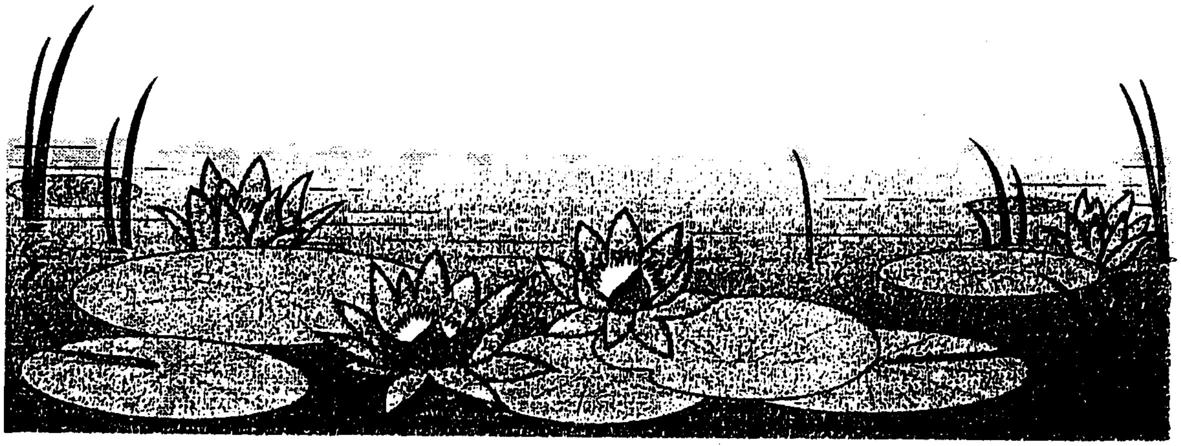
CVC

CREDIT VALLEY
CONSERVATION

STORMWATER MANAGEMENT GUIDELINES



in co-operation with

Our Member Municipalities

MAY 1996

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CVC

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CONSERVATION

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MAY 1996

Produced in co-operation with our member municipalities:

Township of Amaranth
City of Brampton
Town of Caledon
Township of East Garafraxa
Township of Erin
Village of Erin
Town of Halton Hills
City of Mississauga
Township of Mono
Town of Oakville
Town of Orangeville

With financial support from the
Ontario Ministry of Environment and Energy

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1.0 INTRODUCTION AND BACKGROUND

1.1 Purpose

In rapidly urbanizing areas, stormwater resulting from rainfall events has the potential to cause severe and sometimes irreversible environmental problems. In recognition of this, the 1990 *Credit River Water Management Strategy (Phase 1)* recommended that Credit Valley Conservation (CVC) develop policies to address stormwater runoff control. In response to this recommendation, these Stormwater Management Guidelines have been Developed by CVC in cooperation with it member municipalities and provincial review agencies, and are being circulated for comment.

The Stormwater Management Guidelines have been developed primarily as a tool to assist developers, consultants. municipalities and others dealing with stormwater in the Credit River watershed. In particular. the Guidelines are aimed at helping people understand the existing approvals process for stormwater management plan submissions. CVC believes that an increased understanding of the environmental impacts of stormwater and the regulatory requirements for stormwater management will lead to improvements in management practices and an increasingly standardized and streamlined approach to addressing stormwater throughout the watershed.

The Stormwater Management Guidelines are not new. Rather, they represent a collection and overview of existing and emerging requirements, policies and issues relating to the subject. The Guidelines relate to and are intended to complement existing documents including the following:

- *Water Management on a Watershed Basis*, (MOEE and MNR, 1993);
- *Subwatershed Planning*, (MOEE and MNR, 1993);
- *Integrating Water Management Objectives into Municipal Planning Documents*, (MOEE and MNR, 1993); and
- *Stormwater Management Practices Planning and Design Manual*, (MOEE, 1994).

Within the Credit River watershed, general direction for stormwater management is provided by the *Credit River Water Management Strategy, Phase I and II.* This direction is discussed throughout this report.

CVC's Stormwater Management Guidelines are intended to be advisory in nature, not prescriptive. While they contain a recommended approach to developing a Stormwater Management Plan, this illustrates one method of carrying out the task. Site specific differences and data needs may require proponents of projects to use slightly different approaches. Developers, reviewers and others are cautioned against relying too heavily on this document as practices and policies change over time, and may be fine-tuned to reflect site specific projects and conditions. In short, these guidelines are not intended as a substitute for discussions with relevant provincial agencies, CVC, the local municipality, or adjacent property owners.

Sections 1.0 to 3.0 of this document are fairly general in nature, and have been written so as to be comprehensible to a lay audience. Section 1.0 contains the background and general context for stormwater management, Section 2.0 provides an overview of the environmental impacts of stormwater from landuse changes, and Section 3.0 describes the overall water management process in the Credit Watershed. Sections 4.0 and 5.0 deal in a much more detailed way with the development of Stormwater Management Plans, and are aimed at engineers, hydrologists and other technical professionals. Section 6.0 contains a brief conclusion to the document. The Appendices provide a glossary, a bibliography, and detailed information on modelling, sediment and erosion control, and municipal servicing considerations.

1.2 Stormwater Management Goals

The overall goal of the Stormwater Management Guidelines is:

> **To provide direction regarding the design and implementation of stormwater management practices in order to maintain the quantity and quality of surface and subsurface water resources while conserving or enhancing natural habitats and aquatic communities.**

General direction for stormwater management is provided by the *Credit River Water Management Strategy, Phase I and II (CRWMS).* Phase II of the Strategy contains the principle strategic components. The strategic components relating most directly to stormwater management include:

- pollution prevention should be given priority over control measures;
- infiltration of stormwater should be emphasized, as long as groundwater supplies are protected;
- in selected areas, water quality facilities should be provided to reduce the impact of existing and proposed development;
- spill control devices should be provided [where appropriate] on all stormwater outlets;
- the tree canopy, riparian vegetation and baseflow should be maintained and enhanced;
- the impact of increased runoff from existing and future development should be offset through reforestation and wetland creation;
- channels should be constructed and restored in a manner that is both environmentally and hydraulically acceptable using natural materials whenever possible;

- erosion and sediment control [during the construction process] should be incorporated in and enforced through new municipal bylaws; and

- existing municipal servicing and drainage standards should be reviewed to ensure that they are environmentally compatible.

1.3 Changes in Stormwater Management

Historically, stormwater management focused on the prevention of flooding and erosion in rivers and streams which receive stormwater. This reflected a societal view of river channels as conduits for the convenient passage of stormwater. In order to prevent flooding and erosion, agencies in urbanizing areas have taken drastic actions over long periods of time. These have included channelizing rivers and streams, building extensive flood protection works such as dams and energy dissipaters, creating large detention ponds, and construction ever-larger storm drain systems to carry stormwater away from human-built impervious landscapes and into rivers. Unfortunately, such approaches to stormwater management have had a number of unintended side effects including the destruction of aquatic habitats, the diminishment of aquatic communities, the degradation of surface and groundwater quality, channel instability and the depletion of groundwater.

Today, there is a broad understanding of the need to apply ecosystem approaches to stormwater management - to consider the interrelationships between stormwater and water quality, water quantity, and aquatic systems. The quality and quantity of surface and groundwater are interconnected and are influenced by land development and changing land use practices. The physical and chemical condition of surface and groundwater, in turn, influences aquatic habitats and communities (see Section 2.0). As compared to traditional methods of managing water resources, modern watershed and subwatershed planning processes provide a much broader context for stormwater management. These planning processes provide an integrated vision of desired future states, and they provide goals, objectives, and technical requirements for stormwater management that provides a planning horizon that is both longer and broader than traditionally used.

Today, when designing stormwater management facilities, specialists recognize the importance of maintaining and enhancing surface and groundwater systems in a manner that as closely as possible resembles "natural" form and function. Instead of conveying all stormwater into storm drains, designers consider facilities that allow infiltration of stormwater to recharge groundwater and maintain baseflows of rivers. Instead of turning rivers into concrete channels to carry stormwater, designers are re-naturalizing channels to increase riparian cover and to create stable, self maintaining forms. Instead of considering rivers as conduits of stormwater, designers are considering them as complex, self-regulating systems and important habitats for invertebrates, fish, birds, reptiles and amphibians. In short, modern water resource managers try to maintain healthy river systems. In such systems, a river's energy is naturally dissipated through balanced rates of erosion and sediment transport. When erosion and sediment transport occur at natural rates, a variety of aquatic habitats are supported and channel morphology is preserved.

1.4 Credit Valley Conservation's Role

The mandate of the Credit Valley Conservation (CVC) is outlined in the Conservation Authorities Act, RSO 1990, Chapter C.27. In essence, CVC is responsible for developing and implementing programs to conserve, restore, develop and manage natural resources, including water resources on a watershed basis. Accordingly, CVC has taken a lead role in watershed and subwatershed planning studies. CVC's role in detailed stormwater management plans has evolved over the years. Future efforts will be geared toward streamlining the municipal process with member municipalities to remove areas of overlap and duplication. Under Memoranda of Agreement with the Ontario Ministry of Natural Resources, CVC currently has responsibility for development review in the watershed on behalf of both agencies.

2.0 ENVIRONMENTAL IMPACTS OF STORMWATER RESULTING FROM LAND USE CHANGE

Within the earth's atmosphere, water moves through the hydrologic cycle (see Figure 2.1). As illustrated in this figure, water evaporates from lakes and other water bodies and then falls back to earth as precipitation. Some of this precipitation runs off directly into streams which ultimately feed into the nearest large body of water. The rest of the precipitation infiltrates into the earth to become groundwater. Some of this groundwater is taken up by vegetation or recharge aquifers, and some moves laterally or upwards to discharge in streams with fresh water, (see Figure 2.2). The "natural" hydrologic cycle is a complex and balanced mechanism that is mediated by vegetation, geology, geography, climate and soils and topography.

Changes in landuse and particularly urbanization can have dramatic effects on the hydrology of a watershed – on how water moves and where. These hydrologic changes cause modification of river channel morphology, alterations in flows, changes in groundwater flow paths and groundwater quantity, loss of wetlands and habitat, loss of forests, increased levels of erosion, sedimentation and siltation, and pollution of ground and surface waters. The physical, chemical and biological impacts of these stresses are listed in Table 2.1 and discussed in the next sections.

2.1 Water Quantity

Impacts on Surface Water: Surface water storage, evapotranspiration, infiltration and runoff can be greatly altered by urbanization. Typically, urbanization results in removal of upland forest cover and riparian (or stream-edge) vegetation and the creation of large impervious areas such as roads, parking lots and roofs of buildings, (Figure 2.3a) The creation of these impervious areas causes reduced surface storage and infiltration of water; subsurface flow runoff generally becomes nonexistent. As a consequence, the volume of and velocity of surface runoff is increased, (Figure 2.3b). Baseflow (low flow conditions of rivers and streams) is also reduced in an urbanized landscape; This can adversely affect aquatic habitats. Importantly, peak flows of rivers and streams are higher and occur more frequently, (Figure 2.3c). This increase in peak flows can lead to flooding of property, buildings and aquatic habitats, and increased erosion (see Section 2.3).

Impacts on Groundwater: In an urban area, the change in landuse from natural (pervious) ground covers to paved surfaces and rooftops typically reduces infiltration and recharge by 25 to 50% for shallow aquifers and 33 to 80% for deep aquifers. This reduction in infiltration to shallow aquifers can lower the water table which in turn can reduce or eliminate springs and discharge to surface waters. Reductions in the volume of upwelling areas in streams affect spawning areas and coldwater fisheries; loss of baseflow can cause losses of marsh and fen vegetation and can reduce the biodiversity of and lower the quality of marshes, fens, and swamps, (see Section 2.4).

FIGURE 2.1 The Hydrologic Cycle *(Environment Canada 1995)*

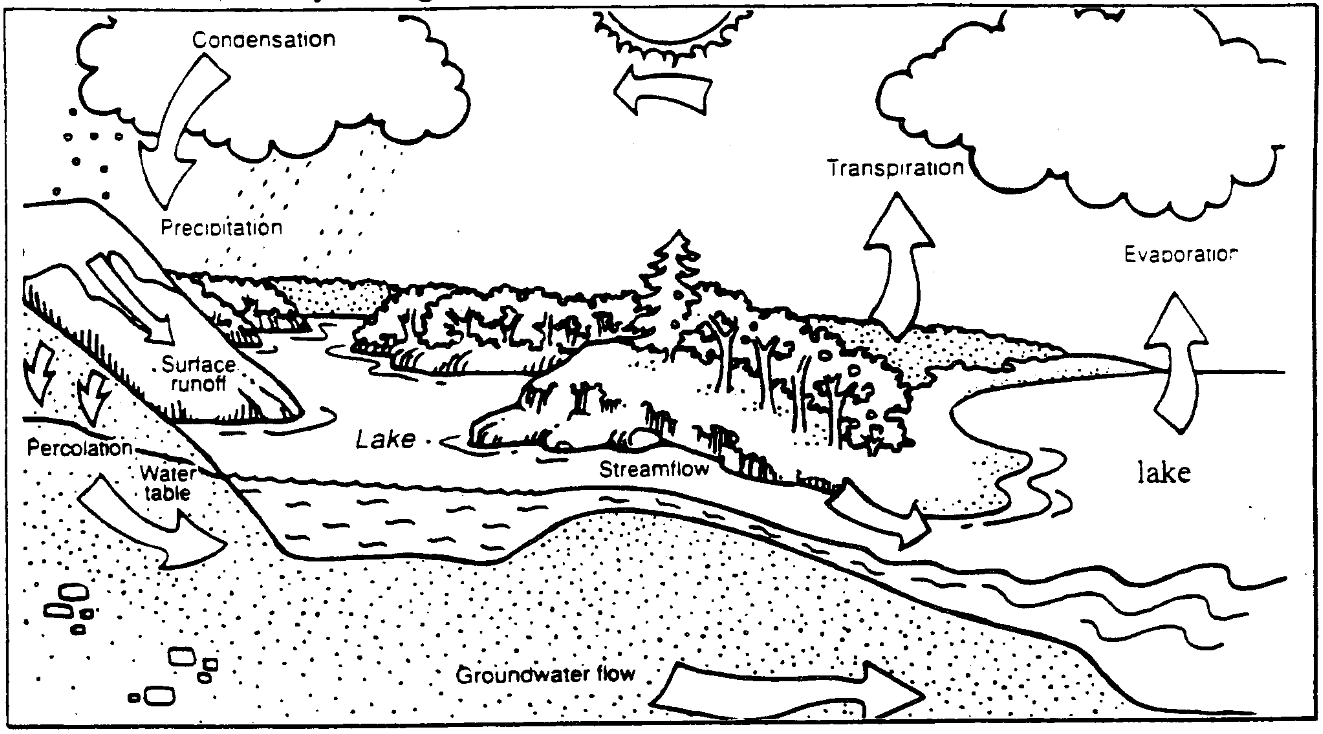


FIGURE 2.2 Groundwater Flow *(Environment Canada 1995)*

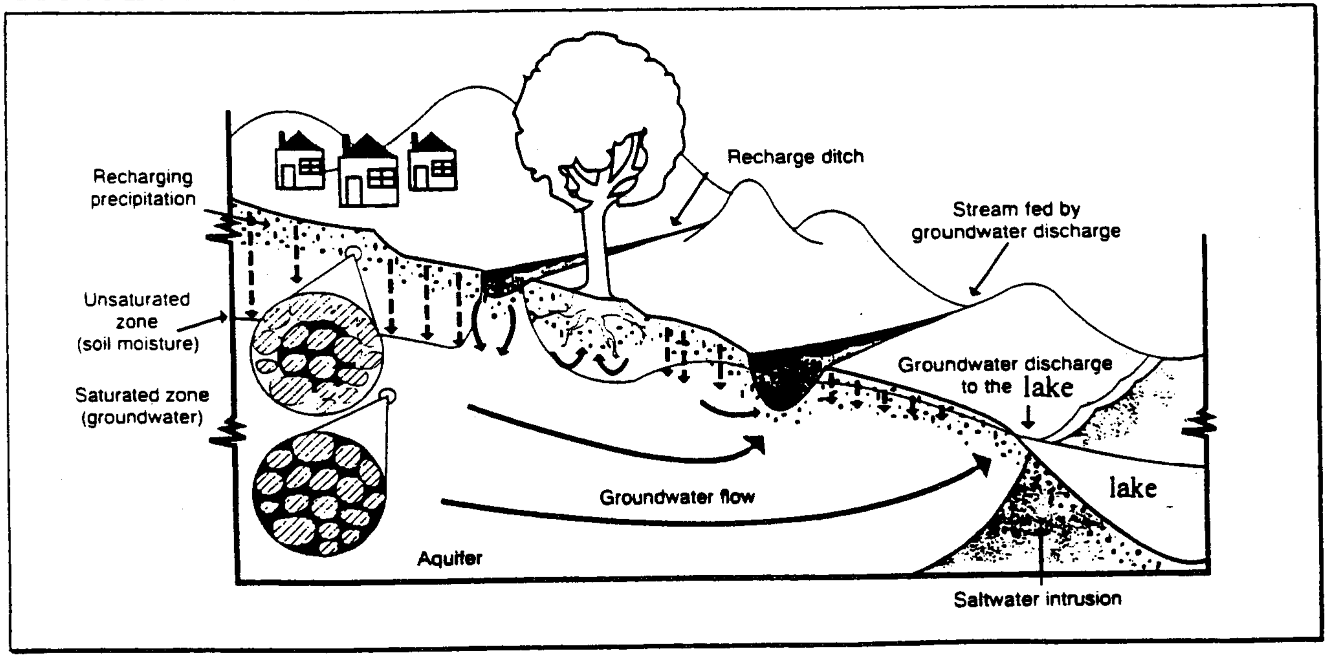
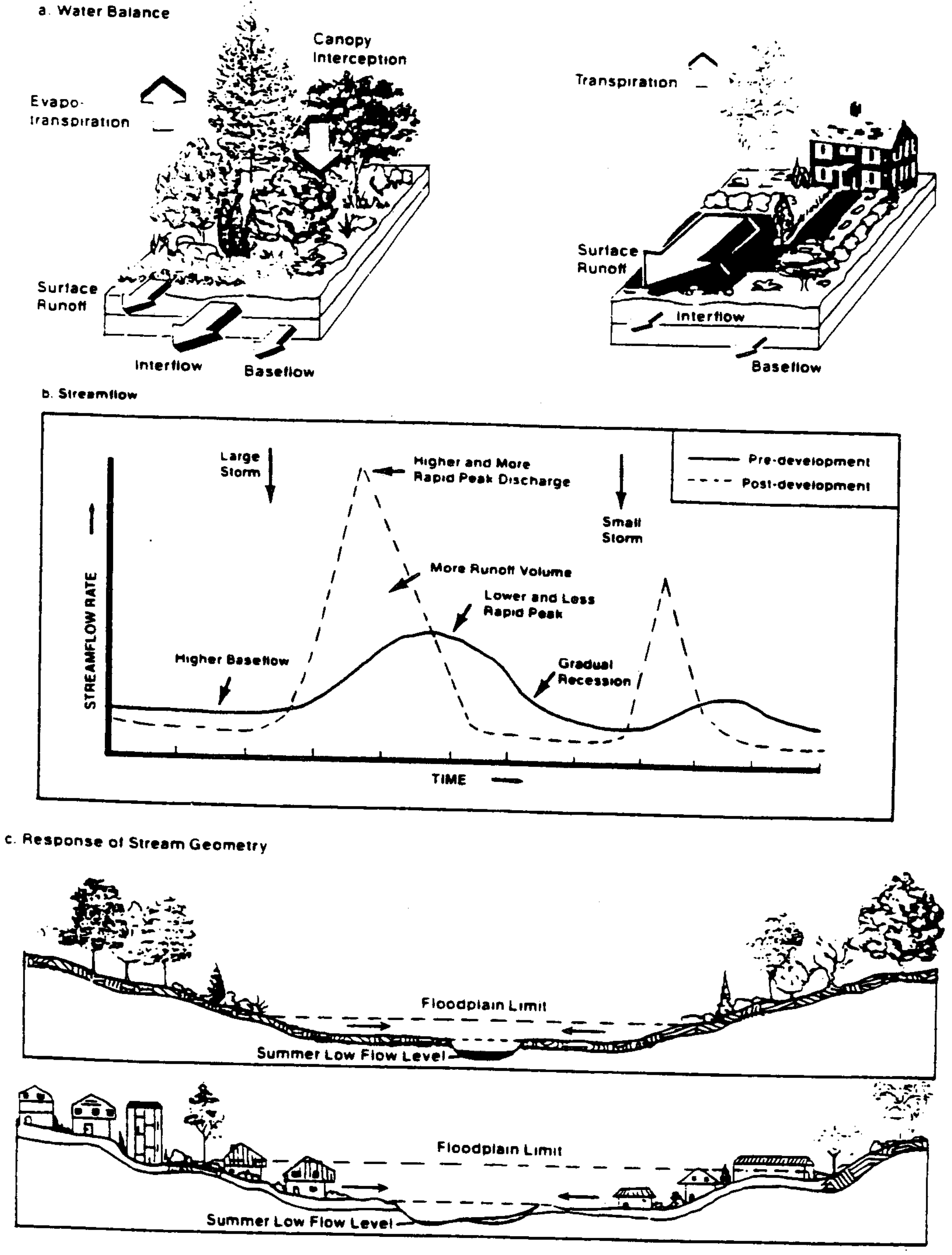


FIGURE 2.3 Pre and Post Development Water Budget Conditions



Source: Scheuler, T.R. (1987)

TABLE 2.1 Potential Effects from the Discharge of Uncontrolled Stormwater

Land Use Change	Potential Impact
Altered channel characteristics	• Changes in available habitat types (reduced diversity) • Loss of some types and increases in other types of habitat • Removal of channel obstructions (reduced micro-habitat diversity) • Increases in channel and bank erosion
Altered flow characteristics	• Changes in mixing characteristics (oxygenation) • Dewatering of key habitat types (time of year effects) • Flooding of property and buildings • Increase in water temperature (see groundwater characteristics) • Changes in erosion/sedimentation balance • Reduced habitat heterogeneity • Flooding of key habitats (time of year effects)
Altered groundwater characteristics	• Impacts on living components of aquatic systems • Loss of/changes in spawning, nursery or adult rearing habitat for some fish species • Reduced baseflow contributions throughout the year • Direct mortality effects on aquatic species • Reduction in habitat since plant species have specific thermal requirements • Rate of change of stream temperature is critical
Loss of wetland and wetland habitat	• Loss of habitat for fish, waterfowl and other birds and wildlife • Reduction in sediment trapping capacity • Reduction in flow moderating effects • Reduction in nutrient removal • Increase in human bacterial counts • Reduction in temperature moderating effects • Loss of recreation values
Erosion/sedimentation/ siltation	• Habitat changes resulting in less stable living systems • Loss of public/private land • Increased potential for bank instability
Pollutants	Silt: •Changes in water quality (turbidity, nutrients, etc.) •Physical destruction of spawning beds (habitat) •Effects on primary and secondary productivity •Physical damage to some species (gill damage) •Suspension of nutrients/contaminants
	Nutrients : •Water clarity, oxygen, odour, aesthetic appeal
	Metals: •Bioaccumulation in aquatic/terrestrial species •Safety for human consumption •Sub-lethal effects on aquatic ecosystem •Trapping/no trapping in wetlands
	Organic Matter: •Oxygen demand (BOD, COD) •Putrefaction and odour
	Chlorides: •Impairment of respiration in aquatic organisms

2.2 Water Quality

Impacts on Surface Water: In the "natural" hydrologic cycle, water is cleansed in streams and wetlands by aquatic plants and also by terrestrial vegetation and the soil itself as it slowly moves through the subsurface. In urbanized landscapes, nature's ability to clean water is severely impaired.

In urbanized systems, easily-mobilized pollutants are picked up and efficiently transported by storm sewer systems into streams and rivers. A significant, concentrated pulse of pollutants is found in this "first flush" after a rainfall. Some of the important pollutants that are transported include sediment, nutrients, hydrocarbons, metals, disease-bearing agents and chlorides.

Sediment is usually the major non-point source pollutant by volume. Suspended sediment causes turbidity which can limit photosynthesis and can impair visual feeding and respiration in fish. Deposited sediment can impair aquatic habitats. Nutrient enrichment can cause eutrophication due to accelerated plant and algae growth. Organic materials that require oxygen for their decomposition can starve surface waters of oxygen for aquatic life. Toxic metals and hydrocarbons can cause direct physiological and behavioural effects, and can bioaccumulate in the food web. Disease agents such as coliform bacteria in pet wastes can cause physiological problems in humans after skin contact. Chlorides - highly soluble compounds from road salting - can impair respiration functions in aquatic life.

In addition to changing water chemistry, stormwater can absorb heat from asphalt and increase temperature in receiving waters.

Impacts on Groundwater: Groundwater quality impacts resulting from urbanization are less easily defined than impacts on surface waters. Water quality impacts occur when contaminants such as metals and organic chemicals are transferred to groundwater through artificial recharge in a stormwater collection and infiltration facility or through stormwater contaminated by leaks, spills or leachate. Contaminants are transported either in solution (bound to fine particulates) or as separate phase liquids (e.g., oils). When such pollutants enter the ground, they are subject to natural processes such as filtration, volatilization and biological degradation that can reduce impacts. There is a greater potential for subsequent contamination of surface waters in areas where the overburden is thin and a shallow aquifer provides baseflow contributions to watercourses.

Substances such as chlorides and nitrates are the most difficult groundwater pollutants to control. Chlorides move through soil with no attenuation. Nitrates - common agricultural pollutants - are found in urban areas as a result of lawn fertilizers and septic systems. The presence of nitrates in drinking water from wells can be toxic to infants, and has been found to be damaging to fish.

2.3 Stream Morphology

As noted in Section 2.1, urban development typically causes an increase in the volume and velocity of surface runoff. It also results in a situation in which baseflow is lowered and peak flows are higher and more frequent. Under virtually any development scenario, the morphology (form and structure) of streams and rivers will change due to alterations in runoff and the resulting flow changes in the channel.

A stable natural channel is self-formed and self regulating. To be stable, it must satisfy two conditions: the transmission of flow and the integrity of the boundary materials. This state is achieved through a dynamic balance between the flow and sediment load characteristics, and the resistance of the boundary material - the materials forming the banks and floor of the channel - to erosion and transport. Artificially high peak flows exert high levels of shear stress on a stream's boundary materials, overwhelming the resisting stress of the boundary materials and causing erosion to take place. This can lead to undercutting and downcutting of the banks and widening of the flood channel. If the supply of sediment from erosion exceeds the ability of the stream to accommodate this material, shifting sandbars and silty deposits form. These deposits can completely bury pools, riffles and other features that provide aquatic habitats. They can compound matters by aggravating bank erosion processes that then cause more sediment to enter the channel through bank failure, resulting in further deterioration of the conditions within the stream channel.

2.4 Aquatic Habitat and Communities

As noted in the above sections, stormwater in urbanizing areas can adversely affect the quality and quantity of aquatic habitats by physical destruction, degraded water quality, increased sedimentation and erosion, reduced baseflows and increased peak flows. This destruction and degradation of habitats, in turn affect aquatic communities. Loss of food supplies, spawning beds, foraging areas, and other vital habitats typically leads to loss of species and diminished biodiversity. Poor water quality also contributes to loss of species: typical heavily urbanized areas can sustain few species, and these tend to be pollution-tolerant varieties such as the carp. Increased water temperatures due to removal of riparian vegetation and increased runoff can also lead to losses of cold water species such as trout.

Loss of one sort of aquatic habitat - wetlands - can have deleterious effects on water quality. These include reductions in the capacity to trap sediment, remove nutrients, moderate temperatures and moderate flows. An increase in human bacterial counts has also been noted.

As noted above, the environmental impacts of stormwater resulting from landuse change are interconnected in complex ways, and often compounding in the sense that one problem often exacerbates another. The severity of these impacts is a compelling reason to adopt preventive, integrated approaches to managing stormwater.

3.0 THE WATER MANAGEMENT PLANNING PROCESS

Figure 3.1 illustrates the sequence and the hierarchy of water resource planning (watershed, subwatershed and stormwater planning) and its relation to the landuse process. An overview of the Credit River watershed plan, subwatershed plans and stormwater management plans is presented in the next sections.

3.1 The Credit River Water Management Strategy

The *Credit River Water Management Strategy (CRWMS)* was developed by Credit Valley Conservation in cooperation with review agencies, member municipalities and the public. Phase II of *CRWMS* was completed in 1992. The goal of the Strategy was to:

- **develop a practical, comprehensive and environmentally sound management strategy for the environmental resources of the Credit River watershed; and**
- **to provide direction for subsequent subwatershed plans.**

The *CRWMS* provides an overall picture of how landuse changes should take place within the Credit River watershed without causing significant impacts to watershed resources over the long term. Along with this strategic direction, the document contains recommendations on implementation and funding and contains resource management goals and objectives. Together these provide direction and a framework for the development of Subwatershed Plans and Stormwater Management Plans.

For each of the Credit's component subwatersheds, the *CRWMS* also provides generic information on resources, constraints, sources of contamination, key issues, resource goals and water resource targets. Table 3.1 illustrates the Fact Sheet for Credit River subwatershed #19 which summarizes this information.

3.2 Subwatershed Plans

As components of watersheds, subwatersheds comprise of lands drained by tributaries of a main watercourse. 20 Subwatersheds have been identified for the Credit River, and *Subwatershed Plans* are being undertaken throughout the Credit River watershed on a priority basis (see Figure 3.2).

Subwatershed Plans are done at an enhanced level of detail to address local environment issues. Typically, they deal with flooding, erosion, water budgets, baseflow, and water quality. Subwatershed Plans also deal with terrestrial resources such as environmentally significant areas, wetlands, woodlots, valley and wildlife corridors, and secondary drainage corridors.

FIGURE 3.1 Stormwater Management Planning in the Landuse Planning Process

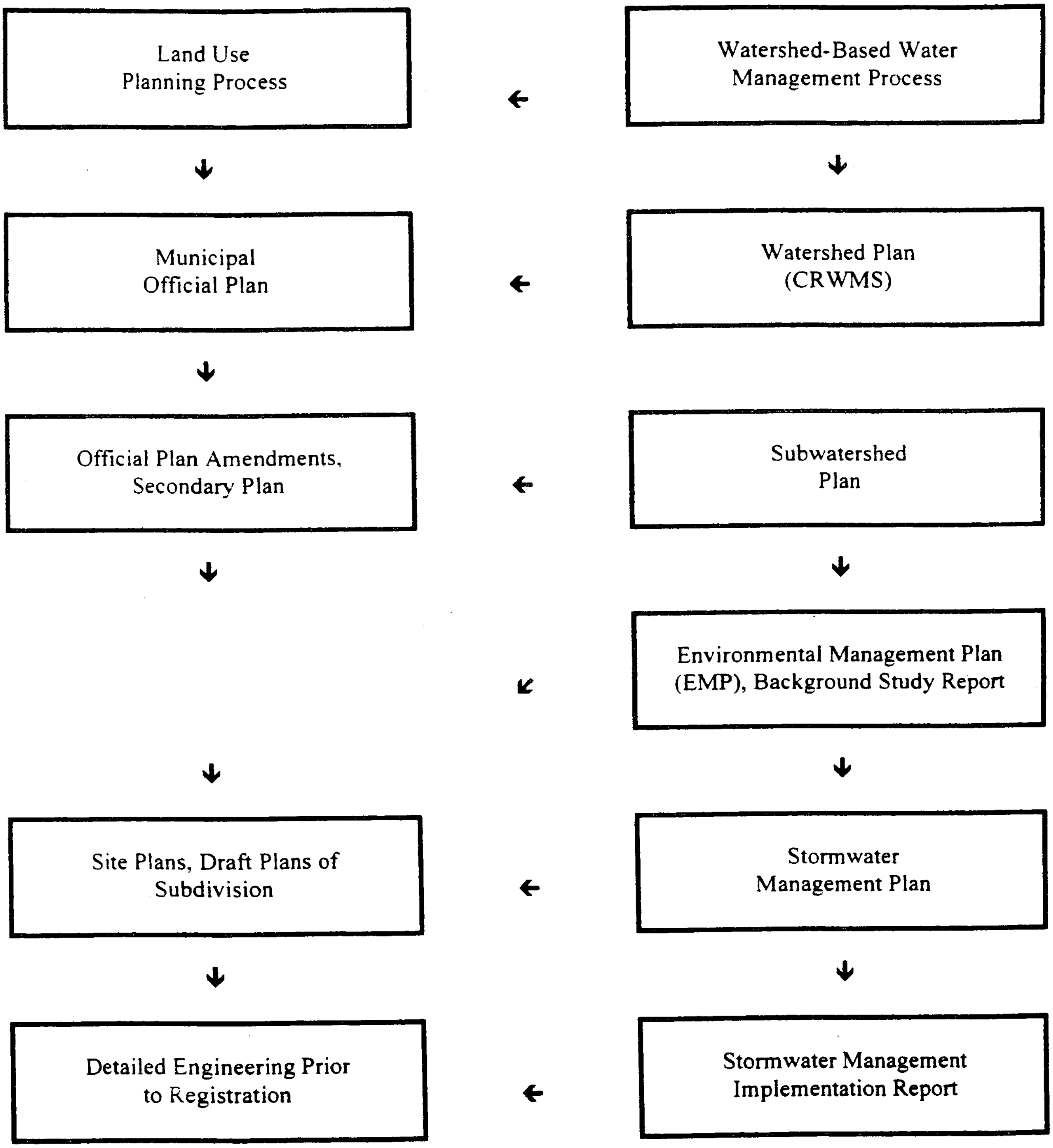
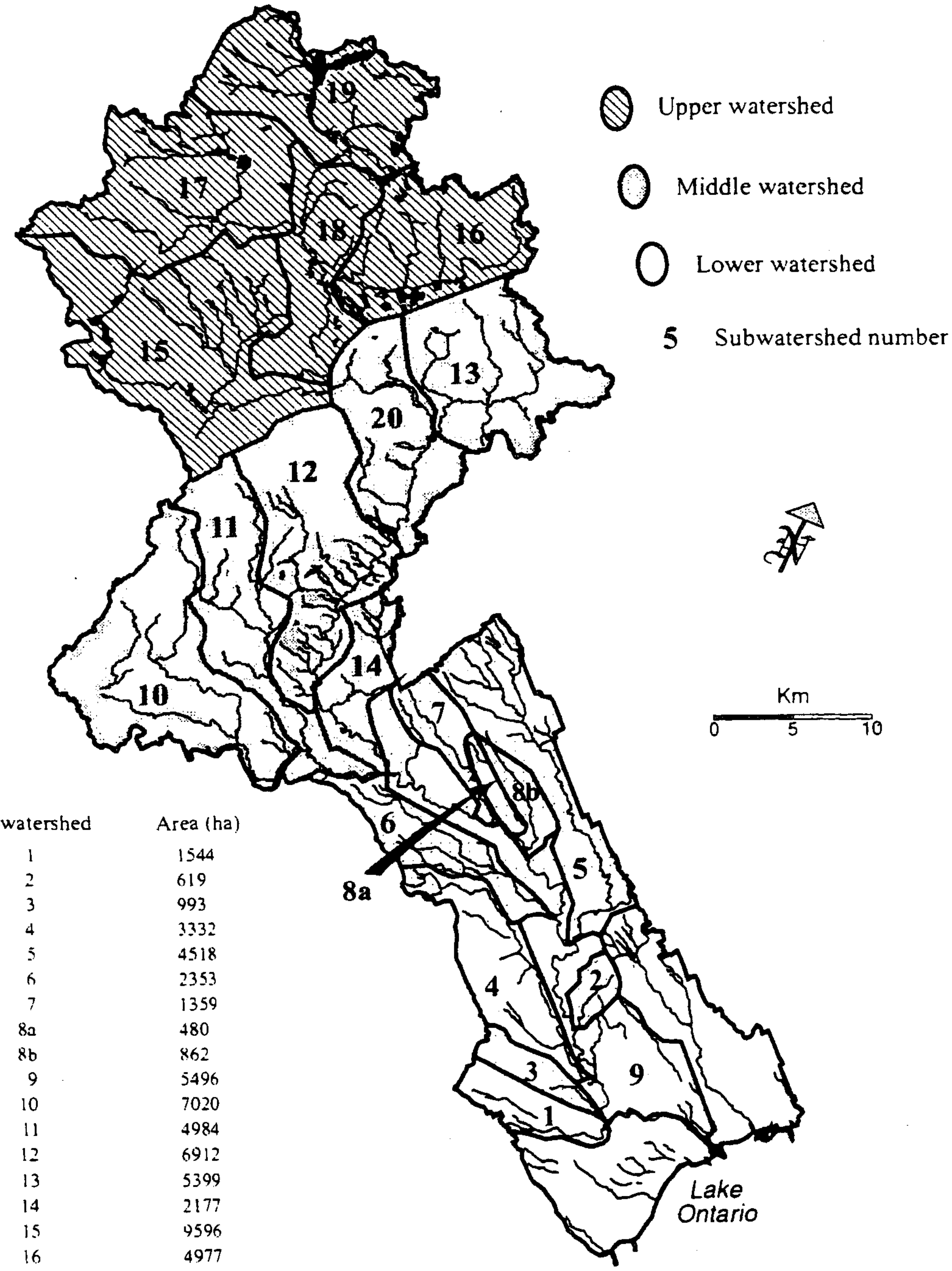


TABLE 3.1. Fact Sheet: Subwatershed Number 19

Resources/ constraints	• Water quality/quantity:headwater streams; well water supply; degraded water quality in Orangeville Reservoir; streambank erosion • Aquatic Community:self-sustaining native coldwater fishery (brook trout) • Natural Features:Orangeville Reservoir wetland (ESA 57, 58; Class 1) • Recreation:Orangeville Reservoir CA - warmwater sport fishing; Monora CA; river swimming; coldwater sport fishing
Sources of contamination	• Urban:existing and proposed development; construction activity; Orangeville STP • Industrial:old dump, aggregates, spills • Rural:septic systems; agriculture runoff; nutrient input from Orangeville Reservoir
Key Issues	• Water quality/quantity:impact of septic systems, stormwater, STP, agriculture; infiltration; groundwater supply • Aquatic Community:maintenance and enhancement of coldwater fishery in streams and warmwater fishery in Reservoir • Natural features:development and drainage of wetlands • Recreation:river swimming; access to warm and coldwater sport fishery • Land use:urban and rural development
Goals	• Water quality/quantity:maintenance of groundwater quality and supply; maintenance of surface water quality • Aquatic Community:maintenance and enhancement of self-sustaining coldwater fishery (brook trout) • Natural features:protection of wetlands • Recreation:provision of adequate public access to cold and warmwater sport fisheries; river swimming • Erosion:minimize erosion potential
Proposed mitigative measures	• Urban:Orangeville STP upgrade (tertiary treatment, e.g., ammonia control); sedimentation basin (capture particles>100 um); infiltration of 25 mm rainfall or 24 hour storage in wet/dry pond, 2 year control • Industrial:spill controls (44 gallon) at all sites • Rural:control of agriculture runoff, communal private services for rural residences • Resources Protection:60 m buffer strip along watercourses; maintenance/creation of riparian canopy; strict land use controls within valley lands; no development of wetlands; protection of ecoctonal buffer zone; reforestation/wetland creation
Water resource targets	• Bacteria:fecal coliform < 100 counts/100 ml • Baseflow (July-August):> 25% of total flow • Dissolved oxygen:> 5 mg/l • Maximum water temperature:< 20°C • Metals:soluble copper < 6 mg/l • Nutrients:total P < 30 ug/l (dry), < 90 ug/l (25 mm event) • Riparian canopy:> 80%

Source: Credit River Water Management Strategy (1992)

FIGURE 3.2 Credit River Subwatersheds



Subwatershed	Area (ha)
1	1544
2	619
3	993
4	3332
5	4518
6	2353
7	1359
8a	480
8b	862
9	5496
10	7020
11	4984
12	6912
13	5399
14	2177
15	9596
16	4977
17	7512
18	4028
19	5937

Components of a Subwatershed Plan include:

- definition and interrelationship of environmental features;
- constraint and opportunity mapping;
- setting of goals, objectives and targets;
- impact assessment of large scale landuse changes;
- development of a recommended subwatershed strategy; and
- identification of implementation and monitoring approaches.

Environmental Features: In a subwatershed plan, environmental features are defined. Study teams identify environmentally significant areas, wetlands, woodlots, valleylands, secondary drainage corridors, define resident fisheries, and determine baseline water quality. Existing landuse and soils' information are also investigated to determine pre development infiltration, recharge and discharge at the subwatershed level.

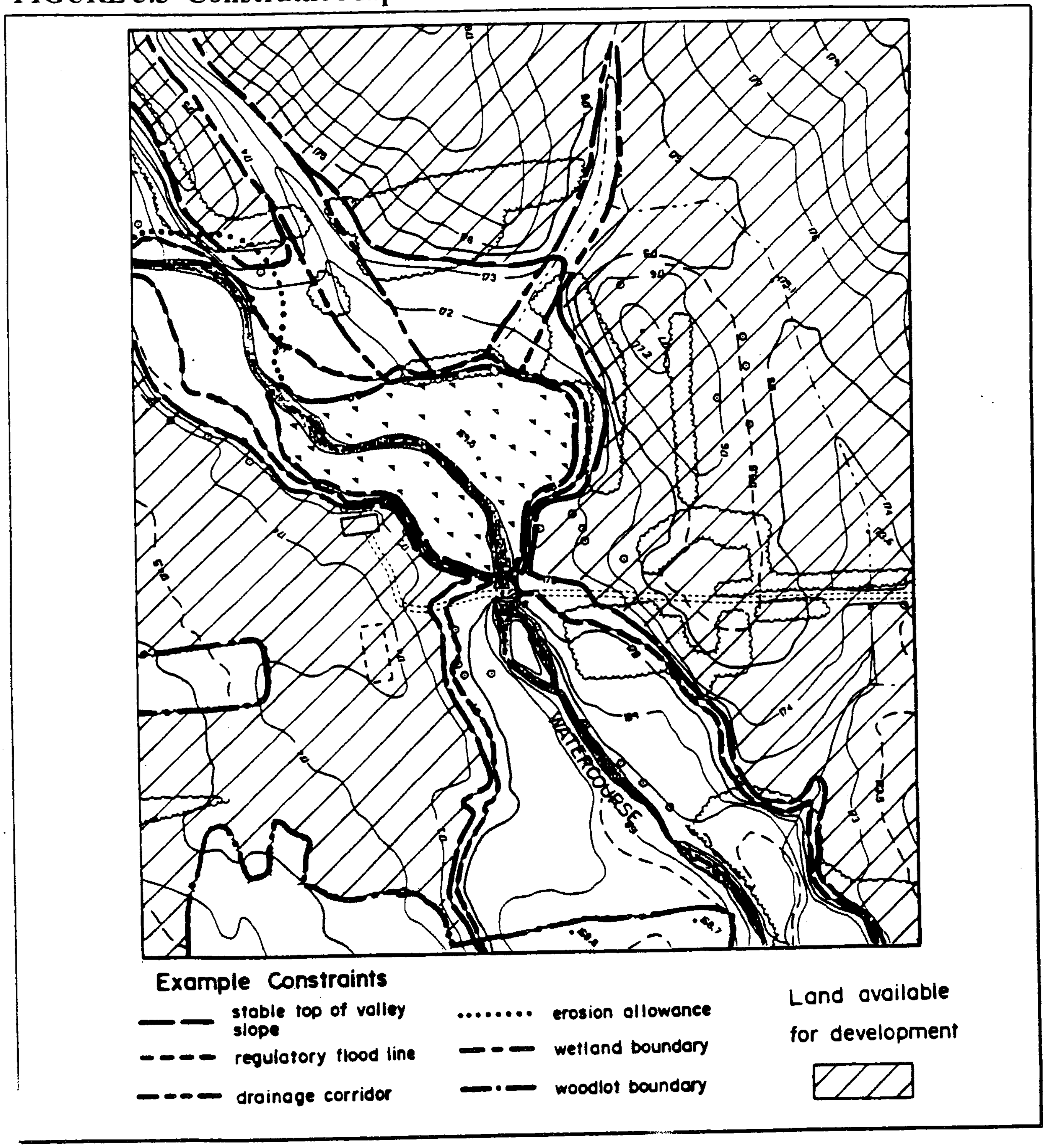
Constraint and Opportunity Mapping: In a Subwatershed Plan, constraint mapping allows the definition of development opportunity for relatively large scale land parcels. The boundaries of significant environmental features and flood plains are overlain using constraint mapping at scales of between 1:2000 to 1:10 000.

Applicable buffer areas as defined by the MNR for wetlands and watercourse fishery classifications are also mapped. and infiltration and recharge/discharge features are shown as appropriate. Flood lines are mapped. If the level of investigation is sufficiently detailed, additional information regarding tops of valley slope and/or channel banks, and the application of the Stability Component and Erosion Component (as defined in the CVCA Watercourse and Valleyland Protection Policies) is shown on the appropriate maps.

In addition, in a Subwatershed Plan, the study team may perform an impact assessment of the future development scenario. This may result in expanded environmental buffers (around wetlands and fisheries), and enhanced protection options for recharge/discharge features and other natural features (i.e., woodlots, wildlife corridors, secondary drainage corridors) that can then be added to the Constraint Mapping. An example of constraint mapping is included as Figure 3.3.

Goals/Objectives/Targets: Goals, objectives and targets are defined in a Subwatershed Plan. Technical targets are set for items such as water quality and desired infiltration rates. These technical targets are especially important as they then provide definitive direction with respect to stormwater release rates and discharges and infiltration requirements which must be met on a tributary-by-tributary basis. This in turn, will assist proponents of development projects to define requirements on a site-by-site basis. Target criteria will also be set for environmental features to be protected.

FIGURE 3.3 Constraint Map



Impact Assessment: As part of a Subwatershed Plan, an impact assessment is done to define the impacts associated with large scale landuse changes. This information will broadly define the alternative scenarios and recommended strategies for protecting, enhancing or restoring the environment. The impact assessment may be detailed enough to expand constraint boundaries to help meet the goals/objectives/targets, or it will identify the level of further assessment that will be required for Draft Plan of Subdivision submissions.

Recommended Strategy: The recommended strategy from the Subwatershed Plan includes:

- administration of the Plan;
- rehabilitation and retrofit strategy;
- land stewardship;
- landuse planning and policies; and
- research, development and monitoring.

The Subwatershed Plan strategy integrates the results of the technical and environmental constraint identification with the goals, objectives, targets and impact assessment results into a cohesive focus for implementation.

Implementation and Environmental Monitoring: As part of a Subwatershed Plan, implementation and environmental monitoring components are developed. These define funding, jurisdictional and timing considerations for implementing the recommended strategy and define an approach for long term monitoring to ensure the plan is successful.

3.3 Stormwater Management Plans

In order to demonstrate that stormwater will not adversely affect the environment, Stormwater Management Plans are required for proposed development, prior to the issuance of conditions for draft approval. Stormwater Management Plans translate specific objectives and targets from Subwatershed Plans into stormwater conveyance and control techniques for specific developments. (If an existing Subwatershed Plan lacks details on objectives, targets and base conditions, or other vital information, proponents may be required to fill these information gaps before proceeding to develop Stormwater Management Plans).

These plans for the management of stormwater are dealt within two stages as illustrated in Figure 3.1. **Stormwater Management Plans** for subdivisions are submitted to CVC before the issuance of draft plan conditions. These describe the approach to managing stormwater, and include calculation of post development flows and preliminary design and sizing of stormwater management facilities. **Stormwater Management Implementation Reports** are much more detailed documents that are submitted to CVC before site registration and pre servicing. They contain detailed designs for flow conveyance and stormwater facilities, drainage systems, sediment controls and revegetation.

In areas where a Subwatershed Plan does not exist, proponents will be required to develop a **Background Study Report.** In the Background Study, proponents will establish and address site level objectives and targets for environmental and technical constraints, and will produce a detailed constraint map. The deliverables expected include:

- hydrologic modelling;
- hydraulic modelling;
- water quality monitoring;
- hydrogeological assessment;
- geotechnical assessment;
- fluvial geomorphology (erosion potential assessment)
- environmental impact assessment; and
- constraint mapping.

The content of these Background Studies is addressed further in Section 5.0 of these guidelines.

4.0 OBJECTIVES OF STORMWATER MANAGEMENT PLANS

4.1 Background

As articulated in Section 3.1, strategic direction for Stormwater Management Plans comes from the *Credit River Water Management Strategy* and the Subwatershed Plans developed under that Strategy. The scope and level of detail required in Stormwater Management Plans relate directly to the available information base and whether a Subwatershed Plan has been done for the area in which a proposed development is to take place. Accordingly, development proponents are advised to meet with CVC at an early stage in the preplanning process in order to clarify stormwater management planning requirements and data needs. CVC can also provide proponents with access to useful documents and the location of other resources.

4.2 Stormwater Management Plans

A Stormwater Management Plan addresses the stormwater requirements of draft plan development concepts by selecting, sizing and locating integrated stormwater management practices (SWMPs). In an ideal situation, the Subwatershed plan will dictate the type of SWMP to be used, and the required performance levels that must be met. In some cases, a Subwatershed Plan may identify centralized facilities that can serve several developments; if this is so, then the levels of detail required in a Stormwater Management Plan may be affected. Where a Subwatershed Plan does not yet exist, proponents must follow the quantity and quality control requirements of old Master Drainage Plans, Water Quality Control Studies, and existing municipal policies may supersede the requirements of Table 4.1. The onus is on the proponent to be aware of such studies and changing requirements.

Proponents conducting Stormwater Management Plans will take the predetermined developable area and calculate post development flows to compare with those occurring in pre development conditions. When applying the development concept to the site, the proponent should aim to minimize changes in topography, consolidate facilities that will ultimately be assumed by the Municipality and preserve and use the natural drainage system. Through the use of such an approach, the development should be confined to the least critical areas and logic will dictate the best locations for stormwater management facilities. Proponents should consider the full range of SWMP's in order to meet the targets set for receiving watercourses. In the hierarchy of SWMP's, lot level and source controls are preferred, however a combination of lot level, conveyance and end of pipe treatment may be required in order to address post development flows. The Stormwater Management Plan should attempt to match pre development infiltration conditions (volumes) through the use of lot level stormwater management techniques and source controls. Where full implementation of SWMP's is not possible and the lack of implementation results in an impact on ecological resources, mitigation is required and must be fully documented in the Stormwater Management Planning process. The Stormwater Management Plan must be accompanied by preliminary grading and drainage drawings, preliminary stormwater management facility design, and discussion of sediment control as appropriate (see CVCA *Sediment Control*

Guidelines). The completed Plan with supporting documentation should be forwarded to the CVC for review and approval.

4.3 Stormwater Management Implementation Reports

Once the Stormwater Management Plan has been received and approved by CVC and the Municipality, proponents can begin to develop the more detailed Implementation Report which must accompany the submission of detailed engineering plans to CVC. The Stormwater Management Implementation Report must include final drainage details, treatment volumes and release rates. Detailed servicing design must be carried out for facilities and conveyance treatments. Proponents also need to produce detailed drawings of lot grading, drainage, servicing and sediment control and detailed designs for conveyance and end-of-pipe controls and outfalls. Recent and future efforts to streamline the review process with municipalities may in the future negate the need to submit this stage of report to the CVC in some municipalities. The Implementation Report would then be circulated directly to those municipalities where the municipal technical reviews would address CVC concerns.

TABLE 4.1 Stormwater Management Requirements in Areas Where Subwatershed Plans or Related Studies do not Exist

1. QUANTITY CONTROL REQUIREMENTS - URBAN

< 0.5 ha	**Flood Potential** : No requirements **Erosion Potential:** No requirements
0.5 - 5.0 ha	**Flood Potential:** No requirements **Erosion Potential:** i) if draining to the major trunk sewer system: No requirements ii) if draining to the minor system: No requirements, unless the minor system outfall is in close proximity to the site and requires remedial erosion control, which should be done in lieu of stormwater management iii) if draining directly to a watercourse: Post development 10% over control of the 25 mm storm to pre development conditions, with zero runoff source control of the first 5mm of any event as feasible (* Note: 5mm source control is not discounted from the 25 mm storm)
> 5.0 ha	**Flood Potential:** i) if draining to the minor/major trunk system: No requirements ii) if draining directly to a watercourse/floodplain: Post development to pre development control for all storms up to and including the 100 year, only if there is a documented downstream flood damage centre **Erosion Potential:** i) if draining to the major trunk sewer system: No requirements ii) if draining to the minor system: same requirements as above for 0.5 - 5.0 ha site areas iii) if draining directly to a watercourse:: a) same requirements as above for 0.5 - 5.0 ha site areas but using Distributed Runoff Control techniques; or: b) post development control of the 25mm storm for site discharge that is at or below the critical velocity or critical tractive force of the least resistant bed or bank toe channel material in the receiving watercourse.

Note:

① *All developments should ensure that the major overland flow route is safely conveyed through or around a site without impacts to neighbouring properties.*

② *All drainage techniques should meet municipal standards and should not compromise receiving system capacity*

TABLE 4.1 cont.....

2. QUANTITY CONTROL REQUIREMENTS - RURAL

< 0.5 ha	**Flood Potential**: No requirements **Erosion Potential**: No requirements
0.5 - 5.0 ha	**Flood Potential**: No requirements **Erosion Potential**: i) if draining by overland conveyance: No requirements, unless the overland conveyance outfall is in close proximity to the site and requires remedial erosion control, which should be done in lieu of stormwater management site controls ii) if draining directly to a watercourse: Post development 10% over control of the 2 year storm to pre development conditions with zero runoff source control of the first 5 mm of any event, as feasible (*Note: 5 mm source control is not discounted from the 2 year storm)
> 5.0 ha	**Flood Potential**: i) if draining by overland conveyance: No requirements ii) if draining directly to a watercourse/floodplain: Post development to pre-development control for all storms up to and including the 100 year, only if there is a documented downstream flood damage centre **Erosion Potential**: i) if draining by overland conveyance: No requirements, unless the overland conveyance outfall is in close proximity to the site and requires remedial erosion control, which should be done in lieu of stormwater management site controls ii) if draining directly to a watercourse: a) same requirements as above for 0.5 - 5.0 ha site areas but using ' Distributed Runoff Control' techniques; or; b) post development control of the 2 year storm for site discharge that is at or below the critical velocity or critical tractive force of the least resistant bed or bank toe channel material in the receiving watercourse

Note:

① *All developments should ensure that the major overland flow route is safely conveyed through or around a site without impacts to neighbouring properties.*

② *All drainage techniques should meet municipal standards and should not compromise receiving system capacity*

TABLE 4.1 cont....

3. QUALITY CONTROL REQUIREMENTS - URBAN AND RURAL

<0.5 ha	Generally no requirements except spills management if appropriate
0.5 ha - 5.0 ha	Lot level and conveyance controls to the extent feasible
> 5.0 ha	SWMPs including end of pipe facilities, as per the MOEE SWMP manual (June 1994) selection process

Note:

① *All developments should ensure that the major overland flow route is safely conveyed through or around a site without impacts to neighbouring properties.*

② *All drainage techniques should meet municipal standards and should not compromise receiving system capacity*

5.0 A RECOMMENDED APPROACH

A recommended approach to developing Stormwater Management Plans is laid out below in Table 5.1. It is intended to be used by proponents and reviewers as a guide, and as noted in Section 1.1, is not intended to be prescriptive. As an additional aid, Table 5.2 contains lists of deliverables required as part of Background Study Reports, Stormwater Management Plans and Stormwater Management Implementation Reports. Questions about these processes can be fielded by CVC staff.

TABLE 5.1 Recommended Approach to Developing Stormwater Management Plans

Phase	If Subwatershed Plan Exists	If Subwatershed Plan Does Not Exist
Get Ready	➢Meet With CVC and municipal staff ➢Review CRWMS ➢Review Subwatershed Plan ➢Review Master Drainage Plans, Water Quality Control Studies, and Municipal requirements	➢Meet with CVC and municipal staff ➢Review CRWMS ➢Review Master Drainage Plans, Water Quality Control Studies, and municipal requirements
Identify Goals, Objectives and Targets	➢From Subwatershed Plan, determine receiving water goals, objectives and targets ➢From Subwatershed Plan, determine water management criteria for quantity, quality, erosion potential and baseflow protection	➢Determine Goals, Objectives and Targets using CRWMS Fact Sheets, Table 4.1, and municipal and CVC input
Collect Data	➢In consultation with CVC, collect any necessary data that is missing from Subwatershed Plan	Conduct Background Study Report which includes the following: ➢Identify data deficiencies and collect data ➢Establish pre-development external and internal surface drainage patterns ➢Calculate pre-development design flows, as required ➢Establish infiltration rates and significant shallow subsurface drainage patterns related to surface water features ➢Identify environmental data deficiencies and collect data ➢Establish technical constraints ➢Establish environmental constraints ➢Plan the development concept ➢Perform impact assessment and, if necessary, refine constraints

TABLE 5.1 cont...

Phase	If Subwatershed Plan Exists	If Subwatershed Plan Does Not Exists
Develop Stormwater Management Plan	➢Refine development concept and rough fit to available lands ➢Calculate post-development design flows, as required ➢Refine water management requirements ➢From long list of SWMPs, identify options to satisfy water management requirements and identify constraints (e.g. conflicts with municipal practices) ➢Create short list of SWMP options ➢Quantify treatment volumes, size and location of preferred SWMPs ➢Submit development concept to CVC and municipality for review and approval	➢Refine development concept and rough fit to available lands ➢Calculate post-development design flows, as required ➢Refine water management requirements ➢From long list of SWMPs, identify options to satisfy water management requirements and identify constraints (e.g. conflicts with municipal practices) ➢Create short list of SWMP options ➢Quantify treatment volumes, size and location of preferred SWMPs ➢Submit development concept to CVC and municipality for review and approval
Develop Stormwater Management Implementation Report	➢Produce detailed drawings of internal drainage system (major/minor systems, SWM controls, Stage 1 sediment controls, and outfalls) ➢Finalize other environmental mitigation, compensation and restoration plans ➢Submit to CVC and municipality for review and approval	➢Produce detailed drawings of internal drainage system (major/minor systems, SWM controls, Stage 1 sediment controls, and outfalls) ➢Finalize other environmental mitigation, compensation and restoration plans ➢Submit to CVC and municipality for review and approval

TABLE 5.2 Deliverables Required for Stormwater Management Planning

Deliverables Required for Background Study Report

1.1 Hydrologic modeling (pre-development flows based on external and internal drainage patterns)
1.2 Hydraulic modeling
1.3 Water quality monitoring
1.4 Hydrogeology assessment
1.5 Geotechnical assessment
1.6 Fluvial Geomorphology/erosion potential assessment
1.7 Environmental Impact Assessment
1.8 Constraint and Opportunity Mapping
  ➢ Base Topographical Map (at appropriate scale)
  ➢ Location of watercourses and drainage features with appropriate fisheries classification setbacks
  ➢ Location of significant recharge or discharge areas
  ➢ Limit of geotechnical hazard area (erosion and stability components)
  ➢ Staked Top of Bank
  ➢ Staked ESA Boundary
  ➢ Staked Wetland Boundary and Identification of buffer area of interest
  ➢ Significant Woodlands
  ➢ Regional Floodline Mapping
  ➢ Development Setback from greatest limit of technical/environmental constraints
  ➢ Area requiring special land use grading and SWM Practices Considerations

Deliverables Required for Stormwater Management Plan Prior to the Issuance of Conditions for Draft Approval

2.1 Post-development flows
2.2 SWMP analysis - short list of integrated preferred options
2.3 Proposed development concept/layout
2.4 Location of stormwater management facilities
2.5 Preliminary design and sizing of SWM facilities
2.6 Preliminary design of control/diversion manholes and/or pond bypass or flow splitter structures
2.7 Confirmation of safe conveyance of Regional overland flows through the proposed development
2.8 Outfall locations
2.9 Proposed instream works
2.10 Revegetation/Landscape Plans to be noted as a requirement of Detailed Engineering Submission
2.11 Proposed zoning of SWM facilities
2.12 Preliminary Sediment Control discussion
2.13 Preliminary Grading and Drainage Plans (to be circulated with the Draft Plan)

TABLE 5.2 cont...

Deliverables Required for Stormwater Management Implementation Report Prior to Site Registration & Pre-servicing

3.1 Detailed design of SWM Facilities, connection and outfalls
3.2 Detailed Lot Grading Design
3.3 Detailed Drainage Design (minor/major system)
3.4 Detailed Sediment Control
3.5 Detailed Revegetation/Landscape Design
3.6 Implementation Strategy of Approved Preliminary SWM Plan
3.7 Appropriate Zoning
3.8 Detailed Fluvial Geomorphological Design of Instream Works
3.9 List of Drawings

- ➢Site Location Plan
- ➢Grading Plan showing limits of development (lot lines) and proposed geodetic elevations
- ➢Storm Drainage Plans showing lot drainage and major overland flow routes, ponding areas and associated zoning i.e. easements
- ➢Servicing Plans showing minor system, stormwater facilities, connections and outfalls
- ➢SWMP Detail Designs
- ➢Natural Channel Design Plans
- ➢Revegetation/Landscaping Plans
- ➢Sediment Controls Plans
- ➢Road Crossing Details

6.0 CONCLUSIONS

The need to develop Stormwater Management Guidelines for the Credit River watershed was identified in the *Credit River Water Management Strategy, Phases I and II* documents. In reflection of this need, these Stormwater Management Guidelines were developed by CVC in cooperation with its member municipalities and provincial review agencies. They have been circulated for comment.

As noted at the beginning of this report, these Guidelines are advisory in nature, not prescriptive. Through their development and distribution, CVC hopes to increase understanding of and facilitate the approvals process for stormwater management. The Guidelines and their supporting documents should assist proponents and reviewers in understanding the environmental impacts of stormwater, the overall water management process, and what needs to be included in Stormwater Management Plans and Implementation Reports (i.e., minimum deliverables). Together with it Appendices, the Guidelines should assist proponents to make sound, integrated plans for stormwater management.

The CVC recommends that the Stormwater Management Guidelines be reviewed annually, and updated if needed to reflect comments received, future streamlining efforts between the CVC and its member municipalities, changing technologies, improvements in information, and applications in the field.

APPENDIX A

GLOSSARY OF TERMS

Aquifer: A saturated permeable geologic unit that can transmit significant quantities of water.

Attentuation: To lessen the amount (e.g. to reduce peak flow rates).

Baseflow: Low Flow conditions in a watercourse.

Bioaccumulation: To accumulate through a biological chain.

Discretization: To break into parts.

Eutrophication: The process of nutrient enrichment (usually by nitrates and phosphates) in aquatic ecosystems which can lead to depleted levels of oxygen.

Evapotransipration: The loss of water from the soli due to evaporation and transpiration by plants.

Groundwater: Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated

Geotechnical: Pertaining to the study of soil types and properties as they relate to strength, stability and erodability.

Hydraulics: The branch of science that deals with practical applications (such as the transmission of energy or the effects of flows) of water in motion.

Hydrology: The science dealing with the properties, distribution, and circulation of water on the surface of the land. in the sol and underlying rocks, and in the atmosphere.

Heterogenity: Having dissimilar ingredients or constituents.

Homogenity: Having similar ingredients or constituents.

Hydrogeology: the study of the physical, chemical and geologic foundations of groundwater; and the interactions between groundwater, the earth and humans.

Invertebrates: Animals without backbones (such as insects, miolluscs and worms)

Putrefaction: The decomposition of organic matter

Physiological: Characteristics of or appropriate to an organism's healthy or normal functioning.

Photosynthesis: The synthesis of chemical compounds with the aid of radiant energy and espically light (i.e. the formation of carbohydrates in the tissues of plants).

Riparian: Relating to or located on the bank of a natural watercourse.

Sheer Stress: A measure of the pressure that flowing water exerts on the channel boundary

Spill Control: A plan to prevent the spill of deleterious substances into drainage systems and watercourses.

Spawning Habitat: The location or type of site where fish produce or deposit their eggs.

Turbidity: The level of cloudiness that is associated with the amount of sediment suspended in water.

Upwelling: Also known as an "upward gradient", a location where groundwater discharges to a watercourse.

Volatilization: to become vapour.

Watershed: A region or area bounded peripherally by a water parting and draining ultimately to a particular watercourse or body of water.

APPENDIX B

HYDROLOGIC/HYDRAULIC COMPUTATION PROCEDURES

Modified from the Drainage Management Technical Guidelines, Ontario
Ministry of Transportation, November 1989

B.1 Computation Selection Procedure

B.1.1 Overview

The following are the purposes of Appendix B:

- To describe a hydrologic/hydraulic computation selection procedure for the design and analysis of water management facilities;
- To describe hydrologic and hydraulic computation procedures for the design and analysis of water management facilities; and
- To provide guidance to analysts/designers of water management facilities and reviewers of development plans.

The term analyst/designer used in this Appendix includes reviewers of development plans. The term hydrology refers to both quantity and quality.

He concern of the analyst/designer is to design a water management system in an acceptable and cost effective manner. In practical terms, a water management system may include but not be limited to storm sewers, ditches, detention ponds, channels or bridges/culverts.

The analyst/designer is interested in the hydrographs or hydraulic stages at various points in the system. Characteristics of the hydrographs (e.g. peak flow rates, runoff volumes) and magnitudes for a specific recurrence frequency or return period are of specific interest to the analyst/designer.

There are two (2) general classes of problems. In the first class, there are hydrograph measurements at the location of interest or a another location from which the data may be transferred. The second class of problem is one in which no measurements exist or are not applicable because of land use changes. In this case,m system outputs must be simulated. Appendix B reviews methos of analysis for both classes of problems.

All hydrologic.hydraulic estimates, including results from the application of methods described in Appendix B, must be carefully reviewed and applied with caution. Most methods require assumptions which are based on the experience and the knowledge of the analyst/designer. Therefore, the results will vary depending upon that experience and knowledge, but to provide insight for the less experienced as well as a consistenet framework for more experienced analysts/designers.

The recommended computation selection procedure, computation methods, descirbed in Appendix B are to be used as guidelines. The analyst/designer is responsible for the selection fof the most appropriate procedures and parameter values.

The objective of water management facilities is to maximize the utility of the facilities whil minimizing the risk to life, property and the natural environment. The optimal drainage solution should consider all areas of uncertainty and not just the hydrologic/hydraulic analysis. Uncertainty may be introduced into design through any number of processes. Included are the selection of the planning and design criteria, cost estimation as well as construction and maintenance of facilities.

B.1.2 Computation Selection Procedure

Figures B-1 and B-2 outline a process for the selection of hydrologic/hydraulic computation methods. Analysts/designers should be sware of all the procedures although some are less frequently used. Other methods which are more accurate in scientific qualities to those listed in Appendix B may be used. It is he responsibility of the analyst/designer to substantiate the accuracy and applicability of the proposed alternative methods.

The computation selection procedure acknowledges the following three (3) design goals of water management facilities:

- **Convey upstream runoff through a development;**
- **Convey/discharge runoff from a development to downstream watercourses;and**
- **Ensure that runoff does not have an adverse effect on downstream or upstream properties.**

Most water management facilities will involve thedesign of channels/crossings to convey upstream runoff through the development and the design of a drainage system (e.g. storm sewers, ditches, etc.) To convey runoff from the development. In many instances the two (2) drainage systems are combined.

The computation selection procedure is based on the premise that a more accurate estimate of the frequency of runoff is required when the impacts of failure are significant. Failure is considered to be exceedence of design criteria and not necessarily a structural failure.

If the results of failure do not increase the risk to life and do not result in significant property damage or flooding, then a less accurate estimate of runoff frequency may be acceptable and a simpler procedure may be used. However, the analyst/designer may use a method that gives a more accurate estimate of runoff than required.

The following text describes the computation selection procedure shown on Figures B-1 and B-2. Text that is italicized and bold in this Appendix describe the boxes shown in the flow chart:

Define The Problem and Identify Information Requirements

The first step in the plannning and design of water management facilities is to define the problem and to determine what information is required to solve the problem.

Examples of water management design problems would include the sizing of culverts, bridges, storm sewers and detention facilities. Examples of required information include peak flow rates, hydrographs, upstream/downstream water levels and channel capacities.

Define the Hydrologic and Hydraulic Processes

This may be a difficult step for the less experienced designers. However, it is important when determining what computational procedures to use to solve a problems, This step can be simplified by considering the following questions:

For hydrologic processes:

- Does the basin contain several different types of land use?
- Are there many branches to the watercourse?
- Is there more than one flow path?
- Do major or minor systems outlet to the same location?

For hydraulic conditions:

- Are water levels or flow rates influenced by downstream conditions?
- Are there steep or erosive reaches which influence conditions at the site?
- Do watercourse diversion exist or are they planned?
- Does the site have an impact on upstream or downstream conditions?
- Are there low lying areas which store significant amounts of runoff?
- Will the use of storage facilities be required?

Figure B-1

Figure B-1 Hydrologic Computations

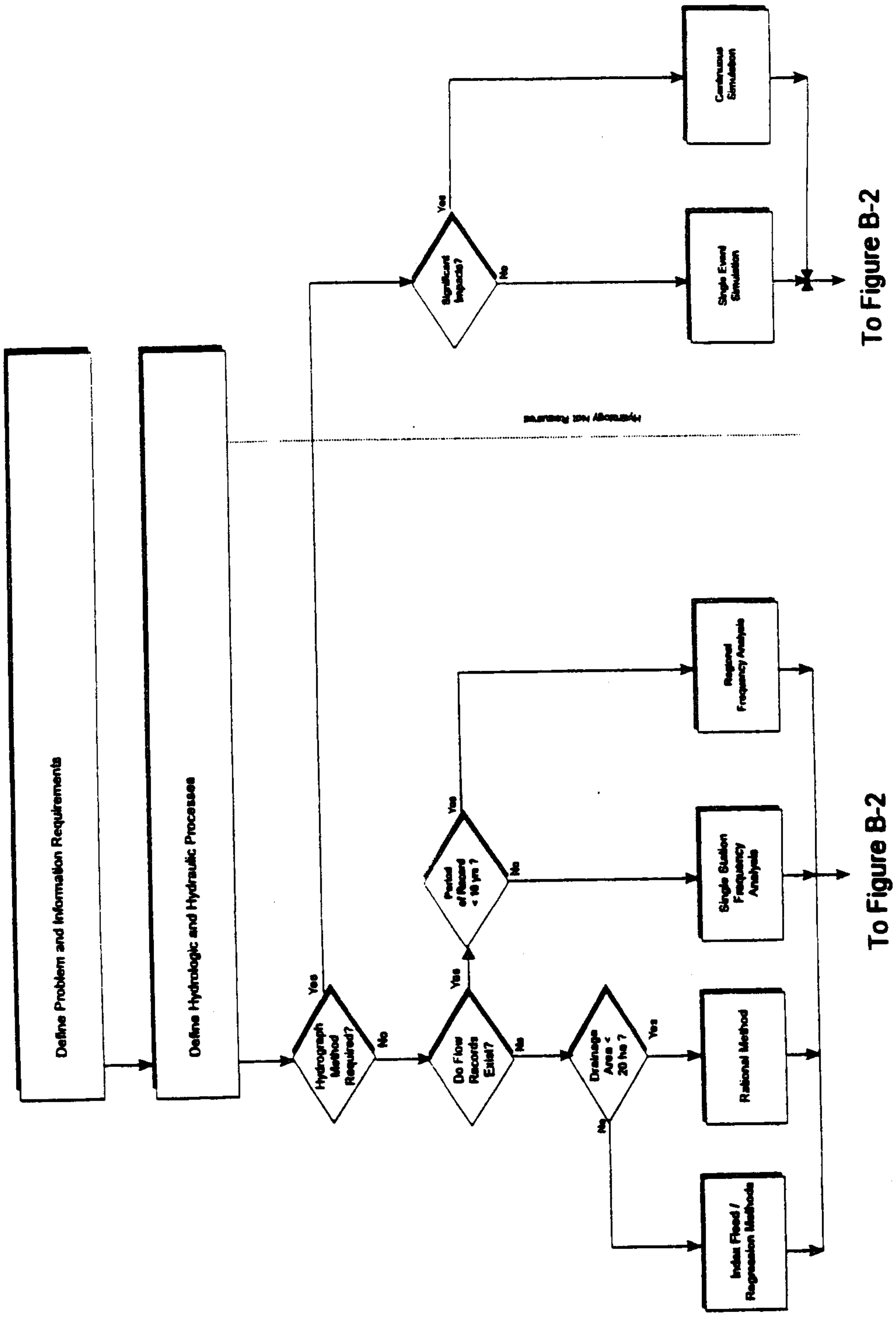
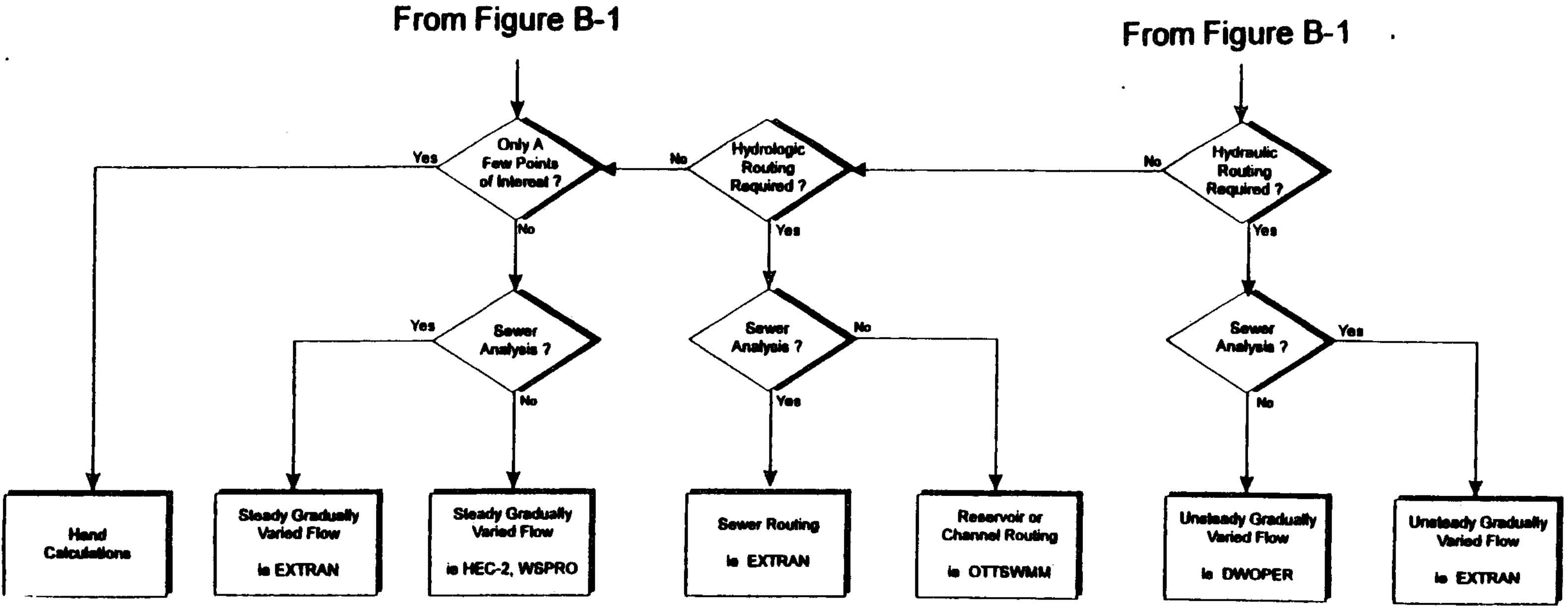


Figure B-2

Figure B-2 Hydraulic Computations



Is A Hydrograph Method Required?

Hydrographs are required for the following conditions:

- The draiange basin is expected to undergo significant land use changes which make methods such as index lood/regression methods inapplicable;
- The draiange area is or will be subject to significant regulation effects including artificial storage or diversion;
- Peak flow rates or volumes of runoff will be calculated form a historical rainfall or precipitation event (e.g. Hurrican Hazel or Timmins Storm);
- Drainage management alternatives are to be tested including regulation, diversion, etc; and;
- Land use, times of concentration or soil conditions vary significantly across the drainage basin.

The majority of hydrograph methods require the simulation of precipitation/runoff process. Most of the simulation methods are performed with computer programs. The programs use two (2) approaches to simulate runoff. One approach simulates runoff for individual storm events wile the otehr simulates runoff from continuouse precipitation records.

Simulation of a single (individual) design storm event isusually simpler and less costly than continuous simulation depending on the models employed and the time resolution of the precipitation records. Examples of the more commonly used computer programs for the simulation of single events include OTTSWMM, SWMM IV, OTTHYMO, HYMO, ILLUDAS, GAWSER AND MIDUSS.

Although event simulation programs can be adapted for continuous simulation, certain models have been specifically written for continuous simulation. Examples of computer programs designed for continuous simulation are QUALHYMO, STORM, HSP-F and GAWSER.

A single event method can be used if runoff must be simulated from a historical storm. One example of a historical storm is Hurricane Hazel. The storm is used by the Ministry of Natural Resources to delineate Regional Floodlines in Southern Ontario. Hurricane Hazel resulted in the loss of lives and extensive property damage.

If runoff from a historical storm is not required, then the procedure (single evernt or continuous) will be dependent upon the impacts due to failure. Failure is defined as exceedence of design criteria. It does no necessarily imply a sturctural failure.

A single event design storm approach can be used to simulate runoff hydrographs if impacts due to failure are not significant. Impacts of failure care significant if the rist to life isincreased and/or there are significant increases in property damage. If the impacts are signficant, then continuous simulation is required. Continuous simulation should give more accurate estimates of peak flow rates for a specific frequency than a single event design storm.

A series of historical singel events is sometimes used in palce of continuous simulation. The time expended and the cost may be lower than continuous simulation. Also, the increment of simulation for single events is usually shorter.

Methods generating only peak flow rates may be sufficient **if hydrographs are not required.**

A Rational Methods, index flood methos, single station frequency analysis or regional frequency analysis approach may be acceptable if land use is generally unchanged across the basin from existing to future conditions.

Do Flow Records Exist?

A frequency analysis of long-term streamflow records can determine peak flow rates required in the design of water management facilities. The results are usually applicable if no significant changes are propsed to the upstream land use. However, long-term flow records are often not available near a development.

A single station frequency analysis and regional frequency analysis may be performed if a hydrograph procedure is not required and flow records exist.

Is the Period of Flow Records<10 Years

A regional frequency analysis can be used if the period of flow records is less than 10 years.

If the period of record is greater than 10 years, a single station frequency analysis courld be performed to determine design peak flow rates. The steps required to carry out a frequency analysis are described in the Consolidated Frequency Analysi (CFA88) or the HYDSTAT programs documentation.

A period of record greater than 10 year is recommended to provide confidence in the results. Generally, the longer the period of record the greater the confidence in the results.

Index flood/regression methods may be used to check design flow rates if the period of record is less than 10 years. The analyst/designer should compare design peak flow rates from the two methods andselect an appropriate value.

Flow Records Do Not Exist

Where there are no flow reocrds and a hydrograph is not required, the Rational Method or an index flood/regression method may be used to calculate peak flow rates.

Rational Method

The Rational Method may be used to estimate peak flow rates if storm sewers are being designed or the rural drainage area is less than 20 ha. The 20 ha upper limit for the Rational method is arbitrary. It is the responsibility of the analyst/designer to apply the most appropriate values in the design of water managment facilities.

The applicability of the Rational Method to rural areas is dependent upon a number of factors. Due to variability in soils, vegetation and rainfall, the applicability of theRational method should be carefully reviewed for drainage basins greater than 20 ha.

Index Flood/Regression Methods

The Index flood/regression methods can be used to estimate peak low rates for undeveloped areas if the draiange area is greater that 20 ha. The application of an index flood method and a regression method can be found in the Ontario Ministry of Natural Resources Technical Guidelines for Flood Plain Management in Ontario. Results from the method should be compared with resluts from at least one other method.

Flow Routing

Flow routing can be classified as either **hydraulic** or **hydrologic. Hydraulic routing** is used to transfer a hydrograph when flow rates through a watercourse are influenced by downstream conditions. Flow rates and levels are calcualted considering both time and downstream conditions. Examples of two (2) computer programs that have been used to route hydrographs influenced by downstream conditions is EXTRAN (sewer systems) and DWOPER (open watercourses).

Flow conditions requiring hydraulic routing are not normally experiencde in the planning and design of water managment facilities. Hydraulic routing is sewers and open channels is usually modelled assuming unsteady, gradually varied flow conditions.

Hydrologic routing is performed along open channels and sewers where there is no downstream influence. Hydrologic routing methods are usually much simpler and require less input dat than hydraulic routing methods. A number of computer subroutines have been used to route hydrographs. Examples of computer programs that include subroutines are OTTHYMO and MIDUSS for open channel watercourses and SWMM and ILLUDAS for sewers.

Hydrologic routing determines only flow rates; **hydraulic routing** determines flow rates and water levels.

Water Levels

There are a number of methods to calculate water levels if flow rates are not affected by downstream conditions. If there are only a few points of interest, then water levels can be calculated by simple hand calculation methods.

The design of bridges/culverts may require only an upstream water level which can be determined by hand calculations. Several procedures are described in the Ontario Ministry of Transportation's Drainage Manual.

When water levels are required at several points of interest, computer simulation programs can be used to minimize computation time. Examples of such programs foropen channel flow include HEC-2 and WSPRO. Water levels are calculated in these programs assuming steady, gradually varied flow conditions. An example of a computer program that calcualtes levels in sewers is EXTRAN.

B.2 HYDROLOGIC COMPUTATIONS

B.2.1 Introduction

Section B.2 summarizes hydrologic computations used in the design of water management facilities. The procedures and programs are guidelines. It is the analyst's / designer's responsibility to recommend and justify the most appropriate methods.

The planning and design of water management facilities should analyze the impact of storm events greater than the design criteria (impact analysis). It is important for analysts / designers to identify potential problems that could be created by their designs. The following criteria should be applied when determining impacts of events greater than the design criteria:

Drainage Area	**Design Criteria**	**Criteria for Impact Analysis**
Less than 20 ha	2 to 50 years	100 year event
	100 year	No additional analysis.
Greater than 20 ha	2 to 100 years	Regional Event
	2 to 50 years	100 years

The hydrologic computation procedures in this section are discussed in the upcomng subsections and organized as follows.

Flow records exist:

- Single Station Frequency Analysis

Flow records do not exist (or not appropiate).

- Rational Method
- Index Flood/Regression Models
- Hydrograph Simulation Methods

B. 2.. 2 Single Station Frequency Analysis

The objective of a frequency analysis is to determine peak flow rates for a specific frequency of occurrence. The single station frequency analysis is conducted using a series of recorded annual maximum flood peaks. However, recorded data is often not available for the design of water management facilities.

Reference to documentation of the Consolidated Frequency Analysis 88 (CFA88) and the HYDSTAT computer programs can also be made when undertaking a single station frequency analysis. CFA88 was developed and is maintained by Environment Canada, Water Resources Branch. HYDSTAT is distributed and maintained by the Ontario Ministry of Natural Resources.

The results of frequency analysis from long term records should be the most accurate estimate of design peak flow rates for water management facilities. Frequency analysis uses runoff recorded in or near the study basin. The estimation of design flood flows by frequency analysis should include a reliability analysis to determine confidence limits on the estimates.

The basic assumption in the application of a frequency analysis is that the basin to which the results are applied is similar to the watershed from which the flood peaks were recorded. This is a major disadvantage and restricts the application of the frequency analysis results. Another disadvantage is that the results cannot be directly used in the analysis of alternative drainage management techniques.

B.2.3 Rational Method

The Rational Method is a widely used computation procedure to design and analyze storm sewers and ditches. The Rational Method can be used to estimate flow rates from small rural basins, size storm sewers and ditches, and to determine gutter flow where the basin area is less than 20 ha.

The Rational Method should not be used where flow storage or diversion is involved. When hydrographs are required, computer simulation of runoff may be conducted.

The following assumptions are inherent in the Rational Method:

- The peak rate of runoff is calculated using drainage area and the average rainfall intensity with a duration equal to the basin time of concentration;
- The calculated peak rate of runoff is assumed to have a return period equal to the intensity-duration-frequency curve;
- Drainage area, rainfall intensity and the runoff coefficients are assumed to be independent variables;
- The rainfall intensity remains constant for the time of concentration and is spatially uniform across the basin; and
- The runoff coefficient does not vary over the duration of the event.

The assumptions inherent in the Rational Method are usually only tenable for small basins which are symmetrical around the main watercourse. The Rational Method is simple to use, widely accepted and the required data is easily obtained.

The disadvantages are that the Method only generates peak flow rates, uses simplified loss procedures, and runoff is assumed to be a linear process. The Rational method has been misused for large basins or where times of concentration and runoff coefficients have been poorly selected. It is the analyst's / designer's responsibility to recommend the most appropriate parameter values for use in the Rational method.

B.2.4 Index Flood / Regression Methods

Index flood or regression methods may be used to estimate design peak flow rates for rural or undeveloped basins greater than 20 ha. The method is usually applied to basins where no flow records exist. The Method is intended for the estimation of design peak flow rates with return periods ranging from 2 to 100 years. Index flood / regression methods should not be used where storage or diversion is involved.

Examples of the index flood or regression methods can be found in the Technical Guidelines for Flood Plain Management in Ontario.

It is good practice to check the results of index flood or regression methods with results from at least one other hydrologic method.

B.2.5 Hydrograph Simulation Methods

Hydrograph simulation methods may be used when the Rational method or the index flood methods are inapplicable.

The optima design of water management facilities is based on several factors including the selection of planning and design criteria, type of drainage facilities, hydrologic / hydraulic analyses, impact analyses, cost estimation, construction and maintenance of the facilities. Hydrograph simulation procedures are one aspect of the analysis. Too much emphasis on the hydrologic modelling to the neglect of other factors may not generate the optimal solution.

As previously discussed, hydrograph simulation methods are required under the following circumstance:

- The drainage basin is expected to undergo significant land use changes which make index flood / regression methods inappropriate;
- The drainage area is or will be subject to significant regulation effects including artificial storage or diversion;
- Peak flow rates or volumes of runoff will be calculated from a historical rainfall or precipitation event (e.g. the Hurricane Hazel or Timmins Storm);
- Different drainage management alternatives are to be tested including regulation, diversion, etc.; and
- If land use, times of concentration, or soil conditions vary significantly across the drainage basin.

There are many hydrologic simulation methods available to the analyst / designer. Most methods that are in use today have been adapted for computers. Table B.1 shows the characteristics of several programs which may be used in the design of water management facilities.

Included are the following programs:

Single Event

·.ILLUDAS
·.SWMM IV
·.OTTSWMM
·.OTTHYMO
·.MIDUSS
·.HYMO

Continuous

·.STORM
·.QUALHYMO
·.HSP-F
·.SWMM IV

The estimation of return periods of flow characteristics from continuous simulation models should be more accurate than from single event models. The return period of runoff from single event models is assumed to equal the return period of the design storm; however, no single event design storm has shown this concept to be valid in all conditions.

The selection of a simulation program is dependent on the impacts of failure, the information required and the hydrologic processes being modelled. Generally, it is more important that a program be used intelligently than it is for any particular program to be used.

A simplified form of continuous simulation is the use of a series of single historical events. The advantages of a series of single events are the use of shorter simulation time steps. Runoff is not computed for periods between events. Antecedent precipitation and soil conditions must be determined for each event.

Both continuous simulation and simulation with a series of historical storm events avoid the use of single design storms and should result in the determination of a more realistic flood frequency estimate.

All of the continuous simulation programs are composed of a group of subprograms which simulate the following hydrologic processes:

- Precipitation losses due to infiltration and depression storage;
- Conversion of runoff into a hydrograph;
- Routing of hydrographs through watercourses or channels; and
- Routing of hydrographs through areas with significant storage.

The most widely used precipitation loss methods include the US Soil Conservation Service Curve Number procedure, Horton's infiltration equation and the Green-Ampt method. The most widely used methods to convert runoff into hydrographs include unit hydrograph methods, the kinematic wave method and the isochrone method.

Generally, hydrologic or hydraulic computer modelling is a time consuming and expensive process that requires a significant amount of hydrologic / hydraulic expertise.

Computer modelling does not offer a panacea of solutions to drainage problems. The real solution lies in the expertise of the analysts / designers.

TABLE B.1 Computer Model Characteristics

	HYDROLOGIC										HYDRAULIC			
	HYMO	OTTHYMO	SWMM IV	OTTSWMM	ILLUDAS	MIDUSS	HSP-F	QUALHYMO	STORM	GAWSER	HEC-2	EXTRAN	DWOPER	WSPRO
HYDROLOGIC														
Basin Type														
Urban		X	X	X	X	X	X	X	X	X				
Rural	X	X				X	X	X	X	X				
Precipitation														
Single Event	X	X	X	X	X	X	X	X		X				
Continuous			X				X	X	X	X				
Temperature			X	X			X	X	X	X				
Evapotranspiration			X				X	X	X	X				
Subsurface Flow							X	X		X				
Infiltration	X	X	X	X	X	X	X	X	X	X				
Water balance			X				X	X	X	X				
Hydrograph Method	X	X	X	X	X	X	X	X	X	X				
Water Quality			X				X	X	X	X				
HYDRAULIC														
Routing														
Watercourse	X	X	X	X	X	X	X	X		X		X	X	
Reservoir	X	X	X	X		X	X	X		X		X	X	
Sewers														
free surface		X	X	X	X	X						X		
surcharged												X		
dry weather			X	X	X	X			X			X	X	
Control Structure										X		X		
Quality			X		X		X	X	X	X				
Water Levels											X	X	X	X
Sub-critical											X	X	X	X
Super-critical														
Major/Minor System				X										
Receiving Water			X				X							
APPLICATION														
Ontario Applications	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Level of Effort	L	L	M	M	L	L	H	M	M	M	M	H	H	M
Data Requirements	M	M	H	H	M	M	H	M	M	H	H	H	H	H

The Association of Professional Engineers of Ontario (APEO) offers the following advice when undertaking the design of engineered structures using computer models:

- Determine the exact nature of assistance the program provides;
- Identify the theory on which the program is based;
- Determine the limitations, assumptions, etc. that are included in both the theory and the program;
- Check the validity of the program for the intended applications;
- Make sure the program is correctly used; and
- Verify that the results are correct for each application.

The application of hydrologic / hydraulic computer simulation models to drainage facilities design should be undertaken with sound engineering judgement.

B.2.6 Calibration and Verification

Calibration and verification will establish confidence in the model results. Calibration is the process of varying model input parameters until a good fit between measured and simulated values occur. Verification on a different set of data determines the success of the calibration process.

Calibration is used to estimate basin parameters which cannot be physically measured directly. Examples include infiltration parameters, directly connected impervious area, Manning's roughness coefficient, depression storage and overland flow widths. The calibration and verification of hydrologic simulation models should at a minimum be performed whenever rainfall / runoff data is available.

The calibration and verification processes require large amounts of data. The measurement of data necessary to calibrate and verify the model is a time consuming and expensive undertaking. If the failure of a facility would increase the risk to life or property damage, then data collection for calibration should be considered.

Continuous simulation models should be calibrated with a minimum of five (5) years of data. Another five (5) years of data should be used to verify the model. Single event models should be calibrated with a minimum of five (5) events. Another five (5) events should be used to verify the model. Hydrologic simulation models may be calibrated to the results of a single station flood frequency analysis. Ontario Ministry of Natural Resources, Flood Plain Management in Ontario

It is also good practice to perform a sensitivity analysis of the input parameters, especially if calibration and verification cannot be undertaken.

Sensitivity analyses are usually carried out on parameters which cannot be measured with significant accuracy. The sensitivity analyses will determine the variation in model output due to changes in input parameters. These analyses give the analyst / designer an understanding of the response of the hydrologic / hydraulic process to model inputs.

Hydrologic parameters that are varied during a sensitivity analysis usually include directly connected impervious area, infiltration parameters, depression storage, hydrograph time of concentration and recession constant. Small changes in impervious areas can result in significant changes in peaks and volumes of runoff. Also, changes in the time of concentration or recession have significant impact on the peak rate of runoff. The actual variation in runoff, as a result of changes to input parameters, varies from case to case.

The results of uncalibrated hydrologic simulations should be checked with results from a different hydrologic computation method.

B.2.7 Design Rainfall

Introduction

When field measurements on a drainage system are not available or are not applicable, then the precipitation / runoff response must be simulated. The precipitation input is a meteorological event described by a distribution of precipitation intensity over time. Natural meteorological events have characteristics such as the following:

- Instantaneous intensity;
- Maximum average intensity over a given duration;
- Maximum volume over a given duration;
- Total storm volume (depth);
- Total storm duration;
- Average storm intensity; and
- Duration between rainfall events, etc.

The specification of the design rainfall can be the single most critical component of the drainage system design process as it drives all subsequent analyses.

The two major approaches to drainage system analysis / design are event and continuous simulation.

In the event simulation approach, one single design rainfall event (or a small number of events) is selected. Catchment parameters and conveyance elements are specified and the precipitation/runoff response is simulated.

In event analysis, design rainfall is specified as a physical event or a statistical event. Hydrologic simulation programs require a physical event as input. The physical event may be an actual recorded historical storm or a synthetic storm based on a statistical analysis of recorded rainfall. The synthetic storm is described as a hyetograph with a frequency of occurrence. In contrast, the Rational method requires a statistical event as input. The event is described as the maximum average intensity over a specified duration corresponding to a given frequency of occurrence.

The basis of event analysis is that the simulated runoff is assigned the same frequency of occurrence as the precipitation. The deficiencies of this assumption are widely known and can be summarized as follows:

- A rainfall hyetograph has many characteristics which have unique return periods. The hyetograph does not have a unique return period. It is essentially impossible for a single rainfall hyetograph to have the same frequency for all of its many characteristics;

- As precipitation has many characteristics, so the output hydrograph will have many characteristics. There is not a single one to one correspondence between any precipitation characteristic and any hydrograph characteristic. Therefore, even if one characteristic of precipitation has a unique return period, the corresponding runoff characteristic does not have that same return period; and

- The drainage system is described by several variables. The frequency of runoff is dependent upon the frequency of precipitation and on the variables describing the system. Therefore, the frequency of runoff cannot be defined on the frequency of precipitation input alone.

The event analysis and the interpretation of a design storm analysis must be undertaken with caution. Since the frequency of drainage system performance assessed by event analysis is only approximate, event analysis is only appropriate in those circumstances where the drainage system design decisions are relatively insensitive to design return period, specifically, when the impacts of system failure are not significant. when impacts of failure increase the risk to life and / or increase property damage, the improved frequency estimation of continuous analysis is warranted.

The second major approach to drainage system analysis / design is continuous simulation. Rather than attempting to assign a unique return period to a specific design precipitation event, continuous simulation analysis uses the entire long term meteorological record as input. As a result, many events are simulated which allow a frequency analysis to be performed on the hydrograph characteristics, thus more confidence can be attached to return period estimates of the drainage system performance.

An alternative approach to continuous simulation is the analytical probabilistic modelling to drainage systems analysis. Characteristics of precipitation for a long period of record is subjected to a statistical analysis which is used to fit a theoretical probability density function (PDF). The PDF's of the meteorological characteristics are mathematically transformed to PDF's of output characteristics which represent the hydrology and hydraulics of the .drainage system. A software package for these analytical models called SUDS (Statistical Urban Drainage Simulator) is available from the University of Toronto. The model is intended for use in screening level analysis.

Intensity-Duration-Frequency (IDF) Values

Intensity-duration-frequency (IDF) values are used directly by the Rational method or indirectly by hydrograph methods to simulate the rainfall/runoff process. Hydrograph methods require a design storm which is either historical or synthetic. Synthetic design storms use the IDF values to determine the total rainfall depth then distribute the rainfall in time and space according to a defined pattern.

The Atmospheric Environment Service (AES) of Environment Canada operates and maintains the largest network of precipitation gauges in Ontario and Canada. Data collected at those gauges may be used in the analysis and design of water management facilities. Data collected by other agencies could be used in special circumstances.

Data from AES gauges have been selected because the gauges are located in all of MTO's Districts and because of AES's consistent collecting and reporting procedures.

Intensity-duration-frequency curves are developed for all AES continuous recording gauges with more than ten (10) years of record. In 1985, AES published the **Rainfall Frequency Atlas of Canada**. The report shows contours of mean annual rainfall extremes and standard deviation of rainfall intensities for durations ranging from five (5) minutes to 24 hours.

When used in the design of water management facilities, rainfall IDF curves should reflect the extreme rainfall characteristics of the drainage basin under consideration. The selection process may be complex when there exist too few or too many meteorological stations.

The selection of a rainfall IDF curve should be based on several factors. Included are the period of record, the length of record, station location and a knowledge of the meteorological conditions within the study basin. A significant amount of experience must be used to select the most appropriate IDF curve.

The contours shown in the **Rainfall Frequency Atlas of Canada** were developed considering the above factors and will significantly reduce the effort required to determine IDF values.

The best estimate of rainfall intensity for a given basin will be determined from values shown in the **Rainfall Frequency Atlas of Canada.**

The IDF values are used in the application of the Rational method and the development of synthetic design storms required for hydrograph simulation methods.

IDF values describe the variation of extreme point rainfall with time for a given frequency. The values do not include an adjustment for the variation with area. Areal reductions should be applied to all IDF values for analysis where the upstream drainage basin has a circular drainage area greater than 25 km^2.

Design Storm Events

Single event design storms are used in most simulated hydrograph applications. Design storms are either historical or synthetic. An example of a historical design storms is Hurricane Hazel. The storm is used to define the Regional Flood Plain in portions of Southern Ontario.

Hurricane Hazel is usually applied by the Ontario Ministry of Natural Resources and Conservation Authorities for drainage basins greater than 130 ha (MNR criterion).

Synthetic design storms are used to define rainfall distributions for return periods ranging from 2 to 100 years. Generally, the same distribution is used for all return periods and multiplied by the rainfall depth determined from the IDF curves.

Several different synthetic rainfall / snowmelt distributions have been used over the last decade to simulate runoff hydrographs. Included are the following:

- Keifer & Chu;
- SCS Type II;
- AES 30%
- - 1 hour;
- - 12 hour; and
- AES/Hydrotek - 1 hour.

Continuous simulation or the use of a series of single events is expected to generate runoff with a frequency which best approximates reality.

Synthetic design storms can be valid for the design of water management facilities even if the calculated return period of runoff is difficult to determine. Synthetic design storms should be used in situations when the impact of failure (design flood exceeded) does not increase the risk to life or create substantial property damage. Drainage system design involves optimizing costs (design, construction and operation) while providing a reasonable level of service. A consistent design storm approach should reflect a reasonable level of service.

Peak flow rates from urban catchments are usually a function of rainfall intensity rather than rainfall depths. Rural basins usually generate runoff with peaks that correlate well with total rainfall depth.

Storm duration has traditionally been set equal to the basin time of concentration which is a function of several factors. Included are basin and channel slope, natural and man-made storage, land use, channel material and shape, precipitation characteristics, etc. It is recognized that basin time of concentration will be longer for basins with significant storage and that it will vary for each basin and for each precipitation event.

Continuous Analysis

Continuous simulation is used to simulate the precipitation / runoff process for long periods. Typical periods of continuous rainfall data range from 10 years up to 30 or 40 years. A frequency analysis is performed on the annual simulated maximum peak flow rates or volumes to determine a flood frequency curve. Continuous simulation is generally expected to give more accurate estimates of the frequency of flood flows than event simulation methods.

Precipitation data for continuous simulation is usually obtained from AES gauges in one hour time increments. The data can be purchased on magnetic tapes or on floppy diskettes.

An alternative to continuous simulation is the simulation of a series of individual historical storm events. Each precipitation event is simulated and a frequency analysis of the simulated results is then performed.

Data required for the simulation of a series of individual storm events is usually obtained from AES gauges. The storms are usually discretized in time increments of less than one hour with typical values of 10 to 15 minutes.

B.3 HYDRAULIC COMPUTATIONS

B.3.1 Introduction

The design of water management facilities will usually involve some form of hydraulic analysis. The purpose of the hydraulic analysis is to determine flood levels or to route hydrographs between points of interest.

Routing refers to the process of transferring a hydrograph between two points of interest along a watercourse. The routing process is often divided into two categories. **Hydraulic routing** considers the effect of downstream conditions through a study reach when transferring a hydrograph. **Hydraulic routing** calculates the time history of flow and water level along a particular watercourse reach.

Hydrologic routing considers only the reach through which the hydrograph is being transferred. Hydrologic routing calculates only the time history of flow. It is usually a simpler procedure than hydraulic routing.

Hydraulic routing calculates flow rates and water levels simultaneously. When downstream conditions or water levels do not influence flow rates through the study reach, then water levels can be calculated independently of flow. Water levels are calculated once flow rates have been determined.

It is the analyst's / designer's responsibility to recommend the most appropriate parameter values. Also, changes to the hydraulic parameter values may be warranted during the calibration or verification of the simulation models.

B.3.2 Hydrologic Routing

Hydrologic routing may be conducted in the design of water management facilities. **Hydrologic routing** considers storage and discharge for a given reach. The continuity equation is solved simultaneously with a storage function to determine outflow and the change in storage. **Hydrologic routing** transfers a hydrograph from one location to another but does not directly calculate water levels. Levels must be calculated for a single flow rate using hand calculations or a computer program such as HEC-2 or WSPRO.

Hydrologic routing has been further subdivided into channel and reservoir routing. Channel routing procedures require the input of physical characteristics of the watercourse such as channel geometry, reach slope and length, and Manning's roughness coefficients. Stage-storage and stage-discharge relationships are usually developed to complete the calculations.

Reservoir routing procedures usually require a table of discharge rates for a range of storage volumes. The continuity equation is applied to determine outflow rates. Mater levels can be indirectly determined from the stage-discharge relationship once the peak outflow rate is determined.

Most of the single event and continuous simulation programs include subroutines to perform reservoir or channel routing. Examples of such programs include HYMO, OTTHYMO, ILLUDAS and MIDUSS.

B.3.3 Hydraulic Routing

Hydraulic routing calculates flow rates and water levels through a reach considering the impacts of downstream conditions. **Hydraulic routing** procedures solve for unsteady, gradually varied flow conditions. The computer program DWOPER solves for open channel conditions while EXTRAN solves for unsteady conditions in sewers.

Hydraulic routing procedures require input of the physical characteristics of the watercourse (channel geometry, reach slope, length, roughness coefficient, etc.) and conditions at the boundaries of the study area. Examples would be a time history of water levels at the downstream boundary and flood hydrographs at the upstream boundary. Boundary conditions are used to simultaneously solve for flow rates and levels through the study reach.

Hydraulic routing procedures can be further subdivided into kinematic wave, diffusion wave and dynamic wave models. The kinematic wave has been incorporated into several computer programs to route hydrographs through channel and sewer reaches. The kinematic wave model does not consider downstream conditions when routing hydrographs and therefore cannot be considered a complete **hydraulic routing** model. The kinematic wave model is used in SWMM, OTTSWM and ILLUDAS computer programs.

Hydraulic routing procedures are not normally conducted in the design of water management facilities. The selection of the most appropriate routing method and computer model is left to the judgement of the analyst / designer. The method should be based on the impacts due to failure. If impacts are high, then **hydraulic routing** methods may be considered.

B.3.4 Water Levels

Maximum flood levels are required during the planning and design of water management facilities that include culverts, bridges, diversion channels, outlet structures and storage ponds.

Water levels and peak flow rates can be calculated independently when **hydraulic routing** is not required. Water levels are calculated once flow rates have been determined. Flood levels can be determined using hand calculations or computer programs depending on the reach length or the number of locations where flood levels are required.

Hand calculations generally assume steady, uniform flow conditions to determine water levels. Examples would include storm sewers, open channel and culvert sizing.

Many of the computer programs used to calculate water levels assume steady, gradually varied flow conditions. Examples would include the WSPRO and HEC-2 computer programs. Computer programs used to calculate **hydraulic** or unsteady flow conditions can be used to model steady, gradually varied flow and steady, uniform flow conditions. Examples would include the DWOPER and EXTRAN programs.

It is extremely important to consider downstream water surface elevations during the design or analysis of water management facilities. Arbitrarily assumed downstream water levels could lead to large errors in upstream simulated water levels.

B.3.5 Calibration and Verification

The calibration and verification of all hydraulic models is strongly recommended. Generally, the calibration and verification processes require large amounts of data including surveyed cross sections, recorded water levels and flow rates. The measurement of data necessary to calibrate and verify the model is a time consuming and expensive undertaking. If the failure of a facility would increase the risk to life or property damage, then data collection for calibration may be considered.

The calibration and verification procedure involves varying input parameters until a good agreement exists between measured and simulated values. The following parameters are usually varied during calibration:

- Channel and flood plain roughness; and
- Expansion and contraction coefficients.

It is the analyst / designer's responsibility to recommend the most appropriate parameter values.

If the results of calibration and verifications are poor, then field conditions and input data should be carefully reviewed before design simulations are carried out.

The hydraulic models developed to simulate the hydraulic processes of water management facilities are not normally calibrated or verified. If the data exists or the impacts of failure are significant, then the models should be calibrated and verified.

It is good practice to carry out a sensitivity analysis of the input parameters. Hydraulic parameters which are varied include roughness coefficients, expansion and contraction coefficients, pier and weir coefficients. The parameter which usually influences water levels the greatest is the roughness coefficient.

APPENDIX C

EROSION ANALYSIS

Although it is understood that detaining runoff to meet quality control targets may also mitigate erosion concerns, this does not account for the sensitivity of the receiving watercourse to changes in hydrology. In order to ensure the long term stability of the receiving watercourses, the existing hydrology must be maintained after development.

Depending on the condition of the watercourse, the proposed land uses, and the length of reach to be assessed, there are three methods that may be required.

Stormwater Management Reports:

- The first method is to use "Distributed Runoff Controls".

- The second method is to determine the critical velocity or the critical tractive force of the least resistant bed or bank toe channel material in the receiving watercourse. This requires the assessment of such data as the bankfull velocity (measured or calculated), bankfull depth, hydraulic radius, channel slope, composition (particle size) of the channel bed and banks, etc. Figures C-1 and C-2 on the following pages illustrate methods that could be used to determine mean velocities and tractive force.

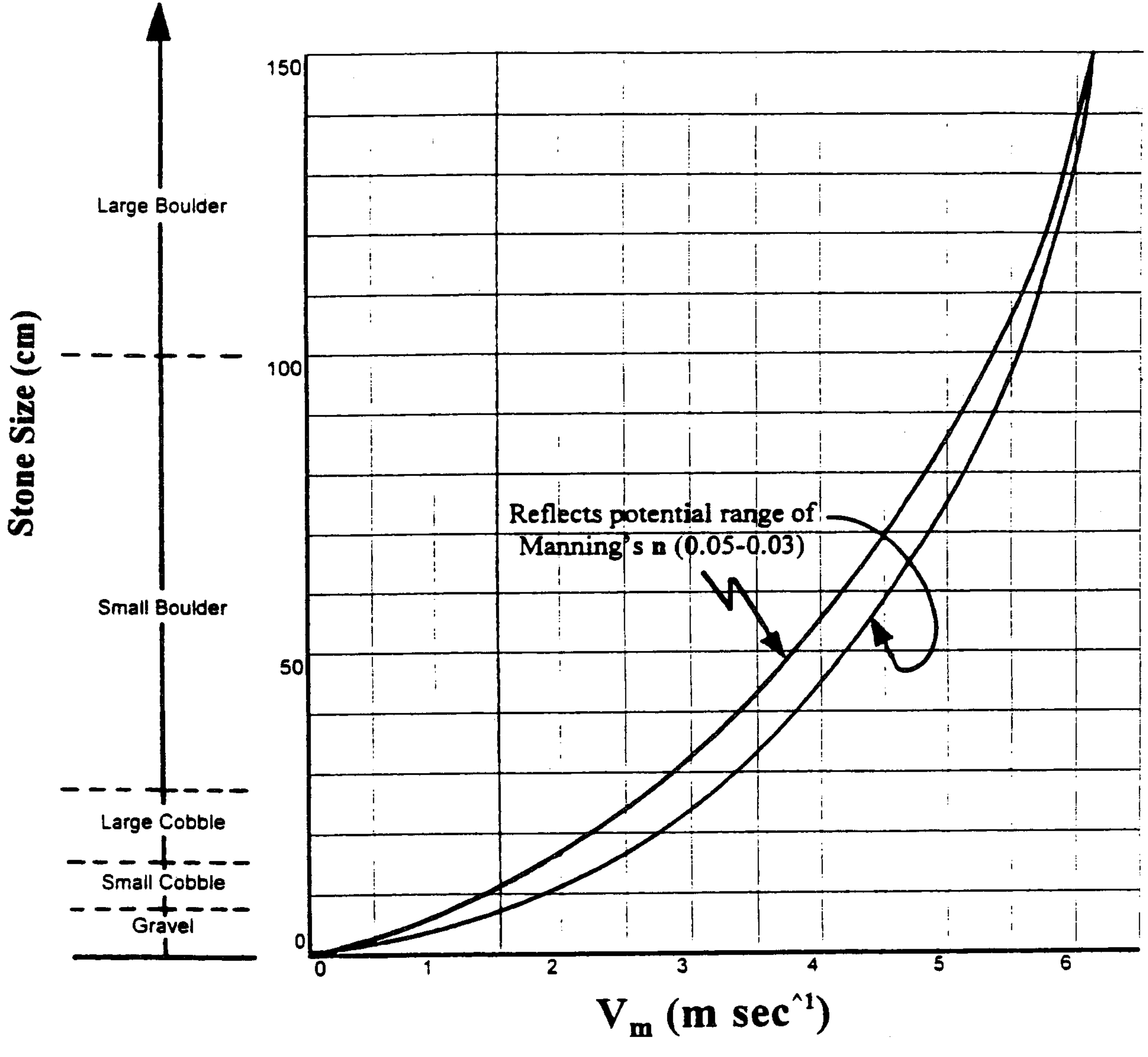
Environmental Management Plans (EMP's), Background Study Reports:

It is likely that the EMP's and Background Studies will be assessed from a reach perspective and consequently will require a third and more detailed method of analysis. In order to determine a long term shear index target, the QUALHYMO model should be used.

The QUALHYMO model incorporates a special routine for calculating erosive indices (SHEAR 1). This was developed by MacRae (1991) to specifically address the need to know how often and for how long critical tractive stresses are exceeded around the wetted perimeter of the bankfull flow channel in a natural watercourse. The SHEAR 1 routine can be used to help design urban stormwater management facilities such that the downstream flow regime will be regulated to provide maximum achievable control of downstream erosive processes. Detailed cross-section geometry, including bankfull dimensions, are input to the SHEAR 1 command of QUALHYMO. Using these data, the program calculates depth versus flow, hydraulic radius, and mean velocity tables. Calculating the Shear Index for a number of points around the channel perimeter allows the erosion potential to be estimated.

Figure C-1

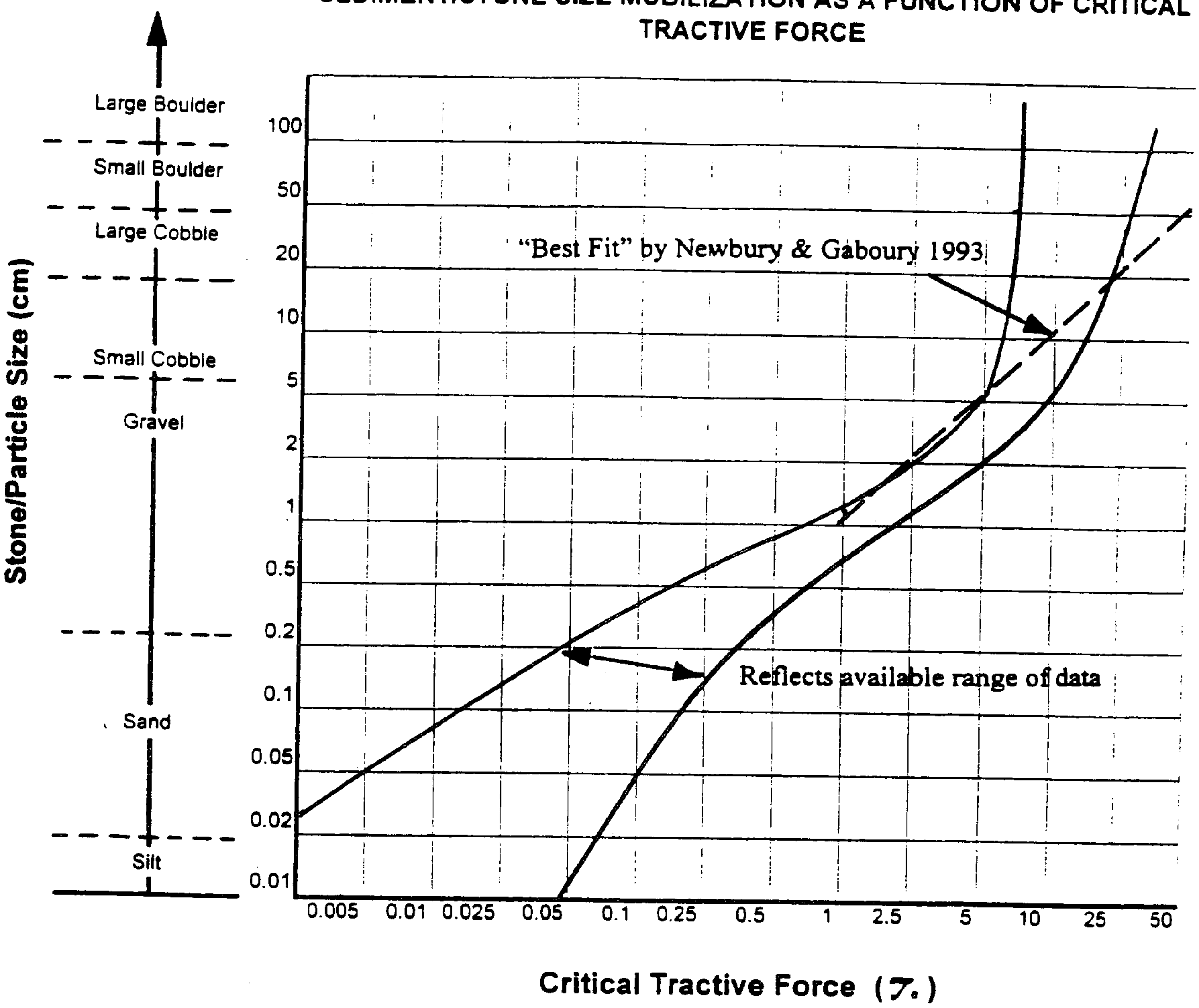
STONE SIZE MOBILIZATION AS A FUNCTION OF MEAN VELOCITY



After: Leopold *et al.* 1963; Magalhaes & Chau 1983; Cooke & Doornkamp 1974; and; Newbury & Gaboury 1993.

Figure C-2

SEDIMENT/STONE SIZE MOBILIZATION AS A FUNCTION OF CRITICAL TRACTIVE FORCE



$\tau_c = \gamma RS$

$(R \approx d_b)$

$kg\ m^{-2}$

Where: τ_c = Critical Tractive Force

γ = Specific Weight of Water

R = Hydraulic Radius

S = Slope

d_b = Bankfull Depth

*** For shale gravel & cobble**

τ_c = 0.4-0.6 times graph values

After: Leopold *et al.* 1963; Magalhaes & Chau 1983; Cooke & Doornkamp 1974; and; Newbury & Gaboury 1993.

APPENDIX D

MUNICIPAL SERVICING

Each municipality has there own servicing requirements and as such each municipality should be contacted.

Some of the requirements that may be applicable to stormwater management issues are listed below and should be considered in the preparation of stormwater management designs.

Lot/Block Grading Standards

- Minimum/maximum slope
- Back to front grading
- Split lot grading
- Swales
- Rear yard catchbasins

Drainage Standards

- Minor system
- Major system
- Overland flow
- Manholes/catchbasins
- Roof leaders/foundation drains
- Roadway cross section (urban and rural)

Open Channel Standards

- Swales/ditches
- Outfalls
- Culverts
- Bridges
- Slope stability setbacks
- Erosion setbacks
- Erosion control - vegetal
- Erosion control - rip rap
- Erosion control - gabion
- Erosion control - armour stone
- Natural Channel design
- Bio-engineering

Sediment Control Standards

- Basins
- Catch basins
- Fencing
- Buffer strips
- Check dams
- Access pad
- Phasing/temporary vegetation
- Other

Stormwater Quantity Control Standards

- Orifice plates
- Roof drains
- End-of-pipe detention facilities
- End-of-pipevolume facilities (infiltration)
- Retrofits

Stormwater Quality Control Standards

- Spill control
- Lot level controls
- Conveyance controls
- End-of-pipe detention facilities
- End-of-pipe retention facilities
- End-of-pipe volume facilities (infiltration)
- Retrofits

Alternative Design Standards

- Minimum lot grading
- Modified minor system
- Modified roadway design
- Cluster development

Legal Requirements/Process Requirements

- Development Charges By-Law
- Sediment Control By-law/Permit
- Servicing Agreement
- Letter of Credit
- Grading Certificate

Hydrotechnical Standards/Reporting Requirements

- IDF curves
- Design storms
- Rational method use
- Computer models - hydrologic
- Computer models - hydraulic
- Sewer design charts
- Culvert nomographs
- Sediment control guidelines
- Standard Drawings and Requirements Manual

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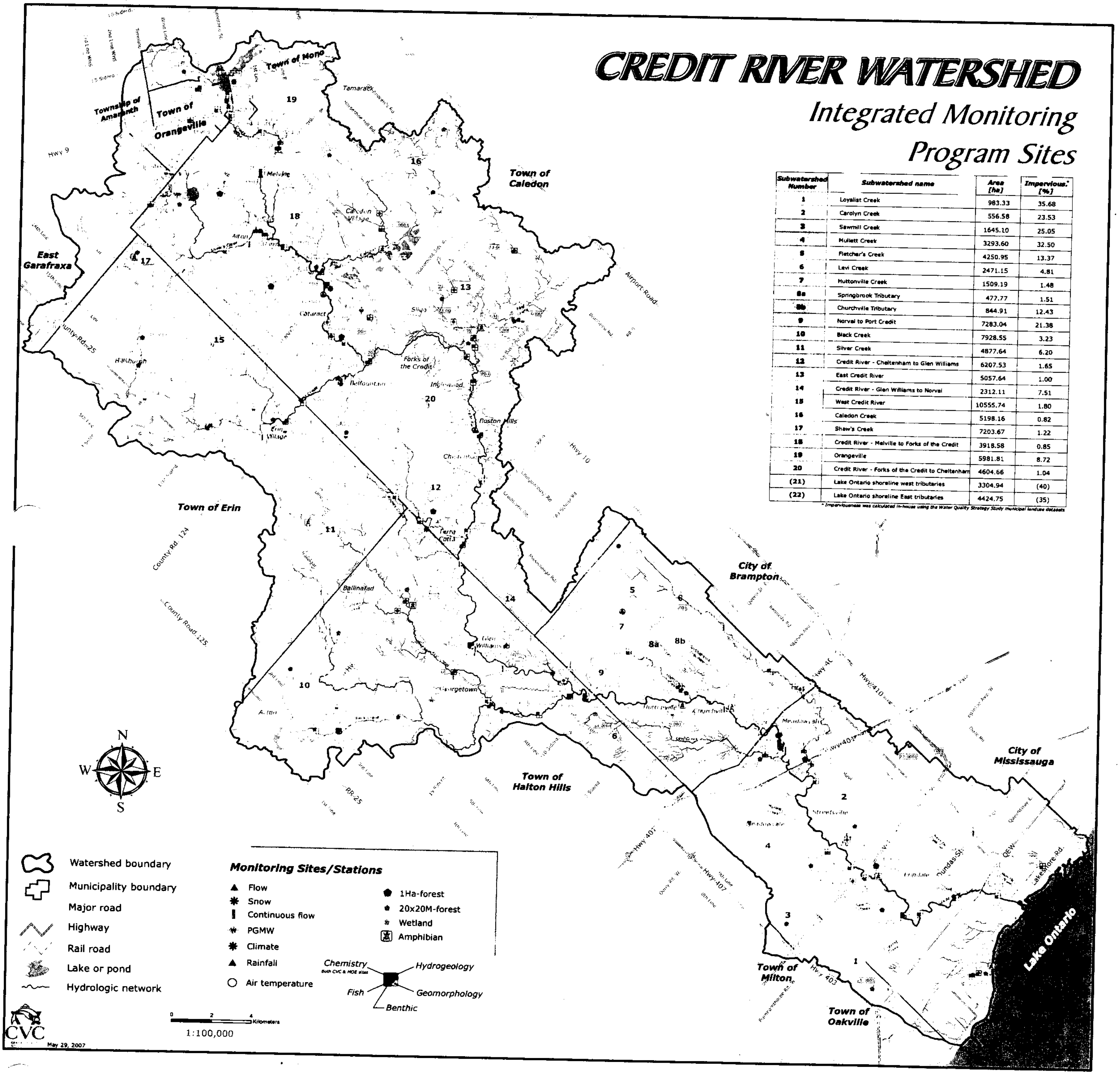
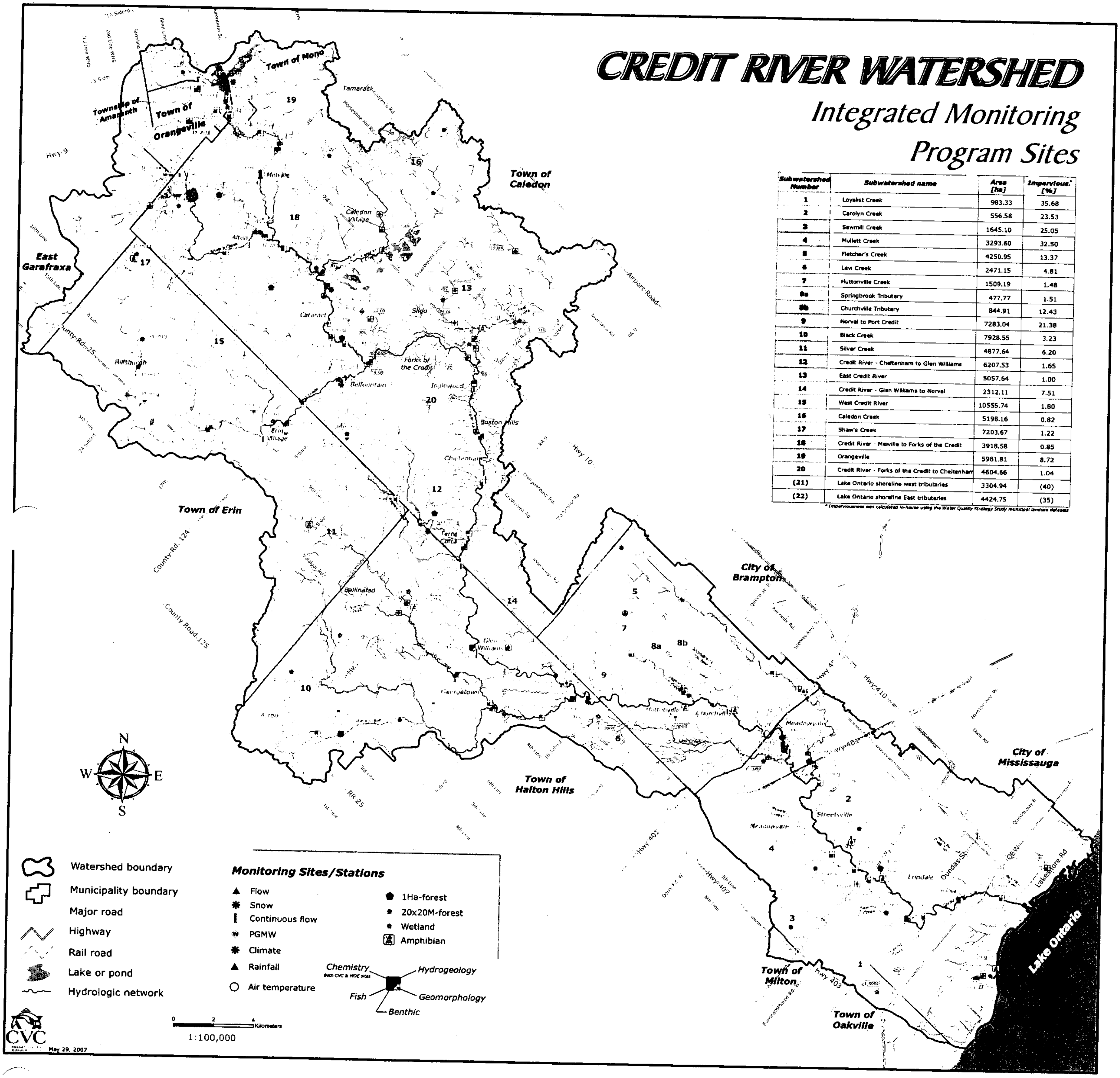
CREDIT RIVER WATERSHED

Integrated Monitoring Program Sites



Subwatershed Number	Subwatershed name	Area [ha]	Impervious.* [%]
1	Loyalist Creek	983.33	35.68
2	Carolyn Creek	556.58	23.53
3	Sawmill Creek	1645.10	25.05
4	Mullett Creek	3293.60	32.50
5	Fletcher's Creek	4250.95	13.37
6	Levi Creek	2471.15	4.81
7	Huttonville Creek	1509.19	1.48
8a	Springbrook Tributary	477.77	1.51
8b	Churchville Tributary	844.91	12.43
9	Norval to Port Credit	7283.04	21.38
10	Black Creek	7928.55	3.23
11	Silver Creek	4877.64	6.20
12	Credit River - Cheltenham to Glen Williams	6207.53	1.65
13	East Credit River	5057.64	1.00
14	Credit River - Glen Williams to Norval	2312.11	7.51
15	West Credit River	10555.74	1.80
16	Caledon Creek	5198.16	0.82
17	Shaw's Creek	7203.67	1.22
18	Credit River - Melville to Forks of the Credit	3918.58	0.85
19	Orangeville	5981.81	8.72
20	Credit River - Forks of the Credit to Cheltenham	4604.66	1.04
(21)	Lake Ontario shoreline west tributaries	3304.94	(40)
(22)	Lake Ontario shoreline East tributaries	4424.75	(35)

* Imperviousness was calculated in-house using the Water Quality Strategy Study municipal landuse datasets



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