Chapter 4

Tools for Evaluating Environmental Quality, Water Quality and Water Quantity Issues

**W. Snodgrass¹, D.E. Maunder²,
K. Schiefer¹ and K.C. Whistler¹**

Beak Consultants ¹ and Aquafor Engineering²
14 Abacus Road, Brampton, Ontario L6T 5B7

4.1 Introduction

The objective of this paper is to present an overview of an integrated approach for using modelling tools, monitoring data, and planning studies for evaluating management options in Watershed Management Studies. Emphasis is placed upon the impacts of urbanization.

The various methods presented have been used to address issues pertaining to ecosystem health (environmental health), water quality and water quantity. The watersheds which are considered include the Rouge River, the Don River, and Duffins Creek. By evaluating the alternative approaches, the reader can gain some insight on the benefits, limitations and appropriateness of each approach for their potential study.

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The methods presented in this paper are illustrative. A comprehensive evaluation of the applicability of these methods to water quality management modelling is beyond the scope of this paper.

4.2 Selection of Modelling Approach

The selection of the modelling approach should follow a pre-defined set of steps. Several steps that we have found useful include:

1. Define the goals and objectives of the model. That is, questions that are addressed by the model.
2. Evaluate the database available or to be gathered during the study. Detailed models require extensive sets of data, either as input data, for calibration purposes, or for testing purposes (ie. comparison of modelling calculations with observed data).
3. Consider monetary constraints. This involves evaluating budget available, and allocating it for additional field studies (monitoring), modelling studies, planning studies and public involvement/institutional review/hearings.
4. Examine uses of the model after urbanization has occurred. Modelling together with monitoring may be required to audit the success of proposed environmental management plans. Models should be selected which are useful both for planning studies and for auditing purposes.
5. Select the modelling approach.

4.3 Environmental Frameworks For Defining Issues

A variety of frameworks are currently in use in the Province of Ontario for defining the environmental issues to be addressed in watershed/subwatershed studies. The way that the issues are defined, and the issues considered in the framework, provide the basis for integration of study results. Two frameworks used in recent studies in Ontario are given in Tables 4.1 and 4.2. Goal statements and management objectives were established for each of the fourteen divisions given in Table 4.1 for the Rouge River watershed. The framework emphasized:

1. the linkage between the riverine watershed and the Great Lakes water, and the quality of human life derived from these ecosystems,
2. water quality, public health and aesthetics,
3. public safety, and
4. fisheries, riparian and terrestrial habitats.

The framework initially used in a subwatershed study, the Hanlon Creek study (Table 4.2) emphasizes:

1. public safety and natural floodplain hydrologic functions,
2. water quality and associated aquatic resources and water supplies, and
3. amenities of rural and urban stream corridors.

Both frameworks emphasize management of water, the lands directly connected with aquatic systems and the associated biological communities. As pointed out by Jack Imhoff (1992), watershed management must emphasize both land and water.

We have found it useful to use the following environmental issues as the framework for managing environmental quality in watersheds impacted by urbanization (page 84):

Table 4.1 Conceptual divisions for ecosystem-based management plan, used in Rouge River study.

I. Quality of Life Within Great Lakes Ecosystem

1. linkage to Great Lakes ecosystem
2. pride in Great Lakes and Rouge River ecosystem
3. balance of economic and environmental value
4. quality of life and land ownership

II. Water Quality, Public Health and Aesthetics

5. contact, non-contact recreation
6. drinking water
7. fish consumption
8. aesthetics

III. Public Safety

9. erosion and flood protection
10. risk to life in valley lands

IV. Fisheries, Riparian and Terrestrial Habitats

11. river beds as fish habitat
12. angling
13. enjoyment of plants and wildlife
14. wildlife and waterfowl and their habitats

Table 4.2 Mission statement and goals and objectives of the Hanlon Creek watershed plan.

Mission Statement

To develop a watershed plan that allows sustainable development aimed at maximizing benefits to the natural and human environments on a watershed basis.

Goals and Objectives

- 1) Goal
 - To minimize the threat to life and the destruction of property and natural resources from flooding, and preserve (or re-establish) natural flood plain hydrologic functions.

Objectives

- *To ensure that runoff from developing and urbanizing areas is controlled such as it does not unnecessarily increase the frequency and intensity of flooding at the risk of threatening life and property.*
- *To adopt appropriate land use controls and performance standards for controlling development of flood plains.*

2) Goal

- **To restore, protect, and enhance water quality and associated aquatic resources and water supplies.**

Objectives

- *To minimize erosion and prevent sedimentation of waterways.*
- *To prevent the accelerated enrichment of streams and contamination of watershed from runoff containing nutrients, pathogenic organisms, organic substances, and heavy metals and toxic substances.*
- *To maintain or restore a natural vegetative canopy along streams where required to ensure the mid-summer stream temperatures do not exceed tolerance limits of desirable aquatic organisms.*
- *To maintain the stream or waterway free from litter, trash, and other debris.*
- *To minimize the disturbance of streambed and prevent streambank erosion and, where practical, to restore eroding streambanks to a natural or stable condition.*
- *To restore, rehabilitate, or enhance water quality and associated resources through the implementation of appropriate Best Management Practices on the land.*
- *To take full advantage of stream baseflow enhancement opportunities.*
- *To enhance the fishery habitat. Specifically to increase the quantity and quality of Brook Trout in the headwaters and to extend their range downstream of the Hanlon Expressway to the Speed River.*
- *To maintain or enhance the buffer provided by wetlands.*
- *To minimize disturbance of wetlands, preserving or enhancing the habitat they provide.*
- *Provide buffers to wetlands to maintain or enhance their biological health.*

3) Goal

- **To restore, protect develop, and enhance the historic, cultural, recreational, and visual amenities of rural and urban stream corridors.**

Objectives

- *To ensure that environmental resources constraints are fully considered in establishing land use patterns in the watershed.*
- *To retain and preserve open space and visual amenities in urban and rural areas by establishing and maintaining greenbelts along stream corridors and adjacent natural areas.*
- *To ensure that development in down stream corridor is consistent with the historical and cultural character of the surroundings and fully reflects the need to protect visual amenities.*
- *To ensure that the recreational and fisheries potential of a stream corridor are developed to the fullest extent practicable.*
- *To maximize the use of creative and imaginative resources to rehabilitate and transform urban stream corridors, which through neglect may represent a source of urban decay and blight, into attractive community assets consistent with historical or other cultural amenities.*

- flooding,
- erosion,
- surface water quality,
- groundwater (quality and quantity),
- natural features (wetlands, ESAs, ANSIs),
- aquatic communities,
- recreation,
- aesthetics (water, valleyland),
- terrestrial (wildlife, woodlots), and
- ultimate receiving body (Great Lakes).

This list is not ranked. Rather, it reflects the historical evolution of watershed management within Ontario.

4.4 Examples of Environmental Issues

This section discusses a few of the key environmental issues for which water quality/environmental quality modelling may be required as a tool in developing a watershed or subwatershed management plan.

4.4.1 Water Balance

The change in the water balance due to urbanization is one of the most profound effects of urbanization. Urbanization increases flood flows, erosion potential (through the increased frequency of full-bank flow), and destroys fish habitat by widening channels and making them more shallow. Mitigating measures can ameliorate these effects to some degree.

Estimated changes in the water balance as a forested watershed urbanizes are given in Table 4.3. The example is used as a reference point in the Duffins Creek study. Depression storage and infiltration are reduced by 33% and 50% respectively, but the volume of runoff increases approximately an order of magnitude after urbanization. Implementation of infiltration

Table 4.3: Distribution of May to November Rainfall for Forested and Urban Areas.

Item	Forested Areas		Urban Areas with 40% Impervious Land			
	Depth (mm)	% Total Depth	No Infiltration		With Infiltration	
			Depth (mm)	% Total Depth	Depth (mm)	% Total Depth
May to November Rainfall	515	100	515	100	515	100
Interception Storage and Depression Storage on Impervious Areas	342	66.5	235	45	235	45
Infiltration	155	30	100	20	200	40
Runoff	18	3.5	180	35	80	15

devices can approximately double the degree of infiltration in urban areas. However, the volume of runoff is still approximately 400% larger compared to the forested condition.

4.4.2 Surface Water Quality

The two major sources of contaminated discharges to surface water quality from urban areas are water pollution control plants (WPCPs) and urban runoff. Typical concentrations of the parameters from the sources given in Table 4.4 often exceed water quality objectives. If natural stream processes do not significantly cause decreases in these discharged concentrations, urbanization requires mitigation for streams which fully drain urban watersheds, if instream water quality is to meet PWQO's.

Many water quality parameters may have to be considered. Traditional concerns have included biological oxygen demand, suspended solids, pathogenic bacteria, and nutrients.

Table 4.4: Comparison of Pollutant Concentrations to Provincial Water Quality Objectives.

Water Quality Parameter	Urban Runoff Concentrations (mg/L)	Sewage Treatment Plant Concentration (mg/L)	Provincial Water Quality Objective (mg/L)
Total Phosphorus	0.35	0.33	0.03
Total Copper	0.035	0.014	0.005
Lead	0.14	0.02	0.05
Fecal ¹ Coliforms	25,000 ¹	250	100

Notes: ¹ Fecal Coliform measurement is x counts/100 mL.

Recent concerns have increased the number of parameters to include:

- trace metals, and
- polynuclear aromatic hydrocarbons and other organics (pesticides, herbicides).

In addition, other effects of urbanization are not found in typical parameter lists. For example, spills of petroleum products are not normally detected in monitoring programs.

Tools for modelling a few water quality parameters are described below.

4.4.3 Wetlands

Factors to be considered include:

- buffer zone;
- alteration in hydrologic cycle (baseflow, fluctuation);
- alteration in groundwater cycle; and
- water quality.

4.4.4 Aquatic Communities

As a part of past watershed management studies, we have developed a conceptual model of the environmental requirements of indicator species of fish within the riverine watershed. Specific requirements for several habitats were synthesized from Habitat Suitability Index models and the general literature for a variety of aquatic communities.

Ecological objectives and the habitat requirements were developed for each of the following aquatic communities:

- i) a native cold-water fishery,
- ii) a self-sustaining cold-water fishery,
- iii) a non self-sustaining cold-water fishery,
- iv) a cool-water fishery,
- v) a warm water fishery, and
- vi) community composed of tolerant species.

These ecological objectives are stated in terms of a fishery but represent an ecosystem at the top of which a quality fishery is a key ecological niche.

An example of habitat factors and their general requirements for a native cold water fishery are the following:

Factor	Requirement
1. Stream order	1 - 3
2. Riparian canopy	> 80%
3. Groundwater	> 35%
4. Peak flows	Maintain historical peaks, volumes
5. Instream cover	Maintain historical cover
6. Stream morphology	Pools/riffles
7. Water quality	Turbidity (clear), dissolved oxygen (> 5 mg/L), and no spills
8. Stream temperature	< 20 degrees Celsius

4.4.5 Groundwater

Key factors to be considered at a watershed and subwatershed scale are:

- water quantity (supply rate for drinking water, water levels for wetlands); and
- water quality (for example, chlorides, nitrates).

At a site scale which is often the focus for public awareness of groundwater problems, the key factors are still both water quantity and water quality. But water quality parameters become site-specific, dependent upon the source of contamination (eg., landfills, industrial operations, etc.)

4.5 Watershed Analysis

This section presents examples of analyses at a watershed scale. The examples consider the impacts of urbanization upon water quality and water quantity.

4.5.1 Data Analysis

Prior to establishing the water quality model calibration, the PWQMN network data in the three watersheds have been analyzed using a locally-weighted time series technique. A typical graph is given in Figure 4.1 for total phosphorus. The dotted line evaluates seasonal effects, while the solid line represents the long-term trend. The advantage of the technique is that it can detect long-term trends in noisy data which are not spaced at equal time points. The results show that there has been a substantive improvement in water quality, due to previous phosphorus control efforts (removal of P from detergents, chemical precipitation in the WPCP). Such results can be used to document the success of past efforts where trends are detected and presented appropriately to the public. In addition the

Figure 4.1: Time and trend analysis for total phosphorous in Credit River.

Figure 4.2: Impact of urbanization on Copper using Monte Carlo simulation techniques.

analysis was used to establish a time period where the database is essentially stationary, and hence useful for calibrating a mass balance water quality model.

4.5.2 Mass Balance Model for Evaluating Water Quality and Water Quantity

The database usually available at a watershed scale are stream gauging stations from the Water Survey of Canada (with daily estimates of flow) and grab samples at approximately monthly intervals for water quality at stations in the Provincial Water Quality Monitoring Network (PWQMN). Inputs of water into the watershed in the form of precipitation are usually measured within the watershed or at a nearby location. Loadings of contaminants into surface waters and groundwaters can be estimated from all sources, but usually have not been measured for all sources.

Accordingly, the database available for calibrating a watershed model is much more extensive for flow-related issues than water quality-related issues. This is a major factor in defining the spatial resolution to be used in a model.

Simplified mass balance and water balance models have been used in watershed studies such as the Rouge River, the Don River and the Credit River recently.

For the Don River, the change in flow and loadings due to different size of events were used to estimate riverine concentrations for different flow conditions. Then the reductions in loadings due to different control measures were established and the resultant water quality calculated. An example of this approach is given in Table 4.5 for the whole Don River watershed for dry weather conditions and a 20 mm event. The water quality calculated for five control options were evaluated, and compared to "existing" water quality and "target" values. The loadings model was calibrated on a time-weighted basis with data from the PWQMN network to establish average annual conditions.

Table 4.5: Estimated response in Don River water quality for alternative control options.

Option	DRY CONDITIONS			20 mm EVENT		
	SS (mg/L)	Copper (mg/L)	FC (#/100 mL)	SS (mg/L)	Copper (mg/L)	FC (#/100 mL)
1. STP Upgrade	6	0.024	2000	235	0.033	22000
2. CSO 90% Removal	6	0.024	2000	231	0.030	10000
3. Urban Offline Wet Ponds	6	0.024	2000	62	0.021	20000
4. Urban Flow Control	6	0.024	2000	170	0.024	19000
5. All (2-4) with STP Removal	1	0.006	1000	33	0.010	5000
Existing	6	0.024	2000	235	0.033	22000
Target Value	200	0.005	100	200	0.005	100

The values for "existing" water quality given in Table 4.5 are those computed by the model for the respective meteorological conditions.

The calculations were used to assist in prioritizing the control options for developing a medium term (2-10 year) and long term (50 year) strategy for improving water quality in the Don River. The calculations were presented in a comparative sense because, except for bacteria, internal sources or sinks were not considered on the model. Hence, for example, instream erosion at high flows is not considered in the estimates of instream concentrations.

4.5.3 Uncertainty Analyses in Water Quality Models

After water quality data is determined, flow effects removed, and a stationary data string selected, there is still substantial variability in the dataset. To address such uncertainty, a Monte Carlo simulation technique was used in the Rouge River watershed study. An example of the results are given in Figure 4.2 for the effects of different degrees of urbanization on a particular subwatershed within the Rouge River.

The graph for existing conditions indicates that close to an order of magnitude range in water quality is computed. The effects of urbanization suggest that urban development of committed lands will have the largest effect upon copper

concentrations, with only small additional increases due to further infilling of the subwatershed.

4.6 Watershed or Subwatershed Scale Analysis: Evaluation of Factors in Fish Habitat Models

This is an example which can be applied at a watershed or subwatershed scale.

More detailed models were used to evaluate the effects of urbanization upon flow and temperature in the Rouge River watershed, two key factors in maintaining a quality fishery.

The habitat suitability index model was used to evaluate the effects of urbanization on the fishery. It is a semi-quantitative tool for assessing the relative importance of factors influencing fish habitat. All factors could be good, except one which is limiting. Key factors include:

- flow parameters,
- bottom characteristics (cobbles, etc.),
- temperature, and
- water quality (toxicity, dissolved oxygen).

The downstream reach of the Main Rouge River below the Milne Reservoir is a candidate stream for an ecological objective of rainbow trout. Three key habitat factors are water velocity, water depth, and water temperature (see Figure 4.3). Each factor is represented in the HSI model on a 0 to 1 scale, with 0 representing poor conditions, and 1 representing good conditions. Hence the graphs indicate the following optimum conditions: stream velocity between 0.5 and 2 fps; a water depth greater than 1.5 ft and a temperature between 55 and 70 °F. Since the HSI model is published in the United States, the graphs are not in SI units.

Calculated frequency curves (see Figure 4.4) indicate that small increases in the velocity are expected due to urbanization

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Coordinates	
x	y
0.00	0.81
0.50	1.00
2.00	1.00
2.46	0.02
2.95	0.02
3.44	0.01
3.50	0.00
100.00	0.00

Coordinates	
x	y
0.0	0.0
1.5	1.0
10.0	1.0
100.0	1.0

Coordinates	
x	y
0.0	0.0
32.0	0.0
55.4	1.0
70.0	1.0
84.2	0.0
100.0	0.0

Figure 4.3: SI curves for rainbow trout adult for water velocity, water depth and temperature.

Figure 4.4: Velocity-duration curve for stream velocity in Rouge River basin.

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for many conditions on an annual basis.

A river temperature model was used to compute temperatures downstream from the reservoir as a function of time of day. The calculations (see Figure 4.5) suggested that a daily temperature range from below 20°C to above 26°C was expected 4 km below the reservoir. This temperature range agreed with diurnal stream measurements during some of the hottest days in the summer providing some veracity to the model's calculations.

The effects of urbanization in the river section are shown as an imposed stream flow at distance 5 km and at 3 km. With the flows evaluated and assumed to enter at 23°C, the inflow streams have a small effect relative to the diurnal range. If it were assumed that the streams contained water at 30°C, there would be a larger effect added to the diurnal perturbation.

Hence these calculations show that the stream temperature in the section of the Rouge River accessible to rainbow trout from Lake Ontario are affected mainly by thermal conditions in the upstream reservoir and the daily heating cycle. Urbanization in upstream reaches does not affect temperatures entering the river section for the range of flows evaluated due to the thermal inertia of the reservoir. It compounds the effect in downstream reaches if water enters at much higher temperatures (say 30°C). In addition, velocity variations would not become a critical factor for the fishery relative to temperature.

Hence, the present stream temperatures preclude maintenance of a resident population of rainbow trout in the main stem of the river during summer months. Stream temperatures will be appropriate during spring or fall conditions - the stream temperatures found for a migratory population of rainbow trout - the current use made of this river section by these species.

Figure 4.5: Calculation of temperature vs. distance curves as a function of time of day.

4.7 Evaluation of Baseflow, Peak Flow and Water Quality in a Subwatershed

For a subwatershed analysis, an integrated approach was adopted using GIS linked to a hydrological model - water quality model. One key question of ultimate concern in the study was to evaluate whether a resident brook trout fishery could be maintained if urbanization with necessary protective measures occurred.

Hence, the hydrological water quality model requirements included:

- integrate groundwater flow with surface water flow where aquifers have a 10-20 years residence time;
- evaluate the annual water balance;
- evaluate peak flow characteristics;
- evaluate stream temperature and effects of canopy destruction; and
- evaluate water quality constituents.

The tools selected were:

- GIS system for display and linking data bases to hydrological model; and
- a model such as HSPF to evaluate baseflow, high flow, water balance, and water temperature.

The GIS system was used to establish the relative key factors affecting the cold water fishery. It showed that discharge from an aquifer intersected with the upstream end of brook trout habitat. This habitat was maintained downstream by the presence of a dense cedar canopy which protected the cold stream water from heating. It was then used to develop the data base for modelling present conditions and to provide a guide to additional monitoring needs for the model.

Figure 4.6: Application of GIS system to show relative location of aquifers; recharge and discharge zones, and brook trout habitat.

From this subwatershed scale study, the pertinent points include:

- more detailed analysis requires more quantitative tools;
- more monitoring data may be available or is required;
- more money may be spent;
- but still need to have general knowledge and descriptive field data, e.g., location of recharge areas.

4.8 Summary

The major area of application of this paper has been toward:

- integrated management planning; and
- assessment of urban impacts upon environmental quality at the watershed scale and subwatershed scale.

Three specific items emphasized are:

- i) Monitoring impacts modelling - ie. the amount and type of data effects the model and modelling approach selected.
- ii) Modelling is only a tool. Since a model is an abstraction of reality, its assumptions and calculations of the response of environmental quality to management actions must be interpreted and integrated into planning processes.
- iii) Complexity of the model. The complexity of the model selected will depend upon whether it is to be used for planning purposes in a relative sense, or for flood-flow forecasting purposes. For planning, relative answers are often sufficient, whereas for flood-flow forecasting, much more accuracy may be required.

These studies suggest the following considerations in terms of selecting tools and directions for future study.

1. Future directions in watershed and subwatershed studies include:
 - environmental quality monitoring and assessment together with integrated studies will be a major focus; and
 - monetary constraints are directing studies towards simplified approaches for overall watershed studies.
2. Monitoring improvements are needed to provide the data base for conducting modelling studies. This data base should maintain PWQMN in some form and create enhanced programs such as the following to address specific questions:
 - event monitoring;
 - additional parameters (PAHs in sediments, stormwater, etc);
 - soluble versus totals for metals;
 - toxicity testing; and
 - benthic community evaluation.
3. Auditing of watershed plans will probably use both monitoring and modelling to establish the effectiveness of plans in protecting environmental quality because the cost of monitoring to establish the effectiveness may be too onerous given environmental variability observed.
4. At best, modelling is only a tool in watershed management.

4.9 References

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