4.3 Design Effluent Quality Requirements

4.3.1 Concept of DEQRs

The DEQRs are the fundamental concept behind the Unitary Plan contaminant management approach. In essence, they represent a reasonable expectation of the effluent water quality from most of the stormwater treatment practices currently regarded as 'best practice'. They have been developed using the best available international data on the effluent water quality from common stormwater treatment practices. This 'bottom-up' approach is intended to ensure that the DEQRs are both realistic and achievable.

In general, the DEQRs represent the median effluent concentration from the *worst-performing* of the stormwater BMPs contained in TP10. In this sense, they are conservative values, and, in most cases appropriate device selection should result in effluent water quality that is better than the DEQRs. Notwithstanding this, it is important to recognise that the DEQRs are derived from median effluent water quality across a range of land uses and contaminant loads. The water quality downstream of a treatment device on a site with low contaminant loads should, in general, be superior to the DEQRs. Conversely, the water quality downstream of a treatment device on a site with high contaminant loads may be inferior to the DEQRs. In this sense, the DEQRs should be considered to represent the expected effluent quality from 'average stormwater'.

The DEQRs have, in general, been generated on the basis that the worst-performing BMPs still represent acceptable treatment for those contaminants. It is possible that, at a later date, the DEQRs could be made more stringent, which might exclude certain BMPs (or less stringent, which might include some currently excluded BMPs). For the present, in general there is no good evidence to exclude BMPs that are currently regarded as acceptable under the ALW Plan and TP10. The notable exception to this is that the temperature DEQR has been set such that wet ponds are specifically excluded where the flow is directed to a river or stream. The reasons for this are included in the discussion, below.

DEQRs were also developed for nutrients; Total Nitrogen (TN) and Total Phosphorus (TP), but are not implemented under the Unitary Plan, because there is no strong evidence that stormwater derived nutrients cause significant issues in the Auckland Region. It should be pointed out that DEQRs for nutrients would most likely exclude several BMPs (swales, wetland swales and living roofs), since they exhibit little or no removal of TP in particular. This is discussed further in Appendix B.

This section discusses the development of the DEQRs and undertakes a comparison with available data on the contaminant concentrations expected from various land uses; primarily using data from the Contaminant Load Model (CLM). The comparison has been used as the basis for defining the high contaminant generating activities, on which the Unitary Plan requires the provision of treatment to achieve the DEQRs. The approach that has been used is that, where the water quality is not substantially worse than the DEQR, there is minimal gain to be had from undertaking treatment. Conversely, where the water quality from a particular land use or surface is demonstrably worse than the DEQR, there are substantial gains to be made from providing treatment. This underpins the fact the Unitary Plan provides a more targeted, risk-based approach to treatment than the ALW Plan. This is designed to achieve environmental outcomes, without unduly constraining brownfield development and intensification in particular.

4.3.2 Methodology for development of design effluent quality requirements

The DEQRs for TSS, TCu and TZn were developed based on a statistical analysis of field data from the International Stormwater Best Management Practices Database (Geosyntec and Wright Water Engineers, 2012) (Geosyntec Consultants and Wight Water Engineers, 2012). A full description of the procedure to derive the DEQRs is contained in Appendix B. Note that this appendix also contains the derivation of DEQRs for TN and TP, based on the same methodology. These DEQRs have not been implemented in the Unitary Plan, however the analysis is retained in the appendix, for reasons of completeness and in order to inform future decision making.

In general, the DEQRs for TSS, TCu and TZn were generated based on the median effluent water quality of the BMP that performs most poorly for the contaminant of concern. This is based on the assumption that most BMPs exhibit acceptable performance. Exceptions to this assumption are discussed in the text below.

One limitation of the analysis in Appendix B is that the BMP Database contains data from devices designed to comply with various policies and requirements, particularly with regard to sizing; and, as such, the performance may differ from a device designed in accordance with TP10. The assumption has been made that TP10 sizing requirements are sufficiently similar to most other jurisdictions to make the comparison reasonable.

The DEQR for temperature has been derived by a different process, and this is discussed in Section 4.3.6, below.

No DEQR was derived for TPH, due to the lack of reliable data on typical concentrations from various land uses, as well a lack of effluent water quality data from treatment practices. As discussed in Section 3.1.4, hydrocarbons tend to adhere to sediment, and devices compliant with the TSS DEQR should provide a degree of assurance of hydrocarbon removal.

4.3.3 Design effluent quality requirements for TSS

On the basis of the analysis in Appendix B, the DEQR for TSS has been determined to be 20 mg/L. As discussed, this represents typical effluent TSS from most of the devices in TP10.

Table 4 presents the effluent TSS concentrations from the CLM. Shaded cells in the table indicate a concentration higher than the DEQR. It is apparent from the data that the TSS load from urban grassland is generally higher than the DEQR of 20 mg/L. Steep urban grassland, in particular, exceeds the DEQR by a substantial amount; however it has been stated by the model's developers that the uncertainties in the TSS concentrations for urban grassland are high (Auckland Regional Council, 2010). Furthermore, as discussed in Section 3.1.1, it is generally understood that sediment from streambank erosion represents a much larger proportion of total catchment sediment load than that which washes off upper catchment areas. Accordingly, the TSS load from urban grassland is not considered problematic. In fact, since it is generally low in other contaminants it may play an important role in diluting the contaminants washed off other impervious surfaces and deposited in estuarine sediments. As such the Unitary Plan does not identify urban grassland as a high contaminant load generating land use, and there is no requirement to treat urban grassland to achieve the DEQR for TSS.

According to the CLM, all roof types discharge TSS at concentrations lower than 20 mg/L. Paved surfaces and low trafficked roads discharge at a similar concentration. High trafficked roads discharge at significantly above 20 mg/L.

Table 4. Effluent concentration of TSS from the Contaminant Load Model (Auckland Regional Council, 2010)

Contaminant Load Model Effluent Concentration (mg/L)		
Roofs	Galvanized Steel Unpainted	4
	Galvanized Steel Poorly Painted	4
	Galvanized Steel Well Painted	4
	Galvanized Steel Coated	10
	Zinc / Aluminium Unpainted	4
	Zinc / Aluminium Coated	4
	Concrete	13
	Copper	4
Roads	< 1,000 v.p.d.	18
	1,000 – 5,000 v.p.d.	23
	5,000 – 20,000 v.p.d.	44
	20,000 – 50,000 v.p.d.	80
	50,000 – 100,000 v.p.d.	132
	> 100,000 v.p.d.	195
Paved Surfaces (other than roads)	Residential	27
	Industrial	18
	Commercial	27
Urban Grassland	< 10°	38
	10 – 20°	77
	> 20°	154

4.3.4 Design effluent quality requirements for copper

On the basis of the analysis in Appendix B, the DEQR for TCu has been determined to be 10 µg/L.

Table 5 presents the effluent TCu concentrations from the CLM. Shaded cells indicate a concentration higher than the DEQR. Note that the CLM had very large values for TCu for the category of paved surfaces (other than roads). The reason for this is that these categories were used to 'calibrate' the CLM, and as such they include all the errors in source yields (concentrations) from other land uses (Auckland Regional Council, 2010). For the purposes of this report more realistic concentrations recommended by an alternative source are used (Pattle Delamore Partners, 2009).

It is apparent, from the data, that most roofs discharge copper at concentrations significantly lower than the DEQR. The obvious exception to this is copper roofing, which discharges at a concentration three orders of magnitude higher than the copper DEQR. On the basis of this, copper roofing has been defined as a high contaminant generating, and any expanse of copper roofing (or cladding) over 25 m^2 in area must be treated to meet the DEQR of 10 µg/L, in order to meet the controlled activity rules.

The CLM contains data on the commonest NZ roofing materials. In fact, a number of less common roofing materials have been shown to leach substantial copper. In particular, field testing indicates that CCA treated (i.e. tantalised) wood can cause extremely high concentrations of copper. In standardised laboratory leaching experiments, the average copper concentration in runoff from treated wood substrates was as high as 160,000 µg/L. Field testing of similar substrates found that copper was routinely in the range up to 5,000 µg/L, and occasionally as high as 20,000 µg/L (Clark, et al., 2008).

Another relatively recent development in the roofing industry is the incorporation of porous ceramic granules incorporating copper oxides into roofing materials for the purposes of algae resistance. The copper ions released from these granules are intended to kill algae that produce unsightly black streaks on roofing materials such as asphalt shingles. Manufacturers claim that these materials continue to leach copper and act as an algaecide for up to 30 years. Literature pertaining to the development of these roofing granules has indicated that, in order to completely inhibit algae growth, a concentration of approximately 0.5 ppm (500 µg/L) is required (Jacobs & Thakur, 1999). In standardised laboratory leaching experiments, the average copper concentration in runoff from asphalt shingles with algaecide was 660 µg/L (Clark, et al., 2008). This indicates copper concentrations approximately two orders of magnitude higher than the DEQR for copper, and indicates that there is most likely substantial environmental risk associated with these products.

As such, the Unitary Plan identifies all of the above roofing materials as high-contaminant generating, and requires treatment to meet the controlled activity requirements.

Inspection of the BMP database data in Appendix B indicates that living roofs also tend to leach copper at rates slightly higher than the DEQR. Whilst the concentrations are elevated, they are substantially less than the high copper generating materials that are identified above. Furthermore, living roofs typically reduce the annual runoff volume substantially, which mitigates the effects of the elevated concentrations. Living roofs designed according to the Auckland Council guidance have been found to eliminate 39 – 57% of the annual runoff, depending on depth (Fassman, Simcock, & Voyde, 2010). On this basis, living roofs should be regarded as compliant with the DEQR for copper.

Whilst the above data indicates that the concentrations of copper from some roofing materials may be extremely high, in fact most of these materials are relatively uncommon in Auckland. A bigger contributer of copper to Auckland's receiving environment is roads. The data in Table 5 indicates that roads carrying more than 5,000 v.p.d. begin to exceed the copper DEQR, and roads of over 100,000 v.p.d. exceed it by an order of magnitude. It is clear that roads and other vehicle activity areas represent the biggest opportunity to reduce the copper loads to Auckland's receiving environments from stormwater. Accordingly, the Unitary Plan requires treatment of all carparks over 1,000 m^2 in area, and all roads of over 10,000 v.p.d.

Table 5. Effluent concentration of Total Copper from the Contaminant Load Model (Auckland Regional Council, 2010)

Contaminant Load Model Effluent Concentration (µg/L)		
Roofs	Galvanized Steel Unpainted	0.3
	Galvanized Steel Poorly Painted	0.3
	Galvanized Steel Well Painted	0.3
	Galvanized Steel Coated	1.7
	Zinc / Aluminium Unpainted	0.9
	Zinc / Aluminium Coated	1.6
	Concrete	3.3
	Copper	2,120
Roads	< 1,000 v.p.d.	0.7
	1,000 – 5,000 v.p.d.	4.2
	5,000 – 20,000 v.p.d.	17.5
	20,000 – 50,000 v.p.d.	40.7
	50,000 – 100,000 v.p.d.	74.4
	> 100,000 v.p.d.	115.2
Paved Surfaces (other than roads)	Residential	4*
	Industrial	10*
	Commercial	10*
Urban Grassland	< 10°	0.3
	10 – 20°	0.6
	> 20°	1.3

* Modified value from alternative source (Pattle Delamore Partners, 2009). See text.

4.3.5 Design effluent quality requirements for zinc

On the basis of the analysis in Appendix B, the DEQR for TZn has been determined to be 30 µg/L.

Table 6 contains the CLM data for Zn from various land uses from the CLM. Shaded cells indicate a concentration higher than the DEQR. Note that, as discussed for TCu in Section 4.3.4, the CLM had very large values for TZn for the category of paved surfaces (other than roads), due to calibration of the model. For the purposes of this report more realistic concentrations recommended by an alternative source are used (Pattle Delamore Partners, 2009).

Inspection of Table 6 shows that the values for TZn for urban grassland provide an indication that the DEQR is still an order of magnitude higher than the zinc concentrations that could be expected from non-urban land uses.

It is apparent from the data in Table 6, that zinc-coated steel roofs represent a significant source of zinc and a significant opportunity to reduce the zinc load to Auckland's receiving environment. Galvanized steel has been recognised as a significant source of zinc for many years. The CLM data indicates that unpainted galvanized steel discharges zinc at concentrations two orders of magnitude higher than the DEQR. Painting or coating galvanized steel improves this significantly, although concentrations may still be an order of magnitude higher than the DEQR.

The CLM data indicates that unpainted zinc-aluminium coated steel discharges zinc at approximately 200 µg/L, which is an order of magnitude lower than the runoff from galvanized steel. The value in the CLM is mid-way between the concentration reported in an Auckland Regional Council report (Kingett Mitchell & Diffuse Sources, 2004), which found the median discharge to be 432 µg/L; and a report prepared for the NZ Metal Roofing Manufacturers Inc., which indicated that median zinc concentrations from zinc-aluminium coated steel were 124 µg/L and 94 µg/L for new and old unpainted substrate (Tonkin & Taylor, 2004). Even the lower values are three to four times the zinc DEQR, and are approximately equivalent to the concentrations from roads with 5,000 to 20,000 v.p.d. As such, unpainted zinc-aluminium coated steel represents a significant source of zinc and a significant opportunity to reduce the zinc to Auckland's receiving environments. As a result, the Unitary Plan defines it as a high-contaminant generating roofing material, unless painted or coated. In order to meet the controlled activity requirements, new buildings that opt to use the uncoated material must provide treatment, in order to comply with the DEQR.

Aside from roofs, vehicle traffic is clearly the biggest urban source of zinc. The CLM data indicates that roads of 1,000 to 5,000 v.p.d. discharge zinc at approximately the DEQR and that roads with over 100,000 v.p.d. discharge zinc at concentrations approximately twenty times higher. This is similar to the case for copper, and confirms that there is substantial benefit to be had from treating roads and other vehicle activity areas.

Table 6. Effluent concentration of Total Zinc from the Contaminant Load Model (Auckland Regional Council, 2010)

Contaminant Load Model Effluent Concentration (µg/L)		
Roofs	Galvanized Steel Unpainted	2,240
	Galvanized Steel Poorly Painted	1,340
	Galvanized Steel Well Painted	200
	Galvanized Steel Coated	280
	Zinc / Aluminium Unpainted	200
	Zinc / Aluminium Coated	20
	Concrete	20
	Copper	0
Roads	< 1,000 v.p.d.	4
	1,000 – 5,000 v.p.d.	27
	5,000 – 20,000 v.p.d.	111
	20,000 – 50,000 v.p.d.	257
	50,000 – 100,000 v.p.d.	471
	> 100,000 v.p.d.	729
Paved Surfaces (other than roads)	Residential	20*
	Industrial	50*
	Commercial	50*
Urban Grassland	< 10°	2
	10 – 20°	3
	> 20°	6

* Modified value from alternative source (Pattle Delamore Partners, 2009). See text.

4.3.6 Design Effluent Quality Requirements for temperature

The DEQR for temperature have been derived using a different process to the other contaminants, since no database of international data exists. A literature review has been prepared for Auckland Council (Young, Voyde, Meijer, Wagenhoff, & Utech, 2013), which provides the technical basis for the requirements.

The literature review identifies that the average runoff temperature from most impervious surfaces is typically in the range of 20 to 25°C, with peak temperatures slightly higher than this (Herb, Janke, Mohensi, & Stefan, 2007). The review also identifies the potential thermal effects of wet ponds and wetlands. It has generally been found that wet ponds increase the influent runoff temperature by between 2 and 10°C, and that this is observed for both baseflow and storm conditions. Wet ponds were found to exceed a 24°C temperature threshold (USA Class IV trout stream threshold) 35% of the time during baseflow and 25% of the time during stormflow. Wetlands were also found to present a thermal pollution risk, however most literature reports that the vegetation mitigates this to some extent. Wetlands have been found to exceed a 24°C threshold 15% of the time during baseflow and 5% of the time during stormflow, which is substantially less often than is the case for wet ponds.

It has been recommended, from an ecological perspective, that the objective for upland streams should be to have water temperatures < 20°C at all times, and the objective for lowland streams should be to have water temperatures < 25°C at all times (Olsen, Tremblay, Clapcott, & Holmes, 2012). Whilst Auckland streams generally have upland character, due to their short length, it is apparent from the literature review that only stormwater infiltration practices can truly achieve this outcome. In this regard the SMAF requirements to retain the first 8 or 10 mm of runoff on site should provide the necessary thermal mitigation in these sensitive areas. Outside of SMAF areas, a temperature DEQR of 20°C would require infiltration devices or underground 'cribs' treating all runoff from impervious surfaces. The latter would be significantly restrictive on development, and might not achieve the desired outcomes in a brownfield scenario, since existing development can discharge without temperature mitigation of any sort.

In view of the above discussion, the Unitary Plan adopts a temperature DEQR of 25°C for discharges to a river or stream. It is considered that this generally allows the runoff from impervious surfaces without a requirement to treat. Wet ponds are regarded as non-compliant with this threshold, since there is substantial evidence that they routinely discharge at temperatures up to 30°C. The situation for wetlands is more complex, since they do cause a degree of thermal enrichment. Presently evidence seems to indicate that exceedances of the 25°C DEQR by wetlands are likely to be relatively infrequent and, as such, wetlands should be regarded as compliant with the DEQR providing they are highly vegetated and shaded.

4.4 Compliance with the Unitary Plan provisions for contaminants

4.4.1 Compliance with DEQRs and provision of enhanced treatment

It has been noted earlier, that the DEQRs are derived from the performance of particular BMPs across a range of land uses and contaminant loads. Therefore, in order to comply with the DEQRs, it is required that the BMP employed (be it from TP10, a proprietary device, or some other new BMP) demonstrates the required effluent quality over a similar range of land uses and contaminants. In this sense the DEQR applies to the particular BMP, rather than to the site on which it is used. Demonstrating compliance with the DEQR is equivalent to demonstrating compliance with 'best practice', and there is no requirement to prove that the water quality from a particular site meets the DEQR concentrations.

The DEQRs were developed from the effluent water quality expected from the suite of BMPs in TP10. As such the same data becomes the basis for demonstrating compliance. Table 7 shows, for each of the BMPs within TP10, whether they are regarded as complying with the Unitary Plan DEQRs. Also included in this table is guidance regarding which BMPs are likely to provide enhanced treatment for a particular contaminant. BMPs are considered to provide enhanced treatment if they have a significantly lower effluent concentration than other BMPs (see the analysis in Appendix B), or if they reduce the volume of annual runoff significantly, by virtue of infiltration. Enhanced treatment is not a requirement of the Unitary Plan; however this information is included to provide some design guidance regarding treatment options where particularly vulnerable receiving environments are identified.

The analysis in Appendix B confirms that some, but not all, proprietary devices will meet the DEQRs. In general, devices employing media filtration are capable of achieving the required effluent water quality, whilst devices that use gravitational settling (hydrodynamic separators) are unlikely to do so. Whether or not a proprietary device meets the DEQRs will be assessed using the Auckland Council Proprietary Device Evaluation Protocol (PDEP). This is a standardised framework for verifying the performance claims made by treatment device manufacturers, and the detail of it may be found in Auckland Council Guideline Document 03 (GD03) (Wong, Ansen, & Fassman, 2012) . A potential issue exists, which is a consequence of the limited data that supports a PDEP application. PDEP requires that data from at least 15 qualifying rainfall events be used to verify the performance claim, which is a very small data set compared to the TP10 devices that have been assessed to generate the DEQRs. In most cases, for each of the BMPs in TP10, this involved data from hundreds of storms across many sites, and as such, there is a fair degree of certainty that the data is representative of typical effluent water quality across a range of land uses and contaminant loads. Conversely, proprietary devices might gather their 15 qualifying events from only one test site, which will have a particular land use and contaminant load. This could conceivably lead to the situation where either the DEQR appears to be met because a site has naturally low load of a contaminants entering the device; or the DEQR is not achieved as a consequence of a higher than usual load of contaminants entering the device. In order to deal with this situation, it will be necessary that PDEP performance claims be assessed in the context of the influent contaminant load. In this context, it will be required that the proprietary device demonstrate equivalent effluent water quality to the BMPs that are compliant with the DEQR, for whatever the range of influent concentrations was during the field trial(s).

Table 7. Ability of TP10 BMPs to comply with DEQRs and to provide enhanced treatment

	TSS		Total Copper		Total Zinc		Temperature	
	DEQR Compliant	Enhanced Treatment	DEQR Compliant	Enhanced Treatment	DEQR Compliant	Enhanced Treatment	DEQR Compliant	Enhanced Treatment
Pond	✓		✓	✓	✓			
Wetland	✓	✓	✓	✓	✓		✓[1]	
Swale	✓		✓		✓		✓	
Filter Strip	✓		✓		✓		✓	
Wetland Swale	✓		✓	✓	✓	✓	✓	
Sand Filter	✓	✓	✓		✓	✓	✓	
Bioretention (lined)	✓	✓	✓		✓	✓	✓	
Bioretention (unlined)	✓	✓	✓	✓	✓	✓	✓	✓
Permeable Paving (lined)	✓		✓		✓	✓	✓	
Permeable Paving (unlined)	✓	✓	✓	✓	✓	✓	✓	✓
Living Roof	✓	✓	✓[2]		✓		✓	✓

[1] Providing the wetland is highly vegetated and well shaded

[2] Providing design is compliant with Auckland Council guidance (Fassman, Simcock, & Voyde, 2010)

4.4.2 Role of device sizing in meeting Unitary Plan requirements

In addition to achieving the required effluent water quality, in order to achieve environmental outcomes any stormwater treatment device must also treat an appropriate proportion of the annual runoff. The Unitary Plan requires that stormwater quality treatment practices be sized to treat the runoff from 90% of the annual rainfall. The basis for this requirement is the current sizing requirements within TP10, which stipulates that devices that are sized on the basis of a Water Quality Volume (WQV) should calculate this volume according to the runoff generated by ⅓ of a two year, 24 hour ARI rainfall event. An analysis of rainfall records over the Auckland region has determined that treating this WQV is equivalent to treating the runoff from 90% of the annual rainfall.

Some stormwater quality devices have little or no storage volume and, as such, are best sized to treat a particular flow rate; the Water Quality Flow (WQF). Devices that fall into this category include swales, filter strips, some bioretention devices (e.g. tree pits and rain gardens with high permeability media) and most proprietary treatment devices (e.g. filters and hydrodynamic separators). TP10 stipulates that swales should be sized to treat a WQF calculated according to the peak flow from ⅓ of a two year, 24 hour ARI rainfall event, calculated using TP108 methodology. TP108 is primarily intended to calculate runoff from relatively large events and the assumptions around the shape of the hyetograph are intended to represent a worst case scenario in terms of flooding. Analysis of the rainfall records (refer Appendix C) indicates that calculating a WQF using TP10 / TP108 methodology treats the runoff from almost the entire annual rainfall (i.e. significantly oversized devices). Further analysis has indicated that a WQF based on 10 mm/hr constant rainfall intensity is equivalent to treating the runoff from 90% of the annual rainfall, irrespective of location within the region. Most flow based devices treat relatively small catchments and, as such, it is reasonable to use the Rational Method to calculate the runoff flows to the device. An appropriate methodology for this is contained in Chapter 10 of TP10 (Oil Water Separators).

4.4.3 Implications of the Unitary Plan stormwater contaminant management provisions

The practical implications of the changes to the contaminant management approach are:

- Wet ponds do not meet the controlled activity requirements. Wet ponds may only be implemented under a restricted discretionary framework where they are demonstrated to be the best option. Wetlands are presently accepted as meeting the controlled activity requirements.
- Galvanized steel, Zn-Al coated steel, copper and CCA treated wood are defined as high-contaminant generating roofing materials, unless coated or painted. Roofing materials with coatings containing copper-based algaecide are also included in this definition. Any of these materials must provide treatment with a BMP that complies with the DEQRs for TCu and TZn, in order to comply with the controlled activity rules.
- While impervious areas are generally assessed as being below the relevant DEQRs, impervious car parking areas receive contaminants from both atmospheric deposition and motor vehicle movements such as access and manoeuvring. For this reason, they are also considered to be HCGAs and require treatment.
- Industrial activities are also considered HCGAs, but are not controlled under the stormwater management provisions as they are managed under the Industrial and Trade Activity provisions of the Unitary Plan. It is appropriate to take a case-by-case approach to these activities as the contaminants present are atypical of stormwater contaminants and dependent on the nature of the industrial activity.

5.0 Flow / volume management

5.1 Introduction

This section discusses how the proposed stormwater flow/volume rules in the Unitary Plan were developed, how they are intended to be implemented, and how they relate to current stormwater management practice in the Auckland Region. The information in this section is largely based on the "Hydrologic basis of stormwater design" report completed by The University of Auckland for Auckland Council (Fassman et al., 2012).

Section 3.2 provides an introduction to hydrology and how development changes hydrology which in turn affects stream health. The main effects of development that affect stream health are increased channel erosion and in some cases reduced groundwater flows. Section 3.2 also identifies that small storm events (<2yr ARI) require management to protect stream health from the effects of impervious surfaces associated with development.

5.2 Current approach to flow management

Current hydrology requirements from Auckland Council aim to protect the physical structure of the receiving stream. Auckland Council specifies an erosion control requirement of detaining runoff from the first 34.5 mm of rainfall and releasing it over a 24 hour period (Auckland Regional Council, 2003).

This section contains a discussion on the current mitigation requirements and whether they adequately mitigate the effects of development on stream health.

5.2.1 Stream erosion protection

Extended detention is a method intended to reduce the frequency, magnitude and duration of post-development bankfull flow conditions, by detention and release of runoff in a gradual manner, thus minimising the exceedance of critical erosive velocities (i.e. critical shear stresses) in the downstream channel. The USA states of Maryland, Georgia, and Vermont adopt requirements of 12–24 hr extended detention of the 1-yr, 24-hr storm event (Maryland Department of the Environment, 2009) (Georgia Stormwater Management Manual, 2001), (Vermont Agency of Natural Resources, 2002), which is similar to the current ARC approach, noting the smaller storm magnitude compared to Auckland requirements. The shorter duration (12-hr) is specified in Vermont where sites discharge to cold water fish habitats. Shorter duration events have lower runoff volumes, reducing size and cost of devices. Additional requirements of erosion prevention measures such as energy dissipation, velocity control and stream bank stabilization, and the establishment of riparian stream buffer are specified in the Georgia manual (Georgia Stormwater Management Manual, 2001), although Shields states that bank protection is ineffective if stream bed degradation is occurring (Shields Jr., Copeland, Klingeman, Doyle, & Simon, 2003). The volume of runoff for extended detention of the 1-yr, 24-hr storm is also known as the channel protection storage volume (C_{pv}), which is roughly equivalent to the volume required for peak flow control of 5 to 10-yr storms (Brown & Caraco, 2001), (Maryland Department of the Environment, 2009), (Georgia Stormwater Management Manual, 2001).

Modelling based on a Maryland site demonstrated that extended detention of 1-yr 24-hour storm significantly reduced the erosive velocities for critical smaller storms and approximated the distributed runoff control (DRC) approach for storms <50 mm in 24 hrs (Brown & Caraco, 2001), (Fassman-Beck, Voyde, & Liao, 2013). The advantage of the extended detention approach over the DRC is that it is relatively easy to apply and it does not require extensive field measurements to determine the appropriate storm event. Therefore, a stormwater mitigation strategy that incorporates on-site controls to mimic pre-development volume, peak flow, and timing for the 1-yr, 24-hr ARI storm is likely to provide significant protection from channel erosion downstream.

The key determinant to successful implementation of an extended detention control measure is determining the allowable release rate. If the specified release rate, such as the peak flow from the 1-yr, 24-hr ARI event, produces greater velocities than the flow velocities responsible for channel erosion, then the extended detention device will not achieve erosion protection.

As indicated previously, current practice is to detain runoff from the first 34.5 mm of rainfall and release it over a 24 hour period (Auckland Regional Council, 2003). The 34.5 mm requirement is a rainfall–based standard, which acknowledged the variation of potential impacts associated with different types of land use. For example, the volume of runoff generated from 34.5 mm of rainfall over an industrial area with high imperviousness will be significantly greater than the volume of runoff generated from 34.5 mm of rainfall over a single family residential development, and thus the impacts to the receiving stream are likely to be different. The volume of runoff to be stored for extended detention from the 34.5 mm of rainfall is calculated based on the entire site area, ignoring pre-development conditions.

The original document which led to the 34.5 mm requirement has not been reviewed herein, as the validity or justification of it was reviewed by the ARC in 2008 (Shaver, 2008), (Teal, 2008). These reviews took the form of discussion papers, which are included as an appendix in a previously published report (Fassman-Beck, Voyde, & Liao, 2013).

Shaver's report documents the ARC's quest to find a simple, regionally appropriate method to provide stream channel erosion protection from stormwater runoff. Development of the method started with a desktop study, the results of which were attempted to be verified with a field study by the National Institute of Water and Atmospheric Research (NIWA). Despite the field study and subsequent additional desktop work, the ARC has not been able to justify nor refute, or invalidate, the 34.5 mm requirement. It was also observed that the erosion process is quite complicated, and a region-wide rule might not be appropriate.

The Teal report compares the 34.5 mm requirement with erosion control policies from three jurisdictions in the western United States (San Diego, San Francisco Bay Area, and Washington State) (Teal, 2008). Determination of shear stress appears to be theoretically the most robust or direct method for assessing erosion potential. The report concludes that without determining the shear stress within a stream specifically, there does not appear to be a simple, agreed upon approach for mitigating erosion potential. Again, the report does not recommend changing the current ARC rule based on current knowledge, but does suggest an investigation into how the rainfall standard for erosion control relates to effective shear stress in the channel.

The 34.5 mm requirement primarily aims to prevent accelerated downstream channel erosion resulting from increases in impervious area. Protection of the amenity value of streams (i.e. protection of habitat and riparian areas; etc.) requires the attenuation of peak flows through the 2- and 10 yr storms since it is the "flashy", high run-off rates which cause "out of bank" destabilisation, vegetation to be damaged, etc. The conclusion from this is that attenuation of the 2-yr and 10-yr events provides benefits beyond flood protection, by protecting stream habitat and planted riparian margins.

Since the 34.5 mm requirement is designed as a volume and not a flow rate, shorter duration 2 and 10 year events may be attenuated by EDV requirements protecting stream habitat and planted riparian margins from flashy, short duration events.

Conclusions from review of local information are summarised as:

1. The stream erosion studies undertaken to date have been inconclusive for scientific justification of the 34.5 mm design storm; and
2. The 34.5 mm design storm may not be appropriate on a catchment specific basis.

The ARC requirements followed the principles of flow control and were international best practice at the time they were developed. The requirements have provided significant benefit over a do-nothing approach.

As discussed in Section 3.2.4, development affects stream health in many ways, one part of which is erosion. The Unitary Plan represents an opportunity to revisit these rules and look at current international best practice. Stormwater management is constantly evolving; therefore the rules in the Unitary Plan should reflect this. A literature review of academic and additional regulatory approaches was undertaken to further investigate relationships between stormwater runoff and stream erosion, and design approaches for controlling these impacts (Fassman-Beck, Voyde, & Liao, 2013). The results of this literature review are summarised in this report, the full text is available from Auckland Council's website.

5.3 International approaches to hydrology management

The emerging goal/approach of international stormwater management is to mimic, as much as possible, the hydrological and water quality processes of natural systems as rain travels from the sky to the stream, through combined application of a series of practices throughout the entire development area and extending to the stream corridor. The philosophical basis for reducing the impact of post-development changes to stormwater is to avoid exposing receiving waters to impact sources or to otherwise minimise that exposure. The concept embraces both water quantity and quality impact sources and specifically raises water quantity to the same level of scrutiny as traditionally applied to water quality sources (National Research Council, 2008).

The water quantity stream channel erosion controls described in Section 5.2 do not fully address the hydrological changes resulting from development. Additional problems related to the stream erosion controls are water quality, thermal impacts, reduced inflow, and reduced baseflow. Internationally, stormwater management has embraced Water Sensitive Design (WSD) as the basis for mimicking natural systems to help avoid or mitigate these problems.

5.3.1 Water Sensitive Design (WSD)

Water Sensitive Design (WSD) is a multidisciplinary design approach to planning and land development that applies a set of key principles to determine land development form and the management of associated environmental effects. Within the literature, the general concept of WSD may be presented as Low Impact Development (LID), water sensitive urban design (WSUD, commonly used in Australia), sustainable urban drainage systems (SUDS, commonly used in the UK), green infrastructure, environmental site design, sustainable site design, or better site design (used relatively interchangeably throughout the USA). The term WSD is used herein to reflect the entire suite of nomenclature.

In GD04, the Auckland Council Guideline for Water Sensitive Design for Stormwater (Auckland Council, 2013), a set of principles is provided to inform Water Sensitive Design approaches to land use planning and development. It must be noted that WSD is not a panacea for land use change, since some sites may be considered too sensitive and/or their existing values too significant to develop. The four principles of WSD are:

1. Promote inter-disciplinary planning and design;
2. Promote the values and functions of natural ecosystems;
3. Mitigate stormwater effects as close to source as possible; and
4. Utilise natural systems and processes for stormwater management.

Stormwater hydrology rules in the Unitary Plan assist with implementation of principles three and four above, providing requirements for hydrology controls using natural systems and processes. The other two principles require integration across departments of the council and sections of the Unitary Plan and while relevant provisions are included in the Unitary Plan, this is out of the scope of this report.

The WSD approach to hydrology management aims to keep post-development increases to runoff volumes out of receiving waters entirely, reducing associated pollutant loads and protecting against separated or combined sewer overflows and hydromodification effects such as channel erosion of the receiving waters. When rainfall is retained, it also provides critical recharge and base flow functions.

Channel erosion literature points to the sources of increased erosion potential (increased peak flow, volume, and duration of elevated flows for bankfull events—often associated with flows from 6-month to 2-yr ARI); while WSD literature points to solutions and management schemes to address all of these problems. Fundamental to the WSD scheme is distributing controls throughout the landscape to manage hydrology on-site, before runoff is concentrated in a significant point of discharge.

It has been proposed that there are two key stormwater design criterion for preservation of environmental values in receiving waters (Argue, Pezzaniti, & Hewa, 2012). The first is to ensure peak flows do not exceed channel forming flow rates. Peak flow control is insufficient alone, as conventional detention techniques still result in erosion due to the extended nature of the hydrograph compared to pre-development conditions. Thus, criterion two is preservation of the channel forming hydrograph volume. The design storm hydrograph volume in the developed catchment should be as close to possible to that estimated for catchment pre-development. Phrasing allows for the fact that achieving identical runoff hydrographs for pre- and post-development is very difficult in practice. Runoff volume increases should therefore be minimised as far as technically feasible; implicit in this statement is a concession that matching pre-development volume may be unachievable in some cases.

5.3.2 International examples of hydrology mitigation

Based on the literature, it is apparent that small, frequently occurring rainfall events dominate catchment hydrologic parameters typically associated with water quality management issues. These small storms are responsible for most annual urban runoff and groundwater recharge. Likewise, with the exception of eroded sediment, they are responsible for most pollutant wash off from urban surfaces. Therefore, the small storms are of most concern for the stormwater management objectives of ground water recharge, water quality resource protection and control of thermal impacts (Clar, Barfield, & O'Connor, 2004).

Many jurisdictions overseas have been developing regulations with the performance requirement to limit hydromodification, including the volume of stormwater runoff and runoff timing. Terminology is not always consistent, but mitigation objectives are reminiscent of the general WSD principles. Table 8 identifies the hydrologic basis of design for a variety of international jurisdictions, organised by country. Jurisdictions have been included based upon their promotion of WSD technology through relevant regulations and guidance, reflecting a progression in current stormwater management approaches from conventional methods.

In addition to Table 8, the USEPA has published a document summarising the post-construction stormwater standards for all US states (US EPA, 2011). Inclusion of every state is outside the scope of the literature review, particularly as the predominant focus has been to identify the regulatory means adopted by states and cities promoting WSD, however the reference is included for completeness.

A number of studies not presented in Table 8 do not specifically designate a hydrologic basis of design, but encourage the use of non-structural controls and design strategies such as WSD (Urban Water Resources Centre, 2008) (National Resources Defense Council, 2011) (Alliance of Rouge Communities, 2012) (US EPA, 2010).

Qualitative literature pertaining to Water Sensitive Design (WSD) suggests that control of frequently occurring, “everyday” runoff events in terms of timing, volume, and peak flow rate is required to mitigate effects of urban runoff (Urban Water Resources Centre, 2008). Therefore hydrology controls for the natural environment focus on channel erosion and stream health (zones 1 and 2 of Figure 9).

Table 8. Stormwater regulations for a selection of international jurisdictions.

Jurisdiction	Reference	Requirement for WSD[1]	Groundwater recharge	Water quality volume	Channel protection/ erosion control/ CSO prevention
USA					
California	(California Environmental Protection Agency, 2009)	Required	Volume control option: Control either 85% of 24-hr storm runoff event or the volume required to capture 80% or annual runoff Flow control option: 10% of the 50-yr peak flow rate, or runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity, or runoff resulting from a rain event equal to at least 5.1 mm hr^{-1} intensity		
California (Santa Monica)	(City of Santa Monica, 2012)	Required for new and redevelopment projects	Manage 19.1 mm onsite through infiltration or treatment and release (~80% of rainfall events annually)		
Georgia	(Alliance of Rouge Communities, 2012)	Requirement to preserve natural drainage systems and reduce generation of additional runoff	Maintain annual GW recharge rates to the MEP[2]	Treat runoff from the 85th percentile storm (the first 30.5 mm of rainfall from a site)	24-hr extended detention of the 1-yr, 24-hr return frequency rainfall event
Illinois (Aurora)	(Kane County Stormwater Management Committee, 2001)	Use of natural drainage systems encouraged	Manage first 19.1 mm rainfall onsite, no direct connection to downstream areas allowed		
Illinois (Chicago)	(City of Chicago Dept of Water Management, 2012)	Recommended	Manage 12.7 mm runoff onsite or reduce the prior imperviousness of the site by 15%		Maximum allowable release rate is 4.2 L s^{-1} or 7.1 L s^{-1} dependant on site size
Kansas (Lenexa)	(Kansas City Mid-America Regional Council, 2008)	Use WSD treatment train approach to the MEP	Capture and treat 34.8 mm (equivalent to 90% of the average annual stormwater runoff volume of all 24-hour storms)		
Maryland	(Maryland Department of the Environment, 2009)	Implement to the MEP	Maintain existing groundwater recharge rates	Catch and treat runoff from 90% of the average annual rainfall (22.9 mm or 25.4 mm dependant on location)	24 hr extended detention of post developed 1-yr, 24-hr storm event
Maryland (Prince George's County)	(Prince Georges County Department of Environmental Resources, 1999)	Recommended	Maintain pre-development hydrology: design storm is the greater of the rainfall at which direct runoff begins from a catchment of woods in good condition, with a modifying factor of 1.5, or the 1-yr, 24-hr ARI event; $P=\max(P_{wood},P_{(1\text{-yr},24\text{-hr})})$		
New York (New York)	(New York State Department of Environmental Conservation, 2012)	Required to make "best efforts" to meet goals	Goals are staged: control the stormwater generated by 25.4 mm of precipitation on 1.5% of impervious surfaces citywide in combined areas by 2015 (on 4% of impervious areas by 2020, on 7% of impervious areas by 2025, and on 10% of impervious areas by 2030)		

Jurisdiction	Reference	Requirement for WSD[1]	Groundwater recharge	Water quality volume	Channel protection/ erosion control/ CSO prevention
North Carolina	(North Carolina Department of Environment and Natural Resources, 2009)	To minimise impervious surfaces and to treat stormwater runoff using BMPs	Sites draining to saltwaters: capture of runoff from the 38.1 mm storm, for "shellfishing" and "outstanding resource" waters the greater of 38.1 mm storm or pre/post difference for the 1-year, 24-hour storm Sites draining to freshwaters: capture of runoff from the 25.4 mm storm All sites: No increase in peak flow leaving the site from the pre-development conditions for the 1-year, 24-hour storm		
Oregon (Portland)	(Portland Bureau of Environmental Services, 2008)	Required for new and redevelopment projects to the MEP	Infiltrate onsite to the MEP	Capture and treat 80% of the annual average runoff volume	Ultimate discharge to a surface water body: detain 2-yr post-development peak to ½ the 2-yr pre-development peak, and 5-yr, 10-yr, and 25-yr post-development peaks to equivalent pre-development rates Discharge to a combined sewer: detain the 25-yr post-development peak to the 10-year pre-development peak
Pennsylvania (Philadelphia)	(Philadelphia Water Department, 2009)	Required, post-development peak runoff rates must match pre-development conditions	The first 25.4 mm of precipitation over directly connected impervious cover must be recharged. (equiv. to 80-90% of runoff on an annual basis) Where recharge is not feasible, remaining volume is subject to an acceptable water quality practice.		The 1-yr, 24-hr storm must be detained and slowly released over 24–72 hrs at a maximum rate of 6.8 L s^{-1} per acre
Pennsylvania (Pittsburgh)	(City of Pittsburgh, 2007) (City of Pittsburgh, 2010)	Required for new and redevelopment projects to the MEP	Manage the first 25.4 mm of runoff onsite Do not increase the post development runoff volume for all storms $\leq$ 2 yr 24 hr duration rainfall. Publicly subsidised projects, manage all runoff from $\leq 95^{th}$ percentile storm (38.1 mm)		Do not increase peak rate of runoff for 1-, 2-, 10-, 25-, 100-year storms (minimum) pre-development to post-development
Tennessee (Nashville)	(Metropolitan Government of Nashville and Davidson County, 2012)	Recommended, identifies future requirement for use to MEP	Capture and use the first 25.4 mm of rainfall per day (equiv. to 80% of average annual rainfall)		
USA Dept. of Defense	(US Department of Defense, 2010)	All Dept. of Defense construction must maintain pre-development hydrology and prevent any net increase in stormwater runoff	Total volume of rainfall from 95^{th} percentile storm is to be managed on site, or the required water quality depth as defined by the State or local requirements, whichever is more stringent. First flush water quality volume defined by the local regulatory agency, generally taken as the first 25.4 mm of rainfall, in localities with sensitive coastal or reservoir watersheds, may be taken as first 38.1 mm of rainfall		
Vermont	(Vermont Agency of Natural Resources, 2002)	Identified as an option	Recharge volume as a multiplier of impervious area (i.e. SCS soil group type A: 10.2 mm x impervious area)	Catch and treat runoff from 90% of the average annual rainfall (22.9 mm)	12-24 hr extended detention of post developed 1-yr, 24-hr storm event
Virginia	(Virginia Department of Conservation and	-	-	Detain the first 12.7 mm rain to fall over impervious surfaces	24 hr extended detention of the 1-yr, 24-hr event

Jurisdiction	Reference	Requirement for WSD[1]	Groundwater recharge	Water quality volume	Channel protection/ erosion control/ CSO prevention
	Recreation, 2004)				
Washington (Seattle)	(Seattle Public Utilities, Department of Planning and Development, 2009)	Implement to the MEP for new and redevelopment projects	Onsite treatment of the daily runoff volume at or below which 91% of the total runoff volume occurs		Match post-development discharge flow rates and durations to pre-developed forest condition for the pre-developed range from 50% of 2-yr ARI event to the 50-yr ARI. The post-development 25-yr ARI flows ≤11.3 L s^{-1} per acre; and 2-yr ARI flows ≤4.2 L s^{-1} per acre.
Washington (Western)	(Washington State Department of Ecology, 2011)	Required for new and redevelopment projects	WQ flow rate at or below which 91% of the runoff volume will be treated; the runoff volume must pass through the treatment device at or below the approved hydraulic loading rate for the device		<u>WSD performance standard:</u> match developed discharge durations to pre-developed (pre-European) durations for the range of pre-developed discharge rates from 8% of 2-yr flow to 50% of 2-yr flow <u>Flow control standard:</u> match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of 2-yr flow up to the full 50-yr flow
Washington, D.C.	(Government of the District of Columbia, 2011)	Required for new and redevelopment projects	On-site retention of the 90th percentile volume, or 30.5 mm		
Wisconsin (Milwaukee)	(Milwaukee Metropolitan Sewerage District, 2010) (Milwaukee Metropolitan Sewerage District, 2012)	Identified in guidance manual for new and redevelopment, recommended in Strategic Objectives	Limit post-development runoff volumes to existing condition runoff during the critical time period[3]; outflow volume must be maintained in both the 100-yr and 2-yr ARI events. Strategic objective to use WSD to capture the first 12.7 mm by 2035		Limit site outflows to a release rate of 14.2 L s^{-1} per acre for the 100 yr ARI event and 4.2 L s^{-1} per acre for the 2 yr ARI event

Canada					
Ontario (Toronto)	(Toronto Water Infrastructure Management, 2006)	On-site control to the MEP to match annual developed runoff volumes to pre-development (current) conditions	On-site retention of 5 mm (equiv. to ~50% of annual average 24-hr rainfall volume) through infiltration, evapotranspiration and rainwater reuse		Control post development peak flows to pre-development levels for all storms up to and including the 100 yr storm Large sites, typically onsite detention of 25 mm with ≥24 hrs release Detain post-development runoff from a 30 mm storm for ≥24 hrs for Tributary "B" of the little Rouge Creek (Rouge River watershed) Detain post-development runoff from a 33 mm storm for ≥48 hrs for the Morningside Tributary (Rouge River watershed)

Jurisdiction	Reference	Requirement for WSD[1]	Groundwater recharge	Water quality volume	Channel protection/ erosion control/ CSO prevention
United Kingdom					
England	(London Department for Environment, Food and Rural Affairs, 2011)	Required for new and redeveloped sites	Surface runoff discharged to the ground where possible Water not infiltrated must be discharged to a surface water body Next alternative is to stormwater reticulation, followed by combined sewer.	Retain onsite the first 5 mm of any rainfall event	Peak flow rate and volume restricted: Peak flow for the 1 yr and 100 yr ARI events ≤ equivalent greenfield runoff rates. Runoff volume < greenfield for the 100 yr, 6-hr event or Peak flow restricted: 1 yr ARI flow rate ≤ greenfield runoff rate from the site or 2 $L\ s^{-1}ha^{-1}$; 100 yr ARI flow rate ≤ greenfield mean annual flood for the site or 2 $L\ s^{-1}ha^{-1}$ Both: 100 yr ARI required storage volume calculated using the critical duration event
Australia					
Lower Hunter and Central Coast Region	(Hunter Central Coast Regional Environmental Management Strategy, 2007)	Requires "water smart development"	Site discharge index (SDI) ≤ 0.1, SDI takes into account source control measures and gives "effective impervious area" Performance standard for stormwater controls: frequent discharge mitigation, complete mitigation of increased runoff from impervious surfaces for rainfall events with a 3 month ARI.		
Southeast Queensland	(Queensland Department of Infrastructure and Planning, 2009)	-	0-40% total impervious: manage onsite the first 10 mm of runoff >40% total impervious: manage onsite the first 15 mm of runoff Storage capacity must be restored within 24 hrs of the runoff event.		Limit post-development 1-yr ARI event peak discharge to the pre-development peak
Western Australia	(Government of Western Australia Department of Water, 2009) (Government of Western Australia Department of Environment, 2004) (Government of Western Australia Department of Environment, 2004)	To maintain the total water cycle balance within development areas relative to pre development conditions	≤1-yr ARI events: Retain/detain runoff from impervious surfaces generated by up to 1-yr, 1-hr ARI events on-site. Detention systems should preserve the pre-development critical 1-yr ARI peak flow rate and discharge volume for the catchment. 1-yr to 100-yr ARI events: Manage runoff from impervious areas for >1-yr, 1-hr ARI events in landscaped retention/detention areas in road reserves, public open space or linear multiple use corridors. Runoff into waterways and wetlands shall be by overland flow paths across vegetated surfaces.		

Notes:

1. WSD = Water Sensitive Design; may be called Low Impact Design(also LID), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDS), Green Infrastructure (GI), Environmental Site Design (ESD) or Sustainable Site Design in some guidelines

2. MEP = Maximum Extent Practicable; may be Maximum Extent Feasible (MEF) in some guidelines

3. Critical time period = also critical duration, the duration of a specific event (i.e.: 100 year ARI event) which creates the largest volume or highest rate of net storm water runoff (Post "Q" less Pre "Q") for typical durations up to and including the 10 day duration event.

Multiple approaches for stormwater management are evident. The main similarity identified in Table 8 is the acknowledgement that peak flow control as an isolated measure is insufficient to protect receiving waters. Better mitigation against hydromodification and water quality impairment is afforded by comprehensive management strategies, such as WSD, that consider multiple hydrologic characteristics: flow, volume, duration, and timing.

Traditional peak flow control is replaced, or added to, with volume control, generally in the form of a water quality volume that ultimately acts to address hydromodification by limiting changes in flow rate and flow duration within the receiving waters (Queensland Department of Infrastructure and Planning, 2009) (Philadelphia Water Department Office of Watersheds, 2011). Volume control and specifications for groundwater recharge are utilised to protect aquatic biota, limit impacts on receiving water quality (maintain stream channel stability, reduce runoff pollution, and reduce combined sewer overflows (CSOs)), and restore natural site hydrology, so as to promote appropriate aquifer levels, recharge and streamflow characteristics (Hunter Central Coast Regional Environmental Management Strategy, 2007) (Philadelphia Water Department Office of Watersheds, 2011) (City of Pittsburgh, 2010). Examples demonstrating general requirements for a water balance approach are:

- "...maintain the total water cycle balance..." (Government of Western Australia Department of Environment, 2004);
- "...infiltrate, evapotranspire, or capture and reuse..." (Metropolitan Government of Nashville and Davidson County, 2012);
- "...recharge groundwater, restore natural site hydrology, reduce runoff pollution and CSOs" (Philadelphia Water Department Office of Watersheds, 2011); and
- "...preserve natural drainage systems..." (Atlanta Regional Commission, 2001) (Kansas City Mid-America Regional Council, 2008)

Auckland's ALW Plan contains some general requirements for a water balance approach including permitted activity rule 5.5.1 (f) "shall minimise changes to the pre-development hydrological regime ….. the volume of stormwater runoff for post-development events shall be minimised" (Auckland Council, 2012). Infiltration and evapotranspiration are not mentioned specifically in the ALW Plan.

A common trend was the restriction to match post development runoff to pre-development conditions for one, or any combination of, the following (Table 8):

- Peak runoff rates (most common);
- Total volume; and
- Duration or hydrograph timing

The ALW Plan references all three of the above factors. Permitted activity rule 5.5.1 (f) contains the following:

1. The peak flows for the 2 year and 10 year ARI post-development events shall not be greater than the corresponding peak flows for pre-development events; and
2. The volume of stormwater runoff for post-development events shall be minimised; and

3. The time of concentration for post-development events shall be maximised so that it is as close as practicable to those for pre-development events.

In practice, only item 1 was widely adopted as items 2 and 3 did not define exactly what design target had to be achieved. The intention of the rule was good, but the implementation of non-absolute statements within a permitted activity rule was not achieved in practice, likely due to uncertainty over exactly what had to be done and an inability to demonstrate non-complinace if it wasn't.

Onsite retention of a water quality volume, or a water quality design depth, is reflected throughout international regulations (Table 8). The water quality volume to be retained and treated is defined using a variety of methods:

- Capture and treat a percentile rainfall event ("rainfall capture rule")
    - Typical range from 80^{th}–95^{th} percentile
    - One exception was the 50^{th} percentile (Toronto Water Infrastructure Management, 2006)
- Capture and treat a specified depth
    - Typical range from 25.4–38.1 mm
    - Often related to a percentile event (80^{th}–95^{th} percentile)
- Capture and treat the volume associated with an ARI event
    - For example the 3 month ARI event, or all events $\leq$2 yr ARI.

The ALW Plan did not specify a design event or depth for volume based controls and, as mentioned above, on-site retention was not widely adopted under the ALW Plan.

The rainfall capture rule is a currently accepted method, commonly used for defining the water quality capture volume. It is based on the long term frequency analysis of daily rainfall depth and is based on the capture of a certain percentile frequency rainfall event. The rainfall frequency spectrum curve gives the percentage of time that a given rainfall depth is equalled or exceeded. In the spectral analysis, the rainfall events which do not produce runoff are eliminated from the analysis (Shamseldin, 2010). The resultant graph typically shows a sharp curvature (knee or inflection point), normally between the 85^{th} and the 90^{th} percentile rainfall depth. The inflection point is recognised as the volume that captures a significant number of rainfall events (Table 8) without attempting to treat the small percentage of much larger events that result in large volumes of runoff (Shamseldin, 2010). Such events would be expensive to treat, are rare in occurrence, and typically diluted in pollution concentration. Hence, optimization of the device size is implicitly taken into consideration (Shamseldin, 2010). Capturing small and frequent rainfall events, in the range of 85^{th}–95^{th} percentile events, retains a large proportion of the total annual runoff volume, reducing discharge volume and pollutant loads (National Resources Defense Council, 2011).

The District of Columbia states that retention, or volume control, of all rainfall events $\leq 95^{th}$ percentile rainfall event is comparable to maintaining or restoring the pre-development hydrology with respect to the volume, rate, and duration of runoff for most sites. The 95th percentile has been selected for the mid-Atlantic region as it appears to reasonably represent the volume that is fully infiltrated in a natural condition and thus should be managed onsite to restore and maintain pre-development hydrology for the duration, rate and volume of stormwater flows. The document recognises that the 95th percentile volume is not a "magic" number; there will be variation based on site-specific factors when replicating pre-development hydrologic conditions. However, this metric represents a good approximation of what is protective of water quantity on a catchment-wide scale (Government of the District of Columbia, 2011). It can be easily and fairly incorporated into standards, and can be equitably applied on a jurisdictional basis.

Many jurisdictions included requirements for groundwater recharge (Table 8), for example:

- Maintain existing infiltration rates (Maryland Department of the Environment, 2009);
- Recharge calculated as a multiplier of impervious area (Vermont Agency of Natural Resources, 2002); and
- Infiltration to the MEP (Portland Bureau of Environmental Services, 2008) (Atlanta Regional Commission, 2001) (London Department for Environment, Food and Rural Affairs, 2011)

The recharge volume is typically expressed as a runoff volume from impervious surfaces (dependant on the climate and soil type of the region). It is usually identified as a depth for which very little runoff occurs from grass or forested areas, which is why runoff from impervious surfaces is used as the criterion (National Research Council, 2008). Groundwater recharge is a significant inclusion to guidance and regulations as it is one of the key hydrologic functions provided by a natural landscape that is often significantly compromised by urbanisation, and typically unaccounted for in conventional stormwater mitigation measures.

Generally, volume retention measures are designed to handle at least the first flush from impervious surfaces; however in retrofit situations, capture amounts as small as 10 mm are a distinct improvement. Extending stormwater requirements to redeveloping property also gradually "levels the playing field" with new developments subject to the requirements (National Research Council, 2008).

In addition to volume control and groundwater recharge requirements, many international regulations and guidelines included in Table 8 had detention requirements for the purpose of channel protection, erosion control and/or CSO prevention. Requirements were again varied:

- Extended detention of a particular design storm
  - 12–24 h extended detention of the post developed 1-yr, 24-hr event
- Maximum allowable release rate from the site
  - From 4.2–11.3 L s^{-1} per acre
- Match post developed runoff rates to pre-developed rates for specified ARI events
  - i.e. 50% of 2-yr up to 50-yr
- Match post developed runoff durations to pre-developed durations for specified ARI events
  - With the aim to increase protection of streams from erosion, the duration standard is seen as harder to meet than the volume standard (Washington State Department of Ecology, 2011).

In all regulations there are exceptions. Regulations pertained to new development alone; included re-development, or projects above a certain area/ imperviousness/ site disturbance; and/or made allowances for where the receiving water is already degraded. Regardless, the similarity amongst jurisdictions was provision of hydrologic control for frequently occurring, small rainfall events not typically accounted for using traditional stormwater management techniques. The literature concur that in-stream flows should be maintained at pre-development levels for frequently occurring rainfall events (while also controlling total volume and timing of discharge).

5.3.3 Recommendations

The definition of "pre-development conditions" varied between jurisdictions. The more stringent definitions encompassed woods, forest, or pasture in good condition while the least stringent referred to the current condition of the site prior to development, even if development was occurring on a brownfield site. The limited scope of this latter definition, development of a brownfield site, does not allow for improvement to an already impaired hydrologic condition.

The parameters of the hydrograph to be matched to pre-development conditions also varied in definition. The US Department of Defence gave the most stringent definition where pre-development hydrology meant "pre-project hydrologic conditions of temperature, rate, volume, and duration of stormwater flow" (US Department of Defense, 2010). The more lenient definitions referred only to matching peak flow rates post-development to pre-development rates.

The US EPA comments that in order for a performance standard requiring pre-development hydrographs to match post-development hydrographs to be effective, it must clearly identify all hydrograph parameters (volume, rate, duration, and frequency) to be matched (US Environmental Protection Agency Office of Water, 2010). Many current hydrology standards focus only on discharge rate, which is primarily a flood control approach. In addition, a pre-development condition should also be defined, and that condition should be one that is reasonably 'natural', rather than simply the conditions that existed immediately prior to the current developed site (US Environmental Protection Agency Office of Water, 2010). For the purposes of the Unitary Plan, pre-development is recommended to be forested if the site is currently forested and pasture for all other situations.

The USEPA give example performance standards to reduce stormwater discharges to the maximum extent possible (MEP) (US Environmental Protection Agency Office of Water, 2010). The requirements below are the options considered for the Unitary Plan:

- Minimum depth to be retained on site:
  - Manage rainfall on-site, and prevent the off-site discharge of the precipitation from [insert guideline, such as "the first 25 mm of rainfall from a 24-hour storm preceded by 48 hours of no measurable rainfall"].
- Minimum storm category to be retained on site:
  - Manage rainfall on-site, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to [insert guideline, such as "the 95th percentile rainfall event"].
- Hydrologic analysis:

- Preserve the pre-development runoff conditions following construction. The post-construction rate, volume, duration and temperature of discharges must not exceed the pre-development rates and the pre-development hydrograph for all storm events up to the 100 year event must be replicated through site design and other appropriate practices.
- Groundwater recharge requirement:
    - Demonstrate through hydrologic and hydraulic analysis that the site and its stormwater management measures maintain 100% of the average annual pre-construction groundwater recharge volume for the site; or
    - Demonstrate through hydrologic and hydraulic analysis that the increase of stormwater discharges volume from pre-construction to post-construction for the two-year storm is infiltrated.
- Limiting total impervious surface (or effective impervious surface):
    - Minimise total impervious cover resulting from new development and redevelopment to [insert guideline, such as <10% of disturbed land cover and/or limit total amount of effective impervious surface to no more than 5% of the landscape].

Requirements should allow for a combination of canopy interception, soil amendments, infiltration, evapotranspiration, and rainfall harvesting and reuse, rather than relying on one technique, such as infiltration alone, to meet performance guidelines (US Environmental Protection Agency Office of Water, 2010) (National Research Council, 2008).

Requirements also need to fit Auckland's unique geological and hydrological conditions. Modeling the ability of WSD approaches to meeting some typical U.S. retention requirements, in different soil types, was carried out by the US EPA (Horner & Gretz, 2011). For Type D soils, with similar hydraulic properties to Auckland's clay soils, it was found that infiltration was *not* capable of *fully* retaining the post-development runoff from the 85th to 95th percentile storms, without additional retention practices, such as living roofs or rainwater harvesting, etc.

Given Auckland's typically difficult soil conditions (i.e predominantly clay), a hybrid minimum storm size approach is recommended. The design storm should be controlled through a combination of retention (volume reduction) and detention (peak flow reduction). The retention criteria should be based on the percent reduction that most retention BMPs can achieve in clay soils. The detention criteria should control the entire design storm event (i.e. the total volume of the device minus volume lost during the storm event should be equal to the design storm runoff volume).

Using a catchment wide approach to implement control requirements is more effective than purely at a site basis (National Research Council, 2008) (National Resources Defense Council, 2011). Sub-catchment classification allows definition of achievable numerical benchmarks in terms of the MEP, particular to the level of development and associated condition of the receiving waters. The goals for water and habitat quality should become less stringent as impervious cover increases within the catchment. This flexibility recognises the greater difficulty and cost involved in providing the same level of treatment in an intensely developed sub-catchment (National Research Council, 2008).

This method should not become an excuse to work less diligently to improve the most degraded waterways—only to recognise that equivalent, or even greater, efforts to improve water quality conditions will achieve progressively less ambitious results in more highly developed catchments (National Research Council, 2008).

A combination of catchment wide (particularly in developing catchments) and a site-based approach (particularly in existing developed areas) is recommended.

5.4 Proposed hydrology management

This section outlines the proposed hydrology mitigation techniques in the Unitary Plan. Rainfall frequency in Auckland is discussed and a suitable design event for the Auckland region is identified. Objectives and options for stormwater mitigation are discussed and proposed hydrology rules for the Unitary Plan are recommended.

5.4.1 Mitigation requirements

Traditionally there are three discrete components regulated for stormwater hydrologic mitigation: volume control, peak flow control, and flow release/timing. Progression in stormwater management methods means it is now more common to consider the full hydrologic cycle, taking an overall water balance approach. Based on findings from the literature review (Fassman-Beck, Voyde, & Liao, 2013), stormwater hydrologic mitigation guidelines for WSD devices in Auckland Region have considered all of the following options:

1. Rainfall depth to be retained onsite (aligns with “Water Quality Volume”, Table 8):
    a. Ideal: manage rainfall on-site, and prevent off-site discharge, from all rainfall events $\leq 95^{th}$ percentile rainfall event.
    b. Minimum: manage rainfall on-site, and prevent off-site discharge, from all rainfall events $\leq 90^{th}$ percentile rainfall event.
2. Groundwater recharge requirement (aligns with “Groundwater Recharge”, Table 8):
    a. Infiltrate onsite to the MEP.
    b. Take into account variation in Auckland’s subsoil conditions.
3. Hydrologic control (aligns with “Channel Protection/ Erosion Control/ combined sewer overflow (CSO) prevention”, Table 8):
    a. Preserve the pre-development runoff conditions following construction; the post-construction rate, volume, and duration of discharges must not exceed the pre-development levels for all events $\leq$2 year ARI event.
    b. Pre-development must be defined, “natural” conditions (i.e. forested) or more lenient (i.e. pasture in good condition).

All the options above aim to create runoff from a developed site that is equivalent to runoff from an undeveloped site, preserving site hydrology. It is recommended that the Unitary Plan require sites to produce equivalent runoff to the pre-development condition where appropriate. Technical criteria to be met to achieve this are discussed in the following paragraphs.

Retention to the MEP was permitted activity condition of the ALW Plan. In practice, the retention requirements of the ALW Plan were not implemented in the majority of cases due to the lack of a clearly defined goal (MEP could mean different things to different people). To avoid this issue in the Unitary Plan, desktop investigations into what is technically feasible on a clay soil site were carried out and a numeric rule based on these results has been developed.

Continuous simulation of the draft rain garden design for Auckland in clays soils found that approximately 40% of the annual rainfall volume can be retained onsite. 35% of the retention is provided through infiltration and 5% of the retention is provided through evapotranspiration. Since approximately 40% of Auckland's rainfall volume falls in events 10 mm or less, this study reinforces the 10 mm runoff depth as a target for retention. For further details on the continuous simulation model, refer to Section 5.5.2 for further details of this.

Rain tank studies on Auckland's North Shore investigated runoff reductions from rainwater reuse (personal communication David Kettle). Rain tanks were plumbed into the toilets and washing machines of the residential properties as well as being available for watering gardens. On average, 40% of the roof runoff was reused on-site. Since this 40% figure is the same as estimated for rain gardens in clay soils, rain tanks and infiltration practices should provide similar retention benefits.

Devices that can meet the 10 mm retention requirement include permeable pavement, gravel trenches, infiltration basins, rain gardens, tree pits, living roofs, rain tanks, soakage pits and French drains. TP10 or device technical reports detail how to achieve retention of stormwater in these devices.

The above examples show that a 10 mm retention requirement is achievable by a range of devices. Environmental outcomes of the retention requirement have been examined to ensure the requirement is producing the desired results. Studies in the USA found that retention of the first 10 mm of runoff in retrofit situations provided a distinct improvement in site hydrology (National Research Council, 2008).

The suitability of a 10 mm retention rule in an Auckland context was assessed against local studies carried out by the ARC, including a study that monitored four small streams over a two year period (McKergow, Parkyn, Collins, & Pattinson, 2006). Rainfall to runoff (including baseflow) rates for the catchments varied from 37% to 48%. Of this runoff 65% to 84% of was from baseflow, with the remainder coming from surface runoff. These figures have been converted to show the proportion of rainfall retained, converted to baseflow and converted to runoff (Table 9).

The ARC's TP10 also includes estimates of retention, baseflow and surface runoff for urban and natural catchments (Auckland Regional Council, 2003). These values are shown in Figure 8 and Table 9. Results from the continuous simulation model are also included in Table 9 to show the effect of the 10 mm retention requirement on restoring natural hydrology.

Table 9. Retention, baseflow and surface runoff results from various studies on an annual basis

	TP312 first order streams	TP10 natural catchments	TP10 urban catchments	Urban catchment (model)	10mm retention (model)
Retained on-site	57%	43%	33%	28%	31%
Baseflow	33%	30%	9%	10%	40%
Surface flow	10%	27%	58%	62%	29%

The results in Table 9 show that the 10 mm retention lowers surface runoff significantly compared to urban catchments (29% vs. 62%). This 29% figure is close to the 27% figure given in TP10 for natural catchments; however it is significantly higher than the 10% figure for first order streams. The difference in the first order streams and TP10 figures could be due to factors such as soil type and catchment size. The first order stream study focused on small catchments whilst the TP10 study covered typical catchments across Auckland.

A recent Auckland Council report, regarding the ecological responses to urban stormwater, recommends that, in order to protect stream health, stormwater flow management should focus on complete retention of small- to medium-sized flow events, mimicking the pre-development condition; retaining events on-site that do not produce surface runoff in completely natural catchments (Storey, et al., 2013). Information on storm depths that produce runoff in natural catchments is unavailable at this time. However, we can infer that if the proportion of rainfall becoming surface runoff is similar to a natural catchment, and that this is achieved by retaining small storm events up to a certain size, then the retention requirement likely meets the recommendation in the report.

The recommended retention requirement for the Unitary Plan is that 10 mm of runoff must be retained on-site for the 24 hr design event in sensitive SMAF 1 stream catchments and 8 mm in SMAF 2 sub-catchments. The retention can be provided through infiltration, evapotranspiration and/or reuse. This requirement is based on what devices can achieve in clay soils and measured reuse rates in Auckland.

If the designer cannot achieve the 10 mm requirements, they will be able to apply for a restricted discretionary activity consent. This assessment will take into account site characteristics and land use constraints in the decision whether to give consent without retention requirements being met. A regional groundwater recharge rule is not recommended for Auckland due to the variability in infiltration capacity of soils. As this retention requirement recommended above will promote infiltration practices, an additional rule is not required.

Existing hydrologic controls are used in Auckland through the requirement for the extended detention volume. This requirement is recommended to be fine tuned from a consistent storm depth (34.5 mm) across the region to a percentile event. This change is recommended so that detention requirements vary with rainfall depth characteristics across the region.

A recent report to define hydrologic mitigation targets for Auckland has calculated rainfall depths for the 90th and 95th percentile events (Fassman-Beck, Voyde, & Liao, 2013), based on rainfall analysis carried out previously (Shamseldin, 2010). Percentile analysis often assumes storms under a certain depth do not produce runoff. In the original rainfall analysis (Shamseldin, 2010) it was assumed that storms less than 5 mm do not produce runoff. International literature showed 0.1 inch; or 2.5 mm, is commonly used for this value, as storms between 2.5 mm and 5 mm can produce runoff on impervious surfaces. Rain data across Auckland was reanalysed with a 2.5 mm assumption to produce 90th percentile (Figure 13) and 95th percentile (Figure 14) rainfall maps for the region. Internationally, the 95th percentile event is the most common design storm for hydrologic control. The 95th percentile storm for the Auckland region has a median depth of 35.7 mm (Figure 14) with a depth of 34 mm across most of the urban area. The 90th percentile event has a median storm depth of 25.8 mm (Figure 13). The storm depths for the 90th percentile event are lower than current requirements and those used internationally. The 90th percentile event is not recommended for sensitive SMAF 1 sub-catchments as it is likely too permissive to meet stream health goals of the Unitary Plan.

The 95th percentile event is recommended for detention on-site as this aligns with the current extended detention requirement and international studies. Also the rain garden continuous simulation model showed that a rain garden sized to meet the 10 mm retention and 95th percentile event detention requirements produced runoff similar to the undeveloped West Hoe catchment. The recommended rule in the Unitary Plan is therefore that the 95th percentile storm volume shall be detained onsite in SMAF 1 sub-catchments.

The 95th percentile detention requirement and the 10 mm retention requirement can be provided in one single device; any storage volume provided to meet the 10 mm retention requirement can also be used to meet the 95th percentile detention requirement. Devices that can meet retention and detention requirements include raintanks (where the water is re-used), permeable pavement, raingardens, gravel trenches and infiltration basins.

For sites with higher permeability soils, the combination of providing detention for the 95th percentile event and providing retention through an infiltration practice will likely result in significant volume reduction, well in excess of the 10 mm requirement. This is desirable for improving stream health and groundwater recharge.

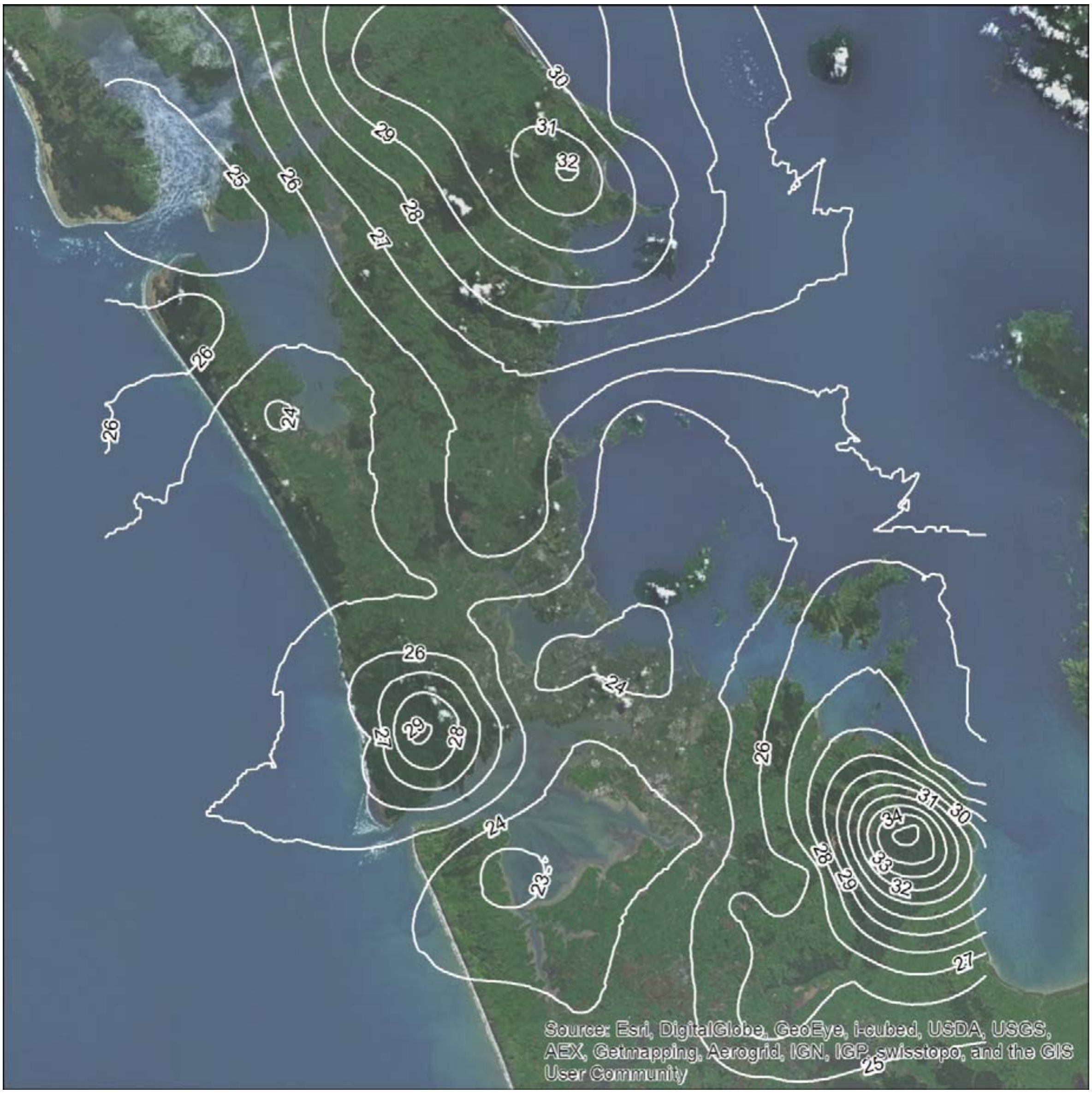


Figure 13. 90th percentile 24hr rainfall depth (mm)

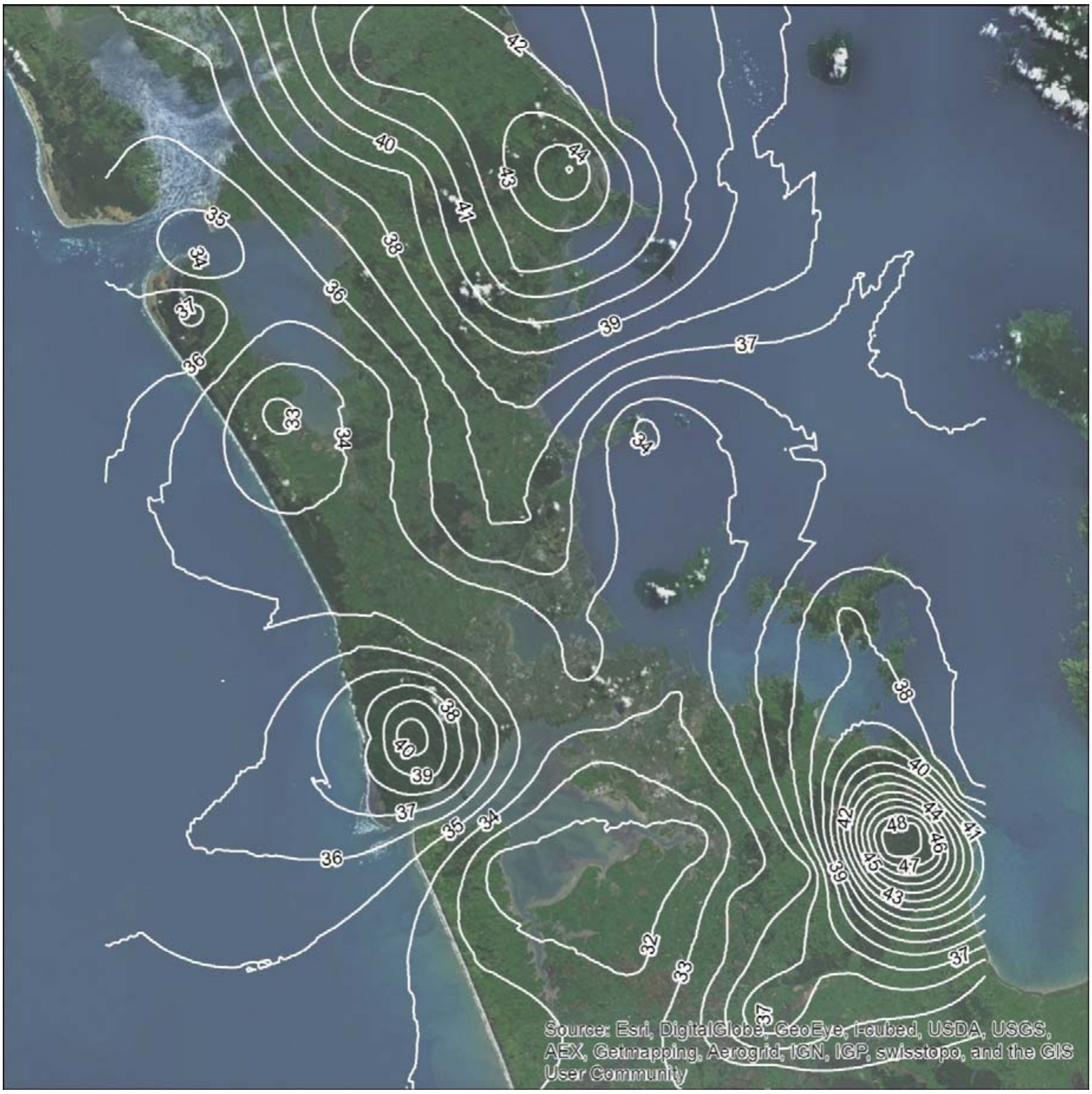


Figure 14. 95th percentile 24 hr rainfall depth (mm)

5.4.1.1 Receiving environment requirements

It is important to recognise that different receiving environments may have different targets for stormwater mitigation. Stormwater in the Auckland region can be discharged to harbours, estuaries, streams or groundwater either directly or through the wastewater system via a combined sewer network. Hydrology mitigation can help these environments in a variety of ways including:

- restoring natural hydrologic process,
- reducing the effect of capacity constraints through lowering runoff volume and peak flow
- reduction of erosion through lowering runoff volume and peak flow

For all the receiving environments mentioned above, typical wastewater pollutants are an issue. Stormwater volume and peak flow contribute to wastewater overflows significantly in combined sewers. Overflows can take place up to 100 times a year in some catchment. Mitigation measures should be targeted at small, frequent rainfall events to reduce the number of overflows per year. Hydrology mitigation is recommended where combined systems are used to capture stormwater runoff as the hydrology measures target small storm events.

Where the stormwater is draining via a separated network, only the stream receiving environment will have significant benefit from hydrologic controls. Coastal and estuarine areas are not sensitive to elevated runoff volume and peaks, as long as outfalls are designed to mitigate localised erosion effects. Stream networks can be significantly affected by changes to hydrology due to increased frequency of disturbance and increased erosion. Hydrology mitigation is recommended for streams to protect against frequent disturbance and reduce erosion.

Guidance for Portland, Oregon requires that *all sites* infiltrate stormwater on-site to the MEP, *in addition* to the following flow attenuation requirements, depending on the receiving waters (Portland Bureau of Environmental Services, 2008):

- For discharge to a surface water body or separated storm sewer discharging to surface water: detention of the 2-yr post-development peak runoff rate to one-half of the 2-yr pre-development peak rate, and 5-yr, 10-yr, and 25-yr post-development peak runoff rates to equivalent pre-development rates;
- For discharge to a combined sewer: detention of the 25-year post-development peak runoff rate to the 10-year pre-development peak rate;
- Sites discharging into specifically defined rivers (Willamette River, Columbia River, or Columbia Slough) through a private or separated public storm sewer may be exempt from flow control requirements. This exemption is for flow control only; the pollution reduction requirements still apply.

In this example, requirements for discharge to a combined sewer are more stringent than to surface waters. This is an attempt to limit the quantity of stormwater entering the combined sewer system. In all cases, sites are required to infiltrate stormwater onsite to the MEP. Where complete onsite infiltration is not feasible, vegetated on-site retention facilities are required to the MEP. Once the opportunity to use vegetated onsite retention facilities are exhausted, only then is it possible to utilise conventional detention methods.

The Unitary Plan provides a requirement to not increase flows to Auckland's combined sewer network. This is a "hold the line" approach which has been implemented on the basis that other mechanisms will be put in place to progressively reduce combined sewer overflows.

For the Unitary Plan, the hydrology rules will apply to the SMAF areas within the Rural Urban Boundary (RUB). While ideally a single requirement for to produce runoff equivalent to the pre-development condition would be applied to both SMAF1 and SMAF2 areas, it is recognised that the SMAF2 areas typically have significantly greater existing development. Accordingly, less stringent retention and detention requirements have been adopted for SMAF2. This is consistent with the view expressed in National Research Council (2008) that the goals for water and habitat quality should become less stringent as impervious cover increases within the catchment.

Stormwater policies set the expectation that hydrology requirements equivalent to a SMAF1 should apply to all greenfield areas draining to streams either within or outside of the RUB. Greenfield areas have the greatest opportunity to implement hydrological mitigation of the effects of development. Hydrology controls are not required for discharge to groundwater, lakes, the inner harbour or the outer harbour.

5.4.2 Recommendations

The discussion in section 5.4.1 gives recommendations for stormwater management in the Unitary Plan. These recommendations are:

1. SMAF hydrology rules apply to the SMAF areas within the RUB
2. Greenfields areas draining to streams achieve hydrology mitigation equivalent to a SMAF1
3. Where the maximum impervious area for rural and open space zones is exceeded, hydrology mitigation similar to a SMAF1 should be achieved.
4. Sites meeting the requirements for hydrology rules are required to produce equivalent runoff for the pre-development condition. This requirement can apply to the whole site or a percentage of the site depending on the SMAF designation.
5. To produce equivalent runoff, sites within SMAF 1 should provide detention (peak flow attenuation) for the 95th percentile, 24 hr storm event runoff volume and retain (reduce volume) 10 mm of the design rainfall event.
6. Sites within SMAF 2 should provide a minimum detention (peak flow attenuation) for the 90th percentile, 24 hr storm event runoff volume and retain (reduce volume) 8 mm of the design rainfall event.

It is reiterated that greenfield development offers more opportunity than is generally present in existing urban areas. It is therefore important that greenfield development implements WSD on a whole of development basis to more comprehensively protect and enhance stream systems and natural hydrology while achieving pre-development flow conditions.

5.4.3 Implementation

The proposed rules can be met using standard design in TP10 with some minor modifications. A summary of devices that can meet the requirements is given in Table 10. A general discussion on how to calculate the require design parameters followed by a discussion on specific considerations for each device is included in this section. Table 10 indicates that some devices require design to incorporate Internal Water Storage (IWS) in order to achieve the 10 mm retention requirement. This is explained further in Section 5.4.3.1.

Table 10. Devices that can meet proposed detention and retention rules

Device	10 mm retention	95th percentile detention
Swales	Yes with IWS	No
Living Roofs	Yes	Yes
Permeable pavements	Yes	Yes
Raintanks	Yes with IWS	Yes
Gravel trenches	Yes with IWS	Yes
Soakage pits	Yes with IWS	Yes with high infiltration
Bioretention	Yes with IWS	Yes
Sandfilters	No	Yes
Detention tanks	No	Yes
Dry ponds	No	Yes
Infiltration basins	Yes with IWS	Yes
Wet ponds	No	Yes
Constructed wetlands	No	Yes

5.4.3.1 Calculating design parameters

To calculate design parameters for the above devices lookup the 95th percentile storm depth in Figure 14. Once the design storm depth is found, use TP108 calculations to determine the runoff volume from the site for the design event, this is the design volume for detention.

The design volume and the storage volume can be different if the practice chosen includes retention through exfiltration or evapotranspiration. Use Equation 1 to determine the required storage volume.

Equation 1. Required storage volume of site devices calculation.

$$\boldsymbol{V_{stor} = V_{des} - V_{losses}}$$

Where:

V_{stor} = required storage volume of site devices

V_{des} = design volume

V_{losses} = losses during the 24hr design event from exfiltration and evapotranspiration

The total storage volume of all on-site devices is required to be higher than V_{stor}.

Once the storage volume is found, consult to see if internal water storage (IWS) is required to achieve retention requirements. Devices do not have to provide the 10 mm retention during the design event; they can store this stormwater using IWS and reduce the volume after rainfall events. If an IWS is required, calculate the volume using Equation 2. For raintanks, losses will be zero.

To calculate the IWS volume, the following formula can be used:

Equation 2. Internal water storage volume calculation.

$$\boldsymbol{V_{IWS} = 10\ mm \times A_{mitigation} - V_{losses}}$$

Where:

V_{IWS} = Internal water storage volume

$A_{mitigation}$ = impervious area to be mitigated

V_{losses} = losses during the 24 hr design event from infiltration and evapotranspiration

5.4.3.2 Device design considerations

Individual device design considerations are given below to allow the user to use TP10 device designs to meet the proposed hydrology requirements.

Swales - Detention requirements cannot be met by swales as they do not store and slowly release runoff. Retention requirements can be met through the use of gravel underdrains with dams in the gravel underdrain. The surface area of the gravel underdrain should be the area used for loss calculations. The storage volume behind the dams in the gravel underdrains should then be greater than the internal water storage volume. The swales cannot be lined if retention requirements need to be met.

Living Roofs - Living roofs can meet retention and detention requirements through high evapotranspiration rates and storage in media pores. A monitoring study in Auckland determined that living roofs 50 mm to 150 mm thick produced no meaningful runoff for the majority events up to 25 mm (Fassman-Beck, Voyde, & Liao, 2013). This 25 mm performance significantly exceeds the 10 mm requirement proposed, therefore living roofs greater than 50mm thick should achieve the 10 mm requirement. Detention requirements can be met by living roofs through ensuring storage provided in the media is greater than that calculated in Equation 1.

Permeable Pavements - Permeable pavements can meet retention and detention requirements through infiltration and storage in media pores. Permeable pavements have a large surface at the base of the pavement available for infiltration. The surface for infiltration in permeable pavement installations is at least 33% of the catchment. This large surface area can infiltrate the 10 mm retention volume over the 24 hour period of the storm even in low permeability soils. As long as permeable pavements are unlined and the base soils are not compacted during construction, retention requirements should be met. Permeable pavements can meet detention requirements through storing runoff in the sub base. The storage volume in the subbase should be calculated and adjusted for the impacts of slope. If the storage volume is not greater than Equation 2, consider thickening the pavement subbase or adding check dams to the subbase.

Raintanks - Raintanks can meet retention and detention requirements through water reuse and storage in the tank. To provide the 10mm retention, the internal water storage volume in the tank should be greater than the volume calculated in Equation 2. The tank must be plumbed into the house (laundry and toilet) to ensure sufficient reuse is taking place. Mains top up may will be required when the tank runs dry in summer months. To provide detention requirements, the total volume of the tank should be greater than the volume calculated in Equation 1. An orifice should be placed at the top of the IWS to ensure the live storage portion of the tank will drain between storm events.

Gravel trenches and bioretention - These devices can meet retention and detention requirements though infiltration and storage in media pores and ponding zones. Retention requirements can be met if the device is unlined. An IWS zone may be required to store water for infiltration between rainfall events, refer to Equation 2 for details. Detention requirements can be met if the total storage volume in the media pores and ponding zone is greater than the volume calculated in Equation 1.

Soakage pits - Soakage pits can meet retention through infiltration and even detention requirements through infiltration provided sufficient infiltration rates can be achieved. Soakage pits are already in use in parts of Auckland disposing of up to 10 year, 24 hour rainfall volumes. In these areas of high infiltration, soakpits will infiltrate the retention and detention volumes in a 24 hour period, meeting the requirements proposed.

Sandfilters - Sandfilters cannot provide retention requirements but they can meet detention requirements. To meet detention requirements, the volume of the sandfilter media pores and live storage need to be greater than the volume calculated in Equation 1. The sandfilter media will sufficiently attenuate flows, an orifice is not required on the outlet.

Detention tanks, dry ponds, wet ponds and constructed wetlands - These devices cannot provide retention requirements but they can meet detention requirements. To meet detention requirements, the volume of the device needs to be greater than the volume calculated in Equation 1. An orifice should be sized using TP10 to restrict flow out of the device.

Infiltration basins - Infiltration basins can meet retention and detention requirements through infiltration and storage. Retention requirements can be met through infiltration through the bottom of the basin. An IWS zone may be required to store water for infiltration between rainfall events, refer to Equation 2 for details. To meet detention requirements, the volume of the basin needs to be greater than the volume calculated in Equation 1. An orifice should be sized using TP10 to restrict flow out of the device; the orifice height should be above the IWS zone.

5.5 Comparison of current and proposed mitigation

In this section proposed requirements are compared against current mitigation techniques to determine which of the following approaches should be included in the Unitary Plan. Section 5.5.1 discusses the ability of the proposed approaches to restore the natural water balance and mitigate the effects of development on stream health. Section 5.5.2 discusses surface runoff and stream erosion and how the current and proposed techniques address this issue. Section 5.5.3 discusses how the current and proposed approaches fit with the development set out in the Unitary Plan.

5.5.1 Hydrologic cycle

The current requirement of extended detention of the 34.5 mm storm has been compared to the proposed requirement of extended detention of the 95th percentile event and retention of 10 mm of runoff during the design event in this section. Table 11 summarises the ability of current (TP10 and ALW Plan) and proposed requirements to mitigate the effects of development on the environment. The ability of requirements to mitigate the effects of development has been ranked on a scale of:

1. Not mitigated;
2. Somewhat mitigated;
3. Partially mitigated;
4. Significantly mitigated; or
5. Completely mitigated.

Following is a discussion on how these values were derived.

Table 11. Mitigation of development effects on the environment

Development Effect	Current requirements	Proposed requirements
Reduced interflow	Somewhat mitigated	Significantly mitigated
Reduced groundwater flow	Not mitigated	Partially mitigated
Reduced evapotranspiration	Not mitigated	Partially mitigated
Increased surface runoff	Partially mitigated	Significantly mitigated

5.5.1.1 Reduced interflow and groundwater flow

As shown in Figure 8, development leads to reduced infiltration and percolation, reducing interflow and groundwater flow. This has the effect of removing the natural filtering of water as it slowly moves to the ground, increasing contaminant loads to the stream. Water temperatures increase as water no longer is cooled as it moves through the ground. Stream flows in dry periods are reduced as interflow and groundwater flow are the main source of water for the stream during dry periods. Permanent streams may become intermittent and intermittent streams may disappear altogether. These changes have the effect of reducing biodiversity in the stream. Fewer species can survive the combination of higher levels of contaminants, warmer water temperatures and reduced flows during dry periods.

The current requirement of extended detention somewhat mitigates the effects of interflow and groundwater flow reduction through attenuating stormwater and slowly releasing it over a 24 hour period. Natural interflow takes weeks to months in Auckland clay soils, and groundwater flow longer, so the 24 hour delay does not mimic interflow well. The current approach does not mimic the natural filtering processes of soils; however this is partially offset if treatment of stormwater is provided. The current approach also does not mitigate temperature changes, and where ponds are used for extended detention temperature increase is exacerbated. For these reasons, the current requirements are considered to be somewhat mitigating the effects of reduced interflow and not mitigating the effects of reduced groundwater flow.

The proposed requirements partially restore interflow and groundwater flow through infiltration and partially mimic these processes through extended detention. The extended detention component has the same drawbacks discussed in the previous paragraph. The proposed approach restores some of the natural soil filtering through infiltration, and as mitigation techniques often are media based, also provides filtering capacity within the device. Temperature effects are also mitigated in most volume reduction techniques through infiltration and shaded storage areas. Effects on interflow are significantly mitigated and effects on groundwater flow are partially mitigated.

5.5.1.2 Reduced evapotranspiration and increased surface runoff

As the volume of water using other transport processes in the hydrologic cycle reduces, surface runoff volume increases significantly. Surface runoff is the fastest runoff process in the hydrologic cycle and this is further increased through the hydraulic efficiency of man-made impervious areas and drainage networks. The reduced travel times increase peak flows during rain events and the volume of water into the stream.

These changes to the hydrologic regime of the stream have several impacts. The most destructive impact is the increased erosion resulting from large volumes of high flow at channel forming flow rates. Increased erosion rates have an effect of straightening channels, creating poor habitat and reducing biodiversity. Increased erosion rates also increase the undercutting of banks causing instability. The sediment carrying capacity of surface runoff increases rapidly with the velocity of flow, transporting significant quantities of land contaminants to streams. These contaminants reduce the number of species that can survive in the stream, reducing biodiversity.

The current requirements do not reduce the increase in volume of water leaving the site as surface runoff, but try to detain the water to minimise stream erosion. This attenuation does help reduce stream erosion from periods of high flow, and does reduce the sediment carrying capacity of the stormwater runoff. Extended detention partially mitigates the effects of increased surface runoff but does not mitigate reduced evapotranspiration.

The proposed requirements partially remove the increase in surface runoff through increasing reuse, evapotranspiration and infiltration and partially mitigate the effects of surface runoff increases through extended detention. Bioretention techniques improve evapotranspiration through the use of engineered media and planting. Rain tanks help remove some of the volume through reuse. The proposed requirements significantly mitigate the increase in surface runoff and partially mitigate the decrease in evapotranspiration.

Overall, the proposed requirements provide better mitigation of changes to the hydrologic cycle for each of the four transport processes when compared to the current requirements. The most significant benefit of restoring interflow is to allow streams to flow during dry periods, helping to reduce the effect of permanent streams becoming intermittent and intermittent streams disappearing altogether as development occurs.

5.5.2 Achieving equivalent runoff

5.5.2.1 Data analysis and modelling

To determine if the recommended hydrology approaches would still provide the stream erosion mitigation of the current extended detention approach, a spreadsheet-based modelling exercise was undertaken. Flow data from the West Hoe and Chartwell catchments was extracted for a ten year period from 2002 to 2012. These two catchments were selected for their development states. The West Hoe catchment is a natural catchment and is used as a baseline catchment for Research Investigation and Monitoring Unit (RIMU) environmental reporting. The Chartwell catchment is a developed catchment typical of Auckland’s urban environment. Both catchments have clay soils and are moderately steep to steep catchments.

The flow data was analysed at a 10 minute time step and catchments were normalised by area and by the number of data points. Flow exceedance curves were generated for each of these catchments; the results are shown in Figure 16.

Extended detention via a detention tank was modelled at the 10 minute time step of the flow data for a 1 Ha catchment for the 10 year dataset. The urban flow from the Chartwell catchment was used as the inflow to an extended detention device. The extended detention device was sized to have the same footprint as the rain garden to ensure a like for like comparison. The volume of the device was 372 m^3 and 1 m deep. An orifice was sized using TP10 to give a diameter of 0.054 m.

A rain garden was also modelled to provide a comparison between the current requirements and the proposed requirements. Rain gardens are difficult to model due to modelling packages being designed around flood mitigation; the movement of water through the rain garden media is not accurately modelled using existing modelling packages or spreadsheet approaches. For this reason, the rain garden modelling results are marked as indicative only, the results align with monitoring results in the literature on rain gardens.

The raingarden was sized using the draft rain garden design technical report (Blackbourn, 2013). The surface area of the rain garden sized using the technical report is 372 m^2 with a 0.5 m IWS layer in the media, a 0.6 m live storage layer in the media and a 0.225 m deep ponding area above the rain garden before bypass occurs. To create the IWS zone the underdrain of the rain garden has an S bend with an invert set 0.5 m above the base of the rain garden. This IWS zone stores water between runoff events, increasing the volume of runoff available to be discharged via infiltration.

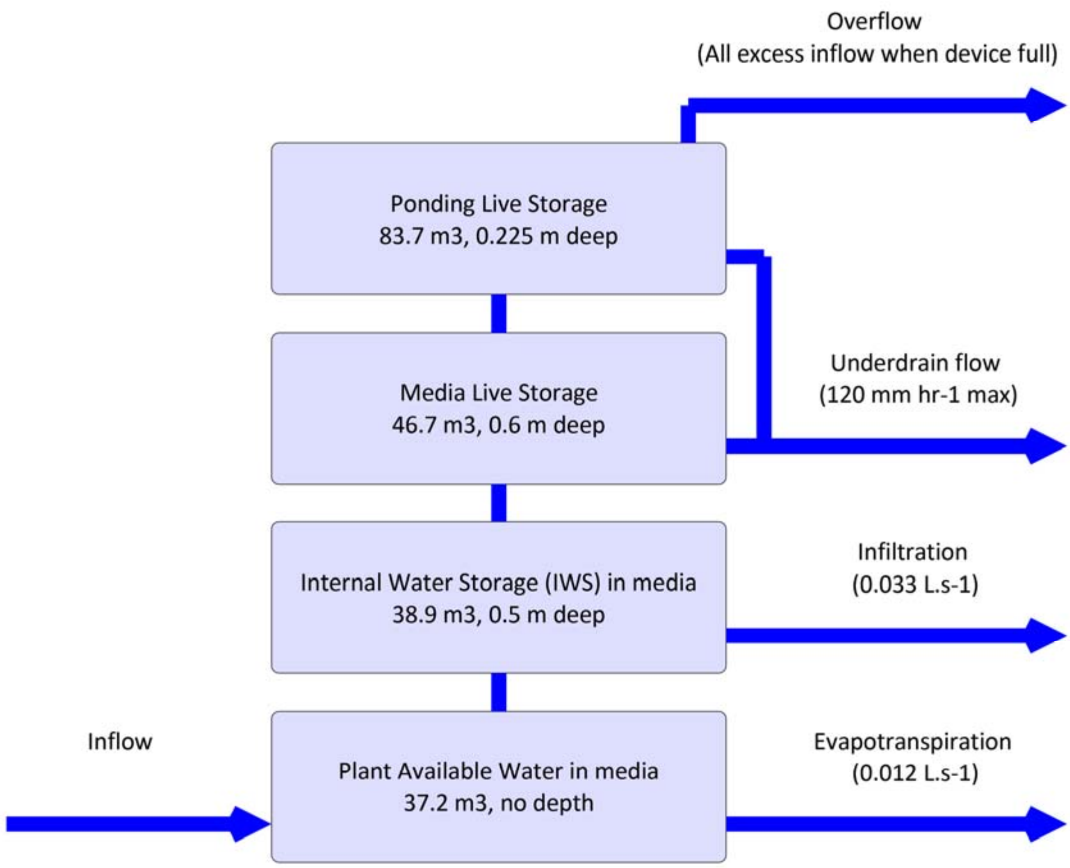


Figure 15. Diagram of the raingarden model

Figure 15 shows a diagram of the raingarden spreadsheet model used to produce the results shown in Figure 16. The device was divided into four functional sections, the bottom sections must fill up completely before storage in the next section is used.

The bottom section, Plant Available Water (PAW) in media, represents the 100 mm minimum water required to be retained in the media for evapotranspiration and plant uptake. When water is stored in this storage block, the evapotranspiration outflow is active. The rate used to estimate evapotranspiration was 0.114 mm/hr, this value was derived through a monitoring study carried out by the University of Auckland (Fassman & Stokes, 2011). Volume used in the PAW zone was taken from the IWS zone and the media live storage zone.

The second storage block in the rain garden is the IWS zone. When water fills the plant available water storage block completely, excess flows into the IWS zone. Once water is in this zone, the infiltration outflow is active. The rate used to estimate infiltration was 2 mm/hr which is a representative rate for Auckland's clay soils (Burford, 2009). In fact, Auckland clay soils typically have higher infiltration rates than this. The median saturated hydraulic conductivity of clay subsoils on Auckland's North Shore have been determined to be 5.1 mm/hr and 6 mm/hr, in two separate studies (Simcock, 2009).

The third and fourth storage blocks are the live storage zone. When the IWS zone is full, water flows into the live storage blocks (media live storage and ponding live storage). Once water is in this zone, under-drain flow is active. The under-drain flow rate is calculated based on the head over the media, and the media's peak permeability of 120 mm/hr. Once all the storage blocks are full, any flow exceeding the combined flow rate of the three outlets was discharged directly via the overflow bypass.

5.5.2.2 Model Results

Figure 16 shows the flow exceedance curves from the West Hoe and Chartwell catchments as well as spreadsheet modelled flow exceedance for the Chartwell catchment routed through extended detention or a raingarden. These curves show the proportion of incident rainfall (y-axis) that leaves a site as surface runoff at or above a particular flow rate (x-axis). Monitored flow data was used to generate the West Hoe and Chartwell curves. The modelled data uses the Chartwell flow data and routes it through each device.

One of the stated goals of Water Sensitive Design is to mimic pre-development conditions. In this case, the West Hoe curve represents the pre-development condition and the Chartwell curve represents the post-development condition. The aim is to apply controls to the Chartwell runoff that changes the flow exceedance curve shape to mimic West Hoe curve.

The extended detention model showed that extended detention is very good at reducing channel forming flow rates through attenuation, illustrated by the very flat shape of the purple curve starting at approximately 2 L s^{-1} Ha^{-1} and extending to the right, well below post development (red) curve. Extended detention has no method for volume loss. Therefore the overall runoff volume is not changed from the post-development condition (illustrated by the y intercept of the red and purple lines being the same).

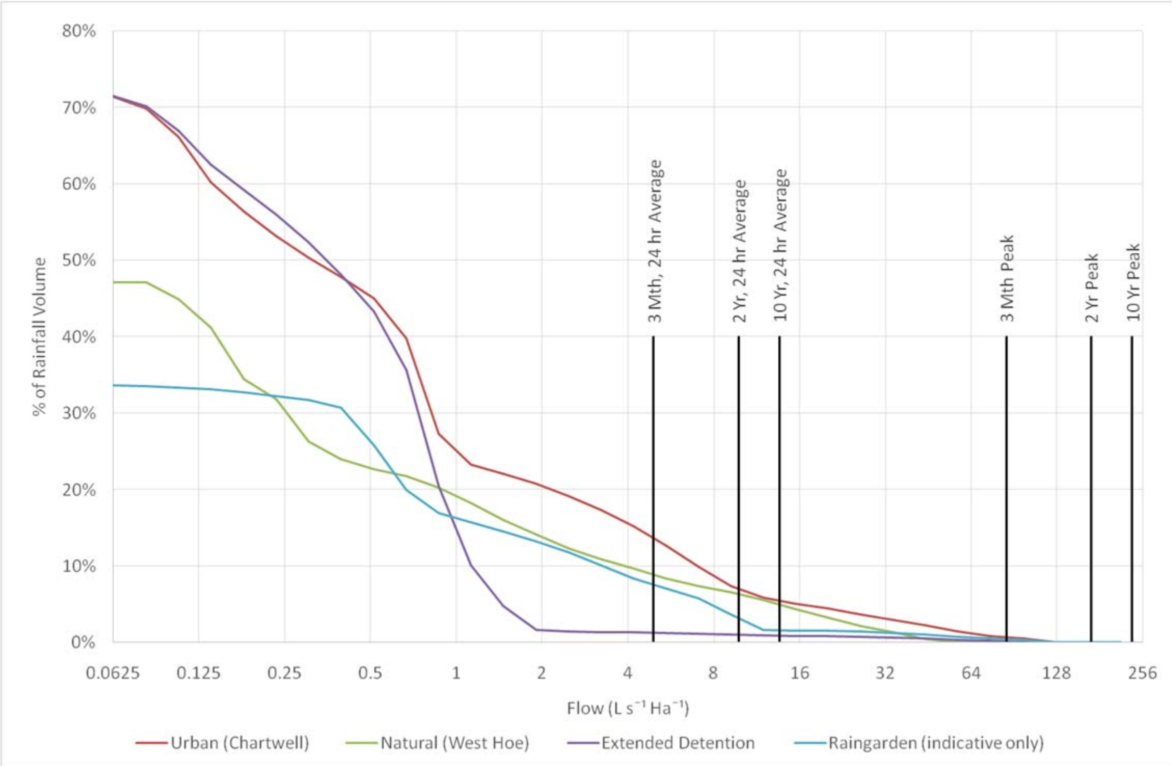


Figure 16. Flow exceedance curves comparing extended detention with raingardens (note the curves are flat below 0.0625 L s^{-1} Ha^{-1}, the data has been clipped for readability)

The raingarden model produced an exceedance curve (blue) that was the closest to the pre-development condition (green). Flow rates were slightly lower than the pre-development condition above 2 L s^{-1} Ha^{-1}, and the overall surface runoff volume was lower (y-intercept), although the pre-development (green) condition includes groundwater flow and the raingarden (blue) does not.

Overall, the raingarden model mimics pre-development flow rates more closely than the extended detention model.

5.5.3 Alignment with development opportunities

Development targets for the Unitary Plan are for 60 to 70% of new housing to be provided within the RUB. This will require intensification of existing lots as most of the developable land within the RUB is already developed. The likelihood of large scale redevelopment taking place within existing urban areas is low due to the difficulties in acquiring one large contiguous section of land. Therefore the predominant form of redevelopment will be small sites.

Providing extended detention for small sites is difficult due to the minute orifice sizes required to attenuate flow for very small catchments. These orifice sizes are susceptible to clogging and are undesirable from a risk of failure point of view.

As an alternative, volume reduction techniques in the proposed requirements work best when implemented on a small scale. Volume loss can be achieved for a single site redevelopment; these rules enable small developments to mitigate the effects of their development where previously mitigation was not possible. Volume reduction is a good fit for the intensification expected through implementation of the Unitary Plan.

6.0 SMAF overlay

6.1 Background and outline

The objective of the Unitary Plan Stormwater Management Areas for Flow Overlay (SMAFs) and associated provisions is to manage the small frequent stormwater flows (less than the 2 year ARI) from new or redeveloped impervious areas to reduce potential stream erosion and maintain/enhance stream health (including biodiversity and ecological functioning). Development and redevelopment of impervious area that occurs within the spatial extent of a SMAF is subject to the controls of that SMAF.

6.1.1 The need for flow controls

Urban development has a profound effect on the quality and quantity of stormwater runoff. The removal of pasture and bush and its replacement with hard surfaces such as roads, buildings and even grassed areas that have been heavily compacted during earthworks, reduces infiltration of water into the ground, reducing groundwater recharge, and increases the volume, flow rates, and velocities of stormwater runoff. An increasing body of evidence indicates that the majority of ecosystem impacts are the result of cumulative damage from ‘everyday’ rainfall events (Alliance of Rouge Communities, 2012) (Argue, Pezzaniti, & Hewa, 2012) (Fassman-Beck, Voyde, & Liao, 2013). The following reasons are provided:

1. The natural stream channel ‘bank full’ (the top of the banks formed in a natural cross section) or ‘channel-forming flow’ is approximately at the 1 to 2 year ARI rainfall event, so events up to and including these events have the most impact on stream erosion and in-stream habitat, in part due to the frequency of occurrence.
2. The development of impervious areas, which route runoff directly to streams, alters the natural flow regime (flow rates and velocities, volumes, duration, frequency and timing) of all rainfall events, including the most frequent rainfall events. These frequent disturbances and fluctuations in flow result in degraded hydrological conditions and habitat, which has a negative impact on ecological functioning and species diversity and abundance.
3. These small events show the greatest proportional change in flow characteristics between the pre-developed (before urbanisation) and post-developed (after urbanisation) conditions.
4. Over 95% of the rainfall in small events results in runoff in post-development (impervious) conditions. The percentage of rainfall which ends up as runoff entering streams is much lower under pre-development conditions, due to infiltration and interception of rainfall by soil and vegetation.

Control of flows from these frequent small events (up to the 1 to 2-year ARI rainfall event) is critical to protecting stream health.

6.1.2 Defining SMAF overlay areas

The SMAF overlay applies to sub-catchments that are identified as being susceptible to erosion from increases in stormwater flows or where streams have been identified as having high (current or potential) aquatic ecosystem values. Within these catchments or sub-catchments, rules require that stormwater flows from additional or redeveloped impervious areas are managed to prescribed levels, in order to minimise erosion and protect or enhance stream health as detailed in section 2.5 of this report.

The SMAFs apply only within (i.e. the urban component) the Rural Urban Boundary defined in the Unitary Plan. The SMAF maps were aligned with property boundaries, taking into account the discharge points of the actual stormwater reticulated (piped) network.

There are two classes of SMAF: SMAF 1 and SMAF 2. While, as discussed below, a range of criteria have been used to define the SMAF classes, in general:

- SMAF 1 are those sub-catchments, within the RUB, which discharge to streams with high current or potential value that are sensitive to increased stormwater flows and that have relatively low levels of existing impervious area.
- SMAF 2: Are those sub-catchments, within the RUB, which discharge to streams with moderate to high current and potential values and sensitivity to stormwater flow and with generally higher levels of existing impervious area within the sub-catchment.

Rural areas were not included in the SMAF overlay, but are subject to maximum impervious area rules which will achieve similar outcomes in rural zones. For the purposes of this analysis, SMAF areas were mapped beyond the RUB to allow for consideration of the entire stream system.

The SMAFs only consider the increase in flows from increasing impervious areas. While it is recognised that altered hydrology has a significant impact on stream health, a number of other factors also have an effect including riparian vegetation, shade, bank stability and slope, water quality, and public access and use. The allocation of SMAFs is not a Council stream prioritisation framework for deciding on the value of streams and the importance of future enhancement, protection and council works programmes as it does not incorporate these other factors. The SMAF overlay and rules provide only one component of any comprehensive approach to stream management, which may also include managing and enhancing other values such as ecologically significant areas, amenity and conveyance, and protecting streams against erosion through other measures, such as gabions and bank/riparian planting.

6.2 Methodology

The process of identifying and classifying SMAFs involved the following steps:

1. Potential SMAF areas were initially identified by combining the scores of three primary criteria that were used to determine the sensitivity of streams to increasing imperviousness and

stormwater flows. This was undertaken through GIS modelling and a review of maps using region wide data layers. The three key factors (which are discussed in more detail in Section 6.3) are:

   a. stream slope;
   b. cumulative imperviousness; and
   c. Macroinvertebrate Community Index scores.

2. A set of 'moderating factors' were identified and considered across all catchments, and the SMAFs identified in the first step were amended as appropriate (these factors are discussed in more detail in Section 6.3). Council staff local knowledge and technical skills were applied during this step through a series of workshops. This analysis included consideration of whole catchments which had some part within the the RUB.
3. These SMAF areas were then mapped as GIS shape files and truncated to only include SMAFs within the RUB to provide the SMAF overlay.

A methodology flow chart is presented in Appendix D.

6.2.1 GIS modelling and mapping review of primary criteria

This process involved detailed GIS modelling and analysis of the primary criteria that contribute to the need for hydrology management. The final output was a compilation of sub-catchment maps delineating preliminary SMAF 1 and SMAF 2 (and NO SMAF) areas.

The slope, cumulative imperviousness and MCI criteria were applied to a stream reach dataset in a GIS exercise. A stream reach was defined as the extent of stream between two stream junctions.

There were inconsistencies between available GIS stream layers (RiverNZMS260 series and Auckland Council ephemeral/intermittent/permanent stream layer) so it was decided to use the council-created overland flow paths that had been generated by the stormwater flood hazard mapping process. Only the flow paths down streams were used. As the entire stream length is important to its overall health, no distinction was made between permanent, intermittent and ephemeral streams.

For mapping purposes a catchment area of two hectares was used to identify the start of a stream. This was considered to be a representative value within the range of one to four hectares (based on soil type), which has been previously recommended (Storey & Wadhwa, Technical Report 2009/028, 2009) for the threshold of contributing area where permanent, intermittent and ephemeral stream channels are initiated.

Previous work by the legacy North Shore City Council for their Plan Change 22 (North Shore City Council, 2011) was used as a starting point to develop the three initial criteria. The basic criteria used for these initial trials were stream gradient (measured at 100 m intervals); cumulative impervious area (measured at a mesh block level); and location of permanent, intermittent and ephemeral streams (as indicated on GIS stream layers). Areas that did not discharge to streams (discharges directly to tidal areas) were automatically designated as NO SMAF areas. Likewise, stream reaches near the tidal areas have a near-horizontal stream slope and flows are more impacted by tidal influences of the coastal environment. For these streams, there is limited benefit from placing flow controls on additional impervious areas at these bottom reaches. An elevation of RL 2 m was used to indicate this tidal influence zone. These NO SMAF tidal boundaries were drawn along boundaries of those properties discharging at an elevation close to a level of RL 2 m.

A discussion of the basis for, and scoring of, the primary criteria is provided in Section 6.3. The Slope, Imperviousness, MCI Score Map and Combined GIS SMAF Score Map for each sub-catchment are reproduced in Appendix E. The markup (white) on the Combined GIS SMAF Score Map indicates the final, post-moderation (see Section 6.2.2) SMAF designation, for each sub-catchment.

6.2.2 Integration of Moderating Factors

The preliminary SMAF scores were assessed through a series of Council workshops, where a set of agreed moderating factors were considered, as listed in Table 12. These moderating factors were used to amend or refine the initial SMAF score.

Table 12. Moderating factors

Moderating factor	Key reason for inclusion
Fish species distributions	An increase in stormwater runoff from increasing imperviousness produces similar detrimental impacts on fish diversity as it does for aquatic insects
Potential growth	An indication of the potential increase in impervious areas from future growth, or redevelopment of impervious areas, which determines what controls will be required and what potential opportunities may arise
Percent natural streams	An indicator of value in terms of ecosystem goods and services
Existing erosion	An indicator of known existing flow problems/issues
Existing investment	An indicator of the need to safeguard and build on existing investment in stream protection and management programs
Community use	An indicator of the value of the stream to the local community

As is discussed in Section 6.4.2, the moderating factors influenced the SMAF class (changed the class from NO SMAF to SMAF 1 or from SMAF 1 to SMAF 2), generally where there were more than three moderating factors assessed as being high for a sub-catchment and the initial combined score was on the “cusp” between SMAF classes.

The fish species distribution had a more significant influence on SMAF class, as the presence of rare or threatened fish species is a notable ecological value of streams that may be adversely affected by increased stormwater flows and protection of habitat is consistent with Auckland Council's biodiversity objectives.

Workshop participants included stormwater catchment planning staff and technical staff from across Council, including the Research Investigations and Monitoring Unit and Biodiversity departments. The workshops captured additional technical and local knowledge important in decision-making.

To ensure the classification system was consistent across the Auckland, an additional combined workshop was held with representatives from all three north, west/central and south catchment areas.

The final moderating tables, along with final SMAF areas and workshop comments, are provided in Appendix F. The IBI and Fish Score maps that were used to quantify this moderating factor are provided in Appendix G.

6.2.3 Generation of SMAF GIS overlay

This comprised the technical mapping process required to finalise the maps.

Coarse SMAF boundaries were refined such that they were congruent with property boundaries, actual catchment areas, and took into account the discharge point of any reticulated (piped) stormwater network. While every effort was made to determine these boundaries as accurately as possible, there is potential that the Auckland Council's piped network and other datasets are incorrect in some areas and/or errors have been made. Later adjustment of some individual property SMAF classifications may be necessary on a case-by-case basis, if this issue arises.

Criteria used to help finalise the SMAF boundaries were:

- Individual lots, wherever practicable, have not been bisected, with the following exception - areas above 1000 m^2 where more than 20% drained to an adjacent SMAF were bisected; otherwise lot boundaries formed the SMAF extent.
- Roads on the perimeter of SMAF 1 and 2 areas are included in the SMAF areas. Refinement of the SMAF boundaries may be required for these roads as runoff from these perimeter roads can change which catchment they drain to, depending on the cross-slope of the road.

The final SMAF area summary maps are provided in Appendix H. They include the following:

- SMAF1, SMAF2 and NO SMAF areas;
- Not assessed areas – areas outside of the urban area with little or no influence on streams within the urban area;
- The RUB;
- Peat areas – these have their own infiltration criteria in order to maintain ground water levels;
- Basalt areas – these have their own soakage criteria;

- Precinct (Structure Plan) areas – these often have catchment specific stormwater criteria.

6.3 Detailed description of criteria

6.3.1 Stream slope

The likelihood of streams eroding is heavily dependent on the slope of the stream bed and soil type (Snelder, Biggs, & Weatherhead, 2010). The steeper the slope, the more susceptible the stream is to erosion. To calculate the stream bed slope of each reach Equation 3 was used.

Equation 3. Stream bed slope of reach calculation

$$m_{stream} \equiv \frac{Ele_{\max} - Ele_{\min}}{L_{stream}}$$

Where:

m_{stream} = the stream bed slope of a reach (m/m)

Ele_{max} = the maximum elevation of the stream reach

Ele_{min} = the minimum elevation of the stream reach

L_{stream} = the length of the stream reach (m)

The maximum and minimum elevations were determined from a regional 2 m digital elevation model (DEM). The DEM was created from Light Detection And Ranging (LiDAR) data flown in the years between 2005 and 2010. The stream reach length was calculated using automated GIS tools.

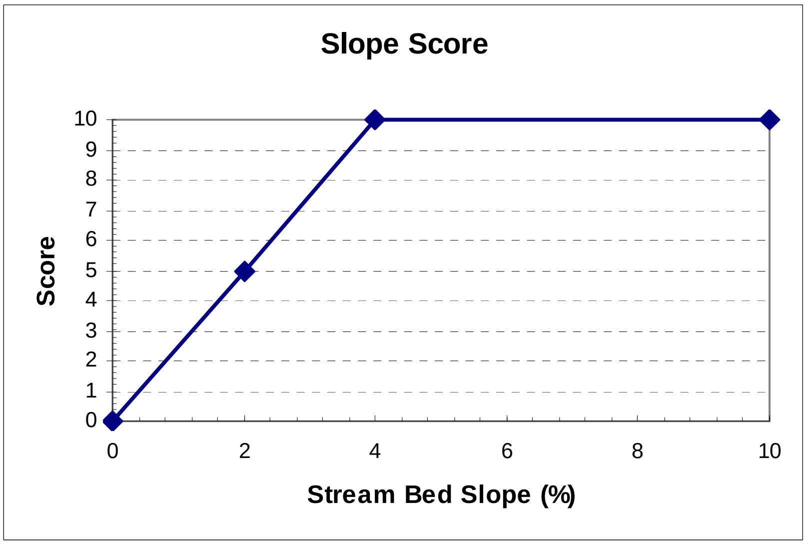
The stream reach slope scores were chosen based on the 'Valley-Landform' factor in the New Zealand River Environment Classification User Guide (Snelder, Biggs, & Weatherhead, 2010). The NIWA classification guide has three landform categories:

- Low-gradient: less than 2% valley slope
- Medium-gradient: 2% to 4
- High-gradient: greater than 4%

Where the valley slope is high, erosion dominates; where the valley slope is low, deposition dominates.

The cut off gradient of 4% stream slope also correlates with the transition from the flatter lower sections to the steeper upper reaches for typical Auckland streams.

The slope score applied to each stream reach ranged from a score of 0 for a slope equal to or less than 0%, to a score of 10 for a slope equal to or greater than 4%. A unique value was calculated for each stream reach and colour coded as per Figure 17.



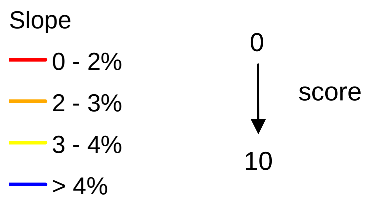


Figure 17. Graph and colour of stream bed slope scoring

While it is recognised that soil type also plays an important role in the susceptibility to soil erosion, there is no regionally consistent GIS soil layer of soil erodibility and so soil type was taken into consideration in the moderating factor of existing erosion.

6.3.2 Cumulative imperviousness

The higher the imperviousness within a catchment or sub-catchment, the greater the existing potential for adverse impacts on stream health. The following classifications were used, based on previous literature (Chesapeake Stormwater Network, 2008):

- Less than 10% - very low imperviousness;
- 10 to 25% - low imperviousness;
- 25 to 40% - moderate imperviousness;
- 40 to 60% - high imperviousness; and
- Greater than 60% - very high imperviousness.

Figure 18 indicates a sharp drop-off in stream quality from 0 to 25% imperviousness and then a general flattening off with increasing imperviousness. The cone shaped range of values represents the observed variability in the response of stream indicators to urban disturbance and also the typical range in expected improvements in the stream quality that could be attributed to sub-catchment treatment (Chesapeake Stormwater Network, 2008).

In areas of high existing imperviousness (in the range of 40 to over 60% impervious) the relative impact on stream health from an increase in imperviousness is likely to be less than in catchments with a low existing imperviousness (less than 10 to 25% impervious). This is because the relationship between stream health and imperviousness is non-linear, as depicted in Figure 18. At high levels of imperviousness, habitats are likely to already be highly degraded and species are likely to already have been eliminated from a stream system, to the extent that additional flows result in a lower relative change in habitat or species values. This non-linear relationship commences at values as low as 5% imperviousness.

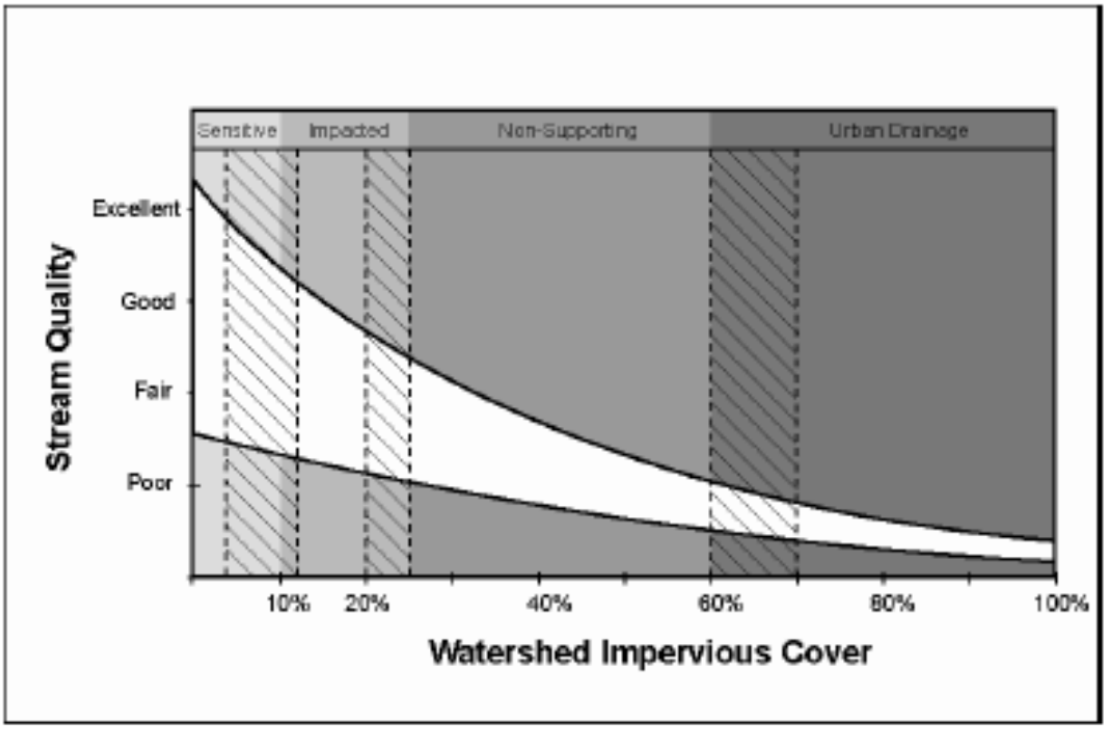


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Figure 18. The 2008 Impervious Cover Model (Chesapeake Stormwater Network, 2008)

Tom Schueler (USA), the primary author of the above stream quality/impervious relationship (referred to as the 'Impervious Cover Model' (ICM)), has visited New Zealand and confirmed that, in general, Auckland streams conform to the assumptions of the ICM. However, the narrower the stream channel and the lower the natural water volume in a streams, the greater the effect of stormwater discharges, due to the proportionally greater change in natural hydrology for small streams affected by stormwater discharges. Auckland streams, generally very narrow and low volume, may therefore be more prone to degradation than the streams Figure 18 is relevant to. The indirect impervious cover effect of heated runoff is also greater under these conditions. It is therefore expected that Auckland streams would be located at the lower end of the impervious cover spectrum (closer to 0%) before degradation takes place, and are likely to be more susceptible to the effects of catchment imperviousness. Some research in Auckland displays similar trends to those in Figure 18, especially with respect to EPT taxa richness (Allibone, Horrox, & Parkyn, 2001).

It is clear from the literature that significant ecological degradation occurs from as low as 5% impervious cover. In streams of ecological importance it is therefore critical to manage streams to achieve as low - impervious cover as possible, or otherwise to manage runoff on site to achieve similar runoff to that of a lower impervious cover (i.e. effective imperviousness).

In areas of high existing imperviousness (greater than 40%), moderate existing and potential values, and low to medium potential for development, imposing the more stringent SMAF 1 mitigation for intensification and redevelopment is considered overly restrictive and would have limited additional benefits over the SMAF 2 mitigation. Using the SMAF 2 criteria mitigates the majority of the increase in imperviousness and helps to prevent the stream quality from deteriorating further.

As discussed above, the imperviousness of a stream catchment has a significant impact on stream health and likelihood of stream erosion due to the way imperviousness affects stream flow regime (Centre for Watershed Protection, 2003) (Chesapeake Stormwater Network, 2008). The imperviousness of each reach was calculated using Equation 4.

Equation 4. Stream Impervious Percentage Calculation

$$imp_{stream} \equiv \frac{A_{imp}}{A_{stream}}$$

where:

imp_{stream} = the stream impervious percentage (%)

A_{imp} = the total impervious area that drains to the stream reach (m²)

A_{stream} = the catchment area of the stream reach (m²)

Impervious areas were identified by using the regional GIS impervious cover layer, which was created by digitising aerial photos. This layer includes impervious areas such as roads, driveways, buildings and other impervious areas. However, some legacy council areas did not include building footprints as impervious areas. The building footprints layer was used in conjunction with the regional GIS impervious cover layer to address these gaps.

The cumulative imperviousness was calculated for each 2 m section of stream. The impervious values were then averaged to form an average imperviousness for each stream reach.

The impervious score applied to each stream reach contained values between 0 and 10. A score of 0 and 10 corresponded to an upstream catchment imperviousness of ≥60% and 0%, respectively. A unique value was calculated for each stream reach and colour coded as in Figure 19.

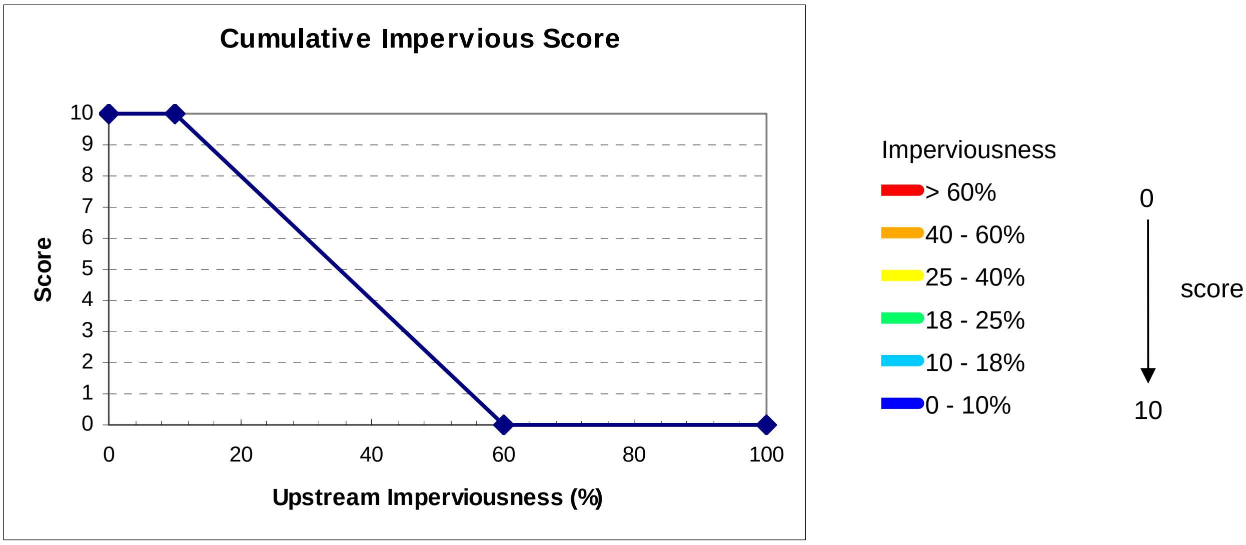

Figure 19. Graph and Colour Coding of Catchment Cumulative Impervious Scoring

The high score of 10 was given to stream reaches of 0 to 10% imperviousness as protection of these low impervious catchments are of the highest priority. A score of zero was given to streams with a catchment imperviousness of greater than 60%, representing ‘urban drainage’ functionality.

6.3.3 Macroinvertebrate Community Index score

The MCI is an index of the types and numbers of invertebrates found at a sampling site. Many species of invertebrates (also known as macroinvertebrates), such as aquatic insects, crustaceans, snails and worms live in rivers, and have been used to indicate the ecological quality of rivers since the early 1900s. Invertebrates are suited to this role primarily because of their high abundance and diversity. Many different types of invertebrates live in rivers and they react differently to various environmental pressures and therefore offer a good system of measuring a wide variation in water quality. Essentially, the MCI assigns a score to each invertebrate found at a sampling site, based on its sensitivity to environmental degradation. The MCI score for a site is calculated based on the average score for all the invertebrates found at that site.

Whilst the MCI score was originally developed to be used as an indicator of organic pollution levels in streams, it may also be used as an overall indicator of the ecological status of stream health, due to the relationship between pollution and aquatic health. The MCI score based on the type and numbers of invertebrates found at each sampling site (Clapcott, Young, Goodwin, Leathwick, & Kelly, 2011). In the wider regional context MCI values are generally divided up into approximately four bands (Stark & Maxted, 2004):

- Greater than 120 – excellent quality;
- 100 to 120 – good quality;
- 80 to 100 – fair quality; and
- Less than 80 – poor quality.

For urban streams the MCI values are typically at the lower end of the scale, in the range of 60 to 100, due to a lower range of species assemblages. Streams with an MCI score in the range of 80 to 100 were classed a 'good quality urban stream'.

While it is recognised that there are many ways to measure stream 'quality' it was important to choose a measure with good GIS data coverage over the entire Auckland region. In discussions with the Auckland Council Research Investigation and Monitoring Unit (RIMU) freshwater experts it was agreed to use the MCI values from a Department of Conservation funded study on the relationships between land use and stream ecology (Clapcott, Young, Goodwin, Leathwick, & Kelly, 2011). While the MCI values from this study may not accurately indicate the absolute quality of the stream at each location, an analysis of the MCI values showed that they could confidently be used as an indicator of the relative quality of sites over the Auckland region and could be used for allocating a 'relative' score in the SMAF scoring matrix (personal communication M. Neale, Auckland Council). A limitation of using the MCI score is that MCI scores are not necessarily representative of fish diversity, MCI scores are naturally poor in lowland areas (which comprises most of the study area), species differences are unlikely to be exaggerated over short distances (such as the short lengths of many Auckland streams), and MCI score may not capture local variation in ecological values as effectively as fish distribution. The above elevated the importance of fish data as a moderating factor, which in conjunction with MCI scores provided a more robust view of stream health.

These MCI scores were superimposed onto the New Zealand river classification geo-referenced dataset. However, the geospatial location of the New Zealand river classification 'shapefile' was misaligned to the actual rivers. The dataset was re-projected to ensure that the geo-referenced dataset was more appropriately aligned with the aerial photography. Additionally, it appeared that the New Zealand River Classification layer was created using a very coarse grid (100 – 200 m) which meant that the MCI observed data was misaligned with the overland flow path layer. The closest (using a search radius) MCI observed score was attributed to the overland flow path layer to ensure that all three primary indicator scores were on one dataset.

Where the geo-referenced MCI scores were not close (within 100 m) to a stream reach (derived from the overland flow path layer) or when a small stream reach had no MCI value associated to it, an average (median) MCI score of the wider stormwater catchment was used. The average MCI observed score for each catchment was calculated using Equation 5.

Equation 5. MCI score for stormwater catchment calculation

$$MCI_{catchment} \equiv \frac{\sum MCI_i \times L_i}{L_{total}}$$

where:

$MCI_{catchment}$ = the median MCI observed score for the stormwater catchment

MCI_i = the MCI observed score (on the NZ river classification layer)

L_i = the stream reach length (on the NZ river classification layer)

L_{total} = the total stream reach length in the stormwater catchment (on the NZ river classification layer)

Of the 233 stormwater catchments covering the wider Auckland region, 145 stormwater catchments cover the urban areas of Auckland with an average 930 ha in size. From observation, the MCI score rarely varied more than 10 MCI points in a given stormwater catchment and taking the average MCI score for the catchment was seen as a pragmatic, representative value for the tributaries missing scores.

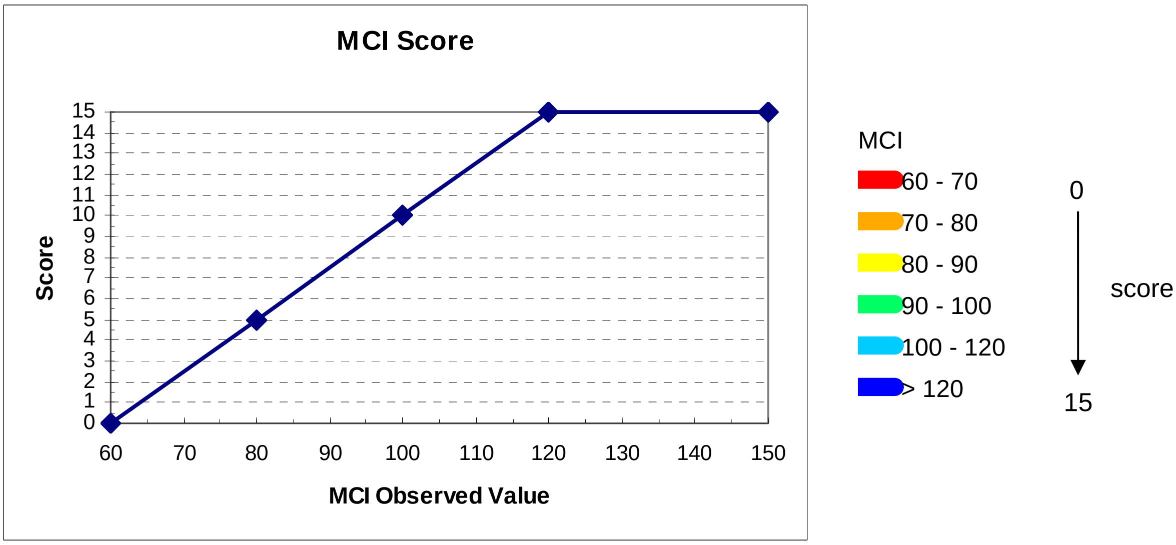

Figure 20. Graph and colouring of MCI scores

The MCI score applied to each stream reach ranged from 0 for a MCI value equal or less than 60, to 15 for a MCI value equal or greater than 120. Although the MCI was potentially scored out of 15, the existing streams in the urban area generally range from 60 to 100, corresponding to a score of 0 and 10 respectively, which was consistent with the slope and imperviousness scoring. The MCI scoring and colour coding are given in Figure 20.

The following sections describe the moderating factors in more detail. Note that the detailed scoring above was only carried out for slope, cumulative imperviousness and MCI. The following moderating factors were only given an approximate ranking of high, medium or low based on what information was available and Council staff local knowledge and technical expertise. The quantity and quality of the background information to these assigned rankings varied markedly between moderating factors and the legacy councils' information bases.

6.3.4 Sensitivity of fish species to Increasing stream flows

Fish species are key indicators of the Present Ecological State (PES), providing an indication of biodiversity value and the health of the entire stream ecosystem. The requirement for many of the New Zealand fish species to migrate up and down streams during various parts of their lifecycles (spending time in freshwater and the marine environment) means that for many fish the health of the entire stream length is important. In general, an increase in stormwater runoff from increasing imperviousness produces the same kind of impact on fish diversity as it does for aquatic insects (Centre for Watershed Protection, 2003); a reduction in fish diversity is typified by a reduction in total species, loss of sensitive species, a shift toward a more pollution-tolerant species, and decreased survival of eggs and larvae. Typically, a notable decline in fish diversity occurs around 10 to 15% catchment imperviousness.

As a consequence of the secretive and nocturnal nature of many of New Zealand's fish species (they are difficult to detect), the presence of many native fish species can go undetected even by landowners who have spent their lifetime living near a waterway. Fish sampling methods are also site-dependent and often require a team approach and expensive equipment. Hence, there may be a paucity of fish records in many streams and the surveys that have been conducted may not have captured all species present. However, it is possible to get around the sampling difficulties using a predictive approach as outlined below.

A fish Index of Biotic Integrity (IBI) has been developed. As a consequence of the high proportion of migratory species in the New Zealand native fish fauna there is a species richness trajectory, where the number of species decreases with increasing distance from the coast (Joy, Henderson, & Death, 2000). This trajectory means that individual sites at different elevations and distance from the coast cannot be directly compared (McDowall & Taylor, 2000). A solution to this issue is to use the IBI developed for New Zealand by Joy & Death (Joy & Death, 2004). The New Zealand IBI is based around distance from the coast and elevation of the site, enabling the direct comparison of sites using fish communities. To enable an accurate assessment of native fish attributes of all New Zealand rivers the predictions of presence for all native fish species were used to calculate an IBI score for all river reaches. The model takes into account fish records and remotely-sensed habitat variables and climate variables. The model serves to "fill in the gaps" as a result of survey bias (including survey effort and differences in methodology). The result is a predictive model of likely fish distribution in the Auckland region (Joy & Death, 2004), (Joy, 2008).

The Q-IBI scores (0-60) for Auckland were separated into three categories to reflect Present Ecological State (PES), namely low (0-20), moderate (21-40), and high (41-60) existing fish values. Recognising potential errors in the predictive model, actual fish records and known habitat integrity were also considered (based on local knowledge and stream walks / survey data; data which was not included in the Q-IBI model). As a benchmark, the following recommendations in Auckland Council Technical Report 2008/002 (Allibone, Horrox, & Parkyn, 2001) were considered: In shady streams a shortfin eel, **longfin eel**, banded kokopu and redfin bully community should be considered high diversity; in open lower gradient streams a shortfin eel, **longfin eel**, common bully, **inanga**, and redfin bully community represents high diversity; other migrant species such as **common smelt**, **lamprey**, **giant kokopu**, and **giant bullies** may occasionally occur and further boost community diversity. The aforementioned conclusions on what constitutes high fish species diversity were taken into account when considering the total number of species recorded; the presence of the described fish communities resulted in a high score for fish distribution. In addition to 'at risk' or rare species (highlighted in bold above), koaro, shortjaw kokopu and torrentfish are also rare, requiring special consideration.

Considering the above information, the 'fish scores' from Table 13 were applied to all of the catchments (refer Appendix G for maps of the fish/IBI scores):

Table 13. Sensitivity of fish species data and ranking

Factor	Score		
Q-IBI Score Present Ecological State (PES)	0 – 20 Low	21 – 40 Moderate	41 – 60 High
Presence of 'at-risk' species	Absent Low	Present High	
Total number of species recorded	< 3 Low	3 to 5 Moderate	>= 6 High
Combined Score	Combination of above – High, Moderate or Low		

6.3.5 Potential growth

Areas of potential growth are both a pressure (threat) on increasing stream flows and an opportunity to make a difference if stormwater flow controls can be implemented, particularly if incorporated in the early planning stages. The expansion of impervious areas (in this case from future urban development, including re-development and intensification) is the single most important factor that increases runoff flows in the urban environment, which in the absence of flow controls potentially impacts on erosion and degradation of streams.

Where available, data of projected population growth to 2050 was used for the ranking. Where more intensive land use zonings are proposed within the Unitary Plan (compared to current zonings), this potential infill/intensification was taken into account, together with Council knowledge of future development areas. For example, the new Mixed Housing Zone is extensive across the region and will lead to increased impervious coverage in existing areas.

6.3.6 Percent natural streams

The percentage of the catchment that remains in natural streams is an indicator of the potential impact of increasing flows from increasing impervious areas. It is also an indication of the extent of habitat that remains and could potentially be utilised by aquatic species if suitable flow controls were achieved, and other stream enhancement activities were undertaken (e.g. riparian planting, stream widening, removal of fish barriers, etc).

If the majority of the catchment is piped (especially with a moderate to high existing imperviousness) then the impact of increasing imperviousness is going to be relatively minor compared to a catchment that still has most of its waterways in a natural condition. The percentage of stream length is also an indicator of value of a stream in terms of ecosystem goods and services, with longer stream reaches delivering greater benefits (ecosystem goods and services) and warranting protection or enhancement for continued or improved delivery of these benefits.

The council GIS stormwater pipe network database was used to determine the length and proportion of streams that had been piped on a catchment basis. Whilst a large proportion of a stream may be piped, in some instances the length of remaining stream can still be important (remnant stream lengths are in some cases longer than completely intact short streams discharging to the coast). Furthermore, where possible and required, the grade of pipes was considered in terms of fish passage. The location of pipes with diameters of greater than 400 mm and 600 mm were plotted on the SMAF individual criteria maps. A visual assessment was then used to estimate the approximate high, medium and low ranking, as per Table 14.

Table 14. Percent natural streams data and ranking

Legacy Council	Source (Reports in addition to workshop staff knowledge)	Ranking (high, medium, low)
Rodney	Mapped council GIS pipe network of pipes greater than 400mm dia and greater than 600mm dia.	GIS visual assessment of percent of mapped overland flow paths with less than 50% pipes = High, 50 to 75% pipes = Medium, greater than 75% pipes = Low
North Shore		
Waitakere		
Auckland		
South (Manukau, Papakura, Franklin)		

6.3.7 Existing erosion

The erosion of stream banks and channel forms have obvious negative effects on stream ecological and aesthetic values and is directly affected by increasing stream flows, particularly the smaller more frequent flows of less than the 2 year ARI rainfall event. Although of limited applicability, where relevant this moderating factor was also used as an indicator of soil type, as the more erodible soils would exhibit more pronounced existing erosion, all other factors being the same. Further work is required to produce a comprehensive GIS dataset of known existing erosion as well as erosion potential of streams in the region.

Information available from the different legacy councils varied from:

- The more technically robust Pfankuch Bank Stability Method (which contains criteria that address both the existing condition, ‘mass wasting’ and the potential conditions of ‘landform slope’, ‘debris jam potential’ and ‘vegetative bank protection’).
- A more simplified Yes/No response to the two questions of; Is erosion an issue? And Is bank stability an issue?
- Generic words in the report text describing the severity of erosion and bank stability.
- Local erosion ‘hotspot’ knowledge was obtained from Auckland Council staff during workshops.

Streams exhibiting existing erosion issues were considered to be more susceptible to further erosion from increased stormwater flows. Thus a stream with significant existing erosion was ranked "high" in respect of the need for stormwater flow controls.

6.3.8 Existing investment

Some catchments have already had significant stormwater management in the form of natural, social, human and financial investment, such as Project Twin Streams in Waitakere and Lucas Creek in North Shore and other areas with significant stormwater management devices.

Given the extent of existing effort and investment, it would be prudent to continue to look after these assets into the future and maintain the outcomes that have been achieved. No formal ranking system was used. The ranking depended on catchment staff knowledge in the moderating workshops.

6.3.9 Community use

While community use may not necessarily correlate to erosion potential and stream health, the community 'ownership' and commitment to looking after a stream is a clear indication of the value of that stream to the community. Community use is seen as an important indicator of the social and amenity value of a stream. Again no formal ranking system was used, with this factor being dependent on catchment staff knowledge in the moderating workshops.

6.3.10 Other

This was an additional catch-all category that could be used to highlight other significant factors with notes being included in the moderating factors tabulated workshop comments column, such as:

- The quality of the headwaters and amount of existing reserves.
- Areas of combined sewers.
- Pipe daylighting opportunities and/or proposed naturalisation of concrete channels.
- Regional significance (e.g. a stream may be relatively degraded on a regional scale but be very important locally or the last local remnant).
- The relative length of streams and overall size of ecosystems, relating to resilience and higher potential system gains
- Existing stormwater management already installed in the catchment, which could mean that the existing 'effective imperviousness' could be lower than the GIS mapped impervious area.
- Existing community programmes.
- Areas of significant groundwater soakage, where there may be few streams or alternative methods of stormwater disposal.

- Low MCI readings skewed by farming practices, causing MCI to be an inadequate indicator, in these instances.

6.4 Results of SMAF process

6.4.1 Preliminary SMAF boundaries

This section provides a step by step outline of the process undertaken to produce the preliminary SMAF maps. The maps produced as part of the initial GIS mapping and analysis process are provided in Appendix E. Two maps were produced per catchment: a map of the individual scores for each of the three primary criteria and a second map with the combined score for the catchment.

The three criteria were given a colour coded score between 0 and 10 for slope and cumulative imperviousness, and 0 to 15 for MCI. The three scores were summed to give a combined score of up to a potential of 35. These colour coded scores were then mapped along all stream reaches.

Examples of these maps are given in Figure 21 and Figure 22, with the colour coded legend showing a progression from the red and orange NO SMAF lines (scores of 0-10 and 10-15 respectively), to the light and dark blue SMAF1 lines (scores of 25-30 and 30-35 respectively).

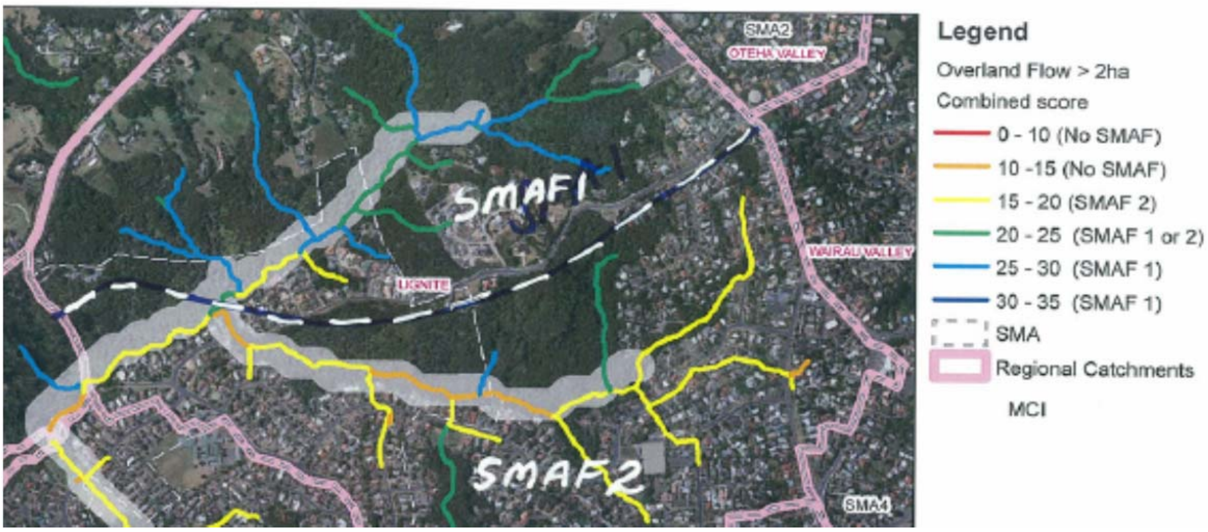

Figure 21. Lignite catchment - Example GIS colour coded combined SMAF1 and SMAF2 score map

Figure 22. Taiaotea catchment - Example GIS colour coded combined NO SMAF score map

SMAF areas are defined on a sub-catchment and catchment scale rather than a reach scale as this was determined to be a sensible scale for applying regulatory controls and for achieving stream outcomes. Due to the variability of the colour coded lines judgement was used in allocating SMAF areas. For example, Figure 21 shows the SMAF 1 area has predominantly blue (SMAF 1 score) and green (SMAF 1/2) scores. The SMAF 2 area has some orange (NO SMAF), yellow (SMAF 2) and green (SMAF 1/2), with one small blue (SMAF 1) reach.

These maps were used for assigning preliminary NO SMAF, SMAF 1 and SMAF 2 areas based on the above scoring range and approximate sub-catchment boundaries. In general:

- Combined scores of 25 – 35 (light and dark blue lines) indicated SMAF 1 areas, where increased flows are likely to have *a significant impact on erosion and stream health*, generally with:
  - Moderate to high slope;
  - Low existing imperviousness; and
  - High stream quality.
- Combined scores of 20 to 25 (green lines) were in the mid-range between SMAF 1 and SMAF 2 (these were initially assigned SMAF 1 or SMAF 2 depending on the relationship to adjacent areas)
- Combined scores of 15 to 20 (yellow lines) indicated SMAF 2 areas, where increased flows have *potential impact on erosion and stream health*, generally with:
  - All slopes;
  - Moderate to high imperviousness; and
  - Moderate to high urban stream quality.

- Combined scores of less than 15 (orange and red lines) indicated NO SMAF areas, where increased flows are likely to have *lesser impact on erosion and stream health*, generally with:
    - o Low to moderate slopes;
    - o Moderate to high imperviousness; and
    - o Moderate to poor urban stream quality.

These maps also showed the location of the council GIS stormwater pipe network as solid black lines.

In areas of doubt between different classifications, the make-up of the combined score could be investigated by looking at the underlying set of base maps with the colour coded individual scores of the three primary criteria. An example of this underlying base map is given in Figure 23.

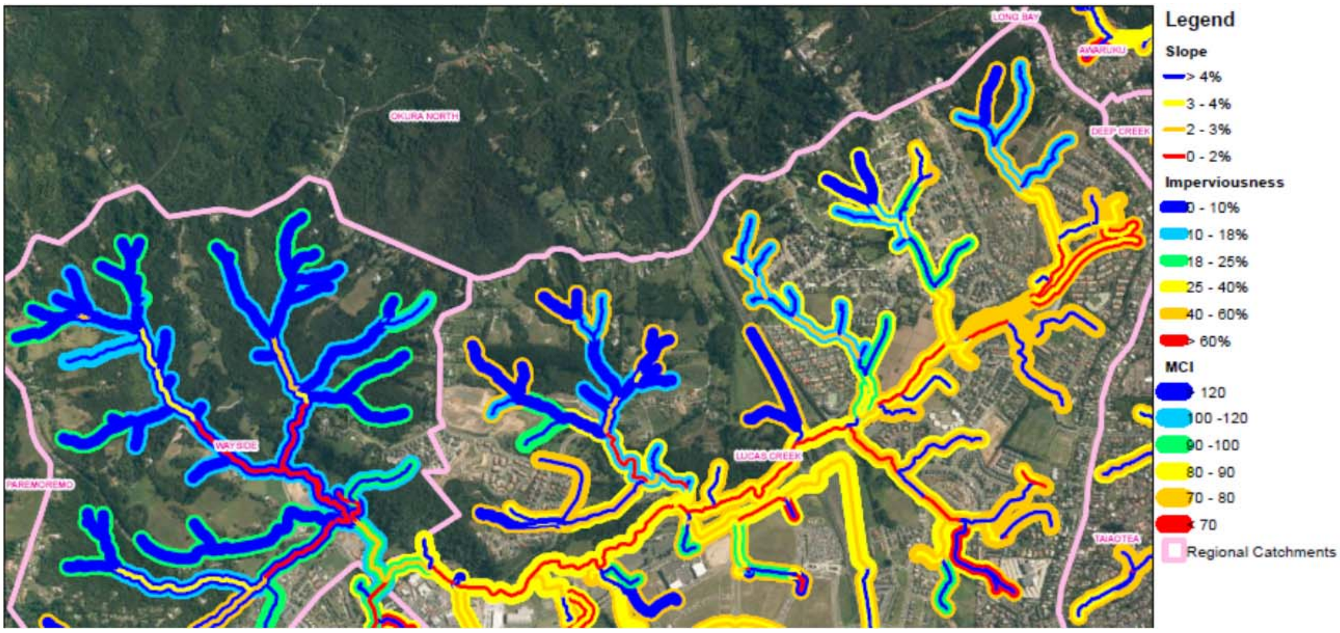

Figure 23. Example GIS colour coded individual criteria scores

Note that the three primary criteria have different thickness lines for each stream reach so that when the lines are superimposed, all three values can be seen, as follows:

- The outer colour is the MCI score.
- The middle colour is the cumulative imperviousness score.
- The inside line is the slope score.

In situations where the map only has two colours, these stream reaches have two criteria with the same score.

These initial SMAF divisions were then reassessed in moderating workshops through use of the seven moderating factors and the catchment specific knowledge of Council's catchment planners and freshwater technical staff). The preliminary SMAF GIS maps were taken into the 'moderating workshops' held with catchment management teams and 'ground proofed' using the moderating factors and local knowledge of the team members. Input from additional Auckland Council units was obtained subsequent to these moderating workshops, which included input from RIMU, STS and Biodiversity.

6.4.2 Final SMAF boundaries

The moderating factors were ranked high, medium or low priority, based on professional best judgement. Due to the highly variable nature of the existing information, the rankings given to the moderating factors were not numerically aggregated or weighted into an overall ranking, but were qualitatively assessed on the basis of the number of highs, mediums and lows assigned to each catchment / sub-catchment.

This assessment was then used to refine the preliminary SMAFs. An example of how this information was used would be if a catchment had a primary criteria combined score of 20 to 25, and therefore could be a SMAF 1 or 2. In this case if a catchment generally had three or more 'High' ranking moderating factors, this would influence it being given a SMAF 1. Alternatively, if it had no 'High' ranking moderating factors and only 'Lows' and 'Mediums', then a SMAF 2 may be more appropriate.

The fish species distribution had a more significant influence on SMAF class than other moderating factors, as the presence of rare or threatened fish species is a notable ecological value of streams that may be adversely affected by increased stormwater flows and which was not always correlated with MCI scores. Invertebrate communities are more dependent on habitat conditions within an individual reach, whereas fish represent the health of the waterway from source to sea. Protection of habitat is consistent with Auckland Council's biodiversity objectives.

All the moderating workshop tables are attached in Appendix F.

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