Urbanization impacts on stream ecology - from syndrome to cure?

Outcomes of workshops held at the Symposium on Urbanization and Stream Ecology
Melbourne University, Melbourne, Australia
8th - 10th December 2003

Edited by:

Peter Cottingham	**CRC Freshwater Ecology**
Chris Walsh	**CRC Freshwater Ecology**
Graham Rooney	**Melbourne Water**
Tim Fletcher	**CRC Catchment Hydrology**

COOPERATIVE RESEARCH CENTRE FOR FRESHWATER ECOLOGY

Melbourne Water

COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY

Summary

The world's population is anticipated to increase from 6.1 billion to 8.1 billion over the next 25 years, with urban expansion expected to accommodate nearly all of this population increase. By 2030, inhabitants of urban areas are expected to account for approximately 60% of the world population. This pattern of population increase is expected in Australia, as it is in other parts of the world.

The benefits we derive from our cities have come at considerable environmental cost. Rivers and streams around the world have been profoundly changed by human activity and urbanization, despite our increasing awareness of the link between stream health and human health. However, streams in urban areas have received relatively little scientific attention when compared with systems in natural (minimally disturbed) or rural areas.

It was within this context that the Symposium on Urbanization and Stream Ecology was convened:
- to bring together and synthesize current knowledge of the effects of urban land use on stream ecosystems,
- to examine priorities and potential for stream rehabilitation in urban catchments, and
- to identify knowledge gaps to direct future ecological research in urban catchments.

Over 100 scientists and management agency staff from 10 countries attended the symposium, including representatives from both developed and developing countries. Workshop sessions were convened at the symposium in order to share experiences related to:
- assessing urban impacts, and
- rehabilitation priorities for streams in urban areas.

The term 'urban syndrome' was adopted at the symposium workshops as a way of communicating the changes that may be expected with increasing urbanization of catchments. Urbanization results in four broad interrelated forms of disturbance or degradation that can affect stream ecology, for example by altering hydrology, geomorphology or ecological processes such as energy transfer, nutrient cycling and the breeding or recruitment of flora and fauna:
1. disturbance of hydrological and hydraulic patterns,
2. disturbance to stream geomorphology,
3. degradation of water quality, and
4. habitat degradation or simplification.

While streams may suffer from the urban syndrome to varying degrees (e.g. due to different geographic, geomorphic and ecological patterns and responses, and socio-economic circumstance), they will commonly maintain ecological or societal values worthy of protection or rehabilitation. Being able to identify the stream responses expected with the urban syndrome means that future scientific investigation of urbanization can shift from cataloguing impacts to improving the conceptual basis and the predictive capacity that guides stream rehabilitation.

The form of rehabilitation adopted in urban areas will be governed by the values assigned to streams by stakeholders. Often rehabilitation is conducted within the paradigm that urbanization is a negative influence on stream condition. However, features associated with the urban

syndrome do not always have negative connotations. For example, general public may place high value on factors such as good access, amenity, and an aesthetically pleasing landscape, even though such features may be of little benefit, or may impair native species and ecological function. Clear specification of values to be enhanced or protected is important as rehabilitation objectives are formulated.

Improving our ability to predict ecological responses to rehabilitation measures will help to ensure we set realistic rehabilitation objectives. Those at the symposium identified a number of important factors that should be investigated to improve predictive capacity, including the spatial and temporal scales of stressors and ecological response, links between habitat availability and ecosystem function, and links between habitat availability and biodiversity.

We now have the conceptual and planning frameworks required to promote improved management of urban waterways. The total water cycle, which integrates rainfall-runoff patterns with the development and management of water resources, stormwater drainage and wastewater treatment, should be a key feature of urban waterway management. An essential part of this process is the identification of objectives to protect or enhance social, economic and environmental values and the measures required to achieve them. This helps to define the spatial and temporal scales at which stressors of waterway condition apply, and ensures that stormwater and waterway management responses are appropriate. For example, meeting national and international obligations (e.g. national or regional water quality programs, international agreements on migratory bird habitat) may require planning at a regional, catchment or sub-catchment scale. Protecting local waterways may require planning or actions (e.g. adoption of water-sensitive urban design that increases infiltration or the installation of stormwater treatment pond and wetlands to reduce pollutant loads) at sub-catchment, local neighbourhood or even house-lot scales.

Those attempting stream rehabilitation are likely to encounter many constraints and challenges. These can vary depending on location and socio-economic conditions, so we cannot expect to apply a uniform approach to rehabilitation. Those at the symposium identified a number of challenges they had experienced, including difficulties in gaining a consensus on rehabilitation objectives and dealing with factors (such as continued development) that can confound or reverse the gains expected from localised rehabilitation efforts. How best to translate scientific insights to a form that is useful for decision-makers was recognised as a difficult but important task if planners are to properly assess the economics of rehabilitation and include features such as water-sensitive urban design in new urban developments. Scientists and managers should look to pursue collaborative research projects that generate ecological information in a form that is useful to decision makers, designers, regulators and landowners. This requires a common understanding of such things as policy settings and how ecological information is used in the decision-making process.

Communities everywhere are spending resources on trying to redress problems associated with previous human development and activity. In most instances it will be much cheaper and easier to protect streams in good condition than it will be to rehabilitate them once they are degraded. However, this will require a shift from responding to crises to implementing better urban design that anticipates and avoids or addresses the urban syndrome problem. Being able to better quantify the value of ecosystem services would be useful in this endeavour, as would be the capacity to predict what would happen if nothing were done.

Those at the symposium identified some key gaps in our understanding of urbanization impacts on streams and additional tools that may be useful for managers. It is to be hoped that these gaps will be the focus of urban waterway research and knowledge exchange in the future:

- Quantification of ecosystem goods and services provided by urban streams remains largely unaddressed.
- The relative efficiency for reducing the export of pollutants from catchments is unclear for:
  - Enhancing aquatic processes through improvement of in-stream and riparian habitat
  - Enhancing riparian and terrestrial processes through replacement of traditional drainage infrastructure with at-source filtration and infiltration systems.
- It is not clear if stream rehabilitation can be achieved by manipulation of stormwater drainage systems alone, rather than a focus on in-stream rehabilitation.
- Historical analyses of the relationships between stream condition, urban growth and socio-economic cycles are lacking.
- Development decisions are made on a small scale and in small increments – cumulative effects go unnoticed. How can the cumulative effects be quantified and incorporated into decision-making?
- Differences in urban impacts on streams across different climatic zones remain largely unaddressed, particularly in tropical areas.
- Many of the insights on urbanization impacts on stream ecology presented at the workshop were based on experience in developed countries. The special challenges faced by developing countries have not been adequately explored.
- Predictive models of stream ecosystem response to urban land management and alternative drainage management scenarios (e.g. varying approaches to and levels of Water Sensitive Urban Design) are required. These need to be incorporated into decision support systems for use by catchment managers.
- How can existing knowledge be best exchanged with the urban communities?
  - Decision makers require “tools kits” (such as decision support systems and predictive models) that define ecosystem services, biological indicators, and management interventions and their relative values.
  - Scientists and managers should pursue collaborative approaches to research that generate ecological information in a form that is easily applied by decision makers, designers, regulators and landowners.

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Acknowledgements

The editors would like to thank the workshop facilitators (Judy Meyer, Nancy Grimm, Derek Booth and Cathy Tate) and Ruth O'Connor (University of Canberra) for useful comments on this report.

The Symposium on Urbanization and Stream Ecology was successful due to the contributions of those who attended and participated in many useful discussions, and the support provided by the Cooperative Research Centre for Freshwater Ecology, Melbourne Water Corporation and the Cooperative Research Centre for Catchment Hydrology.

1 BACKGROUND

There has been an unprecedented growth in urban populations over the past two centuries and this trend is set to continue (UNPD 1999). The world's population is anticipated to increase from 6.1 billion to 8.1 billion between the years 2000 and 2030, with urban expansion expected to accommodate nearly all of this population increase. Inhabitants of urban areas are expected to increase from 2.9 billion to 4.9 billion, approximately 60% of the anticipated world population.

This global trend is also reflected in Australia. Approximately 70% of Australia's population growth in the five years to 2000 occurred in capital cities, particularly on the outskirts of metropolitan areas. Close to 64% of Australia's population currently live in capital city metropolitan areas, and approximately 80% of Australia's population live in urban centres exceeding 50,000 people. This high level of urbanization is expected to continue in the future (Hugo 2001, ABS 2000).

We now recognise that the benefits we derive from our cities have come at considerable environmental cost. Urbanization and associated human activity has profoundly affected rivers and streams around the world and the importance of the links between stream health and human health is increasingly being recognized, both internationally and nationally (e.g. Bunn 2002). However, streams in urban areas have received relatively little scientific attention when compared with systems in natural (minimally disturbed) or rural areas. It was within this context that the Symposium on Urbanization and Stream Ecology was convened to:

- Bring together and synthesize current knowledge of the effects of urban land-use on stream ecosystems,
- Examine priorities and potential for stream restoration in urban catchments, and
- Identify knowledge gaps to direct future ecological research in urban catchments.

The symposium was attended by 100 scientists and management agency staff from 15 countries, including representatives from both developed and developing countries.

This report summarizes the key issues discussed at two workshop sessions that were held at the symposium:

1. Assessing urban impacts – facilitated by Nancy Grimm (Arizona State University) and Judy Meyer (University of Georgia), and
2. Restoration priorities for streams in urban areas – facilitated by Derek Booth (University of Washington) and Cathy Tate (US Geological Survey).

It is anticipated that a number of keynote and invited presentations from the symposium will be published in a special edition of the Journal of the North American Benthological Society in 2005.

2 INTERNATIONAL COMPARISONS OF URBANIZATION IMPACTS ON STREAM CONDITION – COMMONALITIES AND DIFFERENCES

The following discussion is based on the experience of those who attended the symposium, who were predominantly researchers and managers from North America and Australasia (i.e. developed countries) working in temperate and arid climates. There were few present to expand on the special challenges of addressing urban impacts on streams in developing countries or in tropical climates (see Chapter 4.2 – gaps in knowledge).

2.1 Commonalities – streams and the 'urban syndrome'

A number of systematic and predictable environmental and ecological responses have been noted in streams affected by urbanization (e.g. Nilsson et al. 2003, Palmer et al. 2002, USEPA 2002, USGS 2001, and others). Urbanization results in four broad inter-related forms of disturbance or degradation that can affect stream ecology by altering hydrology, geomorphology or ecological processes such as energy transfer, nutrient cycling and the breeding or recruitment of flora and fauna:

1. Disturbance of hydrological and hydraulic patterns,
2. Disturbance to stream geomorphology,
3. Degradation of water quality, and
4. Habitat degradation or simplification.

The term 'urban syndrome was adopted at the symposium workshops as a way of communicating the changes that may be expected with increasing urbanization of catchments (Table 1). The term urban syndrome also implies there are specific symptoms (condition indicators) and treatments (management or rehabilitation actions), and a cure (achievement of management or rehabilitation targets) that may apply to streams in urban areas.

Being able to identify the stream responses expected with the urban syndrome means that future scientific investigation of urbanization can shift from cataloguing impacts to improving the predictive capacity that guides stream rehabilitation. Features of the urban syndrome can provide useful reference points. For example, stream rehabilitation targets may aim to change stream condition from that typical of the urban syndrome to some desired future state. The issue of stream rehabilitation in urban areas is discussed further in Chapter 3.

While streams may suffer from the urban syndrome to varying degrees, they will commonly maintain ecological or societal values worthy of protection or rehabilitation. For example, streams in urban areas and their associated floodplain and riparian zones may be local biodiversity hotspots or provide longitudinal or lateral connection between otherwise isolated flora and fauna populations and their habitat (e.g. wildlife corridors). While often less than optimal, ecological processes such as stream metabolism and the cycling of nutrients can still contribute to ecosystem services such as water-quality improvement. Urban communities often value local waterways for their public amenity, recreation and cultural values. Indeed, the public may place greater value on protecting or enhancing these societal values than on improving the ecological condition of streams.

Table 1: Typical symptoms expected with the urban syndrome in streams

Stream feature affected	Response
Hydrology	• Increased stormwater runoff (total volume) (Leopold 1968, Wong et al. 2000) • Decreased low flow volume (e.g. intermittent flow in previously permanent streams) in temperate and tropical areas <u>or</u> increased low flow volume (e.g. permanent flow in previously intermittent streams) in arid areas (Rose and Peters 2001, but see Nilsson et al. 2003) • Increased frequency and magnitude of peak flow (Leopold 1968, Wong et al. 2000, but see also Grimm et al. In press) • Decreased duration of event (Leopold 1968) • Decreased groundwater recharge and lower water table (Groffman et al. 2003, but see Nilsson et al. 2003)
Hydraulics	• Decreased hydraulic diversity at any one time (Victorian Stormwater Committee 1999) • More variable water velocity, much increased following storms
Geomorphology	• Increased rates of channel erosion, incision (and sediment transport depending on the age of catchment development) (Wolman 1967, Neller 1989, Roberts 1989, Booth 1991, Gordon, 1992) • Simplified channel form
Water quality	• Increased contaminant loads (e.g. nutrients, carbon, sediment, heavy metals, pesticides) (Corbett et al. 1997, Basnyat et al. 1999, Hatt et al. in press) • Decreased water quality (e.g. increased contaminant concentration, altered pH and temperature) (Osborne and Wiley 1988, Aalderink 1990, Hatt et al. in press)
Ecology	• Reduced frequency of connection between the stream channel and association floodplain and wetland systems (Centre for Watershed Protection 2003) • Habitat simplification • Less diverse biotic communities (Paul and Meyer 2001, Walsh et al. 2001, Wang and Lyons 2003) • Decreased nutrient retention and altered patterns of nutrient and energy cycling (few published studies: see Paul and Meyer 2001) • Altered Production: Respiration ratio (few published studies: see Paul and Meyer 2001) • Reduced landscape and stream-riparian connection (Grimm et al. In press)
Biodiversity	• Decreased biodiversity values (genetic, species and community levels) (Richter et al. 1997, Chessman and Williams 1999, Walsh et al. 2004)

2.2 Differences in stream response to urbanization – how and why?

While there are many commonalities that can be expected with urbanization, the response of streams to urbanization may differ. Some differences are well documented. Other potential causes of different responses have been little studied.

Variation in geomorphic effects are relatively well understood:

- Geological and geomorphic conditions that result in differences in features (such as channel base levels, bed rock and geomorphic stability) can affect the way that urban runoff alters channel form, and
- The patterns of channel change vary with age and history of urban development (e.g. mature versus active urban development) (Gregory 1992).

Variation in ecological response to urbanization across geographic areas are beginning to emerge:

- Fish and macroinvertebrate assemblages may respond differently to similar degrees of urban impact in different geographic regions (e.g. Centre for Watershed Protection 2003),
- Algal growth response to urban impacts may not be consistent across regions, nor rates of productivity and respiration (contrasting trends were reported at the symposium), and

- These observed differences might result from:
  - Local and regional climatic differences that lead to different patterns of rainfall and runoff (e.g. different hydrology in temperate, tropical, and arid areas), and
  - The physical response of streams and the riparian zone to past land use (legacy effect due to previous land use change or river management).
  - The nature of the biota and susceptibility of species to the changes associated with urbanization.

Within geographic regions, variation in ecological responses to urban land use may be explained by:

- The type of drainage infrastructure present (e.g. degree of connection between impervious surfaces and local waterways via stormwater pipes) (Hatt et al. in press, Taylor et al. 2004, Walsh 2004),
- Where urbanization occurs in the catchment or drainage network (e.g. upland v lowland) (Morley and Karr 2002), and
- The type of development (e.g. septic tanks, sewerage, stormwater drains, combined (stormwater/sewage) systems).
- The nature of riparian zones.

Very little research has been conducted into the socio-economic factors that may cause differences in stream response to urbanization, for example:

- The extent of existing infrastructure development,
- Socio-economic cycles and the ability of societies to fund or reinvest in urban infrastructure, and
- Global differences in economic development (e.g. for many countries, the emphasis is on the protection of public health rather than stream health).

2.3 Conceptual understanding of urbanization and its interaction with stream systems

Conceptual models are important tools for clarifying what is known about a stream system. They are useful for identifying what elements of a stream ecosystem are likely to respond to disturbance (e.g. urbanization) and the spatial and temporal scales of the response. Conceptual models help us to understand the complexity of systems we seek to manage and to prioritise management actions, research and the search for new insights. Increasingly, the interaction of streams with human systems, such as built environments, is included in conceptual models (Figure 1) and to help prioritise rehabilitation efforts. Setting rehabilitation priorities will be assisted by more and better integration of ecology with social and economic sciences to achieve a more realistic understanding of the impact of human activities on natural systems (Grimm et al. 2000, Nilsson et al. 2003).

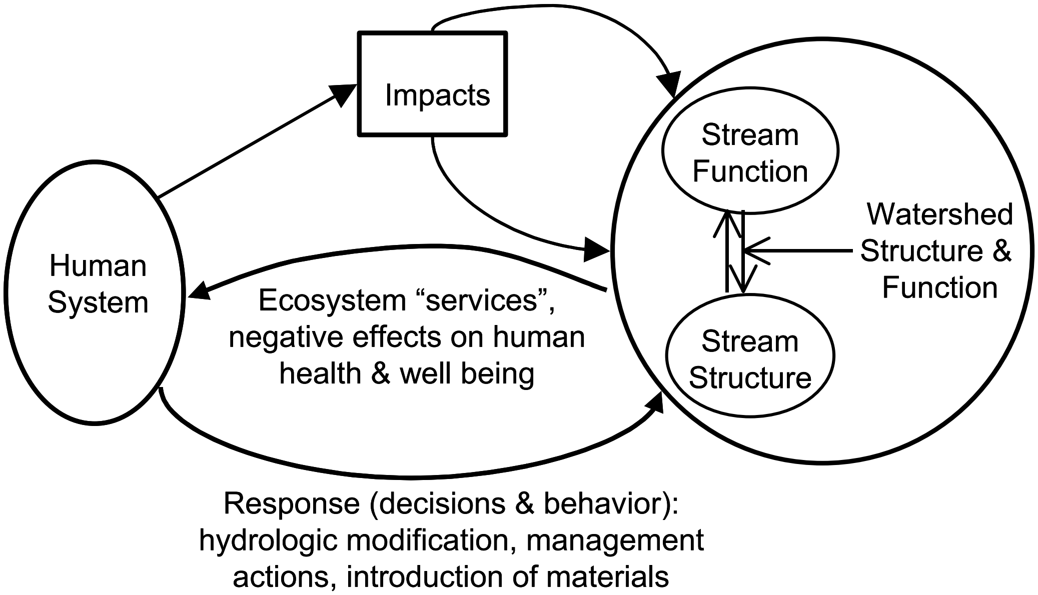

Figure 1: Interactions of stream structure and function with the surrounding watershed and human system. Urbanization is usually conceived as a human impact on streams, but a more complete conceptual model recognizes bi-directional interactions between the human system and streams and watersheds. Recognizing that urban streams are highly modified features of landscapes, humans can design these ecosystems to maximize ecosystem services and minimize risk (adapted from Grimm et al. In press, see also Grimm et al. 2000).

Explicitly acknowledging the interaction between human and stream systems means that we can investigate the key drivers of stream condition in urban areas and identify the points of management required to achieve stream rehabilitation. For example, Walsh et al. (2001) used a conceptual approach (Figure 2) based on that described by Grimm et al. (2000) to evaluate a decision-making framework developed for stormwater management in the Melbourne (Australia) region. They identified a mismatch in scale between models of stormwater pollutant loading and ecological response and suggested that this mismatch could be reconciled by integrating multiple urban impacts into two elements of landuse: (i) catchment imperviousness and (ii) the level of efficient drainage connection between impervious surfaces and local streams via stormwater pipes ('effective imperviousness'). Disconnection of impervious surfaces (e.g. via water-sensitive, or low-impact urban design) that allows increased infiltration of stormwater was considered to offer considerable benefits to stream condition and so allow improved urban design in the future.

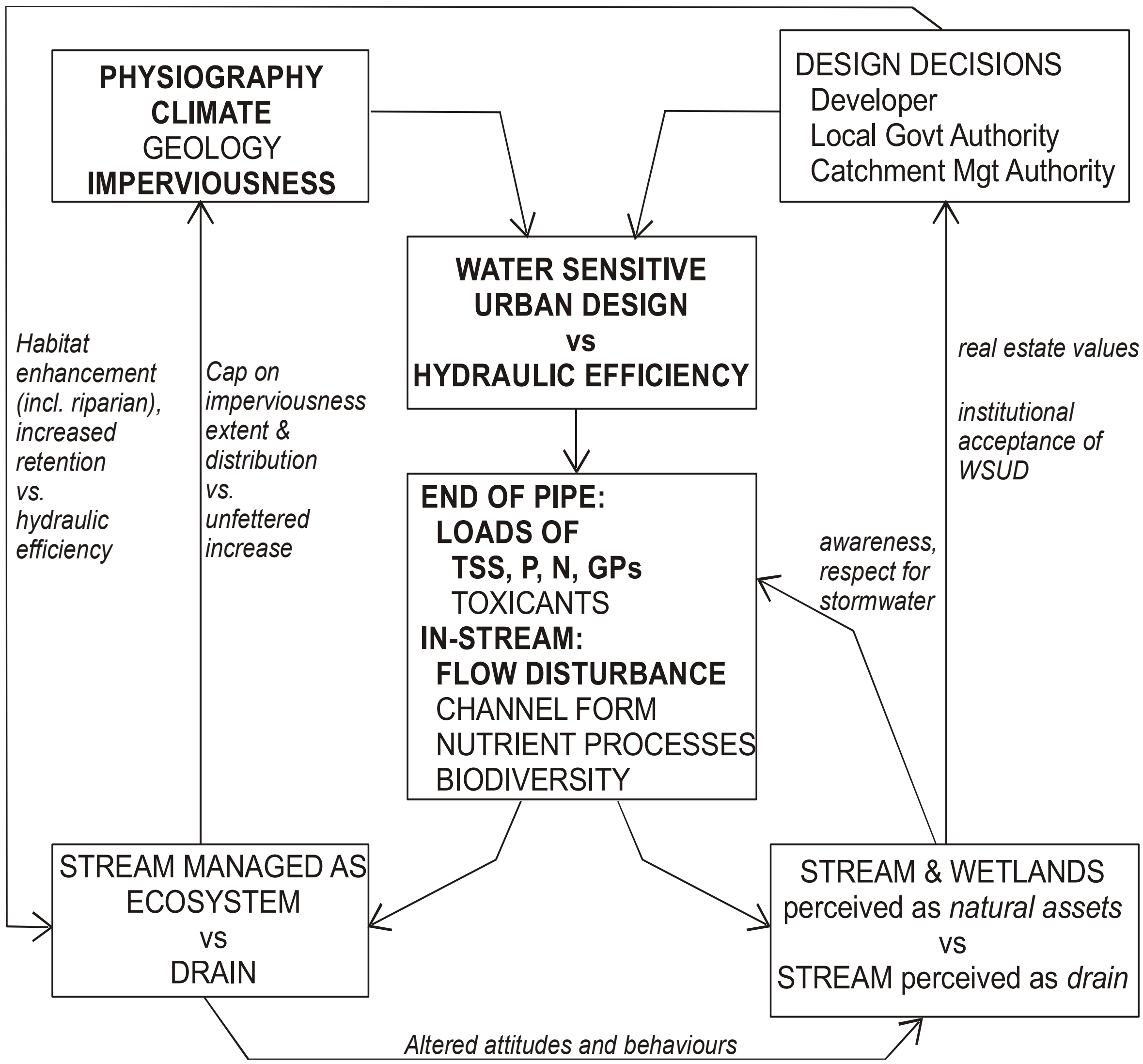

Figure 2: A conceptual model of stormwater management in relation to the ecology of receiving streams and the ecology of the urban area (from Walsh et al. 2001) (WSUD is water sensitive urban design; TSS is total suspended solids; P is total phosphorus; N is total nitrogen, GPs is gross pollutants).

3 STREAM REHABILITATION AND INFORMING FUTURE URBAN DEVELOPMENT

3.1 Defining what we want to rehabilitate – towards knowledge-based decision making

There has been considerable discussion in the restoration ecology literature of terms such as restoration, rehabilitation, remediation and reclamation, and what each seeks to describe (Bradshaw 1996, Kaufman et al. 1997, Palmer et al. 1997, Rutherfurd et al. 2000 and others). Whatever the 'R' word used, the general intention of waterway managers is to 'make things better' by maintaining or improving the condition of streams and protecting the values assigned to them. For consistency, the term 'rehabilitation' has been used throughout this report. Rehabilitation refers to the reinstatement of features of the stream ecosystem (structural or functional) that may have been impaired or lost due to urbanization, rather than a complete return to 'natural' or pre-disturbance conditions implied by the term 'restoration' (e.g. Rutherfurd et al. 2000).

The general process of rehabilitating streams in urban areas is similar to that recommended for streams found elsewhere (e.g. Lake 2001, Hobbs and Norton 1996):

- Identify the drivers/stressors of stream condition and associated ecological response
- Identify rehabilitation goals or objectives
- Identify constraints to rehabilitation
- Determine if rehabilitation is feasible and the spatial and temporal scale of recovery
- Plan and implement rehabilitation measures
- Monitor and evaluate ecological response.

The symposium workshops did not go into detail about each of the above rehabilitation steps but did discuss some salient points related to rehabilitation in an urban setting.

Rehabilitation applied in urban areas will be governed by the values assigned to streams by stakeholders. Often rehabilitation is conducted within the paradigm that urbanization is a negative influence. However, this is not always the case. For example, cities can allow for the efficient use of materials and energy and so can reduce the per capita degradation that might otherwise occur. It is well to remember that features common to streams with urban syndrome will not always have negative connotations for the general public. Streams in urban areas often have aesthetics that are highly valued by the public. For example, good access, landscaping such as well-maintained lawns, and lined stream banks are often given high amenity value, even though such features may be of little benefit, or to the detriment of, native species and ecological function. This is why clear specification of values at the outset is important.

A key issue is who sets the rehabilitation objectives? As rehabilitated streams are likely to be 'designed' systems (a return to some unimpacted condition is not feasible), is the ecological view the best or should this be left to other stakeholders such as civil engineers or the wider public? Ultimately it will be the wider community that sets rehabilitation objectives, based in large part on how much they are willing to pay (although it is to be hoped that water-sensitive or low-impact urban design can be made cost-neutral in the future). However, the objectives set by communities should be informed by science. For example, being able to define a reference condition that serves as a directional target for rehabilitation is useful. Reference condition will not always be 'natural' and may be that which is 'best achievable'. Trade offs between socio-economic and ecological outcomes are likely to be required, particularly when trying to retrofit existing infrastructure, and given the likely high costs relative to the potential benefits.

Rehabilitation of old and newly urbanized areas is likely to require different measures. Indeed, it is likely that opportunities for ecological rehabilitation in some highly urbanized areas will be minimal, although this does not preclude rehabilitation to achieve other valuable objectives (e.g. recreation or amenity outcomes).

We need to move from conceptual models to empirical and predictive models if we are to provide additional tools for those setting priorities for urban stream rehabilitation. Those at the symposium suggested some important factors to be considered when developing a predictive capability include:

- What are the spatial and temporal scales at which stressors associated with urbanization apply and the resulting ecosystem responses?
- What is the likelihood of non-linear relationships (e.g. hysteresis effects) and the potential impact of multiple stressors (e.g. synergistic effects)?
- What is the importance of downstream effects of rehabilitation – there could be a cumulative effect downstream from numerous local efforts?
- What are the links between habitat heterogeneity and ecosystem function – does increased habitat heterogeneity result in increased rates of energy flow and nutrient retention within river ecosystems?
- What are the links between habitat availability and biodiversity – does increased habitat availability result in increased species diversity or richness (or other measure of biodiversity)?
- Are all species important for maintaining ecosystem function or is there some 'threshold' of species diversity required, as some species will have similar ecological roles? Are there taxa that have a high priority for protection because of their functional role?
- Is it better to use some 'critical species' (e.g. endangered, icon or umbrella species) as a surrogate, rather than deal with complexities such as confirming the functional role of species?
- What is the role of invasive species – should rehabilitation efforts focus on the removal of invasive species or on designing streams around their unique character?

3.2 Applying current knowledge

While there is still much to be learnt about stream ecology and its response to urbanization or subsequent rehabilitation, we now have the conceptual and planning frameworks required to promote improved management of urban waterways (e.g. Lawrence 2001). Waterway management should occur within the conceptual framework of the total water cycle, which integrates rainfall-runoff patterns with the development and management of water resources, stormwater drainage and wastewater treatment as part of total catchment management. An essential part of this process is the identification of objectives to protect or enhance social, economic and environmental values and the measures required to achieve them. For example, the following principles adopted by the Victorian Stormwater Committee (1999) when applying water-sensitive urban design are consistent with the issues discussed at the symposium:

Protect natural systems - protect and enhance natural water systems within urban developments. The development of water focussed drainage infrastructure promotes the waterways resulting in it becoming an asset that is to be protected and not exploited. The protected natural system is therefore able to function effectively.

Integrate stormwater treatment into the landscape - use stormwater in the landscape by incorporating multiple use corridors that maximise the visual and recreational amenity of developments. The natural stormwater drainage system can be utilised for its aesthetic qualities within parklands and walking paths, making use of natural topography such as creek lines and ponding areas.

Protect water quality - improve the quality of water draining from urban developments into receiving environment. Through filtration and retention, water draining from urban developments can be treated to remove pollutants close to their source. This approach reduces the effect that polluted water can have upon the environment and protects the natural waterways and environment.

Reduce runoff and peak flows - reduce peak flows and the frequency of runoff events from urban development by local detention measures and minimising impervious areas. Local detention and retention enables effective land use for flood mitigation by utilising numerous storage points in contrast to the current practice of utilisation of large retarding basins. This approach subsequently reduces the infrastructure required downstream to effectively drain urban developments during rainfall events.

Add value while minimising development costs - minimise the drainage infrastructure cost of the development. The reduction of downstream drainage infrastructure due to reduced peak flows and runoff minimises the development costs for drainage, whilst enhancing natural features such as rivers and lakes that add value to the properties of the area.

Clear statements on social, economic and environmental objectives for urban waterway management are important. They help to define the spatial and temporal scales at which stressors of waterway condition apply, and help to ensure that stormwater and waterway management responses are appropriate. For example, meeting national and international obligations (e.g. national or regional water quality programs, international agreements on migratory bird habitat) may require planning at a regional, catchment or sub-catchment scale. Protecting local waterways may require planning or actions (e.g. adoption of water-sensitive urban design that increases infiltration or the installation of stormwater treatment pond and wetlands to reduce pollutant loads) at sub-catchment, local neighbourhood or even house-lot scales.

3.3 Challenges to implementation

Work on streams in urban areas over the past decade has advanced our understanding and capacity to rehabilitate streams in a number of ways, including:

- The conceptual basis of urban impacts on streams and the identification of rehabilitation approaches that match the scale at which key drivers of stream condition apply,
- A clearer understanding of ecosystem services provided by streams in urban environments and the potential costs associated with their loss,
- Ecological risk assessment and clarification of how ecological outcomes can be maximised (i.e. prioritisation of potential management responses),
- Considering stream rehabilitation as experiments within an adaptive management framework so we can 'learn by doing'.

However, those attempting stream rehabilitation are likely to encounter many constraints and challenges. These can vary depending on location and socio-economic conditions, so we cannot expect a 'one size fits all' approach to rehabilitation. The following are some of the challenges experienced or identified by those at the symposium workshops:

- There are likely to be different community perceptions on the objectives that drive rehabilitation – gaining consensus on rehabilitation objectives can be difficult,
- Continued urban development that may confound or reverse the gains from localised rehabilitation efforts,
- There is often a lack of science to support planning schemes and the conditions under which development may proceed,
- Legal systems and precedent can make it difficult to argue against an inappropriate development when consent for similar activities has been given previously,
- Procedure related to development applications, where:
    a. Developer submits an application
    b. Consent conditions are put on the developer (e.g. sediment fences, retention ponds)
    c. There is little science to back consent conditions
    d. There is no one to check to see if the developer complies with consent conditions
    e. There is no long-term monitoring to see if consent conditions work
- Public liability (e.g. balancing improvements to streams against public safety).

In addition, how best to translate scientific insights to a form useful for decision-makers was recognised as a difficult issue. However, this is important if planners are to properly assess the economics of rehabilitation and include features such as water sensitive urban design in new urban developments. Scientists and managers should look to pursue collaborative research projects that generate ecological information in a form that is useful to decision makers, designers, regulators and landowners. This requires a common understanding of such things as policy settings and how ecological information is used in the decision-making process.

Communities everywhere are spending resources on trying to redress problems associated with previous human development and activity. In most instances it will be much cheaper and easier to protect streams in good condition than it is to rehabilitate them once they are degraded. However, this will require a shift from responding to crises to implementing better urban design that anticipates and avoids or addresses the urban syndrome problems. Being able to better quantify the value of ecosystem services would be useful in this endeavour, as would be the capacity to predict what would happen if no rehabilitation or good practice measures were applied.

4 STREAMS IN URBAN AREAS - LESSONS AND GAPS FOR RESEARCH AND MANAGEMENT

4.1 Key lessons

Study of the impact of urbanization on aquatic ecosystems is a relatively new pursuit for stream ecologists, particularly in terms of identifying rehabilitation potential. Research projects conducted in recent years have provided a number of important insights that could be useful to those who study the effects of urbanization in the future. For example, conceptual models or frameworks, such as those presented in chapter 2.3, are helpful research tools. They play an important part in the development of hypotheses and guide the selection of predictor/indicator variables. Conceptual frameworks are also an integral part of adaptive management so that lessons learnt can inform ecological theory and be applied in the future.

The researchers at the symposium workshops related some of the key lessons learnt while implementing research projects in urban areas:

- The design of research and rehabilitation projects must involve multi-disciplinary discussion to help refine the conceptual basis of the study, and gain a common understanding and support for project objectives. This will also help to identify reference conditions and so provide directional targets for rehabilitation, as well as endpoints and response variables against which project outcomes can be measured (e.g. biological communities, lower nutrient concentration, reduced algae, aesthetics, better fishing).
- Traditional project designs based on ANOVA approaches can be very difficult to apply. A potentially better approach is to analyse environmental gradients (e.g. climate, water quality).
- Multiple stressors that act synergistically can affect urban streams. Unravelling cause and effect between multiple stressors and ecological response is likely to be very difficult.
- There may be many measures of stream condition available – so what to choose? The spatial and temporal scales of the stressors/drivers and indicators of ecosystem response will guide this. It is important to start with a well thought-out conceptual model, to help focus the selection of variables or metrics. Simple mathematical models are also useful for testing hypotheses.
- Metrics for measuring urbanization impacts are best linked to management possibilities. Important metrics identified to date include:
  - Level of connection (e.g. impervious area connected directly to stream via stormwater pipes, connection between a stream and its riparian zone or with groundwater),
  - Proportion of directly-connected impervious surface in the catchment,
  - Road density,
  - Human population density,
  - Management of wastewater (e.g. septic tanks vs. wastewater treatment plants),
  - Extent of channel alteration (e.g. piping, concrete lining).

4.2 Gaps in knowledge and management

Those at the symposium identified some key gaps in our understanding of urbanization impacts on streams and additional tools that may be useful for managers:

- Quantification of ecosystem goods and services provided by urban streams remains largely unaddressed.
- The relative efficiency for reducing the export of pollutants from catchments is unclear for:
  - Enhancing aquatic processes through improvement of in-stream and riparian habitat
  - Enhancing riparian and terrestrial processes through replacement of traditional drainage infrastructure with at-source filtration and infiltration systems.
- It is not clear if stream rehabilitation can be achieved by manipulation of stormwater drainage systems alone, rather than a focus on in-stream rehabilitation.

- Historical analyses of the relationships between stream condition, urban growth and socio-economic cycles are lacking.
- Development decisions are made on a small scale and in small increments – cumulative effects go unnoticed. How can the cumulative effects be quantified and incorporated into decision-making?
- Differences in urban impacts on streams across different climatic zones remain largely unaddressed, particularly in tropical areas.
- Many of the insights on urbanization impacts on stream ecology presented at the workshop were based on experience in developed countries. The special challenges faced by developing countries have not been adequately explored.
- Predictive models of stream ecosystem response to urban land management and alternative drainage management scenarios (e.g. varying approaches to and levels of Water Sensitive Urban Design) are required. These need to be incorporated into decision support systems for use by catchment managers.
- How can existing knowledge be best exchanged with the urban communities?
    - Decision makers require "tools kits" (such as decision support systems and predictive models) that define ecosystem services, biological indicators, and management interventions and their relative values.
    - Scientists and managers should pursue collaborative approaches to research that generate ecological information in a form that is easily applied by decision makers, designers, regulators and landowners.

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6 SUSE DELEGATES AND PROGRAM

6.1 Symposium delegates

Dr Nigel Ainsworth	Department of Primary Industries, Victoria
Mr Kane Aldridge	Adelaide University
Prof Takashi Asaeda	Saitama University, Japan
Mr Ian Bate	East Gippsland Shire, Victoria
D.A. Prof Derek Booth	University of Washington, New Zealand
Mr Ian Boothroyd	Kingett Mitchell Ltd, New Zealand
Ms Julie Boyer	University of Ballarat, Victoria
Dr Peter Breen	Ecological Engineering Ltd, Victoria
Ms Wendy Briggs	Colac-Otway Shire, Victoria
Mr David Brown	Biotrack Australia Ltd
Ms Carol Browne	University of Sydney, NSW
Dr Jim Burgess	Australian Defence Force Academy, Canberra
Ms Jane Catford	Ecological Engineering Ltd, Victoria
Mr Josh Cimera	
Mr Peter Coad	Hornsby Shire, NSW
Mr Geoff Coade	NSW Environment Protection Authority
Mr Rhys Coleman	Melbourne Water Corporation, Victoria
Ms Diane Conrick	Department Natural Resources & Mines, Queensland
Mr Peter Cottingham	CRC Freshwater Ecology, University of Canberra
Mr Keiran Croker	Melbourne Water Corporation, Victoria
Mr Andrew De Wet	Franklin and Marshall College, Pennsylvania, USA
Ms Maria Doherty	NSW EPA
Ms Maree Drury	Enviroventures Ltd, New Zealand
Dr Jack Feminella	Auburn University, Alabama, USA
Mrs Susan Flanders	University of Maryland, Maryland, USA
Dr Tim Fletcher	Monash University, Victoria
Mr Matt Francey	Melbourne Water Corporation, Victoria
Dr Takeshi Fujino	Saitama University, Japan
Dr James Gilliam	North Carolina State University, North Carolina, USA
Ms Zoe Goss	Water and Rivers Commission, Western Australia
Dr Mike Grace	Monash University, Victoria
Ms Lia Gray	University of Ballarat, Victoria
Prof Nancy Grimm	Arizona State University, Arizona, USA
Mr Peter Groffman	Institute of Ecosystems Studies, New York, USA
Ms Amy Hahs	University of Melbourne, Victoria
Ms Ernestine Harbott	Monash University, Victoria
Ms Chandramali Jayawardana	University of Ballarat, Victoria
Professor Jacob John	Curtin University, Western Australia
Prof Gary Jones	CRC Freshwater Ecology, University of Canberra
Ms Ruby Jones	Independent
Ms Joanne Kearns	RMIT University, Victoria
Ms Alison Kemp	Cardinia Shire, Victoria
Dr Jonathan Kennan	US Geological Survey, USA

Dr Anthony Ladson	Monash University, Victoria
Mr Paul Leahy	EPA Victoria
Mr Alex Leonard	Monash University, Victoria
Mr Marc Leszinski	Leibniz-Institute of Freshwater Ecology & Inland Fisheries, Germany
Ms Belinda Lovell	WBM Pty Ltd, Victoria
Mr Patrick Maiden	WSL Pty Ltd, Victoria
Dr Adrian Meredith	Environment Canterbury, New Zealand
Ms Judy Meyer	University of Georgia, Georgia, USA
Ms Jessica Miller	Merri Creek Management Committee, Victoria
Ms Wendy Miller	University of New England, NSW
Ms Heidi Millington	University of Georgia, Georgia, USA
Dr Alison Mitchell	CSIRO, NSW
Prof Raymond Morgan	University of Maryland, Maryland, USA
Ms Ellen O'Brien	Envirostrategy Ltd, NSW
Ms Ruth O'Connor	CRC Freshwater Ecology, University of Canberra
Mr Patrick Osaigbovo	
Ms Charlotte Parent	Ecole Nationale des Travaux Publics de l'Etat, France
Mr Shane Perryman	Monash University, Victoria
Mr Vincent Pettigrove	Melbourne Water Corporation, Victoria
Dr Colin Pitts	University of Leeds, United Kingdom
Mr Jaimie Potts	NSW EPA
Mr Simon Roberts	Monash University, Victoria
Mr Graham Rooney	Melbourne Water Corporation, Victoria
Ms Sharyn Ross Rakesh	Melbourne Water Corporation, Victoria
Ms Allison Roy	University of Georgia, Georgia, USA
Mr Ian Rutherfurd	University of Melbourne, Victoria
Mr Peter Schultz	Catchment Boards of South Australia
Ms Claire Sellens	University of Canberra, ACT
Ms Melody Serena	Australian Platypus Conservancy, Victoria
Mr Scott Seymour	Independent
Ms Julie Simpson	University of California, Santa Barbara, USA
Ms Rachel Spencer	Water and Rivers Commission, Western Australia
Mr Randolph Stowe	Watershed Resource Consultants, USA
Dr James Stribling	Tetra Tech Inc., USA
Mr Alastair Suren	National Institute for Water & Atmospheric Research, NZ
Ms Cathy Tate	US Geological Survey, USA
Ms Sally Taylor	Monash University, Victoria
Mrs Celimar Teixeira	Polytechnic University Soa Paulo, Brazil
Ms Monica Tewman	Monash University, Victoria
Dr Simon Townsend	Northern Territory Government
Mr Edward Tsyrlin	Monash University, Victoria,
Dr Robyn Tuft	Robyn Tuft & Associates, NSW
Ms Marjorie van Roon	University of Auckland, New Zealand
Mr Mark Walker	Colac-Otway Shire, Victoria
Ms Tracey Walker	Department of Primary Industries, Victoria
Mr Todd Wallace	Adelaide University, South Australia

Dr Chris Walsh	Monash University, Victoria
Dr Michael Walton	Cleveland State University, Ohio, USA
Mr Michael Williamson	RMIT University, Victoria
Mr Michael Wilson	University of Ballarat, Victoria

6.2 Symposium Program

Monday 8 December - *Theme: the nature of urban impacts on streams*

Plenary Session 1: Chair: Chris Walsh

Opening Address
Gary Jones, CEO Cooperative Research Centre for Freshwater Ecology

Keynote Address
J.Meyer, M.Paul, W.Taulbee
Ecosystem function in urban streams

A.Roy, M.Freeman, B.Freeman, S.Wenger, W.Ensign, J.Meyer
Investigating hydrologic alteration as a mechanism for fish species loss in urbanizing streams

Concurrent Session 1

1A: Chair: ***J. Stribling*** **- Catchment effects and assessment**

I.Boothroyd
Upper catchment urbanization effects on streams in the Wellington region, New Zealand

C.Sellens, R.Norris, B.Chessman
River protection using good management practices: defining a reference condition for the biological assessment of urban streams

D.Conrick, S.Choy
Long-term changes in water quality and macroinvertebrate communities in Southeast Queensland urban streams

1B: Chair: ***V. Pettigrove*** **- Urban Lakes and wetlands**

P.Leahy
The development of hypereutrophic conditions in an urban floodplain wetland: palaeolimnological evidence

J Burgess
Bacterial pollution in Lake Burley Griffin, ACT

T.Weber, M.Barry, B. Lovell, K.Travis
Sustainability of shallow urban lakes in Melbourne

T.Asaeda, J.Matatunge, D.Hai, N.Sahara
Effects of harvesting on the removable nutrient amount and sustainable management of *Phragmites australis*

Plenary Session 2: Chair - Nancy Grimm

Keynote Address
C.Tate, T.Cuffney, M.Meador, T.Short, M.Potapova
Stream ecological responses to urbanization in three contrasting metropolitan regions of the United States

J.Feminella, B.Helms, B.Lockaby, J.Schoonover
Land use change and stream signatures: effects of urbanization on stream biogeochemistry and biodiversity in catchments of western
Georgia, USA

R.Morgan, S.Cushman
Urbanization effects on Maryland fish communities

M.Barbour, J.Stribling
Challenges for establishing reference conditions in urban and agricultural landscapes

J.Kennen, M.Chang, C.Roberts, B.Tracy
Effects of urban growth on fish assemblages in a North Carolina metropolitan area

Concurrent session 2

2A: Chair: *R. Coleman* - Assessment using algae

C.Parent, J.Boisson
The use of periphyton for assessing impacts of urban wet weather flows: assays in artificial streams and in microcosms

J.John
The impact of land use on water quality of urban streams in Perth, Western Australia

S. Komulaynen
Phytoperiphyton communities monitoring in urban rivers

2B: Chair: *I.Boothroyd* - Physical impacts on streams

W.Symmans, J.Hodges
Understanding north shore streams - Streamwalk

M.Williamson
Herbicide contamination of urban streams following remobilisation from hard surfaces

M.Drury, I.Boothroyd, G.Mills
A pressure-state-response model for urban streams in Auckland, New Zealand

Tuesday 9 December - *Theme: Ecological processes in urban streams and watersheds*

Plenary Session 3: Chair - *Judy Meyer*

Keynote Address
P.Groffman, L.Band, K.Belt, G.Fisher, S.Pickett, R.Pouyat
Natural ecosystem processes are important in urban watersheds and streams

E.Harbott, B.Hart, M.Grace
Extracellular enzyme response to dissolved organic carbon in urban streams

K.Aldridge, G.Ganf, J.Brookes
Structure and function of Mediterranean streams along a rural-urban gradient; influence on phosphorus dynamics

Plenary Session 4: Chair - Mike Grace

J.Catford, C.Walsh, J.Beardall
The effect of light on benthic microalgae in streams of different catchment urbanization

W.Miller, A.Boulton
When the shredders leave town: impacts of exotic leaf litter on aquatic macroinvertebrates in an urban stream

J.Simpson, L.Busse, S.Cooper
Urban sprawl in the Los Angeles area promotes nuisance algal blooms

S.Perryman, G.Rees, C.Walsh
Variation in the denitrifying community structure from streams in an urban and non-urban catchment

Plenary Session 5: Chair: Peter Groffman

Keynote Address
N.Grimm, C.Crenshaw, C.Dahm, R.Sheibley, L.Zeglin
Nutrient retention and transformation in urban streams

M.Grace, S.Taylor, C.Walsh
Urbanization effects on the metabolism of small streams

T.Wallace, G.Ganf, J.Brookes
Bioavailability of dissolved organic carbon in rural and urban streams of the Torrens River catchment

Poster Session

Workshop 1: Nancy Grimm and Judy Meyer
Assessment of urban impacts: global comparisons and future possibilities

Symposium Dinner: Guest Speaker - Ian Rutherfurd (University of Melbourne)

Wednesday 10 December – *Theme: Priorities for Restoration (and impacts on vertebrates)*

Plenary Session 6: Chair: Tim Fletcher

Keynote Address
C.Walsh
Stormwater drainage infrastructure: the key to conserving and restoring streams in urban catchments

Keynote Address
D.Booth
Short- and long-term rehabilitation of urban streams

Concurrent Session 3
3A: Chair: ***N. Ainsworth*** **- Riparian and in-stream habitat restoration**

R.Jones, G.Leonard
Waitakere's urban streams - monitoring and restoration

C.Pitts
Assessing the effectiveness of controlling point source pollution to a stream in an urban catchment: a case study of Spen Beck, West Yorkshire, UK

M.Watson, I.Reinfields, F.Torpy
Urbanisation - effects on riparian woody vegetation

A.Suren, S.McMurtrie, R.Barker
Stream enhancement activities in Christchurch: an overview and cautionary tale

Concurrent Session 3B: Chair: ***G. Rooney*** **- Urban impacts on stream vertebrates**

M.Serena, V. Pettigrove
Relationship of sediment toxicants and water quality to the distribution of urban platypus populations

C.Browne, M.Thompson, R.Jeffree
Metal accumulation, reproductive effects, and biomonitoring in Australian freshwater turtles

M.Walton, D.Salling, J.Wolin
Assessing biological integrity within substantially urbanised catchments

J.Kearns, D.Nugegoda, V.Pettigrove
Biomonitoring of trace metals in Melbourne's streams and wetlands using the mosquito fish (Gambusia holbrooki)

Plenary Session 7: Chair ***Alastair Suren*** **- Restoration and management**

E.O'Brien, E.Taylor-Wood
Suitability-priority decision model for selecting sustainable projects

C.Teixeira, A.Roberto, R.Porto
AcquaNet: a model for quantity and quality integrated management of water

A.Bryant
A planning tool to facilitate earlier consideration of stream ecology issues in planning and management processes

T.Ladson
Improving stream health by retrofitting suburbs to decrease the connection between impervious surfaces and waterways

P.Chowdhury
Urbanization and stream ecology: Bangladesh perspective

Workshop 2: Derek Booth and Cathy Tate
Towards restoration priorities

SYMPOSIUM CLOSE