STORMWATER MANAGEMENT:

Emerging Planning Approaches
and
Control Technologies

Chapter 1

" *STORMWATER MANAGEMENT* "

CHAPTER 1

1.1 INTRODUCTION

1.1.1 Training Objectives

The objectives of this Chapter are to:

- provide an overview of the impacts of urbanization on the hydrologic cycle
- describe how those alterations of the hydrologic cycle, and other consequences of urbanization, can affect the environment, and
- provide an introduction to the concept of stormwater management

1.1.2 Urban Stormwater Management

Stormwater management as an area of engineering practice is readily understood and defined. However, the term must be approached with caution since the practice of stormwater management has evolved rapidly over the last ten years, and will no doubt continue to do so for the foreseeable future. As recently as the late 1970's, stormwater management associated with urban development was generally restricted to the practice of drainage engineering. At that time, the objective of stormwater management was essentially to convey stormwater flows from a development conveniently, safely, and at low cost. Flood protection was a separate consideration, and was mostly directed at provision of hydraulic drainage structures adequate to contain and convey flood flows.

These seem like reasonable objectives in themselves, and in fact must still be respected. However, these objectives are not sufficient, since they do not eliminate secondary effects such as environmental damages caused by upstream development. To address such secondary effects, drainage engineering as a sole concern is now rare, and stormwater management in an increasingly holistic form is the rule.

... the planning and control of drainage
so as to preserve life and prevent damage during storm events,
while respecting the need to
preserve and protect environmental features
that might directly or indirectly
be affected by changes in storm flows.

A Working Definition of Stormwater Management

Presently, stormwater management encompasses a whole array of considerations, including water quantity and quality, habitat, groundwater recharge, baseflow augmentation, and other aspects of the environment. Reconciling the needs of these environmental sensitivities while fulfilling the primary requirement for safe and effective drainage of stormwater is the challenge of stormwater management.

1.2 THE IMPACTS OF URBANIZATION ON THE WATER RESOURCES SYSTEM

1.2.1 General

The process of urbanization affects the hydrologic cycle in a number of significant ways. These include impacts on the volume of runoff, the rate of runoff, and the water quality of runoff, etc.

Rate and Volume of Runoff in the Natural Setting

In natural or undeveloped conditions, the runoff hydrograph (runoff flow rates over time) tends to be relatively flat and small compared to what is observed after urbanization. This reflects the hydrologic processes governing infiltration losses and surface routing.

In the natural condition, there is relatively little impervious area on the watershed surface unless intact rock, clay, or water surfaces are present. Therefore in natural soils with vegetative cover substantial volumes of rainfall are lost, first to initial wetting of vegetation and ground cover, and then as a result of infiltration into the ground. In sandy areas with a high soil moisture capacity, the natural volume of runoff can be relatively low. A volumetric runoff coefficient (volume or runoff/ volume of rainfall) in the vicinity of 0.2 or 0.3 can be experienced.

Also, the natural vegetation and uneven terrain tend to hold back runoff. Small ponding areas on the uneven land surface will hold back flow, and flow paths are irregular and meandering. Also, small volumes of flow imply low depths of overland flow and hence low flow velocities overland. Taken together, these factors tend to extend the time which must elapse before flow volumes can leave the watershed.

The net result of low flow volume and a strong surface routing effect is that the undeveloped hydrograph is generally flat and low.

Rate and Volume of Runoff in the Developed Setting

Urban development inevitably changes the watershed, by paving, regrading, adding drainage facilities, and removal or alteration of vegetation. This has a strong influence on both the amount of water which infiltrates, and the rate at which water moves across the catchment.

The removal of natural vegetation and grading of the land eliminates storage associated with interception of rainfall by vegetative cover. Covering the land surface with pavement and concrete prevents infiltration, and hence, effectively eliminates substantial amounts of available soil moisture storage. These factors tend to increase the amount of runoff volume which is associated with a give rain event, compared to the natural condition. Runoff volume coefficients may be has high as 0.8 or 0.9 on an event basis after development. In extreme cases, therefore, development can raise the volume of runoff several times over what is observed naturally.

The surface routing system is also profoundly affected by development. The land surface, graded and manicured to typical urban standards, demonstrates less opportunity for ponding. As well, overland flow routes are less meandering and therefore tend to provide steeper and shorter flow routes. Velocities are therefore higher, and hydrographs tend to be peakier.

Even more extreme changes in the surface routing system are associated with the urban drainage infrastructure. Pipes and gutters or roadways tend to be more direct, steeper, and smoother pathways for water than exist in natural catchments. As well, such structures concentrate flow in defined channels which have relatively less volume than the pre-existing overland surface system. This further reduces the routing effect, compared to the natural case. Again, for a given volume of runoff, flow rates are faster.

Figure 1.1 shows the effect of urbanization on runoff hydrographs.

- imperviousness increases
- vegetative cover changes
- overland flow routes become quicker
- pipes and gutters tend to increase flows

Changes Affecting Runoff Rate and Volume

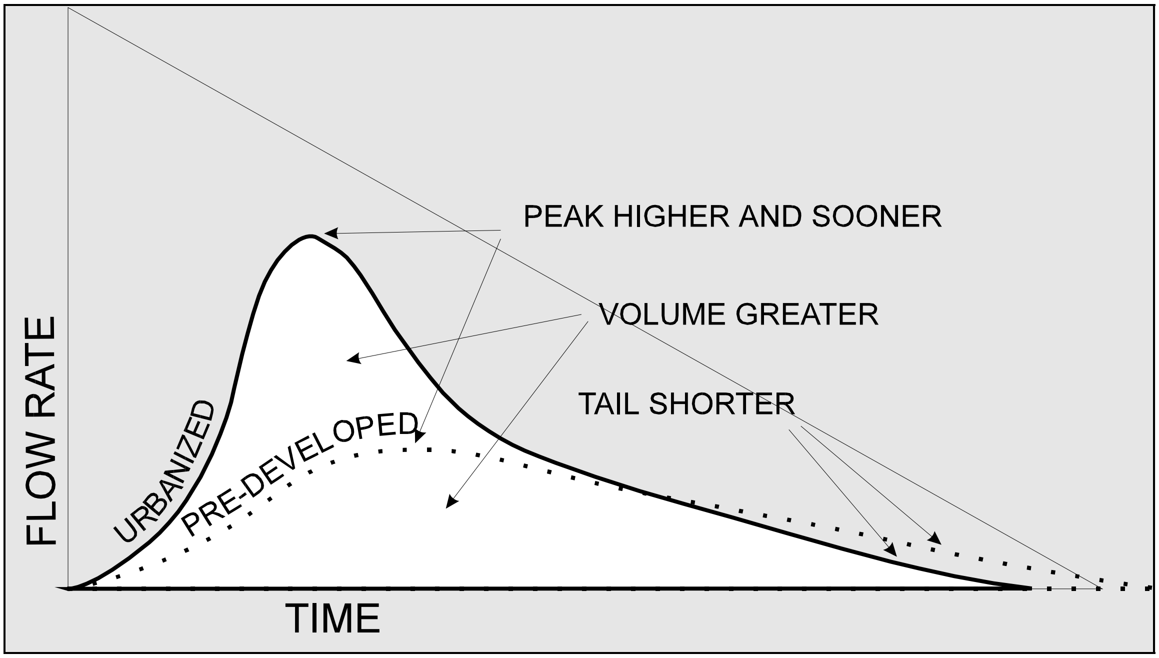

Figure 1.1: Conceptual Sketch of Changes in Hydrograph

Changes in the Channel System

The other major change in the hydrologic system which is associated with urbanization is associated with the drainage network which receives flows. The natural system includes channels which arise naturally as flows cut defined drainage pathways through low points. These natural channels tend to meander, and maintain a net slope that balances the rate of flow, the channel material, and the overall land form of the area. The natural channel form generally has a narrow, meandering channel which conveys flows between events, and during small storms. Also, however, there is a larger floodway which has the capacity to convey flows during larger storm events. This floodway is an important facet of the watershed drainage system, since the floodway not only provides a major hydraulic capacity, but provides a substantial volume for flow routing and peak flow attenuation.

However, historical land development practice tended to promote encroachment of the floodway by human structures or other factors. Fill along the edge of the floodway tended to progressively narrow it. Channelisation to stabilise the channel, or re-direct it to conform to street patterns or other 'desirable' conditions also had an impact. The channelised creek or river tended to be straighter and smaller in section than the natural system. As a result, the channel was steeper, smoother, and possessed of a smaller storage volume. Again, the tendency is for urbanisation to cause higher, larger flow hydrographs.

- encroachment by structures
- reduced storage due to fill or encroachment
- realignment to accommodate urban form

Typical Affects of Urbanization on Stream or River Channels

Water Quality

Water quality degradation also accompany the change to an urban environment. There is a tendency for the changes in land use to be associated with different sources of pollution. The nature of this change is associated with the existing and future land use. A shift from cattle farming to light industry, from example, is not equivalent to the shift from deciduous forest to single family residential neighbourhoods. However, there are a number of generalizations that can be made, to illustrate the nature of the problem.

- Vehicle traffic is probably one of the most significant impacts on water quality. Leaded gas, electrical components, catalytic converters, exhaust emissions, fuels and lubricants, and other factors are or have been all associated with the automobile. Snow removal operations implicitly contribute quantities of de-icing compounds, mainly salts.

- Animal populations also are affected by urbanization. Free roaming pets have been documented as substantial contributors to indicator bacteria. Shifts in bird populations have also been associated with increased indicator bacteria loads.

- Combined Sewage Overflows are a major consideration in stormwater and sanitary system servicing upgrades in many North American cities. Such overflows are not strictly a problem of stormwater management, but are commonly encountered as stormwater quality problems are solved.

- Land application of pesticides, herbicides, and fertilizers accompany the urban dwellers' attempts to improve on the appearance of lawns and gardens.

- Suspended sediment loads are affected by changes in land use. Loads may go down after urbanization, in fact, compared to what might be encountered in some agricultural operations. However, the sediments may have an associated chemical constituent load which is different from that which is encountered naturally.

- Temperature can be affected, as the shift in land cover and stream vegetation alters the balance of radiation and hence land and runoff temperature. Also, a tendency for baseflow to decrease in favour of direct runoff can have an effect on instream temperature.

In general, one might expect changes in water borne loads of heavy metals, organic compounds, indicator bacteria or pathogens, oxygen demanding substances, water temperature, dissolved oxygen, and suspended sediments among other things after urbanization. Floating materials such as styrofoam particles, oils and greases, or other debris also are a consequence of urbanization.

- indicator bacteria and pathogens may increase
- BOD increases, and DO decreases
- suspended sediments change (typically increase)
- temperature increases
- anthropogenic floatable materials increase
- organic compounds can increase
- chlorides can increase

Some Water Quality Impacts

The General Problem

In general, the impact of urbanization can be widespread and considerable, indirectly or directly affecting many aspects of the watershed and receiving waters as a result of the ways in which urban development affects the hydrologic cycle, and the physical components which regulate that cycle.

- increased flooding
- reduced base flow
- channel instability
- impaired water quality
- increased erosion or deposition
- lowered water table
- impaired habitat

Some General Consequences of Urbanization, Induced by Changes to the Hydrologic System

1.2.2 Flooding

The process of urban development in Ontario very often progressed upstream from a river junction or outlet which originally spawned the development of a community. This was the case, for example, along much of the Lake Ontario shoreline.

A predictable pattern was found to accompany this development. An initial development might be at the outlet of a stream. Drainage works for the initial development were sized and placed to provide flood protection. This might include drainage to the river, or lake. If channel capacity was adequate, channelization might not occur. Drainage would initially be adequate, and where is was not, would be countered with local channelization or flood protection. Flow peaks and volumes might increase, but these were handled as a part of the initial design, and were not a major problem otherwise.

Then, development would progress upstream, as the older development area expanded into adjacent lands in response to the pressure for growth. Drainage works in the new area would be again be designed to be locally adequate. However, flows from the new development would also increase compared to undeveloped conditions, as a result of the impacts on the hydrologic cycle described above.

These upstream increases might be accommodated by the downstream drainage system initially. Eventually, however, a point would be reached where the cumulative impact of upstream development increased flows to the point that drainage in the earlier development areas downstream might not be adequate. Flooding would ensue, and drainage works would be placed downstream in an effort to contain the damage. However, responding to such problems is not always simple. Structures such as houses built on or across the flood plain represent a special challenge.

- development begins at the lower end of the watershed
- natural and human factors are sensitive to flow increases
- upstream development occurs, and increases runoff upstream
- downstream developments experience increased frequency and severity of flooding

The Typical Relation Between Urban Development and Flood Potential

Eventually, it became recognized that the solution to flooding would ideally be to guide development so as to respect basic principles that mitigate the problem before it is encountered. It might, for example, be appropriate to:

- avoid changing the rates at which flows are released from a development area compared to what existed before development,

- avoid encroachment on the river floodway by structures that might compromise hydraulic conveyance, reduce storage routing, or be susceptible to damage

- encourage development practices that reduce runoff volumes to an approximation of natural conditions

- regulate development within flood plains.

These are structural and management elements of stormwater management that are focused on mitigation of flooding.

1.2.3 Impacts on Base Flow

Urbanization tends to result in more water runs off the catchment than before development. Recharge of the groundwater system is therefore reduced (infiltration is reduced). In turn, this affects the baseflow in a stream, since base flow is often largely composed of waters which exfiltrate from the groundwater storage system between events. One can view the soil system as a reservoir which fills during events, and empties into the channel between events. If this reservoir is capped, the recharge part of the water cycle is reduced. As a result, the reservoir becomes depleted, and baseflows are reduced. In general, the process of urbanization therefore tends to change streamflows from one form to another; base flows are reduced, flood events become peakier and larger, and the whole system tends to be much less damped than before development.

- imperviousness increases
- recharge is reduced
- soil moisture is depleted
- exfiltration to the river is decreased
- baseflow is reduced

and

- water quality and temperature are affected

Typical Impacts of Urbanization on Base Flow

Reductions in baseflow can affect aquatic species and their habitats, as well as recreational uses and water supply potential of lakes and rivers.

The responses of stormwater management to this phenomenon include:

- promotion of stormwater management practices that encourage infiltration and groundwater recharge.
- promotion of drainage practices that encourage buffering, retention, and slow release of stormwater flows where appropriate

1.2.4 Water Quality

As indicated above, the shift in land use has a direct consequence, in that the contaminants in urban runoff can be different from that in undeveloped areas. The details of this are very site specific, but in general one might expect increases in heavy metals, road salts, and organic materials associated with vehicle access and other urban activity. One might also expect changes in indicator bacteria levels and possibly pesticide, nutrient, and herbicide. Table 1.1 provides some indication of values which can be encountered in some parameters of interest.

Since runoff is not free of contaminants even under non-urban conditions, the degree of change in water quality depends on prior land use as well as on the form of urban development. Agricultural land use, for example, will represent a different initial condition than undeveloped forest areas or wetlands. Either way, there is a need to provide protection and mitigation of water quality degradation after development.

- urban land use changes pollutant sources
    - pesticides, herbicides may increase
    - nutrients may increase
    - indicator bacteria tend to increase
    - road salts and vehicle emissions increase
    - organic materials may increase
    - heavy metals increase
    - anthropogenic floatable materials may increase
- rainfall washes pollutants off catchment surface
- runoff contains increased contaminant loads

Typical Impacts of Urbanization on Water Quality

Stormwater management measures very often are targeted at water quality improvement. Measures which are used include:

- control of pollutant sources, by managing land use or land activity (such as fertilizer application)

- detention of runoff, by implementation of control ponds or other water quality management practices which encourages sedimentation and decay

- control of runoff discharge points, to manage impact locations

- use of the assimilative capacity of the receiving water to diffuse and accept tolerable amounts of some contaminants

The hydrologic analysis which is required for the assessment of stormwater quality facilities is substantially different from that of the quantity facilities since chemical, physical, and biological reactions must be incorporated.

Table 1.1. A Few Representative Urban Stormwater Pollutant Constituent Concentrations.

Parameter	USEPA[1]	E.Yrk[2]	St.Cat[3]	King[4]	Ont[5]
Total Suspended Solids (mg/L)	125	281	250	72	25
Biological Oxygen Demand(mg/L)	12	14	8.2	8.5	/
Chemical Oxygen Demand (mg/L)	80	138	/	/	/
Total Phosphorus (mg/L)	0.41	0.48	0.33	/	0.03
Soluble Phosphorus (mg/L)	0.15	0.06	0.084	0.118	/
Total Kjeldahl Nitrogen (mg/L)	2.00	2.20	0.89	/	/
Nitrate and Nitrite (mg/L)	0.90	0.46	0.65	0.25	/
Total Copper (mg/L)	0.040	0.050	0.021	0.009	0.005
Total Lead (mg/L)	0.165	0.570	0.084	0.013	0.025
Total Zinc (mg/L)	0.210	0.330	0.100	0.064	0.030
Fecal Coliform (No./100ml)	21,000	11,000	68,000	21,000	100

1. U.S. EPA -	Mean concentration for median urban site Nationwide Urban Runoff Program (NURP) (Driscoll & Mangarella, 1990)
-	Fecal coliform, Median Event Mean Concentration (EMC), 11 sites (NURP, U.S. EPA, 1983)
2. East York -	Arithmetic mean, 18 events, 1 site (Kronis, 1982)
3. St. Catharines -	Geometric mean, 4 events, 1 site (SCAPCP, 1990)
4. Kingston -	Geometric mean, 8 events, 1 site (CH2M Hill, 1990)
5. Ontario -	Provincial Objective or Guideline, MOEE or MNR)

1.2.5 Impacts on Stream Morphology

The stream form is determined as the net result of applied load (flow and sediment), and native materials (bank and bed), as affected by urbanization, over time. The stream will tend to erode or aggrade if the natural balance of these factors is altered. It should be recognized that a natural channel does exhibit some variability in any case, since the balance is not static, but is a dynamic interaction that reflects changing seasons, precipitation patterns, and other factors. However, if that dynamic stability is altered, the system will react, and change, until a new stable regime is formed.

- upstream flow and sediment loads are altered
- sections of the stream may be channelised or re-aligned
- flow velocity and depth may change locally, so
- sediment carrying capacity changes, and erosion or deposition occurs, causing
- instability and change in channel form, until
- a new stable form is (eventually perhaps) reached

Typical Impacts of Urbanization on Stream Channel Stability

The impacts of such a change can be numerous, and include channel re-alignment, bank undercutting or instability, and changes in sediment bed load. These changes, aside from their hydraulic consequences, can have a significant impact on the habitat which is available for terrestrial and aquatic populations.

Stormwater management measures which are available to control or moderate changes in stream morphology include:

- placement of structures or other hydraulic controls to affect instream flow rates, energy, and transport potential,

- control of runoff rates using control ponds or other devices so that acceptable transport energies (velocity, depth etc.) are maintained instream, and

- control of runoff volumes by means of suitable stormwater best management practices (BMPs), so that volumes and long term rates of flow are maintained at acceptable levels instream

1.2.6 Impacts on Stream Habitat

The habitat offered by the river system can be affected by urban stormwater in a number of ways. The cumulative effect of water quality changes and flow changes, including possible alterations of the stream morphology, are all potentially important in determining stream habitat. Some important considerations are temperature and water quality, which have a bearing on the value of the resource as a cool water or warm water fishery; dissolved oxygen, which affects the ability of the water to support fish; nutrients which affect trophic status; bedforms, substrate, velocity and depth, all of which affect the suitability of the location for particular species; barriers to fish migration and/or mobility, including jumps or falls, which may result from shifts in the flow rate or channel form; and, contaminants, which may eliminate the stream as a habitat site altogether.

- numerous urban impacts on stormwater affect flows, quality, channel form and result in
    - altered substrate
    - change in base flow regime, altering pools, ripples and other governing stream flow features
    - degraded quality and increased temperature
    - change in trophic status (abundance of weeds, algae etc)
    - change (increase) in sediment load

- these factors govern habitat suitability for existing or any other population
- if habitat suitability changes, the whole ecosystem may change

Typical Impacts of Urbanization on Stream Habitat

The stormwater management measures which are appropriate in the management of these various features are combinations of the measures described above, as they affect water quality, stream morphology, flow rate, and so on.

1.2.7 Wetlands

Wetlands represent a second major habitat group of concern in the practice of stormwater management. There is a clear need to ensure that this particular habitat is respected and preserved, both as a result of developing regulations, and in recognition of its role as an important ecosystem. Wetlands as a stormwater management challenge also represent what is probably one of the most recent and significant expansions of the scope of stormwater management. Historically, where they were not merely filled and developed, wetlands were addressed more as convenient low points for control ponds and/or drainage routes. Now, they must often be protected as primary constraints to stormwater management.

The factors affecting recharge and baseflow, as described above, affect the amount of water in soil storage. If this amount goes down, a result (aside from the change in base flow described above) may be the lowering of the water table in the area. If that happens, it is possible that a wetlands area can be left high and dry, and destroyed. If urbanization and the associated changes in the hydrologic system lead to an increase in recharge that cannot be accommodated by the groundwater system, the opposite may occur. The wetlands may change in elevation, or be permanently inundated. This may also be an unacceptable result.

- urbanization alters surface hydrology, affecting
  - recharge
  - landforms and overland drainage patterns
- the water table shifts
- overland flows tributary to the wetland may change in quantity and quality (usually for the worse)
- the wetland is stressed
  - dried or inundated during interevent periods
  - subjected to increased flows during storm events
- the wetland either adjusts to a new condition, or is eliminated

Typical Impacts of Urbanization on Wetland Areas

Where wetlands are to be preserved, stormwater management must therefore maintain water table elevations. This in turn generally implies a requirement that recharge be maintained. Assessment of measures which will achieve this can extend the tools of hydrology to include groundwater modelling. Stormwater management measures which can be employed to manage groundwater include:

- promotion of BMPs that rely on recharge as a part of stormwater management,

- conscientious attention to water balance as affected by land use (evapotranspiration losses, impervious area, and so on).

1.3 SOLUTIONS TO STORMWATER MANAGEMENT ISSUES

The above sections deal in general terms with the types of stormwater measures which are appropriate as responses to parts of environmental protection, and later Chapters will deal with specific management practices in detail.

As indicated above, understanding has led to new practice, including stormwater management measures designed to reduce the impact of development and hence the need for costly remediation after the fact.

Another complexity arises from the large number of diverse factors in the problem, some of which are only partly defined. This can make selection of the solution difficult. If trade-offs occur between various alternatives, for example in the relative merits of habitat enhancement at one point in a stream versus another, there is no recognised means of making a choice. Subjective judgement, supported by some quantitative information and analysis, becomes the basis for the plan, in turn becomes the solution.

The net result is that derivation of solutions must at present be based on the interpretation and evaluation of a diverse variety of pieces of information. The systematic identification of critical requirements for control, based on an identified vision of the developed watershed, must be the starting point for stormwater management.

The Vision

The solution of the stormwater management problems begins with a vision of the watershed, developed as the result of concerted interaction between stakeholders that includes the public, regulators, developers, and other parties to the decision.

The Criteria

Based on the vision for the watershed, the various elements of the problem can be put into perspective. Key decision elements are identified, and the relative importance of criteria is then known.

The Strategy

Based on opportunities and constraints that physically govern the watershed, various strategies are then evaluated. A strategy includes development scenarios, control measures, and environmental impacts that will be encountered as those measures and developments are implemented.

The steps in planning which follow the above process are fully described elsewhere in this series of Chapters. At this point, it is important to realise that *stormwater management is accomplished as an integrated plan that achieves specific identified goals on a watershed basis.* It is not a device, a control measure, or a single criterion.