Urban form and WSUD in Auckland residential catchments determine stream ecosystem condition

Comment les formes urbaines et l'utilisation de solutions durables de gestion des eaux pluviales sur un bassin versant résidentiel conditionnent les qualités écologiques d'un cours d'eau

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RÉSUMÉ

Les caractéristiques des bassins versants qui, si elles sont présentes, améliorent la santé de l'écosystème du cours d'eau suite à un développement urbain, comprennent la végétation riveraine, le traitement des eaux pluviales via des jardins pluviaux, les bassins élevés au-dessus du corridor riverain et l'irrigation forestière au goutte à goutte avec la surverse du bassin ou du jardin pluvial. La conception urbaine sensible à l'eau présente beaucoup de points communs avec la pratique néo-zélandaise de la conception et du développement urbain à faible impact (LIUDD). En Nouvelle-Zélande, le fait de protéger et de recréer des écosystèmes aussi bien terrestres qu'aquatiques sont des éléments essentiels du concept de LIUDD. Cet article présente les études comparatives réalisées sur 8 ans en Nouvelle-Zélande concernant les bassins versants dans des conditions classiques ou durables de gestion des eaux et pour des densités résidentielles faibles en zone rurale et moyennes en zone urbaine. Les caractéristiques des bassins versants sont liées aux communautés de macroinvertébrés dans les cours d'eau, qui sont un indicateur de l'état du cours d'eau et du bassin versant. Les résultats des indicateurs présents dans le cours d'eau sont comparés aux valeurs à l'échelle régionale et montrent la supériorité écologique des bassins versants durables et à faible impact. Les indicateurs de la santé écologique des cours d'eau dans les bassins de traitement se sont améliorés pour deux cours d'eau en milieu urbain et trois cours d'eaux situés en zone résidentielle rurale au cours de la période de subdivision et de construction d'habitations, contrairement aux attentes normales pour un développement urbain classique.

ABSTRACT

Catchment characteristics that if present concurrently support improvement in stream ecosystem health following urban development include riparian vegetation, stormwater treatment via raingardens, ponds elevated above the riparian corridor and forest trickle irrigation of pond or raingarden overflows. Water Sensitive Urban Design has much in common with the New Zealand (NZ) practice, Low Impact Urban Design and Development (LIUDD). In New Zealand, both terrestrial and aquatic ecosystem protection and re-creation are essential elements of LIUDD. This paper reports on comparative NZ catchment studies over 8 years for conventional and LIUDD subdivision at low/countryside and average/urban residential densities. Catchment characteristics are related to the health of in-stream macro-invertebrate communities as indicators of stream and catchment condition. Results for in-stream indicators are compared to region-wide values and show the ecological superiority of WSUD/LIUDD catchments. Indicators of stream ecological health in treatment catchments have improved for two urban streams and up to three countryside residential streams during the subdivision and house construction period contrary to normal expectations for conventional urban development.

KEYWORDS

Catchment, macroinvertebrate, stream ecological health, urban form, WSUD

1. INTRODUCTION

Ecology embraces a continuum of ideas, concepts and approaches from organism biology to geology, hydrology and meteorology. The focus of ecologists upon other such disciplines results from a need to understand the drivers of change in ecological systems. The adverse ecological effects of conventional urbanisation have their origins in processes explained by these disciplines.

The United Nations, the World Water Forum, and the European Union have supported the use of the Ecosystem Approach (EA) merged with Integrated Catchment Management (ICM). The merging is significant as the EA has evolved from terrestrial ecological methods and ICM has been a water management technique. The promotion of the EA in the Convention on Biological Diversity (United Nations, 1992) was followed by a flurry of research, guidelines, and publications (including Haines-Young and Potschin, 2008; UNEP, 2008a; Luckman, 2006; Pound, 2003) on case studies demonstrating how to implement it. A guide from the UNEP (2008b) recommends inclusion of principles of the EA in national and regional policies, planning processes and sectoral plans. Likewise, since the second World Water Forum in 2000, water professionals have been working to develop land/water integration in a catchment-based EA (Falkenmark and Tropp, 2005; Mitchell, 2005). The blending of ecosystem protection and resource management is slowly occurring as the global water community also seeks to add the land influence to the practice of Integrated Water Resource Management (Falkenmark and Tropp, 2005; Mitchell, 2005) and ICM.

The primary objectives of the European Union’s Water Framework Directive (WFD) include integrated management for all water types, river basins (catchments) as management units, citizen involvement and streamlining legislation. The Directive allows only a slight departure from the biological community, which would be expected in conditions of minimal anthropogenic impact. This is a primary objective of Low Impact Urban Design and Development (LIUDD) as applied in this paper. The WFD requires that within a river basin or catchment all existing technology-driven source-based controls must be implemented to minimise contaminant transfer to water (EU, 2004). Surface waters must be classified according to ecological objectives, and the development of river basin (catchment) management plans is required. States must ensure that deterioration of water quality and ecological status does not take place, and they must develop a framework for protection of water, which conserves aquatic ecosystems (Cleverly, 2004). European countries have diverse responses. By way of example, the Netherlands Fourth National Policy Document on Water Management promoted an urban design focus on the water cycle, riparian ecological corridors, and stormwater infiltration and reuse, which was followed by a National Water Plan (NHR, 2009). The latter, a vision based on the Spatial Planning Act, guides sustainable climate-resistant water management, integrated with spatial planning. The National Water Plan, prepared by central government with the help of the Delta Committee (*Deltacommissie),* asks provinces and municipalities to involve water managers early on, in the drafting of vision statements. Water, nature, landscape, urban liveability and the mobility of people are required to be addressed cohesively, with the aim of increasing green spaces and reserving space for water in city developments (NHR, 2009). Biodiversity policy in The Netherlands addresses this advice of the *Deltacommissie* to combine nature and water management for climate adaptation (MANFQ[1], 2010). To further increase resilience with respect to the effects of climate change, The Netherlands National Environmental Assessment Agency (NNEAA, 2008) has called for the establishment of nationwide corridors of wetland nature reserves to provide for water storage during extreme weather events. The interface of spatial planning, water and biodiversity management is thereby rapidly strengthening.

In New Zealand integrated water cycle management, including the conservation of wetlands outside reservations, is carried out under the Resource Management Act 1991. Regional and local councils have responsibilities with respect to the management of waterway and wetland systems as well as planning responsibilities. The Act specifies that preservation of the natural character of wetlands, lakes, rivers, and their margins is of national importance, and must be taken into account in the making of development decisions.

The protection of ecosystem services and downstream water quality, the buffering of climate change impacts on catchments, the halting of biodiversity loss, and the provision of nature-based recreation opportunities, necessitate the protection and re-creation of aquatic and terrestrial ecosystems within

[1] The Ministry of Agriculture, Nature and Food Quality (MANFQ) has subsequently been restructured with nature management functions relocated within The Ministry of Infrastructure and the Environment.

'water sensitive' or 'low impact' urban developments. The quality and long-term viability of re-created ecosystems of stream and riparian environments in particular, need to be ensured if the objectives above are to be achieved. In-stream habitat conditions are largely determined by human activities in the stream catchment and, in particular, by land use type and intensity, urban form, effective impervious surfaces, riparian corridor condition, sewerage systems, and stormwater drainage characteristics. All of these catchment characteristics are influenced by LIUDD, the principles and methods of which have been outlined, justified, and tested for international applicability (van Roon, 2007, 2010, 2011a; van Roon and Dixon, 2006; van Roon and van Roon, 2009). Furthermore, paired catchment studies have been undertaken (van Roon, 2010) to examine the ecological efficacy and sustainability of the partial implementation of LIUDD in residential and countryside living areas in Flat Bush (van Roon 2011b), Manukau, New Zealand. The sustainability and maintenance requirements of re-vegetation areas within some of these catchments have been reported (van Roon and Rigold, 2012).

This paper provides a comparison between alternative and conventional subdivision over time from 2004 to 2014. The paper extends the research and provides time series results for the aquatic ecosystem response to urban form, subdivision, water sensitive stormwater management, and valley vegetation retention or re-establishment. As development is now nearing completion in most of the catchments and forests replanted in 2004 are maturing, the positive outcomes for stream ecosystems are beginning to show.

2. METHODS

Sub-catchment selection: Four urban sub-catchments were selected, three of which exhibit varying degrees of LIUDD compliance (Jeffs sub-catchments), including existing mature riparian forest, and the fourth (Point View, Figure 1), which is in a conventional development form.

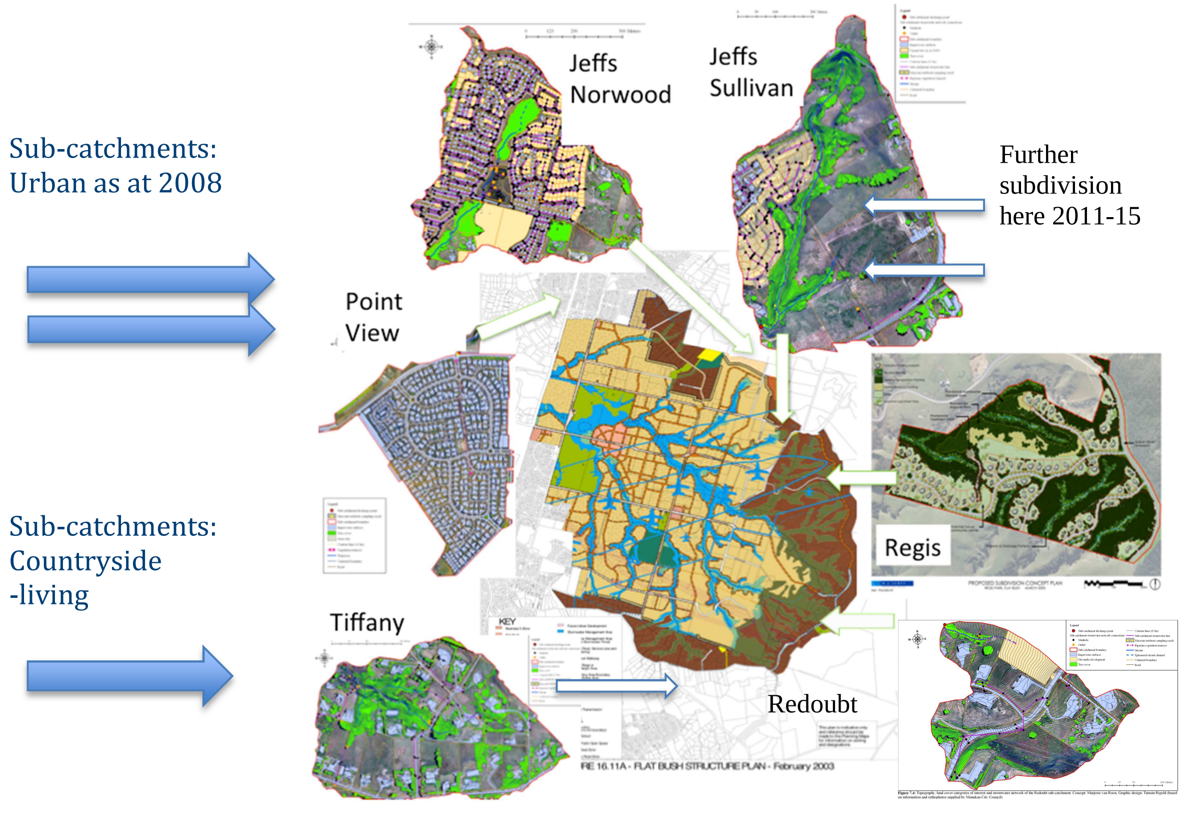

Figure 1: Location and character of sub-catchments. Sources: The Flat Bush Structure Plan (centre of Figure) Manukau City Council; Regis concept plan - DJScott Associates. Remaining sub-catchment images were prepared by the authors.

Six countryside sub-catchments were selected, four of which exhibit LIUDD (Regis), a fifth which is conventional but partially re-vegetated (Tiffany) and the sixth (Redoubt) is in a conventional development form. All sub-catchments occur in close proximity and those within each land-use density have similar soil, slope and meteorological characteristics. In-stream ecological condition: samples were collected and analysed using standard methods for both the New Zealand Macroinvertebrate Community Index (MCI) (MfE, 1999) and the modified 'soft-bottom' Index (MCIsb) (ARC, 2004). The Jeffs Norwood sub-catchment was sampled above and below a stormwater pond. Sampling, which was concurrent for conventional and LIUDD sub-catchments, was undertaken using Protocol C2 (Stark *et al.,* 2001). Macroinvertebrates were identified, counted, and taxonomic richness and community composition assessed. Species composition was observed, and the occurrence and dominance of species, particularly indicators such as Ephemeroptera, Plecoptera and Tricoptera (EPT), were noted. An additional biotic index calculated was the quantitative MCIsb (QMCIsb).

3. RESULTS AND DISCUSSION

The location and character of sub-catchments both urban and countryside are shown in Figure 1. The land-use of most sub-catchments in 2013-14 closely resembled that represented in Figure 1. The Jeffs Sullivans sub-catchment has undergone further subdivision in 2011-15 in the locations indicated. Sub-catchment characteristics of relevance to receiving-water sensitivity and health are summarised in Table 1. This table indicates the degree of residential lot clustering to enable increased common open space for re-vegetation; the occurrence of piped or diverted streams, stormwater ponds, artificial wetlands, raingardens and forest infiltration of stormwater; the degree of imperviousness; the state and width of riparian vegetation and the proportion of each sub-catchment in trees. The relative intensity of shading has been used by the author in Table 1 to show the degree of LIUDD implementation (van Roon and van Roon, 2009, Appendix 1) within sub-catchments. This implementation includes attention to urban form and re-vegetation not just at-source stormwater control.

Table 1: A summary of some of the LIUDD/WSUD relevant characteristics of the sub-catchments compared within urban and countryside residential development clusters respectively. Sites should be compared for urban (green) and countryside (red) separately. The intensity of colour is indicative of the authors opinions of the degree of LIUDD implementation within that sub-catchment. The degree of implementation relates to criteria set by van Roon and van Roon, 2009 Appendix 1.

Lot density	Urban average lot 400 – 500m^2				Countryside average lot 5000m^2		
Name, year subdivided, Clustering of houses	Jeff Sullivan 2003 - ongoing, cluster	Jeff Norwood upper 03 cluster	Jeff Norwood Lower 2003-7 cluster	Point View 1980s no cluster	Regis 2004, Houses clustered	Tiffany 1985, no cluster	Redoubt 1990, no cluster
Area ha	34	14	89	39	17	25	6.5
Stormwater treatment	Pond upslope of riparian to stream	Diverted	river diverted pond in valley wetland then to stream	No treat, stream piped	raingarden then to forest infiltration	No treat; overland to stream	No treat; overland to stream
Long-term impervious	40%	40%	40%	60%	17%	15%	17%
Riparian vegetation-metres wide	Mature forest - 70	Mature forest - 89	Mature forest - 79	Nil	Re-afforested 2005 - 100	Patchy forest - 74	shrub 7
catchment % in trees 2012	22	20	11	3	60	29	11

The maturity, density, degree indigenous, and proximity of trees to each stream may be important also in influencing stream ecosystem response to riparian vegetation within residential sub-catchments. Data for urban sub-catchments only (adapted from van Roon 2010), for two tree size classes (Table 2) demonstrates the difference between LIUDD and conventional sub-catchments. Equivalent data for the countryside sub-catchments is unavailable as the re-vegetation there was too young at the time of surveying.

Of the macroinvertebrate indices determined during this investigation, that which most clearly demonstrates the stream ecosystem response is the Quantitative Macroinvertebrate Index for soft-bottomed streams (QMCIsb). QMCIsb plotted against the year of sampling for each of the four urban sub-catchments is presented in Figure 2.

Table 2: A summary of data on riparian trees in two size classes larger than 2.5 centimetres diameter at breast height for urban sub-catchments (adapted from van Roon, 2010).

		Jeffs Sullivans	Jeffs Norwood Upper & Lower	Point View
Trees > 10 cm diameter	Number of Species	13	9	7
	Percent Native Species	100.00	100.00	28.57
	Mean Distance to trees (m)	4.17	2.59	11.74
	Absolute Density (stems/ha)	543.70	1510.48	11.22
	Mean Basal Area (cm^2)	681.9	537.5	121.8
	Basal Area/ha (m^2/ha)	37.1	81.2	0.1
	Highest Basal Area - single tree (cm^2)	4301.4	4128.8	238.2
Trees 2.5 - 10 cm diameter	Number of Species	13	9	7
	Percent Native Species	92.31	100.00	14.29
	Percent Native Individuals	97.37	100.00	21.05
	Mean Distance to trees (m)	6.33	6.66	11.16
	Absolute Density (stems/ha)	224.61	123.24	24.09

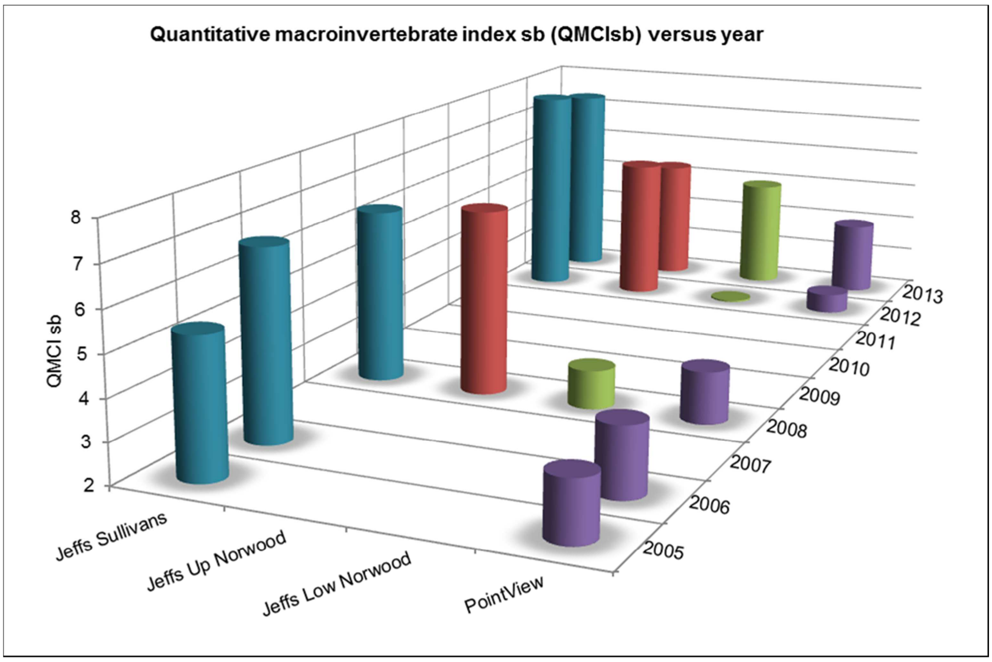

Figure 2: Urban stream ecological health as indicated by Quantitative Macroinvertebrate Index for soft-bottomed streams as determined at intervals between 2005 and 2013.

The Jeffs Norwood upper and lower sub-catchments were not sampled on the first two occasions. Point View, the control and the Jeffs Sullivans LIUDD sub-catchment were sampled on all five occasions. Figure 2 illustrates the differences in QMCIsb for these sites and this coincides with differences in urban form and stormwater treatment. The figure also shows for the Jeffs Norwood sub-catchment the decline in QMCIsb that occurs downstream of the stormwater pond overflow and artificial wetland even though both upstream and downstream sampling sites were located within stretches of stream bordered by wide mature native forest. QMCIsb downstream of the pond and wetland approximates that of the Point View fully piped stream with no stormwater treatment suggesting that the presence of this form of stormwater treatment and stream diversion has degraded stream ecology as much as if the streams had been piped. Water temperature increase in the pond might account for the ecological effects (Young et al. 2013). However, stream temperatures taken at the sampling sites during the surveys up to 2009 (van Roon, 2010 p318) indicated an insignificant difference in temperatures upstream versus downstream of the pond.

Scatter diagrams of two stream health indices, MCI and Taxa Number, for Auckland urban and Flat Bush Jeffs urban catchments are shown in Figure 3. These illustrate the superior stream ecological health within Flat Bush catchments with an alternative urban form, in contrast to 35 urban streams throughout Auckland that are in a similar condition to the Point View piped waterway of Flat Bush. The availability of data for the whole Auckland region determined which index was chosen for this comparison. Results for QMCIsb for Countryside Living sub-catchments are presented in Figure 4.

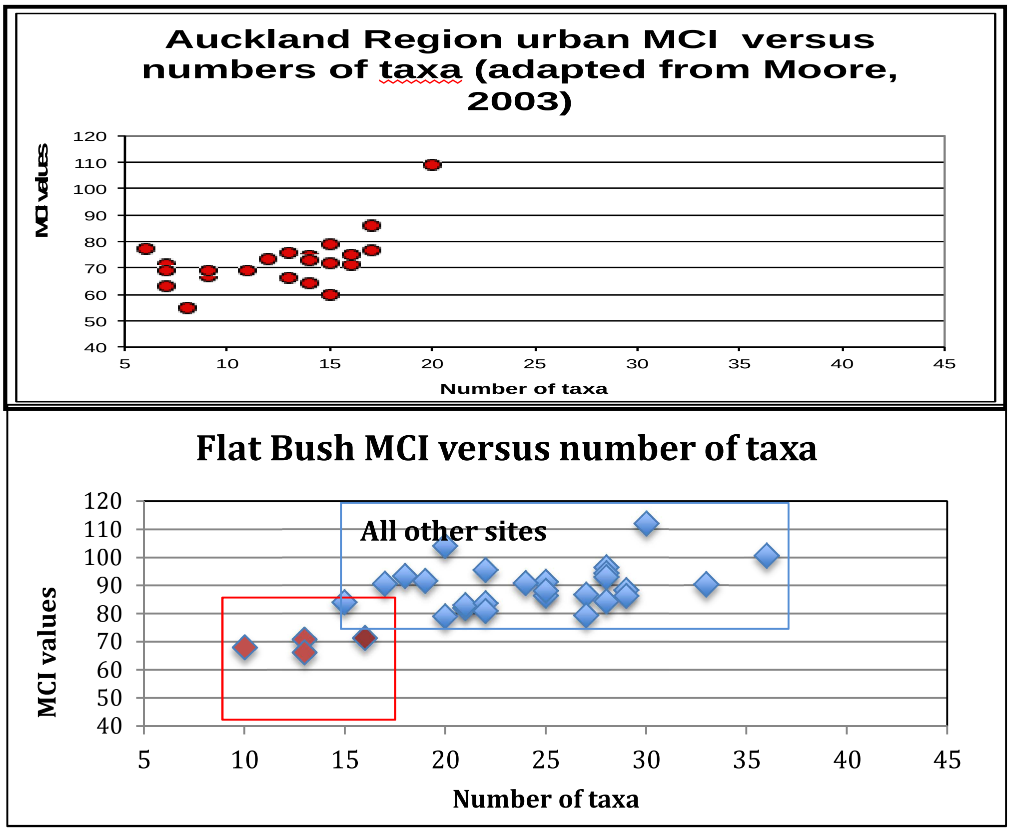

Figure 3: Spatial distribution of Macroinvertebrate Community Indices versus Number of Taxa. The upper plot presents data for 35 urban catchments across Auckland (adapted from Moore, 2003). The lower plot presents the same indices at the same scales using data for Flat Bush urban sites only. Point View is the conventional urban development control.

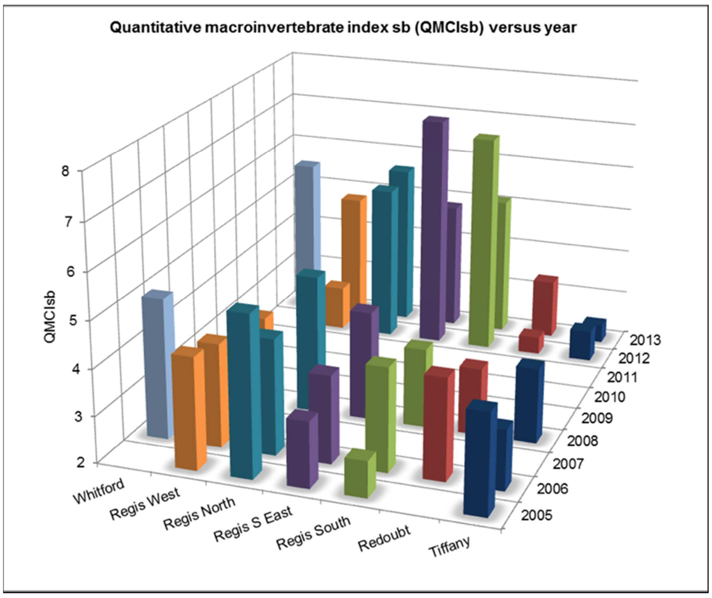

Figure 4: Stream health response over time during subdivision, house and infrastructure construction, and re-vegetation in Countryside Living sub-catchments. Stream health response is indicated by changes in Quantitative Macroinvertebrate Indices for soft bottomed streams.

At Regis, subdivision earthwork that excluded stream valleys was carried out in 2004, followed by street landscaping and lot grassing. Existing irregularly spaced exotic trees in valleys were not disturbed. Seedlings of native trees and wetland species were planted throughout all valleys in 2005 and show steady growth up to 2013. Also throughout this eight-year period houses were constructed each with a raingarden that overflows to the replanted valleys. As shown in Figure 4, this coincides with the improvement in stream ecology indicated by QMCIsb in all Regis sub-catchments except Regis West, which receives effluent from the neighbourhood sewage treatment plant. The control catchments of Redoubt and Tiffany with steady-state land use and vegetation and no stormwater treatment do not show improvement in stream ecology as indicated by biotic indices, including QMCIsb, during this period. The Whitford sub-catchment is a neighbouring pastoral site with valley re-vegetation.

4. CONCLUSIONS

This New Zealand case study demonstrates that aquatic and terrestrial biodiversity retention is possible during low to medium density residential development where separated drainage systems are employed for stormwater and sewage. The exclusion of stormwater from combined sewers in Europe is increasingly necessary as populations increase and sewer capacities are limited. Treatment of stormwater at-source will protect natural receiving waters from degradation. In the reported case study, the urban catchments that simultaneously have the largest, most mature native trees close to streams, the least stormwater input and no stream diversion are the catchments that have the highest occurrence of sensitive stream insects and the highest biotic index scores. High quality in-stream values were lost following either stream piping or from stream diversion accompanied by direct stormwater (wetland) pond overflow even when mature forest was present. Indicators of stream ecological health have improved or at least not decreased for two urban streams (Jeffs Sullivans and Jeffs Upper Norwood) and up to three countryside-living streams (Regis North, Regis East and Regis South) during the subdivision and house construction period contrary to normal expectations for urban development. Stream ecosystem health is influenced by diverse catchment characteristics. Those supportive of stream health if present concurrently include a riparian vegetation corridor enabled by house clustering, stormwater diversion or treatment at source via raingardens, ponds elevated above the riparian corridor and forest trickle irrigation of pond or raingarden overflows. Many of the streams with the highest ecological values in this survey are ephemeral and these are the streams that have in the past been disregarded by resource managers as being of little ecological value and therefore permitted to be destroyed or piped.

5. **LIST OF REFERENCES**

ARC (2004) *Macroinvertebrate Community Indices for Auckland's Soft-bottomed Streams,* Technical Publication 303, Auckland Regional Council (ARC), now Auckland Council. http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalpublications301-350.aspx. (20/10/15).

EU (2004) *European Union Water Framework Directive*. European Union (EU). http://europa.eu.int/comm/environment/water/water-framework/overview.html. (20/10/15).

Cleverly, G. (2004) CIWEM and the Water Framework Directive, in Earl, R. (Ed.), (2003) *The Water Framework Directive: The Ecological Implications – Costs and Environmental Benefits*, Delegate Notes, Chartered Institute of Water and Environmental Management (CIWEM) Conference 12 November, 2003. http://www.coastms.co.uk. (11/11/15).

Falkenmark, M. and Tropp. H. (2005) *Ecosystem approach and Governance: Contrasting Interpretations*, Report of the Stockholm International Water Institute. http://www.siwi.org.

Haines-Young, R. and Potschin, M. (2008) *England's Terrestrial Ecosystem Services and the Rationale for an Ecosystem Approach*, Technical Report to the Department of Food, the Environment, and Rural Affairs, United Kingdom, Project Code NR0107.

Luckman, P. (2006) KiwiGrowTM – a Universal Ecosystem-based Framework for Sustainable Development. *A paper presented at the 12th Annual International Sustainable Development Research Conference*, Hong Kong, 6- 8 April.

MANFQ. (2010). *Convention on Biological Diversity: Fourth National Report of The Netherlands.* Ministry of Agriculture, Nature and Food Quality (MANFQ), Department of Nature, Landscape and Rural Affairs, The Hague.

MfE (1999) *The Use of Macroinvertebrates in Water Management, Macroinvertebrate* Working Party, Ministry for the Environment (MfE), Wellington, New Zealand.

Mitchell, B. (2005) Integrated Water Resource Management, Institutional Arrangements, and Land-use Planning, *Environment and Planning,* 37: 1335–1352.

Moore, S. (2003) *The Nature of Auckland Lowland Stream Invertebrates, and Assessing the Effects of Urban Development,* Proceedings of The Third South Pacific Conference on Stormwater and Aquatic Resource Protection, Auckland, New Zealand, 14-16 May.

NHR. (2009). *National Water Plan.* Netherlands House of Representatives (NHR).

NNEAA. (2008) Wetland habitat. Netherlands National Environmental Assessment Agency http://www.pbl.nl/en/publications/2008/NB08-wetland-habitat (11/11/15).

Pound, D. (2003) *Systems Thinking*, Joint Nature Conservancy Council 2003 Annual Report, United Kingdom: Joint Nature Conservancy Council, 15–18.

Stark, J.D., Boothroyd, I.K.G., Harding, J.S., Maxted, J.R. and Scarsbrook, M.R. (2001) *Protocols for Sampling Macroinvertebrates in Wadeable Streams*, Prepared for the New Zealand Ministry for the Environment, Sustainable Management Fund Contract no. 5103, Wellington.

United Nations (1992) *The Convention on Biological Diversity*, United Nations (UN): New York. http://www.cbd.int/convention/. (11/11/15).

UNEP (2008a) *The Ecosystems Approach to Urban Environmental Management: Operationalising the Cities as Sustainable Ecosystems (CASE) Initiative*, United Nations Environment Programme (UNEP) New York.http://www.unep.org/. (11/11/15).

UNEP (2008b) *Beginners' Guide to Using the Ecosystem Approach*, United Nations Environment Programme (UNEP): New York. http://www.cbd.int/ecosystem/sourcebook/beginner-guide.shtml. (11/11/15).

van Roon, M. and Dixon, J. (2006) *A Policy Framework for Sustainable Urban Design and Drainage.* Accelerating Excellence in the Built Environment Conference. 2-4 October, Birmingham.

van Roon, M.R. (2007) *Testing and refining a policy and methods framework for Water Sensitive Urban Design.* Proceedings 'Rainwater and Urban Design 2007' Conference, 21-23 August, Sydney.

van Roon, M. R. (2010) Low Impact Urban Design and Development: ecological efficacy as a basis for strategic planning and its implementation. PhD thesis (Planning), University of Auckland.

van Roon, M. R. (2011a) Water sensitive residential development: Application of LIUDD principles and methods in the Netherlands, Australia and New Zealand. *Urban Water Journal 8 (6): 325-335.* DOI: 10.1080/1573062X.2011.614695.

van Roon, M. R. (2011b) Low Impact Urban Design and Development: Catchment-based structure planning to optimise ecological outcomes. *Urban Water Journal*, 8 (5): 293-308. DOI: 10.1080/1573062X.2011.598172.

van Roon, M. R. and van Roon, H.T. (2009) *Low Impact Urban Design and Development the big picture: an introduction to LIUDD principles and methods framework.* Landcare Research Science Series No. 37, Manaaki Whenua Press, Lincoln, New Zealand, 63 p. http://www.mwpress.co.nz/store/listCategoriesAndProducts.asp?idCategory=34 (4/11/15)

van Roon, M.R. and Rigold, T.P.M. (2012) Ecosystem condition and sustainability in Water Sensitive developments in peri-urban Auckland. 7th Water Sensitive Urban Design Conference, Feb. 2012, Melbourne.

Young D, Afoa E, Meijer K, Wagenhoff A, Utech C (2013). Temperature as a contaminant in streams in the Auckland region, stormwater issues and management options. Prepared by Morphum Environmental Ltd for Auckland Council. Auckland Council technical report, TR2013/044

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