PROVING LOW IMPACT DESIGN AND DEVELOPMENT WILL DELIVER BIODIVERSITY GAINS

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ABSTRACT

The post-urbanisation retention of native fish and invertebrates (particularly mayfly and stonefly nymphs) in streams where they occurred naturally prior to development is an indication of good urban catchment management and bodes well for the quality of receiving waters such as harbours and lakes. Retention of predevelopment aquatic biotic integrity is one of the objectives of Low Impact Urban Design and Development (LIUDD) which will only succeed if stakeholders are convinced of the scale and significance of environmental improvement that could be achieved. Another primary objective of LIUDD, implemented on a catchment scale, is the achievement of hydrological neutrality, that is a nil or at worst negligible change in the hydrologic regime. One of the anticipated outcomes of such hydrological stability throughout and after the development process is the retention of aquatic ecosystem health and biodiversity. In a major research project by the Centre for Urban Ecosystem Sustainability, ecosystems will be monitored in both greenfield and brownfield low impact developments to determine gains in physiochemical condition and biotic integrity relative to that in conventionally developed urban catchments.

KEYWORDS

Low impact, ecology, catchment, urban, development, hydrological, design

1 INTRODUCTION

A primary objective of Low Impact Urban Design and Development (LIUDD) is maintenance of the integrity of receiving water ecosystems. Stakeholders need to be shown the ‘cause and effect’ relationships between land use practices and aquatic ecosystem function (van Roon & Knight, 2004) in order to justify the effort required to change firmly established practices and habits in urban development form and lifestyle. A succession of steps is evolving to convince stakeholders of this ‘cause and effect’.

The first step, in progress over the past few decades, has shown the effects of impervious surface cover in an urban catchment, on hydrological and water quality changes in receiving waters (Shaver, 2000). It has been accompanied by remediation and mitigation measures such as the installation of stormwater detention and decontamination devices in the stream path (ARC, 2003). These have reduced flooding and stream bank erosion and slowed, but not stopped, the accumulation of stormwater toxins in receiving environments such as harbours (Williamson et al., 2003), estuaries and lakes. Ecologically critical concentrations of these toxins will still be reached in receiving water sediments and organisms. LIUDD is expected to be more effective than stormwater treatment alone at slowing the rate of accumulation.

The second step, which remains active, is demonstrating which contaminants (zinc for example) are of particular concern, how they bring about ecological degradation, where they originate (Seyb, 2003) and if their use cannot be avoided, what technologies (Pandey et al., 2003) can be installed to effectively remove them. Demonstrating how to prevent changes in hydrological regimes is important. We have already established that the relationship exists, for example, between percentage of the catchment in impervious cover and macro-invertebrate community index (MCI) (Moore, 2003; Herald, 2003), or the proportion of species that belong to the sensitive Ephemeroptera – Trichoptera – Plecoptera (EPT) group (Allibone, 2001). MCI and EPT values are often correlated; a high MCI score is typically the result of a high proportion of EPT species in a community.

The third step in convincing stakeholders involves the implementation and monitoring of LIUDD on a catchment scale to prove to stakeholders that gains in flood control, and enhancement of biodiversity and amenity can be achieved without significant increase in costs.

This paper, which extends analyses reported by Herald (2003), will now explore the relationship between the sensitive EPT species and hydrograph characteristics within Glen Eden catchments with different land uses. The ecological significance of changes in the hydrological regime, as a result of urbanization, that are discussed include: ascending slope of the flood hydrograph, the proportion of time spent at extreme flows, and current speed. Recolonisation of streams by EPT species is discussed in relation to retention of natural conditions in catchment headwaters. This will improve our understanding of ecologically desirable changes in catchment management for greenfield developments and provide both evidence and conviction that these changes must extend beyond the stream corridor.

2 LINKING URBAN FORM AND STREAM ECOLOGICAL HEALTH

2.1 MAYFLIES AND STONEFLIES AS INDICATORS

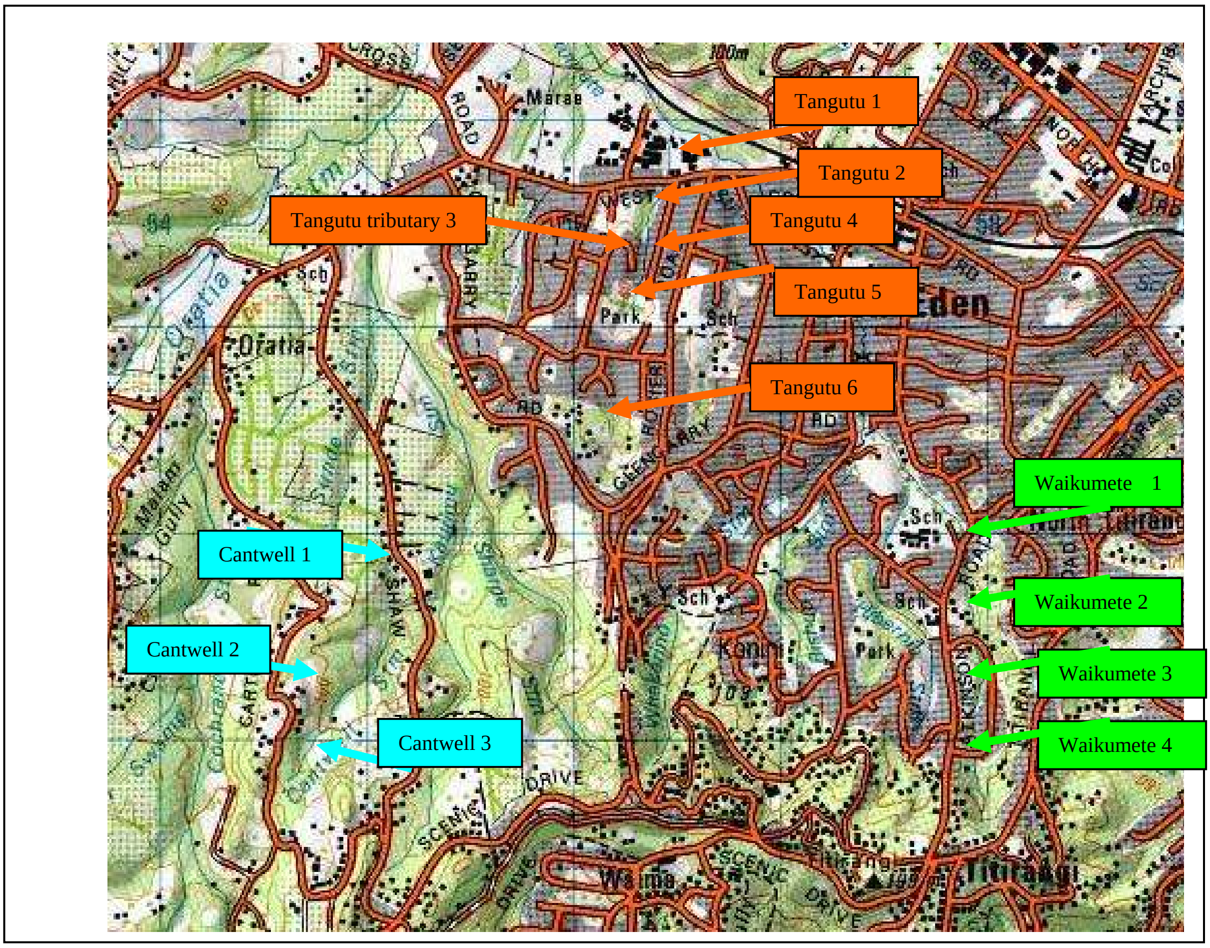
Mayflies and stoneflies are particularly sensitive to habitat degradation and are often used as indicators (Froude, 1998). To convince stakeholders of the need to change certain characteristics of urban form that give rise to flashy hydrograph characteristics, it is necessary to demonstrate which of these characteristics trigger EPT species losses. Discerning stakeholders will also want to know why it matters that these sensitive species are lost. Although EPT species play important roles in stream food chains and biodiversity maintenance these are not the only reasons for focusing on them. If streams have adequate flows, good water quality and riparian vegetation cover enabling populations of EPT species, they will contribute positively to fisheries (EPT species are ideal food items for most freshwater fish species). Also EPT are indicators of good stream water quality necessary for quality estuaries, harbours and lakes (that are particularly valued for recreation and amenity), and they will be indicative of competent catchment management.

2.2 STUDY LOCATION AND INFORMATION TO DATE

The study catchments in the Glen Eden –Titirangi area of Waitakere were chosen to demonstrate the effects of conventional development and urban stormwater systems upon the hydrology and ecological health of streams. As methods for choosing and describing the catchments, mapping impervious areas, monitoring flows and water quality, sampling macro-invertebrates and calculating perennial stream loss to piped stormwater systems have previously been described for the study sites by Herald (2003), only a brief summary of relevant parts will be given here.

The study catchments (Figure 1) are the Cantwell characterised by bush and pastoral lifestyle blocks (76ha, 6% impervious), Waikumete peri-urban (54ha, 16% impervious) and Tangutu in intensive urban/industrial use (84ha, 33% impervious). Relatively impervious clay soils and rainfall in the range of 1100 to 1700 mm (Herald, 2003) provide the hydrological context. The Waikumete Stream has good regenerating native vegetation in the upper catchment but urban use intensifies with distance down the catchment. The lower catchment is in low to medium density housing. The hydrological and ecological characteristics of the Waikumete Stream are expected to be altered by the diversion into the stream's headwaters of stormwater from Titirangi township (Herald, 2003).

Figure 1: Sites assessed in the Cantwell, Waikumete and Tangutu Streams, September 2002.



On the 17th of September 2002 macroinvertebrate sampling was undertaken at the outlet of the catchments, at all sites identified in Figure 1. Invertebrates were collected by kick/sweep sampling using a 0.5mm mesh pole net. This method involved disturbing the streambed and instream vegetation and collecting fine matter (including invertebrates) in the net. In sites lacking significant current speed the net was swept through the water and instream vegetation to collect the fine matter. Solid substrata (stones, woody debris and live plants) were targeted for sampling rather than soft/loose substrata (open areas of sand or mud) because few stream invertebrates are suited to soft/loose bed material. Sampling was carried out within an estimated area of 0.5 to 1.0 m^2 until approximately 400ml of fine material had been collected. This sample material was preserved with 10% formaldehyde until they were analysed under stereomicroscopes for invertebrate content. Invertebrates were generally identified to the genus taxonomic level. Stream stage was monitored continuously from July 2002 to March 2003 using pressure transducers connected to data loggers. Stage was converted to discharge using theoretical rating curves. Crump weirs were installed to increase resolution during low flows. The monitoring equipment was installed at sites with a stable channel cross section and ease of access.

2.3 RESULTS

This paper focuses on EPT species such as mayflies and stoneflies as indicators of the effects of urbanisation, particularly with respect to changes in the hydrological regime, so only relevant parts of the data collected are reported. Biological data collected for the Hibernia catchment is not reported as there is no flow record for this stream. Interpretation of other invertebrate data (including Macro-invertebrate Community Index) will be reported to a conference in mid-2004 (van Roon & Moore, in review).

2.3.1. PRESENCE OF EPT SPECIES IN CATCHMENTS

The total number of taxa and the percentage of total invertebrate species that belong to the generally sensitive EPT group for each sampling location on each of the three streams are shown in Figures 2 and 3 respectively. The highest percentages occur at all stations on the Cantwell Stream, which has the bush and pastoral catchment. Declining percentages from headwaters to stream mouth characterise the urban streams. Mayfly and stonefly genera that are present in the Cantwell, but absent in the Tangutu and lower Waikumete streams, include *Coloburiscus, Arachnocolus, Deleatidium, Neozephlebia, Austroperla and Zelandobius.* The significance of this is discussed below.

Figure 2: Number of EPT taxa in Glen Eden Streams

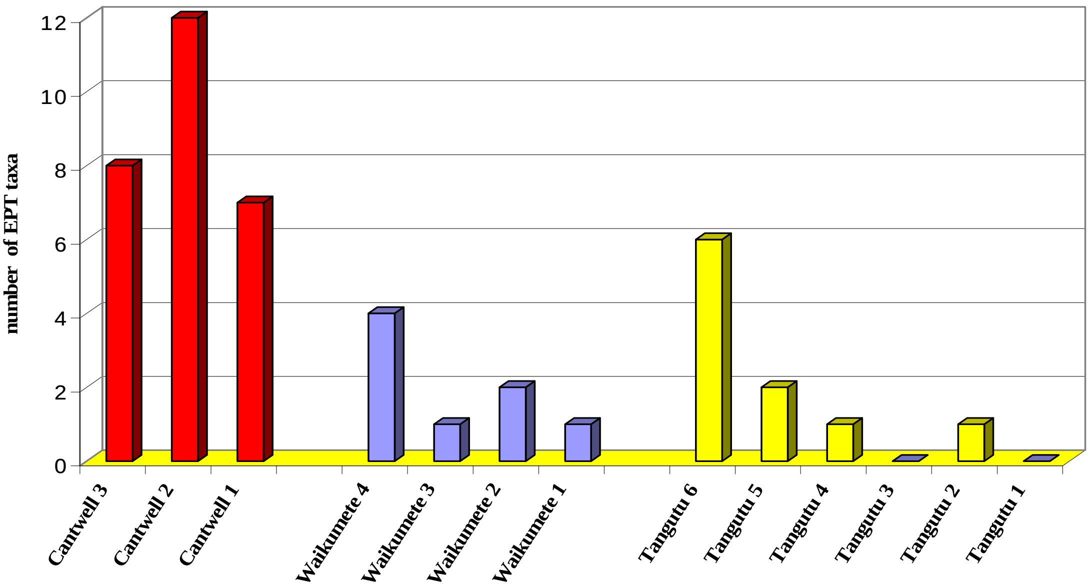
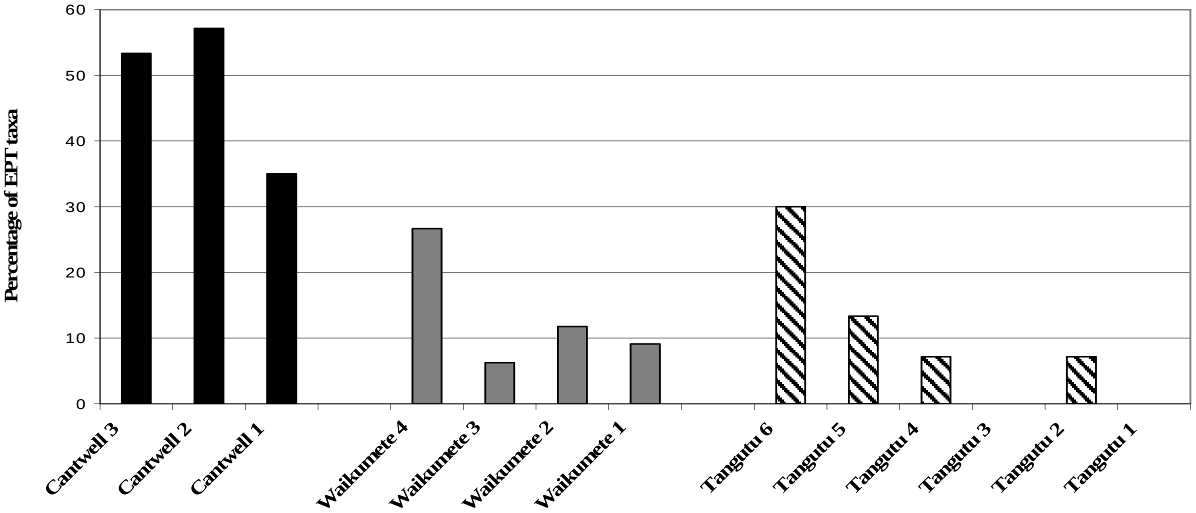


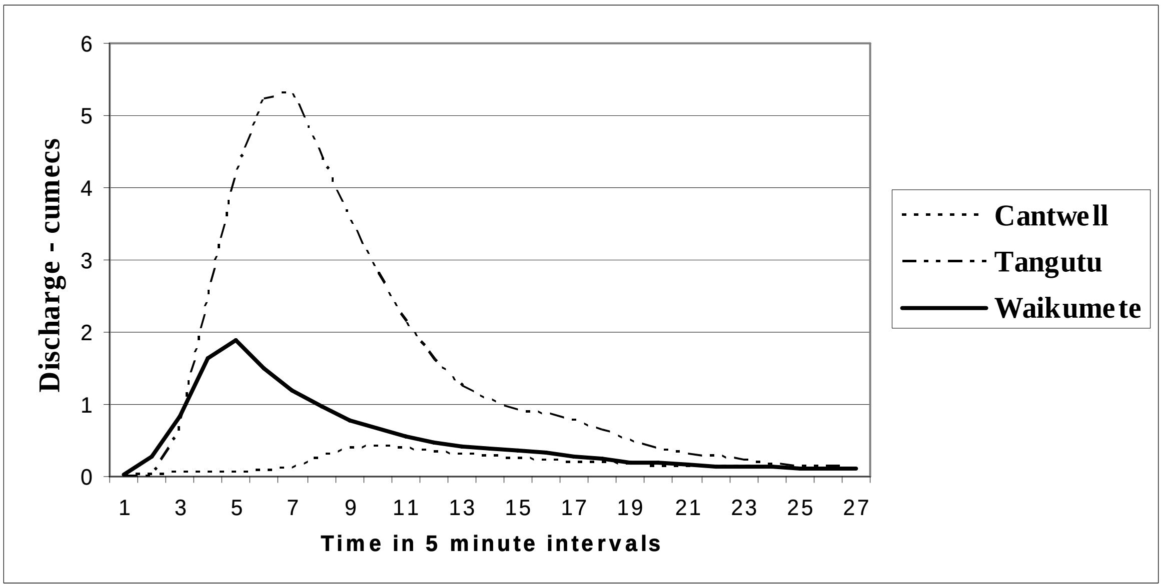
Figure 3: Percentage of invertebrate taxa belonging to EPT groups from Glen Eden Streams



2.3.1 HYDROGRAPH DIFFERENCES OF RELEVANCE TO MAYFLY AND STONEFLY SPECIES IN CATCHMENTS OF DIFFERING LAND USE

Hydrographs for 8 flood events in the Cantwell, Waikumete and Tangutu streams between July 2002 and March 2003 were examined to determine both ascending slope and maximum discharge relative to land use in the catchments. A flood discharge curve for each of the catchments, for 29 September 2002, is shown in Figure 4 as an example of a typical high rainfall event.

Figure 4: Flood discharge curve for Glen Eden Streams on 29 September 2002



Peak discharge and ascending hydrograph slope increase with the percentage of each catchment in impervious surface cover. These changes are combined in Figure 5 where the three streams, during each of eight rainfall events, are compared for the ratio of discharge peak: time to reach that peak. Flow duration curves for the 3 streams are reported in Herald (2003) and these are reproduced, for reference here, as Figures 6 and 7.

Figure 5: Ratios of discharge at peak: time to peak discharge – represents the slope of the ascending hydrograph for Tangutu, Waikumete and Cantwell Streams during eight rainfall events in 2002 –3

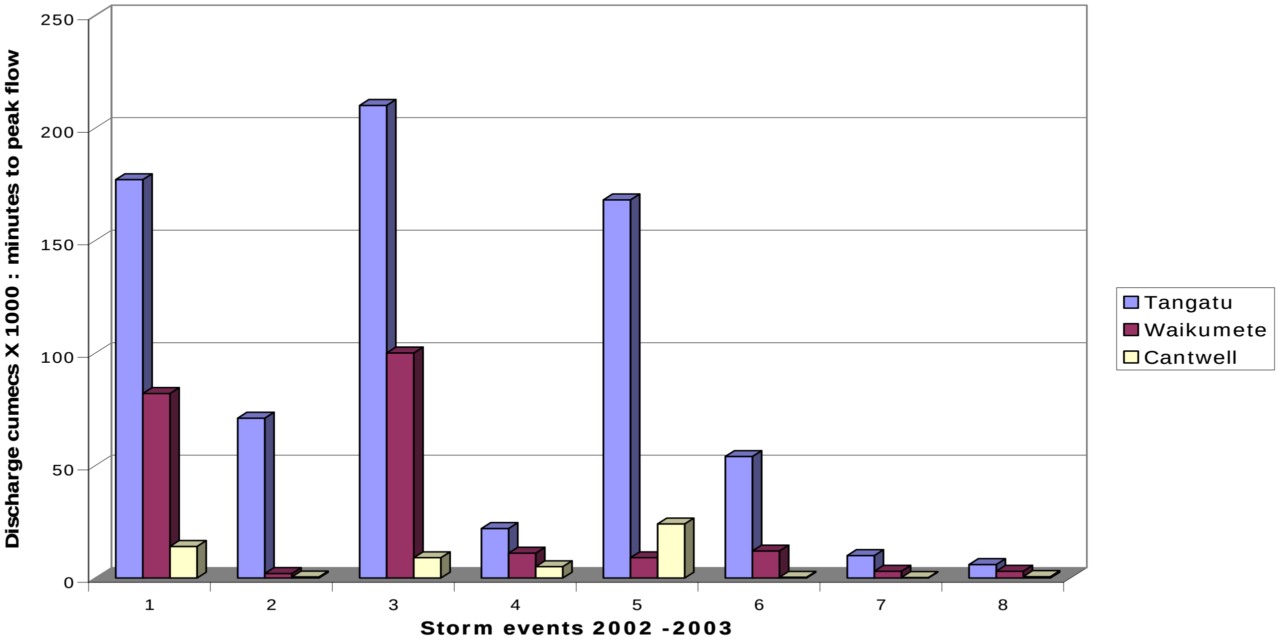


Figure 6: *Discharge duration curves for the Cantwell, Waikumete and Tangutu Streams (Herald, 2003)*

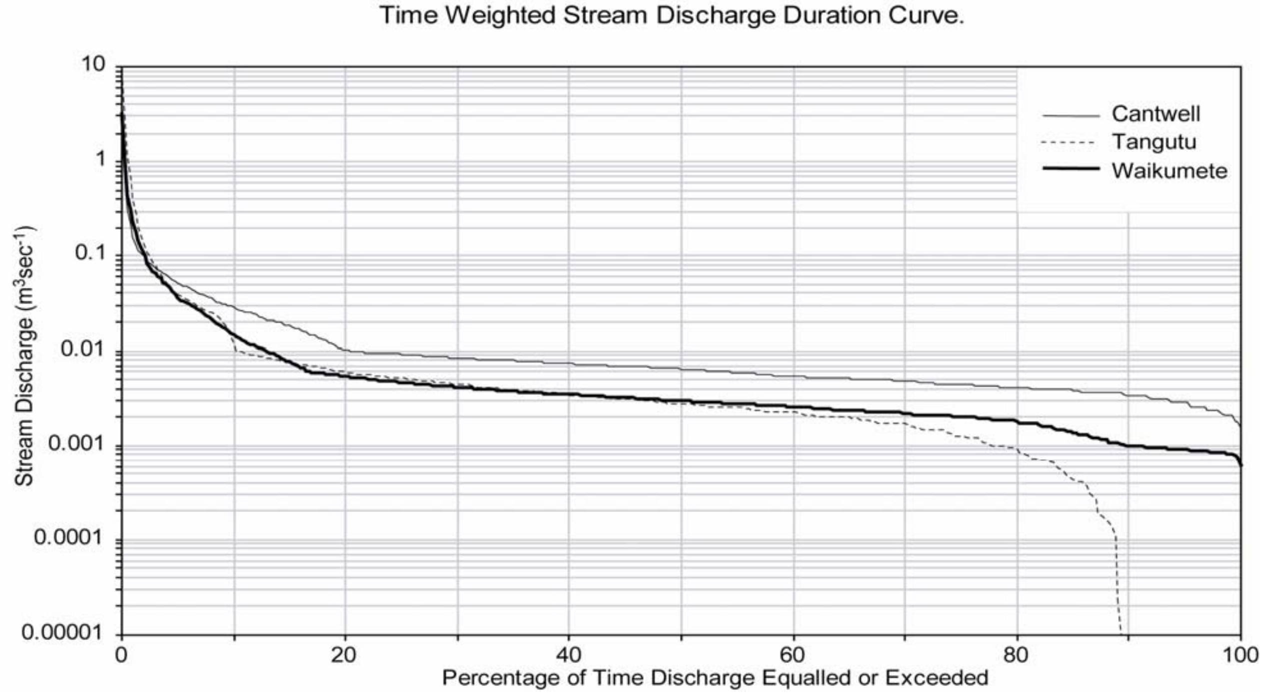
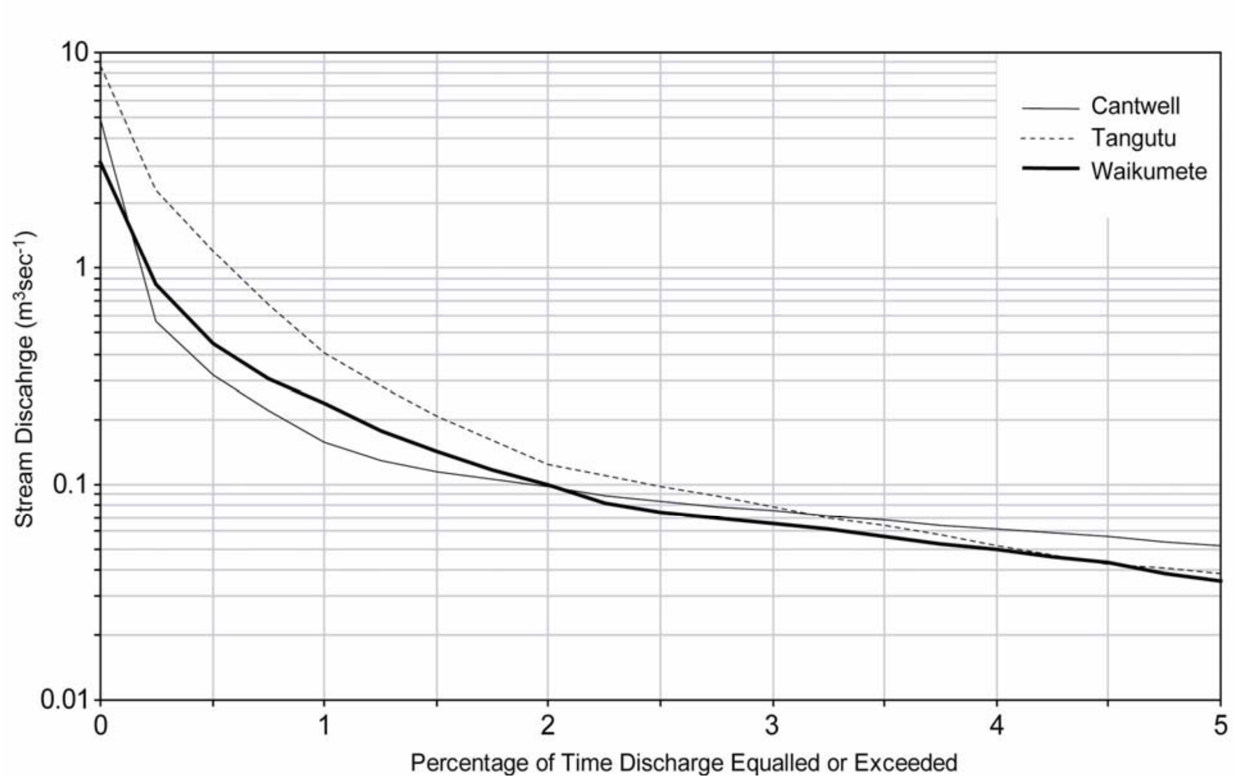


Figure 7: *Flow duration curves for the largest 5% of flows from the Cantwell, Waikumete and Tangutu Catchments (Herald, 2003)*



2.4 DISCUSSION

Nymphs of the mayfly *Coloburiscus humeralis*, found in Cantwell Stream during this study, were investigated in nearby Opanuku Stream by Tan (1964) who recorded population densities in relation to stream current speeds and benthic substrata. Tan established a normal distribution for density of nymphs relative to current speed, with population density peaking at around 0.6 m/sec and occurrence confined within the range 0.1 to 1.5 m/sec. Another close to normal distribution of nymph density versus benthic substrate size showed that optimal conditions for *Coloburiscus* occurred in gravel and pebbles with substantially reduced populations as rocks became smaller or larger. Nymphs were not found by Tan in the presence of sand and silt. Laboratory studies by Tan, made it clear that current speed was of direct importance for survival of this mayfly nymph in addition to its role in enabling aeration of the stream and therefore the maintenance of high dissolved oxygen concentrations. Although Tan found that dissolved oxygen concentrations are important to survival, *Coloburiscus* nymphs lived for lengthy periods in concentrations as low as 3.5mg/l provided there was water movement. Still water with high dissolved oxygen concentrations was eventually fatal to *Coloburiscus* nymphs. Tan concluded that the current is necessary both to replace oxygen deficient water close to the gills and to deliver food particles that are strained from the water.

Current speed varies with a number of stream conditions including flow, depth, stream bed profile, eddies, the presence in the stream bed of vegetation, debris and stones that provide refuge in reduced current areas. Many of these stream conditions are known to be altered during and after urbanisation of catchments (Shaver, 2000; Herald, 2003). The hydrological regime of the stream will be a strong determinant of both the persistence of current speeds suitable for mayfly survival, bed profile and the presence of gravel and cobbles that provide refuge.

Changes in stream flow resulting from urbanisation of catchments have been well documented and indicate increased storm peak flows, more abrupt rise and fall of storm hydrographs, increased frequency of high flow events, and lower baseflows. These findings are confirmed for the three study catchments. The flow duration curves (Figures 6 and 7) for the Tangutu, Waikumete and Cantwell Streams (Herald, 2003) clearly show the increased proportion of time that flows in the urban Tangutu and Waikumete catchments lie in upper and lower extremes increasing stress on all stream life and providing further explanation for the reduction in EPT species like *Coloburiscus* that is intolerant of extremes in current speed and substratum type. The Tangutu Stream was dry for many days in the summer of 2002 – 2003 thereby necessitating at least annual recolonisation by invertebrates. (See discussion on life cycle duration below.) It should be noted however that Stark et al.(1999) observed increases in macro-invertebrate community indices (MCI) during storm events five or six times the magnitude of the preceding baseflow and concluded that high flows may wash high scoring (EPT) species downstream (thereby increasing downstream MCI scores) and also wash away algal proliferations not well tolerated by such species. Flood events in Tangutu Stream in 2002 -3 had flows between 80 and 1000 times preceding baseflows.

The dislodgement of benthic stream invertebrates by a steep rise in the flood hydrograph, compared with a more gradual stepped rise to the same discharge, was examined by Bosco and Perry (2000). Relative to reference streams, Bosco and Perry found that the percentage of benthic invertebrates in the drift increased 10 fold in streams with the gradual-stepped flood rise and 33 fold in streams with the abrupt-steep rise. Behavioural responses to changing flow probably mean that a gradual rise gives some benthic animals like mayfly nymphs time to seek refuge rather than being immediately swept into the drift and downstream. This suggests that the steeper ascending slopes for the urbanised Tangutu Stream and Waikumete Stream flood hydrograph (Figure 5) may partially explain why mayflies like *Coloburiscus* are rare or absent here but abundant in the Cantwell Stream.

The impact of catchment urban use upon sensitive EPT species is indicated by Figures 2 and 3. Intermediate population values in catchment headwaters of the Waikumete and Tangutu Streams reflect more natural stream conditions, including the presence of native riparian vegetation, relative to conditions in lower parts of each catchment. However, note in Figure 3, the number of EPT taxa in the headwaters of the Waikumete is lower than in the headwaters of the Tangutu despite good riparian vegetation in the former. This may be a result of the diversion of Titirangi township stormwater into the headwaters of the Waikumete. This reinforces our observations that stream corridor naturalisation on its own is inadequate in providing good habitat conditions for mayflies and stoneflies in urbanised catchments. This reinforces the need for the implementation of LIUDD throughout urban catchments in order to achieve stream (and consequently lakes and harbour) restoration or protection.

Other recent New Zealand research reinforces this view. Benthic invertebrate sampling of 5 Christchurch urban streams before (1995) and after (2000) extensive restoration of riparian corridors and naturalisation of stream paths, showed the lack of recolonisation of these streams by mayflies, including *Coloburiscus* and *Deleatidium*, known to have been present before urbanisation (Suren et al., 2003). The authors indicate ongoing intensification of urban use within catchments of these spring-fed streams and have suggested that high metal and sediment concentrations in stormwater may contribute to the lack of recolonisation. Comparison of the hydrological characteristics of Glen Eden streams in differing landuse, in the context of relevant research on EPT tolerances, suggests that these characteristics are critical to achieving suitable habitat. Changes in the hydrological regime in the catchments of these Christchurch streams (preventable with LIUDD) will have a direct impact on mayfly populations as well as ensuring the overly efficient delivery of metals and sediments to the stream. Also in an analysis of data from 26 North Island, New Zealand, river sites over 9 years, Scarsbrook (2002) concluded changes in stream community structure are more tightly linked to changes in flow conditions than water quality.

Additionally in Christchurch (and many other lowland areas around New Zealand), there may be a lack of adult mayfly in the neighbourhood to enable recolonisation. In a Waikato study of recolonisation of rural streams, by invertebrates including mayflies, following land slips and floods, Collier et al. (2004) emphasised the importance of the survival of stream-headwater populations that are able to drift down the stream once conditions return to normal. However, even with stream recovery, it took one year for mayfly and caddis fly populations to re-establish. Scarsbrook (2002) observed that most New Zealand stream invertebrates complete at least one generation per year, and Winterbourn (1964) showed that the life cycle of many common stonefly species takes the best part of a year. *Coloburiscus* mayfly nymphs tend to be most abundant in winter to spring, they mature over many months, and more adults hatch in spring to early summer than in other seasons (Tan, 1964). Therefore the seasonality, frequency, peak flow and steepness of the ascending hydrograph of flood events may all contribute to determining whether "healthy" habitats get depopulated or whether recolonisation ever occurs. LIUDD practices aim to naturalise all of these hydrological characteristics.

We question the adequacy of stormwater treatment ponds within the stream path, for achieving suitable conditions for EPT species. Such detention and sedimentation devices are typically installed in mid-lower catchment thereby reducing peak flows, ascending hydrograph slope, delivery of fine sediments and some contaminants to downstream reaches. Baseflows below such ponds may deliver inadequate flows. Ecologically important first order streams in catchment headwaters, the source of EPT populations needed for stream recolonisation after storms will remain impacted unless on-site stormwater generation is minimised.

In the introduction we discussed ongoing steps towards convincing stakeholders of the need for LIUDD. The third step therefore includes convincing stakeholders that avoidance of damaging hydrological and water quality changes is most effectively achieved by preventing the generation of stormwater at source. To be successful this requires not only the use of alternative stormwater structures and management techniques but most importantly it requires a change in urban form. Restoration of stream corridor habitat through riparian revegetation, naturalisation of streams in conjunction with stormwater treatment appears to be inadequate for complete recovery of stream ecosystems. What is needed is a catchment wide focus on LIUDD that is broader than just alternative stormwater management.

These conclusions lend support for the (Shaver, 2000, inspired) catchment based structure planning undertaken by North Shore City Council (NSCC) for Long Bay (NSCC, 2002) within which the gradation from large lot to high density development with distance down the catchment, makes feasible the minimisation of stormwater generation and revegetation of catchment headwaters. This is complemented by plans to fully revegetate the riparian corridor. Some elements of this design have also been included in the Flat Bush Concept Plan (MCC, 2002). Such sound catchment design needs to be complemented by attention to sound water cycle management (commonly termed 'three waters' management) as planned by NSCC and the maintenance of vegetation on individual lots within the subdivision.

3 CONCLUSIONS

In catchments where particular sensitive species (such as mayfly) are known to have occurred prior to urbanisation, these species can be used as indicators of the maintenance of healthy catchment and stream conditions during and after urbanisation. Maintenance of stream conditions suitable for these species will indicate a high probability of good overall ecological condition throughout the catchment and downstream receiving waters. As these species are sensitive to changes in hydrological regime, stream current velocity, benthic sediment grading and riparian vegetation cover (amongst other factors) most of which are altered by conventional urbanisation methods, naturalisation of the catchment water cycle as well as the stream corridor should be an objective.

The Centre for Urban Ecosystem Sustainability is therefore forming partnerships with local communities and Councils to design and build LIUDD greenfield and brownfield developments that will demonstrate their effectiveness and cost efficiency. We are currently developing a research framework to measure improvements resulting from LIUDD practices. Such a framework would include the monitoring of catchment sites and technologies in both greenfield and brownfield low impact developments to determine gains in physiochemical and hydrological conditions, and biotic integrity, relative to that in conventionally developed urban catchments, both with and without stormwater treatment devices.

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