Evaluating the Ecological Efficacy of Low Impact Urban Design and Development

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Abstract
It is anticipated that implementation of low impact urban design and development (LIUDD) on a catchment scale will lead to a quantum leap in ecological improvement in both terrestrial and aquatic environments. One of the primary objectives in LIUDD is the achievement of hydrological neutrality, that is a nil or minimal change in the hydrologic regime. This might be measured using indicators of water body functionality and sustainability. One of the anticipated outcomes of improved hydrological stability throughout and after the development process is the retention of aquatic ecosystem health and biodiversity. In addition, the achievement of hydrological neutrality demands much higher catchment coverage with vegetation of high biomass, ensuring high evapotranspiration rates. This is particularly necessary in locations where soils have limited infiltration capacity. Much of this vegetation is likely to be within riparian margins where it can contribute to both terrestrial and aquatic biodiversity enhancement and improve water quality. This paper explores the type of research framework that might be developed to measure these ecological gains. This would include the monitoring of low impact developments to determine gains in physicochemical condition and biotic integrity relative to that in conventionally developed urban catchments.

1. Introduction
Achievement of sustainable cities, as intended by the New Zealand Government programme of action for sustainable development (MfE2003), necessitates avoidance of the level of degradation of receiving water ecosystems typical of past urbanisation. This degradation has resulted from changes in hydrological regime, contaminant burden and habitat alteration, that has accompanied conventional urbanisation. In order to increase economic, ecological and social components of urban sustainability simultaneously, management of the total urban water cycle should be integrated into urban design and development (van Roon and Knight 2004; Lloyd et al. 2001).

The Centre for Urban Ecosystem Sustainability (CUES, a partnership between Auckland University and Landcare Research) is pursuing a research programme (Eason et al. 2003) directed at making Low Impact Urban Design and Development (LIUDD) mainstream in New Zealand. The five objectives of the programme target stakeholder buy-in, changing plans and policies, testing technologies, comparative catchment studies and economic efficiencies. LIUDD is derived from Low Impact Development (LID), which has its origins in the United States of America. LID is focused on alternative stormwater management that utilises natural drainage features (Shaver 2000) in the landscape rather than piped systems. LID is alternatively termed Water Sensitive Urban Design (WSUD) in Australia.

LID has been extended in Washington State by Holz (2002) who promotes ‘Zero Impact Design’ (ZID) within which development must adhere to characteristics of a healthy watershed, no stormwater is collected and released, broad stream buffers are maintained, stream and road crossings are minimised. This necessitates the retention or re-creation of predevelopment or natural hydrological conditions to the maximum extent possible (City of Lacey 2002). ZID retains the critical functions of a forest including evapotranspiration and infiltration after site development such that near ‘zero effective impervious surface’ area is achieved (City of Lacey

2002). Holz (2002) considers that in Washington State sixty percent or more of the watershed should be retained in indigenous forest.

The definition of LID in New Zealand and particularly within CUES is evolving well beyond a stormwater management process into what we now term LIUDD. It is an urban design method that is expected to protect aquatic and terrestrial ecological integrity, improve urban amenity and reduce the cost of infrastructure while accommodating increasing population densities.

The biotic integrity of terrestrial, stream, and either lake or estuarine ecosystems form a hierarchical co-dependence. Healthy stream ecosystems throughout a catchment are therefore a sound indicator of the health of co-dependent ecosystems up and down stream. The monitoring of stream ecosystem health is expected to give a cumulative assessment of the combined benefits of diverse in-catchment LIUDD practices.

Following a brief review of the relationships between stream ecosystem condition and measures of conventional urbanisation such as impervious surface area, this paper compares stream ecosystem condition in four Waitakere catchments with varying land use. Catchment land use ranges from semi-forested and pastoral (lifestyle blocks) through to conventional urban residential. Results are then used as a basis for envisioning alternative residential design and development scenarios (to be monitored) that avoid characteristics giving rise to aquatic and terrestrial biodiversity degradation in conventional developments.

2. Urban use – aquatic biotic integrity relationship

The ecological justification for LIUDD comes from research demonstrating the loss of aquatic ecological integrity in catchments subjected to varying degrees of human disturbance. This disturbance may be anything from recreational use of forested catchments to high-density urban use with 100 percent effective[1] impervious surfaces. The percentage of a catchment covered in impervious surfaces has frequently been used as a measure of the intensity of urbanisation. Higher storm discharges also facilitate transference of damaging fine sediments and toxic contaminants from urban surfaces to receiving ecosystems. Over the past three decades stormwater management focussed on the construction of stormwater detention technologies that contributed to a reduction of these adverse hydrological effects but did little to address the primary land-based causes, beyond the riparian zone, of aquatic ecosystem degradation.

Measures of aquatic biotic integrity have been widely used, including in the USA and New Zealand, to monitor the effects of catchment use and urbanisation. Biotic indices are based on information on complete assemblages of macroinvertebrate organisms and are designed to simplify a mix of complex community data (MfE 1999). Research in Washington streams (USA) showed that the Benthic Biotic Index (B-IBI) fell by half after only five percent of the catchment was converted to impervious surfaces (Horner and May 1999). The installation in catchments of various Best Management Practices (both structural and non-structural) provided very limited mitigation (Horner and May 1999; Maxted and Shaver 1997). Similar New Zealand research (Allibone 2001) shows a loss of half of indicative EPT[2] species with 15 percent of the catchment in impervious surfaces. These researchers have concluded that in order to retain a high quality aquatic ecosystem, it is necessary to limit effective impervious surfaces to below 15 percent of the catchment.

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1 An effective impervious surface is one that forms a continuous impervious connection with a piped stormwater system that delivers almost all rainfall to that surface to the receiving water.

2 EPT: Ephemeroptera, Plecoptera and Trichoptera – or mayflies, stoneflies and caddisflies, are sensitive insect groups used as indicators of stream and river health.

The hydrological and water quality changes in urban streams resulting from increased imperviousness include:

- Higher flood peaks causing increased scouring of stream habitats and biota.
- Increased contamination of stormwater (sediment, metals, and organics).
- Reduced flows during dry spells (baseflow), reducing aquatic habitat area.
- Reduced baseflow also means reduced dilution of contaminants, and, frequently, increased temperatures and reduced dissolved oxygen levels.

All of these changes affect urban stream habitats and biota. Comparison of the ecosystem health of urban streams with neighbouring semi-forested, pastoral streams gives an understanding not only of the cumulative effects of urbanisation but it indicates the potential benefits of aquatic ecosystem protection if characteristics of the forest catchment are designed into greenfield urban catchments.

3. Glen Eden Case Studies

3.1. The Case Study Context and Objectives

The state of the aquatic biota of the Cantwell, Waikumete, Hibernia and Tangutu Streams in the Glen Eden area, were assessed in relation to surrounding landuse. This programme also included monitoring of water quality, hydrology and riparian vegetation types, all of which influence the aquatic biology of these streams.

Freshwater fish, invertebrates and algae can be used as indicators of the state of their watercourses, and the composition of these aquatic communities can provide clues about the various stresses affecting their habitats. The survey was designed to characterise the aquatic ecosystem values in the selected streams, and to determine which habitat variables are acting as limiting factors (limiting the life supporting capacity of each stream). This would indicate which (if any) land-based management activities might need to be modified in order to improve stream habitat and biological quality.

3.2. Methods

The Cantwell, Waikumete, Hibernia and Tangutu Streams in the Glen Eden and Titirangi area provide comparisons between contrasting land use, ranging from bush and lifestyle blocks in the Cantwell catchment, to the intensive urban surrounds of the lower Tangutu Stream. The Waikumete and Hibernia Streams originate in upper Glen Eden where the streams are well shaded by riparian vegetation, but they flow through areas of increasing urban development downstream.

Invertebrate and periphyton sampling and analysis

Most sampling emphasis was placed on stream invertebrate communities because these have proved to be easiest to sample, and most useful as indicators of specific habitat conditions. Invertebrates were collected by disturbing the streambed and collecting fine material using a 0.5mm mesh pole net. The sampling methods used in this survey were based on the national protocols for wadeable streams (Stark et al, 2001). 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 it was analysed under stereomicroscopes for invertebrate content.

Invertebrates were identified to the taxonomic level (mostly genus) required for application of the Macroinvertebrate Community Index (MCI) and Semi-Quantitative MCI (SQMCI). These indices are described in Stark (1998), but essentially they measure the effects of water quality changes (including nutrient enrichment, dissolved oxygen levels and temperatures) on invertebrate community composition.

Periphyton (algae and heterotrophic micro-organisms) sub-samples were taken from the invertebrate samples and scanned under a compound microscope and the dominant taxonomic groups were recorded.

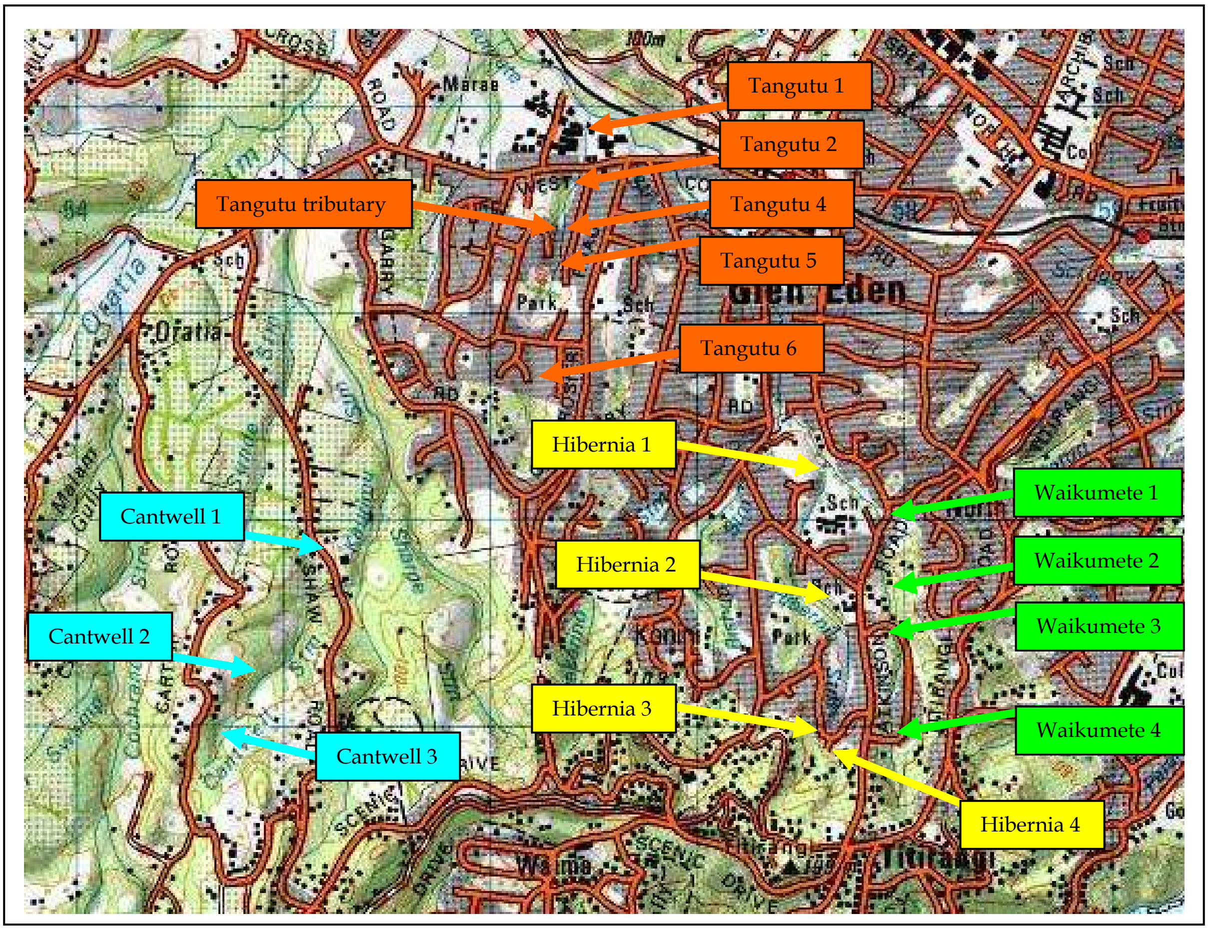

Fig 1. Sites assessed in the Cantwell, Waikumete, Hibernia and Tangutu Streams, September 2002.

Fish sampling

Although this survey was designed primarily to assess invertebrate communities, fish were observed or collected in the invertebrate net at several sites. The small size of most of these streams meant that the net could block much of the stream channel off, and therefore fish retreating from the kick-sampling process were likely to be captured. The sites assessed during the current investigation are illustrated in Fig. 1.

3.3. Results

Habitat Characteristics

The essential differences between these sites are described below, and illustrated in Figure 2:

- The three Cantwell Stream sites were stony-bedded, bush-covered riffles and runs located upstream of the Glen Eden - Titirangi urban area.

- The upper reaches of the Hibernia Stream (Hibernia 3 and 4) and the Waikumete Stream (Waikumete 4) were shallow runs (riffle-like in patches) located near the uppermost limits of urban influence, where there was still abundant native vegetation along the riparian margins, and abundant woody debris in the stream channels.

- The six Tangutu Stream sites and lower Hibernia and Waikumete Stream sites were more extensively modified by urban landuse, with Tangutu Site 1 being the most unnatural being a concrete-lined channel. These sites were pools or slow-flowing runs. While the substrata differed between sites (including willow root systems, aquatic plants, artificial bed matting, bedrock and concrete), they all were characterised by abundant fine sediment.

Fig 2. Principal habitat types recorded from the Glen Eden – Titirangi study area September 2002. *Upper left,* stony-bedded Cantwell Stream site 3. *Upper centre,* tree-root substrata of the Waikumete Stream site 3. *Upper right,* muddy bed of the Tangutu Stream site 4. *Lower left,* artificial bed matting and stones lined the Waikumete Stream site 2. *Lower centre,* weedy substrata at the Hibernia Stream site 2. *Lower right,* concrete-lined channel of the Tangutu Stream site 1.

Invertebrate Results

Habitat conditions in lowland streams of the Auckland area are often dominated by slow current speed due to the generally small catchment sizes and low gradient. Slow current speeds allow fine sediments to settle, resulting in muddy and sandy beds that often become colonised by submerged or emergent aquatic plants. Many Auckland stream invertebrate communities are therefore dominated by weed-associated taxa, including those commonly found in ponds rather than fast-flowing streams. Relatively few invertebrate taxa can survive in warm, oxygen-depleted waters, and such conditions are more likely to occur in slow-flowing waters where there is little shade from riparian vegetation.

Among the most abundant invertebrate taxa in the current survey (Fig. 3) were several "tolerant" groups dominating the slow flowing, weedy/muddy habitats, but also some "sensitive" taxa in the stony/woody bedded upper catchment habitats.

Fig 3. The most abundant invertebrate taxa found in the Cantwell, Waikumete, Hibernia and Tangutu Streams, September 2002. Top row; oligochaete worms, *Potamopyrgus* snail, and *Physella* snail. Middle row; *Zephlebia* mayfly, orthoclad midge and *Polypedilum* midge. Bottom row; *Paraleptamphopus* amphipod, *Polyplectropus* caddis and *Coloburiscus* mayfly. *Coloburiscus* and *Zephlebia* were abundant only at the upper catchment (less urbanised) sites.

The numbers of taxa recorded in the current survey ranged from 11 at highly urbanised Waikumete 1, to 21 at the bush covered Cantwell 2. As a general rule, higher numbers of taxa tend to occur in "good" habitat and water quality conditions; however, there are many cases where "natural" habitat limiting factors result in low numbers of invertebrate taxa. The Cantwell Stream sites were clearly more natural than those of the lower (urbanised) catchment streams, but the numbers of taxa recorded in the Cantwell Stream were not significantly higher than the urban sites, partly because much of the biomass in the Cantwell Stream samples was terrestrial leaf litter rather than aquatic biota.

Community composition provides more useful information, and the number of taxa belonging to the generally "sensitive" ephemeroptera, plecoptera and trichoptera (EPT) groups (the mayflies, stoneflies and caddisflies) is commonly used as an index (Fig 4).

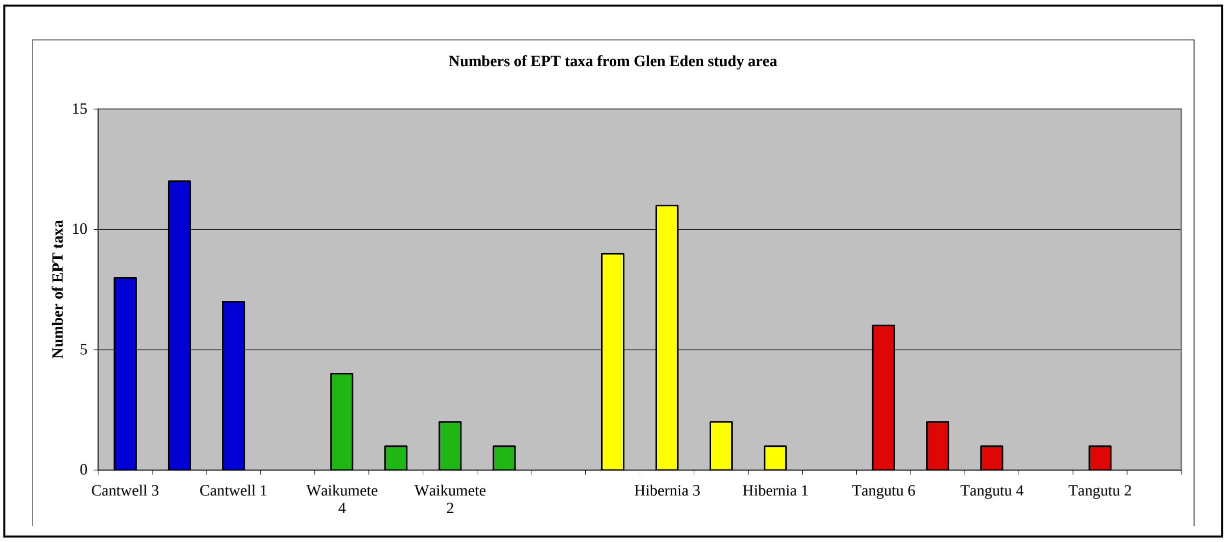

Fig 4. Numbers of invertebrate taxa belonging to the generally "sensitive" EPT (ephemeroptera, plecoptera and trichoptera) groups, found in the Cantwell, Waikumete, Hibernia and Tangutu Streams, September 2002.

Figure 4 shows that the least urbanised sites (Cantwell Stream and upper Hibernia Stream) supported the highest numbers of EPT taxa. This will be because of the well-vegetated riparian margins (shading the water and limiting stream warming), and the lack of (or minimal) urban influence including discharges of urban stormwater to these sites. A similar trend is shown when the numbers of EPT taxa are expressed as a percentage of the total taxa recorded at each site (Fig 5).

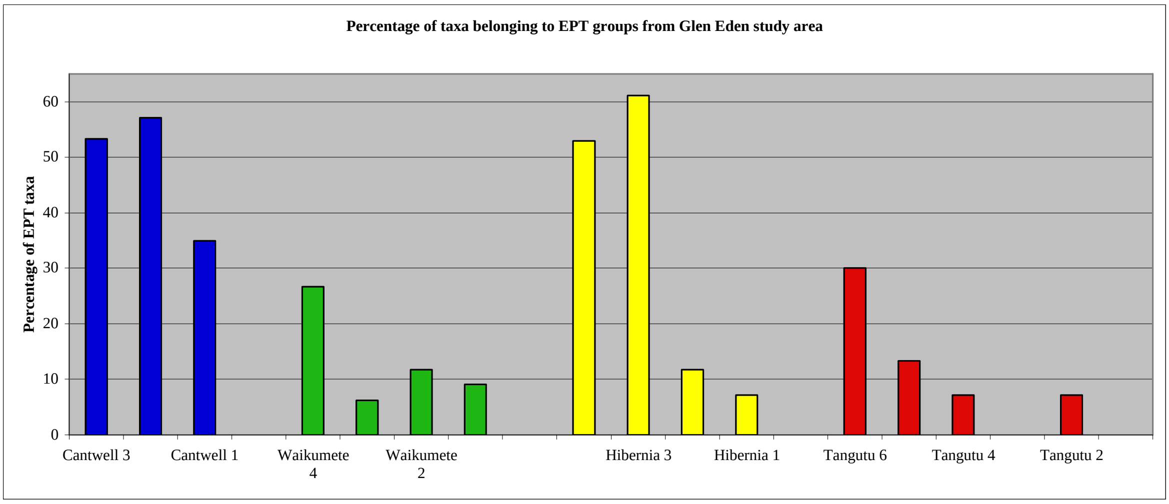

Fig 5. Percentage of invertebrate taxa belonging to the generally "sensitive" EPT (ephemeroptera, plecoptera and trichoptera) groups, found in the Cantwell, Waikumete, Hibernia and Tangutu Streams, September 2002.

The highest EPT and %EPT values recorded from the Waikumete and Tangutu Stream sites were also the uppermost sites in these streams. The EPT taxa are known to be more suited to bush covered, cool-water streams where there is an abundance of stony or woody material to colonise. The flying adults of these insects are also known to benefit from bushy riparian vegetation as they rest amongst such vegetation.

The EPT taxa are generally "sensitive" to a range of pollutants including fine sediment and nutrient enrichment, but they are also sensitive to increases in temperature and decreasing dissolved oxygen levels, both of which can naturally occur with distance downstream. The most intensive urban development in the Glen Eden area is not surprisingly in the lower catchment where gradient is lower (more suitable for development). There may be less opportunity to restore the lower reaches of urban streams where the naturally low channel gradient may not allow the constant swift flow and hard substrata favoured by many "sensitive" invertebrates.

In addition to sediment, contaminants including copper, zinc, lead, poly-aromatic hydrocarbons (PAHs) and organic waste, are all common in streams draining areas of intensive urban development. Water quality analyses of urban streams typically show increasing concentrations of these contaminants with distance downstream (Herald 2003) unless there is significant dilution provided by confluences with less contaminated streams or rivers**.**

Hydrological regimes also tend to be more "hostile" for many stream invertebrates in urban areas. Rapid stormwater runoff from impervious surfaces often results in current speeds in excess of those tolerated by many stream invertebrates. Straightening of steam channels, as in the case of the concrete-lined lower Tangutu Stream site, also removes the natural shelters from storm flows previously provided by channel meanders and natural eddies and backwaters. During base flows however, the lower Tangutu Stream site is slow-flowing and muddy-bedded, and this muddy substrata will be severely scoured during storm flows.

The loss of most (or all) EPT taxa from the lower reaches of the urban streams resulted in a decline in Macroinvertebrate Community Index (MCI) values because the EPT group includes most of the high-scoring taxa that contribute to high MCI values (Fig 6).

It should be noted that the MCI was designed primarily for use in stony streams, and that muddy/weedy streams naturally tend to produce lower MCI values than stony streams due to physical habitat and dissolved oxygen conditions (even without any change in levels of contamination). The invertebrates suited to muddy/weedy-bedded, pool-like habitats are generally the more "tolerant", low-scoring taxa that tend to reduce MCI values. The most tolerant, lowest-scoring invertebrates such as oligochaete worms, *Chironomus* midges, orthoclad midges and psychodid flies (each of which have very low scores), made up a greater proportion of the communities at the lower catchment urban sites.

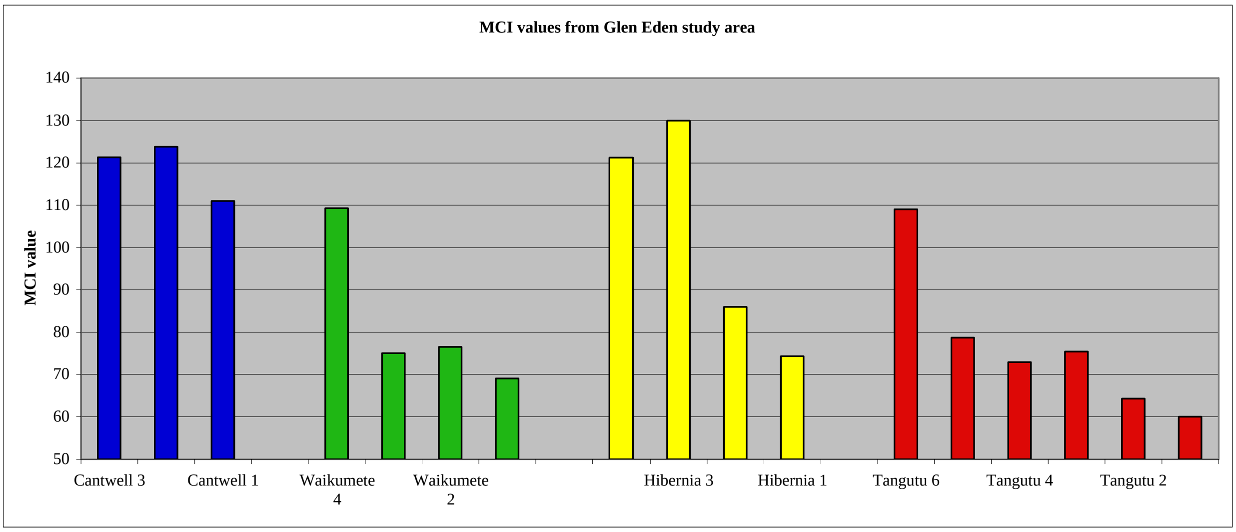

Fig 6. Macroinvertebrate Community Index (MCI) results from the Cantwell, Waikumete, Hibernia and Tangutu Streams, September 2002.

The Semi-Quantitative MCI (SQMCI) is also based on the ratios of "sensitive" to "tolerant" taxa, but SQMCI results are primarily determined by the most abundant taxa (unlike the MCI where all taxa are given equal weight in the calculation). The SQMCI is also designed primarily for stony streams, and Figure 7 confirms that the muddy-bedded lower catchment (urban area) sites produced much lower ("poorer") SQMCI values than the stony or woody-bedded Cantwell Stream or upper Hibernia Stream sites.

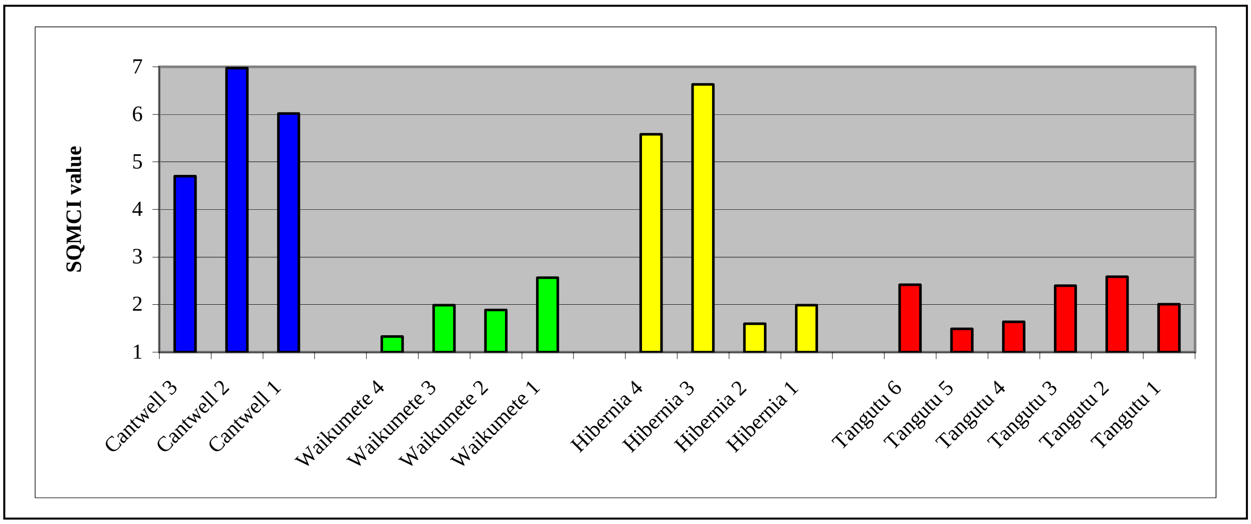

Fig 7. Semi-Quantitative Macroinvertebrate Community Index (SQMCI) results from the Cantwell, Waikumete, Hibernia and Tangutu Streams, September 2002.

Fish species recorded

Past surveys of streams in this catchment have shown that fish communities are generally of low diversity. Only two freshwater fish species were recorded in the current survey, and these were the banded kokopu (migratory native *Galaxias fasciatus*) and shortfin eels (migratory native *Anguilla australis*).These are the two most commonly recorded fish species in the Auckland Region (Auckland Regional Council 2000) and there are many records of both species in Auckland urban streams (Allibone et al. 2001, and author's personal experience). Both fish are migratory species and have a seawater larval stage and therefore the returning juveniles must migrate back into freshwater (McDowall 1990, McDowall 2000).

Eels and kokopu usually shelter under overhanging banks, submerged root systems (of bank-side or emergent vegetation), coarse bed material (particularly woody debris and rocks) or submerged aquatic plants. The banded kokopu recorded during this assessment were found underneath overhanging banks and emergent plants. A sub-adult shortfin eel was found in the lower Tangutu concrete channel, however, lack of shelter from flood flows make it unlikely that eels remain in this habitat during high flow events. Adult banded kokopu are commonly recorded in small, well-shaded, clear-water streams in upper catchment areas. Some of these streams may not flow all year round and kokopu will have to survive in stagnant pools or escape downstream as flows become dangerously low. The banded kokopu found in this assessment were of small to medium size (60-120mm), probably of 1-2 years old. Fully-grown kokopu (200mm or more) are rarely recorded in urban streams. It is likely that kokopu have a reduced chance of surviving in many urban streams due to the increased flooding and pollution hazards.

Water clarity is important for banded kokopu because these fish are visual feeders (Richardson et al, 1998). This will be one of the reasons why banded kokopu are often found in upper catchment areas (water often becomes more turbid with distance downstream, especially in urban streams). The greater supply of terrestrial invertebrates from streams with abundant overhanging vegetation is another reason why adult kokopu are found in upper catchment sites (where overhanging vegetation typically covers a higher proportion of the stream). Banded kokopu were recorded at the upper Hibernia and Tangutu Stream sites under, or close to overhanging vegetation and where the water would normally be relatively clear.

Bank-side vegetation may also be beneficial to native fish and invertebrate populations in urban streams, as decomposing vegetation can assist with the binding of common stormwater contaminants including heavy metals (Mills 1999). Leaf litter from bank-side vegetation provides a significant food source to stream communities (Quinn and Scarsbrook 2001).

Juvenile native fish, including the "whitebait" of banded kokopu and elvers are more commonly found in lower catchment sites, especially during spring and summer, because most species found in the Auckland region migrate into the lower reaches of streams following their sea water planktonic larval phase. Unfortunately there are often poorly designed road culverts on urban streams and this prevents migratory fish with limited climbing abilities to migrate upstream. Juvenile banded kokopu and shortfin eels however, have excellent climbing abilities.

Periphyton results

The only sites characterised by significant growths of filamentous algae found in this assessment were the lower Tangutu Stream (concrete channel), and the Waikumete Stream at lower Woodfern Crescent. The lower Tangutu Stream lacks significant shade due to the wide concrete channel, and most solid surfaces had a covering of *Melosira* diatoms or *Oedogonium* green algae (the latter covering freshwater snail shells). The Waikumete Stream at lower Woodfern Crescent had moderate shade from riparian vegetation, but algae growths can still accumulate at such sites if there is a long period between flood-flows and if there are abundant surfaces for attachment (in this case root systems).

The other urban stream sites in the Tangutu, Waikumete and Hibernia Streams did not support significant growths of any algal taxa, probably because of a lack of light, a lack of firm attachment sites, or a combination of both. Each of the Cantwell stream sites would have been too shaded for significant growths of algae to establish. Providing shade with tall riparian vegetation will not prevent all algal blooms in urban streams, but it will reduce the frequency and duration of such blooms.

3.4. Concluding Comments on Case Studies

This survey confirmed that streambed invertebrate community composition and "health" in these Glen Eden streams relates to physical habitat and water quality, both of which are strongly influenced by topography, surrounding landuse and riparian vegetation. With increasing urban influence streams were characterised by lower gradient, wider channels, reducing cover by riparian vegetation, and increasing amounts of fine sediment and emergent vegetation. These changes in habitat conditions result in invertebrate communities becoming more like those of ponds and less like those of stony-bedded, bush-covered streams.

The most "natural" habitats in the bush-covered Cantwell Stream supported aquatic communities dominated by "sensitive" invertebrates, while the most unnatural habitat in the concrete-lined lower Tangutu Stream supported only "tolerant" invertebrates suited to muddy beds and low dissolved oxygen levels.

Fish communities were sparse throughout the study area, and this is not unusual for streams that flow through urban areas, where barriers to fish passage and unreliable water quality commonly limit fish species diversity and abundance. Banded kokopu, which can climb many waterfalls and migrate through culverts were the dominant species in the study area, and were always found at sites with abundant instream cover.

Generally these results suggest that urban stream habitat quality could be improved by:

- providing moderate shade-producing riparian vegetation where none currently exists
- providing firm substrata (stony bed material and woody debris)
- reducing inputs of fine sediment (improving bed composition and water clarity)
- reducing concentrations of other contaminants in stormwater (including organic wastes and metals)
- buffering flow regimes by increasing flood detention devices (reducing severe scouring) and increasing groundwater recharge (increasing base-flows)
- ensuring that there is abundant instream cover/shelter (not straightening and lining channels with concrete).

These are all anticipated improvements from LIUDD in greenfield residential developments. Relationships between impervious surfaces and aquatic ecosystem health are over-simplistic for demonstrating the causal effects of urbanisation. We continue to examine such regressions in the hope of identifying key causes that can easily be removed permitting continuance of conventional development form with only minor modifications. Effective imperviousness measures lost opportunity for rainwater infiltration to ground but if soils are relatively impervious the addition of impervious surfaces may have minor hydrological consequences. Many interacting changes, typical of conventional urbanisation within a catchment, contribute to both stormwater loss, change in hydrologic regime and aquatic ecosystem degradation. These include: climate, topography/slopes, evapotranspiration capability, soil type and compaction, biomass and type of vegetation, and stormwater detention in ponds and wetlands.

Protection or restoration of both aquatic and terrestrial biodiversity, as signalled by the New Zealand Biodiversity Strategy (Doc and MfE 2000), during urbanisation requires attention to all of these factors. In order to conserve receiving water ecosystems during and after urbanisation it will be necessary to rethink the urbanisation process and urban form, imitating as close as possible the natural catchment condition. Ecosystem degradation begins at the initial disturbance of the intact indigenous catchment ecosystem. In the lowland New Zealand case, where most urbanisation occurs, this was typically up to 150 years ago with initial conversion to pasture. Conventional lowland urbanisation in New Zealand adds to this degradation.

The challenge is to reverse rather than compound pastoral ecosystem degradation by designing and building urban areas that simultaneously recreate forest ecosystems. In a comparison of invertebrates from 76 rural stream sites and 64 urban stream sites Moore (2003) concluded that urban stream macroinvertebrate communities tend to have lower taxonomic richness, lower numbers of EPT taxa and lower MCI values (Fig. 8) than rural streams. MCI values for forest covered sites were substantially higher than those for rural and urban streams. It is our objective to use LIUDD to improve stream ecological health so that urban stream results cluster with the lowest quality forest streams in Fig. 8.

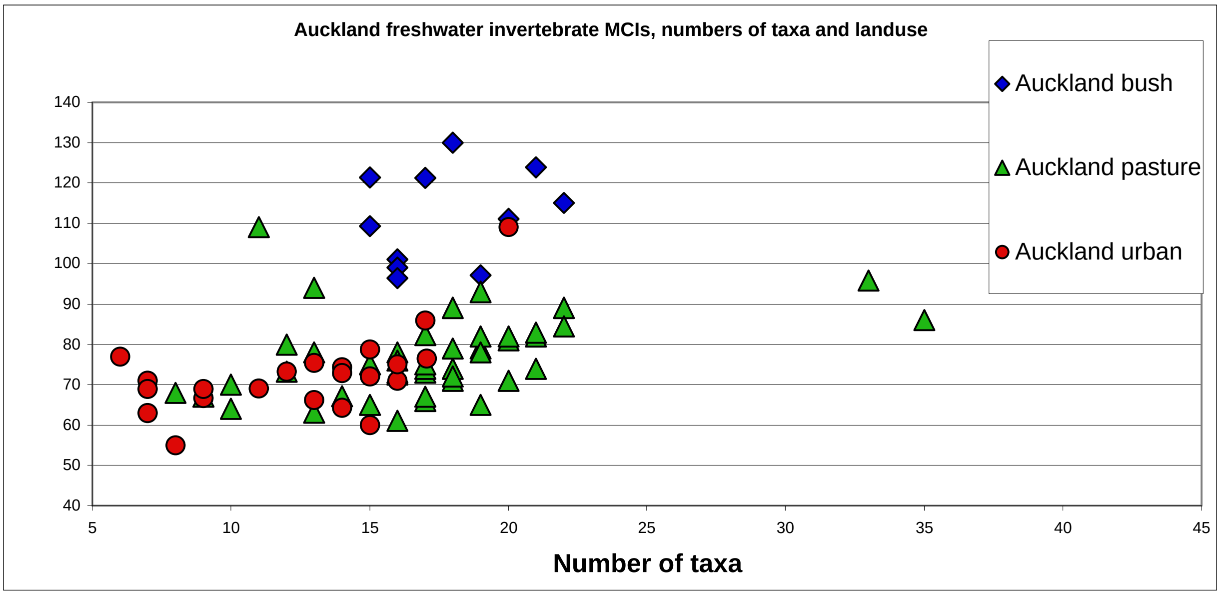

Figure 8 A comparison of Macroinvertebrate Community Index (MCI) and Taxa richness for Auckland streams in different landuse catchments (Moore 2003)

4. A LIUDD Vision for Stream Ecosystem Health

4.1 The challenge

A challenge for LIUDD is to ensure that when a catchment is developed for residential purposes, intensity of development (human population density) does not, of necessity, determine receiving water ecosystem health. Over past decades in New Zealand we have begun to naturalise our waterways, revegetate riparian corridors and detain and treat contaminated stormwater in residential developments. As is apparent from previous research (Horner and May 1999) prevention of stream ecosystem degradation requires much more than remediation within the stream corridor. Riparian restoration has quite rightly, been promoted as the most important objective for stream health. However as long as the catchment remains in conventional urban form beyond the riparian zone, there will be minimal ecological improvement in streams lakes and harbours. The next step is to naturalise the urban catchment. Improvement to stream habitat quality in brownfield areas will take as long as is required to gradually refurbish individual lots and infrastructure as structures become obsolete. There are often limitations to the potential for enhancement in intensively urbanised brownfields located on naturally low gradient land, where streams will be slower-flowing, and more prone to sedimentation, stream warming and low dissolved oxygen levels.

Typical characteristics of conventional residential, LIUDD residential (anticipated) and forested land uses in northern New Zealand are compared in Table 1.

Table 1 Characteristics of anticipated LIUDD Residential compared with Conventional Residential Development and Forest.

	Forested	Residential LIUDD	Residential conventional
Typical location in catchments	Medium – steep slopes	lowland	lowland
Stream bed	erosional	depositional	depositional
Stream condition	Natural, vegetated, flowing	Natural, vegetated, may be flowing, medium baseflows, medium storm peak	Channelled/lined, ponding, low baseflow
Hydrological regime	Natural, stream buffered from minor rainfall events. Low – moderate storm peak flows, adequate baseflows for biota.	Natural, stream buffered from minor rainfall events. moderate storm peak flows, adequate baseflows for biota.	High storm peak flows, very low baseflows, discharge spikes evident in hydrograph from all minor events.
Catchment water retention	High	High	Low
Riparian zone	Vegetated	Vegetated	Exposed
% effective impervious surfaces	0%	< 15%	40 – 85%
Catchment shrub or tree cover	100%	> 60% desirable especially where soils are impervious	10%
Contaminant/toxin entry to streams	negligible	Low –reduced generation, increased containment & bioremediation	High
Water recycling	High, via natural water cycle	High, natural ecosystem services optimised; water, sewage/ stormwater services integrated & localised	Very low. Linear system. Water, sewage and stormwater services dispersed & not interfaced. No water reuse.

There is a need to engage urban designers, planners, engineers, architects and sociologists in a major revamp of urban design thinking away from the limitations of conventional city layout. Most greenfield urbanisation in New Zealand occurs either directly on pastoral lands or following a rural-residential transition. The following sections canvas a LIUDD vision for each of these alternatives.

4.2. LIUDD for the rural-residential to urban transition

LIUDD should be extended to include rural-residential in addition to greenfield suburban and brownfield central city sites. The reasons include:

- Many rural residential sites eventually evolve to higher densities. Good design at the 1 – 4 ha density scale may provide the foundation for later transition to higher densities without ‘strip and scrape’ earthworks ecosystem and landscape destruction.
- Higher risk of destruction and degradation of indigenous ecosystem remnants in rural areas.
- Rural-residential subdivisions have typically not resulted in an improvement in receiving water ecosystem health or water quality when compared with previous pastoral use of the catchment (author’s observations from Hingaia, Beachlands and Whenuapai). Increased density of house construction, roads and septic tanks contribute ongoing yields of sediment and nutrients to waterways.
- Lost opportunities to **restore** ecosystems when a catchment/neighbourhood is subdivided into geometric blocks the configurations of which over-ride natural land and ecosystem form and function. Hence the need for LIUDD to be incorporated at an early stage eg, at the Catchment Management Plan stage where guidelines can be developed for a large area.
- Observed high levels of under-utilised space on rural-residential properties that might be reduced if lot sizes were more suited to residents needs and owners were given more choice in property size and configuration.
- Observed high rate of ownership turnover in these properties indicating a high degree of long-term owner disillusionment with the life style.

Our perception of an alternative rural-residential approach would include:

- Development, or at least planning and design, would proceed on a subcatchment scale. This would require districts to prepare subcatchment structure plans (or Catchment Management Plans) that identify and provide for the protection of ‘Environmentally sensitive areas’.
- All wetlands, flood retention areas and riparian corridors to be protected and restored to indigenous vegetation within a balance of either communally owned land or reserve. (Subcatchment landowners are potential shareholders of those areas not included in reserve contributions.) It is acknowledged that restoration to indigenous vegetation requires a commitment to ongoing weed control especially around urban areas.
- Houses in the subcatchment could be clustered. Each landowner would have title to his house site, title to any other land allotment he wishes to buy within the subcatchment, plus shares in the ‘body-corporate’ that manages these communal areas and facilities.
- Sewage from house clusters should be collected for treatment with the option of greywater recycling.
- Rainwater collection devises or ecoroofs as standard fittings on buildings.
- Streets designed to minimise impervious surfaces and maximise use of stormwater technologies for infiltration, decontamination, bioremediation, evapotranspiration and retention.
- Council to work with landowners to find ways to maximise the planting of indigenous vegetation on private land for productive, landscape and biodiversity benefits.

- The possibility of long-term intensification within the subdivision should influence the initial design and construction of all infrastructures.
- Once this basic structure is in place there should be no cause for or expectation of any future intensification up to urban densities being accompanied by ‘strip and scrape’ recontouring of the whole catchment landscape with destruction of restored ecosystems, compaction or removal or pervious topsoils and inevitable loss of sediment to waterways despite the use of best management practices for erosion and sediment control.

This type of rural-residential development is consistent with approaches taken by the NZ Permaculture Institute (Williams pers.comm.). Institute members were recently involved in planning processes for the Manakau Subdivision in Horowhenua (Ibid). A proposed conventional subdivision concept plan from the developer divided the site into rectangular lots of a few hectares, each with a house site. The conventional plan did not indicate any riparian planting. Some small bush areas were retained. In the permaculture alternative, subdivision-layout considered catchment form, moulded uses and vegetation to topography, protected riparian margins, encouraged revegetation, reconstructed wetlands, and clustered houses thereby reducing the need for individual access roads and separate sewage treatment. Due to developer resistance, the conventional subdivision was eventually built on the site (Williams pers.comm.).

The transition from such a permaculture based rural-residential development to medium density residential would necessitate the construction of medium to high density housing complexes and service centres within allotments previously set aside for agricultural purposes. This would eliminate the need for catchment wide earthworks, limit the need for impervious surfaces in excess of 15% by area (above which adverse effects on stream ecology are likely), and allow for the retention of rural-residential amenity and previously restored biodiversity. Such a design would be accompanied by stormwater infiltration and evapotranspiration through raingardens, biofiltration trenches, swales and wetlands.

The achievement of the above ideal could be expected to bring about the desired improvement in urban receiving water ecosystem integrity, which would be monitored throughout the transition.

4.3 Greenfield Development on Pastoral Land

North Shore City Council (NSCC) has provided an excellent model for LIUDD of a pastoral catchment in its structure planning process and community consultation for the Long Bay Vaughans Stream catchment (NSCC 2003). Landuse configuration within the structure plan indicates minimal stormwater generation in catchment headwaters, and restoration of riparian and aquatic ecosystems. NSCC has indicated to the community that implementation of the plan would likely include requirements for rain water tanks and effective impervious surfaces not exceeding 15% of any residential site. Post-construction monitoring of stream biota, hydrology and water quality would confirm or refute the success of this project.

The challenge in catchments such as Long Bay is to both avoid the current scale of urban earthworks and to revegetate private as well as public properties. LIUDD approaches are not only important for freshwater receiving environments around Auckland. The short receiving water streams lead to the many and varied Auckland coastal habitats. Minimising the impacts of urban development in Long Bay is particularly important given that the eventual receiving water is the Long Bay Marine Reserve; one of the most popular recreational areas in the Auckland Region.

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