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Small headwater streams of the Auckland Region Volume 1: Spatial Extent

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Small Headwater Streams of the Auckland Region Volume 1 : Spatial Extent

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1 Executive Summary

Small headwater streams can be highly vulnerable to modification from landuse changes and stormwater control (e.g., piping). Currently, streams providing year-round habitat for fish, invertebrates or aquatic plants are given greater protection under the Proposed Auckland Regional Plan: Air, Land and Water (Variation 1). The Auckland Regional Council (ARC) requires information on the value of small headwater streams in terms of their function and natural values, to aid development of management options. The first step in understanding the potential importance of headwater streams is to establish the nature and extent of this habitat resource in the Auckland region.

The objective of the survey was to characterise and measure the extent of headwater streams in representative landuses and hydrogeological areas (HGAs) of the Auckland region. Our aim was to provide an assessment of spatial extent based on catchment area and an indication of the length of streams not currently mapped on 1:50 000 topographic maps.

We surveyed a wide range of headwater streams from the top of the catchment to the point where they join a permanently flowing stream and characterised them by assessing channel morphology and surface water state. The most useful codes to delineate the transitions within the headwater streams were: dry channels, mud channels, isolated pools, standing water or slow flow, and flowing. Therefore, for the purposes of this report we have used the term 'headwater stream' to cover a range of water states from permanently flowing to dry channel, and we use this term to describe the small tributary streams that are generally not marked on topographic maps.

165 tributaries were assessed from 32 catchments in the Auckland region. Sites were selected to investigate the influence of four hydrogeological areas within the region (Franklin volcanics (FV), sand country (S), Waitemata sandstones (WS), and mudstone (M)) and three land use classes (pasture (P), pasture with riparian protection (PR), and native forest (NF)).

Stream surveys began at the upstream end of a perennial stream, where practical, and the entire stream network upstream of this point was mapped. Measurement of stream length was discontinued at the point where the stream was dry and had no defined streambed or banks. Catchments were surveyed twice to document the change between wet (spring) and dry (autumn) seasons.

Average stream length ranged from 35 to 65 m per ha of catchment area with the shortest stream length in sand country and longest in Waitemata sandstones. Headwater streams draining Waitemata sandstones and Franklin volcanics had similar spatial extents in terms of total length (per catchment area) and the length of each habitat type. Variability between streams was high, but generally channel lengths with intermittent isolated pools made up the greatest proportion of stream length in the headwaters of Waitemata sandstone and Franklin volcanic HGAs during both spring and autumn. Mudstone streams dried out to greater extent in autumn than the other HGAs. Sand country streams were very stable, in terms of total length and the spatial extent of wetted habitat (flowing, standing and isolated pools). The total length of sand country streams was shorter than Franklin volcanics and Waitemata sandstone streams. Sand country streams often emerged from springs that flowed year round, providing a clear demarcation of the start of the stream.

The effect of land use on the spatial extent of headwater streams interacted with the effect of hydrogeological areas. Variation between streams was high, but some patterns were apparent. Mudstone streams showed the greatest difference between land uses with much longer stream channel length in native forest than pasture. Pasture streams in Waitemata sandstone had a higher proportion of mud in the wet season than other land uses, perhaps because of greater susceptibility to pugging by stock. For sand country and Franklin volcanics, extent of flowing and standing water was greater in pasture streams compared to native forest, which may be a consequence of channelisation or increased catchment runoff. Unsurprisingly, streams with riparian management were highly variable, having the longest length in Franklin volcanics and the shortest length in mudstone catchments, because of differences in age, buffer size and low number of replicates.

A comparison of blue lines mapped on 1:50 000 topographic maps with our surveyed reaches showed that of the 21 km of total stream length surveyed (total length in spring), 8.5 km is shown as blue lines on topomaps. In total, 52% of the sites surveyed coincided with blue lines. The sand country sites were better represented by the topomap blue lines than Franklin volcanics, mudstone, and Waitemata sandstone catchments where 50 – 66% of sites not marked on maps, and 40 – 50 m/ha were added to overall stream length on average. All sites in sand country were marked with blue lines on topomaps for at least part of their length, but our survey extended the length by about 10 m/ha on average.

In summary, HGA type was found to be more important in determining overall stream length than land use per se. Isolated pools were found to be the most abundant habitat type in headwater streams and therefore, represent an important habitat in the Auckland region.

2 Introduction

2.1 Background

Streams that do not flow year round have received relatively little specific research in New Zealand or internationally. There is considerable inconsistency in the terminology describing streams that do not flow year round (Dieterich & Anderson 2000). Headwater streams are highly vulnerable to modification from landuse and management changes (e.g., urbanisation, cultivation, grassing), and re-engineering (e.g., piping and damming).

The definitions of a stream under the Proposed Auckland Regional Plan: Air, Land and Water (Variation 1) are currently based on habitat permanence and ecosystem values (Appendix 1). The terminology used in the Plan (Category 1 and Category 2 streams) is the subject of appeals and may change. As it currently stands, flowing water is not a prerequisite for Category 1 streams but the presence of perennial pools and aquatic habitat is, with streams that dry out completely (Category 2) potentially given less protection under the plan (pending results of this research and a consideration of management options).

The Auckland Regional Council (ARC) requires information on the value of headwater streams in terms of their function and natural values, to aid development of management options. There are several components to this project, to which Parkyn et al. (2003) provides an introduction and outline. The first step in understanding the potential importance of headwater streams is to establish the nature and extent of this habitat resource in the Auckland region. This report describes the spatial extent of headwater streams in the Auckland region, investigating the different habitat types found in headwater streams and the influence of geology and land use. It provides a basis for subsequent reports on natural values of headwater streams and their importance for processing contaminant runoff (e.g., nutrients, bacteria).

2.2 Framework and aims

ARC identified that the research should be focused on the predominant land use within the Auckland Region, dry stock agriculture, with consideration of peri-urban areas (lifestyle blocks) and market gardening. The influence of landuse and management options on headwater stream spatial extent were also important to ARC, so sites were selected in pasture with and without riparian protection, and in native forest catchments.

We delineated the study area into four main hydrogeological areas (HGA) namely: Franklin volcanics, Awhitu/Kaipara sand country, Waitemata sandstones, and Dairy Flat/Wellsford mudstone, based on data and knowledge supplied from ARC.

A number of other hydrogeological units exist in the region, but were not studied. These include the greywackes of the Hunua Ranges, the volcanic and associated sedimentary rocks of the Waitakere Ranges and the volcanics on the Auckland Isthmus. The Hunua and Waitakere ranges are dominantly in Regional Parks where development is not an issue. Streams in the foothills are not dissimilar to Waitemata sandstone streams. Waitemata sandstone covers a large proportion of the region and was well represented in this study. The Auckland Isthmus is completely urbanized, and most of the smaller headwater streams have been piped, so was not included in this study.

Each HGA has different land-form, hydrogeological characteristics and runoff rates, so the influence of HGA on spatial extent of headwater streams was expected to be important in this study.

Most of the time stream flow is dependent on flow into the stream from groundwater. The amount of flow is dependent on the hydrogeological characteristics of the groundwater aquifer (such as hydraulic conductivity), the characteristics of the materials in the streambed and the groundwater gradient. The groundwater gradient changes over time, particularly seasonally, which changes the inflow to the stream. Groundwater gradient is also often controlled by topography. When the groundwater surface drops below the bottom of the streambed, groundwater inflow to the stream ceases, and the stream starts to dry up.

The objective of the survey was to characterise and measure the extent of headwater streams in representative land-uses and HGAs of the Auckland Region. Our aim was to provide an assessment of spatial extent based on catchment area and an indication of the length of streams not currently mapped on 1:50 000 topographic maps.

2.3 Definitions and spatial extent

Parkyn et al. (2003) reviewed the definitions of streams for streams that flow for only part of the year and that text was adapted for this report. It is estimated that ephemeral streams drain over one-third of the earth's land surface (Donath & Robinson 2001), but the hydrological regime of small, ephemeral and/or isolated waters is poorly understood (Brooks & Hayashi 2002). In most catchments, downstream floods are preceded by a longitudinal expansion of the channel network. Soils become saturated and formerly dry channels become an integral part of the drainage system. The length of formerly dry channels may well exceed that of permanent streams, and function to modify water quality as well as to provide habitat (Dieterich & Anderson 2000).

There is considerable inconsistency in the terminology for streams that only flow for part of the year. Temporary, intermittent, and ephemeral are all terms used to describe streams and ponds with irregular flow. Flow duration is generally used to differentiate the different stream types – but despite this, flow duration is seldom measured or verified to delineate the stream types (Hansen 2001). Under these definitions, perennial and intermittent stream types flow well beyond storm events.

Under normal circumstances, perennial streams flow all year. Intermittent streams cease flow for portions of a year. Ephemeral channels may flow during, but typically not for extended periods following, storm events.

Because it is often difficult to monitor flow duration at a large number of sites, it is helpful to use field indicators of flow duration and of channel responses to flow (Hansen 2001). Field criteria that Hansen (2001) used to determine stream type are listed in Table 2.1 below.

Table 2.1:

Field criteria used by Hansen (2001) to determine stream type.

Criteria	Stream type		
	Perennial	Intermittent	Ephemeral
Channel	Defined	Defined	Not defined
Flow duration (estimated)	Almost always	Extended, but interrupted	Stormflow only
Bed water level	Above channel	Near channel surface	Below channel
Aquatic insects	Present	Few, if any	None
Material movement	Present	Present, less obvious	Lacking or limited
Channel materials	No organic buildup	Lacks organic buildup	Mostly soil materials Organic buildup

Streams that only flow for part of the year may also be termed wetlands in some instances, especially where the channel is poorly defined or spread out. Emergent wetland vegetation can be expected to develop where water velocities during floods are not high enough to scour the channel. Of the wetland types described by Johnson & Gerbeaux (2004), seepages (including flushes) are the type most likely to also be termed headwater streams. A seepage is an area of slope with surface and groundwater flow that is “less than that which would be considered as a stream or spring” and which receives periodic flushes of water from rainfall.

This project looks at a wider spectrum of small headwater streams in the Auckland region, including streams that may be termed ephemeral, intermittent or perennial in various texts. We have categorised these small headwater streams according to both channel form and flow characteristics and for the purposes of this report the term ‘headwater stream’ is used to cover a range of water states from slow flowing, standing, pools and muddy or dry channels.

3 Methods

3.1 Site Selection

The research focused on the predominant land use within the Auckland region, dry stock agriculture, with consideration of peri-urban areas and market gardening. We selected sites within the four main HGAs (hydrogeological areas):Franklin volcanics (Pukekohe), sand country (Awhitu/Kaipara), mudstone (Dairy Flat/Wellsford) and Waitemata sandstones. Sites were selected to fall into three land use categories: pasture, pasture with riparian protection, and native forest. Readers are referred to Edbrooke (2001) for a description of Auckland geology and ARC (2002) for more information on groundwater and surface hydrology in the region.

The Franklin volcanics (of the South Auckland Volcanic Field) include at least 97 volcanic centres. These produced scoria cones and associated basalt lava flows or tuff rings from explosive centres. The volcanic rocks are often overlain by a thick weathered profile consisting of silts and clays. The main streams of the area are strongly spring fed from basalt flows.

The sand country of the Awhitu and Kaipara Peninsulas consists of sand dune and inter-dune deposits, as well as alluvial sediments. The streams are also strongly groundwater fed.

The mudstones of Dairy Flat, and around Wellsford, are from a rock unit called the Northland Allocthon. These rocks are highly impermeable, and have very low groundwater flows. Streams in this geological unit typically dry up for long periods even in relatively large catchments.

The Waitemata sandstones are a series of rocks or formations that make up the Waitemata Group. These rocks underlie a large proportion of the region. They generally consist of alternating sandstones and mudstones, which are overlain by a thick weathering profile consisting of silty clays. These soils are well known in the region and are often referred to as 'waitemata clay'. The Waitemata Group rocks have low to moderate hydraulic conductivity, and hence have low inflows to streams.

In total, 165 tributaries were assessed from 32 catchments in the Auckland region, with the breakdown by land use and HGA provided in Table 3.1. Site locations are shown in Figure 3.1 and described in Appendix 2. A map and photo of each site is provided in Appendix 3. Initially, we focused on small catchments that were likely to be ephemeral. It became apparent that in order to describe the extent of streams upstream of the permanently flowing sections, we needed to select larger catchments where the stream was permanently flowing. For this reason, some of the smaller catchments surveyed during spring were not re-surveyed in the dry season (Appendix 2).

We also required sites with consistent land use within the catchment upstream of, and including, the permanently flowing section. Locating sufficient numbers of sites with riparian protection was difficult, particularly in the smaller HGAs, e.g., sand country where no pasture-riparian sites were found (Table 3.1). The most extensive HGA in the region, Waitemata sandstones yielded the highest number of catchments and tributaries surveyed (Table 3.1).

Catchment size ranged from 1.5 to 69 hectares (Appendix 2). Most HGAs were represented by catchment areas of a similar size range, though selected sand country catchments were generally larger (average 43.4 ha; compared to an average of 11 to 14 ha for the other HGAs).

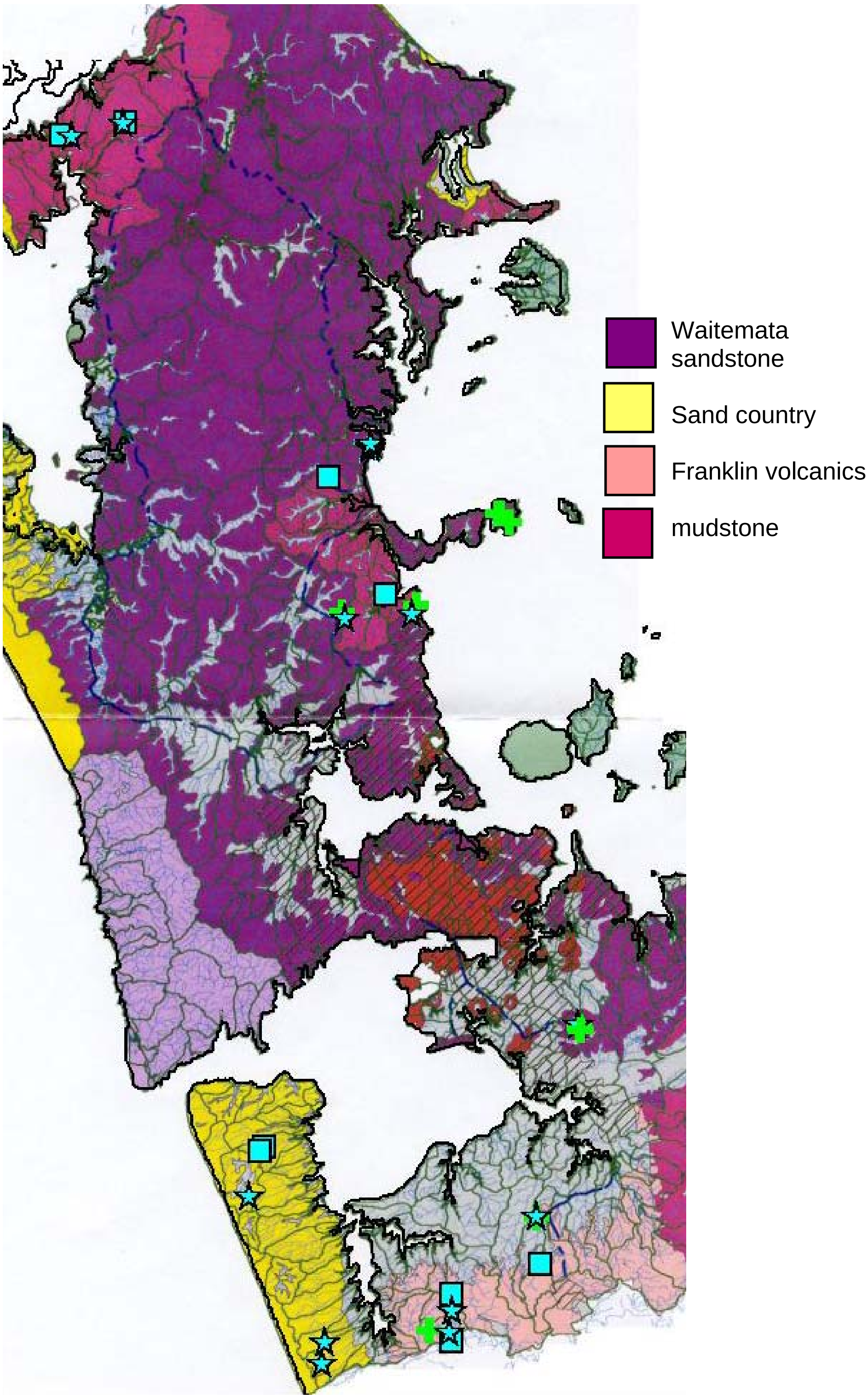
Table 3.1:

Number of catchments assessed for each land use and hydrogeological area (spring survey). The number of tributaries are given in brackets.

	Native forest	Pasture	Pasture with riparian protection	Total
Franklin Volcanics	3 (7)	3 (16)	2 (6)	8 (29)
Mudstone	2 (11)	3 (21)	1 (1)	5 (33)
Sand	2 (5)	3 (37)	0 (0)	5 (42)
Waitemata Sandstone	2 (21)	4 (24)	7 (16)	13 (61)
Total	9 (44)	13 (98)	10 (23)	32 (165)

Figure 3.1:

Study sites in the Auckland Region and the hydrogeological areas. Site markers are colour-coded to indicate the landuse at each site (blue square – native forest; blue star – pasture; green cross – pasture riparian). For individual site maps see Appendix 3.



3.2 Survey Methods

Channel form (morphology) as well as surface water characteristics can be used to define the extent and describe the type of headwater streams in the Auckland Region.

In our study, channel form was described using four categories that largely represent the increasing size and power of a stream to form a channel and can be used as an indication of the permanence or regularity of flow (Table 3.2). At the point where streams first begin, the stream does not have the power to erode a defined channel or scour plant growth (Code C – no banks, bed vegetated), but with increasing frequency and magnitude of flow, substrates are scoured to leave a stream bed and are unsuitable for plant growth (Code B – stream bed substrate, no banks, no terrestrial vegetation). As stream power increases, the channel generally becomes incised, forming stream banks (Code A – channel incised, no terrestrial vegetation). Wetlands are a unique channel form, defined by the presence of wetland vegetation (e.g., sedge, reeds, raupo), and designated as Code D.

The amount of surface water present was described using five categories (Table 3.2). If a stretch was broken at less than 10 metres by pools, then this was classed "isolated pools", and conversely if the pool was greater than 10 m long it was classed as "slow flow or standing". Mud was distinguished from open-water by a depth of water less than 10 mm. This distinction, though at first glance trivial, was necessary because the water level in mud is at the surface, so there is a gradual continuum from mud to open-water. When the water is turbid, it is sometimes useful to jab a stick into the bed – if the hole left behind does not fill instantly, then it is classed as mud. At the other extreme, mud was distinguished from dry substrate using the 'gumboot test'. Walking through mud, your feet sink in and mud/water oozes out. This does not happen with moist soil.

Table 3.2:

Coding system used to describe channel form (rows) and amount of surface water (columns). Each section of stream was described using this system.

		Water				
		1. Obvious flow	2. Slow flow or standing	3. Isolated pools	4. No open water, muddy	5. Dry
Channel	A. Channel incised, no terrestrial vegetation	1A	2A	3A	4A	5A
	B. Stream bed substrate, no banks, no terrestrial vegetation	1B	2B	3B	4B	5B
	C. No banks, bed vegetated	1C	2C	3C	4C	5C
	D. Wetland	1D	2D	3D	4D	5D

The coding system produces 20 different combinations of channel-form and flow (Table 3.2). These codes were used to describe and delineate each stream segment in the catchment - a change in either channel-form or surface water delineated the start of the next stream segment. A summary of the raw data is presented in Appendix 4. For each segment various physical attributes were described including proportion of substrate types, channel size, the amount of open water, amount and type of in-channel vegetation, channel slope, amount of riparian shading and riparian vegetation type (Table 3.3).

The uppermost extent of the stream channel was considered to be at the point where the stream was dry and had no defined streambed or banks (code 5C). On occasions the stream would switch back to a wetter, more defined channel a short distance upstream of the 5C section. Where this occurred the survey continued until the 5C channel persisted. The same criteria were used in deciding whether to survey tributaries.

Sites were surveyed twice to document the change between wet and dry seasons. The first survey was in November to mid-December, representing a wet season, with a second ‘dry’ survey in late March to April (see Appendix 2 for survey dates). Relative flow conditions at the time of survey were available from water level recorders in nearby catchments (Figure 3.2). High rainfall in November and December provided high water levels at most sites for the wet season survey. Heavy rainfall occurred in February, so dry season surveys took place in late March and April. Good contrast in flow was achieved for most sites. Franklin volcanics sites did not experience the same extremes, especially those re-surveyed in late March, rather than April (dates given in Appendix 2). As most of the region is exposed to similar weather patterns, the slow recession of flows for Franklin volcanics sites is considered part of the seasonal effect we are interested in investigating.

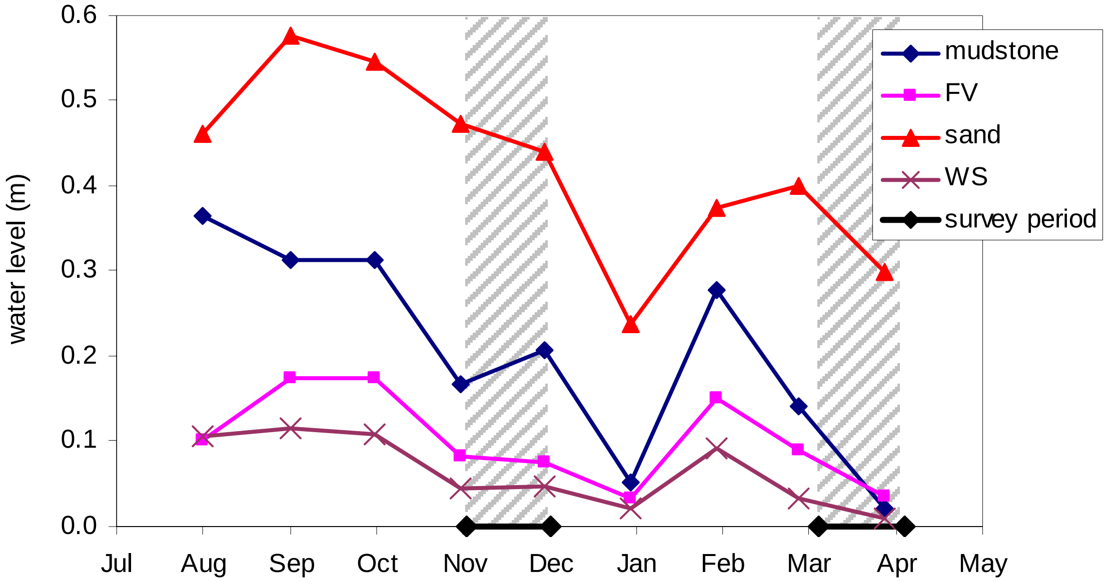
Table 3.3:

Features assessed for each stream segment during the spatial extent surveys (delineated by a change in stream code – Table 3.2). These habitat descriptors will be reported in subsequent reports in relation to the aquatic biodiversity and natural values of headwater streams.

Feature	Components	Description
Substrate (%)	Bedrock	
	Cobble & gravel	
	Sand, silt and clay	
Channel description	% Open water	Proportion of stream length with open water
	Stream width (m)	
	Flood channel width (m)	As defined from the top of the stream bank or zone of frequent inundation
	Maximum depth (m)	Average depth would be a less informative habitat measure for isolated pools.
In-channel vegetation (%)	Grass	
	Macrophyte emergent	Wetland vegetation (raupo, sedge, etc.)
	Macrophytes submerged	Elodea, charophytes and other submerged plants
	Sprawling marginals	Watercress, sweet grass, starwort, polygonum
Slope		Estimated, with periodic checks using an inclinometer and survey poles
Shade (%)	Riparian	Canopy level shade
	Grass	Shade offered by groundcover and banks
Riparian vegetation (%)	Bare	
	Pasture	Grazed grasses
	Wetland	Rushes, kiekie, raupo
	Shrub	
	Native trees	
	Exotic trees	

Figure 3.2:

Monthly average water levels from continuous recorders in perennial streams in the Auckland region (2003-04). Levels were subtracted from the minimum value for each site and then averaged across sites. Values provide a relative measure for comparing stream flows between the spring and autumn surveys (Nov.-Dec. & March-April respectively). The time of survey is indicated by black bars. Water level sites used: mudstone – Orewa Stream at Kowhai Road; FV (Franklin volcanics) – Waitangi Stream at SH bridge and Whangapouri Stream; sand country – groundwater bore at Maraeorahia; WS (Waitemata sandstone) – West Hoe Stream, Puhinui Stream and Vaughan at site 4.



3.3 Comparisons between catchments of different shapes and sizes

Differences in catchment size between our study sites may mask any differences in stream length caused by HGA or land use type. Intuitively, the larger the catchment the longer the stream, but shape of catchment may also affect the relationship between catchment area and stream length.

We created theoretical catchments of different shapes to identify what type of relationship is expected. Taking the hypothetical example of a circular catchment (Figure 3.3 scenario A), adding a unit of catchment adds the same length of channel. The equation for this relationship is linear (with a negative y-intercept). The next scenario is a long thin catchment (Figure 3.3, scenario B). Once the catchment size exceeds the critical size to form a channel, any further increase in catchment size produces a stream channel over the entire length of the added segment. Again this produces a linear response between catchment area and stream length, but with more channel produced per unit of catchment area (Figure 3.4). A real world scenario of several small catchments feeding into a larger catchment effectively starts off like a circular catchment (scenario A) then approaches and exceeds the channel length of the linear catchment (scenario B) (Figure 3.4). This is because the growing main channel cancels out the catchment area above the start of each tributary that has no channel. This forms a positive polynomial response between catchment area and stream length (Figure 3.4).

Using some real world data, the results from the present study gave an approximately linear relationship between stream length and catchment area (Figure 3.5). The scatter of points is not surprising given the residual effects of catchment shape, geology, land use, etc. Isolating the effect of catchment shape would involve producing a theoretical catchment map for each site using contour maps. Fine scale topographical data was not available and would be needed to produce such channel networks (topographical contours of 5m or less may be needed for these small streams, compared to the 20 m contours currently available). Instead, comparisons were made after correcting for catchment area only (using stream length per hectare), which relies on having adequate site replication to average out the effect of catchment shape.

Figure 3.3:
Hypothetical catchments demonstrating the effect of catchment shape on stream channel formation (i.e., how much channel is formed for a given catchment size). Scenario A produces the least channel (imagine this drains to a small bottomless lake). Scenario C ultimately produces the most channel for a nominal habitat area, though less than B initially.

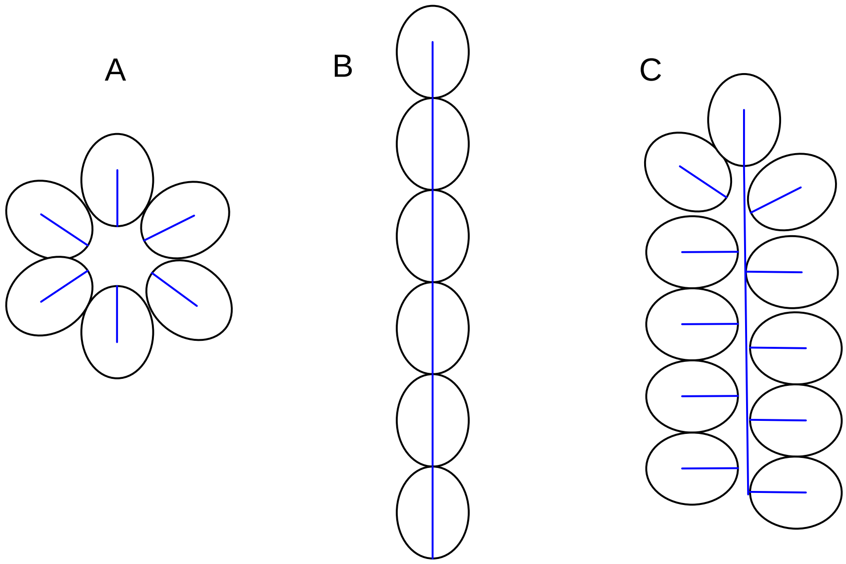


Figure 3.4:
The relationship between channel length and catchment area for the theoretical scenarios given in Figure 3.3 (nominal units).

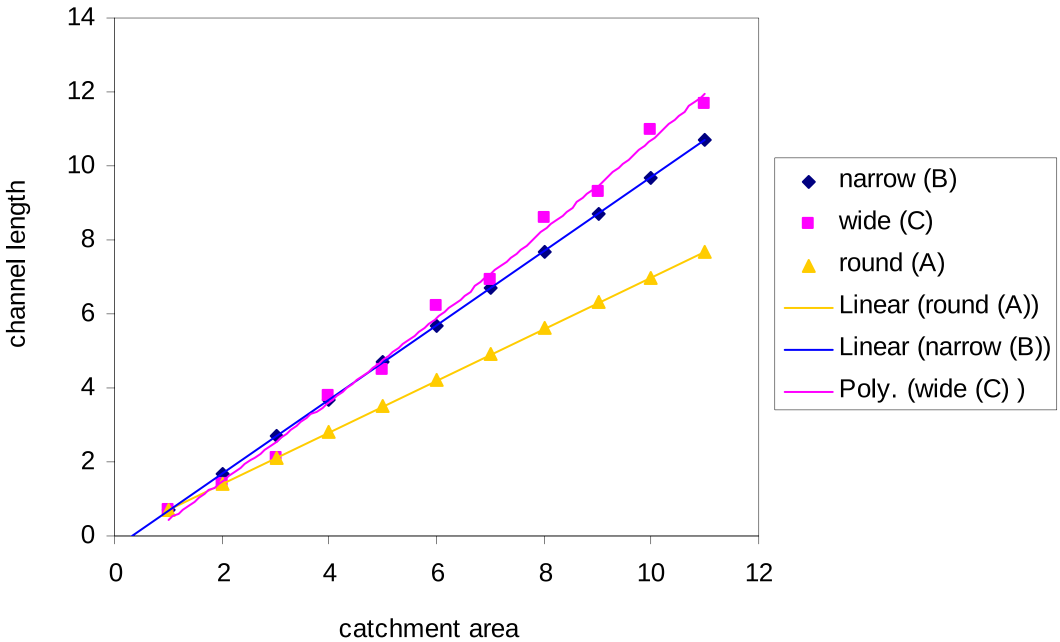
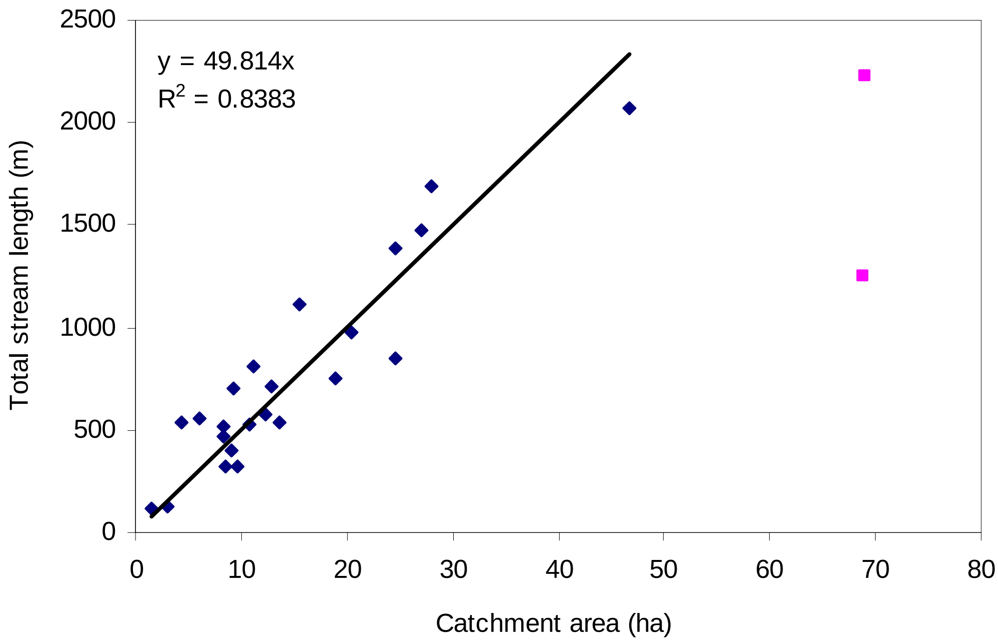


Figure 3.5:

Relationship between total stream length and catchment area. Spring survey data is presented. The two outliers (shown as square points) were omitted from the trendline (S4 & S5), and the y-intercept was changed from a positive value (118 m) to zero to produce an equation more consistent with that predicted from hypothetical scenarios (Section 3.3).



4 Results

Five surface-water codes and four channel-codes were used in the survey (Table 3.2). It was found that the surface-water codes most adequately described the transitions within streams so the analysis focused on these categories. The two primary factors investigated for their effect on surface water were HGA (hydrogeological area) and land use. The results are presented individually for each HGA and land use to provide a systematic depiction of the results, before drawing comparisons between HGAs and land uses. Variability is high for most parameters, and this is reflected in the wide standard deviations depicted in the following graphs. For this reason, descriptions focus on general patterns that are less likely to be the product of site variability.

4.1 Hydrogeological Areas

4.1.1 Franklin Volcanics

The average length of flowing water habitat was relatively short, reflecting in part the small size of the streams chosen in this study (Figure 4.1). Isolated pools formed the greatest length of headwater stream habitat in the Franklin volcanics streams, closely followed by standing water. The proportion of isolated pool habitat was similar between spring and autumn (Figure 4.1).

The length of muddy channel nearly halved between spring and autumn, but with a small increase in dry channel length. The length occupied by standing water or isolated pools increased in autumn, possibly as a consequence of unseasonal heavy rain in February. Most sites had receded to baseflow by the time re-surveys had started in late March, with the exception of some Franklin volcanics sites where water levels remained elevated in March (Figure 3.2). Although we may not have surveyed these streams at their driest, the results highlight the slower recession of water levels in Franklin volcanics, which is important in terms of the aquatic habitat value of these streams.

4.1.2 Mudstone

The most common habitat type in mudstone catchments was dry channel, particularly in autumn, while flowing water was encountered only in spring (Figure 4.1). Mudstone catchments experienced a net loss of extent in all water codes in autumn, except dry channel which extended as a consequence of the drying-out process. Pools remained present in autumn, but the extent of standing water and mud was much lower than in spring. A very large mudstone catchment would need to be surveyed to include perennially flowing sections, given that the 973 hectare

Orewa catchment has an annual low flow of 0 m^3/s (from continuous flow records, ARC 2002).

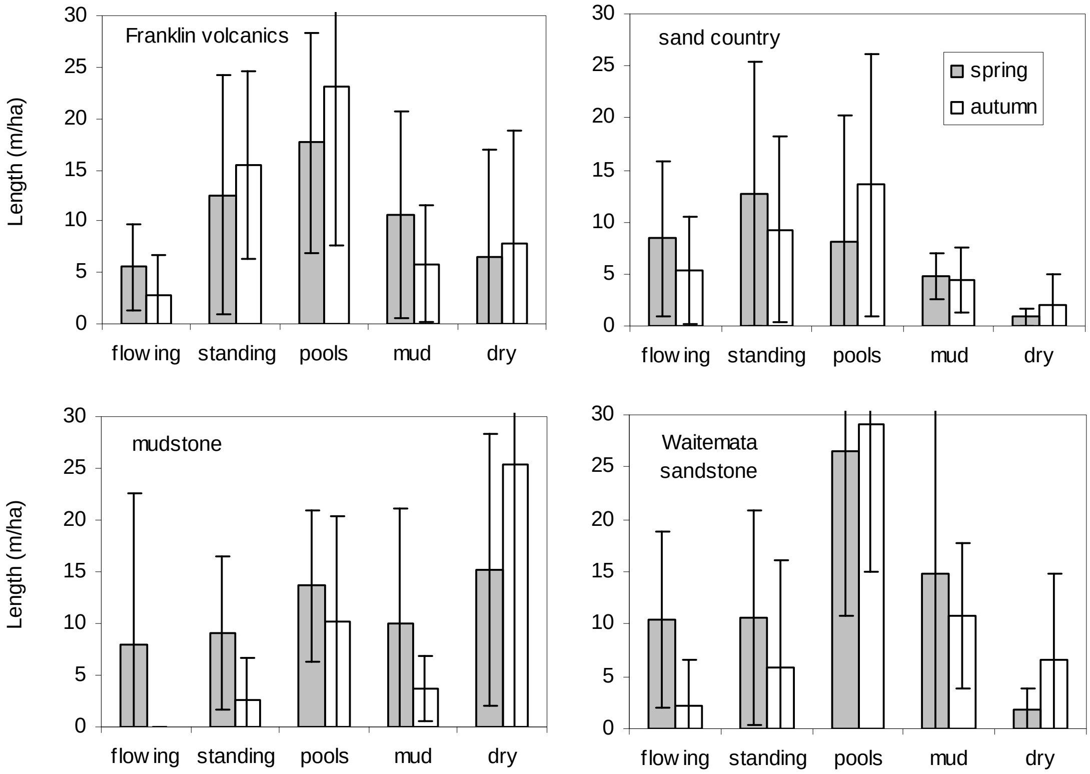
4.1.3 Sand Country

Relatively short sections of dry and muddy channel were present in the sand country streams (< 5 m/ha average; Figure 4.1) and most of the channel length was isolated pools, both in spring and autumn. There appeared to be some expansion of isolated pool habitat in autumn, with a corresponding loss of flowing and standing water habitat.

4.1.4 Waitemata sandstone

Isolated pools made up the greatest proportion of stream length (on average 25- 30 m/ha) in Waitemata sandstone streams (Figure 4.1). The proportion of isolated pool habitat was similar in spring and autumn, which presumably balanced out from gains when flowing sections were reduced to pools, and losses when shallower pools dried out. Despite some drying out, mud remained a significant proportion of the stream in autumn.

Figure 4.1:
The average length of each water code presented for each HGA. The spring and autumn results are presented (dark and light shaded bars). Length was standardised by catchment area for each site (metres per hectare). The water codes are as described in Table 3.2. Error bars are ±1 standard deviation.



4.1.5 HGA comparison

It is important to recognise that because of the high variability between catchments, few of the observed differences between HGAs would be statistically significant. To improve the visual clarity of the data, however, Figure 4.2 provides a simplified representation of the data without error bars.

For Waitemata sandstone and Franklin volcanics, reaches with isolated pools made up the greatest length of headwater streams on average (Figure 4.2). Sand country streams had less isolated pool length by comparison, with less than half the length of pools in spring than Waitemata sandstone and Franklin volcanics streams. Mudstone catchments likewise had less pool habitat than Franklin volcanics and Waitemata sandstone, and, in addition, had less flowing and standing water (particularly in autumn). Mudstone streams dried out the most between spring and autumn, and this was the only HGA to experience a net loss of pool habitat in autumn.

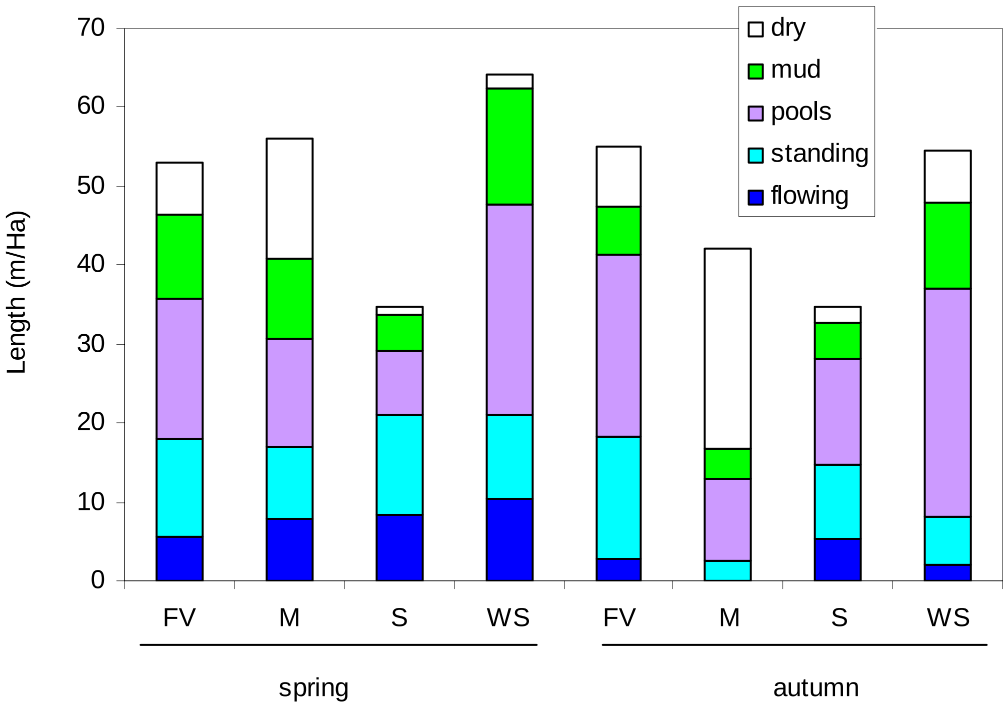
Flowing water length was reduced in autumn for all HGAs, although this was least pronounced in sand country and Franklin volcanics catchments, where flows are expected to be more stable. Presumably groundwater inflows are larger in Franklin volcanics and sand country catchments.

Sand country streams differed from the other three HGAs by the short length of dry and muddy channels. This may be a consequence of high infiltration rates for sand country soils, producing limited surface runoff. A greater proportion of rainfall would soak into the soil, emerging lower in the catchment as wetland springs and perennially flowing streams.

The maximum depth was measured in each section of each stream. Sections with obvious flow (code 1) were deeper than isolated pools (code 3), with medians of 0.25 m and 0.10 m respectively (ANOVA $p<0.001$, log transformed data). However, the depth of most isolated pools is still expected to provide acceptable habitat for fish and invertebrates. Only Waitemata sandstone streams offered any indication of being deeper than the other HGAs (median 0.20 m in isolated pool habitat for Waitemata sandstone, compared to 0.10 m in pool habitat for other HGAs; ANOVA $p<0.005$). The depth of isolated pools was similar in spring and autumn (median 0.10 m in spring and 0.12 m in autumn; ANOVA $p=0.297$).

Figure 4.2:

The average length of each surface-water code is given for the four hydrogeological areas (Franklin volcanics, mudstone, sand country and Waitemata sandstone respectively) in spring and autumn. Length was standardised by the catchment area for each site (metres per hectare). The water codes in the legend are described in Table 3.2.



4.2 Land use

The effects of land use appear relatively minor when data from all HGAs are combined (Figure 4.3). There may be more wetted channel length (flowing, standing water, and pools) in native forest catchments, compared to pasture and pasture-riparian, but the contrast is not great compared to the differences between HGAs (Figure 4.3 compared to Figure 4.2). If the dataset is first divided by HGA, then the contrast between land uses becomes more pronounced (Figure 4.4). There are two possible explanations for this; either the effect of land use varies depending on which HGA is considered or, alternatively, the differences specific to land use/HGA combinations are an artefact of the small sample sizes produced by fragmenting the dataset into so many groups. Whether the differences are real or not, it seems likely the effect of land use on stream formation is secondary to the effects of geology.

Waitemata sandstone is the most extensive HGA in the Auckland Region and consequently more sites were selected within this HGA. Land use comparisons for Waitemata sandstone are therefore the most reliable. The effects of land use in other HGAs are worth mentioning, but the small sample sizes need to be kept in mind (see Figure 4.4 and Table 3.1 for sample sizes).

Mudstone catchments showed the greatest difference between land uses with a longer channel in native forest (albeit with a high proportion of dry channel length presumably formed largely through stormflow).

4.2.1 Native Forest

Native forest sites generally had longer sections of wetted channel length (pools, standing and flowing water) than the other land use types in each corresponding season (Figure 4.3). In the dry season, autumn, there appeared to be a contraction in obvious flow and an increase in isolated pools (Figure 4.3).

4.2.2 Pasture

Pasture streams were longer compared to other land uses in Waitemata sandstone catchments. In spring this was largely because of greater mud channel length than other land uses, which subsequently became extended dry channels in autumn. Pugging in wet weather could have exacerbated the extension of mud channels in WS, M, and FV catchments. For sand country streams, stock access did not appear to increase the length of muddy channel in spring (Figure 4.4).

Pasture streams draining sand country and Franklin volcanics appeared to have less isolated pools and more flowing/standing water compared to native forest streams (Figure 4.4). This may be a consequence of realignment and channeling of pasture streams (or wetland drainage), producing more concentrated flow, or the absence of interception by tree canopy and roots allowing more runoff in pasture catchments. The pasture sites selected in sand country were larger than the native forest sites, which may also have contributed to the greater length of flowing habitat (average 62 hectares, compared to 16 hectares on average for forested sand country streams).

4.2.3 Pasture-Riparian

Pasture-riparian sites draining Waitemata sandstone catchments appeared to have dried out more in autumn compared to native forest and pasture, leaving less isolated pool length (Figure 4.4). This drying out was most apparent for the Shakespeare Regional Park sites (WS2 A, B and C), which had more rank grass and smaller trees than the pasture-riparian site at Totara Park (WS1D, see Appendix 3 for photos). One of the driest sites in autumn was a pasture-riparian site draining a mudstone catchment. However, with only one site to represent this combination of land use and HGA, the result cannot be taken as representative.

Figure 4.3:

The average length of each surface-water code is given for the land uses surveyed in spring and autumn. The different colours represent the proportion of each water code (water codes described in Table 3.2). The three land uses are native forest (NF), pasture (P) and pasture-riparian (PR). Length was standardised by the catchment area for each site (metres per hectare). These results are divided into separate graphs for individual water codes in Appendix 5, to allow the display of standard deviations.

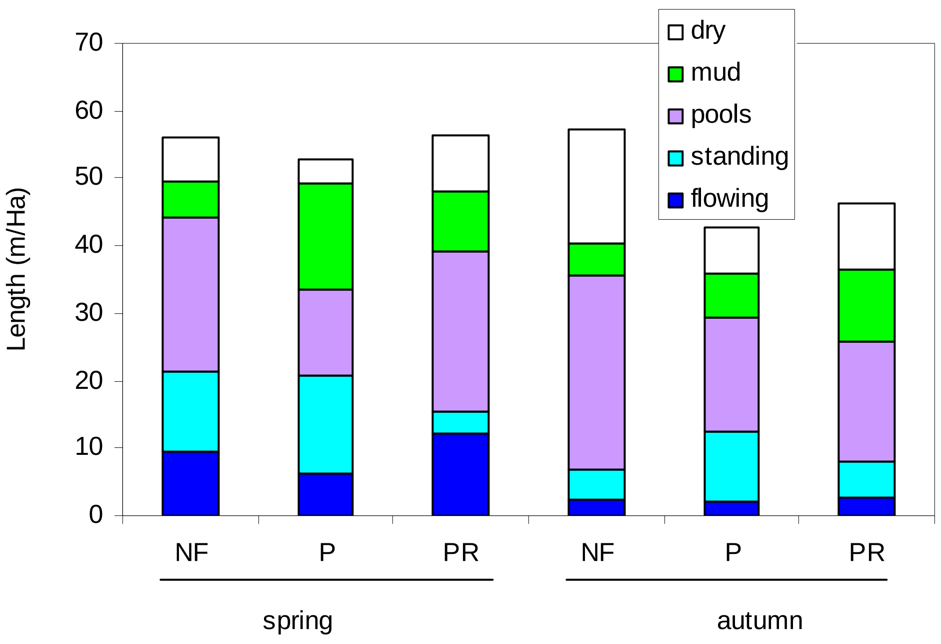
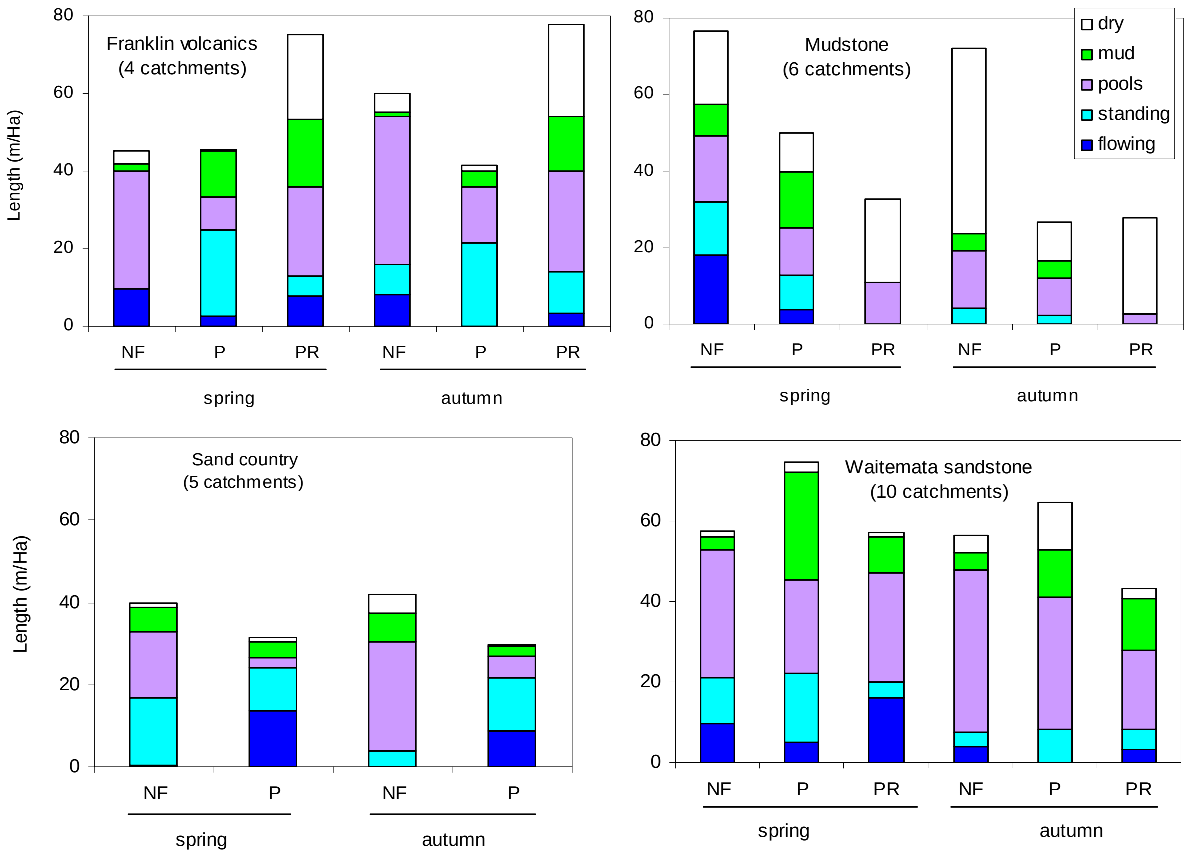


Figure 4.4:

The average stream length for each land use is summarised for spring and autumn, and is plotted individually for each HGA. The different colours represent the proportion of each water code (water codes described in Table 3.2). The three land uses are native forest (NF), pasture (P) and pasture-riparian (PR). The spring and autumn results are presented as separate bars. Length was standardised by catchment area for each site (metres per hectare). Catchment replication is limited within a given HGA for each land use in some cases, and the total number of sites in each HGA is indicated on each graph with more detail given in Table 3.1.



4.2.4 Land Use and Wetlands

The analysis for this report has so far focused on the surface-water codes (relative length of flowing, pools, etc.). Channel type was also surveyed and, of the channel codes used, the length of wetland will be of interest for subsequent NIWA studies for Auckland Regional Council into functional values of headwater streams (e.g., processing of contaminants such as nitrate and faecal coliforms). The length of wetland was recorded as channel code D, which is defined as having emergent wetland vegetation. Tall canopy wetlands were not recorded for this survey (e.g., pukatea, swamp maire); therefore results only reflect the distribution of low canopy wetlands (e.g., reeds, raupo).

In total, 17% of the surveyed stream network was recorded as wetland, across all HGAs and land uses. Pasture catchments produced a greater length of wetland, per hectare, than forest (average 11.3 m/ha versus 5.5 m/ha respectively, ANOVA on square root transformed data, $p=0.24$), averaged across three of the HGAs (Franklin volcanics, Waitemata sandstone and mudstone). Presumably the forest shades out small wetland areas, which also explains the smaller proportion of wetland in riparian management catchments (average 2.7 m/ha). For sand country, the reverse applied between land uses with an average of 20.1 m/ha of wetland in native forest and 3.9 m/ha in pasture catchments (ANOVA on square root transformed data, $p=0.004$). The pasture catchments in sand country often had obvious realignment and drainage of what was presumably once wetland. Catchment morphology appeared more conducive to wetland formation in sand country, with low-gradient valley floors that were often wide enough to prevent shading of wetland amongst forest.

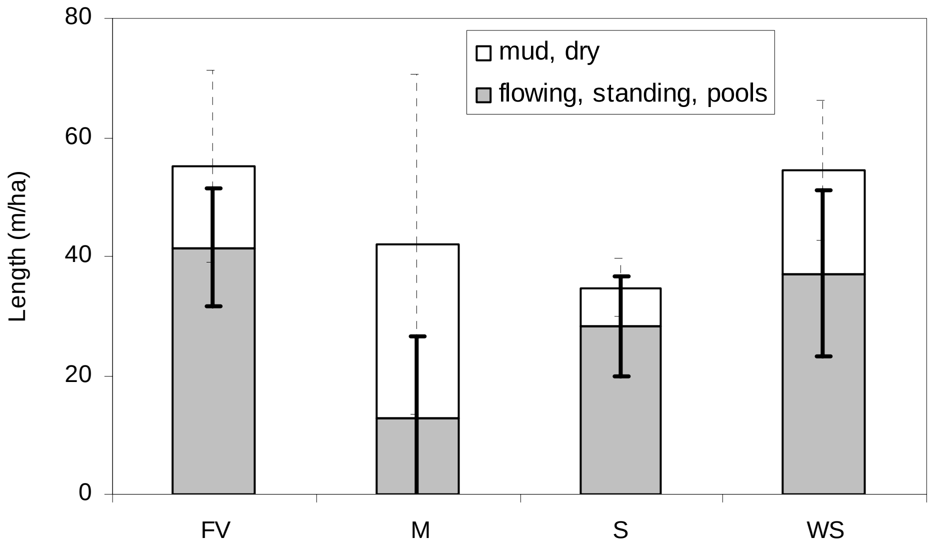
4.3 Comparison to Auckland Regional Plan Definitions

The Proposed Auckland Regional Plan: Air, Land and Water currently provides two definitions of a stream (Appendix 1). The definitions, as they stand, are the subject of appeals and may change. Currently, Category 1 streams provide aquatic habitat year round (flowing water or pools), while Category 2 streams are dry for part of the year. The data from this survey were composited into water codes corresponding to the definitions given in the Auckland Regional Plan. Summing together the flowing sections, standing water and isolated pools (codes 1A to 3D) from autumn surveys gave an approximation of Category 1 streams under the plan. This is only an approximation because pool size requirements stipulated in the definition (0.15 m deep, surface area 0.5 m^2) are not necessarily met. Sections of mud or dry channel from autumn surveys default to the Category 2 definition under the plan.

The proportion of flowing, standing water and pools in autumn was high for most HGA's (Figure 4.5), with the exception of mudstone catchments, which had the least aquatic habitat, averaging short of 13 m/ha.

The Resource Management Act does not require a stream to be flowing for it to be covered by the act (RMA 1991, Section 2), however, regional councils have often limited the application of their regional plans to permanently flowing streams. The latter approach omits significant areas of perennial aquatic habitat, compared to the definition adopted by Auckland Regional Council. On average, 58% of the total stream length surveyed for this study was isolated pools and standing water, compared to only 6% of the stream network that flowed during autumn. The small proportion of perennially flowing stream is partly a product of the small size of streams chosen for this study (larger catchments would produce more flowing stream, but the network of pools and standing water would also increase). On average, 36% of the surveyed stream length fell outside the ARC Category 1 definition of stream (mud and dry channels in autumn). These would default to Category 2 streams, receiving less protection under the regional plan.

Figure 4.5:
The water codes used in this study are aggregated to correspond approximately to the definitions given in the Auckland Regional Plan. Combining water codes 1 to 3 (flowing plus standing water plus isolated pools) from autumn surveys gives an approximation of Category 1 streams in the plan. Combining muddy channel and dry channel (from autumn surveys) gives an approximation of Category 2 streams under the plan. Averages for each of the four hydrogeological areas are given (Franklin volcanics, mudstone, sand country and Waitemata sandstone respectively). Length was standardised by catchment area for each site (metres per hectare). Error bars (± 1 standard deviation) are given for each category, with error bars for mud/dry reduced to dashed lines for clarity.



4.4 Spatial extent & blue lines

On the NZMS260 Topomap series (1:50,000 scale) streams are represented by blue lines. Blue lines are referred to in the definition of streams in the Auckland Regional Plan (see Appendix 1), but we do not know how well these blue lines represent headwater streams. Comparison of the GPS coordinates for each surveyed stream, with the blue line shown on topomaps (Appendix 3), gave some unexpected results. In many cases the blue line gave a very close approximation of the extent of the primary stream channel, often to the top of the surveyed stream. The blue line is therefore extending beyond the perennially flowing section, as far as the end of the dry un-vegetated channel. The starting point for the topomap blue lines was not rule-based, instead relying on the expertise of the photogrammetrist, who converted the aerial photos to maps (pers. comm. David Balm, cartographer for LINZ, Wellington). The topomap technical specifications acknowledge the inclusion of seasonal watercourses in the drainage pattern (National Topographic/Hydrographic Authority 2003).

What the blue line omits, however, is the side tributaries. These side tributaries can be quite sizeable with perennial flow, or at least perennial pools. The West Hoe

Stream provides a good example (Figure 4.6). The top of the blue line corresponds very closely to the top of the surveyed stream, but pursuing the side tributaries to the same extent (code 5B) reveals a more extensive network of tributaries. There were several flowing tributaries of the West Hoe Stream, downstream of the surveyed catchment, that are not shown as blue lines on the topomap (dashed blue lines on Figure 4.6). Using sites in Shakespeare Regional Park as a second example (Appendix 3, WS2), one of the three catchments surveyed (WS2A) is represented surprisingly accurately by the blue line, while the other two (WS2B & WS2C) have no blue line at all. There is a simple reason for the absence of tributaries from the topomaps. As described in the topomap technical specifications, streams less than 500 m long were not mapped as a rule (National Topographic/ Hydrographic Authority 2003). The methods and rules used to develop the blue lines are clear and reasonable, but different rules would be needed to consistently represent stream habitat values of headwater streams. It is worth noting that there are differences between topomaps, with older revisions typically omitting more tributaries (though in some cases the reverse was found to apply).

Of the 21 km of total stream length surveyed for this study (total length in spring), 8.5 km is shown as blue lines on topomaps. Extrapolating this result to the rest of the region is difficult because the variable effect of the 500 m rule. Surveyed streams are either well represented by the blue line, or not at all, which makes for large between site variability. In total, 52% of the sites surveyed coincided with blue lines. The sand country sites were better represented by the topomap blue lines than the other HGAs (Figure 4.7). All sites surveyed in sand country were represented by blue lines on topomaps, compared to 50 – 66% of sites in the other HGAs. Compared to the blue line network, our surveys extended the channel network by only 10 m/ha on average for the sand country sites, compared to 40 – 50 m/ha for the other HGAs (Figure 4.7). This may reflect the limited spatial extent of sand country streams above springs, or perhaps is an artifact of site selection with more sand country sites chosen that coincide with blue lines.

Reviewing the various site maps (Appendix 3), the blue line extends close to, or past, the top of the surveyed stream channel for both forest and pasture catchments (where a blue line exists). The 500 m rule appears to be applied consistently between land uses. Catchment shape is expected to have a bigger effect on tributary representation than land use. More complex catchment shapes with lots of sub-500 m catchments will have more stream habitat omitted from the blue-line network.

An alternative digital stream network was developed by NIWA as part of the REC (River Environment Classification) (NIWA 2004). The REC shows a total of 3.9 km of stream in the study catchments compared to 21 km observed. Catchments less than 20 hectares were consistently omitted from the REC stream network, compared to the topomap blue lines which offered blue lines for some of these small catchments but not for others (Figure 4.8). The REC network gave a better depiction of flowing streams for the sites surveyed (correlation of REC length with obvious flow in autumn gave an R^2 of 0.64; the blue line gave an R^2 of 0.30). This network does not extend far enough upstream to represent isolated pools. Extending the REC network may require higher resolution contour lines than are currently available (from the 1:50,000 topomap series).

A map of the West Hoe catchment was produced to provide a visual comparison of how the blue line network compares to the current stream definitions given in the Auckland Regional Plan (Figure 4.9). Following Section 4.3, the survey data was composited into two groups that correspond to the definitions given in the plan (note that the Auckland Regional Plan definitions are the subject of appeals and may change). Autumn data for flowing, standing water and isolated pools were summed to provide an approximation of Category 1 streams, with mud plus dry channels equivalent to Category 2 streams. The blue line represents half of the flowing, standing and pool habitat in autumn (744 m covered by the blue line; with an additional 730 m in unmapped tributaries). This is a best-case scenario, because tributaries not incorporating a first-order blue line are completely unrepresented (half the surveyed catchments have no blue line).

For the West Hoe Stream, the importance of small tributaries was further considered in terms of the area of wetted habitat (Table 4.1). The stream was nominally divided into small, medium and large tributaries, with most of the surveyed blue-line nominated as a large tributary (below the second inflowing tributary, Figure 4.9). Small and medium sized tributaries extended the total stream length to more than double that of the larger tributary (Table 4.1). The large tributary contained a greater area of wetted habitat, however, with more frequent pools that were deeper and wider, on average, compared to the small and medium tributaries (Table 4.1, ANOVA on log transformed data, $p=0.001$ for width and 0.014 for depth). The small tributaries have less wetted area for a given length of stream and a smaller proportion of open water (Table 4.1). Native fish (kokopu) were observed in the medium and large tributaries where there are greater areas of wetted habitat (Figure 4.9). However, burrows of the large dragonfly larvae *Uropetala carovei* were only found in the small tributaries and they appear to prefer seepage habitat rather than pool habitat (Figure 4.9).

Table 4.1:

Comparison of stream attributes between different sized tributaries of the West Hoe Stream. Medians were calculated for stream width and maximum depth for sections of flowing, standing or pool habitat in the West Hoe Stream (autumn data). Percent open water was estimated visually for each stream segment, and averages are presented (weighted by segment length). Wetted area provides a measure of aquatic habitat and was calculated by multiplying width by percent open water by total stream length. The stream was nominally divided into small, medium and large tributaries. The blue line below the second inflowing tributary (Figure 4.9) was nominated as large tributary for this analysis.

	Maximum pool depth (m)	Width (m)	Open water	Total length (m)	Wetted area (m^2)
Small tributaries	0.2	0.3	43%	494	64
Medium tributaries	0.3	0.5	59%	568	168
Large tributary	0.45	0.8	89%	500	358

Figure 4.6:

West Hoe Stream (WS6, Orewa) comparing the extent of blue line on the Topomap (NZMS260) to the observed stream network. The red dots are GPS locations (where possible) marking the start and finish of the surveyed catchment. The dashed red lines represent the observed channel network (approximate). The dashed light-blue lines represent larger streams in the catchment that are not shown on the topomap. The later were not surveyed but were observed at their confluence.

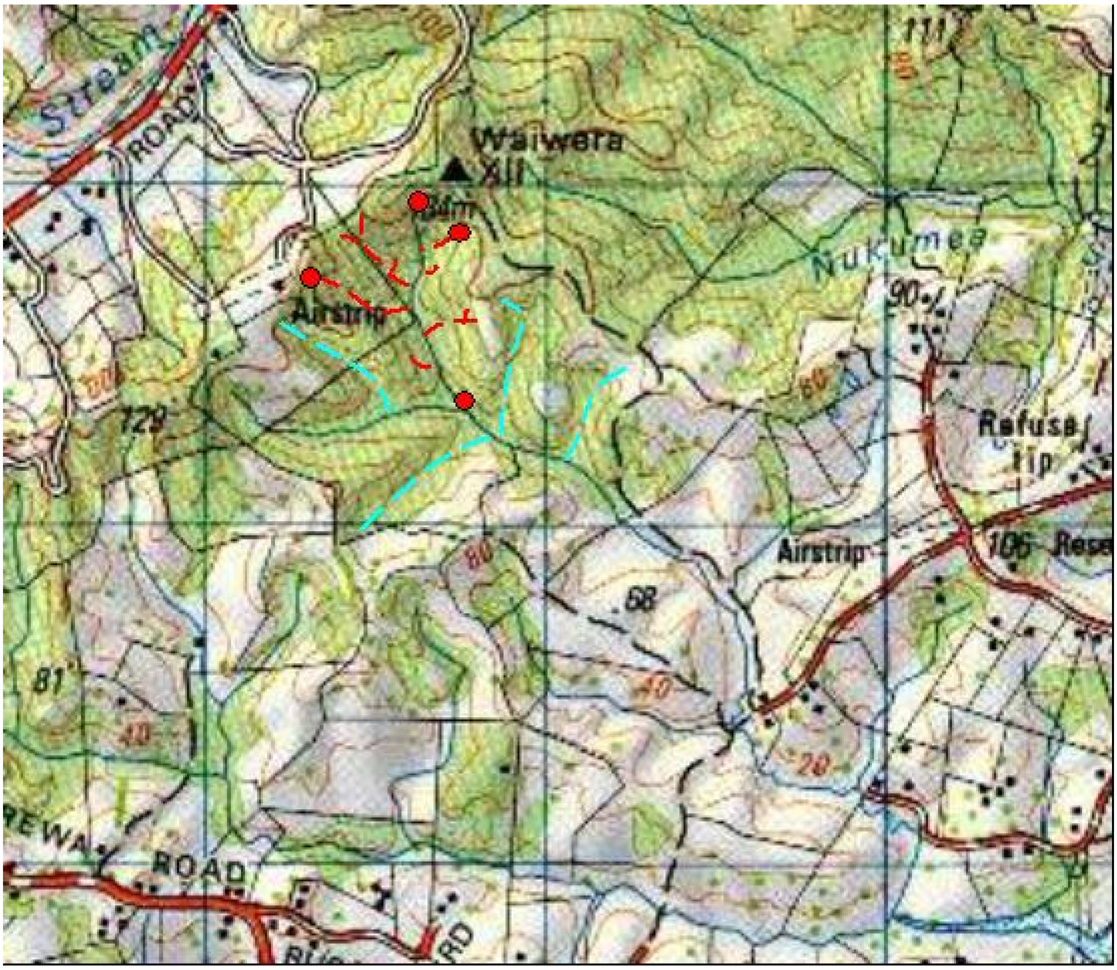


Figure 4.7:
The observed average length of streams surveyed in spring compared to the average length of blue lines on Topomaps (NZMS260, 1:50,000 scale). The percentage of sites that coincided with a blue line on the Topomap is also presented for each HGA (e.g., 50% of FV sites had a blue line length >0). Length was standardised by catchment area for each site (metres per hectare). Error bars (± 1 standard deviation) are given for each category, with error bars for mud/dry reduced to dashed lines for clarity.

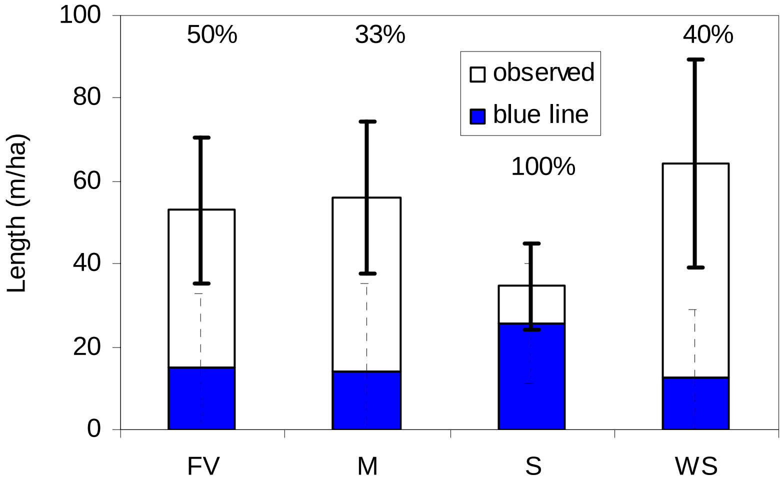


Figure 4.8:
Relationship between stream length and catchment area. Observed total stream length (during autumn) is compared to the length of topomap blue lines (NZMS260 series, 1:50000 scale) and REC stream network (River Environment Classification database). The linear trendline was fitted to the observed stream lengths, as per Figure 3.5.

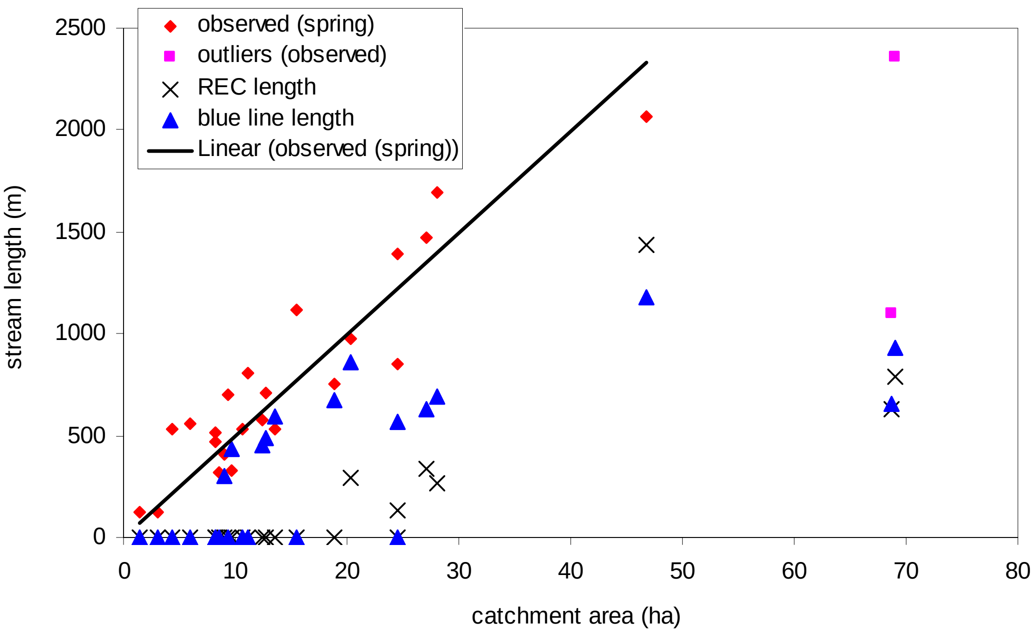
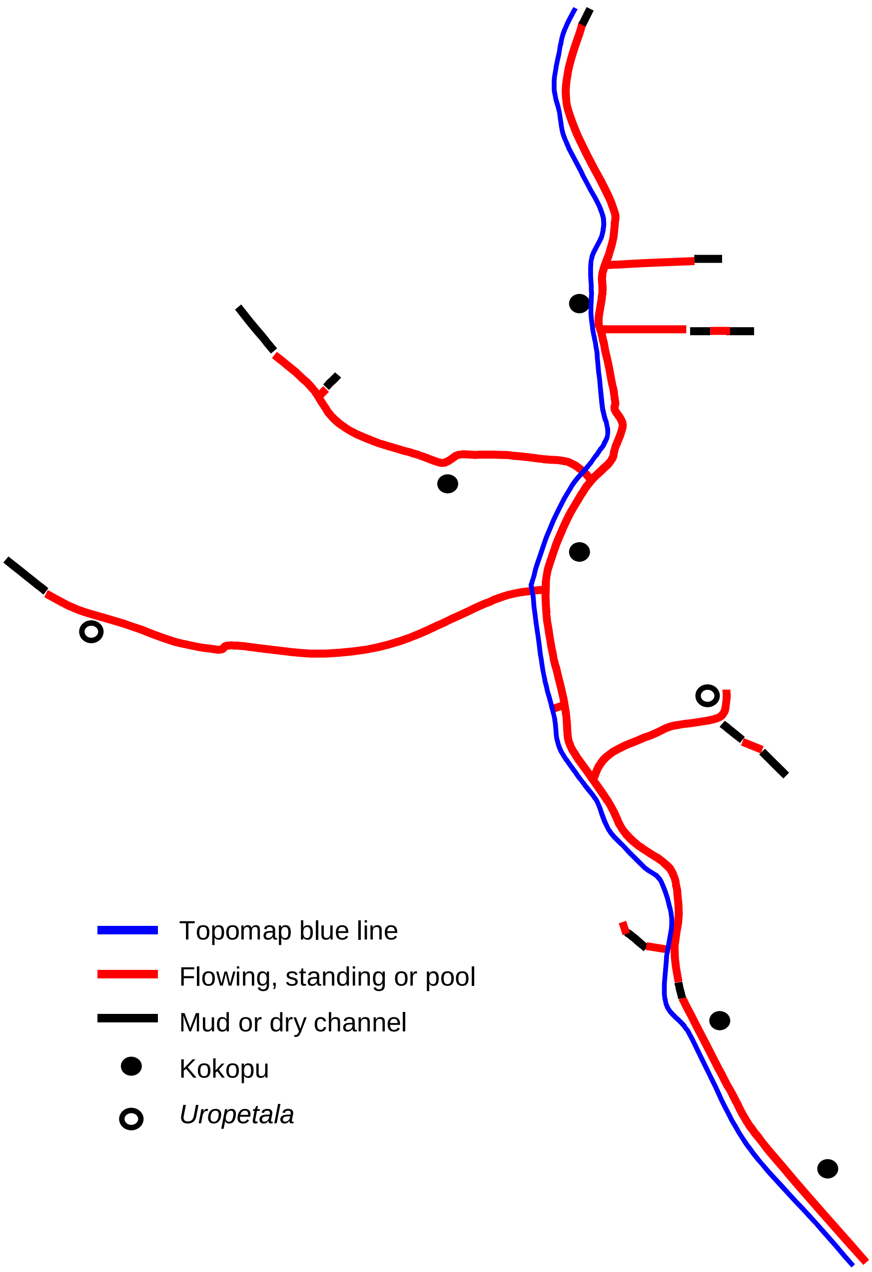


Figure 4.9:

Map of the West Hoe Stream (site WS6) approximately to scale. The blue line from 1:50,000 scale topomaps (Figure 4.6) is compared to the surveyed stream network. The water codes were lumped into two groups. The autumn data for flowing, standing water and isolated pools combined is comparable to Category 1 streams described in the Auckland Regional Plan (Appendix 1). Mud and dry channel default to Category 2 streams under the plan. Sightings of kokopu during the survey (probably banded kokopu) and burrows/exuviae of the dragonfly larvae *Uropetala carovei* are also marked adjacent to the relevant stream section.



5 Discussion

We believe this to be the first systematic study in New Zealand of the spatial extent of streams that do not flow year round. This study describes the type and extent of available habitat found at the top of catchments in the Auckland region, and explores some of the factors influencing spatial extent of small headwater streams.

Streams draining Waitemata sandstone and Franklin volcanics were found to have similar spatial extents (per catchment area) of each water code. Some differences were apparent, but these are probably not sufficient to affect the management of these streams. Together, Waitemata sandstone and Franklin volcanics cover more than half the Auckland Region, and are therefore key to the management of streams in the region. Mudstone streams showed peculiarities that would affect their management. These streams were more seasonal and the headwaters are expected to have lower habitat values as a consequence. Sand country streams were very stable, in terms of total length and spatial extent of flowing and pool habitat. The total length of sand country streams was shorter than Franklin volcanics and Waitemata sandstone streams. Sand country streams often emerged from springs that flowed year round, providing a clear demarcation of the start of the stream (these points may be hard to predict using spatial modeling). Although not surveyed, there are a number of permanently flowing streams in the Franklin Volcanics that also emerge from springs (A. Smaill, ARC, pers. comm.). Wetlands were often a dominant feature of sand country streams, particularly if native forest was intact.

Hydrogeology was found to be an important factor determining the spatial extent of headwaters streams. The hydrogeological characteristics of the underlying geology and overlying soils, such as hydraulic conductivity, determine the amount of flow that groundwater delivers to a stream. These characteristics, along with topography, and groundwater recharge rates, determine how the groundwater flow gradient changes in response to changes in rainfall. It is the changing groundwater gradient that causes the changes in streams that are observed in the field, between sites and between seasons.

Although flow data for sand country streams is limited, landowners at site S5 remarked on the constant flow of this small stream (catchment area 69 ha). In contrast, the Orewa Stream draining a mudstone catchment of 973 ha has an annual low flow of 0 L/s, and the Kaukapakapa Stream has a specific discharge of 0.04 L/s/km^2 under five year low flow conditions (ARC 2002). Franklin volcanics have reliable base flows (specific discharges at five year low flows in the order of 2 to 5 L/s/km^2, ARC 2002), explaining the lack of seasonal contrast in spatial extent observed for this HGA (hydrogeological area). Waitemata sandstone produces more baseflow than mudstone catchments, but produces less than half that of Franklin volcanics with specific discharges in the order of 0.3 to 1 L/s/km^2 at five year low flows (ARC 2002). The degree of similarity in spatial extent of streams between Franklin volcanics and Waitemata sandstone is therefore surprising. The specific discharge figures for the Franklin Volcanics (sourced from ARC 2002) are based on flow recorders on strongly spring-fed and permanently flowing streams. The sites selected for this study are not typical of these streams, although they are typical of small headwater streams that occur in sub catchments that have a lesser spring influence. Drought conditions may reveal a greater difference in spatial extent between Waitemata sandstone and Franklin volcanics than was observed for this study. It is also possible that the permanence of isolated pools is not directly related to the magnitude of flow further downstream.

Topography is an important factor affecting the interaction between groundwater and streams. A shallow stream channel that drains flat to rolling land (often characteristic of mudstone areas) can become perched and dry from a relatively small drop in groundwater level, compared to the steeper topography more characteristic of Waitemata sandstone where streams cut through deeper valleys and are more likely to remain in contact with groundwater.

The more ephemeral sections of streams may not be fed by groundwater, and instead would be fed by surface runoff during rainfall events. Less permeable soils will produce more surface runoff and hence increase the peak flows of these ephemeral streams (and hence the frequency with which vegetation is scoured and a channel formed). Clay soils produce more surface runoff and are therefore expected to scour a channel that extends further up the catchment. This explains why the total length of mudstone streams (including dry channels) is longer than sand country streams.

Available data indicate that pasture and native forest catchments appear to produce a similar spatial extent of streams, although for some HGAs there was a possible land use effect (e.g., pasture streams in mudstone may be shorter than native forest streams). Overall, the influence of hydrology and geology appeared to be greater than land use in determining spatial extent of headwater stream channels. Teasing out land use effects that are peculiar to certain HGAs from the effects of catchment size and catchment shape, would have required much larger sample sizes.

Riparian protection in pasture catchments was expected to have a variable influence on stream characteristics, because of the wide range of buffer widths and planting age of riparian vegetation included in this land-use. Most pasture-riparian sites were selected from Waitemata sandstone areas because it was not possible to provide sufficient sample sizes of planted riparian sites in all HGAs. Pasture-riparian streams had greater changes between spring and autumn surveys than native forest and pasture streams, perhaps partly as a consequence of water uptake by grasses. Streams with more recent riparian planting were often smothered by rank grass (Appendix 3, WS2 A).

Half of our sites were completely omitted from the blue-line network marked on 1:50,000 scale topomaps, and only 8.5 km of the 21 km of stream length surveyed for this study were represented with blue lines. Most of the unmarked stream lengths were small tributaries. From our survey it seems that second order[1] blue line streams shown on topomaps will represent perennial flow in most Auckland streams, with the exception of mudstone areas (mudstone streams have less flow in

[1] Two first order stream combine to form a second order stream; two second order streams combine to form a third order stream, and so on (Strahler 1952).

autumn). The type of habitat category represented by first order blue lines was less consistent. Where a blue line occurred it represented habitat ranging from perennial flow to dry channels. Blue lines exclude significant areas of aquatic habitat because tributaries shorter than 500 m long are omitted from the topomaps. NIWA's River Environment Classification network provided a more consistent representation of perennial flow than the topomaps, but consistency was achieved at the cost of poor representation of isolated pools. Developing a stream mapping network that better represents isolated pools would require more detailed contour maps because headwater streams have such small catchments.

Most overseas researchers use flow permanence to define stream types (Hansen 2001). The North American definitions are appropriate for catchments where isolated pools are a short-lived transitory phase for streams. This was not the case for most of the Auckland streams studied, where the extent of perennial isolated pools was significant. Section 2 of the Resource Management Act defines a river as being permanently or intermittently flowing. A stream does not have to be flowing to meet the definition in the act, so it is considered unnecessary to base all definitions on flow permanence. The current definition of Category 1 streams used in the Auckland Regional Plan (Appendix 1 of this report) recognises isolated pools as stream habitat. This definition better recognises important habitat components of Auckland headwater streams compared to definitions based solely on flow permanence. (Note, the stream definitions currently used in the Auckland Regional Plan are the subject of appeals and may change).

Isolated pools are an important habitat type in small headwater streams of Auckland and can offer viable habitat for aquatic ecosystems. Habitat-flow modeling using RHYHABSIM often shows significant habitat areas at zero flow for species such as eels and banded kokopu (Wilding 2003). Other factors can become critical as the flow approaches zero, such as deoxygenation (from rotting vegetation) and overheating in summer. Banded kokopu and eels were observed in isolated pools during this study, confirming previous observations that water quality is not always a limiting factor when flow ceases. While these pools are isolated from surface water flow, most perennial pools are presumably still connected by groundwater flow. If groundwater sustains these pools then water would flow through these pools at a similar rate to groundwater flow. This flow may be important for maintaining oxygen and temperature for inhabitants. The water quality of these pools could therefore be dependent on hydrogeological factors that influence groundwater supply. Riparian shade is also expected to be critical for maintaining cool temperatures for kokopu in isolated pools. Dissolved iron is mildly toxic to aquatic life at high concentrations, and iron floc can smother habitat (ANZECC 2000, Section 8.3.7.1) particularly in isolated pools where there is limited scouring. Observations from the field survey suggest that isolated pools in sand country streams could be the worst affected by iron floc, which is most likely a consequence of the iron-rich coastal sands that the soils are derived from (Edbrooke 2001).

Although wetted area would provide a good correlate of habitat value for many species in small Auckland streams (e.g., banded kokopu), other species may have a preference for the more ephemeral stream sections (e.g., larvae of the large dragonfly *Uropetala carovei*). This will be investigated further as part of the natural values report (Parkyn et al. in prep.). Values of headwater streams for contaminant attenuation is also being investigated by NIWA, and may be an important function of smaller tributaries.

Our estimates of the contraction and expansion of stream length and habitat types were based on one-off surveys in spring and autumn. To gain a better appreciation of the scale of change of stream length over time, frequent repeated or continuous monitoring of headwater streams would be advisable. In the present study, more effort was invested in spatial representation of Auckland streams, given our lack of basic knowledge of the spatial extent and habitat conditions of these systems. Ongoing monitoring of a few sites would give a better representation of seasonal response during typical and non-typical years.

6 Conclusions and Recommendations

This report is part of four volumes of research on the values of headwater streams and overall conclusions and recommendations are summarized below.

6.1 Implications for Management

6.1.1 Values of headwater streams

Collier (1993), in his review of the conservation of freshwater invertebrates, advocated a habitat- rather than species-based approach to conserving biodiversity. The protection of a range of rare, endangered, or representative habitats is most likely to ensure the protection of a wide range of invertebrate species, as well as maintain natural ecosystem processes.

Our research on the natural values of headwater streams has shown that there are significant biodiversity values associated with headwater habitats that dry up or contract in length for part of the year and are often not mapped as blue lines on topographic maps (Parkyn et al. 2006). For all land uses assessed, additional taxa occurred in the mud, pools, and flowing habitats that were not found in the perennial streams sampled. Therefore, protection of these habitats would enhance the overall biodiversity of stream communities.

However, our research also showed that despite the presence of additional taxa, the overall community composition and structure, and invertebrate metrics of ecosystem health were not significantly different between perennial stream habitats and the smaller headwater habitats. Mud samples were the most different from perennial samples as might be expected, but surprisingly, mud also contained communities of freshwater invertebrates. It seems likely that mud can act as a short-term refugium for some species, but other species may have adapted to exploit this habitat more permanently.

Based on the invertebrate species composition, there does not seem to be a rationale to separate Category 1 and 2 streams. However, it seems reasonable to suggest that stream reaches that are completely dry would have less value than streams with moisture, at a given point in time. In order to rank the differences between streams that all have a dry phase we would need to know the proportion of time that streams are wet and able to support aquatic life. Hydrological studies in one area of Auckland (Totara Park, Waitemata sandstones) indicated that 2 of the 4 streams ceased flowing for part of the year at the point where the weirs were placed (McKergow et al. 2006). In the smallest pasture catchment (0.7 ha) the stream stopped flowing for only 10 days in summer, while in a larger pastoral catchment (2.1 ha) stream flow dried up to occur only as storm flow between January and mid-April. Because of the influence of groundwater on these headwater areas, it is difficult to predict flows based on catchment areas. Currently we have estimates of the stream length per hectare that is intermittently flowing (or changing in length) from the Spatial Extent survey (Wilding & Parkyn 2006), but little understanding of how flow varies over time for these headwater systems.

The main differences in natural values occurred between land uses. Clearly, riparian vegetation improved the conditions of the streams towards that of native forest and allowed the existence of aquatic species associated with native forest streams. This suggests that riparian planting is a valuable method for managing headwater streams and it also shows that headwater streams with existing vegetation could be valuable sources of recolonists for stream restoration. Small, vegetated gullies are often pockets of refugia for native forest stream species within a pastoral catchment. Protecting these areas could be particularly valuable as source areas for restoration downstream and could mean that successful restoration is achieved after several years rather than several decades. For instance, if the headwater streams in a catchment were piped and filled (e.g., during urban development of a pastoral area), and only the perennial streams were restored with riparian planting, then it would take much longer for the recolonisation of stream communities to occur as there would be no upstream source of recolonists. Retaining headwater streams that already have riparian vegetation would improve the speed and success of the restoration process.

6.1.2 Recommendations for current management

Small headwater streams and wetlands are extensive in the Auckland region compared to the length of higher-order streams. Management of these areas is complex and decisions on the protection of these areas may ultimately depend upon socio-economic factors as well as ecological factors. An important question that remains unanswered is that of the cumulative effect of widespread loss or deterioration of headwater stream habitat. However, our research does provide information to help with management of rural and urban headwater streams.

Rural

There are several ways that headwater streams and wetlands could be managed under dry stock agriculture. One way is to fence all small waterways and plant them with native riparian plants, as was the case in the PR streams that we studied. This clearly has biodiversity benefits, particularly in summer, when even the remaining moist mud habitat was able to support EPT taxa. Communities of invertebrates in pastoral streams have changed from that of the original forested condition, but significant improvements in habitat and biodiversity of pastoral streams could be gained by fencing and planting riparian buffers. When there is adequate shade from riparian vegetation, water temperatures are lower and dissolved oxygen levels are higher during the summer months, creating healthier conditions for the invertebrate communities. Shade and cover from planted buffers also provides habitat for fish and koura (no koura were found in non-perennial pastoral headwater streams, but they were common in native forest).

The other important function of riparian buffers is for water quality in most stream systems. Fencing stock out of streams at Totara Park produced lower annual loads of *E.coli* than in streams open to stock (McKergow et al. 2006). However, headwater stream flow is greatly influenced by groundwater and subsurface flow. This means that the water can be carrying leached pollutants from the surrounding land use or historical land uses that have bypassed the riparian zone. Nitrogen loads in the riparian protected stream at Totara park were similar in the protected (Bush) and open (Swamp) sites.

Significant processing of nitrate and phosphorus (>90%) can occur in headwater wetlands under base flow conditions but this function can be reduced by stock access (Sukias & Nagels 2006). Hoof prints can create holes in wetlands that allow subsurface water to flow up and over the surface of the wetland where negligible denitrification occurs. Stock can also eat vegetation that would have naturally added to the organic build up in the wetland and therefore, stock reduce the processing capacity. Where headwater wetlands occur, best practice would be to fence stock out and allow wetland vegetation to develop. Planting with taller tree species is not recommended if the goal is to reduce nitrogen loads, as wetlands will revert to streams once shaded. Storm flows contribute significant amounts of pollutants and reduce the functioning of the wetlands. Efforts to extend protection or rough vegetation (e.g., encourage long grasses above wetlands by electric fencing in winter) may help to slow flood flows and give time for settling and infiltration of contaminants from the water flow.

The consequences of not managing these areas by removing stock are a continued export of sediments and faecal bacteria that will contribute to pollution and, in the case of sediment, accumulation downstream. With no riparian buffers on headwater streams, direct fertilizer additions and open access to stock, exports of nitrogen and phosphorus will remain high.

If fencing and/or planting headwater streams is not feasible then an alternative could be to construct wetlands at the base of catchments before the streams enter significant waterbodies (e.g., lakes, estuaries). However, this option would provide no biodiversity protection for the headwaters and may impede fish passage. Another alternative could be strategic protection of some of the headwater stream network. Existing tools for predicting fish assemblages could assist with this process, at least for fish biodiversity (John Leathwick, NIWA. pers. comm.). We recommend further research in order to make predictions about the placement, or the percentage, of streams that should be protected.

<u>Recommendations</u>

Based on research carried out over the last three years, we strongly recommend fencing stock out of headwater streams and wetlands for water quality improvements. For wetlands, fencing could take the form of hotwire fences that could be removed for stock grazing if the wetland dried up in summer.

For biodiversity goals in headwater streams, we recommend riparian protection with planted buffers of native trees. While shaded buffers reduce the nutrient processing capacity of headwaters, they provide multiple ecological benefits.

It may not be necessary to protect every headwater tributary to achieve improved biodiversity and water quality. We recommend further research into catchment-based approaches to assess the cumulative impacts of not managing all pastoral headwater streams and potential methods to select important or representative reaches.

Urban

When catchments are converted to urban land use there is potential for severe loss of stream function through piping and infilling (Rowe et al. 2006, Wilding 1996). Effectively all habitat values are lost and functions such as natural attenuation of contaminants, connectivity for species dispersal, food webs etc., are impaired. Urbanisation of catchments can also mean a loss of groundwater recharge from the increased impervious area. Therefore, it is likely that streams in urbanized catchments dry up for longer periods of time in summer and/or over a greater length.

Our research has shown that temporary headwater streams have similar aquatic invertebrate communities to those in perennial streams, but can also provide habitats that add additional species to the overall biodiversity of the catchment. The consequences of losing these streams will be loss of habitat values and a decline in overall biodiversity. Furthermore, urbanization that increases the duration of the dry period may decrease the biodiversity values of these headwater streams.

While intercepting nitrogen and phosphorus in urban streams may not be as necessary as it would be in pasture, it is worth noting that groundwater flow to these streams may still be carrying nutrients from historical land use, and simply piping them would transport these nutrients downstream without any instream attenuation. In addition, headwater streams may be just as important for the processing of stormwater contaminants as for rural contaminants, and incorporating natural stream functioning into urban design could make these streams important resources for treating urban runoff.

<u>Recommendations</u>

Our recommendation is that headwater streams be protected with riparian planting when catchments are converted to urban land use, for the sake of instream habitat, biodiversity, and ecosystem functioning – i.e., contaminant processing.

We recommend further research into the cumulative effects of the loss of headwater streams and better spatial modeling of the impact of urban development on catchment biodiversity and stream functioning.

6.2 Recommendations for future research

From the state of the science currently, we have concluded that intermittently flowing headwater streams do have values similar to that of perennial streams and their management should therefore be similar. However, we recognize that it may not be feasible for all headwater streams to be protected. Thus, there are a number of additional research areas that could allow us to differentiate between streams of higher and lower ecological value or provide a process for sustaining ecological and economic values.

Cumulative effects

Currently, the ARC has to deal with applications to alter headwater streams and wetlands on a piecemeal basis. There are no tools available to assess the cumulative effects of changing land use, or piping and damming streams. How many waterways can be lost (to infilling, piping or damming) in a catchment before this has impacts on catchment functions such as downstream water quality and quantity, or habitat provision? Conversely, is there a proportion or spatial arrangement of streams in a catchment that could be restored to enhance habitat and biodiversity, and improve water quality but still be affordable for the region?

This will be a difficult question to answer but one that is very important to consider. The first step would be to ascertain whether it is possible to assess the cumulative effects of stream loss and to consider the wide-ranging implications from species protection and habitat provision through to downstream effects on water quality and quantity and ecosystem functioning.

Variation through time

Can the length of time that headwater streams are wet be used to rank or value the headwater streams? At present, we have a widespread estimate of the amount of stream length that is intermittently flowing or changing in length (Wilding & Parkyn 2006), but no widespread estimates of the variability in flow through time of these headwater systems. Are headwater streams typically dry for a matter of days or a matter of months through the year, and how does this period differ between years? Do the streams typically dry out at the same time each year? Is this the best time of year to make a stream valuation?

These questions could be answered by incorporating monitoring of the weirs installed at Totara Park into a monitoring network and by investigating means to economically survey the temporal variation in hydrology of a wide range of headwater streams.

Urban headwaters

Traditional urban development creates large areas of impervious surfaces, which means a large proportion of rainfall can no longer infiltrate and extensive stormwater systems are required. This can have a profound impact on stream hydrology, resulting in a stream flow regime that is more flashy, has a higher risk of flooding in lowland areas. Water quality is also affected, as pollutants that accumulate on impervious surfaces enter streams more rapidly and effectively (Brydon et al. 2006). Headwater wetlands can provide water detention and water storage during rain events, and water release during dry periods. Headwater streams and swales could be managed to slow flood flows and trap contaminants to reduce downstream effects. Together with measures to reduce impervious area in urban catchments, headwater streams and wetlands could be managed as important resources to ameliorate the effects of stormwater run-off and they could also provide significant areas of natural and biodiversity values within an urban context. To further the management of headwater streams in urban areas, studies of the present values and functions of urban headwater streams are needed and, in particular, investigation of the effects of low–impact urban design on the values and functions of urban headwater streams.

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9 Appendix 1: Auckland Regional Plan stream definitions

The following definitions of a river/stream are taken from the Proposed Auckland Regional Plan: Air, Land and Water (Variation 1, June 2002, downloaded September 2005). This can be accessed at http://www.arc.govt.nz/arc/publications/proposed-arp-alw.cfm and following the links to Section 12, Definitions And Abbreviations. This terminology is the subject of appeals to the Plan and may change.

Definitions and Abbreviations – 12 Proposed Auckland Regional Plan; Air, Land and Water Plan **Category 1 River or Stream** A river or stream which meets any one or more of the following criteria: (a) has continual flow; or (b) has natural stable pools having a depth at their deepest point of not less than 150 millimetres and a surface area of not less than 0.5 square metres present throughout the period commencing 1 February and ending 30 April of any year; (c) has any of the following aquatic biota at any time of year: - eels - kokopu - crayfish - shrimp - mayflies, stoneflies or caddisflies - oxygen weed species Elodea sp., Egeria sp. and Lagarosiphon sp. - pondweed species Potamogeton sp. Notes: (1) This definition does not include: a. any artificial watercourse (including an irrigation canal, water supply race, canal for the supply for electricity power generation, and farm drainage canal); or b. any stream which does not meet criterion (a) or (b) of the definition and which only meets criterion (c) because there is a dam or artificial pond (on the stream) containing any of the listed fauna and flora. (2) Most, but not all, streams which appear as blue lines on Map Series 1 of the Proposed Auckland Regional Plan: Air, Land and Water are Category 1 rivers or streams. In addition some Category 1 rivers or streams do not appear on this map series. (3) Where there is uncertainty over the status of any stream the ARC will provide assistance and advice concerning the steps involved in making that determination.
Category 2 Stream Any stream that is not a Category 1 stream. Note: This definition does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply for electricity power generation, and farm drainage canal).

10 Appendix 2: Site locations

Study locations in the Auckland region, including grid reference (NZ map grid), land use and dates visited. The HGAs (hydrogeological areas) are FV (Franklin volcanics), M (mudstone), S (sand country), WS (Waitemata sandstone). Land uses are NF (native forest), PR (pasture-riparian) and P (pasture).

Site Code	Area	Easting	Northing	HGA	Land use	Catchment area (ha)	Spring survey	Autumn survey
FV1	Pukekohe	2676923	6444966	FV	NF		7/11/2003	
FV2	Pukekohe	2669379	6442539	FV	NF	6.87	13/11/2003	
FV3	Pukekohe	2667570	6439344	FV	PR	15.65	18/11/2003	
FV4 (A)	Pukekohe	2676784	6449204	FV	PR	9.33	1/12/2003	13/04/2004
FV4 (B)	Pukekohe	2676756	6449135	FV	P	8.29	1/12/2003	13/04/2004
FV5	Waiuku	2669525	6441221	FV	P	20.33	10/12/2003	
FV6	Waiuku`	2669313	6438487	FV	NF	12.37	17/12/2003	24/03/2004
FV7	Waiuku	2669367	6439160	FV	P	24.58	17/12/2003	24/03/2004
M1 (A)	Wellsford	2641534	6542562	M	NF	1.49	17/11/2003	14/04/2004
M1 (D)	Wellsford	2641475	6542649	M	P	3.11	17/11/2003	14/04/2004
M2	Wellsford	2636039	6541445	M	NF	15.43	16/12/2003	21/04/2004
M3	Dairy Flat	2660223	6500872	M	PR	9.63	20/11/2003	13/04/2004
M4	Dairy Flat	2660327	6500181	M	P	12.81	20/11/2003	13/04/2004
M5	Wellsford	2637185	6541505	M	P	24.53	16/12/2003	21/04/2004
S2	Awhitu	2653345	6454998	S	NF	13.53	3/12/2003	16/04/2005
S3	Awhitu	2653018	6454675	S	NF	18.87	18/11/2003	25/03/2004
S4	Awhitu	2652232	6450812	S	P	69.09	3/12/2003	16/04/2004
S5	Waiuku	2658518	6436534	S	P	68.76	5/12/2003	25/03/2004
S6	Waiuku	2658704	6438470	S	P	46.80	5/12/2003	15/04/2004
WS1 (A)	Totara Park	2680426	6465320	WS	PR	0.60	21/11/2003	
WS1 (B)	Totara Park	2680412	6465411	WS	PR	3.89	21/11/2003	
WS1 (C)	Totara Park	2680398	6465626	WS	P	8.08	21/11/2003	
WS1 (D)	Totara Park	2680504	6465189	WS	PR	11.08	21/11/2003	22/04/2004
WS2 (A)	Shakespeare	2673612	6509242	WS	PR	9.08	2/12/2003	22/03/2004
WS2 (B)	Shakespeare	2673762	6509249	WS	PR	8.28	2/12/2003	14/04/2004
WS2 (C)	Shakespeare	2674407	6508493	WS	PR	10.69	2/12/2003	14/04/2004
WS4	Okura	2663831	6502134	WS	NF	28.02	19/11/2003	15/04/2004
WS6	Orewa	2658772	6512364	WS	NF	27.06	4/12/2003	23/03/2004
WS7 (A)	Long Bay	2666556	6501471	WS	PR	5.05	17/11/2003	14/04/2004
WS7 (B)	Long Bay	2666122	6500747	WS	P	8.55	17/11/2003	22/04/2004
WS8	Long Bay	2666030	6500716	WS	P	20.37	20/11/2003	22/03/2004
WS9 (A)	Orewa	2662694	6514837	WS	P	5.99	4/12/2003	22/04/2004
WS9 (B)	Orewa	2662669	6514920	WS	P	4.43	5/12/2003	22/04/2004

11 Appendix 3: Site Maps and photos

Maps of each site, overlain on NZMS260 Topomaps. The top and bottom of each site is shown as red points, obtained using Garmin E-trex GPS. The tops of side tributaries are sometimes shown. The gridlines provide scale at 1 km spacing. Photos are also presented for each site.

WS1 A, B, C & D Puhinui Stream Totara Park

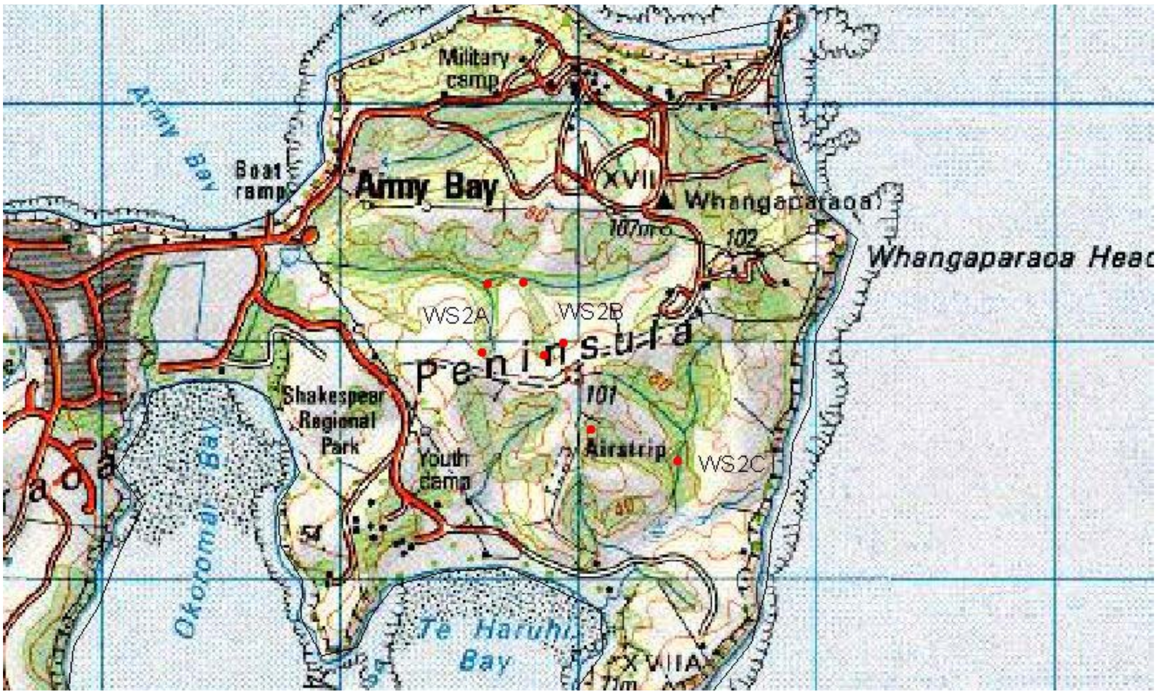
WS1 A

WS1 B

WS1 C, showing catchment and a collapsed tile drain (also found at site A and B).

WS1 D

WS2 A, B & C Waterfall Gully Shakespeare Regional Park

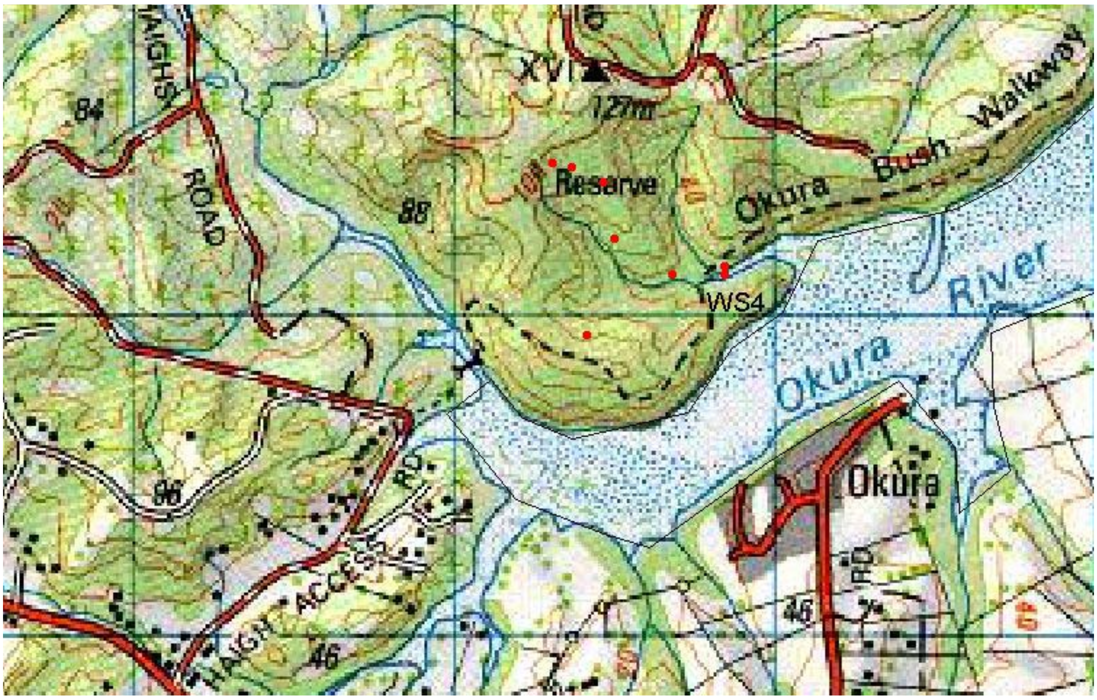


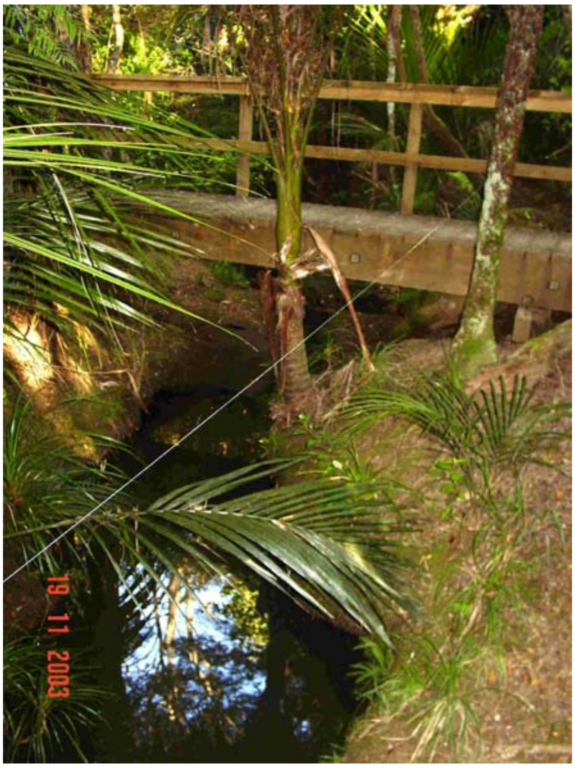

WS2 A

WS2 B

WS2 C

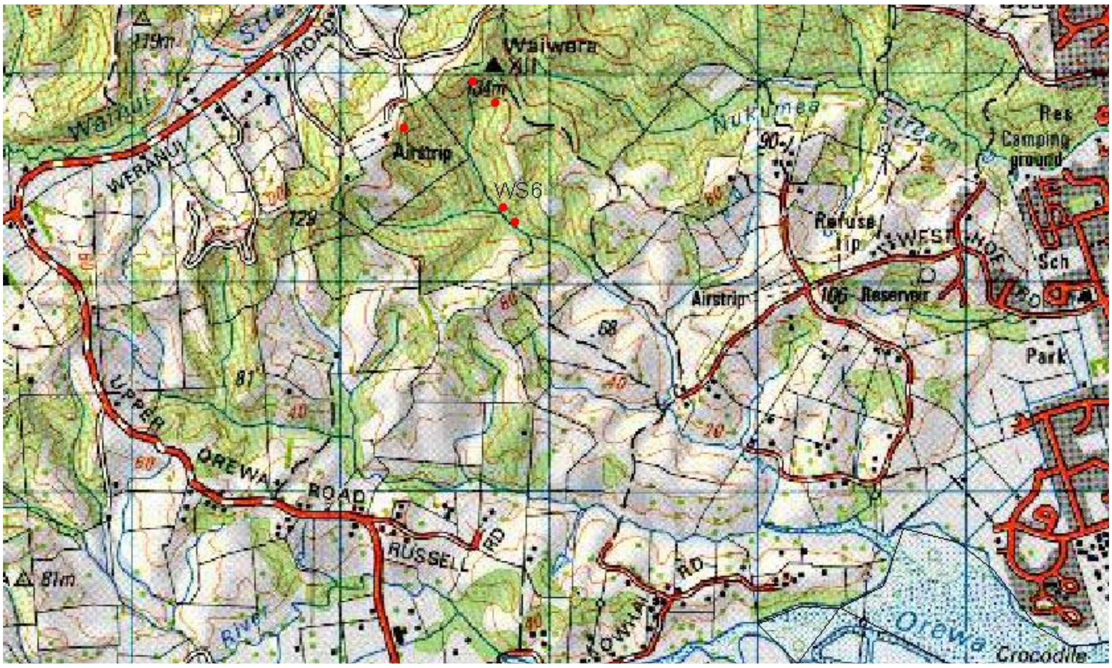
WS4 Okura River Okura





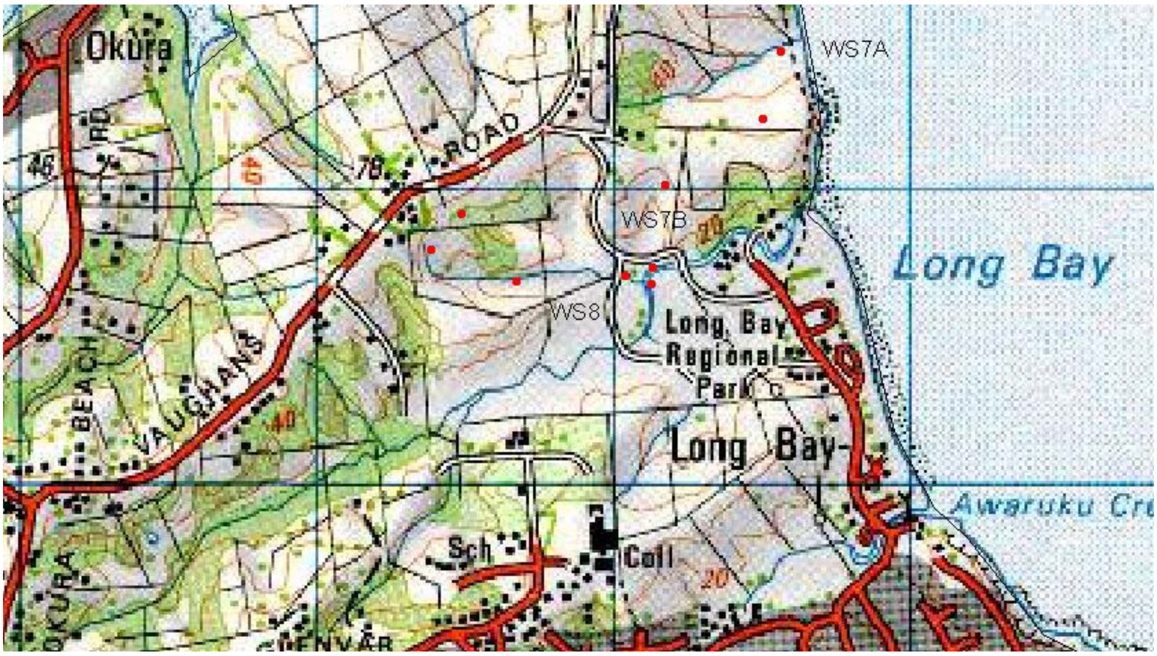
WS4

WS6 West Hoe Stream Orewa



WS6

WS7 A & B + WS8 Long Bay

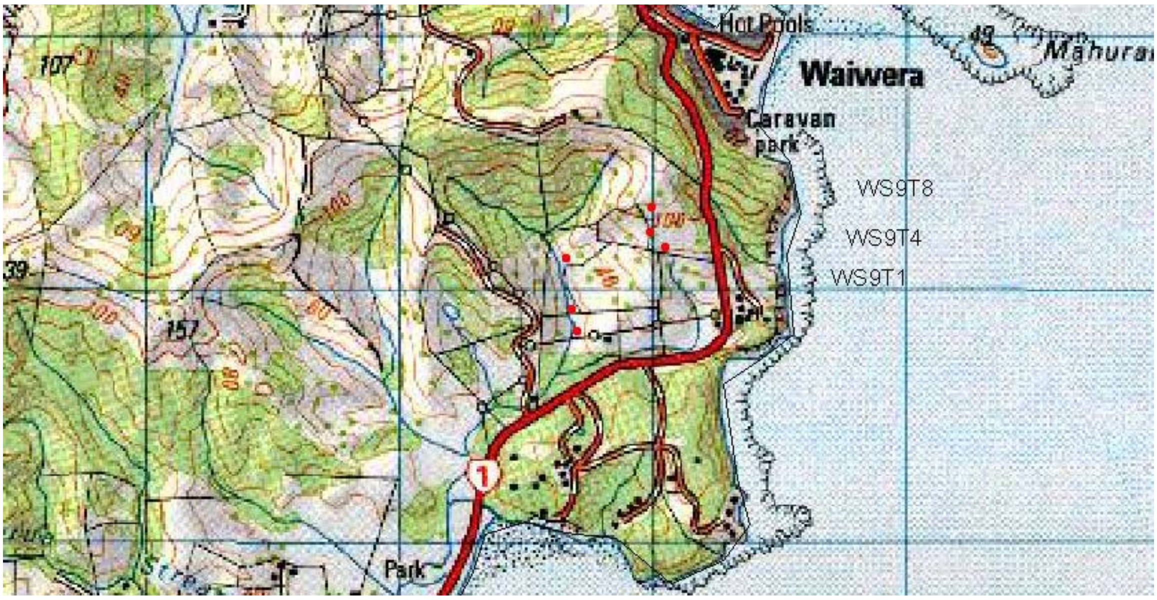


WS7 A

WS7 B


WS8 (top of catchment)

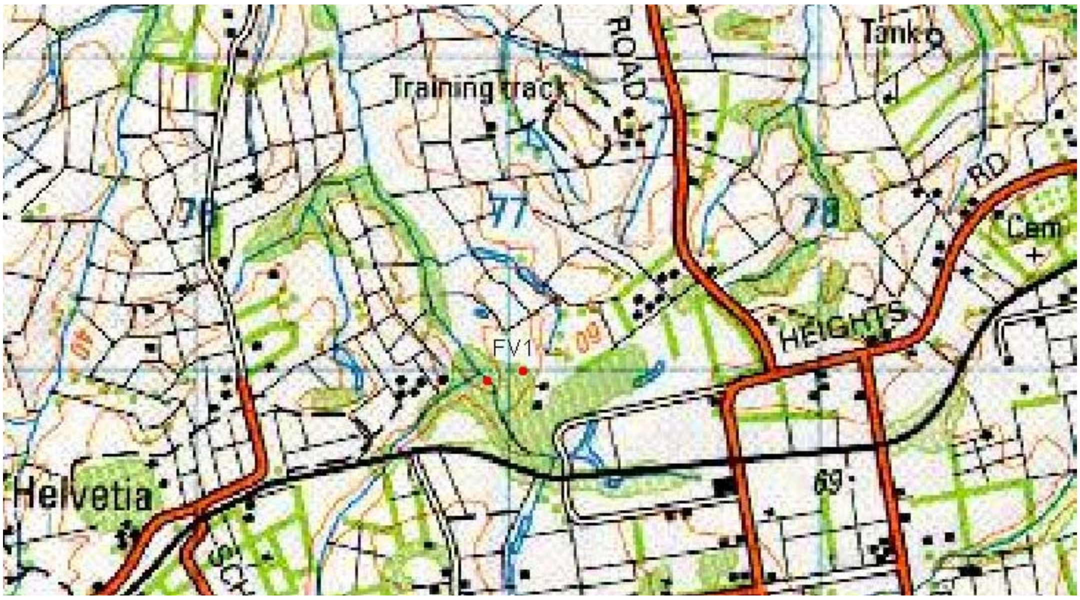
WS9 Hatfields Beach (Orewa)



WS9, top of one of the tributaries.

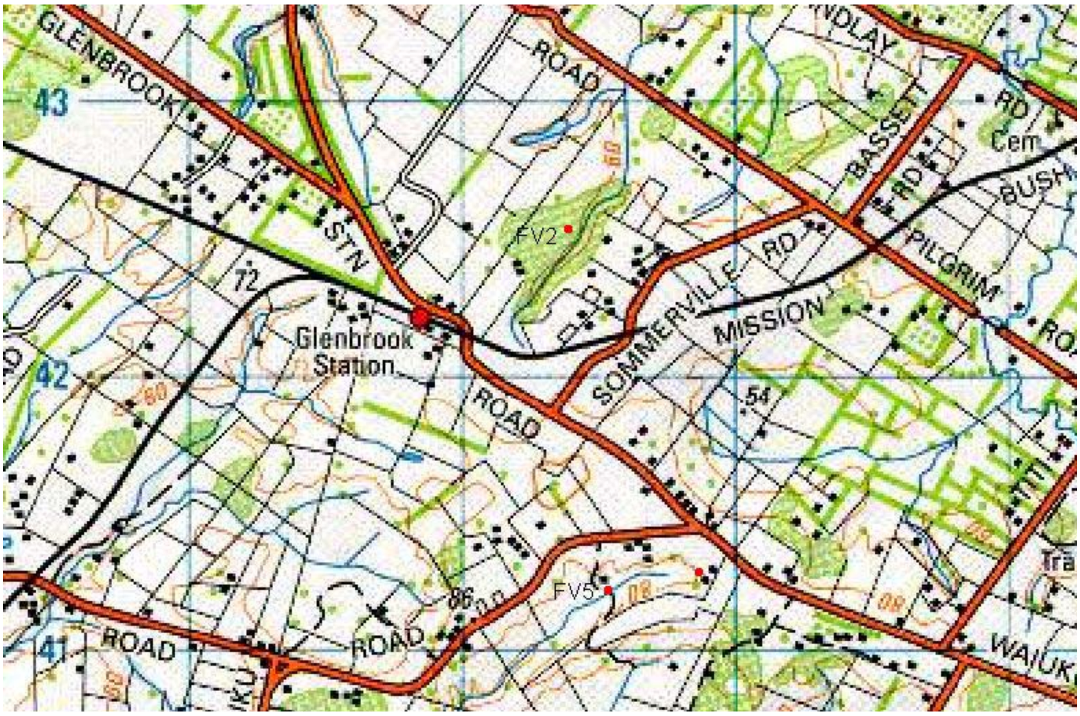
WS9, tributaries visible as lines of tussock/reeds running up the opposite slope.

FV1 Schlaepfers Bush Waiuku



FV1, wettest section of stream.

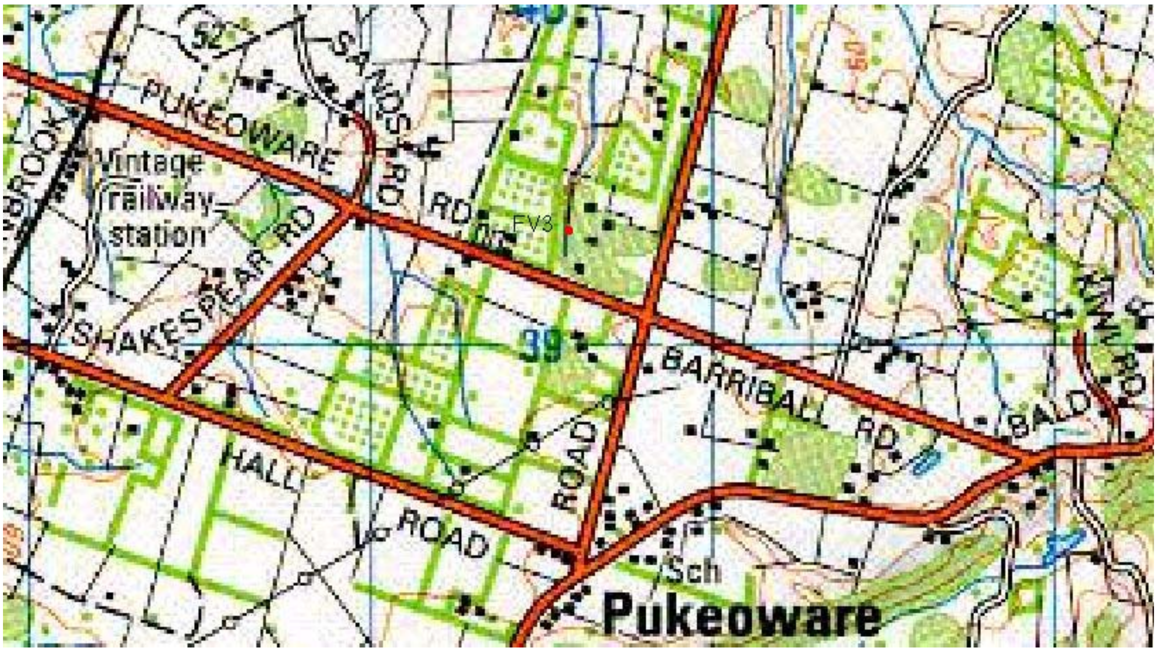
FV2 & FV5 Mauku Bush & Morley Road Waiuku



FV2, showing confluence with larger stream (after rain).

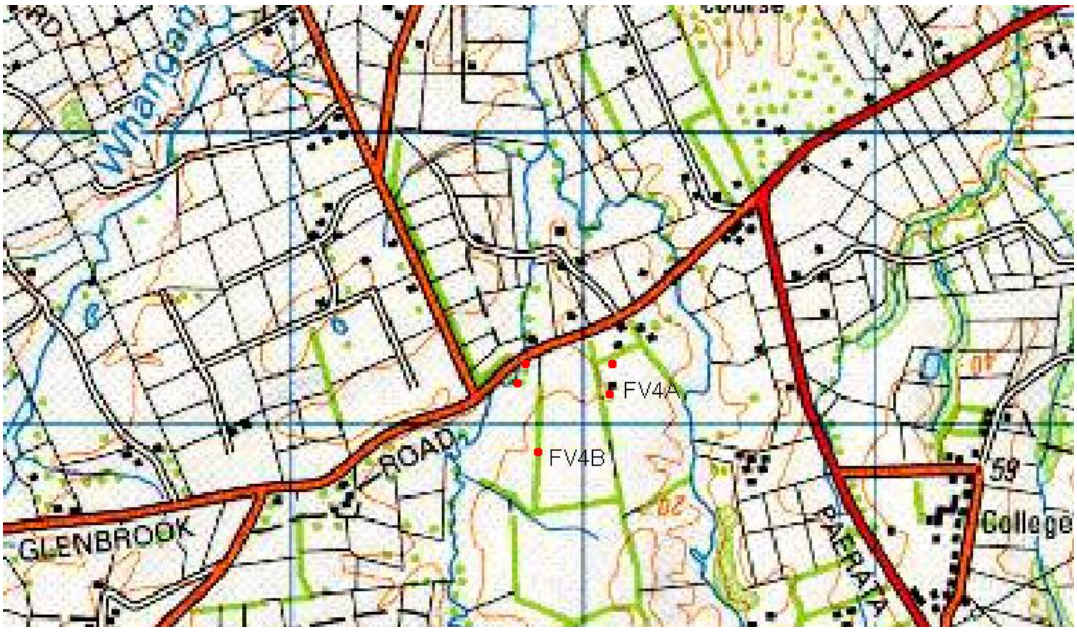
FV5, during heavy rain.

FV3 Pukeoware Bush Waiuku



FV3

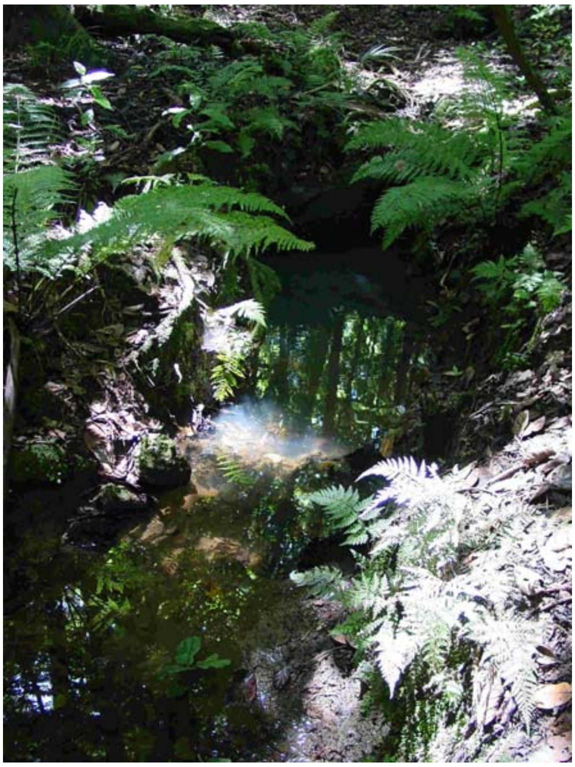
FV4 A & B Glenbrook Rd tributaries Pukekohe



FV4 A, watercress up to several metres tall smothered the channel in places.

FV4 B, pole marks top of mapped stream.

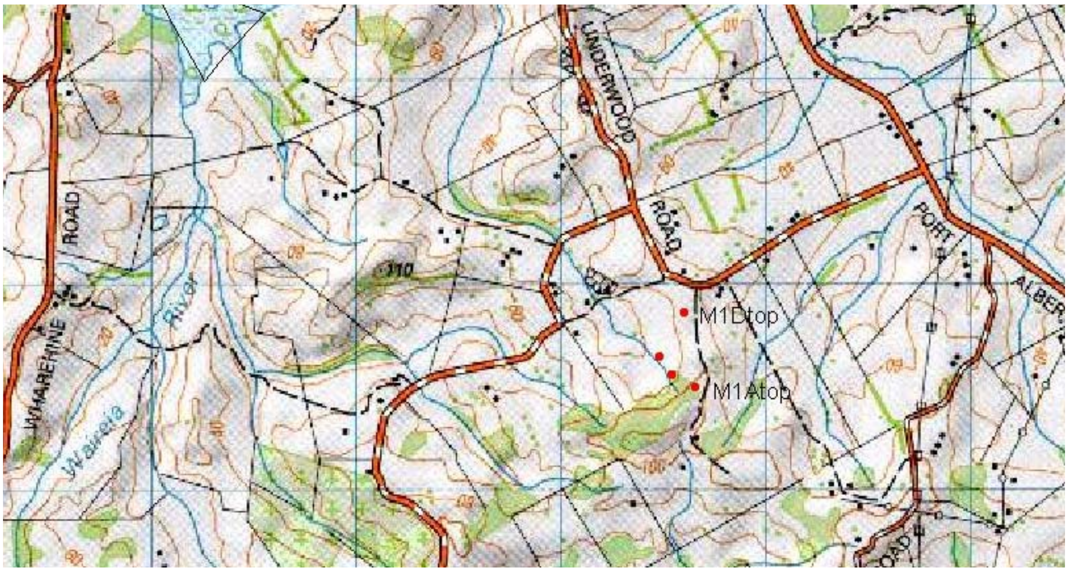
FV6 & FV7 Bald Hill Waiuku



FV6


FV7

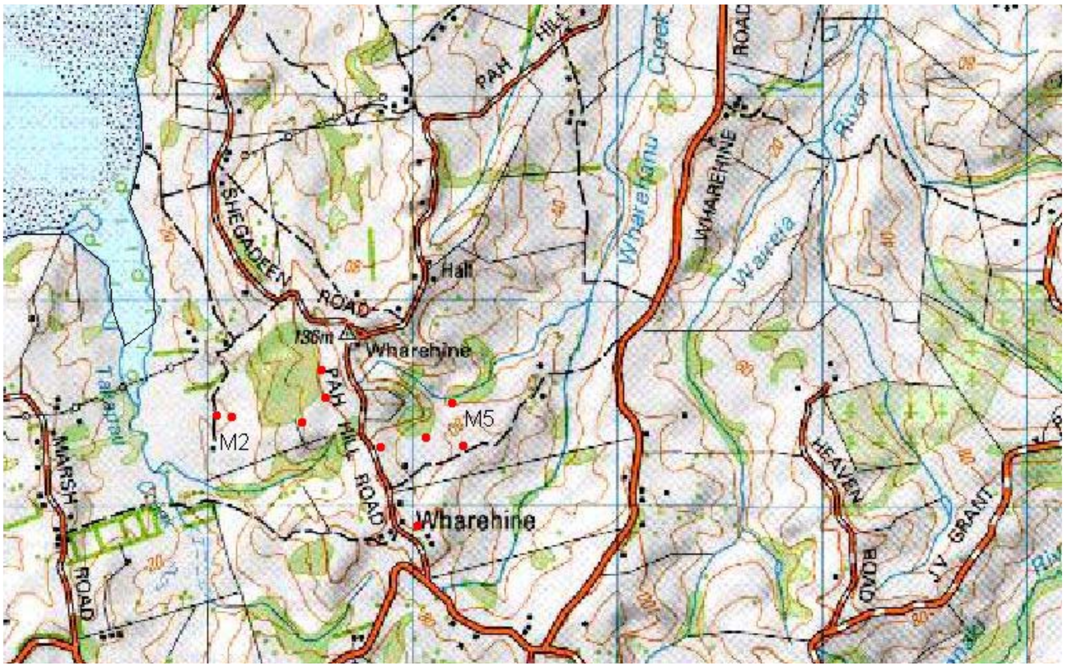
M1 A & D Underwood Road Wellsford



M1 A

M1 D, approaching top of catchment.

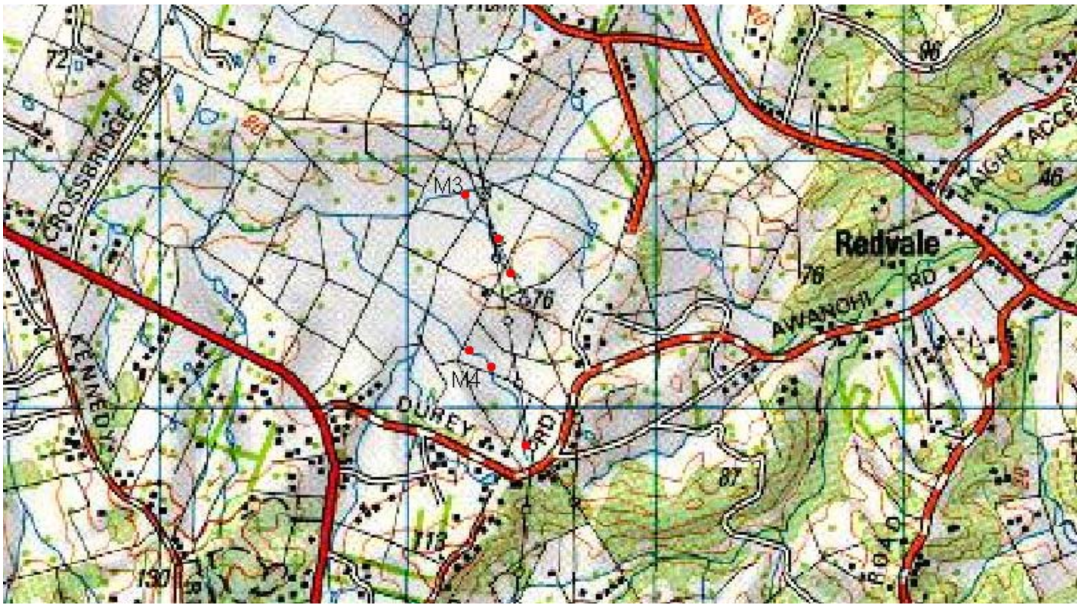
M2 & M5 Pah Hill Road Wellsford



M2


M5, lower section bordering bush.

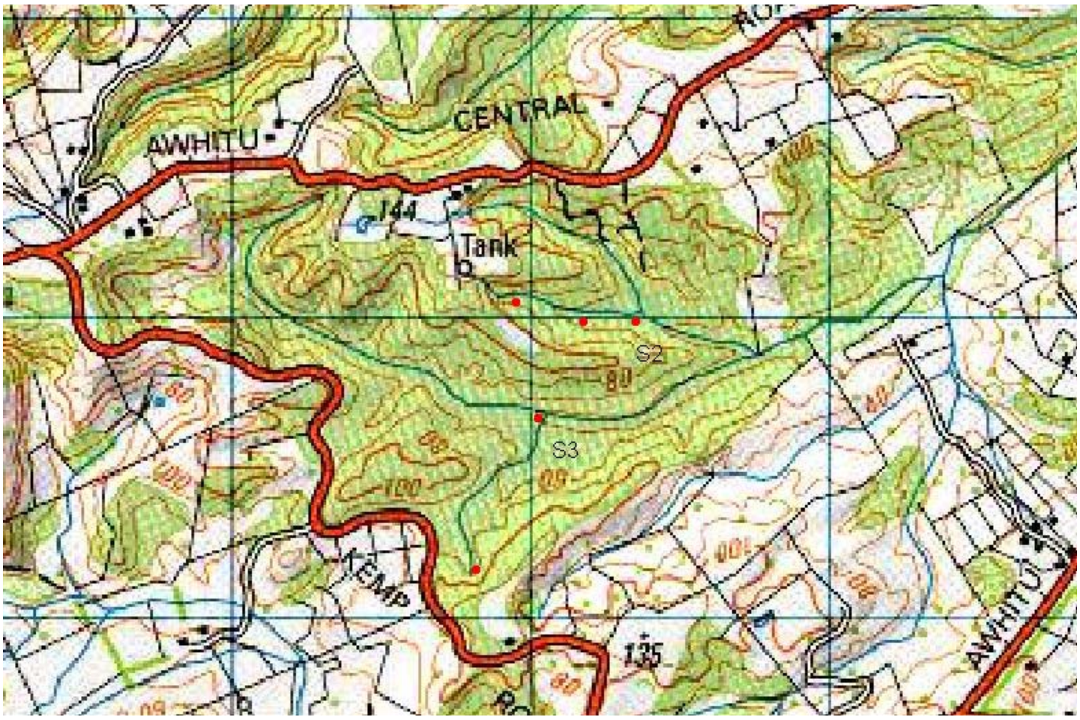
M3 & M4 Durey Road Dairy Flat



M3, the odd pool found by 'foot' (covered by grasses).


M4, summer.

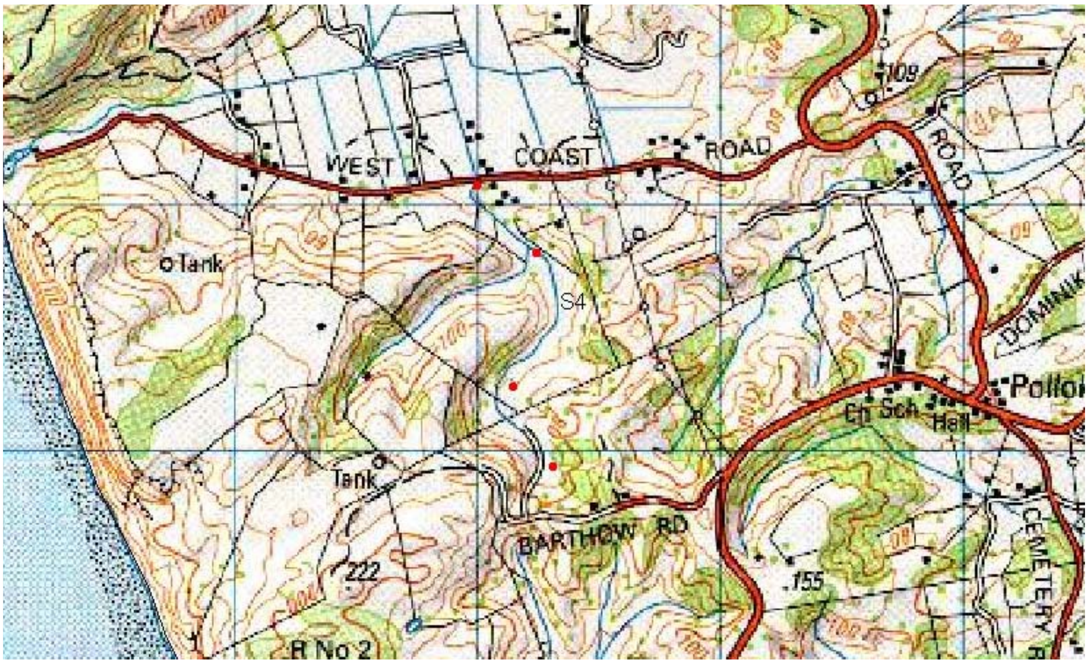
S2 & S3 Lee's Bush Awhitu Peninsula



S2

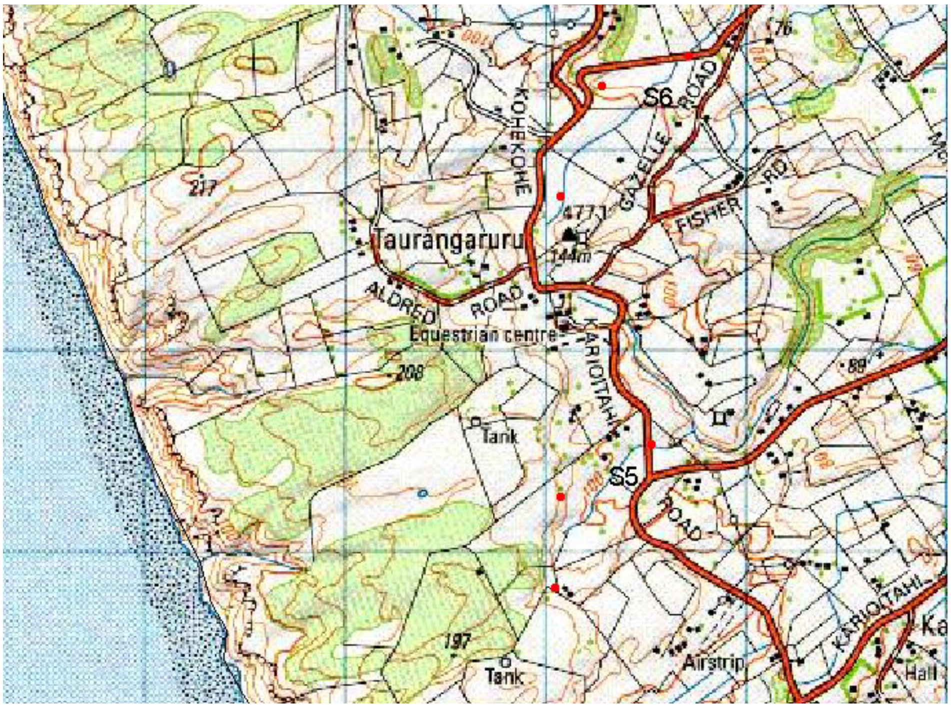
S3, wetland section.

S4 West Coast Road Awhitu Peninsula




S4, spring emerges at foot of hill.

S5 & S6   Karioitahi Road Waiuku




S5, wetland tributary.


S6, drain at top of stream.

12 Appendix 4: Data summary

Table 1:

The total length (m) of each **water code** is given for each site used in the survey (codes simplified from Table 3.2). A breakdown by season is given for each water code, (spring wet, autumn dry). The site name indicates which hydrogeological area the site is located in (sites starting with FV – Franklin volcancics, M – mudstone, S – sand country, WS – Waitemata sandstone). Land use categories are NF – native forest, P – pasture, PR – pasture-riparian.

		Flowing		Standing		Pools		Mud		Dry		Total	
Site	Land use	spring	autumn	spring	autumn	spring	autumn	spring	autumn	spring	autumn	spring	autumn
FV4 A	PR	72	32	50	101	213	241	163	129	205	224	703	727
FV4 B	P	40		188	121	68	225	175	50		13	471	409
FV6	NF	119	99		96	375	473	22	13	41	63	557	744
FV7	P			545	701	224	37	52	63	28	17	849	818
M1 A	NF			20		27	3	21	3	52	126	120	132
M1 D	P			32			44	22	6	69	20	123	70
M2	NF	561		217	132	252	429	38	103	50	200	1118	864
M3	PR					104	26			212	242	316	268
M4	P					226	30	387	48	99	193	712	271
M5	P	277		415	175	466	303	162	204	38	209	1358	891
S2	NF	14		37	65	401	287	59	127	24	25	535	504
S3	NF			560	52	50	602	141	95		131	751	880
S4	P	1123	416	449	1093	272	594	327	255	60		2231	2358
S5	P	952	723	118	93	33	182	99	78	11		1213	1076
S6	P	503	467	1066	1015	161	173	261	140	76	61	2067	1856
WS1 D	PR	281	145	5	138	441	298	49	93	33	38	809	712
WS2 A	PR	144		68	67	80	109	93	119	19	9	404	304
WS2 B	PR	78		58		336	161	41	217		20	513	398
WS2 C	PR	152				209	213	170	44		31	531	288
WS4	NF	367	26	518	113	672	1017	110	162	23	154	1691	1472
WS6	NF	171	196	116	79	1066	1199	73	78	44	74	1470	1626
WS7 B	P	14		234		73	246		105		37	321	388
WS8	P	363		390	664	152	193	68	161			973	1018
WS9 A	P			132		156	289	232	104	35	146	555	539
WS9 B	P					230	199	285	41	19	86	534	326
Total		5231	2104	5218	4705	6287	7573	3050	2438	1138	2119	20925	18939
HGA totals													
FV		231	131	783	1019	880	976	412	255	274	317	2580	2698
M		838	0	684	307	1075	835	630	364	520	990	3747	2496
S		2592	1606	2230	2318	917	1838	887	695	171	217	6797	6674
WS		1570	367	1521	1061	3415	3924	1121	1124	173	595	7801	7071

Table 2:

The total length (m) of each **channel code** is given for each site used in the survey (codes simplified from Table 3.2). A breakdown by season is given for each water code, (spring wet, autumn dry). The site name indicates which hydrogeological area the site is located in (sites starting with FV – Franklin volcancics, M – mudstone, S – sand country, WS – Waitemata sandstone). Land use categories are NF – native forest, P – pasture, PR – pasture-riparian.

		Incised		No banks		Overgrown		Wetland		Total	
Site	Land use	spring	autumn	spring	autumn	spring	autumn	spring	autumn	spring	autumn
FV4 A	PR	490	338	56	284	109	68	48	37	703	727
FV4 B	P	437	340			8	36	26	33	471	409
FV6	NF	391	543	75	81	25	20	66	100	557	744
FV7	P	428	538	128	17	28		265	263	849	818
M1 A	NF	67	103	38	14	15	15			120	132
M1 D	P	48				29	26	46	44	123	70
M2	NF	704	476	201	28	55	11	158	349	1118	864
M3	PR	114	73			202	181		14	316	268
M4	P	163	116	120	48	350	97	79	10	712	271
M5	P	617	397	54		355	101	332	393	1358	891
S2	NF	152	93	103	77			280	334	535	504
S3	NF	109	140	160	383	182		300	357	751	880
S4	P	1304	1785	53	40	613	116	261	417	2231	2358
S5	P	943	771	58	10	13	110	199	185	1213	1076
S6	P	1501	1490	313	129	113		140	237	2067	1856
WS1 D	PR	420	601	345	87	44			24	809	712
WS2 A	PR	297	263			59	12	48	29	404	304
WS2 B	PR	434	342		18	10		69	38	513	398
WS2 C	PR	458	288	64		9				531	288
WS4	NF	1372	1328	287	116	9	8	23	20	1691	1472
WS6	NF	1248	1447	177	75	5	5	40	99	1470	1626
WS7 B	P	167	153	106	82	8	153	40		321	388
WS8	P	592	446	125	86	256	386		100	973	1018
WS9 T1	P	176	186	28		231	57	120	296	555	539
WS9 T4	P	230	181			241		63	145	534	326
Total		12862	12438	2491	1575	2969	1402	2603	3524	20925	18939
HGA totals											
FV		1746	1759	259	382	170	124	405	433	2580	2698
M		1713	1165	413	90	1006	431	615	810	3747	2496
S		4009	4279	687	639	921	226	1180	1530	6797	6674
WS		5394	5235	1132	464	872	621	403	751	7801	7071

13 Appendix 5: Water codes and land use

The average stream length is presented individually for each water code. The three land uses are native forest (NF), pasture (P) and pasture-riparian (PR). The spring and autumn results are presented separately as dark and light shaded bars. Stream length was standardised by catchment area for each site (metres per hectare). The water codes are as described in Table 3.2. Error bars are ±1 standard deviation.