2 ENVIRONMENTAL PROCESSES

2.1 INTRODUCTION

This chapter contains a brief summary of the broad environmental processes, which occur in catchment systems. The information has largely been drawn from the New South Wales Environment Protection Agency, Australia (1996a).

This information is presented to enable development of an understanding of the impacts of urbanisation on these processes and to help assess the appropriateness of stormwater management practices. It should be noted that these processes are often highly variable within and between catchments, and this variability needs to be recognised when developing stormwater management strategies.

2.2 CATCHMENT PROCESSES

2.2.1 Hydrologic Cycle

The hydrologic cycle is the continuous, unsteady circulation of water from the atmosphere to and under the land surface and back to the atmosphere by various processes. It is dynamic in that the quantity and quality of water at a particular location may vary greatly with time. Temporal variations may occur in the atmosphere, on land surface, in surface waters, and in the groundwater of an area. Within the hydrologic cycle, water may appear in all three of its states; solid, liquid, and gas. Figure 2.1 shows the hydrologic cycle in schematic form. The important processes are described below with emphasis on factors that influence each process and its significance in the planning, design, and operation of stormwater management systems (Walesh, 1989).

(a) Precipitation

Precipitation can occur primarily as rain. Annual amounts of precipitation are unpredictable and variable, ranging from approximately 1500 mm to 4000 mm in various locations in Malaysia. In essence, precipitation is the most important process in the hydrologic cycle because it is the 'driving force' providing water that must be accommodated in the urban environment.

(b) Interception

Interception is the amount of precipitation that wets and adheres to aboveground objects (primarily vegetation) until it is evaporated back into the atmosphere. The annual amount of interception in a particular area is affected by factors such as the amount and type of precipitation, the extent and type of vegetation, and winds. Interception is not likely to be an important process in urban stormwater management programs.

(c) Depression Storage

This process is defined as the amount of total precipitation detained in and evaporated from depressions on the land surface. Depression storage is water that does not run off or infiltrate. Surface type and slope, and the factors influencing evaporation affect depression storage. Its magnitude, likely to be important in urbanised environment.

(d) Infiltration

Infiltration is defined as the passage of water through the air-soil interface. Infiltration rates are affected by factors such as time since the rainfall event started, soil porosity and permeability, antecedent soil moisture conditions, and presence of vegetation. Infiltration is a very important process in urban stormwater management and, therefore, essentially all hydrologic methods explicitly account for infiltration. Urbanisation usually decreases infiltration with a resulting increase in runoff volume and discharge.

(e) Evaporation and Transpiration

Evaporation is the process whereby water is transformed from the liquid or solid state into the gaseous state. Transpiration is the mechanism whereby water moves up through vegetation and is subsequently evaporated. Evapotranspiration rates are affected by factors such as temperature, wind, vapour pressure, plant characteristics, and availability of soil moisture. Although evaporation is of little practical significance during precipitation events, it is an important factor used in preparing hydrologic budgets for catchments, lakes, or reservoirs.

(f) Surface Runoff

Surface runoff, sometimes referred to as overland flow, is the process whereby water moves from the ground surface to a waterway or water body. Surface runoff is affected by other processes in the hydrologic cycle, such as precipitation and infiltration, plus factors such as imperviousness and land slope. Surface runoff determines the quantity of stormwater that must be locally managed and affects the magnitude of potential pollutants transported to receiving waters. In the absence of stormwater management programs, urbanisation usually dramatically increases surface runoff volumes and rates.

(g) Interflow

Interflow, sometimes referred to as subsurface stormflow, is the process whereby water moves laterally beneath the land surface, but above the groundwater table. Interflow occurs until water enters a waterway or water body, or is evapotranspired. Interflow is affected by the same factors as those for surface runoff. Interflow is rarely explicitly analysed; it is usually considered part of the surface runoff. Surface runoff, interflow, and precipitation falling directly on water bodies are sometimes lumped together and called direct runoff.

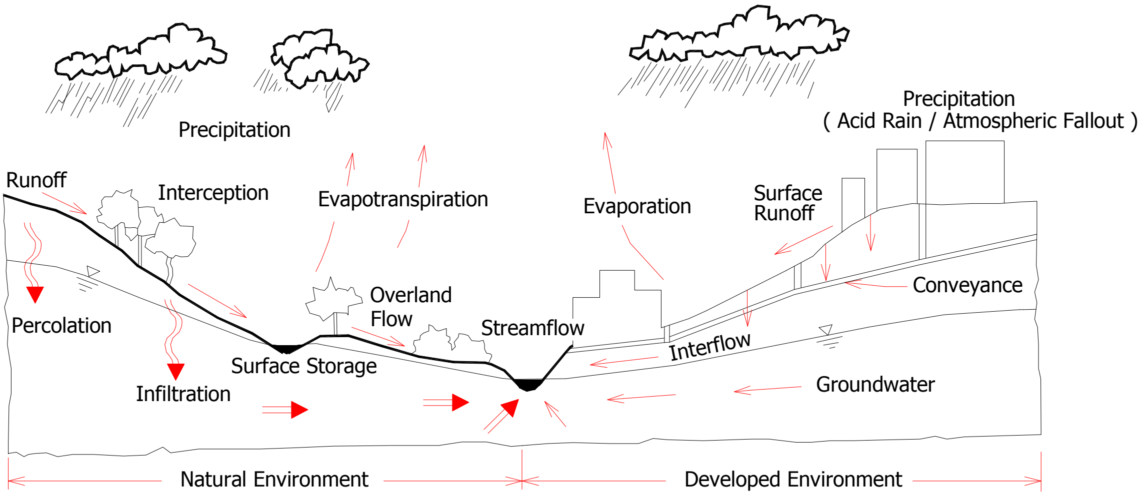


Figure 2.1 Hydrologic Cycle

(h) Groundwater Flow

Groundwater flow, sometimes referred to as baseflow, is water moving laterally beneath the water table toward and into a waterway or water body. Unlike most other processes in the hydrologic cycle, groundwater flow is essentially a continuous process. It maintains flows in natural and man-made conveyances and water impoundments. Urbanisation usually causes the groundwater depletion.

2.2.2 Runoff

In non-urban catchments with low-medium permeability soil, runoff primarily occurs from 'source areas' (Dunne et al, 1975). These are areas with relatively high soil moisture located in valleys and can increase in extent with rainfall. The extent is related to topography, soil and vegetation characteristics, and the amount of evapotranspiration. Due to the dependence of runoff on soil moisture and the extent of source areas, the runoff characteristics from these non-urban catchments can be highly variable.

Catchments with sandy, high permeability soils can have minimal surface runoff, with most of the rainfall infiltrating into groundwater. Following periods of prolonged rainfall, groundwater levels can rise, potentially flooding low-lying areas.

The soil, topography, and vegetation characteristics also influence the volume and rate of runoff from the catchment. The runoff volumes from catchments with highly permeable soils can be comparatively low, and relatively low runoff rates can occur from flat catchments. The presence of vegetation influences evapotranspiration rates and groundwater characteristics, with runoff volumes and rates generally being higher from a rural catchment than those from a forested catchment.

As a consequence of these factors, runoff characteristics from non-urban catchments can be highly variable. For example, it is possible for two adjacent catchments to have different responses to the same rainfall event due to different topography, soils, and vegetation.

2.2.3 Fluvial Geomorphology

The generalised characteristics of natural watercourses and associated sediment transport regimes vary from upland (or headwater) streams to lowland rivers. This fluvial system can be divided into three geomorphic zones, as illustrated in Figure 2.2, based on flow and sediment transport considerations (Schumm, 1977).

The size of a watercourse channel has traditionally been related to the 'dominant discharge', being a balance between the frequency of occurrence and the magnitude of flow. The resulting dominant discharge or bankfull flow (to the top of the channel) corresponds to a 1.5 year average recurrence interval (ARI) event (Leopold et al, 1964), although more recent studies have indicated that the bankfull flow is more variable (Knighton, 1984).

(a) Upland Reaches

These reaches tend to have a low sinuosity and narrow widths, with high bed slopes, flow velocities, and bed shear stress. The substrate (or bed) of the stream can be coarse (boulders or bedrock) and erosion resistant. These streams are commonly sediment source zones as the supply of sediment is less than the sediment transport capacity. Floodplains are generally absent in this zone.

(b) Middle Reaches

The middle reaches of a natural watercourse commonly have moderate sinuosity, width, bed slopes, flow velocities, and bed shear stress. The substrate size tends to be medium (cobbles/gravel). The sediment supply rate is often similar to the transport rate, with sediment transported through these reaches without significant net scour or deposition. Floodplains are generally present although not extensive.

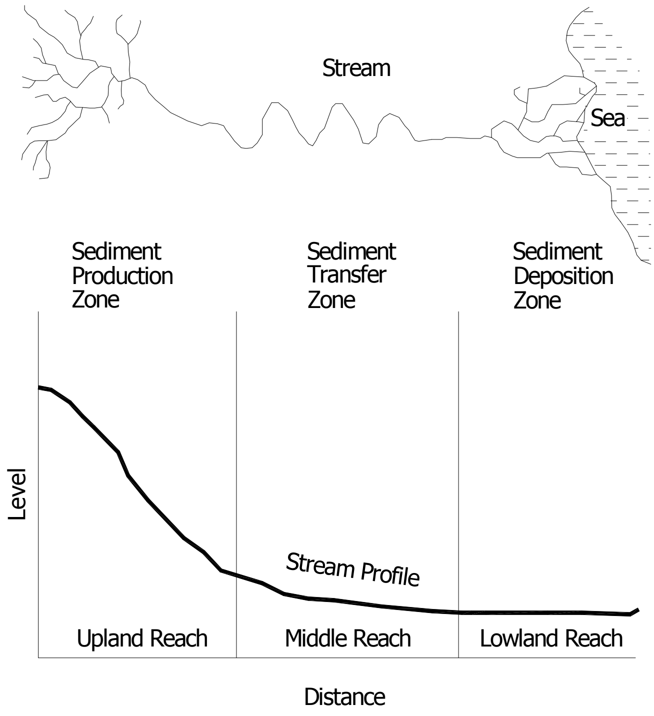


Figure 2.2 Idealised Fluvial System (Schumm, 1977)

(c) Lowland reaches

The lowland reaches of a natural watercourse commonly have high sinuosity (possibly braided) and are comparatively wide, with low bed slopes, flow velocities, and bed shear stress. The substrate is generally fine (sand and silts). Sediment is deposited in these reaches as the sediment supply rate exceeds the transport rate. These reaches generally have extensive floodplains. These simplified and idealised characteristics are often modified by local conditions (e.g. bedrock outcrops) and the prevailing streamflow regime.

The channel geometry of a natural watercourse is rarely uniform. In upland reaches, a series of rock steps and pools are commonly present, with a sequence of pools and riffle zones (rapids) generally occurring in the middle and some lowland reaches (Knighton, 1984). Pools generally occur on the inside of bends and the riffle zones occur between bends. In lowland streams, the riffle zone may be just an elevated portion of the bed without the coarse bed material that occurs in upland riffle zones.

(d) Estuaries

The morphology of estuaries may be classified into three main categories (Roy, 1984). These estuary types are:

- *drowned river valleys* : estuaries with open mouths and full tidal range
- *barrier estuaries* : estuaries behind coastal sand barriers with an entrance channel, through which tides are attenuated
- *saline coastal lakes* : lakes (or lagoons) behind coastal sand barriers with ephemeral channels that are scoured during infrequent storm events, and are non-tidal

These estuary classifications are based on their early, or 'youthful' development stage, prior to the commencement of significant infilling by sediment from tributary watercourses. This infilling can alter the tidal regime and result in the formation of wetland sediment deposits within the estuary (Roy, 1984).

2.2.4 Water Quality

Many of the substances present in water that may be classified as pollutants (at excessive concentrations) are essential to the function of aquatic ecosystems. These include:

- *suspended solids*, which contain organic matter for processing by micro-organisms and aquatic invertebrates
- *nutrients*, which encourage the growth of aquatic plants and algae. In freshwater systems, this primary biological productivity is generally controlled by the amount of phosphorus present, while nitrogen often limits productivity in estuaries;
- *oxygen-demanding substances*, which cause harmful reduction in dissolved oxygen levels;
- *bacteria and viruses*, which may be harmful to human health;
- *heavy metals*, which may be toxic. Metals are generally associated with sediments from urban areas; and
- *other pollutants*, including oil, grease, pesticides and herbicides.

In forested catchments, water quality is related to the geochemistry of the underlying bedrock and the catchment soils, in addition to the characteristics of riparian and catchment vegetation (Likens and Bormann, 1995). This can result in variability in the concentrations of pollutants within and between these catchments. Water quality from a catchment with agricultural landuse often also reflects human impacts, including fertiliser and pesticide use and the reduction of organic matter inputs due to the removal of riparian vegetation. This relationship between geochemistry, vegetation, landuse, and water quality can result in variability in pollutant concentrations within and between catchments.

The concentration of pollutants in a watercourse or water body is not constant over time, due to variability in the inputs of pollutants and range of in-stream processes. These physical, chemical, and biological processes (summarised in Table 2.1) generally result in a reduction of high concentrations of pollutants to a lower level, during normal flow conditions. In addition, the relationship between flow and concentration is also not constant within a watercourse, as evident in a number of relationships (refer Figure 2.3) that are similar to those observed by Characklis et al, 1979. This can result in a 10 to 100 fold variation in concentration for a given flow. The most widely known relationship is type I, termed the 'first flush' effect, where the concentration peaks prior to the peak flow. Due to the variability in freshwater quality and runoff and the interaction with coastal waters, water quality in estuaries can also be highly variable. The mixing of salt and freshwater in an estuary is often highly variable. Water quality (particularly salinity) in drowned river valley estuaries is generally less variable than barrier estuaries due to the greater tidal flushing (Pollard, 1994).

2.2.5 Riparian and Foreshore Vegetation

(a) Riparian vegetation

The typical zonation of vegetation in a freshwater riparian zone is presented in Figure 2.4. Riparian zones (also known as vegetated buffer strips or zones) play a number of important roles in the water environment outlined in the following paragraphs.

Shading : Riparian vegetation reduces water temperatures and light penetration, particularly in upland streams. This vegetation maintains the in-stream biological productivity of the watercourse and shading can provide camouflage for prey and predators.

Table 2.1 In-stream Water Quality Processes

Name	Process	Pollutant Affected
Volatilisation	Evaporation and aerosol formation	Hydrocarbons, mercury
Sedimentation	Gravity settling of particles and absorbed pollutants	Sediments, hydrocarbons, heavy metals
Re-suspension	Re-mobilisation of particles by wind or hydraulic turbulence	Sediments, hydrocarbons, heavy metals
Filtration	Mechanical filtration of particles through substrate, aquatic flora or fauna	Sediments
Absorption	Bonding of ions to sediments or organic matter (generally colloidal)	Hydrocarbons, phosphorus, nitrogen, heavy metals
De-sorption	Release of ions from sediments under adverse conditions (e.g. low pH, anaerobic)	Phosphorus, heavy metals
Oxidation/reduction (decomposition)	Oxidation of organic matter by microbial organisms, reduction of metals	Hydrocarbons, metals, nitrogen, phosphorus
Complexation/ Chelation	Formation of a complex ion by combining a metal ion with an inorganic ion	Metals, phosphorus
Precipitation	Formation or co-precipitation of insoluble compounds	Hydrocarbons, metals, phosphorus
Fixation	Fixation of atmospheric nitrogen to ammonia by microbial organisms and chemical fixation	Nitrogen
Nitrification	Microbial conversion of ammonia to nitrate, then to nitrite	Nitrogen
Denitrification	Microbial conversion of nitrate to atmospheric nitrogen	Nitrogen
Biomass uptake (assimilation)	Uptake of ions from soil by aquatic plants through root system, limited uptake directly from water uptake by algae	Metals, phosphorus, nitrogen
Aeration	Exchange of oxygen from the atmosphere to the water body	Oxygen demanding substances
Dislocation	Movement of organic matter and algae downstream during high flows	Organic matter, nutrients

Source: Cullen (1986), Harper et al. (1986), Manahan (1991) and Lawrence et al. (1996)

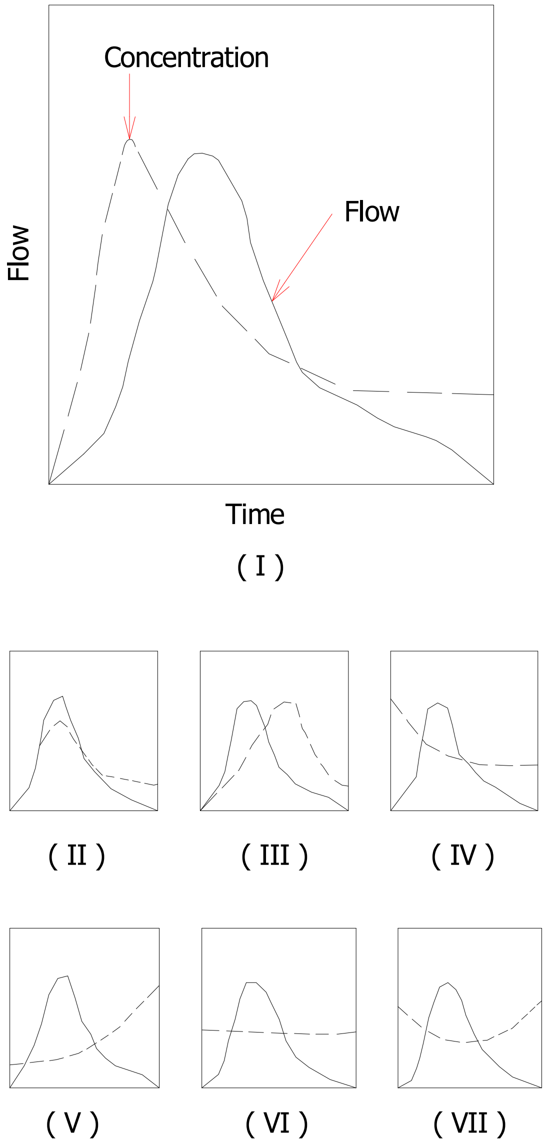


Figure 2.3 Relationships of Flow and Pollutant Concentration Variations (Sharpin, 1992)

Energy input : Leaves and other organic debris provide a major source of organic carbon and nutrients to support aquatic ecosystems, primarily in upland streams. Debris from native vegetation is preferred by native aquatic fauna over that from exotic vegetation, and avoids the potential detrimental effects from some introduced species (e.g. leaf-fall timing and composition).

Organic debris : Logs and other coarse organic debris from native vegetation provide an important habitat for fish and invertebrates, and assist with the retention of organic matter in a watercourse (by the creation of debris dams) for a sufficient period to enable it to be used by aquatic fauna. The habitat value is greatest when the bed (substrate) of the watercourse is sand or mud.

Bank stabilisation : Riparian vegetation stabilises channel banks and floodplains. This reduces bank erosion, floodplain stripping, alteration to the channel geometry and alignment, and reduces sediment loads. Tree roots can also provide a habitat for fish and invertebrates.

Habitat : Riparian zones provide a habitat for terrestrial fauna, including birds, mammals, and reptiles. It also provides a linkage to terrestrial flora zones and can act as a wildlife corridor, linking larger habitat areas. Riparian vegetation also provides a habitat and food source for terrestrial insects, which can be a food source for fish.

Pollution control : Vegetation in riparian zones reduces the concentrations of a range of pollutants (particularly sediment) carried in overland flow.

Weed control : Native vegetation in riparian zones can inhibit the growth of noxious weeds, due to a reduction in light levels below that required for exotic weeds to prosper (Arthington et al, 1993; Barling and Moore, 1993).

(b) Foreshore vegetation

The zonation of foreshore vegetation on soft sediments adjacent to an estuary is indicated in Figure 2.5. This vegetation includes mangrove forest in the tidal zone and saltmarsh at the upper limit of the tidal zone. This vegetation in estuarine systems plays similar roles in the water environment as those for riparian vegetation in freshwater systems, as outlined in the following paragraphs.

Shading : The mangrove forests can provide shading to hide predators from prey, and prey from predators.

Energy input : Leaves and other organic detritus from the mangrove forest (and to a lesser extent saltmarsh) provide a food source for bacteria and plankton. This is a food source for certain fish species and invertebrates (including crustaceans and shellfish), with the invertebrates being a food source for other fish species and waterbirds. The algae, which grow on the peg roots of mangroves, are also a food source for some fish species.

Foreshore stabilisation : Mangroves (and saltmarsh to a lesser extent) can reduce bank erosion due to wind or boat waves. Mangroves can also stabilise bottom sediments and reduce turbidity.

Habitat : Mangroves provide an important habitat for crustaceans (e.g. prawns and crabs) and are nursery areas for juvenile fish, providing food and shelter from predators. Mangroves and saltmarshes provide habitats for waterbirds and saltmarshes also provide habitats for invertebrates.

Pollution control : Saltmarshes and mangroves can reduce the concentration of pollutants in overland flow, including sediment and nutrients (Underwood and Chapman, 1995).

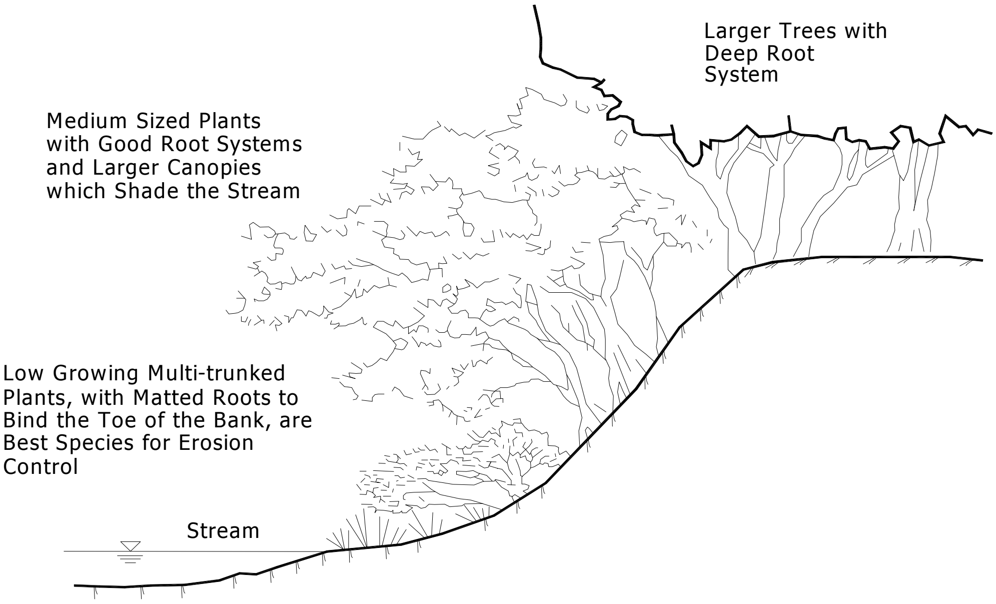


Figure 2.4 Freshwater Riparian Vegetation (Raine and Gardiner, 1995)

2.2.6 Aquatic Ecosystems

(a) Freshwater ecosystem processes

The nature of aquatic ecosystems is a complex interaction between channel, streamflow, water quality and habitat characteristics, and energy cycling (including the influence of riparian and aquatic vegetation). The food chain within a freshwater aquatic ecosystem is illustrated in Figure 2.6. These processes are generally similar in estuarine ecosystems.

These processes vary within and between watercourses depending on the characteristics noted in the previous paragraph. A simplified and idealised representation of this variation along a watercourse can be described by the River Continuum Concept and nutrient spiralling (Vannote et al, 1980), as summarised in the following paragraphs.

Upland streams: The organic matter in these streams is coarse, derived directly from riparian vegetation. As a consequence, the dominant energy source is derived externally from the stream (allochthonous). The dominant aquatic flora in these streams is attached algae. The primary macroinvertebrate communities are shredders and collectors and the dominant fish diet (if fish are present) is invertebrates.

Middle reaches: The organic matter in these reaches is fine material processed from upstream (releasing dissolved nutrients) and some coarse matter from tributaries. Energy is therefore derived from both within (autochthonous) and outside of the watercourse.

Lower reaches: Fine organic matter from upstream sources enters these reaches, with dissolved nutrients derived from within the watercourse providing the primary sources of energy. Phytoplankton and some macrophytes are the principal aquatic flora in these areas. The dominant invertebrates are collectors and predators, with the primary fish diet being plankton.

These characteristics will also be influenced by factors such as the presence of weir or dams.

Aquatic fauna, particularly fish, generally migrate upstream and downstream along watercourses depending on the species and stage of their life cycle. Aquatic invertebrates can also move or 'drift' within the bed material (substrate) and the watercourse.

(b) Estuarine ecosystem processes

Estuaries are highly productive environments in terms of the rate at which organic matter is produced, with productivity rates being approximately 10 times greater than marine waters. The most productive estuarine habitats are mangroves, seagrasses, and saltmarshes, which is attributed to nutrient inputs from both freshwater sources and oceans. This productivity tends to increase with tidal range due to the higher tidal flushing rate and resulting nutrient removal rates (Morisey, 1995).

The highest productivity in estuaries results in an abundance of aquatic fauna, although the diversity is relatively low compared to freshwater and marine environments. The fluctuating salinity is considered to result in a relatively stressful environment for aquatic fauna (Morisey, 1995).

Numerous fish species and invertebrates (crustaceans and shellfish) spend part or all of their life in estuaries. Certain marine and freshwater fish use estuaries only for spawning, while other species live in estuaries either their entire lives or only as juveniles. Due to the relationship between ecosystem characteristics and salinity, the three estuary types noted in Section 2.2.3 (d) can have distinctly different ecological characteristics. Diversity of fish in coastal saline lakes was found by Pollard (1994) to be less than that in a drowned valley estuary, although the abundance was higher.

(c) Freshwater aquatic habitats

In-stream objects in watercourses are important in providing structure to freshwater aquatic habitats (Koehn, 1992). These objects provide shelter from high flow velocities and sunlight, spawning sites and locations for fish to hide from predators, or for predators to hide from their prey. These objects fall into three main categories, which are indicated in Figure 2.7 and summarised below.

Substrate : Substrate particles provide refuge areas for juvenile fish and invertebrates, with substrate undulation providing a variety of habitats through depth fluctuations (pool and riffles).

Woody debris : Fallen tress and branches (snags) form a significant component of in-stream habitats. They cause flow and depth variations and provide habitats and spawning sites, and attachment sites for macroinvertebrates.

Aquatic plants : Plants provide habitat and spawning sites for fish, and macroinvertebrate attachment sites. They also provide bed and bank stability and shade.

Wetlands and floodplains are also important aquatic habitats. The food chain (particularly nutrient cycling) noted in Figure 2.6 also occur in wetlands, often resulting in a diverse aquatic fauna of fish and invertebrates. These wetlands can also act as a nursery area for some species of juvenile fish. Floodplains also play an important role in nutrient cycling. During flood events, nutrients are released from organic matter, providing a food source for algae and phytoplankton, which in turn provide food supply for zooplankton. Invertebrates and juvenile fish then consume the zooplankton.

(d) Estuarine aquatic habitats

There are broad similarities in the functions of estuarine habitats when compared to freshwater habitats, although their form varies considerably from freshwater systems. The principal estuarine habitats are the mud flats and sand flats in the subtidal and intertidal zones, and the plants, which develop on these flats (Morisey, 1995). These specific habitats are described in the following paragraphs.

Seagrass beds : Seagrass beds (or meadows) occur in shallow sub-tidal areas. They provide an important habitat for juvenile fish and invertebrates (particularly prawns and crabs). The seagrass blades ('leaves') provide a host surface for epiphytes (algae and protozoans) and epizoa (rotifers, small encrusting animals), which are an important food source for a number of fish species. The seagrass blades are a direct food source for sea urchins and some crustaceans, although their primary role in the food chain relates to the decay of organic matter (detritus). This detritus is decomposed by bacteria, which provide a food source for zooplankton (microscopic animals). The zooplankton is a food supply for invertebrates (including crustaceans, shellfish, and worms) and some fish species, with other fish species preying on the invertebrates. In turn, the invertebrates and fish are prey for seabirds. Seagrass beds also play an important role in stabilising the bottom sediments in an estuary, reducing turbidity levels.

Figure 2.5 Estuarine Foreshore Vegetation (Lynch and Burchmore, 1992)

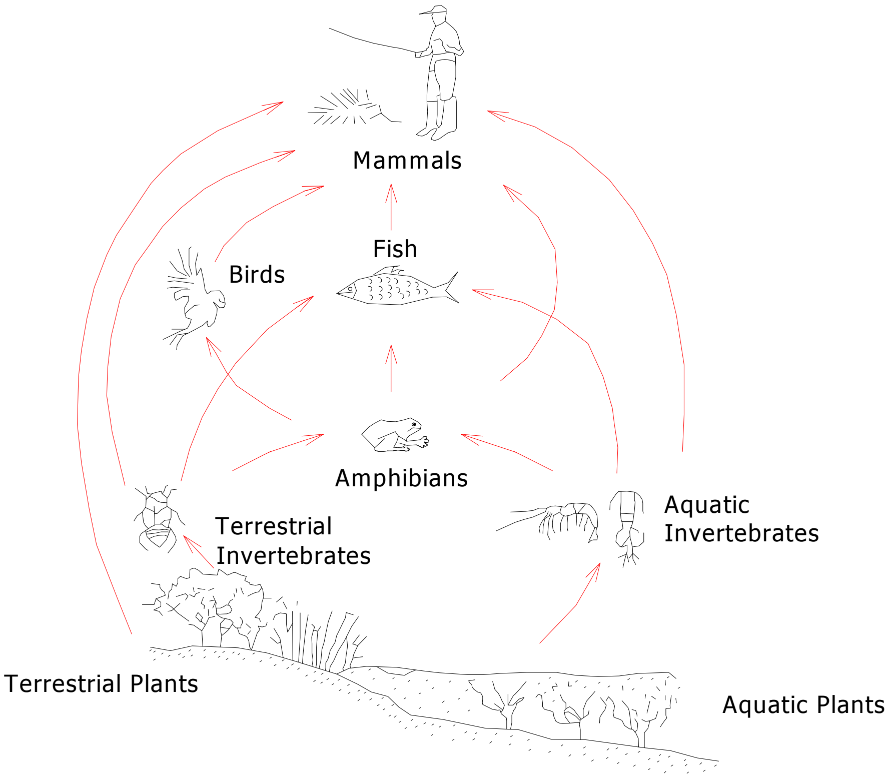


Figure 2.6 Food Chain in Aquatic Ecosystems (DCEV, 1990)

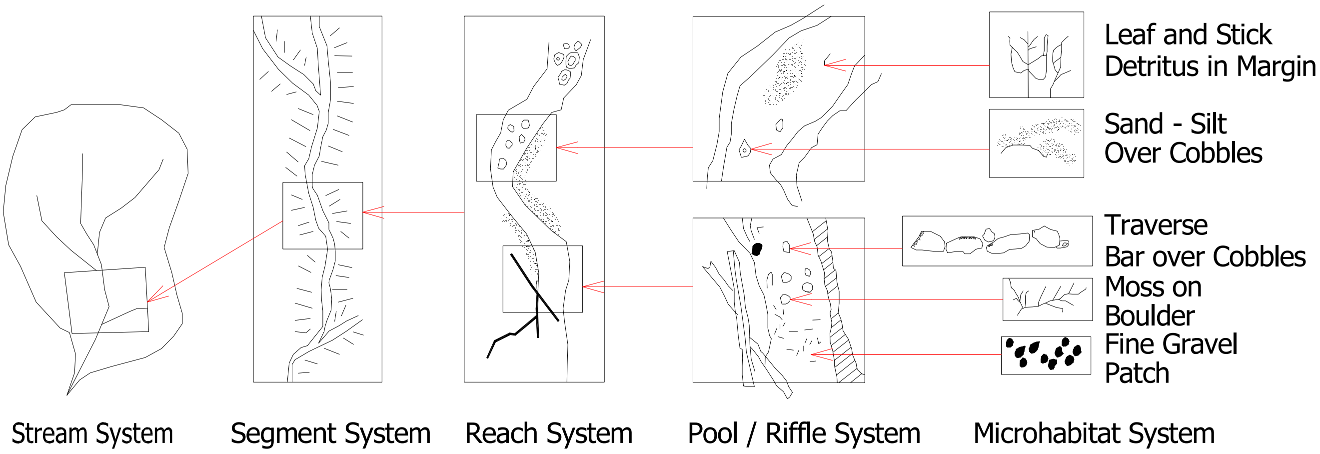


Figure 2.7 Freshwater Aquatic Habitats in Watercourses (Newbury and Gaboury, 1993)

Mangrove forests and saltmarshes : As previously noted in Section 2.2.5 (b), mangroves are an important aquatic habitat for fish and invertebrates.

Soft sediments : These provide a habitat for a range of invertebrates, including worms, shellfish, and crustaceans. These fauna can provide a food source for fish and wading birds.

2.3 IMPACT OF URBANISATION

2.3.1 Runoff Quantity

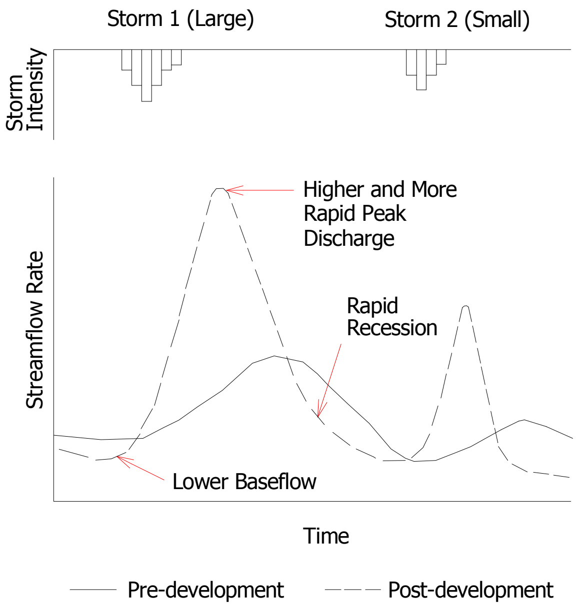
In densely vegetated undeveloped areas, overland flow rates are generally small and losses such as evapotranspiration, interception, depression storage, and soil infiltration tend to be large. Most of the rainfall infiltrates into the soil. Plants use some of this infiltrated water and, depending on soil conditions, some of it percolates until it reaches the groundwater table or flows laterally as interflow until it reaches a stream or river. Generally, undeveloped areas deliver water to streams by subsurface pathways that are much slower than surface runoff pathways from cleared or developed lands. Runoff characteristics from undeveloped areas are strongly dependent on soil characteristics, vegetation cover, and antecedent moisture conditions.

When a catchment is urbanised, large areas of natural vegetation are replaced by development containing a high percentage of impervious surfaces such as roads, roofs, car parks, and surface paving. These human alterations to land surfaces change the physical and biological features that affect hydrologic processes (Figure 2.1).

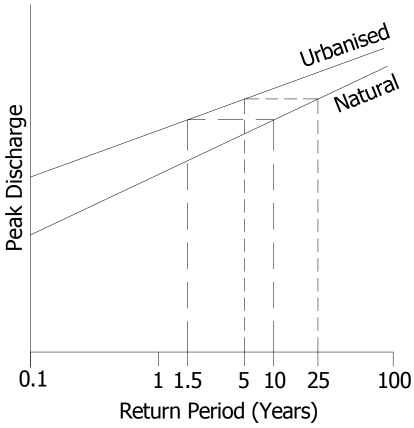
The majority of the runoff from an urban area occurs from impervious areas, particularly for frequent events (e.g. less than 2 year ARI). Impervious areas decrease the natural occurrence of rainfall infiltration and depression storage, which increases runoff volumes. They also accelerate overland flow velocities, which reduce flow travel times. In addition, urban stormwater conveyance systems can be more hydraulically efficient than natural watercourses, which further reduce flow travel times. The inevitable consequence is a significant increase in peak discharge due to a larger runoff volume occurring over a shorter time. This increase in peak discharge for any storm means that a related high discharge occurs more frequently.

Runoff characteristics in urbanised areas are therefore not strongly dependent on soil characteristics or vegetation, and are consequently less variable than those under undeveloped conditions. Urbanisation has a greater impact on frequent storm events than on rare events.

Figure 2.8 (a) illustrates typical changes in catchment hydrology that can be expected as a result of urbanisation. This figure shows that the post-development hydrograph differs from the pre-development hydrograph in three important ways; firstly, the total runoff volume is greater, secondly, the runoff occurs more rapidly, and thirdly, the peak discharge is greater. After the urban development, a given rainstorm may produce 2 to 10 times higher peak discharge than before (Roesner, 1999). As such, the overall effect is that the flow frequency curve for a developed area is significantly higher than for an undeveloped area as shown in Figure 2.8 (b). Schueler (1987) reported that if peak flow from the predeveloped area was exceeded once in two (2) years, it exceeded three (3) times per year if the area is developed as residential; and six (6) times per year if the area is developed as commercial property. This is an increase in peak flow rate of six (6) to twelve (12) times.



(a) Discharge



(b) Frequency

Figure 2.8 Impact of Urbanisation on Streamflow Quantity

2.3.2 Fluvial Geomorphology

The increased flows, runoff volumes and sediment loadings following urbanisation and the removal of riparian vegetation have the potential to alter the form of a watercourse. The cross-sectional area can increase, often by a factor of 2-3 times (Rutherford and Ducatel, 1994). This is partially due to the increased frequency of occurrence of bankfull floods, which influence the channel morphology. The potential impacts can also change over time with changing streamflow and sediment yields during the development and stabilisation phases of a catchment (Hammer, 1972). Channel widening and particularly deepening (or incision) can also be due to partial channelisation of the watercourse, which increases bed shear stresses (Rutherford and Ducatel, 1994). The removal of riparian vegetation on bends has also been found to significantly increase erosion, with Beeson and Doyle (1995) noting in one case study that bends without vegetation were 30 times more likely to erode than non-vegetated bends. Some of the morphological impacts of urbanisation may appear many decades after changes in catchment landuse.

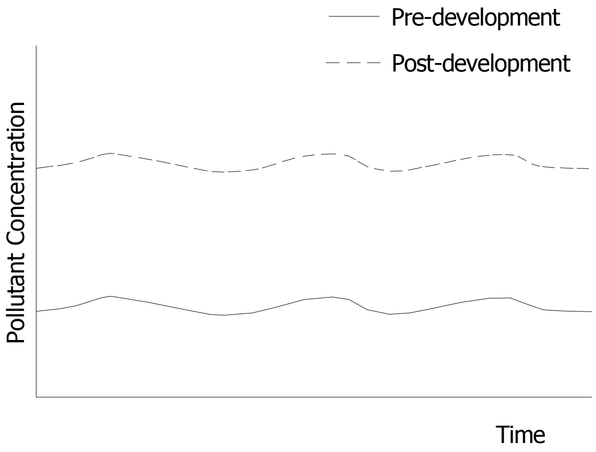
The actual extent of these impacts will be influenced by factors including:

- the nature of riparian vegetation, including roots through creek banks
- soil characteristics, particularly cohesiveness
- the extent of any rock armouring of the banks
- the location of any bedrock outcrops
- planform characteristics of the watercourse
- bed slope and associated stream power

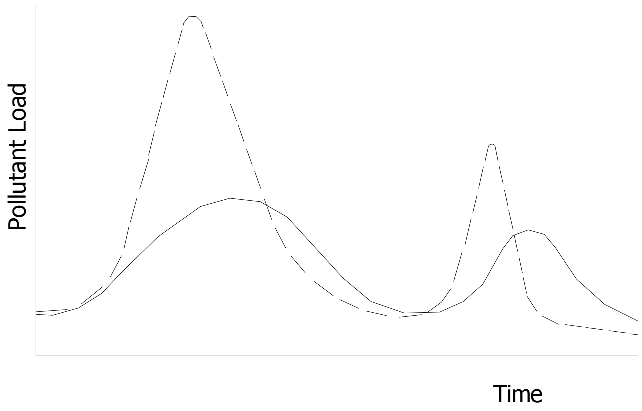
2.3.3 Runoff Quality

Urbanisation and the resultant increase in population and activities associated with urban life can dramatically change the quality of runoff within a catchment and its receiving waters. Rainfall in urbanised areas washes contaminants from the atmosphere and the resultant runoff washes material accumulated on surfaces into the urban stormwater system whereby they are transported to receiving waters. The greatest increase in pollutant loadings generally occurs for frequent storm events, due to the more significant increase in runoff volumes under these conditions. Typical effects of urbanisation on stormwater pollutographs and loadographs are, respectively, shown in Figure 2.9 (a) and Figure 2.9 (b).

Urbanisation also causes an increase in the types and quantities of pollutants in surface and groundwaters. Runoff from urban areas has been shown to contain many different types of pollutants, depending on the nature of the activities. The runoff from roads and highways is contaminated with vehicular pollutants. Oil and grease, polynuclear aromatic hydrocarbons (PAH's), lead, zinc, copper, cadmium, as well as sediments (soil particles) are typical pollutants in road runoff. Runoff from industrial areas typically contains even more types of heavy metals, sediments, and a broad range of man-made organic pollutants, including PAH's and other petroleum hydrocarbons. Residential areas contribute to runoff the same road-based pollutants as well as herbicides, pesticides, nutrients (from fertilisers), bacteria and viruses (from animal waste). All of these contaminants can seriously impair beneficial uses of receiving waters. Regardless of the eventual landuse conversion, the sediment load produced by a construction site can turn the receiving waters turbid and be deposited over the natural sediment of the receiving water. Urbanisation can also increase the median suspended sediment particle size (Mann and Hammershmid, 1989; Sharpin, 1995). This has implications on the deposition of sediment in water bodies, as coarser particles settle at a faster rate than fine particles.



(a) Pollutographs



(b) Loadographs

Figure 2.9 Impact of Urbanisation on Runoff Quality

The pollutants added by urbanisation can be dissolved in the water column or can be attached to particulates that settle in streambeds, lakes, wetlands, or marine estuaries. Some urban bays have contaminated sediments due to pollutants associated with particulates in stormwater runoff. Urbanisation also tends to cause an increase in water temperature receiving heated stormwater from the impervious surfaces exposed to sunlight (O'Loughlin et al, 1992).

Urban stormwater runoff may contain concentrations of sediment and other substances classified as pollutants which may be in excess of or foreign to the essential requirements for the function of aquatic ecosystems. These pollutants can significantly change the natural environmental balance of flora and fauna within such systems.

Classes of pollutants typically found in urban stormwater runoff include:

- suspended sediments
- heavy metals
- nutrients
- organics
- oxygen-demanding substances
- bacteria

Typical sources of urban pollutants include:

- air emissions (chemicals)
- household gardens, public open spaces, sporting facilities (soils, pesticides, fertilisers)
- street litter and garbage (leaves, refuse, packaging)
- refuse dumped in open drains and waterways (garden waste, litter, packaging)
- domestic and wild animals (faeces, BOD, bacteria)
- automobiles (petrol, oil, heavy metals, exhaust deposition, tyre and brake materials)
- wastewater discharges and sewer overflows (nutrients, BOD, bacteria)
- sewage infiltration and exfiltration, septic tanks (nutrients, BOD, bacteria)
- industry and industrial processes (chemicals, metals)
- commercial activities (service stations, wet markets)
- construction sites (soils, building products and rubble)
- accidents and spills (petrol, oil, chemicals)
- landfills (nutrients, metals, pesticides)
- sewer breakages and overflows from emergency relief structures (nutrients, BOD, bacteria)

2.3.4 Receiving Water Quality

Considerable variations in water quality from urban catchments can occur under both dry and wet weather conditions. This is due to the variability in pollutant concentration-flow relationships and in-stream processes within a catchment and receiving waters. The most significant pollutant concentration-flow relationship is the 'first flush' effect. This effect is a phenomenon which can occur primarily in small catchments for some pollutants (particularly dissolved pollutants).

Stormwater runoff and dry weather discharges can impact on the environmental values and intrinsic value of receiving waters. The degree of impact depends on the hydrology, chemistry, and beneficial uses of the receiving water body, as well as the quantity and quality of the urban runoff. Receiving water impacts are caused by a combination of physical and chemical effects. More frequent occurrences of high discharges may cause or intensify channel erosion problems, disrupting the riparian habitat both where the erosion occurs and where the additional sediment is deposited downstream. Development-related changes in water quality and dry-weather flows may also alter the riparian habitat. Receiving water impacts may not be detectable at the site of a stormwater discharge, but may become significant at a downstream location that is more susceptible to an increase in pollutant loading.

The types of impact that stormwater pollutants may have on ecosystems were classified by Harremoes (1988) as acute and cumulative. Acute effects are short-term effects typically resulting from a single event of duration measured in hours. Cumulative effects are characterised by a gradual build-up of the pollutant mass and concentrations in the receiving water, leading to environmental damage after some threshold levels have been exceeded. For these pollutants, instantaneous concentrations are generally not relevant. Examples of such effects include discharges of nutrients or some toxicants in stormwater. In this instance, the main interest focuses on loads accumulated over extended time periods.

The actual impacts at a specific site will be dependent on the nature, magnitude, duration and frequency of the change in receiving water quality, and the physical and ecological characteristics of the water body. Further, the impacts may not be detectable at the site of the stormwater discharge, but may occur at a downstream location with physical and ecological characteristics that are susceptible to the pollutant loading. For example, upland streams with short hydraulic residence times can be more sensitive to poor low-flow water quality (particularly for dissolved pollutants), rather than loads from storm events. Lowland streams, lakes and estuaries with long residence times may respond primarily to loads from storm events, and may effectively inherit pollution from upstream sources where direct impacts may be minimal. These impacts may also only be detectable after prolonged pollutant loadings.

In an estuarine environment, the water quality impacts will be dependent on the type of estuary and the location within the estuary. The well-flushed drowned river estuaries are generally least susceptible to urban stormwater pollution, with the coastal lake being most susceptible due to the absence of tides. The areas within drowned river valleys and barrier estuaries that tend to be most susceptible to pollution occur at the tidal limit on the tributary watercourses. At these locations, the tidal excursion (the longitudinal movement of water) is generally small, often resulting in a long residence time for pollutants. This can stimulate algal growth and result in depressed oxygen concentration (e.g. Onkaparinga Estuary Task Group, 1990).

As a generalisation, poor stormwater quality in freshwater systems has often been found to result in a reduced diversity of aquatic fauna and flora, and a dominance by less ecologically desirable species (Hogg and Norris, 1991; Lenat and Crawford, 1994).

2.3.5 Aquatic Ecosystem

The removal of riparian or foreshore vegetation (either directly or indirectly through bank erosion) and the planting of exotic vegetation can result in a range of negative impacts, including those on aquatic ecosystems. These impacts are broadly similar for freshwater and estuarine systems, although the ecological consequences of the impacts will be site-specific.

The potential impacts include:

- reduced input of coarse organic matter to aquatic ecosystems
- altered litter composition and litterfall timing from any exotic vegetation, reducing the bioavailability of this organic matter
- increased water temperatures and reduced shading, increasing predator visibility
- decreased bank or foreshore stability, possibly increasing sedimentation of the substrate and turbidity levels
- increased pollutant inputs from overland flow (Morison and Williams, 1995; Underwood and Chapman, 1995)

The alteration of physical freshwater habitats can occur by either direct human intervention or indirectly by altered channel morphology caused by changes to the streamflow regime or sedimentation. Channel improvement works, often undertaken to increase the hydraulic capacity of a watercourse, generally result in the creation of a uniform channel geometry. Pool and riffle zones, organic debris and aquatic flora may be removed and a uniform substrate created. As a consequence, flow distribution and velocity characteristics are likely to be less variable within a reach. This can result in reduced abundance and diversity of aquatic fauna and flora (Shields et al, 1994).

Estuarine habitats can also be affected directly or indirectly by stormwater-related impacts or activities. Dredging may be undertaken to increase the hydraulic capacity of the upper portion of an estuary for flood mitigation purposes. This may result in the direct loss of seagrass during the dredging operation and the increased depth (and resulting light penetration) may provide unsuitable conditions for recolonising. Further, seagrass recolonisation occurs at a slow rate, with some species not recolonising at all. The dredging may also affect mangrove forests.

Flood mitigation works such as levees with outlet gates or road embankments across estuaries with small bridge (or culvert) waterways can significantly alter the tidal regime and/or the salinity. This can have a negative impact on mangroves, saltmarshes and seagrass habitats upstream of these barriers. Further, seagrass generally grows in low current areas and increased tidal or freshwater flow rates downstream of these bridges or gates may reduce the extent of any seagrass beds.

If drains are installed through mangrove wetlands or saltmarshes, the altered tidal conditions may also have a negative impact on these habitats.