Integrated Urban Land & Water Management

Planning and Design Guidelines

Ian Lawrence

Technical Report 1/2001

Cooperative Research Centre for Freshwater Ecology

February 2001

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The Cooperative Research Centre for Freshwater Ecology is a national research centre specialising in river and wetland ecology. The Centre provides the ecological information upon which sound management decisions can be made to improve the health of our rivers. In the Centre, university, government and industry partners work together to understand river systems.

The Cooperative Research Centre for Freshwater Ecology is a collaborative venture between:

- ACTEW Corporation
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- Department of Natural Resources, Queensland
- Department of Natural Resources and Environment, Victoria
- Environment ACT
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- Environment Protection Authority, Victoria
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1. Foreword

The material contained in this report has its roots in early stormwater management practices and innovation in Canberra, commencing with the adoption of major and minor pathways in the mid 1970s.

The importance placed on landscape values in relation to waterways and associated open space corridors, and the sensitivity of Canberra's inland waters to pollution, created the conditions for an integrated drainage, open space/landscape, recreation and water quality management approach. Incorporation of pollution control ponds & wetlands, gross pollutant traps, and detention basins into the stormwater management infrastructure commenced in the late 1970s.

ACT investment in comprehensive hydrological, water quality and biological monitoring of lakes, streams and drainage, and in the assessment of performance of management measures, established a valuable database against which the development and assessment of management practices could proceed.

The Cooperative Research Centre for Freshwater Ecology was launched in 1993 with a strong urban water ecology program, covering catchment rainfall-runoff processes and mobilisation of a range of pollutants, assessment of a range of urban water management measures, assessment of the impact on the ecology of receiving waters, and assessment of restoration techniques. The urban research was a joint CRC for Freshwater Ecology and CRC for Catchment Hydrology Program. These Guidelines have built extensively on the research outcomes.

Assistance provided to a range of State & Local Government authorities and community groups developing more sustainable urban water management practices, has highlighted the diversity of contexts and environments being addressed, and the dearth of information and data available to guide agencies and the community.

Growing concerns amongst consultants and approval agencies along the mid north coast of NSW regarding the application and assessment of integrated urban land & water based approaches, led to the running of a CRC for Freshwater Ecology and Newcastle Division of Institution of Engineers Australia Workshop in Newcastle in June 2000. The Workshop highlighted the need for improved information on selection of appropriate management measures, and for guidance on design and assessment of health and safety issues.

The contribution of the Workshop in identifying urban water management issues, and the contribution made by Dr Brett Phillips and Dr Peter Liston to the development of the Guidelines, is gratefully acknowledged.

Caveat

Many of the management measures identified in the 'integrated approach' outlined in this document represent a significant shift from existing practice. The author has drawn on published and validated methods where available, established theory, and new research findings, in an attempt to provide a sound overview of the efficacy of the new approaches, and in presenting it in an integrated framework. However, as with any new area, there will be ongoing development of practices and assessment of performance against experience, leading to the revision of documented practice.

2. What is integrated urban land and water management?

2.1. Definition

An ‘integrated urban land & water’ based management approach considers management issues, objectives and measures in terms of the land & water association or whole, rather than separate consideration of the land & water components.

It integrates water sensitive urban design based techniques in respect to residential blocks and streetscape, the integrated urban waterway based management techniques in respect to sub-catchment drains & easements, and Total Catchment Management based approaches in respect to the protection of regional waterways and their floodplains or foreshores.

The approach is based on integrated land & water processes and their management in relation to broad functional, aesthetic and amenity goals. It recognises the critical relationship between land & water management across the catchment and full community partnership.

It requires:
- identification of the major ‘landscape – water’ association categories and their interrelation;
- consideration of the multiple values of the ‘land & water’ association;
- consideration of the management measures in terms of the ‘land & water’ association; and
- partnership of stakeholders in identification of goals and management of the resource.

The major ‘landscape – water’ associations comprise:
- buildings & their surrounds;
- residential blocks & their streetscape & neighbourhood;
- urban sub-catchment drains or waterways & their corridors; and
- regional waterways (primary streams, lakes, estuaries, ocean) & their floodplain or foreshore zones.

Integrated urban land & water based management represents a further evolution in an urban stormwater approach, which began with a single drainage focus in the late nineteenth century. A multi-function (drainage, landscape, recreation) approach was adopted in the 1970s, and a multi-objective focus (social, economic & environmental objectives) approach in the mid to late 1980s.

2.2. Why is ‘integrated urban land & water management’ emerging as a major new direction?

An integrated urban land & water based management approach offers substantial benefits to urban communities, in terms of:
- social benefits – enhanced open space, landscape, recreation, educational, movement corridors (access) & water supply values; enhanced equity; while maintaining the health & safety (flood protection) amenity;

- economic benefits - significant savings in infrastructure provision costs, opportunity for low cost water supply alternatives, significant enhancement in property values and associated tax base; deferment of expensive water supply headworks requirements; and
- environmental benefits - restoration of more natural water balance and flow regimes across urban areas, reduction in water pollution, the retention or creation of waterways having substantially enhanced ecological values, the enhanced health of regional waterways, the enhancement of ecosystem and bio diversity.

The approach offers a more sustainable use of finite resources in terms of:
- reduced urban footprint resulting from reduced water abstraction & reduced emissions of substances harmful to the environment, and retention of more natural vegetated waterways, wetlands and lakes;
- improved household, neighbourhood, sub-catchment and regional water balance and environmental flows;
- economies of integrated ‘land & water’ focussed management measures; and
- more equitable use of resources and balance of social, economic & environmental values.

The approach also offers more direct opportunities for community partnership in the choice of futures and in the implementation of actions and programs necessary to secure agreed goals, thereby securing outcomes better reflecting the community‘s life style values and priorities.

Economic analysis of integrated land & water based management approaches in the ACT have indicated Benefit/Cost ratios of 4 to 6 times conventional approaches, not withstanding the ACT being a long way from fully exploiting the opportunities offered by the approach. Housing value surveys indicate a doubling in the value of blocks fronting onto open spaces containing waterscape, and a 70% increase in value of blocks having a view of these open spaces.

In the ACT, stormwater now meets some 20% of the total water supply demand. Analysis is currently proceeding on the adoption of a distributed wastewater treatment plant strategy, with discharge of suitably treated wastewater to local urban waterways. The strategy potentially offers a means of securing enhanced water balances, environmental flows, increased re-use of wastewater, and removal of the need for expensive trunk sewer augmentation.

In the ACT, some 93% of all outdoor recreation (other than competitive sports) is water based or related. Urban stormwater based lakes and waterways meet 70% of this demand, indicating the substantial social benefit available with integrated stormwater based management.

A 1991 US Department of Housing and Urban Development and Department of Commerce survey indicated an average 28% increase in the value of homes which are within 300 ft of a body of water. Surveys of individual developments including constructed ponds and wetlands, indicated increases in property values of 10% to 100% for properties having a water view, and up to 150% increase for properties having a waterfront location. (Economic Benefits of Runoff Control, US EPA Office of Water 1995).

By their nature, integrated land and water based management requires a more coordinated approach to related programs. This may yield significant savings as a result of removal of duplication, reduction in overheads, and reduced risk of negative effects of unforeseen externalities. The integrated assessment also enables more rigorous and comprehensive identification of external costs and benefits.

The investment in constructed ponds and wetlands may provide opportunities for the integration of significant conservation opportunities, particularly in regions where diversion of streamflow for water supply or agriculture has resulted in serious loss in natural ponds and wetlands.

2.3. Conclusion

Substantial social, economic and environmental benefits are available through the adoption of a more integrated approach. Stormwater is being recognised as a valuable resource, which, with innovative approaches, can dramatically enhance urban amenity & sustainability.

3. Implementation of an 'integrated' strategy

3.1. Integrated assessment framework

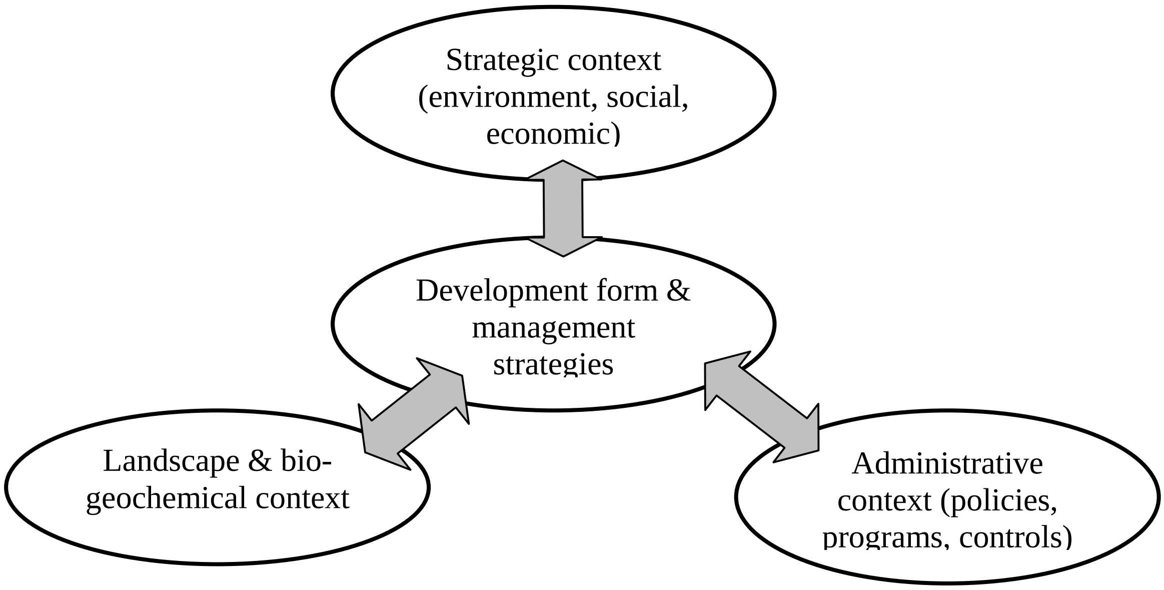
State and local government planning agencies seek to guide the land development process in a manner securing a range of residential amenity values. This typically requires the identification of the external factors and interests to be protected as part of the design, and the local health, safety and amenity principles to be incorporated into the design.

Previously, these requirements have been identified in a prescriptive and reductionist (separate services and functions) manner. This approach is counter the adoption of integrated land & water based development and management. Councils, in partnership with communities and developers, are seeking more adaptive approaches to better securing these desired outcomes. The adoption of an integrated assessment framework and development of integrated catchment based management strategies are evolving as powerful tools in this endeavour.

Three key elements make-up the integrated land and water management framework:
- strategic and policy related considerations, including partnership of stakeholders;
- landscape and environmental components and bio-geochemical processes which maintain life support systems; and
- administrative instruments and programs available to Council or agencies to implement and maintain the required conditions.

The interrelationship between these components and the development form and management measures is illustrated in Figure 1

Figure 1. Integrated land & water management framework



Strategic and policy context

The strategic and policy context comprises the broad array of environmental, social & economic objectives, policies and programs that have evolved in response to emerging needs and issues at the international, national, regional, metropolitan, district and local levels. The context includes the stakeholder/partnership arrangements & processes enabling the collective resolution of these issues.

These needs, conditions and constraints occur across a range of scales, with requirements for the conditions and constraints for each scale to be factored into smaller scales. They typically comprise:

- international (environmental accords), national (environmental agreements, economic & social programs) and regional (economic development, environmental concerns, transport issues) scales;
- metropolitan (economic development, environmental concerns, infrastructure provision & maintenance, social programs), district (district environmental features, trunk infrastructure corridors, district level community facilities) and neighbourhood (local services & facilities, landscape & open space, paths/cycleways, residential amenity, noise, etc) scales.

A critical component of the strategic context setting is the identification by stakeholders of the environmental, social and economic objectives to be adopted as the basis of catchment management.

An example of environmental, social and economic objectives drawn from the ‘Review of the Tank Paddock Development Proposal Report (Lawrence 2000) is included at Tables 1, 2 & 3.

Table 1. Environmental objectives

Objective	Performance criteria
Maintain ecological sustainability & bio-diversity	Maintain morphology, habitats, & levels & patterns of flows & constituent loads
	Maintain movement corridors & critical size of habitats necessary to sustain population & bio-diversity
	Manage risk of exotic species introduction into the area
	Minimise discharge of toxicants
Promote conservation & restoration of existing environmental values	Designation of conservation areas
	Amelioration of peak flow, and sediment, nutrient, organic material & toxicant loading
	Removal of movement barriers, exclusion of stock, re-establish riparian vegetation
	Complimentary, buffer & movement corridor role of open space systems
	Restoration of degraded waterways through rural areas
Promote enhancement of environmental & use values of modified ecosystems	Selection of sustainable ecosystems having the highest feasible value
	Amelioration of sediment, nutrient, organic material, toxicant loading
	Maintain present gully & creek drainage morphology and flow regimes
Conservation & efficient use of non-renewable & finite renewable resources	Minimise disturbance of soil, soil stabilisation & drainage management
	Minimise the consumptive use of water & energy, maximise opportunities for re-use
	Exploit opportunities for passive solar energy capture
Meet international, national & regional environmental obligations	International obligations in respect to migratory birds
	State SEPP 14 obligations
	Protection of State designated rare & endangered species protection & heritage sites

Source: Review of Tank Paddock Development Proposals Report, (Lawrence 2000)

Table 2. Social objectives

Objective	Performance criteria
Access to & choice of housing	Contribution to the stock of detached & semi detached dwellings, medium density and rural residential options
Safety & security	Level of flood protection
	Risk of bush fire damage
	Potential for health hazards (mosquitoes, re-use of wastewater, roof water potable use)
Urban amenity (services, open space, recreation, landscape, cultural)	Range of local services & access to district & metropolitan level services
	Open space provision & quality
	Serviceability of surfaces
Urban function (identity, inter-connectivity, accessibility, choice, adapatability)	Distinctive local features & value rating
	Movement corridors – roads, cycle-paths, walkways, links with public transport
	Range of movement systems
Equity (accessibility to services, cost allocation)	Range of services & location relative to residential areas
	Cost allocation
Partnership in choices & management information access	Community partnership in planning decisions
	Community partnership in caring for the natural & built environment
	Programs and structures for provision of information

Source: Review of Tank Paddock Development Proposals Report, (Lawrence 2000)

Table 3. Economic objectives

Objective	Performance criteria
Efficient use of scarce financial resources	Benefit/cost analysis
	Metropolitan trunk service capacity constraints or utilisation
Economically sustainable conditions	Whole of life costing, including externalities
	Basis for recovering development & recurrent costs
Balance between development (private) & recurrent (public rates) costs	Development costs vs recurrent costs for services
	User pays
Regional economic development	Enhanced valuation of infrastructure (private & public)
	B/C analysis for development
	Wider economies of scale & catchment
	Tourism opportunities
	Home business opportunities

Source: Review of Tank Paddock Development Proposals Report, (Lawrence 2000)

Landscape and bio-geochemical context

The landscape & bio-geochemical processes are integral to the maintenance of land form, vegetation and fauna, and the pattern and quality of rainfall-runoff to streams. Urban development profoundly modifies these processes, with implications for the local, district, metropolitan and regional landscape and environment.

Through sensitive zoning of land uses, set-backs, development conditions and urban design, and the application of infrastructure, these impacts can be significantly reduced. In the past, there has been a uniform application of urban design and utility services, which took little account of the local landscape and environment.

Each local area is unique in terms of its topography, soils, local and downstream environmental values and ecosystems. This requires the selection of urban designs and management measures appropriate to meeting the urban amenity and safety requirements, and to the opportunities and constraints of the local terrain, soils, and environmental values.

An integrated landscape and bio-geochemical based approach needs to be catchment based, in terms of analysis of the inter-dependencies of landscape elements across the catchment. These elements comprise the catchment slope, the local drainage gullies, the sub-catchment waterway, the primary or secondary receiving streams and floodplains, wetlands and lakes, and the estuary.

Changes in the pattern and magnitude of flows, sediment transport, nutrients, organic material, have potentially significant implications for downstream ecology and ecosystems. There are also local implications for the nature of ecosystems and their qualities within the local development area.

Administrative and management context

The administrative and management context comprises the legislative instruments, policies, programs, regulations/approval processes, infrastructure provision, operations and maintenance activities, including:

- metropolitan/strategy planning – land use, location, conditions, easements, conservation areas;
- planning & development controls, building regulations, environment protection guidelines/licences/mgmt plans, design guidelines, discharge licences, protection species/trees;
- provision and operation of infrastructure;
- operation & maintenance activities;
- information and awareness raising – community partnership;
- performance monitoring & review programs and processes; and
- financial programs, tariff structures & incentives designed to enhance economic efficiency.

Role of integrated land & water management plans

The development of integrated land & water management plans is used as:

- a vehicle for securing partnership of stakeholders in identification of values, management objectives, and the management measures appropriate to securing them;
- the document detailing the agreed values, management issues and objectives, and agreement on the range of management measures to secure these objectives and their implementation program;
- the set of actions across program areas, community and developers required to achieve the implementation program; and
- the arrangement for overall performance assessment and review of the management plan.

3.2. Analysis of landscape & bio-geochemical components

At the urban level, there is a need to consider urban water on the basis of the total urban water cycle, including the local rainfall and catchment slope interflow, throughflow and surface runoff, groundwater, imported municipal water supply, and wastewater streams. In the interests of minimising impacts on environmental flows (both in terms of impacts of water supply reservoirs on regional streams and impacts of urbanisation on local streams), and economy (defer augmentation to water supply headworks, savings in local reticulation), how can these urban water streams be integrated into the development?

The analysis comprises an assessment of the three major land- water association levels:

- the slope & terrestrial components of the catchment upon which residential and commercial blocks, streets and neighbourhoods will be superimposed;
- the gullies and channels draining the sub-catchment which will become the urban waterways; and
- the regional receiving waters which are to be protected.

Figure 2. Structure of analysis

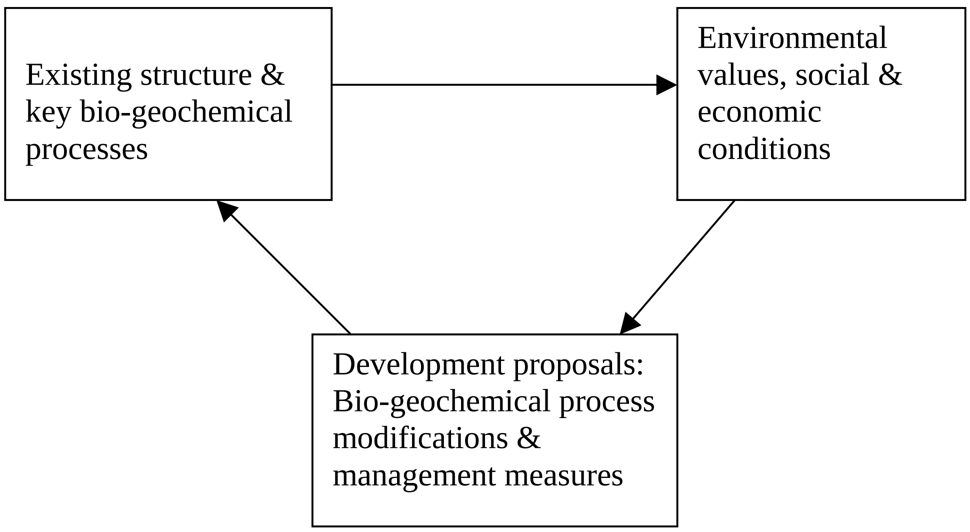


Figure 3. Integrated 'landscape & water association' levels framework

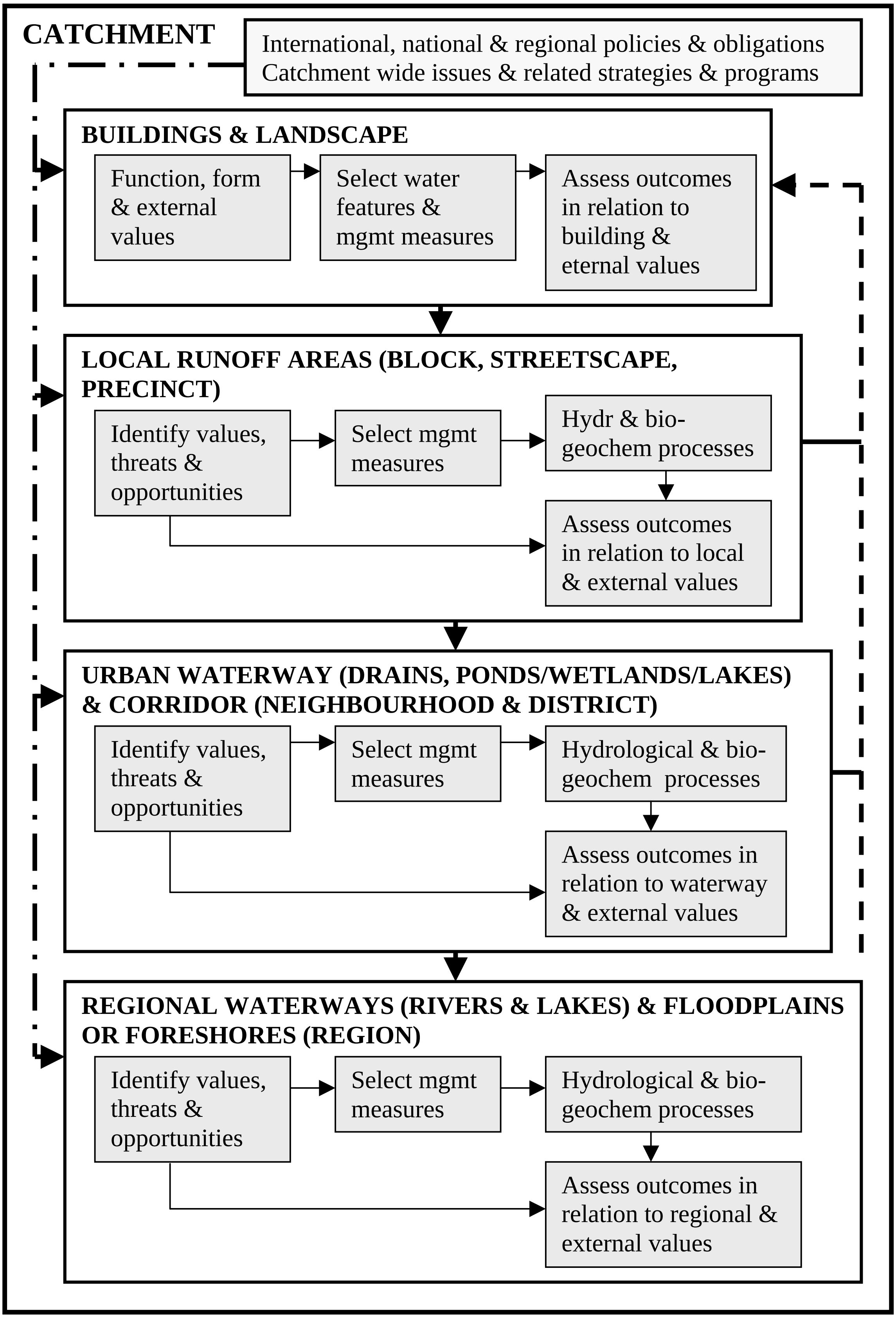
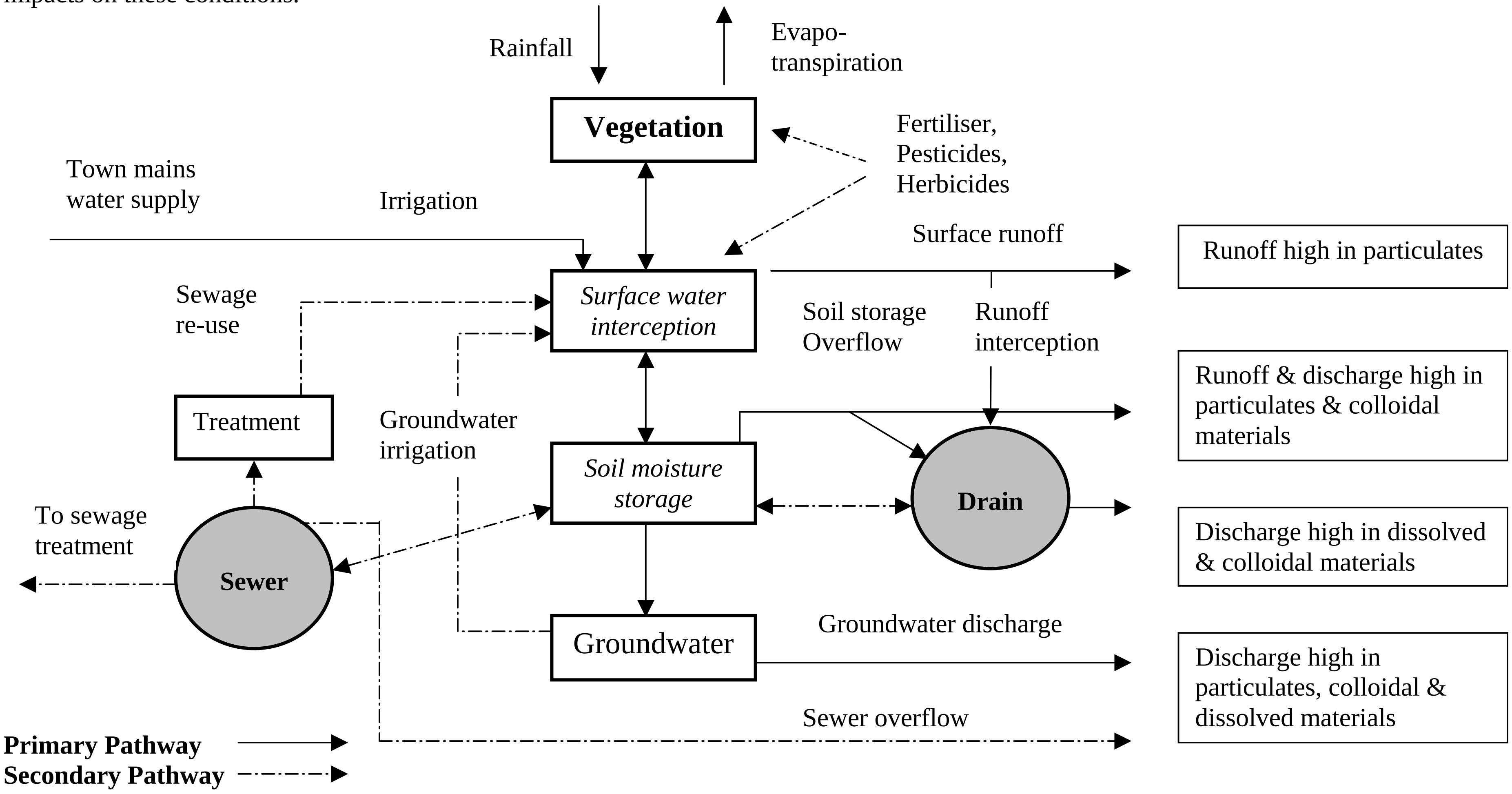


Figure 4. Outline of urban water cycle pathways & processes (Source: CRC for Freshwater Ecology)

This Figure outlines the urban water cycle pathways, constituent mobilisation and transport processes, and the way in which urbanisation impacts on these conditions.



Local areas (blocks, buildings, streetscape & precinct) analysis:
- existing bio-geochemical components, processes & values;
- analysis of development proposals & management measures; and
- analysis in terms of local area social, economic & environmental management objectives.

Sub-catchment urban waterways & their corridors (neighbourhood & district) analysis:
- existing bio-geochemical components, processes & values;
- analysis of development proposals & management measures; and
- analysis in terms of urban waterway & corridor social, economic & environmental management objectives.

Regional waterways & floodplains or foreshore zones (region) analysis:
- existing bio-geochemical components, processes & values;
- analysis of development proposals & management measures; and
- analysis in terms of regional waterways & floodplains or foreshore zones social, economic & environmental management objectives.

Appendix B outlines the major water quality and ecology management issues for urban waterways, in terms of the major catchment drivers of processes, and the in-stream response processes.

3.3. Legislative & administrative structures

The administrative & management context comprise the legislative instruments, policies, programs, regulations/approval processes, infrastructure provision, operations & maintenance, financial programs/resources, whereby the strategic objectives and policies are secured. There are also constraints in respect to what the City can and cannot do.

Responsibility for urban land & water development and management is fragmented across multiple geographic and functional jurisdictions and related legislative and administrative structures. They typically include:
- local council (Planning, Engineering, Landscape Departments);
- regional water authorities;
- catchment management authorities;
- state or territory agencies (planning authorities, natural resource management agencies, environment protection agencies); and
- land or property developers and builders.

In the past, Local Government has successfully used prescriptive standards and processes as an effective and administratively efficient basis for control of development and building. An ‘integrated land & water’ based management approach requires an ability to respond to the opportunities and constraints of terrain, soils, drainage and natural features in securing the mix of outcomes desired by the community. By its very nature, it is an adaptive and innovative set of responses to local landscape and development objectives.

While the conventional infrastructure provision approaches are straight forward in terms of powers, approvals, and operation and maintenance resourcing, some of the more intrinsic components of the Water Sensitive Urban Design type approaches may not be covered by current Local government powers. In addition, they raise potential difficulties in terms of Council meeting its safety, amenity and health obligations when it does not have full access to the range of measures designed to collectively secure the desired safety, amenity and health outcomes.

Adoption of Water Sensitive Urban Design type management measures involves a strong focus on measures on private land, and development by the developer in relation to streetscape and neighbourhood systems. These shifts raise questions regarding the issues of standards, coordination, and maintenance liability, and questions regarding the agency liability in situations of discretionary private participation.

Financial programs are predominantly line program (separate water supply, sewerage & stormwater, open space/landscape departments) based, with primary focus on construction and maintenance of services. In times of financial stringency, there may be a low risk-taking position adopted with discouragement of 'collaborative approaches'. This reluctance may be reinforced by professional institutionalisation factors, wherein current practices reflect old problems, with substantial vested interests in maintaining the status of related knowledge and programs.

In view of the complex range of interrelationships between programs, significant overlap in infrastructure and maintenance, and opportunities for major savings in integrated approaches, there is a need for coordination across programs.

A number of legislative and administrative mechanisms have been adopted to secure more effective catchment coordination. They include:

- the establishment of catchment management agencies having overriding authority in respect to land & water related resource development and management;
- a requirement for regional or catchment programs as a condition of funding approval;
- the establishment of maintenance control provisions in respect to private components of land & water management;
- the setting of special rates or levies to finance integrated management processes; and
- the identification of non-line program funds to foster collaborative and integrated approaches across program areas, or to non-structural type strategies.

The issue of public control over private on-site management measures impacting on the wider community interest is an evolving area. There have long been strong public health powers in respect to facilities such as septic tank operation and maintenance. Where on-site measures are promoted, it will be important to address the private versus public interest conflicts.

3.4.Community partnership & ownership of strategies

There is an expectation across the community regarding their participation in decisions affecting their quality of life, and in more direct partnership in securing a more sustainable urban form and activities. Urban communities are forming local waterway, wetland, landcare and waterwatch groups, with substantial commitment to local action. A number of urban groups are seeking government action in the recovery of the urban waterway values of local streams and their corridors.

Partnership of community in an integrated land and water based approach is critical. Effective partnership can only be secured through joint ownership of management plans and measures, and this can only be secured through full and open participation of community in the identification of management issues and objectives, and the selection and implementation of management measures. This poses particular challenges of open communication, information and education regarding new approaches, and the development of trust between stakeholders.

Out of the Total Catchment Management program, there has developed a range of community involvement processes, from consultation to wide participation. Given the 'advisory' nature of these management plans and activities, the opportunities for development of true partnership based approaches have been limited.

The 'integrated urban land & water' based management approach requires ownership and accountability by all of the stakeholders involved, including the management agencies, the developers, the residents and property owners.

The 'integrated land & water management plan' becomes the instrument documenting agreements on values, objectives, management measures, implementation programs and responsibilities. Against these agreements, programs of works, development guidelines & controls, and approval & operation criteria for measures on private land will be developed.

3.5.Performance assessment

One of the current limitations of Total Catchment Management plan development is the qualitative treatment of options, with limited availability of numeric or quantitative analysis tools to make real comparison of alternative management measures, or to assess the overall performance of the strategy in securing the objectives. This difficulty is often further exacerbated by the failure to identify indicators and target levels against each of the objectives.

The environmental, social and economic objectives identified in Section 3.1 provide a basis for presentation of a system of accounts, that measures the assessed performance against each of the objectives performance criteria. The accounts provide a basis for systematic measurement of the performance of options across a range of competing values, making these trade-offs explicit. This adds an important dimension to the information available to stakeholders in their assessment of options.

The techniques used here build on the multi-objective assessment techniques developed by the Australian Water Resources Council in the mid 1980s.

Environmental assessment

Tables 1, 2 & 3 provide a summary of the key environmental, social & economic objectives respectively and related performance criteria developed by Newcastle groups in relation to the Tank Paddock development proposal. It provides the framework for undertaking detailed performance assessment.

The revised Australian & New Zealand Guidelines for Fresh and Marine Water Quality 2000 (WQ Guidelines) identify three protection levels:

- pristine/slightly modified – protection.
- slightly to moderately modified – restoration.
- moderately to highly modified – selection & management of facilities meeting a range of local values.

The bulk of urban waters fall into the moderately to highly modified category. This represents a significant step forward for urban water management, with the recognition that the extent of modification of urban landscapes is such that often reference to 'restoration of pre-development conditions' is irrelevant. The challenge now becomes one of selecting the (constructed) ecosystems that will sustain a range of ecological, aesthetic and water use values, while being economically sustainable in terms of meeting the flow and water pollution control requirements.

The revised WQ Guidelines also adopt a risk based approach to protection or restoration of stream health, based on the major threats to stream health. Table 4 summarises these management issues and the related stressors. Appendix B provides further information on water quality & ecological health assessment.

The following list of major physical and chemical stressors are based on the eight major issues identified in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. The table relates these issues or conditions to the range of stormwater related sources, impacts and related stressors.

Table 4. Stormwater Management Issues

Environmental impairment issues	Typical Sources	Impacts	Related stressors & modifiers
Impact of pathogens on health	Sullage, sewer overflows, septic, animals	Closure of Beaches Human infection Illness and disease	Faecal coliforms, bacteria, viruses, hydraulic retention time
Impact of oxygen depletion	Sullage, sewer overflows, septic animal waste, grass and leaf litter	Low dissolved oxygen Smells, stress to aquatic life	Organic matter, ammonia, mixing, temperature, nitrate
Impact of toxicants including metals and pesticides	Cars, car parks, roads, processing industries, spills, atmospheric deposition.	Bio-accumulation Death of aquatic life	Pesticides, herbicides, lead, zinc, suspended solids, sulphate, organic material, pH

Environmental impairment issues	Typical Sources	Impacts	Related stressors & modifiers
Impact of particulate matter	Roads, urban land use, construction sites, modified drainage	Smothering of aquatic plants & animals, impact on feeding, impact on light	Silt, sand, gravel, clays, retention time
Impact of floating debris and surface scums	Commercial areas, fast food outlets, plant debris	Mainly visual, interferes with aquatic life	Paper, plastic, leaves, dead vegetation, algal scums, oil
Nuisance plant growth	Sullage, septic, sewer overflows, animals, STP discharges, leaves	Promotes plant and algal growth, blue green algal blooms	Phosphorus, nitrogen, organic matter, mixing, retention time, temp
Impact of changes in flow regimes Increased stormwater runoff.	Changes in catchment land use & vegetation, changes in drainage morphology	Pattern of particulate deposition & re-suspension, washout of biota – succession processes, DO regimes.	Volume, frequency, velocity
Changes in physical habitat		Loss of riparian vegetation, change in substrate	Modification to channel morphology, change in flow & frequency

The application of a range of rainfall-runoff, pollutant mobilisation, transport & sedimentation models is required to assess patterns of flow and water quality.
The application of the models parallels the structure of the integrated land & water management structure, namely at-source control; urban waterway transport & flows, and regional receiving water responses.

Social assessment

Key social objectives and related performance criteria are listed in Table 2. It provides the framework for undertaking detailed performance assessment.

Analysis draws on some of the physical, chemical & biological related models identified above. In the case of landscape quality, the application of a landscape assessment method is required which has an 'urban aesthetic' based approach.
This approach integrates natural, cultural factors with human preference features.
These techniques are described in *Kaplan, R & Kaplan, S. 1989. The Experience of Nature: A physiological perspective, Cambridge University Press*, and in *Saegenschnitter, D. 1994. Landscape quality assessment of urban waterways, Post Graduate Diploma Thesis, University of Canberra*.

Economic assessment

Key economic objectives and related performance criteria are listed in Table 3. It provides the framework for undertaking detailed performance assessment.

One of the strengths of the integrated land & water based management approach is its ability to consider jointly the range of factors which collectively result in some economic outcome. It provides an ability to capture many of the externalities and to provide links between conditions and economic outcomes.

Section 2 outlined the range of property value benefits resulting from the adoption of integrated land & water management based approaches.

3.6.Guidance on new management techniques

The shift to a more integrated land and water based approach requires the application of new and broader skills for managers. The introduction of a range of new management measures to local conditions will require the application of new design & assessment tools.

There are a number of existing technical BMP guidelines, describing individual management practices and their design. There is a need to provide improved guidance and training on the selection of overall land & water management measures, and the assessment of their performance for a range of terrain, soils, climatic and urban development conditions. (Refer to Appendix C for guidance on selection of management measures).

This is an area of rapid innovation and development across both the tertiary and commercial sectors. The importance of performance data for the measures for a range of applications cannot be over emphasised. There is also a need to develop practical 'Decision Support Tools' that assist the practicioner in applying these new technologies to local conditions under conditions of limited local scientific and technical knowledge. (Refer to Appendix D for guidance on design of selected measures).

One of the important underpinnings of both the catchment management and integrated land & water based management is the adaptive management based approach to the selection and assessment of management measures. This requires assessment of the performance of selected management measures and their review in the light of their performance and cost effectiveness over time. If there is no performance monitoring undertaken, then it is not possible to address this component of the overall strategy.

The *National Guidelines for Water Quality Monitoring and Reporting 2000* builds on the major management issues identified in the WQ Guidelines, in providing guidance on good monitoring design practice. The key elements of the Guidelines are summarised in Table 5. Monitoring categories.

Table 5. Monitoring categories

Management Issues	Information requirements	Monitoring category
Identification of environmental values	Current uses & ecological significance of water bodies.	Characterise flows, water quality and ecology.
Outline of problems and issues	Current water pollution (exceedance of criteria) having a potential to impact on river health or uses.	Characterise water quality, ecology & processes. Trend analysis of changes in water quality & ecology.
Determine sustainable loading	Sustainable loading of key runoff constituents consistent with maintaining water quality, ecosystem composition &	Characterisation of water quality and ecological processes.

Management Issues	Information requirements	Monitoring category
	structure.	
Determine existing or future loading	For existing land use & management practices across the catchment, estimate of cumulative loads on critical downstream water bodies.	Characterise rainfall - runoff & constituent exports as a function of land use and management practices.
Evaluation of export reduction for management strategies	Estimate of level of pollutant interception or immobilisation for different management practices	Characterise water quality & ecological processes. Undertake performance monitoring for a range of management practices.
Review of the performance of the strategy and its components	Evaluate reduction in exports and changes in water quality and ecology in relation to objectives	Performance monitoring of overall system. Performance monitoring of components. Trend analysis.

4. Selection & design of management practices

4.1. Catchment context

Typically, the task of consultants or approval agencies is the design of infrastructure or planning approval of a local sub-division. In an integrated land & water based approach, this needs to be undertaken in a catchment wide context.

Ideally, an integrated or total catchment management plan will have been developed for the region, including the translation of catchment wide strategies to local implementation principles. An excellent example of this approach is the *Blue Gums Hills Catchment (Wentworth Creek & Hexham Swamp) Management Strategy*, undertaken by Hassell & WBM for Newcastle City Council. The Report translates the Catchment Strategy into specific design objectives and performance standards for each of the local sub-division precincts.

As noted in the Workshop, the situation is more often one where either a catchment management strategy is so broad as to limit its use in the guidance of local area design or assessment, or there is no comprehensive catchment assessment.

In these cases, Councils often resort to State or region wide standards or guidelines in respect to planning approvals. The broad nature of these standards or guidelines limits their ‘integrated land & water based management’ consideration, as well as their assessment of appropriateness of designs to local conditions. In these cases, how are local community expectations in respect to a more sustainable approach to urban design and management to be accommodated?

One means of resolving this situation may be the adoption of guidelines and standards for developments in similar topographic, soil, land use and climate conditions in the region, which have had the benefit of a well considered catchment context.

Another commonly adopted approach is to undertake, in association with Council or other relevant agencies, a preliminary assessment of catchment water use and ecological values and land use and management related issues. The approach requires the identification of the major management issues and pollutants (stressors) of concern, including an assessment of the current level of loading and the reduction required to restore the water use or ecological values. Based on this analysis, the approach determines the pollutant reduction requirement on a land use sector & area basis to determine the local sub-division design objectives. This assessment is included in the sub-division design report (substantiation of standards).

This analysis may draw on local water quality and/or ecological survey data, or in the absence of local data, require the application of pollutant export algorithms to local rainfall or annual area based export rates (Catchment Management System) to estimate annual loads. (Refer to Appendix D Analysis of catchment loads).

4.2. Local area context

The ecological, water use & landscape values of urban water facilities, and their performance in retarding flows and intercepting pollutants, is a function of the size and pattern of inflows and pollutant loads relative to the facility shape, size and vegetation. We modify these inflows & loads by:
- land use & management practices; and
- selection of urban waterway drainage form & associated facilities.

The opportunities, constraints and economics of incorporation of different management measures will be strongly influenced by whether the development is a part of a greenfield development, re-development within an existing urban area, or a rural town setting.

In the case of greenfield development, not only are the constraints minimal as compared to re-development, but there is also an opportunity to capture a range of values (benefits) through integrated design approaches.

Re-development sites are always going to be more constrained by existing land uses and infrastructure. Nevertheless, through forward strategic planning, there are often excellent opportunities financially and through the changed structural arrangements re-development opportunities offer, to secure more integrated and sustainable solutions.

In the case of rural towns, the availability of lower cost – limited development of adjacent land and lower level of development (scale of loads) often results in on-site management measures (OSMM) being much more viable than would be the case for city type residential development. There are also often opportunities for linking with agricultural re-use of stormwater and treated wastewater.

The steps involved in the selection & design of management measures at the local level comprise:

i) identification of the catchment strategic issues & related management objectives, including performance criteria established for catchment or area (Tables 1 to 3);
ii) description of existing conditions (environment, land use, infrastructure, rainfall) and identification of opportunities & constraints, and the critical stressors in respect to protection or restoration of water use or ecological values;

iii) identification of the range of available management measures (Appendix A) appropriate to interception of the critical stressors, the level of required interception, and to meeting other management objectives (Table 6);
iv) assess which of the relevant measures are viable for the local area (technical viability (Appendix C), spatial & hydraulic opportunities & constraints, administrative capacity to implement);
v) undertake preliminary design of measures (education & OSMM, structural measures (Appendix D), or combination) for initial assessment purposes;
vi) undertake a preliminary assessment of performance of the preliminary design (Appendix D) against the management objectives & related performance criteria; and
vii) if necessary, refine the design arrangement of measures to improve its performance across the management objectives or in relation to particular objectives & re-assess.

As noted at sub-section (iii), the level of required interception is often an important determinant of whether on-site management measures or structural measures should be adopted (refer to Appendix C). Table 6. 'Pollutant removal and flow attenuation capacities of management measures' indicates that for most pollutants, on-site management measures are limited to less than 20 to 40% interception.

Note that the level of removals will be subject to the level of provision of the management measure volume or surface area relative to the catchment runoff or pollutant loading, and to local soil and terrain conditions. In the case of catchments having silty clay or clay soils, higher pond volumes or wetland & infiltration surface areas will be required relative to catchment runoff or pollutant loads to achieve these removal rates.

It should also be noted that where dealing with measures in series, that generally the removal levels are not additive – the facility having the highest individual removal rate will prevail. Where facilities are in parallel, then the total removal will be the sum of the separate parallel management measures.

4.3. List of management measures by land & water association categories

A list of management measures is attached at Appendix A

4.4. Assessment of management measures

In an integrated land & water management based approach, assessment of management measures relates to the land & water whole, rather than to separate components. Consequently, assessment needs to consider a range of outcomes, as outlined in Table 7.

Table 6. Pollutant removal and flow attenuation of management measures

Management Measures	Pollutant removal							Flow attenuation	
	Trash	Solids	P	N	BOD	Metal	Bact	Peak	Vol
Infiltration trench, pits	❑-■	❑-■	❑-■	❑	❑-■	❑	❑-■	❑-■	❑-■
Infiltration basins	■	■	■	❑	■	❍	■	❑-■	❑-■
Grassed swales	NA	❑	▲-❑	▲-❑	▲-❑	▲	▲	▲-❑	▲
Grassed buffer zones	NA	▲	▲	▲	▲	▲	▲	▲-❑	▲
Filters	NA	●	❍-●	❍-●	❍-●	■-❍	■-❍	NA	NA
Pervious pavements	▲-❑	▲-❑	▲-❑	▲-❑	▲-❑	▲-❑	▲-❑		▲-❑
Vegetated waterways	NA	❑	❑	▲	❑	▲	❑	▲-❑	▲
Inlet traps, gross pollutant traps	●	❑	▲	▲	❑	▲	▲	NA	NA
Detention basins	NA	●	■	❑	■	❍	●	■-●	▲
Retention ponds, wetlands	NA	❍-●	■-❍	❑-■	❑-■	❍	■-●	▲-❑	▲
Extended detention ponds, wetlands	NA	❍-●	■-❍	❑-■	❑-■	❍	■-●	❑-■	▲
Aeration	NA	NA	NA	NA	●	NA	NA	NA	NA
Street sweeping	■	❑	▲	▲	▲	▲	▲	NA	NA

Removal efficiency: ▲ 0-20% ❑ 20-40% ■ 40-60% ❍ 60-80% ● 80-100%
Source: Adapted from Lawrence, AI et al 1996

Table 7. Summary of management measures by objectives

Strategic Management Objectives	Means of meeting objective	Development form & management measures
Ecological sustainability & bio-diversity Conservation or restoration of existing values Enhancement of environmental & use values	Protection, restoration or construction of habitats	Restoration of existing waterways, wetlands & their corridors
		Construction of vegetated waterways, wetlands, ponds & corridors
	Creation of wildlife movement corridors	Creation & linking of vegetated waterway corridors & natural areas
	Recovery of environmental flows necessary to sustain morphology, ecological functioning & health of ecosystems	Infiltration trenches, pits, wells, basins
		Groundwater injection/abstraction bores
		Water conservation measures
		Discharge of suitably treated wastewater to local waterways
		Channel full frequency necessary to maintain morphology
Maintenance of water quality Enhancement of environmental & use values	Limit sediment & suspended solids discharges	Erosion & sediment controls, sediment traps
		On-site filter zones, swales
		Detention or retention basins, ponds & wetlands
	Limit organic material (BOD) discharge	On-site filter zones, swales
		Trash racks, baskets, booms
		Ponds or wetlands
	Limit nutrient discharge	On-site filter zones, swales
		Ponds or wetlands

Table 7. cont'd. Summary of management measures by objectives

Strategic Management Objectives	Means of meeting objective	Development form & management measures
Maintenance of water quality Enhancement of environmental & use values	Limit toxicant discharge	Education & information
		On-site filter zones, swales
		Ponds or wetlands
	Limit pathogen discharge	Education, information
		On-site filter zones, swales
		Sewer overflow control devices
	Limit trash & debris discharge	Education, information
		On-site filter zones, swales
		Trash racks, baskets, booms
Conservation & efficient use of finite resources	Conservation of water	Rainwater harvesting
		Re-use of stormwater & greywater
		Mulching of landscape areas
		Efficient use of water
Urban amenity (security, health, open space, recreation, landscape)	Provision of drainage & flood control	Establish drainage conduits & overland flow paths
		Stormwater detention
	Open space provision & access	Establish landscaped waterway corridors, pond & wetland foreshore zones
		Linking waterway corridors with other open space systems
	Recreation opportunities & access	Integration of sports grounds into waterway (flood) corridor
		Establish movement trials within waterway corridors
		Water based recreation facilities – waterways, wetlands, ponds, lakes
		Fish stocking of constructed ponds & lakes
	Landscape values	Vegetation interest: Compo-sition, structure & diversity
		Mix of open space & vegetation & interrelation
		Water features & visual quality & interest
		Interrelation of built & natural forms
		Incorporation of cultural features

Table 7. cont'd. Summary of management measures by objectives

Strategic Management Objectives	Means of meeting objective	Development form & management measures
Social equity	Provision & access to services	Provision of open space, recreation facilities & movement corridors
	Who benefits, who pays	Distribution of private & public costs in provision of management measures
Economic efficiency	Benefit/Cost analysis	Construction & maintenance cost of measures, benefits in terms of value of services, enhanced land values, recreational values, water supply values
		Existing infrastructure utilisation or replacement costs & benefits
Economic sustainability	Asset costs versus rates	Metropolitan wide infrastructure assets value, serviceability & returns
		Impact of proposals on financial viability of service provision

5. Conclusions

The scale of urban development has reached a level where significant impacts are occurring on downstream waterways, and on streams diverted for water supply. Urban communities are voicing concerns regarding the need for more sustainable water management and recovery of the environmental and use values of urban waterways.

Over the last 20 years, there have been a number of shifts in water management practice with a view to reducing these impacts and achieving a more sustainable resource use. The new approaches have included catchment based management, recovery of the pre-development detention and ponding character of waterways draining urban catchments, and at the block level, the application of water sensitive urban design techniques and wastewater re-use practices.

Increasingly, the distinctions between traditional water supply, wastewater and stormwater utilities are becoming blurred, given the growth in recycling of wastewater, sewer infiltration problems of aging infrastructure, and on-site harvesting and soil infiltration of rainwater. An integrated approach requires the consideration of the land and water association as a whole, rather than separate consideration of landscaping and water services, together with multiple social, economic and environmental costs and benefits based analysis.

The development of viable 'integrated land & water management' practices is a balance between strategic considerations (environmental, social & economic issues), landscape and bio-geochemical benefits & impacts, and administrative capacity (development & environmental controls, infrastructure provision, operation & maintenance). Four levels of 'landscape and water association' are emerging as the basis of application of the approach across the catchment. They comprise the building and its immediate landscape, the local runoff areas (residential block and streetscape), the urban waterway (sub-catchment drain), and the catchment primary waterway.

Integrated landscape & water management measures comprise:

- at the buildings & landscape level, management of household chemicals, wastewater recycling options, water conservation measures (mulching, rainwater tanks), land use capability based siting, provision of set backs, rainwater tanks, swales, ornamental ponds;
- at the residential blocks & streetscape level, erosion & sediment controls, buffer strips, traps, infiltration trenches, water conservation measures (mulching, water efficient irrigation systems), wetlands, porous pavement, sand filters, on-site detention tanks, break stormwater pipe connections, swales, wastewater recycling options;
- at the urban waterway & corridor level, sediment traps, screens, booms, detention or extended detention basins, vegetated waterways, wetlands, pollution control ponds, lakes, wastewater recycling & overflow management options, and groundwater recharge; and
- at the regional waterway level, stabilised banks, fencing, inlet sedimentation forebays, protection riparian & floodplain vegetation, buffer zones, setbacks of land use from waterway edge, wastewater recycling & treatment options, and regional water supply abstraction.

Integrated urban land & water based approaches to urban water management offer substantial social, economic and environmental benefits to urban communities, in terms of enhanced open space, landscape, recreation and water supply. The approaches also secure significant savings in infrastructure and service costs, while substantially restoring the natural flow, water quality and ecology to downstream waters.

The effective application of the approach requires a more holistic and strategic based approach to assessment of issues and management options at each landscape level, and the application of new design and assessment tools.

During the Workshop, a number of information needs were identified. In response to these needs, the attached Appendices summarise:

A) the range of management measures for each of the ‘landscape and associated water’ levels;

B) the basis of assessment of water quality and ecological health of catchment waterways;

C) guidance on selection of appropriate management measures, and

D) the techniques for analysis of catchment pollutant exports and interception for a range of management measures.

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Appendix A. List of management actions and measures

A.1 Building, surrounds & local area (block, streetscape & precinct level)

Education:
- information on household chemicals potentially harmful to the environment;
- information on recycling options & safe disposal options;
- information on the fate of stormwater & implications for managing discharges; and
- information on water conservation practices: rainwater tanks, local recycling of grey water, automatic watering controls, watering practices.

Design & siting:
- land use capability assessment (slope, soils, erosivity, flooding, goundwater hazards);
- siting controls, set backs.

On-site wastewater management measures:
- mulching/evaporation systems
- on-site physical, biological, chemical treatment; followed by adsorption fields, sand filters, biological filters, wetlands, or by effluent collection systems.

Erosion control on building & construction sites:
- interception & diversion of drainage around the site;
- exclusion from non-construction areas;
- maintenance of buffer strips (nature strip);
- grass or mulch or chemical stabilisation of re-graded surfaces;
- establish temporary silt traps, basins, sediment ponds;
- vehicle exit sediment interceptors or wash down facilities.

Sediment interception:
- use of vegetated swales, buffer zones and infiltration drainage measures;
- incorporate sediment sumps or basins into drainage;
- sand filters; and
- wetlands, ponds.

Infiltration techniques:
- infiltration vegetated swales, trenches, pits, wells, basins;
- porous pavements, mulched permeable areas; and
- groundwater injection/abstraction bores.

Surface (vegetation) filtration:
- buffer zones, filtration strips, grassed swales, sand filters; and
- neighbourhood wetlands, swales.

Trash & vegetation interception:
- use of vegetated swales, buffer zones and infiltration drainage measures;
- wire mesh baskets in collector bowls for down pipes, or stormwater sumps.

Flow detention:
- swales (avoid direct pipe connection), porous pavements, infiltration trenches;
- integration of extended detention into block or precinct wetlands or ponds;
- on-site & neighbourhood detention basins.

A.2 Sub-catchment drains or waterways & corridors (Neighbourhood & District)

Education:
- information of urban water uses & values & potential impact of pollutant discharges; and
- information on discharge of drainage water to downstream regional waters

Design & siting:
- set-backs of land uses from waterways & their riparian vegetation; and
- land use capability assessment

Erosion controls:
- exclusion of activities from erosion susceptible areas;
- sustainable designs in terms of erosion management measures;
- stabilisation and rehabilitation of degraded waterways;
- construction of vegetated waterways in zones such as erosion gullies.

Sediment interception:
- sediment traps, basins; and
- wetlands, ponds.

Infiltration techniques:
- infiltration basins; and
- conjunctive design of surface drainage & groundwater aquifers.

Surface (vegetation) filtration:
- vegetated waterways;
- restoration/protection of riparian vegetation; and
- aquatic plants in wetlands & ponds.

Trash and vegetation interception:
- screens or racks, baskets;
- booms; and
- swirl separators, proprietary devices.

Flow detention:
- vegetated waterways & corridors;
- detention basins; and
- extended detention wetlands, ponds.

Oil interception:
- oil booms; and

- oil separators.

A.3 Regional lakes and streams & foreshore of floodplain zones (Regional level)

Education:
- information on water use & ecological values; and
- information on activity locations & facilities.

Design & siting:
- land use capability assessment; and
- land use activities related to water quality zones.

Erosion controls:
- as for blocks & waterways; and
- stabilisation of erosion areas, banks, exclusion of stock, provision of pathways for intensively used areas.

Sediment interception:
- use of inlet sedimentation forebays; and
- protection/restoration of riparian vegetation and floodplain vegetation.

Surface (vegetation) filtration:
- protection/restoration of riparian zones; and
- floodplain or foreshore zone vegetation.

Trash interception:
- as for building surrounds & local area.

Appendix B. Water quality & ecological health assessment

B.1 Assessment of ecological values

Undertake comparison of biological assessment of local test sites with local or regional reference site (reference *ANZECC (2000) Guidelines for Fresh and Marine Water Quality*).

Steps in assessment of threats to aquatic environmental values:

- identify designated environmental values & levels of protection for waters;
- identify major threats to values – refer to Table B1;
- assess against trigger levels for ecosystem type, region, levels of protection; and
- assess implications for catchment land use & management.

Levels of protection adopted in *ANZECC (2000) Guidelines:*

- pristine waters management objective is protection;
- slightly to moderately modified waters management objective is restoration; and
- highly modified waters approach is the selection by the local community of the ecosystem types providing the desired range of values.

Table B1. List of major management issues and related indicators

Management Issues or threats to stream health	Condition indicator	Stressor indicator	Potential modifiers
Nuisance plant growth	Chlorophyll ‘a’, ΔpH, DO, algal composition	TP, TN, TOC loads (indirect)	Detention time (flow), turbidity, SS (nutrient sorption), pH, temperaturee
Depletion of oxygen	ΔDO	TOC or BOD load, NH_4	Mixing (flow), re-aeration (flow), temperature, photosynthesis
Increased levels of suspended solids	Turbidity, algal composition, SS conc	Suspended solids loads	Flow
Changes in salinity	EC	Salt loads, evaporation losses	Flow
Changes in temperature	Δ temperature	Temperature of inflows	Flow
Modifications to pH (direct & indirect)	Δ pH	Acids, alkalies, photosynthesis, respiration	Alkalinity
Changes in optical properties	Δ turbidity	SS, nutrient loads (direct), TOC loads (indirect)	TDS, flow
Changes in flow regime	Seasonal flow regimes	Δ seasonal flow duration	
Toxicants (metals, inorganics)	Biological effects	Cd, Cu, Pb, Zn NH_4	TDS, DO, SS, DOM, temperature, hardness, pH

Ecosystem categories adopted in *ANZECC (2000) Guidelines* comprise rivers & streams (upland, lowland); wetlands; lakes; estuaries (open, closed, deltaic); and marine (embayments, open coast).

B.2 Water use values and quality guidelines

Table B2. Water quality guidelines for water uses

Indicator	Drinking water	Recreation & aesthics	Irrigation water supply	Stock water supply	Aquaculture production	Aquaculture consumption
Turbidity NTU Suspended Solids (mg/L)	Site specific				25	
pH Units	6.5 – 8.5		4.5 – 9.0	4.0 – 9.0	5.5 – 8.0	
Temp $^{\circ}$C		15 - 35			<2 $^{\circ}$C change/hr	
DO (% saturation)	>80%				>60%	
Total Dissolved Salts (mg/L)	<1000		site specific	<2000	<1000	
Hardness as $CaCO_3$ (mg/L)	<500				<100	
Chloride (mg/L)			<100			
Sodium Adsorption Ratio			site specific			
Total N (mg/L) Nitrate N (mg/L)	- < 10		< 5 long term	- <400	- <50	
Total P (mg/L)			< 0.05 long term		<0.1	
Faecal Coliforn (cfu/100 mL)	see note *	<150 median	<10 raw <1000 proc.crop	<1000		<14
Algae (cells/mL)	<5000	<15000	<15000	<15000		Free toxins
Heavy metals	Refer to Guideline		Refer to Guideline	Refer to Guidel	Refer to Guideline	Refer to Guideline
Pesticides	Refer to Guideline		Refer to Guideline	Refer to Guidel	Refer to Guideline	Refer to Guideline

Notes: * capable of treatment such that Faecal coliform = 0/100 mL

Source: ANZECC/ARMCANZ (2000) Guidelines for Fresh & Marine Water Quality, NHMRC & ARMCANZ (1996), Australian Drinking Water Quality Guidelines

B.3 Outline of bio-geochemical processes for major management issues

The following diagrams are included as a way of explaining the dominant bio-geochemical components and processes on a management issue by management issue basis. These 'concept models' constitute the basis of the risk assessment protocols adopted in the ANZECC (2000) Guidelines. The significance of the various stressors and modifiers in respect to the response processes, will vary on a site by site basis.

The conceptual models may also be used to estimate the critical stressor load reduction required to meet the environmental or water use management objectives. This is a key factor guiding the selection of the appropriate management measures.

Figure B1. Stimulation of nuisance plant growth by nutrients and/or organic material

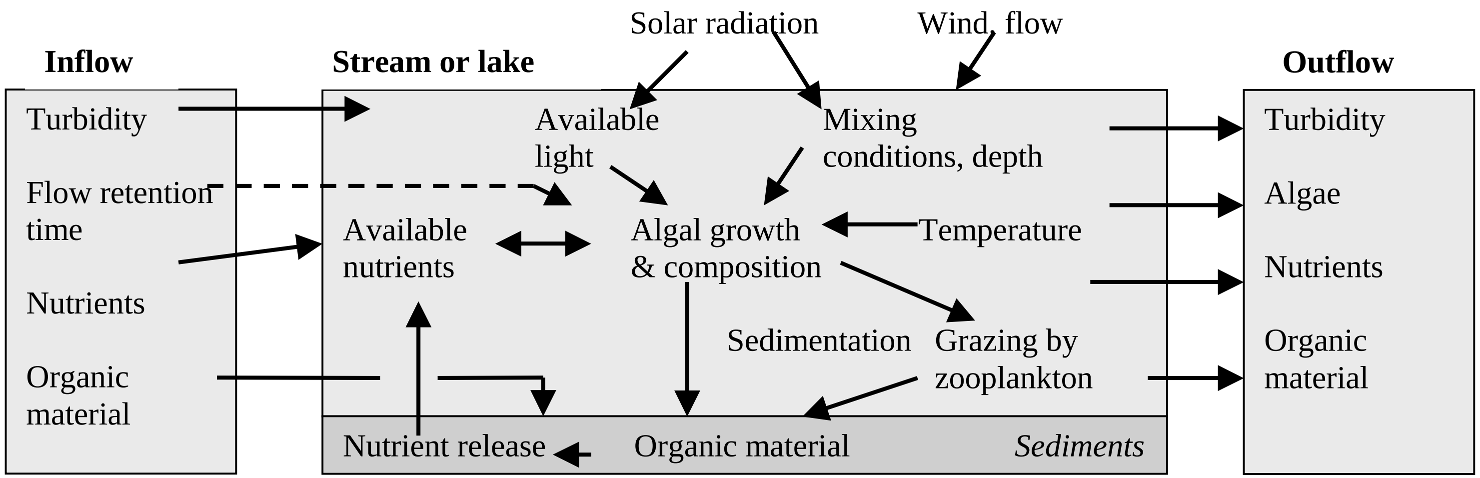


Figure B2. Depletion of dissolved oxygen by organic loads and/or chemical oxygen demanding substances

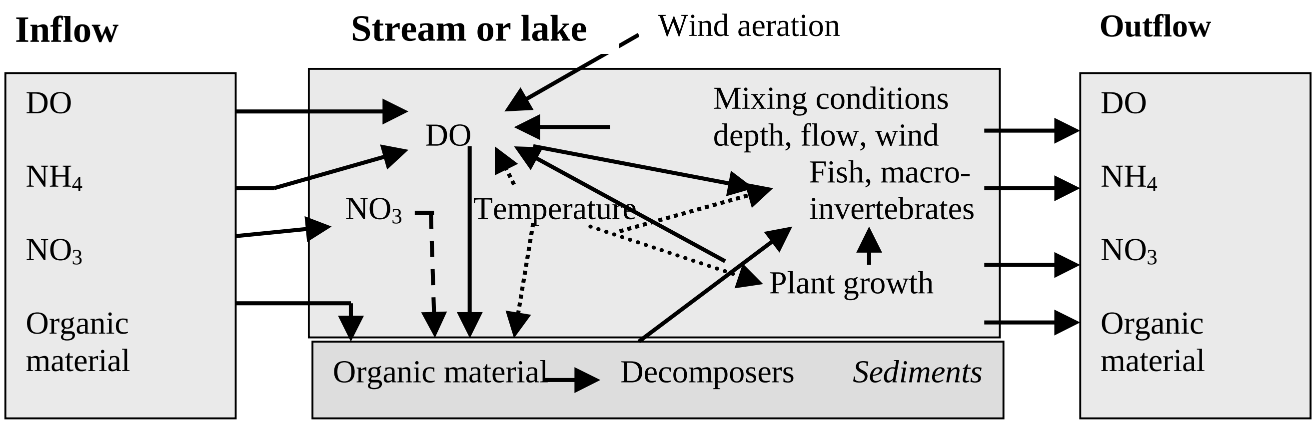


Figure B3. Effects of suspended solids on nutrient adsorption/removal, algal growth & burial of benthic biota

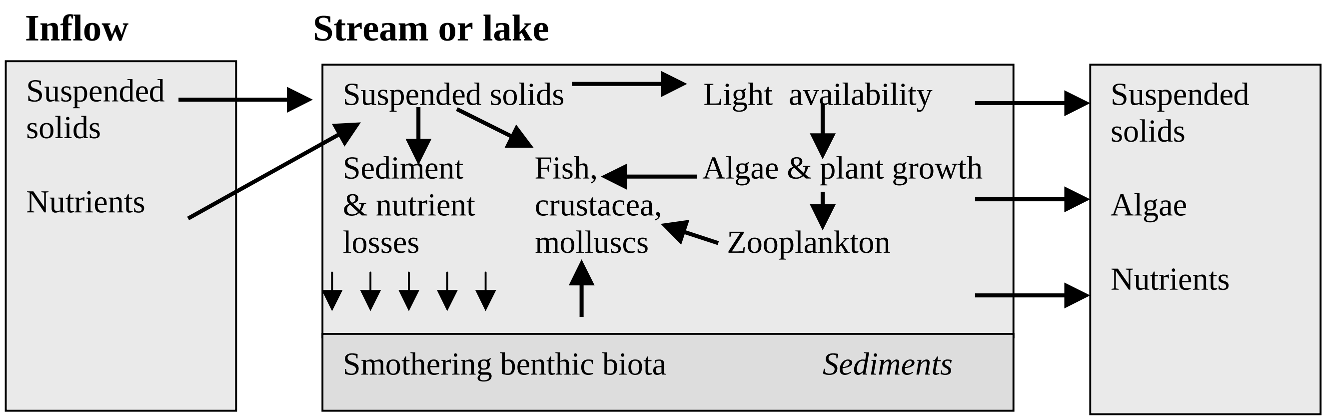


Figure B4. Effects of salinity on biota, suspended solids and chemical equilibrium

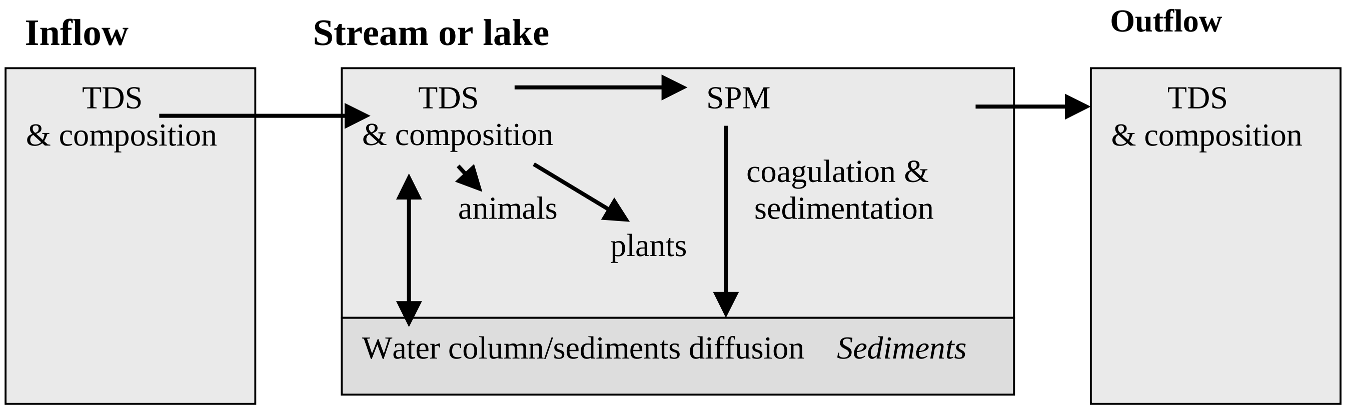


Figure B5. Effects of temperature change on biological processes

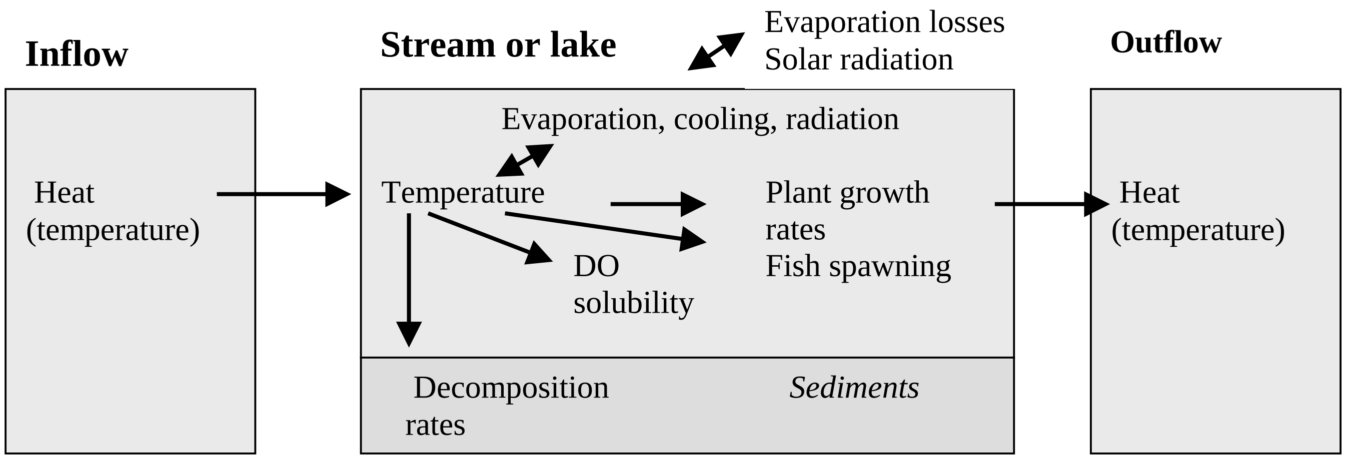


Figure B6. Factors driving pH change, and its effect on chemical equilibrium and composition

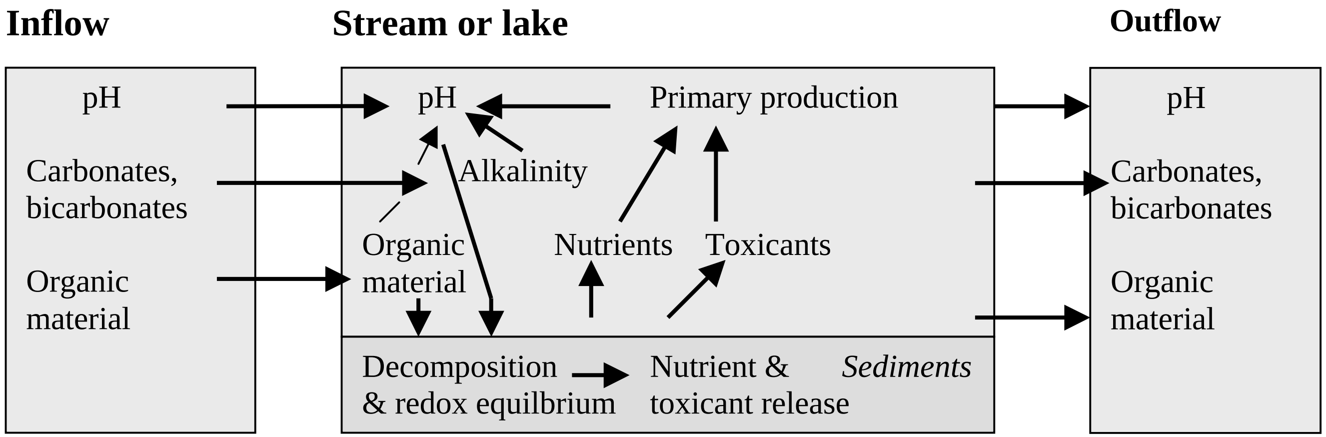
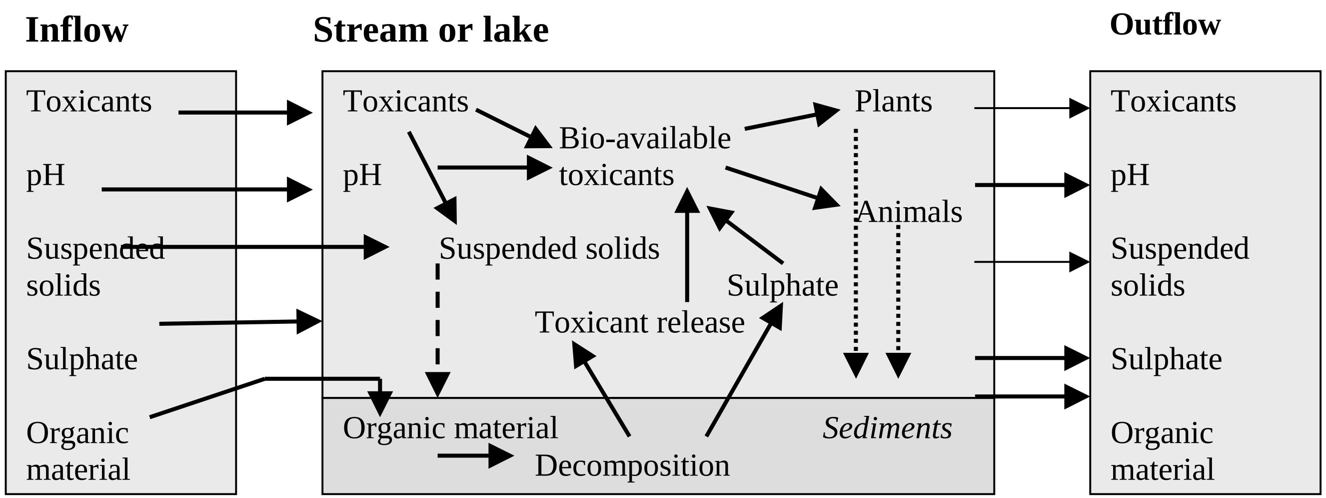


Figure B7. Effects of toxicants on biota and bio-geochemical processes



Appendix C. Selection of management actions and measures

C.1 Background

This Appendix contains a decision tree, guiding the practitioner in the selection of treatment actions and measures appropriate to the local context.

The decision tree matches devices having bio-geochemical interception processes consistent with the discharge and pollutant composition conditions. In the case of non-point source pollutant discharge, there are 3 dominant pollutant mobilisation, transport & interception pathways:

- elevated suspended solids & adsorbed nutrients, metals, toxicants & bacteria, usually associated with surface runoff or washoff, and intercepted by way of settling of particles in ponds or detention basins, or physical filtering by vegetation;
- dissolved & fine colloidal forms of pollutants, usually associated with interflow and groundwater discharges, and intercepted by way of adsorption onto fine particles in soils, or by biological uptake by biofilm in wetlands; and
- remobilised pollutants from deposited sediments, as a result of organic material decomposition (de-oxygenation), and interception by way of adsorption onto or biological uptake by biofilm in wetlands.

C.2 Dominant event discharge conditions

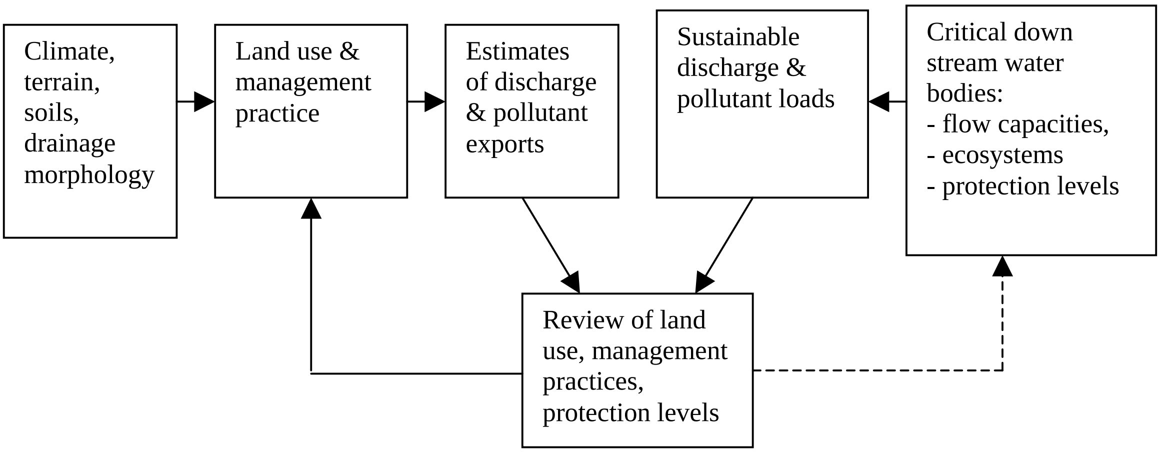
The decision tree has been compiled for urban standard residential development for which rapid runoff of rainfall is the dominant form of discharge. In the case of attenuated event flows or base flows low in Suspended Solids, the extended detention components of ponds & basins are not required. Biofilm based wetlands may be located 'off-line', depending on the magnitude of flood flows, to ensure that the biofilm is not washed-out.

C.3 Discharge & pollutant reduction targets

Appendix B outlined the process for determining threats to stream health or water use values, and the critical stressor load reduction required to meet the environmental and water use management objectives.

The required level of reduction in pollutants discharged or flows is an important determinant of the appropriate treatment measures. For example, high rainfall, steep terrain or soil types may limit the effectiveness of block and neighbourhood based measures, necessitating the adoption of urban waterway structural measures where significant reductions are required.

Figure C1. Assessment against external constraints: Setting reduction targets



C.4 Treatment measures in series or parallel

Cumulative interception assessment

Commonly, in retrofitting the installation of ponds or sedimentation based wetlands, the required treatment is met by adopting a number of ponds or wetlands in series. Also, the effectiveness of a treatment train is often calculated on the basis of addition of interception rates for each of the components. These practices are inefficient, and may result in exacerbation of impacts on receiving waters, rather than their amelioration, or significant over estimate of the effectiveness of measures.

In the case of GPTs or ponds in series (devices where interception is a function of detention time), except where there may be substantial further stormwater input below the first device, the theoretical interception of individual devices are not cumulative. The interception level for the device having the highest theoretical interception level is the total interception for the treatment train.

In the case of biofilm based wetlands (contact area based interception), the interception by wetlands in series is cumulative. It should be noted however, that biofilm based wetlands are rare in the case of urban stormwater systems.

Another common error in calculating the total interception of the treatment train, is to sum the theoretical percentage interception of each of the devices. Where ‘at-source’ swales are established upstream of a GPT, for example, there will be significant reduction in the coarse sediment loading on the GPT, thereby reducing its ‘percentage of catchment’ interception.

In the case of treatment measures in parallel, the cumulative interception is the sum of the separate parallel treatment measures.

Treatment train considerations:

Note that in the case of a number of treatment measures (ponds, wetlands, vegetated waterways), it is necessary to first remove the medium silt to coarse sand range of sediment (usually constituting some 90% of the total sediment load) in Gross

Pollutant Traps upstream of the ponds or wetlands. This action is required in order to protect the biological treatment components in the ponds or wetlands. This is analogous to the primary, secondary & tertiary treatment within wastewater treatment technologies.

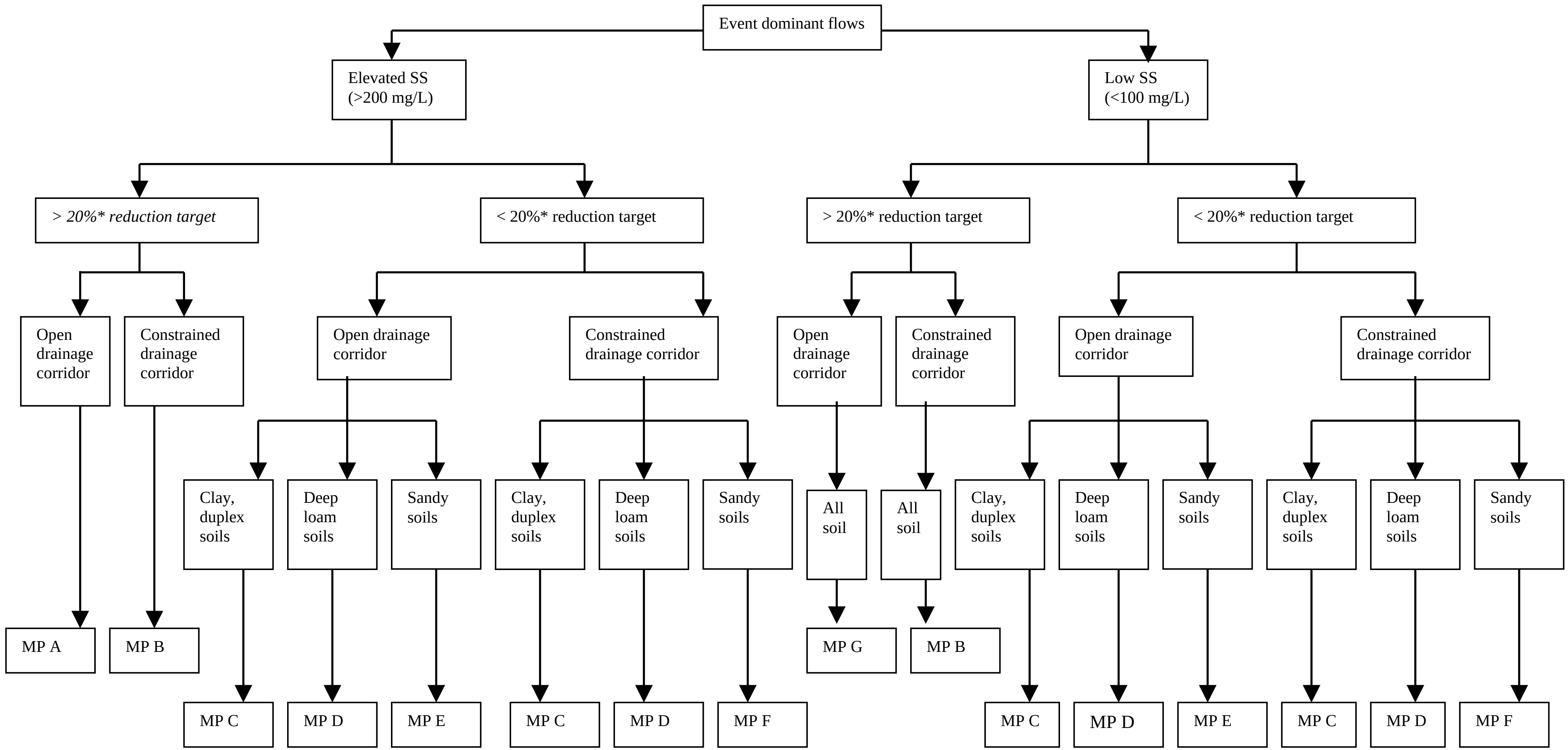
In addition to sequential removal of different pollutant components, it may be necessary (in the case of wetlands) to attenuate flow such that the storm event discharge velocities do not result in sloughing-off the fragile biofilm from macro plants and sediments.

C.5 Environmental values of treatment devices

As addressed in the body of the Workshop Report, the treatment devices are integral components of the urban environment, often providing significant open space (drainage corridors), landscape enhancement (wetlands, ponds, ephemeral plant zones) and interpretative facilities.

Over and above their flow attenuation and pollutant interception function, they may be required to meet a range of other environmental values. Integration of these requirements may require some modification to the suite of treatment measures generated by the decision tree.

Figure C2. Decision tree: Selection of management practices (MPs) for the standard residential development & event dominant flow condition. (Refer to next page for Management Practice (MP) key and descriptions).



Notes on Decision Tree:

Management Practice (MP) descriptions:

MP A. Waterway based GPTs, extended detention ponds & basins, vegetated waterway.

MP B. Block & neighbourhood scale pollutant traps & OSD basins, sand or fine screen filters in the case of high SS discharges, or vegetated buffer zones or wetlands in the case of low SS.

MP C. Block & neighbourhood based swales, gravel trenches with agricultural drains. Waterway based extended detention ponds in the case of high SS, or wetlands in the case of low SS.

MP D. Block & neighbourhood based swales, infiltration trenches.

MP E. Block & neighbourhood based infiltration techniques. Pre-treatment of surface drainage prior to infiltration in the case of deep sandy soils (protection of aquifer), or use of waterway wetlands to intercept and treat drainage in the case of shallow sandy soils over impermeable material.

MP F. Block & neighbourhood based infiltration techniques. Pre-treatment of surface drainage prior to infiltration in the case of both deep sandy & shallow sandy soils.

MP G. Waterway based GPTs, extended detention wetlands & basins, vegetated waterway.

* The 20% reduction target cut-off level for some management practices may be varied where:

- the rainfall depth (increase cut-off value for rainfall < 700 mm, decrease for rainfall > 900 mm);
- the terrain gradient (increase cut-off value for slopes of 1% to 2%, decrease for slopes < 1% (groundwater constraints), decrease for slopes > 7%). The potential for groundwater constraints will be further modified by soils;
- increase cut-off value (up to 40%) in cases of new (greenfield) developments where sub-division design incorporates treatment measures as an integral part of the landscape design & water cycling and on an area wide basis.

Reduction targets are relative to standard residential development & stormwater provision without flow detention or pollutant interception measures.

Appendix D: Estimation of catchment loads & pollutant interception

D.1 Urban Catchment Exports

D.1.1 Catchment discharge volume

Volumetric runoff coefficients based method

$Q_{urb} = R \times A_{urb} \times [(\%_{imp}/100 \times C_{imp} + (100-\%_{imp})/100 \times C_{perv}) + A_{rur} \times C_{rur} \times R] \times 10^{-2}$

where Q_{urb} = discharge in Ml,
R = rainfall in mm,
A_{urb} = urban area in ha,
$\%_{imp}$ = impervious area as a % of the total urban area
C_{imp} = impervious volumetric runoff coefficient (0.95),
C_{perv} = pervious area volumetric runoff coefficient (typically 0.15 to 0.4, depending on terrain, soils, antecedent rainfall conditions)
A_{rur} = rural area in ha
C_{rur} = volumetric runoff coefficient for rural parts of the catchment (typically 0.1 to 0.2 depending on terrain, soils, antecedent rainfall conditions)

Rainfall excess method

Long term runoff (including groundwater discharge) = Rainfall excess (mm) = Rainfall (mm) – Evaporation losses (mm)

Penman – Monteith ET_0 method

$ET = G \times Pan$

where ET is Penman-Monteith reference crop evapo-transpiration
Pan = Class A pan evaporation
G = the gradient of the ET_0 versus Pan regression line (refer to Table 4.4.1, Grayson et al 1996)

Evapo-transpiration (Thornewaite) method

$ET = 0.0444 \times N \times d \times (10T/I)^a$

where ET = reference crop evapo-transpiration mm/month
N = maximum number of hours of sunshine = $7.64 \arccos(-\tan\varphi \tan\delta)$
φ = latitude (radians) (negative for southern hemisphere)
δ = solar declination (radians) = $0.409 \sin(0.0172J - 1.39)$
J = Julian day (1 to 365)
d = number of days in month
T = mean temperature
I = annual heat index = $\Sigma(T/5)^{1.514}$
a = heat coefficient
$= 0.675 \times 10^{-6} \times I^3 - 0.771 \times 10^{-4} \times I^2 + 1.792 \times 10^{-2} \times I + 0.4924$

Event peak discharge (Rational formula)

$Q = 1/360 \times C \times I \times A$;

where Q = peak discharge rate in m^3/s

C = runoff coefficient for terrain, soil type & land use

I = rainfall intensity (mm/hr) for a storm duration equal to the time of concentration and for the desired return frequency

A = area of catchment (ha)

Source: Institution of Engineers Aust (1999), Australian Rainfall & Runoff

D.1.2 Catchment pollutant exports

Catchment sediment yield (Revised Universal Soil Loss Equation)

Average loss of soil/annum = R x K x LS x C x P

where R is the Rainfall erosivity factor = $164.7 \times 1.1177^{s} \times s^{0.644}$

s = 2 year ARI, 6 hr storm event intensity mm/hr

K is an erodibility factor for soil types

LS is the slope length & steepness factor

C is a cropping cover factor

P is a conservation factor

Refer to NSW Department of Housing (1998), *Managing Urban Stormwater: Soils and Construction* for detailed information on coefficient values and USLE application.

Nutrient exports

Table D1. Runoff depth – pollutant load correlation based estimates

Land use	Pollutant exports kg/km^2 as a function of runoff (R mm/event)				
	Sediment	Susp Solids	BOD	TP	TN
Native vegetation Canberra Sydney Brisbane	$200R^{1.1}$ $400R^{1.1}$	8R 20R 84R	$R^{1.6}$ $1.5R^{1.6}$ $2.6R^{0.57}$	$0.05R^{0.57}$ $0.12R^{0.57}$ $0.10R^{0.57}$	$0.15R^{1.6}$ $0.30R^{1.6}$ $0.07R^{1.6}$
Rural grazing Canberra Sydney Brisbane		20R		$0.12R^{0.57}$	$0.3R^{1.6}$
Urb residential Canberra Sydney Brisbane	$1000R^{1.4}$ $1000R^{1.4}$	$220R^{1.2}$ 300R $215R^{0.75}$	$20R^{0.81}$ $25R^{0.8}$ $9R^{0.9}$	$0.32R^{0.9}$ 0.35R $0.29R^{0.9}$	$2.0R^{1.08}$ $2.5R^{0.91}$ $2.6R^{0.86}$

Notes: R is runoff depth in mm per event or day.

Algorithms are based on event discharge – pollutant load correlations for pollutant loads calculated from storm event based monitoring.

Brisbane City Council has extended the runoff depth – pollutant export correlations to separate surface flows and throughflow (low flow) components. This resolves the apparent extreme concentration levels generated by the event based algorithms for low flow conditions. Source: Brisbane City Council (2000), Guidelines for Pollutant Export Modelling in Brisbane, Version 6

D.2 Estimates of pollutant interception

D.2.1 Pollution control ponds (sedimentation processes)

Appropriately sized pollution control ponds have been shown to sustain high levels of interception of urban stormwater pollutants. Typically, design objectives for pollutant interception are average annual values of 70 to 80% interception of SS, 60 to 70% of TP, and 40 to 60% of TN.

In the case of urban stormwater, there are two catchment discharge & pollutant composition categories:

i) elevated event discharges, high in suspended solids, with adsorption of nutrients, metals & toxicants onto surfaces of suspended solids;
ii) attenuated event discharges, low in suspended solids, with nutrients, metals & toxicants in dissolved or fine colloidal form.

In the case of the elevated discharges high in suspended solids, sedimentation based interception processes (pollution control ponds) are used to detain a significant proportion of the storm discharge, and to detain the discharge for sufficient time to permit the required removal (sedimentation) of pollutants. In the case of the attenuated flows low in suspended solids, biofilm based adsorption & biological uptake processes (wetlands) are used to intercept pollutants.

The design of pollution control ponds must address three issues:

i) the interception of a significant proportion of the discharge event volume;
ii) the detention of the intercepted runoff for sufficient time to permit the required interception (sedimentation) of suspended solids and adsorbed pollutants;
iii) the limiting of organic deposition per unit surface area of pond or wetland to levels that minimise the potential for creation of anaerobic & reducing conditions leading to the re-mobilisation of sedimented nutrients and toxicants in highly bio-available forms.

The first two of these issues are addressed through selection of an appropriate volume for a pond, and shaping to minimise the potential for short circuiting of flow.
The third issue is solved by ensuring that there is sufficient surface area of the pond to disperse the organic load, and designing the pond to ensure that deposition of organic material occurs as evenly as possible across the pond.

Suspended solids interception in ponds

Theoretically, the pollutant interception equals the proportion of inflow detained in the pond, times the percentage sedimentation of suspended solids in the inflow over the period of detention in the pond following the storm event.

However, because of mixing of the inflow with pond water during the event inflow (Continuous Stirred Tank Reactor assumption), a part of the theoretical portion of detained inflow is directly discharged from the pond during the event.

Percentage inflow volume detained ≈ $(1 – 0.3 \times V_{inflow}/V_{pond}) \times 100\%$

This approximation is valid for $V_{inflow} < 2 V_{pond}$

The adoption of extended detention ponds or wetlands is often used to maximise the inflow detention (replace V_{pond} with $V_{extended}$ in the equation above).

For the detained inflow, the % sedimentation of detained pollutants is a function of the detention time, temperature, grading of suspended particles and particle settling velocity.

Simple interception curves can be calculated for local discharges, based on the grading of suspended solids and the settling velocity for the range of particle sizes, using the formula:

$y/y_0 = 1 – (1 + nv_0/Q/A)^{-1/n}$

where y/y_0 = the proportion of particles removed in sedimentation basin

n = coefficient of sedimentation performance (function of flow variability over inflow period, with values of 0.5 to 1.0 for poor performance)

v_0 = settling rate of particle of diameter d mm

Q = inflow rate & A = surface area of pond

Hazen, A., On sedimentation, Trans.Am.Soc.Civil Engrs., 53, 63 (1904)

Table D2. Settling velocity of particles (for SGs of 2.5 to 2.65)

Properties	Particle size classification					
	Medium sand	Fine sand	Coarse silt	Medium silt	Fine silt	Clay
Diameter (mm)	0.6 to 0.2 (0.2)	0.2 to 0.06 (0.06)	0.06 to 0.02 (0.02)	0.02 to 0.006 (0.006)	0.006 to 0.002 (0.002)	< 0.002 (0.0005)
Efficiency	0.9	0.9	0.8	0.7	0.6	0.5
v_0 (cm/s)	3.9	2.6×10^{-1}	2.6×10^{-2}	2×10^{-3}	1.9×10^{-4}	1×10^{-5}

Notes: Values in brackets are diameters used to calculate v_0

$v_0 = \eta \times 9.81/18 \times (SG – 1) \times d^2$ m/s, d in mm. (for particles d < 0.08 mm)

For open ponds, subject to a range of inflow rates during the event, the sedimentation performance coefficient is very poor, with a value of n = 1 providing a good reflection of field performance. $y/y_0 = 1 – 1/(1 + nv_0A/Q)^{-1/n} = 1 – 1/(1 + v_0A/Q)$

Table D3. Interception (proportion of inflow) of SS as a function of detention time & particle size. (Values for 5 ha pond & 2 Ml/d dry weather inflow)

Size range	Av v_0 (m/day)	Detention time between events (days)			
		1	3	10	20
0.2 to 0.06	224	1.00	1.0	1.0	1.0
0.06 to 0.02	22	1.00	1.00	1.0	1.0

0.02 to 0.006	1.8	0.98	0.99	1.00	1.00
0.006 to 0.002	0.16	0.80	0.93	0.98	0.99
0.002 to 0.0005	0.01	0.20	0.47	0.71	0.83

Computational method:

For local SS grading & average retention time between storm events, calculate the proportion of SS intercepted, where:

Total interception

= proportion inflow detained x Σ(interception$_{\text{detention period}}$ x proportion of total grading x SS_{inflow}) across the full range of particle grading.

Av retention time between events = $^{(365 - \text{no rain days}>5\text{ mm})}/_{(\text{no rain days}>5\text{ mm})}$

It should be noted that this is an approximate solution. More accurate estimates, taking into account the event period and changing y_0 values on a daily basis, are available in models such as the CRCFE Pond Model.

Calculation of TP, TN & organic material (BOD) removal:

Nutrients, organic material, metals etc are adsorbed onto SS and removed as part of sedimentation. The weight of nutrients, metals, etc adsorbed onto SS particles is a function of the particle surface area, which in turn is a function of the particle diameter. Laboratory adsorption tests have established the following adsorption ratios:

TP = $0.7e^{-0.011d}$ mg of P/g SS

TN = $6e^{-0.014d}$ mg of N/g SS

BOD = $50e^{-0.014d}$ mg of BOD/g SS

where d is particle diameter in μm

Total TP interception = proportion inflow detained x Σ_d(Interception$_{\text{detention period}}$ x proportion $TP_{adsorbed}$ x TP_{inflow}) across the full range of particle grading. TN & BOD interception as for TP.

Check for remobilisation potential

If the level of sedimented organic material ($\Sigma BOD_{5\text{ day}}$)>5 g/m^2 of pond surface area, there is a potential for major remobilisation of a range of sedimented pollutants (nutrients, metals, pesticides) in a highly bio-available form. There is a need to check that this limit has not been exceeded.

i) Estimate organic loading for storm event (refer to Section 1.2)

ii) Estimate retention of organic material

Total BOD interception = Σ_d(Interception$_{\text{detention period}}$ x proportion $BOD_{adsorption}$ x BOD_{inflow}) across the full range of particle grading.

iii) Estimate loading/m^2 pond area

Sizing (area) criteria: Limit BOD load/event < 5 g/m^2 of pond surface area.

Example:

Calculate SS interception for a storm discharge of 20 Ml into a pond of 80 Ml, followed by a 10 day detention period. SS grading 5% fine sand, 15% coarse silt, 25% medium silt, 35% fine silt & 20% clay.

Calculate the BOD interception & check for remobilisation potential for a 200 kg BOD catchment discharge.

Table D4. In-pond interception of SS & BOD at 1 day post event

Size range (mm)	SS grading proportion of total SS	Interception individual SS range Table D3	SS interception (proportion of total)	BOD adsorption (mg/g SS)	BOD adsorption proportion	Interception individual BOD range (SS intercept x BOD_{adsorb} proportion
0.2 0.06	0.05	1.0	0.05	12	0.07	0.07
0.06 0.02	0.15	1.0	0.15	25	0.14	0.14
0.02 0.006	0.25	0.98	0.24	40	0.23	0.22
0.006 0.002	0.35	0.80	0.28	47	0.27	0.18
0.002 0.0005	0.20	0.20	0.04	50	0.29	0.06
Total			0.76	174	1.00	0.67

In-pond interception of SS = 0.76. Total proportion of SS interception = event inflow retention x in-pond interception = 0.9 x 0.76 = 0.68 at 1 day detention.

In-pond interception of BOD = 0.67. Total proportion of BOD interception = event inflow detention x in-pond interception = 0.9 x 0.67 = 0.60.
For a storm event BOD export of 200 kg:

pond loading = 200 x 0.6 x 10^3/(5 ha x 10^4) = 2.4 g/m^2 of pond surface area.

This is within the 5 g/m^2 limit. It is concluded that there is a low potential for remobilisation of sedimented pollutants.

Note that there is an integrated mixing, washout, sedimentation & sediment redox model (Excel spreadsheet based) available on the CRCFE Web page for downloading. (refer to http://freshwater.canberra.edu.au, Main Menu, What's New, Latest Activities, water quality models, Pdmod9E.xls).

D.2.2 Wetlands (biofilm adsorption & biological uptake processes)

In many cases, wetlands applied to urban stormwater systems in fact operate as sedimentation processes. In these situations, analysis should be based on pond interception estimate techniques.

In the case of the attenuated flows low in suspended solids, biofilm based adsorption & biological uptake processes (wetlands) are used to intercept pollutants.

The order of biofilm uptake for urban stormwater inflows and constructed wetlands is:

TP uptake = 0.03 g/m^2/d
TN uptake = 0.2 g/m^2/d
DOC uptake = 1.2 g/m^2/d

Analysis needs to also consider detention time and washout of pollutants. The CRCFE Wetland Model (refer to http://freshwater.canberra.edu.au, Main Menu, What's New, Latest Activities, water quality models, Wmod2.xls).

D.2.3 Gross pollutant traps

Gross pollutant traps comprise screens or booms and tanks for the physical screening of trash and sedimentation of suspended particles.

Sedimentation of fine particles

$y/y_0 = 1 - (1 + nv_0A/Q)^{-1/n}$ * or $(1 - \exp(- 1.05v_0A/Q)$ **

* Hazen, A., On sedimentation, Trans.Am.Soc.Civil Engrs., 53, 63 (1904)

** ACT Gross Pollutant Trap Guidelines (1992)

where y/y_0 = the proportion of particles removed in sedimentation basin
n = coefficient of sedimentation performance (function of flow variability over inflow period, with values of 0.5 to 1.0 for poor performance)
v_0 = settling rate of particle of diameter d mm
Q = flow rate
A = surface area of sedimentation basin (channel)
L = length of Trap (m)

For sedimentation basin subject to a range of flows and elevated velocities, sedimentation performance is poor, with a coefficient 'n' of 0.5, the Hazen formula yields:

$y/y_0 = 1 - 1/(1 + 0.5v_0A/Q)^2$

Traps are normally designed for trapping of sediments above a specific size particle, based on the protection of downstream water features. Typical interception criteria are 70% of 0.04 mm & larger particles. Note that the hourly based flow method of the ACT Guidelines provides the more accurate basis of estimation.

Total proportion intercepted per event = Σ(Interception x proportion grading) across all particle grading (size) ranges for the event inflow condition.

To calculate average annual interception, generate a discharge frequency histogram for the catchment, and apply formula for predicting sediment export & GPT interception for each discharge range and frequency. Multiply catchment export and GPT interception by frequencies to calculate average annual interception.

Example: Calculate the interception of sediment 0.04 mm or larger, for a 400 m^2 trap for a storm event having an average discharge of 1.0 m^3/s, and a sediment grading of 15% coarse sand, 25% medium sand, 35% fine sand, 35% coarse silt to 0.04 mm size.

Table D5. Interception by particle size range

$d_{min'm}$ mm	v_0 m/s	Interception (Hazen)	Interception (ACT Guideline)	Grading proportion	Proportion interception
0.6	2.0×10^{-1}	1.00	1.0	0.15	0.15
0.2	4×10^{-2}	0.99	1.0	0.25	0.25
0.06	2×10^{-3}	0.49	0.55	0.35	0.17
0.04	1×10^{-3}	0.31	0.33	0.35	0.11
Total					0.68

Total interception = 68% of the > 0.04 mm suspended solids

D.2.4 Infiltration trenches

Infiltration interception devices comprise the direct infiltration of polluted waters into fine soils media, physically filtering out the particulate material, and adsorbing the dissolved and fine colloidal forms on soil particles.

Laminar flow in granular material

$v = ks$ (Darcy's Law)

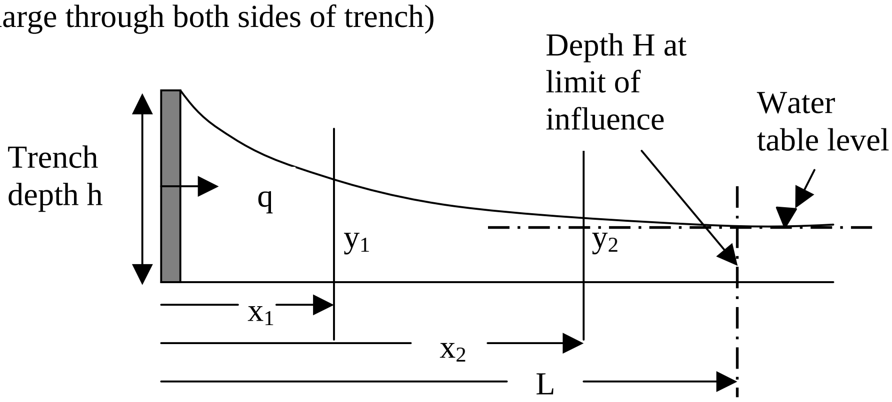
where v = pore water velocity (m/s),
k = coefficient of permeability (m/s),
s = head loss per unit length of flow,
q = flow rate m^3/s

Typical k values:

Sandy loam 10^{-4} to 2×10^{-5} m/s,
Loam 3×10^{-5} to 10^{-5} m/s,
Clay loam 2×10^{-5} to 10^{-6} m/s

Source: Craze, B & Hamilton, G.J (1991), Soil Physical Properties, in Chapman, P.E.V & Murphy, B.W. (Eds), Soils: Their Properties and Management, A Soil Conservation Handbook for NSW

a) Trenches (recharge through both sides of trench)



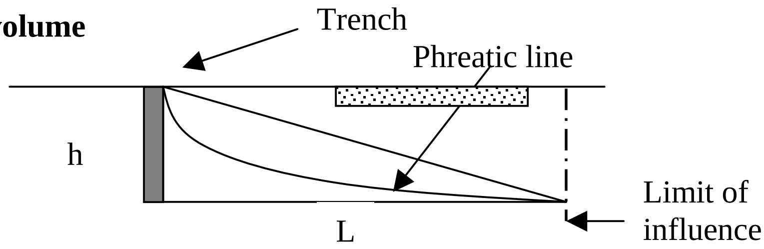
Infiltration computation

$q = 2 k y \, dy/dx$ for two sided trench flow
$2 y \, dy = q/k \, dx$
$y_2^2 - y_1^2 = q/k (x_2 - x_1)$ (Dupuit's theory)

$q \approx k (H^2 - h^2)/L \approx k h^2/L$ (for small initial values of H) $\approx 3.6 \times 10^3 k h^2/L$ m^3 per metre length of trench per hour

where q = recharge rate per unit length in m^3/hr
h = depth of water in recharge trench in metres
H = depth at limit of influence in metres
L = distance to limit of influence in metres
k = coefficient of permeability in m/s

Infiltrated water volume



Infiltration volume = 2 x area under curve x length of trench x porosity x 1000 litres
= 2 x h/5 x L x 0.3 = 0.12 h L m^3/m of trench (fine grained material)
= 2 x h/3 x L x 0.3 = 0.20 h L m^3/m of trench (coarse grained material)

Volume trench water = h x width x length x porosity of gravel backfill
= 0.4 h litres/m length for 1.0 m wide trench

Assume that in the case of fine soils, all of the SS in infiltrated water is trapped by fine soil in walls of trench, and that dissolved & colloidal material is adsorbed by soil.

Reduction in pollutants (kg) = infiltration volume (m^3) x concentration pollutant (mg/L) x 10^{-3}

Solution strategy:
Assume that the soil moisture content at start of the event is low, with small values of H relative to h. Initially, the distance or limit of influence will be small, with gradual increase as the cumulative recharge volume is increased over time.
Solve using an hourly stepwise based analysis, balancing rate of infiltration for period with incremental volume of water stored for increase in limit of influence volume.

Example: Trench in sandy loam over clay C horizon at a depth of 0.8 m. Inflow has SS content of 1000 mg/L & TP of 1.0 mg/L. Assume trench full condition over period of event, and a 'k' value of 2×10^{-5} m/s. Calculate infiltration & pollutant interception for a 2 hr event & trench 100 m long.

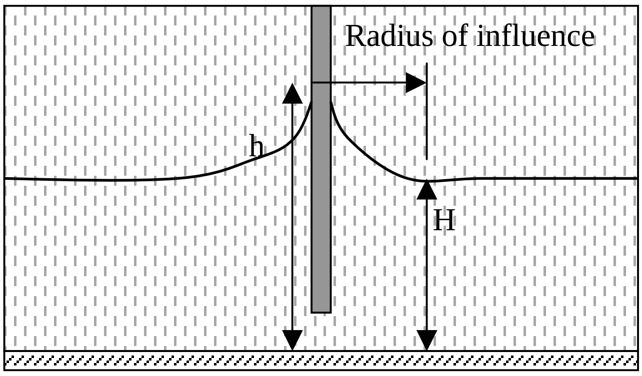
q_{max} $= 3.6 \times 10^3 k h^2/L = 3.6 \times 10^3 \times 2 \times 10^{-5} \times 0.64/L$
$= 0.047/L$ m^3/hr/metre length of trench.

Table D6. Stepwise solution of trench infiltration

Time increment	Trial L (m)	ΔV infiltration (q_{max} = 47/L) m^3/m	ΔV for ΔL (0.12 h L) m^3/m	Adjusted trial L (m)
1st hr	1.0	0.047	0.096	0.7
	0.7	0.066	0.067	OK
2nd hr	1.0	0.042	0.040	OK

Total infiltration + storage = (0.107 + 0.32) m^3/metre x 100 m = 43 m^3.
SS interception 43 x 1000/10^3 = 52 kg.
TP interception 43 x 1.0/10^3 = 0.052 kg.

b) Wells (unconfined aquifer above impermeable bed)



Infiltration computation

$Q = 2\pi\ k\ x\ y\ dy/dx$
$y\ dy = Q/(2\pi\ k)\ dx/x$
$y^2 - h^2 = Q/(\pi\ k)\ \ln(x/r)$ (Dupuit's theory)
$Q \approx \pi\ k\ (H^2 - h^2)/\ln(R/r) \approx \pi\ k\ h^2/\ln(R/r)$ for small initial values of H

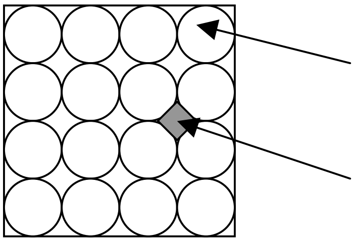
where
- Q = recharge rate m^3/s
- H = depth at limit of influence (m)
- h = depth of water in recharge well (m)
- R = radius of influence (m)
- r = radius of well (m)
- k = coefficient of permeability (m/s)

(Refer to **Trenches** section for analysis techniques)

D.2.5 Drainage cells

Coarse 'no fines' gravel packed in trenches may be used to address a range of functions, including infiltration trench, grounwater interception/recharge, and as a drainage conduit. This section provides guidance on the estimates of capacity of the trench as a drainage conduit.

Because of the high Reynolds number associated with flow through coarse gravel or aggregate, the flow conditions are non-laminar. To estimate flow capacity, treat as a series of parallel tubes through the trench, having a diameter of the mean of the void sizes, and a high roughness value.



Calculate discharge rates for 600 mm wide x 600 mm deep gravel cell for a 3% grade

For a gravel 38 mm in diameter, $D_{void} \approx 25$ mm
For a relative roughness = $\varepsilon/D = 0.1$, $f = 0.09$
$h_L = f\ L/D \times v^2/2g$
$v = [h_L/L \times 2gD/f]^{0.5} = [0.03 \times 2 \times 9.81 \times 0.025/0.09]^{0.5} = 0.4$ m/s
For trench 0.6 m x 0.6 m = 0.36 m^2 csa, void area ≈ 0.36 x 40% = 0.14 m^2
Q = 0.14 x 0.4 =0.06 m^3/s

D.2.6 Infiltration & groundwater recharge basins

Recharge basins are used to intercept and store stormwater runoff with a view to promoting infiltration into soil layers or the recharge of deeper groundwater aquifers, as a means of reducing stormwater peak flows, storing water (groundwater abstraction), and/or pollutant interception.

Infiltration involves simple movement of surface water under gravity through permeable surface layers into soil voids. The rate of infiltration assisted by development of hydraulic head, while temporary surface storage enables retention of surface drainage until full infiltration has occurred.

As stored water begins to infiltrate into the underlying soil, its initial pathway is short, with a high inflow rate associated with a steep hydraulic gradient.
Sequentially over time, the pathway is lengthened as a result of infiltrating water filling voids, while the surface water depth is reduced as a result of water lost to infiltration, but increased as a result of the depth of saturated soil voids.

$\Delta V_1 = Q_1 \Delta t = \Delta t\ k\ A\ (h_1 + d_1)/d_1$
$d_2 = d_1 + \Delta V_1/v_p$
$h_2 = h_1 - \Delta V_1 + d_2$
where ΔV = infiltration volume for time increment Δt
Q_1 = inflow for hydraulic gradient h_1/d_1
Δt = time increment for computation of infiltration volume
k = coefficient of permeability m/s
A = surface area (1 m^2)
h_1 = surface water ponding depth

d_1 = depth of saturated soil voids

Example:

Ponding of 200 mm depth of stormwater has occurred over a loam soil of coefficient of permeability of 5 x 10^{-5} m/s & a void ratio of 0.4. Calculate the time to infiltrate into the underlying soil, using time increments of 10 minutes & starting d_1 = 100 mm. $\Delta V_1 = \Delta t\ k\ A\ (h_1 + d_1)/d_1 = 0.03\ (h_1 + d_1)/d_1$

Table D7. Time increment based calculation of infiltration rates & drainage time

Time interval	d_1 (m)	h_1 (m)	(h_1+d_1) (m)	$\Delta V_1 =$ $0.03\ (h_1 + d_1)/d_1$ (m^3)	$d_2 =$ $d_1 + \Delta V_1/v_p$ (m)	$h_2 =$ $h_1 - \Delta V_1$ (m)
10 min	0.1	0.2	0.3	0.09	0.33	0.14
10 min	0.33	0.14	0.47	0.043	0.44	0.10
10 min	0.44	0.10	0.54	0.037	0.63	0.06
10 min	0.63	0.06	0.69	0.033	0.71	0.03
10 min	0.71	0.03	1.01	0.043		0

Time to drain = 50 minutes

D.2.7 Porous (cellular) pavements

Operate in a similar manner to the infiltration trenches, with granular material built into the modular cells providing storage for initial interception and detention of rainfall, with longer term infiltration through the sub-base as a function of the coefficient of permeability of the sub-base and insitu soil base. Refer to manufacturer’s design information for infiltration rates.

D.2.8 Sand filters

Where significant reductions in levels of stormwater suspended solids related pollutants are required, slow sand filters offer a robust basis for management. Their ongoing effectiveness requires periodic removal & replacement of filter media.

Detention tanks used in association with sand filters (attenuation of peak discharge) may also provide significant sediment interception by way of sedimentation of SS during detention. The GPT Section 2.3 above provides a method for determining the contribution of the detention tanks to SS removal.

Filter flow-through rates vary as a function of the sand media coefficient of permeability, the hydraulic head over the filter, and build-up of intercepted SS. Initially, rates of the order of 0.3 m/hr may be experienced. As SS accumulates, flow-through rate drops off to 0.050 to 0.075 m/hr (accumulated SS layer become the hydraulic control).

Colorado Urban Drainage & Flood Control District Method

Filter flow-through rates:

$q = k_f \times L_m^{-c} = 0.8\ L_m^{-1.165}$ (Suggested design equation)

where q = unit flow rate in m/hr

L_m = cumulative SS removed kg/m^2

k_f = empirical flow-through constant

c = empirical exponential constant

For field conditions of catchment determined event discharges & SS loads

$q = V_w/At$

$L_m = 0.83/q^{0.86}$

where V_w = volume of water to be filtered

A = area of filter (m^2)

t_h = detention time (hrs)

Source: Urbonas, BR. 1999. 'Design of a Sand Filter for Stormwater Quality Enhancement', *Water Environment Research V.71;1, pp.102-113*

For trial filter area & detention capacity (drainage time):

- Calculate through-flows (& by-passed flow) for filter for range of event discharges, and SS interception ($L_m = 0.83/q^{0.86}$)
- Compare with interception objective and adjust the trial filter area as required.

Auckland Regional Council Method

$A = V_w/Kt(h + D)$

where A = area of filter m^2

V_w = volume to be infiltrated (m^3)

K = hydraulic conductivity (0.033 m/hr)

t = drainage time (hrs) (16 – 24 hrs, depending on inter-event period)

h = average head above filter (50% storage depth)

D = depth of filter (m) (min'm of 0.4 m)

Source: Auckland Regional Council. 1992. *Design Guideline Manual: Stormwater Treatment Devices*, prepared by Beca Carter Hollings & Ferner.

D.2.9 Swales

The interception of pollutants by Swales comprises two processes:

- infiltration of storm runoff, with reduction in pollutants proportional to reduction in discharge as a result of infiltration (for fine soils, this is a minor component);
- sedimentation of Suspended particulates and adsorbed pollutants as a function of detention time & suspended solids grading.

Calculation of flow & depth

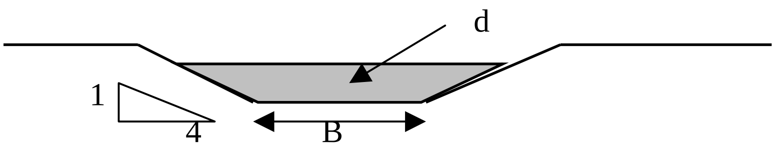
Flow in grassed trapezoidal channels

$v = 1/n \times R^{0.67} \times s^{0.5}$; $Q = v \times A$

where v = velocity m/s
Q = discharge in m^3/s
n = Manning's roughness value = 0.2 for shallow flow through dense grass to 0.02 for deeper flow over grass
R = hydraulic radius = A/wetted perimeter ≈ flow depth 'd' for shallow flow conditions
s = hydraulic gradient (0.01 to 0.05 for 1% to 5% gradients)

Roughness coefficients as high as 0.2 are possible for low depths of flow and lush grass cover in warm and humid areas on well drained loams. However, for regions experiencing periodic extended dry or hot conditions, or cold winters or poorly drained soils, maximum roughness values of only 0.1 to 0.15 may be achieved.
For low gradients (< 0.02) or poorly drained soils, the installation of a sub-soil drain or a lined low flow invert is recommended to limit potential water logging or mosquito hazards.

Example: Calculate the flow for a trapezoidal channel base width 1 m & gradient of 1% for a depth of flow of 0.013, 0.025, 0.05, 0.1 & 0.2 m



Wetted perimeter = B + 8.25 x d; A = d(B + 4d); R = (B + 4d)/(B + 8.25d)

Table D8. Computation of flow in swales

Depth (m)	'n'	R	Slope s	v (m/s)	Q (m^3/s)
0.025	0.20	0.023	0.01	0.04	0.001
0.05	0.15	0.042	0.01	0.08	0.005
0.10	0.10	0.08	0.01	0.18	0.025
0.20	0.10	0.14	0.01	0.27	0.097
0.025	0.20	0.023	0.03	0.07	0.002
0.05	0.15	0.042	0.03	0.138	0.009
0.10	0.10	0.08	0.03	0.311	0.043
0.20	0.10	0.14	0.03	0.467	0.168

Sedimentation of fine particles

Refer to Equation D??

Example: Calculate y/y_0 for SS for a trapezoidal channel base width 1 m, length of 30 m & 60 m, flows of 0.005, 0.025, 0.200 m^3/s & n values of 0.15, 0.10 & 0.05 respectively. Calculate the total SS interception for a grading of 20% fine sand & coarser material, 30% coarse silt, 30% medium silt & 20% finer material.

$y/y_0 = 1 – (1 + nv_0A/Q)^{-1/n}$

$= 1 – 1/(1 + 0.5v_0A/Q)^2$ for sedimentation performance value n = 0.5

Table D9. Computation of swale SS interception (as proportion of inflow)

Depth of flow (m)		0.025	0.05	0.2
Slope of Swale(%)		1	1	1
Flow Q (m^3/s)		0.001	0.005	0.100
Swale Width (m)		1.1	1.2	1.8
Swale Area (m^2)		33	36	54
A/Q		33000	7200	540
v0 by SS grading	Fine sand	3×10^{-3}		3×10^{-3}
	Coarse silt	0.3×10^{-3}		0.3×10^{-3}
	Medium silt	0.02×10^{-3}		0.02×10^{-3}
	Fine silt	2×10^{-6}		2×10^{-6}
	Clay	0.1×10^{-6}		0.1×10^{-6}
SS interception	Fine sand	1.00	0.70	0.99
	Coarse silt	0.97	0.15	0.78
	Medium silt	0.44	0.01	0.13
	Fine silt	0.06	0	0.01
	Clay	0	0	0
SS proportion	Fine sand	0.1		0.1
	Coarse silt	0.3		0.3
	Medium silt	0.3		0.3
	Fine silt	0.2		0.2
	Clay	0.1		0.1
Total interception	Fine sand	0.1	0.07	0.099
	Coarse silt	0.29	0.045	0.234
	Medium silt	0.132	0.003	0.039
	Fine silt	0.012	0	0.002
	Clay	0	0	0
Total SS interception		0.534	0.118	0.374

To calculate average annual interception, generate a discharge frequency histogram for the catchment, and apply formula for predicting sediment export & swale interception for each discharge range. Multiply catchment export and swale interception by frequencies to calculate average annual interception.

Note: With sequential discharges from residential blocks along the swale, there is either a requirement to increase the width of the swale or the addition of a substantial length at the end of the swale to maintain performance.

Calculation of TP, TN & organic material (BOD) removal:

Nutrients, organic material, metals etc are adsorbed onto SS and removed as part of sedimentation. The weight of nutrients, metals, etc adsorbed onto SS particles is a function of the particle surface area, which in turn is a function of the particle diameter. Laboratory adsorption tests have established the following adsorption ratios:

$TP = 0.7e^{-0.011d}$ mg of P/g SS
$TN = 6e^{-0.014d}$ mg of N/g SS
$BOD = 50e^{-0.014d}$ mg of BOD/g SS
where d is particle diameter in μm

Total TP interception = Σ_d(Interception x % grading x SS_{total} x TP adsorption) across the full range of particle grading. Total TN & BOD interception as for TP.

D.2.10 Vegetated filter strips

Vegetated filter strips have limited application in urban areas, due to the difficulty of maintaining uniform (sheet) flow across the full length of the strip (short circuiting), and often adverse gradients imposed as a result of sub-division design.

For calculation of suspended particle interception, apply the same estimation method as for the swales in Section D.2.8 above.