
3 STORMWATER MANAGEMENT

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3.1 DEFINITION

Urban stormwater management, simply stated, is everything done within a catchment to remedy existing stormwater problems and to prevent the occurrence of new problems (Walesh, 1989). It involves the development and implementation of a combination of structural and non-structural measures to reconcile the conveyance and storage function of stormwater systems within the space and related needs of an expanding urban population. It also involves the development and implementation of a range of measures or Best Management Practices (BMPs) to improve the quality of urban stormwater runoff prior to its discharge to receiving waters. Typical measures used for stormwater management are represented in Figure 3.1.

There is increasing recognition in developed countries that stormwater management needs to be undertaken in a safer and more ecologically sustainable manner. Stormwater should be regarded as an asset and a resource to be valued, rather than the traditional attitude of regarding it as a nuisance to be disposed of as quickly as possible. Many rivers, lakes, and coastal waters are currently degraded by urban stormwater due to excessive flows, poor water quality, removal of riparian vegetation, and the destruction of aquatic habitats. This has resulted fundamentally from a primary focus on a rapid disposal/conveyance-oriented approach to stormwater management. Stormwater management practices need to be broadened to consider environmental issues such as water quality, aquatic habitats, riparian vegetation, and social issues such as aesthetics, recreation, and economics.

3.2 STRATEGIC APPROACH

In a number of developed countries, greater awareness of the sensitivity and importance of the natural environment has led to a marked change in the approach to managing the environment by governments and communities at large. This change has been embodied in the concept of ecologically sustainable development, which is aimed at ensuring that development can occur without long-term degradation of natural resources and the environment.

Management of water resources has traditionally focused on protecting human health-oriented values. The control of both the quantity and quality of urban runoff is now being seen to be also of major importance in the management of catchments and receiving waters. A different approach to the management of urban stormwater that has been evolving over the past decade has involved:

- the establishment of a storage-oriented approach for controlling runoff quantity from development sites;
- the identification of the environmental values (or beneficial uses) of particular water bodies which are to be protected;

- the establishment of objectives which will achieve required levels of flood protection and water quality enhancement;
- the establishment of water quality management strategies;
- the development and implementation of monitoring and surveillance programs to ensure that runoff quantity and water quality (or environmental) objectives are being maintained; and
- the implementation of research programs to gain a better understanding of the behaviour of aquatic systems in order to improve water quality design and management techniques.

Public involvement is emphasised at all stages of this approach. This reflects the philosophy that all organisations and individuals (*stakeholders*) who influence, or are affected by the stormwater system, should have a say in its management.

This approach is based on the following set of broad and holistic principles for effective stormwater environment management within a catchment and its receiving waters:

- *hydrological* : minimising changes to the hydrological characteristics of a catchment, including wet and dry weather flows, to achieve appropriate flow objectives
- *water quality* : minimising the amount of pollution entering the stormwater system (housekeeping/source control) and removing an appropriate amount of any residual pollution by implementing treatment BMPs
- *vegetation* : maximising the value of indigenous riparian, floodplain, and foreshore vegetation
- *aquatic habitat* : maximising the value of habitats for aquatic fauna within the stormwater system

These principles are inter-related and the failure to consider any one of them may compromise the values of a stormwater system. The relative importance of these principles can, however, vary within and between catchments and some compromises between them may be needed at any particular site to achieve a balanced environmental outcome.

An appropriate hierarchy for stormwater management based on these principles is shown in Figure 3.2.

3.3 WATER CYCLE MANAGEMENT IN URBAN AREAS

3.3.1 Urban Water System

Chapter 2 has described the *hydrologic cycle*. This natural process has been very extensively modified in urban areas (Musiak, 1991).

Figure 3.3 gives a representation of the urban water

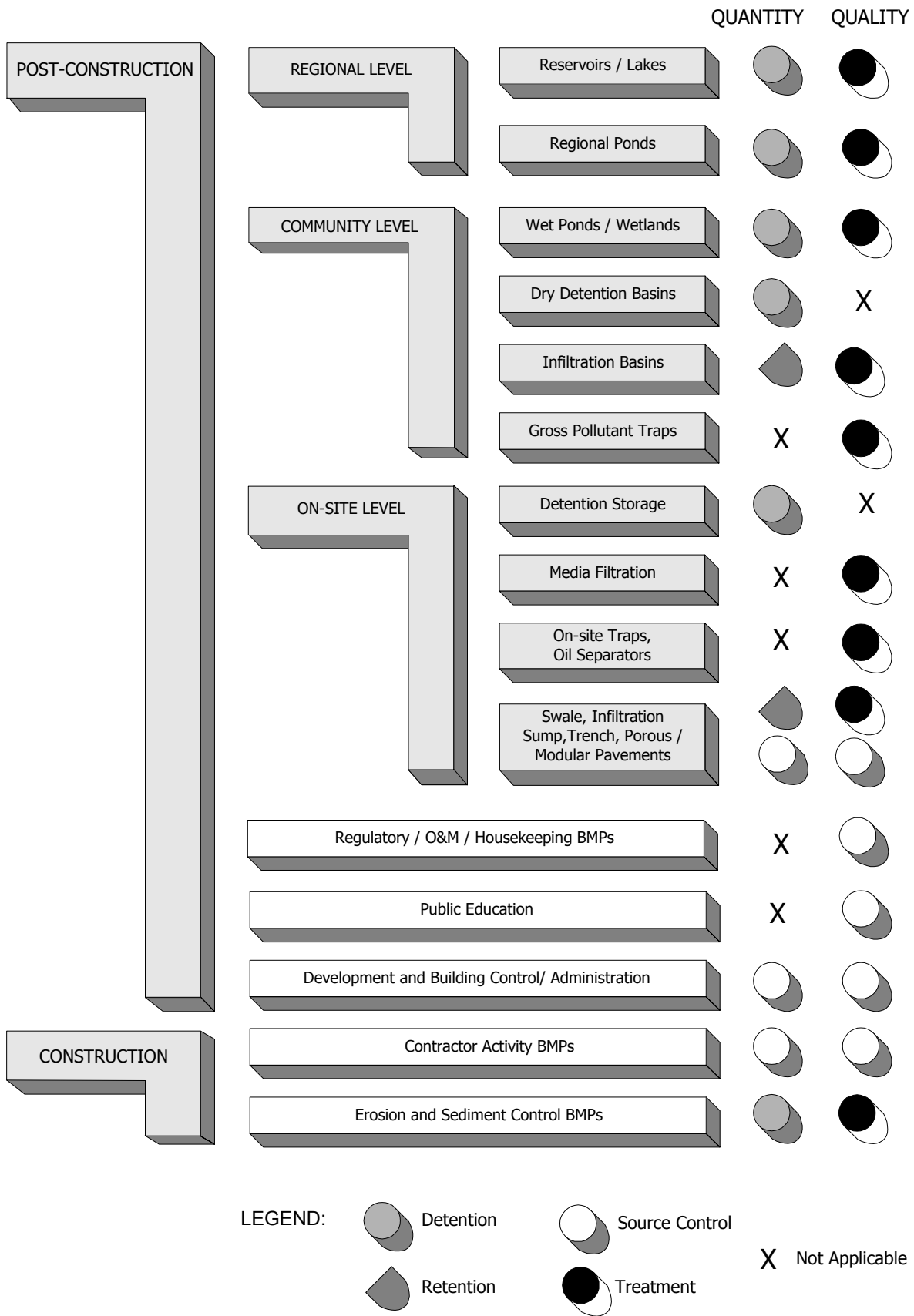


Figure 3.1 Typical Stormwater Management Measures

system. The flows taking place in the system can be classified into three streams:

- the natural processes of rainfall, infiltration, evapotranspiration and runoff;
- the artificial paths for drainage of stormwater such as gutters, pipes, open drains, detention basins and engineered waterways; and
- the water supply system, which feeds into the sewerage system

- increased impervious areas which increase flash flooding and reduce natural groundwater recharge,
- reduction in flow of river systems due to urban water supply diversions. Much of the flow is conveyed in sewers to discharge points further downstream,
- the economically wasteful use of high-quality drinking water, for low-value uses such as toilet flushing and garden watering
- wet weather wastewater overflows, caused by infiltration and impacting on receiving waters.

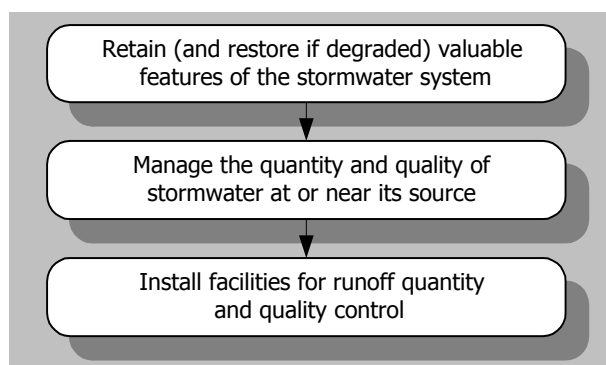


Figure 3.2 Stormwater Management Hierarchy

These flow paths are not fully independent but are partly connected to each other. To fully understand the urban water system, it is necessary to quantify each of these components and their interrelationships in the cycle.

3.3.2 Need for Integrated Management Approach

Many examples can be quoted of the interdependence of the three urban water systems:

Major problems in Malaysia related to urban water management include the shortage of water, pollution of water bodies, urban flood hazards, and deterioration of the environment surrounding rivers. To date a piecemeal approach has been adopted to solving these problems.

Appropriate adjustments of these previously piecemeal efforts are needed in order to achieve efficient and environmentally sustainable operation of the urban water cycle. As noted by Musiaka (1991), the inertia of the existing fragmented administrative arrangements makes this adjustment difficult. Nevertheless, it must be pursued. Some examples of integrated measures which can be adopted include:

- integrated landuse planning to achieve multiple uses for urban land,
- capture and storage of roof runoff in order to reduce demands on the household potable water supply,
- ponding of surface runoff for community non-potable water supply use,

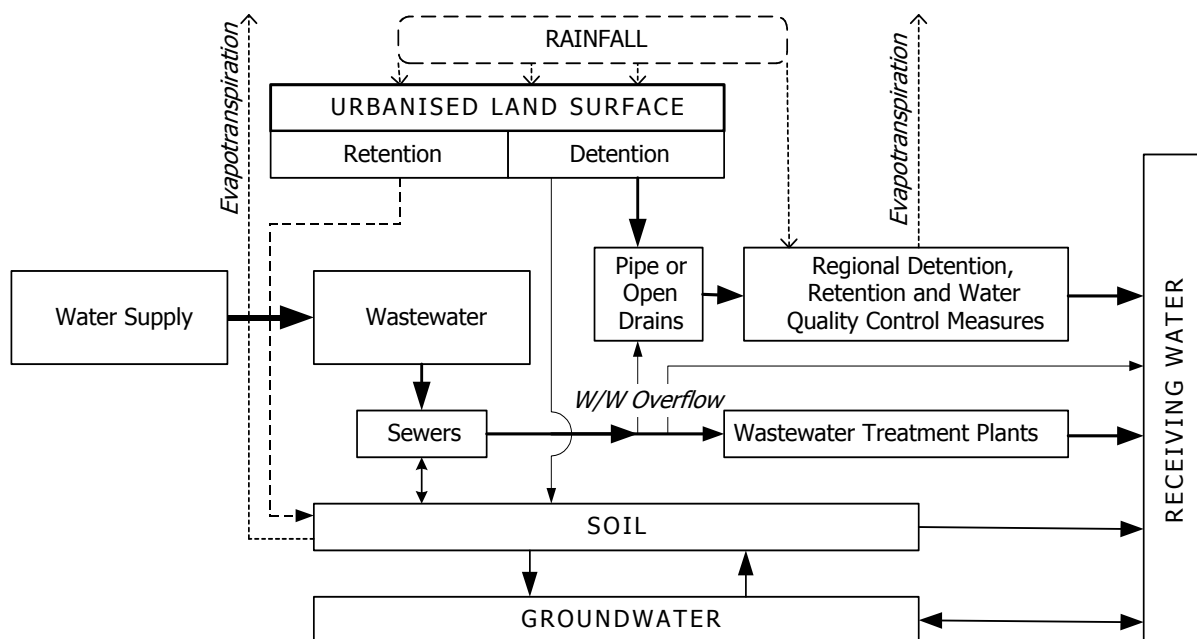


Figure 3.3 Urban Water System

- use of infiltration facilities to reduce direct storm runoff and increase base flows in rivers during dry periods.

Integrated stormwater management has been adopted as a major theme throughout this Manual.

3.4 OBJECTIVES

An idealised goal for urban water management would be the restoration of each component of the hydrological cycle to its natural level (Musiak, 1991). However, this is not achievable with the present-day urban systems.

Within the broad objective of achieving an optimum urban environment, the underlying objectives can be set for responsible stormwater management as (ACT DUS, 1994):

- to provide safety for the public,
- to minimise and control nuisance flooding and to provide for the safe passage of less frequent flood events,
- to stabilise the landform and control erosion,
- to protect property,
- to enhance the urban landscape,
- to optimise the land available for urbanisation, and
- to minimise the environmental impact of urban runoff on water quality

These objectives will be seen as being achieved when:

- the planning, design and construction of new stormwater facilities are adequate to service the requirements of new and future developments
- there is compatibility with existing stormwater facilities, operational methods, and maintenance techniques
- stormwater facilities provide adequate environmental, community, and asset protection consistent with acceptable planning, design, and construction requirements and the principles of ecologically sustainable development.

3.5 STORMWATER MANAGEMENT PRINCIPLES

The followings have been identified (NSW EPA, 1996a) as important management principles for achieving the stated objectives outlined in Section 3.4.

3.5.1 Accepting Shared Responsibility

Catchments do not normally follow jurisdictional boundaries and will often cover a number of jurisdictional areas. Effective stormwater management requires cooperation and coordination between the various stakeholders with legitimate roles and responsibilities for

stormwater within the catchment. Cooperation and coordination can be difficult to achieve in large catchments as the many stakeholders involved can cover a wide and often conflicting range of attitudes and interests. Compromises may need to be made in order to achieve an effective workable arrangement.

Because a large number of stakeholders may be involved in a catchment, stormwater management needs to recognise and build on the important part that each stakeholder should play in developing and implementing stormwater management strategies. Agreeing that there are shared responsibilities, clearly defining actual management roles is the most fundamental requirement for effective stormwater management. These stakeholders are often in unique positions to solve particular parts of the problem, and if each contributes what they are best positioned to do, the most effective and efficient results will be achieved. Institutional arrangements and management programs need to be developed in such a way as to ensure that responsibility for the development and implementation of management solutions is shared equitably and efficiently.

3.5.2 Integrated Landuse Planning

Existing and future stormwater quantity and quality problems are closely tied to existing and future landuse patterns. The nature and density of landuse will significantly influence the volume and rate of runoff and the quantity and quality of pollutants carried from the land surface to the stormwater system. Landuse is therefore a primary determinant of the location and severity of urban flooding and pollution problems.

Decisions on landuse, which do not consider stormwater quantity and quality management, may limit opportunities and impose significant costs on the community. There are many instances where development has been allowed in floodplains with subsequent adverse consequences.

Stormwater management must respect the principle of the interdependence of land and water resources. Planning directed to the resolution of existing stormwater quantity and quality problems and the prevention of future problems in proposed and existing urban areas should be done within an agreed area-wide or catchment landuse plan. If such a plan does not exist, a forecast of likely future landuse based on the best information available must be undertaken.

Development must be guided by a coordinated approach associated with:

- catchment-based planning and management
- integrated urban landuse planning
- infrastructure provision and management practices which reflect social, economic, and environmental values.

3.5.3 Water-Sensitive Urban Design

The form of development in new urban areas should be based on water-sensitive design principles. These principles are based on minimising the impacts of development on the total water cycle and maximising the benefits of multi-purpose use of stormwater systems.

The overall objectives of water-sensitive urban design include:

- preservation of existing ecosystems, and topographic and natural features
- protection of surface water and groundwater resources
- adoption of appropriate development forms, e.g. reducing individual lot sizes and increasing communal open space (and stormwater drainage) areas to achieve the same density as a standard residential development
- adoption of water-sensitive development standards, such as reduced road pavement widths and the use of grass swales instead of hard lined open channels or kerb and gutter and underground pipes
- conservation and recreation of viable natural habitat within a development area, primarily with open public space areas
- integration of the major stormwater system with the residential design, e.g. by avoiding back fences adjacent to major stormwater reserves
- integration of public open space with major stormwater drainage corridors, to maximise public access, passive recreational activities, and visual amenity
- minimising runoff at or near its source, by directing runoff from impervious surfaces to pervious areas to reduce the quantity and improve the quality of runoff.

3.5.4 Multi-Purpose Use of Stormwater Infrastructure

In many urban areas, stormwater drainage is the highest cost component of hydraulic infrastructure. The current practice of adopting only a conveyance-oriented approach for runoff control is not cost-effective in either the short or long term when external social and environmental factors are taken into account. Substantial benefits may accrue where facilities are planned and managed to accommodate a number of functions such as stormwater drainage and flow control, pedestrian movement corridors, active and passive recreation, wildlife habitats etc.

Potential benefits of adopting a multi-use planning approach include:

- a reduction in the capital cost of providing drainage infrastructure,
- lower cost open space and recreational facilities compared with non-drainage corridor areas,

- access to a low cost secondary water supply source,
- increased real estate market values enabling a greater return on investment, and
- opportunities to commercially exploit the recreational values of drainage corridors and waterways.

3.5.5 Promoting Ecologically Sustainable Development (ESD)

Stormwater management practices need to be consistent with the objectives of ESD, which aim to achieve sustainable usage of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development. Stormwater management practices need to be based on ecologically sustainable development principles and should be integrated with total water cycle management.

The ESD definition that is the most relevant is (Australia National Strategy for ESD, 1992):

Development that uses, conserves, and enhances the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life now and in the future can be increased.

The four core objectives of ESD are:

- enhancing individual and community well-being and welfare by economic development that safeguards the welfare of future generations;
- providing equity within and between generations;
- protecting biological diversity and maintaining essential ecological processes and life-support systems; and
- improved techniques for evaluating environmental values.

In practical application, this definition of ESD can be broken into four objectives:

- sustainable quality of life
- biodiversity conservation
- pollution minimisation
- resource conservation

The major challenge for stormwater management policies is to effectively combine the multitude of sectoral policies that affect the quality of life of city dwellers and the ecological balance of cities. If implemented, ESD policies can help realise the goals of a sustainable quality of life by:

- providing good opportunities for open space
- preserving landscape and cultural values
- avoiding reductions in biologically significant resources of any given site
- conserving biodiversity

- reducing local and regional pollutant discharges.

Rijsberman and Van den Ven (1999) argue that different people have different perceptions of ESD, and that there are at least four basic approaches to sustainability: (1) a carrying capacity approach, and (2) ratiocentric, (3) sociocentric and (4) ethnocentric approaches. Differences in approach will lead to different assessments of whether or not projects are truly “sustainable”. However these theoretical arguments do not negate the basic proposition that existing methods are unsustainable and efforts should be made to move towards more sustainable methods.

An ecologically-based stormwater management and planning approach aimed at protecting the ecology and environmental values of receiving waters is represented in Figure 3.4.

3.5.6 Developing the Best Mix of Strategies

There is no single universal solution to managing urban stormwater problems. A mix of strategies including planning, education, economic instruments, monitoring, public reporting, and structural management principles will be needed to address these problems on multiple fronts and reflect the individual characteristics of a catchment and its stormwater management issues. Choosing a mix of strategies particular to a catchment will allow a balanced and cost-effective outcome to be obtained.

3.5.7 Encouraging Innovation

Current management techniques have evolved rapidly in advanced countries over the last five to ten years. The continued development of new and innovative management techniques or the modification of existing techniques to suit the Malaysian conditions should be encouraged. These techniques can range from improved education techniques to the design of stormwater treatment devices.

3.6 STORMWATER MANAGEMENT ISSUES

The following are some issues that stormwater managers should consider in the planning and implementation of stormwater management programmes (ANZECC, 1996).

3.6.1 Urban Stormwater as a Resource

As growing urban communities approach the economically viable limits of water supplies, opportunities associated with use of local water sources such as urban stormwater and groundwater are being recognised.

Better management of the water cycle at the residential lot needs to be achieved to reduce demand for domestic irrigation. Where urban areas are located over or adjacent to groundwater aquifers, there is potential for stormwater to be used to recharge aquifers provided the water quality is protected. This requires very careful management.

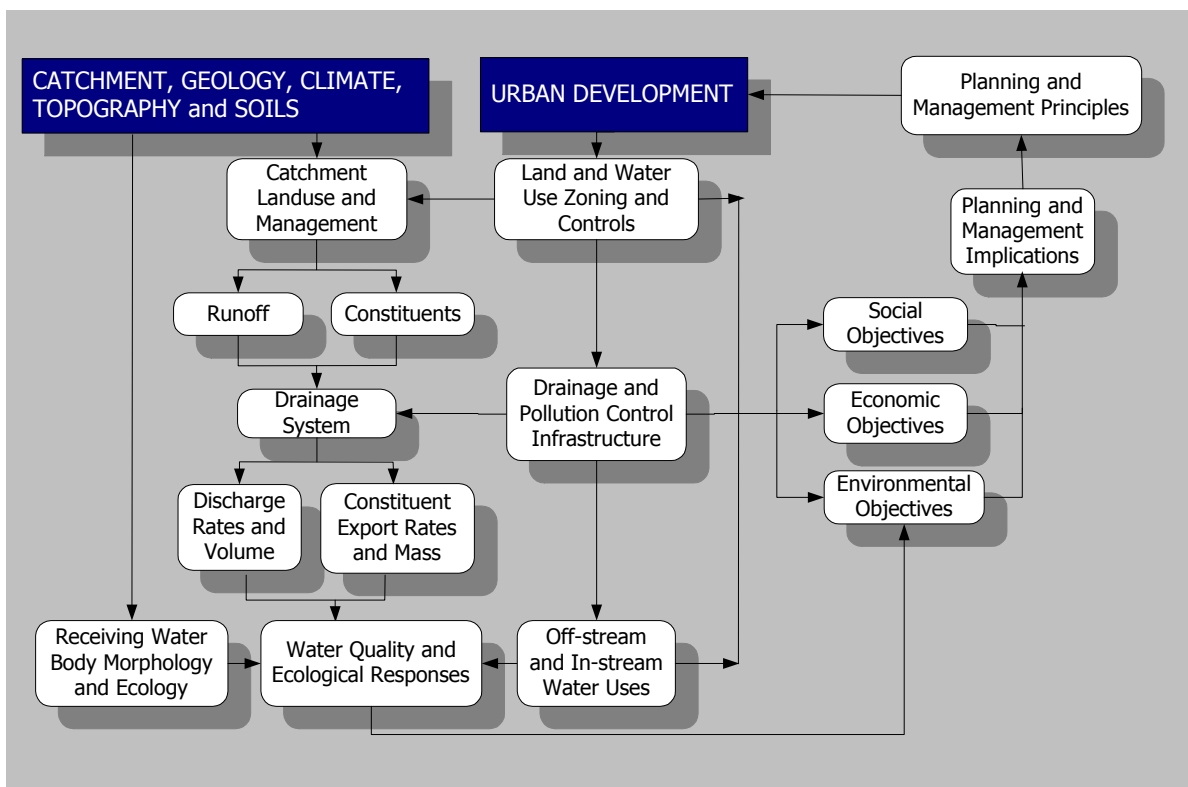


Figure 3.4 Ecologically-based Stormwater Management Planning Approach

The quality of urban open space has been compromised by intrusive drainage structures designed without regard for aesthetics and ecological impacts. Some waterway corridors have adversely affected the amenity of the surrounding area through loss of natural vegetation, loss of visual amenity, and minimal regard for public safety. Long-term social, environmental, and economic benefits can be achieved for open space drainage corridors through planning and design approaches which recognise urban stormwater and streams as valuable resources. Opportunities to retrofit pollution control devices and re-establish an aesthetically appealing environment to degraded drainage corridors by restoring flora and fauna habitats should also be investigated.

3.6.2 Community Values and Participation

Most urban communities enjoy a reasonable level of flood protection due to conventional stormwater conveyance systems constructed in the past. These stormwater systems need regular routine maintenance and, at times, upgrading to continue to provide an adequate level of flood protection for the community. Community interest in stormwater facilities tends to fluctuate widely, usually being most intense during and immediately after a damaging and disrupting flood event.

Managing stormwater only for flood protection is no longer an adequate response to changing community values in most advanced countries, which now reflects concern for protecting the environment, ecologically sustainable development, and improved access to open space and recreational facilities. Attention must now focus equally on providing flood protection and providing improved environmental quality and recreational opportunities.

For these reasons, it is essential that stormwater management programmes provide adequate opportunity for the community to be involved in the development and implementation of stormwater management strategies.

Community involvement helps to:

- engender a spirit of openness
- identify strategies which are responsive to community concerns
- explore and improve understanding of problems, issues, and community values
- generate a comprehensive range of management options
- increase public ownership and acceptance of proposed solutions
- generate broader decision-making perspectives not limited to past practices or interests
- draw on the knowledge and skills available across the wider community
- reflect the community's life style values and priorities.

Public participation programs have three objectives, namely:

- To demonstrate to the community that the responsible authorities are aware of stormwater problems in a catchment and want to learn more about them and seek solutions.
- To gather supplementary data and information pertinent to the preparation of a stormwater strategy plan for a catchment.
- To build support for the implementation of a stormwater strategy plan. Members of the community, who have been informed about a stormwater management program and have been given an opportunity to participate in the preparation of a plan, are likely to become supporters of the plan and add impetus for its implementation.

3.6.3 Fragmented Jurisdiction

Fragmentation in political jurisdiction, and institutional and administrative responsibilities across drainage catchments often presents serious obstacles to coordinated and integrated catchment planning and management. In most jurisdictions, opportunities exist to put in place structures and procedures enabling joint development of strategies to address local authority boundary issues and promote integrated catchment planning and management. Possible approaches include:

- single agency responsibility, with strong emphasis on liaising and collaborating with other groups
- joint agency based programs
- establishing drainage/basin trusts or authorities
- establishing total catchment management (TCM) planning and management structures.

3.7 RUNOFF QUANTITY MANAGEMENT STRATEGIES

3.7.1 Conveyance-Oriented Approach

Stormwater management in Malaysia has traditionally focused primarily on managing the impacts of flooding by adopting a *conveyance-oriented approach*. Stormwater systems designed in accordance with this approach provide for the collection of runoff, followed by the immediate and rapid conveyance of the stormwater from the collection area to the point of discharge in order to minimise damage and disruption within the collection area. Stormwater runoff is viewed as a nuisance to be disposed of as quickly and efficiently as possible.

The apparent advantages of this approach are:

- rapid removal of stormwater from the service area
- maximum area of land available for development by minimising landtake requirements for drainage

- accepted analysis and design procedures.

The principal disadvantages of this approach are:

- conveyance systems must be sized for the total increase in flows resulting from urbanisation
- downstream conveyance systems often have insufficient capacity to contain these increased flows peaks and flow durations, which can result in new or aggravated flooding and erosion and sedimentation problems
- traditional hard lined open conveyance systems can be a hazard to the public during and after rain due to high flow velocities
- urban pollutants are transported to downstream areas.

A typical conveyance channel is illustrated in Figure 3.5.

3.7.2 Storage-Oriented Approach

Stormwater management has developed to the point where there are now two fundamentally different approaches to controlling the quantity, and to some extent, the quality of stormwater runoff. In addition to the traditional *conveyance-oriented approach*, a potentially effective and preferable approach to stormwater management is the *storage-oriented approach*. The function of this approach is to provide for the temporary storage of stormwater runoff at or near its point of origin with subsequent slow release to the downstream stormwater system or receiving water (detention), or infiltration into the surrounding soil (retention).

This approach can minimise flood damage and disruption both within and downstream of the collection area. Runoff may also be stored for re-use as a second class water supply for irrigation and domestic purposes.



Figure 3.5 Vegetated Channel

The principal elements and techniques used in a *storage-oriented* system are stormwater detention facilities and retention facilities.

Detention facilities (Figure 3.6) are commonly provided as a combination of the following:

- *on-site storage*: small storages constructed on individual residential, commercial, and industrial lots
- *community storage*: larger facilities constructed in public open space areas, or in conjunction with public recreation and sporting facilities
- *regional storage*: large scale community facilities constructed at the lower end of catchments prior to discharge to receiving waters, often provided as flood storage within urban lakes and reservoirs



Figure 3.6 Community Detention Facility

Detention facilities are designed principally to reduce peak flow rates from large infrequent storm events. On-site detention is normally provided to reduce nuisance flooding in the surrounding local area whilst larger community and regional facilities are provided to increase public safety and to minimise property damage, channel erosion, and the disturbance of aquatic habitat in the downstream catchment and receiving waters.

Detention techniques include the temporary storage of runoff in the following:

- small on-site tanks and above-ground storage areas
- dry detention basins
- ponds and wetlands
- flood reservoirs
- urban lakes

Retention facilities are designed primarily to reduce the volume of stormwater runoff from small frequent storm events by storing collected runoff and allowing it to infiltrate into the surrounding soil. Retention is a suitable technique for infiltrating pre-treated runoff into areas with relatively high permeability soils. Pre-treatment by filtering to remove coarse sediment and debris is necessary to minimise blockage of the infiltration media. Regular maintenance is also essential for their effective operation.

Retention techniques include the following:

- dispersion trenches, pits, wells, and 'soakaways' (for infiltration of roof runoff) either on an individual or multiple lot basis
- directing roof runoff to ponding areas within lots for infiltration
- grassed swales
- pervious stormwater pipes
- porous pavements
- infiltration trenches and basins
- recharge wells

Stormwater re-use can be undertaken at either the individual lot level or on a broader community or regional basis. The use of rainwater tanks or similar devices for collecting roof runoff from buildings can be encouraged. Water collected by these devices within individual lots may be used for non-potable purposes such as garden watering and toilet flushing. At the community and regional levels, runoff stored in ponds, wetlands, and urban lakes may be used as a non-potable water supply for irrigating areas such as golf courses, sporting fields, and public parks.

A comparison of various characteristics of *conveyance-oriented* and *storage-oriented* stormwater systems is provided in Table 3.1.

The main advantage of using a *storage-oriented approach* is that it may offer substantial cost advantages over the traditional *conveyance-oriented approach* when the total life cycle costs of the stormwater system are considered. These cost advantages may include:

- a reduction in the size required for conveyance systems downstream of storage facilities
- opportunities for multi-use of storage and conveyance facilities by incorporating them with open space systems, public and wildlife movement corridors, active and passive recreational areas such as public parks, and playing fields.

Other advantages and benefits of a *storage-oriented approach* include:

- improved public safety
- a more aesthetically pleasing urban landscape
- enhanced property values adjacent to open water bodies such as ponds/wetlands and urban lakes
- enhanced flora and fauna habitats associated with open water bodies
- recharge of groundwater resources.

The perceived disadvantage of a *storage-oriented approach* is that the area of landtake could be greater than a *conveyance-oriented approach*. However, this is partly a mis-conception caused by inadequate existing provisions for open space and flood control. Properly designed multi-

purpose facilities, such as detention basins incorporating recreational facilities and waterways with pedestrian and cycleway corridors, can be included as part of the open space contribution for a development whereas lined open drains (for example) have no recreational value and should not be included. There is a need for review of the planning regulations in Malaysia to facilitate this change.

The *conveyance-oriented* and *storage-oriented* approaches to stormwater management are not mutually exclusive within the same system. Depending on the circumstances, the two approaches may be compatible, and integrated use of the two approaches is encouraged to give a more optimum stormwater drainage system. An example of the combined use of the two approaches could be to use *conveyance-oriented* facilities for the minor drainage system and *storage-oriented* facilities for the major drainage system. Another example is that in existing heavily built-up areas, the constraint of high land values may make it impossible to retro-fit storage and there will be no alternative to costly conveyance system enlargement.

3.8 RUNOFF QUALITY MANAGEMENT STRATEGIES

To date, the main form of control of stormwater runoff quality adopted in Malaysia has been the installation of sediment basins to control the transport of sediment from land development/construction sites. Source control and treatment control of stormwater runoff from established urban areas to remove urban pollutants and enhance the quality of discharges to receiving waters has not been addressed.

3.8.1 Housekeeping BMPs

Housekeeping BMPs are techniques that aim to change human behaviour to reduce the amount of pollutants that enter stormwater systems by targeting the control and/or prevention of pollution at its source. Techniques can include the introduction or improvement of:

- community education and participation activities
- management activities, such as landuse planning and development control
- operations and maintenance activities, such as garbage collection and street sweeping
- improved site planning and management

The main advantages of using these BMPs are:

- long-term sustainability
- cost-effectiveness
- reduced ongoing operations or maintenance liability compared with 'end of pipe' techniques
- effective use of all resources, including the community.

Table 3.1 Comparison of Conveyance and Storage Approaches (after Welsh,1989)

Characteristic or Feature	Approach	
	Conveyance-Oriented	Storage-Oriented
Function	Provides for the collection and rapid conveyance of stormwater runoff to minimise disruptive and possibly damaging surface ponding in streets and low-lying areas and possible inundation of residential and other sites and structures	Provides for the temporary storage of stormwater runoff and subsequent slow release to downstream systems or receiving waters, thus minimising disruption and damage within and downstream of the urban area and reducing the required size and cost of any constructed downstream conveyance facilities
Components <i>Principal</i> <i>Secondary</i>	Open drains, pipes, lined channels, floodways Stormwater inlets, manholes, culverts, energy dissipaters	Detention and retention storage facilities Open drains, swales, pipes, stormwater inlets, engineered waterways, manholes, culverts, energy dissipaters
Applicability	Suitable for installation in existing and in newly developing urban areas	Most suitable for incorporation in newly developing urban areas but may be used in existing urban areas if suitable sites are available
Downstream Impact <i>Quantity</i> <i>Quality</i>	Tends to significantly increase (relative to pre-development conditions) downstream discharges, stages, and areas of inundation Transports suspended material and other potential pollutants to downstream areas	May be designed to cause no significant increase (relative to pre-development conditions) in downstream discharges, stages, and areas of inundation. Decreased discharges, stages, and areas of inundation are possible Provides for removal of sediment and other suspended material by the natural settling process, thus reducing pollutant loadings on receiving waters
Multi-purpose Capability	Drains serve only a stormwater collection and conveyance function Hard lined channels can provide a limited basis for development of linear parkland and open space areas	Quantity control, quality control, recreation, aesthetics, water supply, and groundwater recharge Soft lined waterways provide greater potential for development of linear parkland and open space areas
Operation and Maintenance	Require periodic cleaning	Sediment and debris removal Weed and insect control
Hazards	Minimal hazard associated with closed drains. High velocities in open lined channels may pose safety hazard to the public	Minimal hazard associated with storage systems provided that due care is exercised in design
Hydrologic-hydraulic analysis and design procedure	Requires determination only of the peak flow rate associated with a specified design ARI	Requires determination of both a peak flow rate and a volume of inflow associated with a specified ARI and an estimate of an allowable outflow rate to satisfy discharge conditions

3.8.2 Source Controls BMPs

Source controls BMPs are those practices that tend to keep both runoff and pollutants contained at their source. They are analogous to the source controls that we speak of hydrologically. These include pervious areas and buffer strips towards which runoff is directed, infiltration controls, porous pavement, etc.

3.8.3 Treatment Controls BMPs

To protect the quality of local streams, lakes, and river systems, a number of treatment controls BMPs may be adopted as follows:

- the establishment of urban lakes, primarily as biological treatment systems
- the utilisation of water quality control ponds and wetlands, as physical and biological treatment systems, upstream of urban lakes (Figure 3.7)
- the incorporation of gross pollutant traps on inlets to urban lakes and water quality control ponds and wetlands to intercept trash and debris and the coarser fractions of sediment (Figure 3.8)
- the incorporation of 'off-stream' sediment basins into land development and large building projects to intercept (and chemically treat if necessary) runoff prior to its discharge to stormwater systems and/or receiving waters.



Figure 3.7 Water Quality Control Pond



Figure 3.8 Above-ground Gross Pollutant Trap