Rouge River Watershed

Scenario Modelling and Analysis Report

Chapter 3.0
Integrated Study Design

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INTEGRATED STUDY DESIGN

3.0 INTEGRATED STUDY DESIGN

3.1 Study questions

The scenario modelling and analysis study design was guided by the following questions, which arose from a review of the five primary watershed issues and opportunities noted in Chapter 2.0:

- **Urban growth:** How will different extents of urban growth affect watershed conditions? Can different forms of urban community design reduce the impacts? How would the protection of lands in the Greenbelt, Rouge Park, and as conceived in Markham's draft Small Streams study affect watershed conditions?
- **Natural cover:** What are the opportunities for expanding natural cover and how would expanded natural cover affect watershed conditions?
- **Stormwater management/retrofits:** How effective would retrofits of end-of-pipe stormwater management ponds be in addressing water management problems? What would be the cumulative effect of extensive and innovative lot level, conveyance and end-of-pipe stormwater management practices in new Greenfield developments and retrofits in existing urban communities?
- **Sustainable practices:** What would be the cumulative effect of a range of sustainable practices on watershed conditions, if implemented throughout the watershed?
- **Climate change:** How will climate change affect watershed conditions? Can the adoption of sustainable practices mitigate these effects?

Current watershed conditions were defined in the *Rouge River State of the Watershed Report* (TRCA, 2007) according to a set of indicators and targets of health associated with goals and objectives for surface water quantity and quality, groundwater, aquatic and terrestrial systems, cultural heritage and nature-based recreation. This information provided a basis from which to assess the significance and acceptability of how anticipated future stresses and management options may affect conditions. A first step, though, involved the further definition of these potential futures.

3.2 Land Use and Management - Scenarios

<u>Scenario Selection</u>

This study formulated a series of land use and management scenarios to depict the possible futures contemplated in the study questions. The scenarios thereby provided a common basis from which to model/predict and evaluate the watershed's response for a range of ecosystem indicators.

Although achievement of the watershed goals and objectives guided the choice of assumed management approaches, more emphasis was placed on building the scenarios from the "bottom up" (i.e. describing likely future land uses and reasonable assumptions of practice) rather than "back-casting" from the objectives back to the required set of actions. It was recognized that the results of a "best possible effort" scenario would have to be strengthened even further if it proved to fall short of the objectives, and/or could indicate areas where less effort may be adequate if it surpassed the objectives.

Five main issues/opportunities were identified in a conceptual framework for the development of scenarios (See Table 3-1). The first column represents issues (e.g. urban growth, climate change, etc.) and the second column shows a conceptual gradation of options in the level of effort, time to implement etc. Any given scenario could include varying degrees of effort for each issue, potentially resulting in numerous combinations and an endless list of scenarios.

Table 3-1: Conceptual Framework for Development of Scenarios

Key issue/opportunity	Increasing time, level of effort--------→
Urban growth	Current-----------→Approved OP--------------→ Full build out
Development design	Current---→ "Sustainable"
Natural cover	Current--------------------------------→expanded, mature cover
Stormwater retrofit	Current --→End of pipe retrofit--→full treatment train retrofit
Climate	Current---------------→climate change 2050-----------→2080 (wetter/drier)

The challenge was to establish a "reasonable" number of distinctive scenarios. Considerations included:

- Available budget would likely support 5-6 main scenarios, with perhaps 2-3 additional, minor variations;
- Scenarios should be discrete enough, such that the primary factors causing change can be distinguished;
- Model capabilities – differences in assumptions between scenarios should be detectable within the bounds of the model's sensitivity;
- Data must be available to reasonably define the scenario in defensible, modellable terms

Eight experimental scenarios were ultimately defined with input from all members of the technical team, municipal staff representatives, and the multi-stakeholder Task Force (See Table 3-2). The scenarios take the form of a mapped delineation of future land cover and a description of assumptions, quantified to the extent possible in modellable terms. A land cover map and detailed description of the assumptions for each is documented in Appendix A.

The set of scenarios represents an urban development continuum ranging from baseline conditions that existed in 2002 where 35% of the total watershed area is urban to implementation of the approved municipal Official Plans, which represents about 47% urban cover. A potential full build out of the watershed on all remaining lands not protected by existing municipal, provincial or federal policy or through public ownership assumes that up to 55% of the watershed would become urban. Environmental measures such as expanded natural cover (from the current 24% to over 31% of the watershed), better stormwater management, and alternative “sustainable” community design were superimposed on these basic situations. All scenarios were examined under existing climate conditions, with the exception of the full build out and sustainable community scenarios that were also examined under potential future climates predicted for the 2080 period.

Table 3-2: Rouge River Watershed Scenarios

No.	Name	Description	Rationale
1	**Baseline conditions (2002)**	Watershed conditions that existed in 2002.	Baseline for comparison.
2	**Official plan (OP) build-out**	Official plans completed with current stormwater management practices and Ontario Realty Corporation (ORC) land transferred to TRCA to be managed as part of Rouge Park.	Evaluate the effect of approved and adopted OP completion.
3	**End-of-pipe stormwater retrofit**	Scenario 2 plus implementation of ‘905' municipalities’ end-of-pipe stormwater retrofit plans.	Evaluate the effect of end-of-pipe stormwater retrofit on approved and adopted OP completion.
4	**Expanded natural cover**	Scenario 2 plus implementation of the (1) TRCA Terrestrial Natural Heritage Strategy and (2) the draft ecological corridor for the Little Rouge Management Plan for the Ontario Realty Corporation lands north of Steeles Avenue.	Evaluate the effect of increased natural cover on approved and adopted OP completion.
5	**End-of-pipe stormwater retrofit and expanded natural cover**	Scenarios 2, 3 and 4 combined.	Evaluate the effect of end-of-pipe stormwater retrofit and increased natural cover on approved and adopted OP completion.
6	**Full build-out**	Scenario 2 (OP build out) plus development of all available areas to boundaries of the Oak Ridges Moraine Protection and Greenbelt Plan Areas, including current stormwater management practices in developing areas.	Evaluate effect of full development of the Rouge Watershed.
7	**Sustainable community** programs in new and existing developments	Scenarios 5 and 6 plus more intensive implementation of sustainable community initiatives, including expanded natural cover, more sustainable designs in new developments, delineation and protection of Rouge Park North corridors, and improved stormwater management practices in new and existing developments with emphasis on lot level measures.	Evaluate the effect of sustainable community design and enhanced stormwater management on complete development.
8a	**Climate change**:	Scenario 6 with a predicted 2080 period climate (CGCM), which is 5°C warmer and	Evaluate impact of climate change on complete

No.	Name	Description	Rationale
	Full build-out with warmer wetter climate	6% wetter than recent average annual conditions	development
8b	**Climate change:** Full build-out with warmer much wetter climate	Scenario 6 with a predicted 2080 period climate (Hadley) which is 7°C warmer and 19% wetter than recent average annual conditions.	Evaluate impact of climate change on complete development.
8c	**Climate change**: Sustainable community with warmer wetter climate	Scenario 7 with a predicted 2080 period climate (CGCM) which is 5°C warmer and 6% wetter than recent average annual conditions	Evaluate impact of climate change on complete development with sustainable communities programs implemented
8d	**Climate change**: Sustainable community with warmer much wetter climate	Scenario 7 with a predicted 2080 period climate (Hadley) which is 7°C warmer and 19% wetter than recent average annual conditions.	Evaluate impact of climate change on complete development with sustainable communities programs implemented

Scenario Interpretation

All scenarios were conceived to be equilibrium conditions that would exist when all development or management implementation assumed in the scenario had been completed. Thus, the study did not attempt to consider all the transitional stages that might occur in reaching the final state. For example, in the expanded natural cover scenarios, mature forest cover was assumed. In the urban growth scenarios, erosion and sediment control impacts associated with the construction phase were not addressed in this modelling approach (these issues are however addressed in the watershed plan). Development has tended to move steadily north across the face of the watershed over time, and therefore while these scenarios represent a development continuum they also contain some information about the temporal and spatial continuum. For example, the official plan scenario can be thought of as an intermediate stage in the full development scenario.

The greatest value of scenario modelling results arise when the results are compared to one another, rather than using the models to attempt to predict actual future conditions. A relative comparison is conducive to the study design, which involved a selection of representative scenarios along a general continuum of management effort. This approach avoided the need to model an infinite number of scenarios and assumed that the final set of management strategies would be drawn from elements of the various scenarios and the information their modelling revealed. Relative comparison is also a way to address any concerns associated with uncertainties in the modelling predictions, in that much of the potential error inherent in modelling would be common to all scenario results.

Modelling and consideration of alternative futures among members of the interdisciplinary technical team and other study participants required that a clear understanding and common description of the scenario be provided, including implicit and explicit assumptions. Therefore the documentation of these assumptions in Appendix A was an important aspect of this work.

Broader Role of Scenario Analysis

In addition to providing technical input during the study, the scenario modelling results can be used to serve broader roles in support of the watershed plan's implementation:

- Motivate action – demonstrate what will happen to the watershed if limited or no actions are taken
- Describe potential future vision – predict likely watershed conditions if certain actions recommended by the plan are implemented
- Compare the vision with outcomes of scenarios showing what will happen if only some of the actions are implemented
- Compare issues, needs, benefits for different subwatersheds
- Scenarios themselves provide a tool for fostering discussion about possible implementation barriers and solutions of various strategies
- Establish a basis for priority setting and phasing of actions

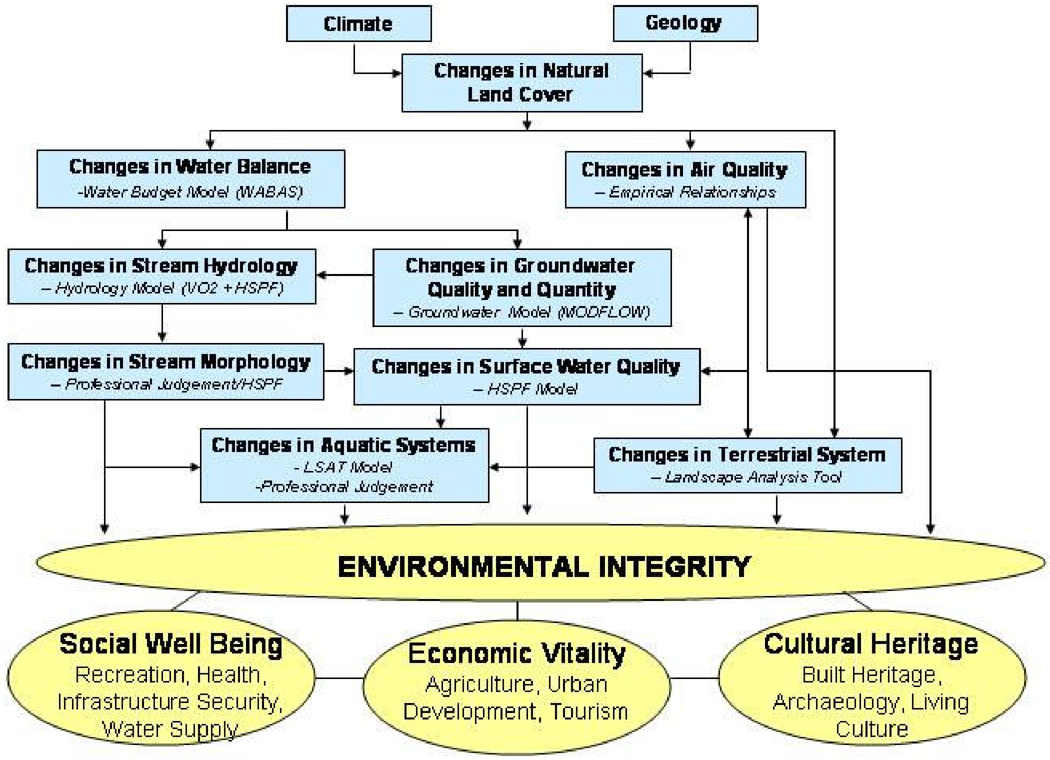
3.3 Predictive Modelling and Analysis Tools

Overall Modelling Framework

The Watershed Response Model (Figure 3-1) is being used by TRCA as an overall guide to analyse the watershed's response to the future scenarios. The Model illustrates the pathways and sequential order in which changes in individual watershed systems occur in response to changes in land cover, climate or management practices. Predictive modelling tools have been identified to evaluate each individual watershed system. Through coordination among technical team members, common measures have been identified for evaluating interdependencies between systems and have ensured that the output data requirements of one model meet the input requirements of the next model in sequence (i.e. units, time scale, etc.) and/or that appropriate translations can occur.

TRCA adapted the watershed response model from an initial model developed by Snodgrass *et al.* (1996), which focused on impacts on aquatic ecosystems, and on later adaptations of that work by Credit Valley Conservation (CVC, 2003 and 2007). TRCA used the adapted model in its Duffins Creek Watershed Plan (2003) and is attempting to build upon that work in the Rouge River watershed study by improving the sophistication of the aquatic and terrestrial predictive tools over previous efforts.

Figure 3-1: Rouge Watershed Response Model and Predictive Tools



The Watershed Response Model begins to illustrate the scientific complexity and challenges of undertaking the integrated, multi-objective analysis that is a necessary basis for sustainable watershed management. The ability to understand and quantify relationships between human and natural systems and the availability of tools to simulate these relationships and allow predictions of change varies from one discipline to another (Snodgrass *et al.*, 1996). By extension, there is no one computerized model, or “decision support system”, capable of predicting all of the effects of a given scenario on all of the various watershed systems.

Although the trend in water resources planning, if not also in other forms of planning, is toward the consideration of broadened spatial and temporal scales, multiple objectives, data sharing, and virtual simulation approaches, the tools available to support this are limited at present (e.g. Simonovic, 1996; Werick, approx. 2005). The use of single model decision support systems or “shared vision models”[1] appear to be limited in application to more narrowly defined projects, such as water level regulatory planning or environmental assessment type projects which evaluate discrete alternative solutions to a specific problem (e.g. International Lake Ontario – St. Lawrence River Study Board, 2004, Werick and Palmer, approx. 2005).

[1] Shared vision model is a single computer model of the system being studied that decision makers, experts and stakeholders all use to test new management ideas and investments (Werick and Palmer, approx. 2005 – specific date unknown)

In a brief review of other related scenario modelling efforts, the study team noted use of a regional scale computer simulation tool, QUEST, used to evaluate growth scenarios against sustainable regional visions (www.envisiontools.com/questsite). However, this model was not capable of modelling the natural systems of the watershed to the degree of sensitivity desired for the current undertaking. Other innovative scenario modelling studies such as those focussed on stormwater retrofit schemes and conventional and "low impact" development concepts, have largely focused their analysis on effects within one system (i.e. surface water hydrology) by using models such as HSP-F and GAWSER (e.g. City of Toronto, 2003; Conservation Design Forum, 2003; Zimmer *et al.*, 2005). Neighbouring conservation authorities who have been undertaking urban growth and management scenario modelling concurrently with this study have employed a suite of models to address various water and natural heritage objectives (e.g. LSRCA and NVCA, 2006; CVC, 2007).

Considering the current state of practice in decision support tools, the Rouge River watershed modelling study team believed the most robust approach to scenario analysis could be achieved by adopting well-respected, specialized models or other predictive methods for each individual system, many of which were already established for the watershed, thus allowing team members to focus their efforts on reconciling the model inputs and outputs and interpretation of results.

Predictive Tools and Their Linkages

These predictive tools within the overall Watershed Response Model framework include a combination of computerized mathematical models, empirical relationships and professional judgement. The individual tools are identified according to each watershed system as follows:

- Surface water balance - WABAS (Water Balance Analysis System) – a distributed continuous water budget model;
- Surface water hydrology and water quality - HSP-F (Hydrological Simulation Program – Fortran) – a continuous hydrologic model with water quality simulation capabilities;
- Groundwater - MODFLOW (Modular Flow System – Fortran) – a three-dimensional finite difference numerical groundwater flow model;
- Aquatic system - LSAT (Landscape Stream Assessment Tool) – an aquatic community predictive model based on established relationships between land cover and habitat/species;
- Terrestrial system – TRCA's Landscape Analysis Model and Terrestrial Natural Heritage System Design Tool - GIS based terrestrial natural heritage models based on principles of landscape ecology;
- Cultural Heritage – TRCA's probability model for archaeological site potential and professional judgement;

- Nature-based Recreation - Professional judgement and literature.

A detailed description of each predictive tool and its set up and calibration for this study is provided in the relevant section within Chapter 4.0. During the process of coordinating the various models and predictive tools, a number of technical considerations were incorporated to facilitate the synthesis and comparison of output:

- Standardization of data sets: where applicable, consistent input data such as base mapping and land use information were used.
- Common reporting units: consistent model output areas, locations and nomenclature were used.
- Consideration of temporal scale: annual or seasonal averages were used to reconcile continuous model results with steady-state modelling or predictions.
- Compatibility of model assumptions: wherever possible, consistent assumptions were clearly defined in terms relevant to all applicable models and predictive tools. Where differing assumptions were used this was considered in the analysis of model output.
- Recognition of model purpose and differences in computational routines: it was recognized that results from different models may not be directly compatible due to variations in input data, model accuracy, model specialization, and computational approach.
- Visualization of outputs: some modelling tools generate more intuitive and graphical output than others which required a manual process of data presentation using GIS or other means
- Realization of model limitations: in many cases model output was limited with respect to the spatial and temporal detail that could be provided, as a result of the quality of the input or calibration data, or practical restrictions on model resolution. Model output was verified through review of applicable literature and/or empirical data to confirm that simulated outcomes were consistent with current scientific knowledge.

Lam *et al.* (2003) encountered similar technical factors in their development of a technical user interface to link multiple models. The linking of models to facilitate integrated studies is an area that requires further guidance to assist future studies.

The water-related models were interconnected in that much of the same input data was used and many of the same output parameters were calculated by each. However, as noted above it was important to consider the purpose and accuracy of each model in determining appropriate applications and use of output from each model. For example, HSP-F can generate estimations of the amount of precipitation that infiltrates and provides recharge to the groundwater system, and MODFLOW requires an external application to calculate recharge volumes in order to conduct groundwater simulations. However, the Rouge River HSP-F model adapted for the analysis was originally developed for the City of Toronto to model surface flow and water quality from urban land change and was not intended or designed to estimate groundwater recharge. As a result, while the resolution of recharge estimates was sufficient to provide an accurate depiction of surface flow and water quality throughout the Rouge River watershed for the purposes of the current study, it was not sufficient to conduct complex modelling of the groundwater system using MODFLOW. To address this issue, a WABAS water budget model was developed to specifically provide recharge input data of the type and resolutions required for the MODFLOW model. While this could potentially have been achieved by modifying the HSP-F model, it would have required significantly more time and effort than developing the much less complex WABAS model and would not have appreciably improved the quality of surface flow and water quality output for which the HSP-F model was intended. Further, the simplicity of the WABAS model allowed for faster calibration in conjunction with the calibration of the MODFLOW model. To ensure consistency, care was taken to ensure that the WABAS and HSP-F models utilized similar meteorological input data and compatible assumptions regarding changes to land use and management action associated with each of the modelled scenarios.

The interrelationships between water models also provided additional insight regarding the behaviour of the complete hydrologic system of the Rouge River watershed, and resulted in improvements to the accuracy of both the surface water and groundwater models. For example, the surface water modelling team did not initially have calibrated output from the groundwater modelling team and so their model did not account for a significant recharge zone north of the surface watershed boundary. The result was that the surface water model required more infiltration on the flanks of the Oak Ridges Moraine to replace the “missing” water from the north, which improved the calibration of the HSP-F model (Ford and Ness, 2006).

Facilitation of a linked modelling approach, or at least an interdisciplinary analysis of modelling results, provides a more accurate and robust approach at establishing defensible watershed science as a basis for decision-making. In the modelling of hydrologic systems, groundwater and surface water modelling studies have typically been conducted in isolation. Coordinated surface and groundwater modelling allows for recognition of interrelated processes that might not have been otherwise considered, and that are usually addressed through acceptance of calibration error or ‘black box’ arbitrary adjustments to model parameters to achieve sensible results. However, with separate surface and groundwater models the process of integration requires manual transfer of information between disciplines which practically limits the degree to which model congruence can be achieved. Fully-coupled hydrologic modelling applications, which integrate surface and groundwater processes to simulate the entire land-based hydrologic cycle, are currently being developed to address this issue. Although complex and potentially time-consuming to develop, fully-coupled models should be considered in future multi-disciplinary watershed analyses where a complete understanding of the hydrologic cycle is required.

3.4 Analysis and Evaluation

Scenario analysis represents one input to the overall determination of the preferred set of management strategies for the Rouge River watershed. Therefore, the process of scenario analysis and evaluation must be distinguished from the subsequent process of watershed plan development.

Scenario analysis and evaluation

The primary criterion for evaluating the watershed's response to each of the future scenarios was:

- *the ability for watershed conditions to meet defined watershed management targets*

A framework of indicators and targets of watershed health associated with goals and objectives for surface water quantity and quality, groundwater, aquatic and terrestrial systems, cultural heritage and nature-based recreation was presented in the *Rouge River State of the Watershed Report* (TRCA, 2007). This information provided a basis from which to assess the significance and acceptability of how anticipated future stresses and management options may affect conditions. Indicators provide a useful means of summarizing complex information into understandable, relevant terms, and therefore they have also been widely used by TRCA and other jurisdictions for state-of-the-environment reporting (e.g. Conservation Ontario, 2003). TRCA adheres to a standard reporting framework as defined in Table 3-3.

Table 3-3: Reporting Framework Definitions

Goal	A desired outcome or endpoint.
Objective	A general statement of intended management approach and directions.
Indicator	A fact or device that provides specific information about the objective of interest.
Measure	Quantitative or qualitative ways to measure the state of the indicator.
Target	A numerical threshold or directional aim, associated with a measure, and chosen as the minimum (or maximum) state necessary to achieve the desired objective.

Not all watershed indicators were capable of being "modelled" quantitatively, or in some cases they were not able to be assessed in terms of scenario effects as they represented information that was beyond the scope of assumptions contained in each scenario. The subset of indicators used as a focus for the scenario analysis is shown in Table 3-4. This set was expected to provide a reasonable indication of the overall effects of each scenario across a representative range of watershed concerns.

Table 3-4: Indicators Used in Rouge River Watershed Scenario Analysis

Theme	Indicators
Surface Water Quantity	Variablity of stream flow Flooding and flood risk (peak flow, flood vulnerable areas) Erosion and erosion potential (erosion index) Baseflow and surface water withdrawls
Surface Water Quality	Total suspended solids Nutrients Lead and heavy metals Bacteria

Theme	Indicators
	Chloride Organic contaminants
Groundwater	Recharge Aquifer water levels Groundwater discharge Water balance
Aquatic System	Fish community
Terrestrial System	Quantity of natural cover Quality of natural cover Quality of distribution of natural cover
Cultural Heritage	Known archaeological sites Potential or undiscovered archaeological sites Listed or designated built heritage properties Living culture of the 21st century
Nature-based Recreation	Variety of uses and experiences Access to greenspace Trail network and its connectivity

In addition to a comparison to targets, undertaken within each disciplinary team, the watershed's response to each scenario was analysed according to other "integrated" considerations:

- *effect of the action(s) on overall watershed health (e.g. length of stream channel affected)*
- *effects beyond the Rouge River watershed*
- *significance of the action to critical targets (e.g. health risk? critical ecological function?)*
- *number of targets met by a given action*
- *short term vs. long term effects*

This integrated analysis was undertaken within each discipline and in technical team "integration workshops", which were held on several occasions as results became available. This approach involved a combination of quantitative and qualitative based observations. The overall scenario analyses were summarized in a set of "management considerations" which were presented to the Rouge Watershed Task Force for further consideration in the development of the watershed plan.

Development of Preferred Management Strategies

The scenario modelling results, as summarized in this report, provided just one source of information to the Rouge Watershed Task Force in the development of its preferred set of management strategies for inclusion in the final watershed plan. Additional technical information and implementation considerations were drawn from other background references, workshops (e.g. "management summits") and studies, conducted concurrently with this modelling work. All of the background information was reviewed and discussed by the Task Force during collaborative meetings and workshops that arrived at consensus on a final set of recommendations. These recommendations found in the final Watershed Plan (TRCA, 2007) are in keeping with

Task Force Principles and comprehensively address the full set of Rouge River watershed goals and objectives.

3.5 Watershed and Subwatershed Units

The Rouge River watershed can be described in terms of five major constituent subwatersheds: the Upper Rouge/Beaver Creek; Middle Rouge Tributaries including Berczy Creek, Bruce Creek, Eckardt Creek, Robinson Creek and the Middle Rouge River; Little Rouge River; Morningside Creek; and the Lower Rouge River and Rouge Marsh (see Figure 3-2). These subwatershed units are referred to in this report for consistency in the presentation and discussion of modelling results.

Figure 3-2: Subwatershed Units

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