ANALYTICAL HYDROLOGICAL MODELLING OF GREEN ROOF TECHNOLOGY ON A WATERSHED BASIS

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Analytical Hydrological Modelling of Green Roof Technology on a Watershed Basis

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Abstract

Urban stormwater design usually involves a continuous simulation model (CSM). A CSM can determine numerous scenarios and outputs implementing best management practices (BMP). Green roof technology has recently emerged as a BMP. Although a CSM is accurate, an alternative type of model can be used for preliminary planning stages. Based on statistics, analytical modelling does not involve complex computer simulations and is appropriate at planning stages. This applied study calibrated an analytical model using outputs from a CSM created for the Highland Creek watershed in Southern Ontario. The analytical model predicted total runoff volume and runoff volume reduction (from green roof technology) within 0.6-6% and 4-8% respectively. Runoff reduction from other research has been found in the range of 1-12%. Analytical tools combined with the Unit Response Function (URF) method can easily be changed for any watershed and highlights the usefulness for predicting runoff on a volumetric basis for watersheds.

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Table of Contents

List of Tables

List of Figures

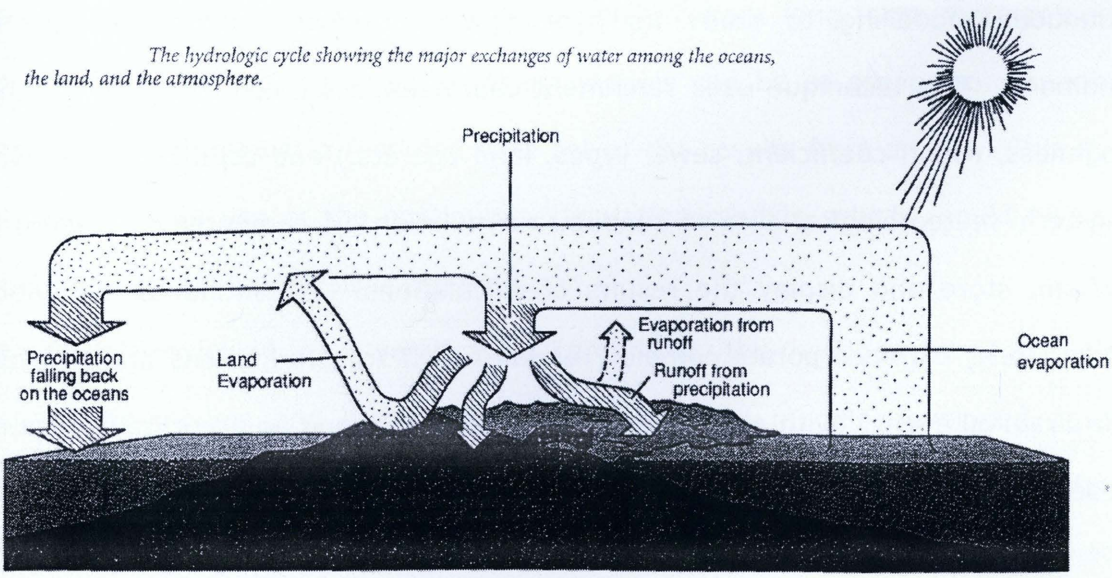
List of Appendices

CHAPTER 1

1.0 INTRODUCTION

Urbanization of city centres has drastically modified the movement characteristics of water within city boundaries. This movement of water on a larger scale is known as the hydrologic cycle. The basic components of the hydrological cycle include precipitation, evaporation, evapotranspiration, infiltration, overland flow, stream flow and ground water flow (Bedient & Huber, 2008). The various components can be spatial and temporally erratic, resulting to extremes that may lead to flooding and drought. Figure 1-1 show the components of the hydrological cycle. Within urban areas, the components of infiltration and overland flow are the most affected. Precipitation is converted to overland flow or runoff and termed 'stormwater' when outlining urban problems. Analysis of the hydrological cycle, specifically in urban systems is necessary for the protection of society and the environment from events such as flooding, erosion and water pollution.

Figure 1-1: Hydrological Cycle (Marsh & Grossa, 1996)



Stormwater conveyance systems were first observed and studied in 1852, when Roe published a table of observations of London sewers (as cited in Adams & Papa, 2000). Early drainage system design focused on estimating and predicting the peak discharge of an event. The Rational method was one of the earlier adopted methods for calculating peak discharge. Also known as the Lloyd-Davies method in the United Kingdom, the Rational method was the first to include the variable of rainfall frequency in the prediction of peak flow and greatly aided the design of culverts (as cited in ASCE, 1992). However, the rational formula did not provide the 'shape' or the instantaneous volume vs. time during the storm water event (known as a hydrograph). A new unit hydrograph method, advanced by Sherman in 1932 (as cited in Guo, 1998), was proposed to overcome this shortcoming. This method attempts to relate both the peak discharge and the volume of the total runoff to storm characteristics. Additional meteorological, geographical and economic inputs have been factored into the development of other models. To fully characterize the hydrological cycle of a drainage system, designers today use continuous modelling to study its hydrological response under a variety of conditions. This technique uses catchment characteristics (such as slope, channel roughness, runoff coefficient, sewer types, land use etc.) and combines them with long-term meteorological data to conduct a simulation. A computer is required to perform, store and display the results of calculations. A continuous simulation model (CSM) can incorporate complex rainfall-runoff transformations and map the entire rainfall event. With a long history of rainfall data and an accurate simulation model, the results can be accurate to within 5% (Adams & Papa, 2000).

Several stages during urban development do not require the accuracy of a complex analysis tool, such as a CSM. There are different needs from designers and planners at different stages of urban drainage design. During the earlier planning, screening and preliminary phases, limited details are available with which to design a complete system. Although most decision makers want to have solid scientific and mathematical assurances, a continuous model based on assumptions that may change later is not beneficial. Further, continuous simulation modelling can introduce excessive costs and delays to the early design stages, being relatively cumbersome and time consuming due to the data gathering, synthesis and the model creation required. The learning curves for some modelling packages can be steep. The preliminary phases of system design are meant to be relatively short and would benefit from a simpler method or model.

Analytically-derived models and tools can be used as alternatives to continuous simulation modelling. Analytically derived models have evolved such that they offer ease and flexibility while considering long-term meteorology (Smith, 1980). This type of modelling is based on statistics derived from long-term meteorological inputs. Although lacking in detail, these models can be of great use, especially when calibrated against a recorded data set or the results from a CSM. This does not preclude the use of the continuous simulation models, which should be used when more detailed analysis is required.

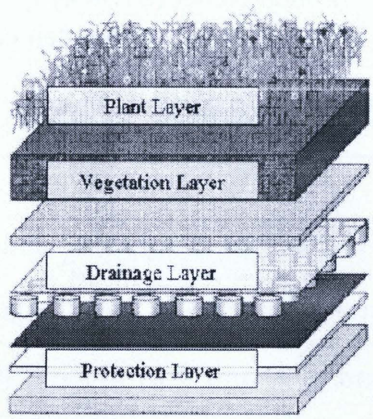
Papa (1997) reviewed the theoretical background for the development of analytical probabilistic models and highlighted the more useful models developed at the University of Toronto. Adams and Papa (2000) published a reference textbook outlining the development and use of analytical models for storm water management planning. Guo (1998) continued this research and further enhanced the analytical models to account for additional parameters such as infiltration (water seepage into the soil) and depression storage (water ponded on natural land surfaces). Since the most important components of the hydrological cycle for urban applications is runoff (overland flow), the analytical methods by Adams and Papa (2000) and Guo (1998) do not provide models for stream flow and ground water flow. A comparison of CSM and analytical models for urban stormwater applications is shown in Table 1-1. The analytical models developed from the researchers at the University of Toronto show promise as planning tools.

Table 1-1: Comparison of CSM and Analytical Models

	Continuous Simulation Models	Analytical Models
Representation of Catchment or Watershed	Simple to complex Can capture very specific characteristics	Simple, may not capture specific characteristics
Inputs	Complex, variable Rainfall, antecedent conditions, soil conditions, evaporation, evapotranspiration, depression storage, reservoir storage, runoff coefficient, slope, infiltration, stream/ground water flow	Simple, uniform and/or area-averaged Uniform rainfall, depression storage, runoff coefficient infiltration
Outputs	Single or time series response Runoff volume, combined sewer overflow events, water quality	Single event response Runoff volume, combined sewer overflow events, water quality
Resources	Usually computerized	Not necessarily computerized
Usage	Detailed design, engineering Provides specific response characteristics	Planning, preliminary Provides average values of long term performance
Water Routing Mechanics	Yes	No
Example Models	HSP-F Storage, Treatment and Overflow Runoff Model (STORM) US EPA Storm Water Management Model (SWMM) Quantity-Quantity Simulator (QQS)	Adams and Papa (2000) Guo (1998)

The ultimate purpose of these models is to simulate different scenarios to determine the best outcomes for design problems. Within urban areas, the components of infiltration and overland flow are the most affected. In the case of urban drainage systems, green roof technology was recently identified as a potential control measure to reduce storm water impacts. Green roof technology has been identified as a storm water best management practice (BMP) along with other traditional methods (Banting et al., 2005). A green roof is a roof covered with a layer of soil, subsurface matrix and selective vegetation, having various terms such as eco-roof, nature roof or living roof (Perry, 2003). Application of green roof technology is typically only feasible in an urban setting. The sloped and often widely dispersed roofs of rural areas do not make the implementation cost effective. Two main types of green roofs have been illustrated in the literature: intensive and extensive. Intensive green roofs can involve manicured lawns, shrubs, trees, flowers and usually have deeper soil material. They typically require ongoing maintenance and in some cases are expensive and impractical (Perry, 2003). Extensive green roofs include ground cover plants, a thinner soil layer and reduced maintenance costs. Extensive green roofs can be installed on roofs with slopes of up to 40 degrees (Gedge & Kadas, 2005). Current literature and development focuses on the extensive green roof type (Perry, 2003).

Figure 1-2: Layers of a Green Roof (Moran et al., 2003)



Research and pilot studies have analyzed the hydrological benefits of green roofs (Complete discussion provided in Chapter 2). Studies show that the conversion of a roof space into a pervious area can both reduce the quantity and improve the quality of the storm runoff. Liesecke (1998) showed that a green roof with a media depth of 2-4 cm can retain 40 to 45% of the annual rainfall. Li (2006) showed that green roofs have the ability to intercept, store and retain moderate and small storm events. Similarly, according to Moran et al. (2003) and Rowe et al. (2003), green roofs can retain up to 100% of the rainfall volume depending on the volume, intensity and duration. Several of the reviewed studies were performed in Europe, where research and implementation of green roofs is more mature than in North America (Banting et al., 2005).

In 1997, the City of Toronto initiated the development of a Wet Weather Flow Management Master Plan (WWFMMP) (City of Toronto, 2003). The main problem that initiated the plan was the degradation of the City's watersheds and near-shore zone of Lake Ontario. The project goals were to develop a strategy to manage wet weather flow on a watershed basis, to improve the health of Toronto's watercourses, and to enhance the natural environment. The WWFMMP also gave support to the implementation and use of green roof technology (City of Toronto, 2003). In support of this initiative, the Toronto and Region Conservation Authority (TRCA) retained a consultant to develop a "Hydrological Simulation Program—Fortran" (HSP-F) model and a "Unit Response Function" (URF) model in 2004 (Banerjee, 2004). The HSP-F model is a continuous simulation model. The URF model is a simplified model, relating the rainfall to runoff transformation to parcels of land and their corresponding land use. The URF model also incorporates land use types assuming the implementation of green roof technology which was based on the York University green roof monitoring program undertaken by the TRCA in 2003-2004 (TRCA, 2006). The HSP-F and URF models were developed and calibrated using meteorological data, based on a hydrological response of a 10 ha test catchment. Eligible green roof area was assumed to be 75% pervious (green roof) and 25% impervious (roof). The HSP-F model was calibrated for the Highland Creek and used to estimate the runoff reduction and peak flow reduction of implementing green roof technology (Banerjee, 2004; Maunder, 2004).

Another CSM was created with the Quantity-Quality Simulation (QQS) model used to predict the total annual combined sewer overflow (CSO) of several watersheds in the GTA (Li, 2007). An analytical model, the Sustainable Urban Drainage System (SUDS) model was calibrated to the QQS model to predict CSO events and cost savings (Li, 2007). The number of research studies is still somewhat limited on the overall effect of green roof technology on a watershed basis. Results from these watershed-wide studies have shown that benefits are more modest when compared to individual green roofs. Since predicting the impact of green roof technology on a watershed basis is impractical to study on an experimental or laboratory basis, modelling tools and methods must be used.

An established analytical model to predict the runoff reduction resulting from the implementation of green roof technology on a watershed basis would greatly benefit the planning and preliminary stages of urban stormwater management systems. Currently, the existing green roof projects in North America are isolated, single building efforts within large urban areas. One or two buildings in a watershed will have a small effect. If planners are able to determine the benefits of green roofs under different scenarios, cities, regions and municipalities may be able to enact policies to encourage the use of green roofs. The development of green roofs across an urban centre will have a more dramatic effect.

The analytical model is simple to use and has the ability to predict annual total runoff volume over an entire watershed. Although such a model still requires data collection per watershed, the calculations are easy to reproduce and based on well-known methods of statistical analysis. If the results are demonstrated to be reasonable the model could be considered successful. Hydrological models should be calibrated using observed data or post-calibrated data to increase the confidence of the model results (Au, 2007). The HSP-F model developed for the Highland Creek watershed provides a solid foundation for calibrating the analytical model presented by Adams & Papa (2000), thereby creating a simple, powerful tool by which to assess the impact of green roof technology in storm water management on a watershed basis.

1.1 Objectives

Important parameters for urban drainage systems are total runoff volume and peak discharge. These parameters can be positively affected using green roof technology, but requires scientific predictions on a watershed basis. Although green roofs have generated increased interest and research, many of the studies have focused on the micro effects of individual green roofs. Some modelling has been performed on the hydrological benefits of green roof technology; however, research has focused on using a CSM to determine the benefits. Using models suitable for planning or preliminary design not been intensively investigated. This applied study has the following goals:

- Develop a watershed modelling approach for green roofs using analytical probabilistic models

- Calibrate an analytical probabilistic model using the results from a continuous model and obtain reasonable agreement (within 10 to 15%);
- Estimate the total runoff volume, runoff volume reduction and peak flow reduction within a watershed from the use of green roof technology;

1.2 Scope

The objective is a quantitative analysis and model development to predict hydrological benefits of green roof technologies on a watershed basis. Runoff control systems are designed based on the single event total runoff volume, rather than time dependant outputs (Adams & Papa, 2000). The scope of this research study is:

- To apply the probabilistic analytical model developed by Adams and Papa (2000) and Guo (1998)
- To focus on a specific case study, such as the data and models developed for the Highland Creek watersheds
- To focus on three (3) parameters of interest in a hydrologic system, total runoff volume, peak flow and total runoff volume reduction.

1.3 Organization of Thesis

The thesis is comprised of five chapters. Chapter 1 provided an introduction to urban drainage systems, analytical models and green roofs. The research needs, objectives, case studies and scope concluded Chapter 1. Chapter 2 expands on certain introductory elements, explores current and past research and forms the literature review of the thesis study. The theories and methodologies used to complete the objectives are outlined in Chapter 3. This chapter develops and provides details of the analytical model and explains how model calibration was completed. Chapter 4 outlines the Highland Creek case study where the continuous HSP-F model is used to calibrate the analytical model. This chapter is comprised of several sections showing the results of the initial model calibration, sensitivity analysis, use of the calibrated model and the peak flow models. Discussion of the results is also included in Chapter 4. Chapter 5 concludes the study, providing a summary and recommendations for future research.

CHAPTER 2

2.0 LITERATURE REVIEW

The topic of this study is applied and multi disciplinary, combining analytical tools for modelling with new innovative technologies for storm water management and design. As such, this chapter reviews the literature in three main topic areas: analytical hydrological modelling, hydrological benefits of green roofs and hydrological modelling of green roofs.

2.1 Storm Water Modelling - Analytical Models

Initially, analytical models were used to determine the performance of storage/treatment systems. Howard (1976) developed the model (as cited in Guo, 1998) with rainfall volume and interevent time to analyze the runoff diverted to a storage reservoir. Smith (1980) carried forward the Howard model by solving for the steady-state probability distribution function. The model was taken a step further by modelling a series of catchments in sequence by Schwarz & Adams (1981) and Adams & Bontje (1984). Analytical models were well developed.

A comparison between analytical and simulation models was performed by Kauffman (1987). The results showed that favourable agreement existed between the two models. Since the analytical model is dependent on statistical data of rainfall an extensive database for parameters was initially developed and published by Belanger (1992). Validation of the analytical model with continuous simulation models has shown reasonable agreement (within 5-20%) (Li, 1991; Li & Adams, 1990; Li & Adams, 1993; Li & Adams, 1994; Papa & Adams, 1997). Chen & Adams (2005) were able to obtain analytical model results within 3-10% of results from a continuous simulation model. Adams & Papa (2000) collected all of the theoretical background of the analytical model into a reference book. Their work then developed the analytical probability models and highlighted their applicability to storm water design for prediction of total runoff volume, peak flow, water quality, combined sewer overflow and reservoir capacity. Guo (1998) expanded on the initial work of Adams & Papa (2000) by further developing the analytical model and incorporated additional parameters such as infiltration into the model. Guo (1998) also provided the development of the analytical model for peak flows, storm water quality control and flood control. Cost-effective urban storm water system design was completed with a screening level analytical model by Li & Adams (2000) and Chen & Adams (2004). Analytical model analysis of runoff quality was completed with simple to use spreadsheet tools by Behera et al. (2006). It was found that the long-term runoff quality control assessment could be accurately determined by analytical models.

Analytical models for runoff estimation provide a cost-effective method for analysing the long term performance of urban drainage systems. Analytical models have been validated by a variety of studies and provide good accuracy, in some cases as accurate as continuous simulation models (~5-10%). They are regarded as simple and relatively straight forward to use, with well developed statistical rainfall data basis. Considerable work has been conducted at the University of Toronto; the works by Guo (1998) and Adams & Papa (2000) forms the main basis of the study. The models to predict total runoff volume and peak flow assume uniform rainfall and cannot capture all of the catchment parameters. The literature review did not cover the development of analytical models for water quality. Guo

(1998) and Behera et al. (2006) provides additional information concerning the development of models to predict water quality.

2.2 Benefits of Green Roofs

Municipalities considering using green roofs as part of any policy require information about their tangible and intangible benefits and costs. Although the green roofing industry in North America is not as mature as in certain places in Europe, considerable resources have been spent on researching the benefits of green roofs on both continents (Banting et al., 2005). With the identification of green roof technology as a BMP, there has been greater interest in their inclusion in urban drainage systems.

Green roof research incorporates a wide array of disciplines including soil and horticultural science, civil and construction engineering, architectural and landscape designing, ecology, urban planning and policy development (Currie, 2005). There are a variety of benefits to the implementation of green roofs, including:

- Energy savings in buildings;
- Reduction of urban heat island effects
- Effects on air quality;
- Effects on health and well-being;
- Reduction of storm water quantities;
- Improvement of storm water quality; and
- Promotion of horticulture and landscaping (Banting et al., 2005).

The additional material placed on the roof of a building typically has good insulating properties. Soil prevents heat transfer during winter and summer, reducing the energy spent on controlling the building climate. Liu & Baskaran (2003) reported field research in Ottawa that green roofs reduced the energy requirement for air conditioning by 75%. The phenomenon of the "urban heat island" where air over urban centres is typically warmer than the surrounding areas, can also be reduced by green roofs. A simulation performed by Bass et al. (2002) showed that green roofs could reduce the urban temperatures by 1°C and 2°C with irrigated green roofs. Using the Urban Forest Effects (UFORE) model, Currie (2005) was able to show a statistically significant air quality increase with city-wide implementation of green roofs. Green roofs help to offset the habitat lost to development (Gedge & Kadas, 2005). Economic studies have been conducted to evaluate and quantify the costs and savings of implementing green roofs (Banting et al., 2005; Clark et al., 2008; Niachou et al., 2001; Wong et al., 2003). The studies show that all of the benefits provided can produce significant savings for a building. Although not the main focus of this study, green roofs offer a variety of non-hydrological benefits. Many of these benefits have been studied and found to be significant, providing further support for the usefulness of green roofs.

2.2.1 Hydrological Benefits of Green Roofs

Since roof areas typically comprise 40-50% of the impermeable surfaces in urban areas, green roofs can have a large impact on the hydrological response of the drainage system (Dunnett & Kingsbury, 2008). Unlike some other BMPs, green roofs offer improvements to both the quantity and the quality of storm water runoff. Green roofs are known to retain storm water, delay peak flows and offer filtering effects to improve water quality (Banting et al., 2005). The hydrological benefits of green roof technology have been studied in a variety of locations around the world, as shown in the literature reviewed. Storm water management implications of green roofs fall into two main categories: quality and quantity.

Johnston & Newton (1993) showed that plants have the capability to degrade contaminants by direct intake or by binding them with the plant or roots. Their study concluded that over 95% of cadmium, copper and lead and 16% of zinc can be removed from storm water runoff with green roof technology. The Toronto and Region Conservation Authority (TRCA) monitoring of storm water performance of a green roof at York University found that loadings of suspended solids, nitrogen complexes, aluminum, copper, biological oxygen demand (BOD), and most poly-aromatic hydrocarbons (PAH) were reduced (TRCA, 2006). The green roof at York University in Toronto has an area of approximately 241m^2, covered with grass and wild flowers, and designed to be light-weight. However, higher levels of phosphates, metals, cations and anions were found to be leached from the soil medium than the control green roof. Studies in North Carolina by Moran et al. (2003) found the same leaching trend with increased loadings of nitrogen. The study concluded that careful selection of the soil medium should help ensure that naturally occurring compounds are not leached. Due to the soil matrix, plant and organism relationships, green roofs act as a filter and can improve the water quality.

Over the same monitoring season at York University, total runoff volume was reduced by 55% and peak flow rates up to 85% for storm events <10mm (TRCA, 2005). Long rain events were found to saturate the green roof decreasing the storage capability and runoff retention. Results were also affected by the season, with warmer weather showing improved storm water reduction. Two green roofs were constructed for field studies in North Carolina, 27 and 70 m^2 in size. Approximately 32-100% of the total rainfall was retained in those constructed green roof (Moran et al., 2003; Moran et al., 2004). Similar to the results obtained at York University, the study found that storm water retention greatly decreased when there was not sufficient time between rain events for the green roof to dry. Storm runoff reduction was decreased by 32-75% during consecutive rain events. This indicated that the green roof was partly saturated, thereby reducing its remaining capacity. The effectiveness of green roofs for water detention was found to be highly dependent on the volume and intensity of rainfall.

In Sweden, field studies on a small scale green roof with an area of approximately 2m^2 found that 39-62% of the rainfall was retained (Bengtsson et al., 2005) and that retention diminishes as the slope of the green roof increases (Bengtsson et al., 2005; Nicholaus et al., 2005). In Portland, Oregon (Hutchinson et al., 2003), two green roofs were established. The results over the 15 month period showed that water retention ranged from 59-92% and favoured warmer weather (Hutchinson et al., 2003). Another American study showed that stress on municipal sewer systems can be reduced by green roofs and 70 to 90% of the runoff diverted (Perry, 2003). Experiments at the National Research Council, in Canada, showed that a green roof could delay runoff by up to 1.5 hours and reduce runoff volume by 85% (Liu, 2004). In Rio de Janeiro, Kohler et al. (2002) found that an installed green roof was able to evaporate 60-79% of the annual precipitation diverting the water from the sewer systems. Green roofs have therefore been shown to have good storm water retention and runoff reduction potential.

Effects on the peak flow were also considered in several studies. The peak flow of the green roof at York University was delayed by 4% to 88% (control roof as 0%) (TRCA, 2006). The magnitude of peak flow was also reduced by 46-85%. In North Carolina, a green roof delayed peak runoff up to 2 hours and reduced peak flow by 90% (Moran et al., 2003; Moran et al., 2004). Table 2-1 summarizes the findings of research studies on the hydrological performance of green roofs.

Table 2-1: Performance Summary of Green Roofs

Source	Total Runoff Volume Reduction	Peak Flow Reduction
Bengtsson et al. 2005	39-62%	Not performed
Hutchinson et al. 2003	59-92%	Not performed
Kohler et al. 2002	60-79%	Not performed
Liu, 2004	85%	Not performed
Moran et al. 2003 Moran et al. 2004	32-100% 32-75% Sequential rainfall events	90%
Perry, 2003	70-90%	Not performed
TRCA, 2005	55%	46-85%

The existing literature and studies conducted on green roofs show that they significantly retain and reduce storm water while delaying the time to peak flow. The effectiveness of green roofs has been shown to diminish with longer and consecutive rain events as might be expected. Green roofs also show better results in warmer weather, due to increased evapotranspiration and looser soil density. Most of the studies were conducted at the bench and pilot scale levels and did not consider the entire watershed and downstream dynamics. The next section examines studies that have considered modelling the hydrological response of single green roofs along with consideration for an entire watershed.

2.3 Hydrological Modelling of Green Roofs

The current literature has focused on evaluating the hydrological reaction of single green roofs to rain events. Little research has been conducted on how to predict the implementation of green roofs on a watershed basis. City and municipal planners want to know how much storm water can be reduced to determine the benefits from smaller sized storm water infrastructure such as pipes, ponds and outfalls. Combined sewer overflows are also a major problem for some cities and reducing the magnitude and frequency of combined sewer overflow (CSO) events can greatly reduce environmental impacts.

Research in this area is based on predicting the expected runoff and peak flow reduction using a variety of techniques. At Lund University, in Sweden, a *Sedum album* green roof was placed in a parking area. The plot area was monitored and a variety of synthetic rain events were applied over the plot area. Once completed, the researchers fitted a unit hydrograph (time vs. runoff flow plot) and made comparisons with observed data. The average unit hydrograph, from uniform rainfall intensities can accurately simulate the green roof response for any slope and rain event (Bengtsson et al., 2005). This unit hydrograph can be used to model the storm water outflow from a green roof.

Using the data from the York University green roof, Banerjee (2004) developed HSP-F's Unit Response Functions (URF). The URFs describe how certain land use types with and without green roof technology reacts to rain events and how much runoff occurs. The original HSP-F model was first calibrated to meteorological data. Non-green roof URFs were developed representing the control roof at York University. The actual garden roof was used to develop the URFs representing green roof technology. The URF model was calibrated by using the HSP-F model to predict actual outflows from the control and roof garden. Good agreement of runoff was obtained (within 0-9%) for specific storm events. Results were noted to be inconsistent during winter months. Using the calibrated URFs, from Banerjee (2004), Mauder (2004) simulated the results of implementing green roof technology within the Markham Branch of the Highland Creek watershed. Results showed a 3-4% reduction in total runoff volume. Peak flow was also reduced by 6-20%. Taking this a step further, Banting et al. (2005) extracted the the HSP-F created URFs and directly applied them to the various land uses of all the watersheds in the GTA. Potential runoff reductions ranged from 4% to 12% and specific results are provided in Section 4.2 (Banting et al., 2005). Their method provided quick results without the use and time resources needed for a full continuous simulation model.

Li (2007) estimated the reduction of CSO storage volume and the cost savings of implementing green roofs in the City of Toronto. Using the same URF method as Banting et al. (2005), and using analytical models from Adams & Papa (2000), Li was able to estimate the annual CSO volume. The analytical model, by Li (2007), was calibrated to an existing continuous simulation model (QQS) under a base scenario and then used to estimate the reduction in storage volume for CSO events. Unit cost savings of implementing green roofs are estimated to range from $570 to $15,580 per hectare of green roof for the City of Toronto (Li, 2007). This translates to approximately $2.8 to $78 million in BMPs infrastructure in Toronto (Li, 2007). The study concluded that using the analytical method is suitable for annual runoff volume calculations and reduces the resources needed to run the City of Toronto continuous simulation model, which requires a long time to develop.

The Green Build-out Model (Casey Trees & Limno Tech, 2007) was developed to quantify all of the storm water benefits of trees and green roofs. It is based on the land use areas of the District of Columbia in the US State of Washington and the Mike Urban model (Casey Trees & Limno Tech, 2007). Using a pre-calibrated continuous simulation model, developed for the District during an earlier project, green roofs and trees were added to the model and scenarios were re-analyzed. The model assumed that only 75% of the roof area could be covered with a green roof and that green roofs can be applied to 90% of all buildings over 465 square metres. Implementation of green roofs in Washington State was predicted to reduce combined sewer flows by 16.6% to 24.8% in various watersheds (Casey Trees & Limno Tech, 2007). The Green Build-out Model found that their intensive green roof scenario prevented 10% of total annual stormwater from entering the system (Casey Trees & Limno Tech, 2007). During the research it was found that the model was complex and time-consuming to set up and run the various scenarios. A "Mini-model" was developed for planning purposes and was not intended to replace the Green Build-out Model. Unit-area reduction factors (UARF) were developed from the Mini-model based on a 100-acre sewershed. The Mini-model found that green roofs can reduce the storm water quantity by 3,685 cubic meters per year per hectare.

The methodology used by Banerjee (2004), Li (2007) and Casey Trees & Limno Tech (2007) have several differences and similarities. The work by Banerjee (2004) used real time monitoring data from an actual green roof to provide calibration data for a CSM. In comparison, Li (2007) and Casey Trees & Limno Tech (2007) did not use measurements from a green roof, but instead changed watershed parameters based on the assumptions of installing green roofs. Once parameters had been changed, their CSMs were re-run. Out of the three studies only Li (2007) used an analytical model, developed by Adams & Papa (2000), calibrated to a CSM. Casey Trees & Limno Tech's (2007) method to develop the UARFs is similar to the development of the URFs by Banerjee (2004) and can be used quickly during the planning of future green roof installations. Li (2007) also concluded that the calibrated analytical model for CSO events is accurate enough for planning purposes.

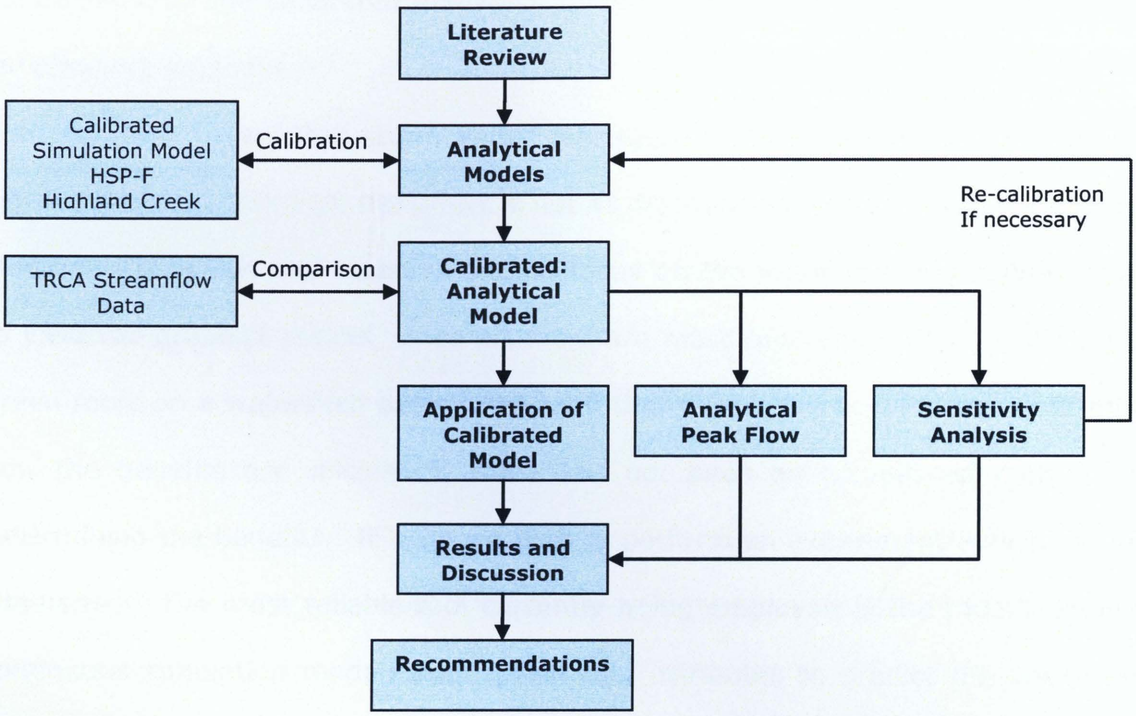
The literature shows that storm water management benefits are achievable on a watershed basis, although the effect is not as dramatic as with individual green roof studies. Strategies and research should focus on the entire sewershed/watershed to yield the greatest results, since planners are most concerned with implementing green roofs on a watershed basis. Although there are a few studies that determine how the benefits are calculated, there has not been an established method for determining the benefits. It is impractical to perform an experiment over an entire watershed. The most reliable tool currently being employed is the modification of continuous simulation models with green roof attributes to predict the watershed results. Continuous simulation modelling has been described as time consuming and data intensive. The level of detail and accuracy provided by this method may not be warranted during the initial planning stages. Analytical tools have been used and validated to determine storm water runoff (Li, 1991; Li & Adams, 1990; Li & Adams, 1993; Li & Adams, 1994; Papa et al., 1997) and reduction of CSO events (Li, 2007) from green roofs on small catchments and areas. Research and results on analytical models to determine the runoff volume reduction of large catchments and watersheds is limited. This study provides research into the overall watershed effect of green roofs.

CHAPTER 3

3.0 THEORIES AND METHODS

Figure 3-1 is a graphical representation of the methodology and data sources for the applied research study. The main steps taken are in bold and data sources identified on the left.

Figure 3-1: Flow Diagram of Applied Study



3.1 Analytical Probabilistic Models

The development of analytical probabilistic models began with the need to directly solve problems involving urban drainage systems. The probabilistic model involves the statistical analysis of long-term rainfall records. With a long-term record a probability distribution function (pdf) can be developed (Adams & Papa, 2000). This probability distribution function represents each of the possible rainfall events as a statistical value. For example, with a pdf developed for a certain area, the percentage that a rainfall event exceeds 10 mm or any other amount can be determined. Secondly, a mathematical representation of the rainfall-runoff transformation is developed and with the pdf of rainfall events, the corresponding pdfs of runoff characteristics are found. The process of derivation is based on probability distribution theory, which relates the probability distribution of a dependant random variable to those of the independent variable. The relationship of the independent and dependant variables are expressions of the catchment characteristics and their responses to rainfall. A brief explanation of the corresponding runoff model development is provided; however, it is not the intention of this study to explain in detail the development of probability distribution theory and corresponding analytical models. A more detailed description and derivation of analytical models is outlined by Guo (1998) and Adams & Papa (2000).

3.1.1 Rainfall Characteristics

The main input of the analytical probabilistic model is collected rainfall data. This data needs to be manipulated before being used. A distinction needs to be made between meteorological and statistical events. Actual meteorological events include many characteristics that make them almost impossible to be discretely categorized. However, with enough long-term data, certain characteristics such as rainfall event volume (v), duration (t), and average intensity (i) may be approximated as statistically random variables.

Statistical analysis of rainfall data is started by dividing the continuous data into discrete rainfall events (Adams & Papa, 2000). A criterion for establishing discrete rainfall events is to determine a minimum time period without rainfall, or interevent time definition (IETD). Periods of rainfall separated by a time interval longer than the IETD are considered as separate events. Once events have been discretely separated, the characteristics of these events can be statistically analyzed. Selection of the IETD is based on the intended application. Guo's (1998) recommendation is to ensure that the IETD is greater than the catchment response time and an IETD of 6 hours is appropriate for urban applications. IETDs between 1 and 6 hours had also been suggested for most urban applications by Adams et al. (1986). Once the rainfall events have been separated, the volume, duration and average intensity values can be calculated for every individual rainfall event and analyzed statistically as a sample. Parameters for different IETD values are presented in Appendix A. Selection of an appropriate IETD period and location for the case study is discussed in Chapter 4.

Approximate representation of the pdf of volume, duration and average intensity values is required because real world data does not perfectly match known theoretical probability density functions. Frequency analysis can be performed on the magnitude of such parameters from their histograms and fit to a continuous pdf to the histograms of the rainfall events. There are several types of pdfs, however work by others (Adams & Papa, 2000; Guo, 1998) has selected an exponential pdf, which using the mathematical constant 'e', as a reasonable match due to the long records of rainfall data that are usually available. The rainfall characteristics of volume, duration and intensity are expressed as exponential pdfs as outlined in Equations 1-3:

$$Volume, v\ (mm): f(v) = \zeta e^{-\zeta v} \tag{1}$$

$$Duration, t\ (\text{h}): f(t) = \lambda e^{-\lambda t} \quad (2)$$

$$Average\ intensity, i\ (mm/hr): f(\text{i}) = \beta e^{-\beta i} \quad (3)$$

where ζ (mm^{-1}) is the inverse of the average rainfall per event parameter, $\overline{v}$; λ (hr^{-1}) is the inverse of the average duration of rainfall parameter $\overline{t}_{avg}$; β (hr/mm) is the inverse of the average rainfall intensity parameter. $\overline{v}$, ζ, λ and β have been derived for various locations and IETDs, based on long term rainfall data. A compilation of this data is included in Appendix A for IETD = 1hr. These equations are used as the basis for subsequent model development when discussing the probability of the occurrence of a value taken by a random variable. To obtain a probability, an interval must be selected and an integration of the pdf must be performed. For example, to determine the probability of rainfall volume that is less than 10 mm, the integration is performed as follows using Equation 4:

$$Prob\ [0 < v < 10] = \int_0^{10} \zeta e^{-\zeta v} \quad (4)$$

Note that the pdfs outlined in Equations 1, 2 and 3 have a range from 0 to infinity.

3.1.2 Rainfall-Runoff Transformation

Mathematical models of physical processes are used to predict outcomes or values of random variables, such as runoff (Adams & Papa, 2000). The runoff is directly related to the corresponding rainfall event and can be determined using a rainfall-runoff transformation such as the U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM) (Adams & Papa, 2000).

$$v_r = \phi(\text{v} - \text{S}_\text{d}) \quad (5)$$

Where v_r is the runoff volume (mm), v the rainfall volume (mm), Φ the runoff coefficient (dimensionless proportionality), and S_d the depression storage (mm). The rainfall event volume is typically an input and is provided by the long-term data set. Depression storage refers to the water that accumulates in surface depressions and on foliage during a storm (ASCE, 1992). This water is assumed to eventually evaporate following the storm. Although S_d is recognized to be a function of past rainfall, snowmelt and evaporation (ASCE, 1992), for simplicity it is treated as a spatially and temporally averaged constant based on the land use of the catchment. The model assumes that the full value of depression storage is available at the beginning of every rain event. Typical depths of depression storage are provided by ASCE (1992).

Table 3-1: Values for Depression Storage (ASCE, 1992)

Land Type	Depression Storage (inches)	Depression Storage (mm)
Impervious surfaces	0.05-0.1	1.25-2.5
Lawns	0.1-0.2	2.5-5
Pasture	0.2	5
Forest	0.3	7.5

The runoff coefficient is a dimensionless value, which represents a ratio of runoff volume to effective rainfall volume. It accounts for the integrated effects of rainfall interception, infiltration and other abstractions (ASCE, 1992). The runoff coefficient is usually assumed to be spatially and temporally averaged over the entire rainfall event. Considerable variation exists in this parameter. A table of typical runoff coefficients, by Viessman et al. (1996), is shown in Table 3-2.

Table 3-2: Values for Runoff Coefficients (Viessman et al., 1996)

Land Use	Area	Runoff Coefficient
Business	Downtown	0.70-0.95
	Neighbourhood	0.50-0.70
Residential	Single Family	0.3-0.5
	Multi units, detached	0.4-0.6
	Multi units, attached	0.6-0.75
	Suburban	0.25-0.4
	Apartment dwelling	0.5-0.7
Industrial	Light areas	0.5-0.8
	Heavy areas	0.6-0.9
	Parks, cemeteries	0.1-0.25
	Playgrounds	0.2-0.35
	Railroad yard areas	0.2-0.4
	Unimproved areas	0.1-0.3
Streets	Asphalt	0.7-0.95
	Concrete	0.8-0.95
	Brick	0.7-0.85
	Drives and walks	0.75-0.85
	Roofs	0.75-0.95
Lawns, sandy soil	Flat, 2%	0.05-0.1
	Average, 2-7%	0.1-0.15
	Steep, 7%	0.15-0.2
Lawns, heavy soil	Flat, 2%	0.13-0.17
	Average, 2-7%	0.18-0.22
	Steep, 7%	0.25-0.35

Equation 5 is the fundamental basis for the development of the probabilistic analytical model. It is assumed that Φ and S_d can be determined for a given catchment and that v is a statistically random variable, thereby making v_r a random variable. Using the meteorological inputs developed earlier as pdfs, the catchment can transform the rainfall volume to runoff volume according to the following relationship, developed by the STORM model:

$$v_r = \begin{cases} 0 & \begin{cases} v \leq S_d \\ v \geq S_d \end{cases} \\ \phi(\mathrm{v} - \mathrm{S_d}) & \end{cases} \qquad (6)$$

The system of equations states that the rainfall must exceed the depression storage before any runoff occurs. The runoff is generated as a square hydrograph that is transformed into runoff instantaneously without change in shape. This assumption is adequate because designers are more interested in the total runoff volume rather than the exact shape of the runoff hydrograph (Adams & Papa, 2000). A flow diagram of the analytical model is shown in Figure 3-2 and the rainfall-runoff transformation shown in Figure 3-3.

Figure 3-2: Flow Diagram of Analytical Model (Adams & Papa, 2000)

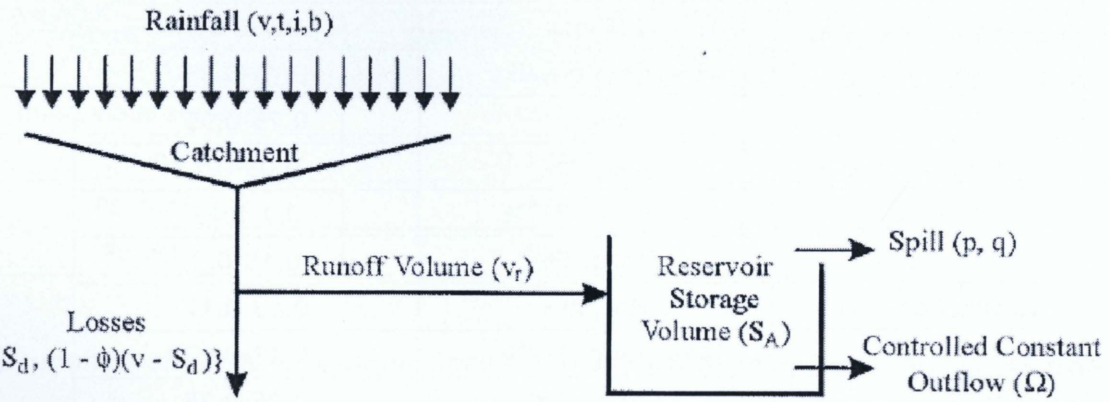
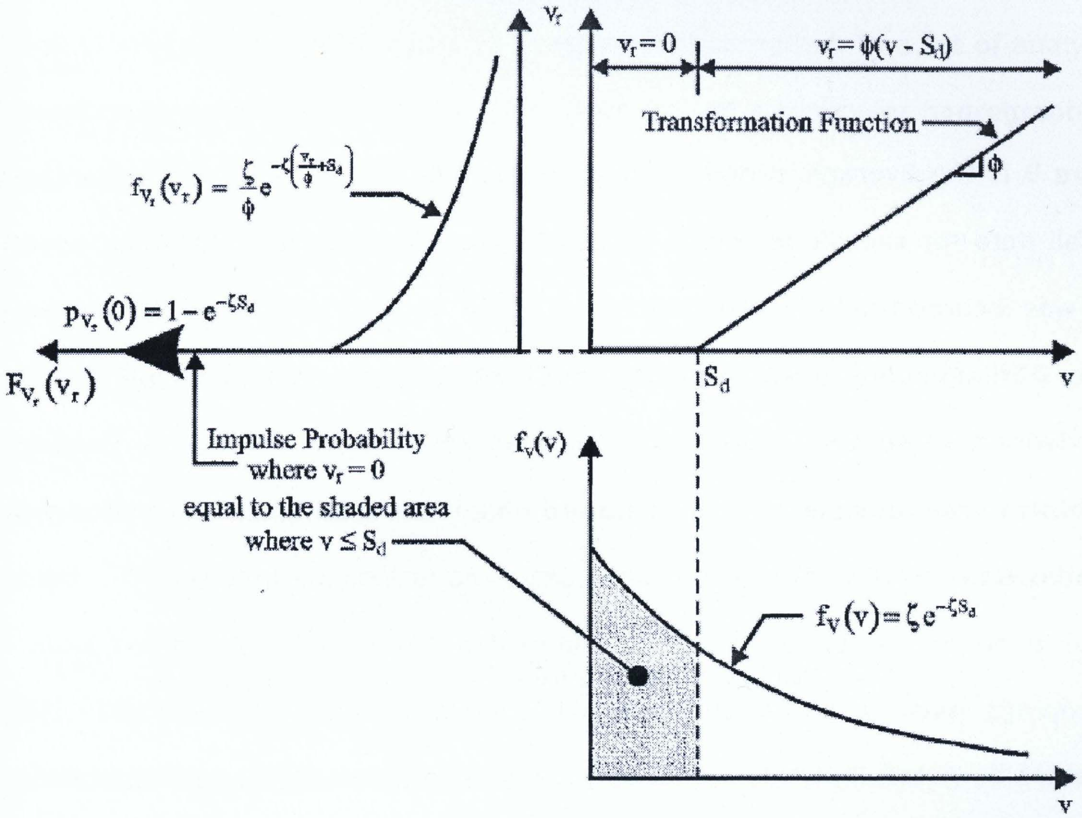


Figure 3-3: Transformation of PDF of rainfall volume to PDF of Runoff (Adams & Papa, 2000)



With the previous pdfs developed (Equations 1, 2 & 3) the cumulative distribution function and pdf of runoff volume may be obtained using derived probability distribution theory. The exact details of this development are outlined in Adams & Papa (2000) and Guo (1998). The pdf of runoff volume is;

$$f(v_r) = \frac{\zeta}{\phi} e^{-\zeta\left[\left(\frac{v_r}{\phi}\right)+S_d\right]}, \qquad v_r > 0 \qquad (7)$$

The expected value ($E[v_r]$, mm) and average annual volume of runoff (R, mm) are then:

$$E[V_r] = \frac{\phi}{\zeta} e^{-\zeta S_d} \tag{8}$$

$$R = \theta \frac{\phi}{\zeta} e^{-\zeta S_d} \tag{9}$$

Where θ is the average annual number of rainfall events, derived from long-term rainfall data for specific locations (Appendix A). Equation 9 is the main equation that was incorporated into the bulk of the runoff volume calculation and calibration work. Although quite simple it incorporates two important factors, runoff coefficient and depression storage. Once the depth of runoff is known, the corresponding catchment area provides the calculation to obtain the total volume (V) as shown in Equation 9a.

$$V = Area\ of\ Catchment\ x\ \theta \frac{\phi}{\zeta} e^{-\zeta S_d} \tag{9a}$$

It should be noted that this model only generates expected average annual runoff volumes and requires long-term data. The benefit of this simplicity allows all types of users to quickly generate runoff volumes. The equation is easily incorporated into a spreadsheet program that facilitates the calibration with other models and the determination of runoff volumes. Using Equations 9 & 9a and specific catchment data, the expected annual runoff volume can be calculated from a catchment.

3.1.3 Peak Flow

Peak discharge is the maximum flow rate observed during a storm event. While total runoff volume describes how much water flows over a given time, the peak discharge describes the maximum instantaneous flow during a storm event.

Similar to the analytical models developed for total runoff volumes, peak discharge values can also be determined using derived analytical models. Previous research by Guo (1998) and others was able to transform a hydrograph to a set of analytical expressions to determine peak flow. The peak flow of a triangular hydrograph can be expressed as:

$$Q_p = \frac{2v_r}{t + t_c} \quad (10)$$

With the peak discharge rate Q_p (mm/hr); runoff volume v_r (mm); rainfall event duration t (hr); and time of concentration t_c (hr). The term t_c, time of concentration, has several definitions; however, a commonly used definition is adopted. The time of concentration is the time required for runoff to travel from the most remote location of the catchment to the outlet or design point (Guo, 1998). There is a variety of methods to determine t_c for a given catchment, grouped into three categories: empirical equations, velocity methods, and kinematic wave theory models. In this research, the t_c of the Highland Creek watershed was estimated by using a velocity method. The velocity method is less complex than using the kinematic wave theory and provides suitable values for the analytical analysis. The velocity method (also known as the Uplands method) developed by the Natural Resources Conservation Service (NRCS) was used to determine travel time (Fang et al., 2007; NRCS 1972). The Uplands method determines velocity (m/s) as a function of slope, type of land cover and travel time, as:

$$V = kS^{0.5} \quad (11)$$

$$t_c = \frac{L}{3600V} \tag{12}$$

Where S is the unit-less slope of the catchment and k is an overland flow coefficient specific to the Uplands method. The length of flow (m) that the water travels within the catchment is represented as L. Empirically developed values of k exist from the National Land Cover Data Overland Flow Coefficients (Fang et al., 2007) and are shown in Table 3-3.

Table 3-3: Overland Flow Coefficients for NRCS Velocity Method (Fang et al., 2007)

Classification	Coefficient
Open water	15.7
Low intensity residential	20.4
High intensity residential	20.4
Commercial/industrial/transportation	20.4
Bare rock/sand/clay	7.0
Quarries/strip mines/gravel pits	7.0
Transitional	7.0
Deciduous forest	1.4
Evergreen forest	1.4
Mixed forests	1.4
Shrub land	1.4
Grasslands/herbaceous	7.0
Pasture/hay	7.0
Row crops	4.6
Small grains	4.6
Urban/recreational grasses	7.0
Woody wetlands	15.7
Emergent herbaceous wetlands	15.7

The time of concentration for a large watershed can be approximated by summing the t_{ci} of the individual sub-catchments within. The general methodology to determine the t_c of the Highland Creek includes the following steps:

1. Choose, by visual inspection, several of the longest routes from a sub-catchment map.
2. Determine the t_{ci} of each sub-catchment within the route of interest, using the NRCS Velocity method, Equations 11 & 12
3. Determine the total t_c by summing the t_{ci} from Step 2 for each sub-catchment.
4. The catchment t_c is the largest value of all the routes examined.

The division of sub-catchments is provided in Appendix C and corresponding parameters for the Highland Creek watershed are provided by Aquafor Beech (2004), Appendix F.

Using the previously developed rainfall-runoff transformation (Section 3.1.2) and Equation 10, Guo (1998) found that the peak discharge rate can be analytically determined as a set of equations:

$$Q_p = \begin{cases} 0, v \leq S_{di} \\ \dfrac{2h(v - S_{di})}{t + t_c}, S_{di} < v \leq (S_{il} + f_c t) \\ \dfrac{2[(v - S_d - f_c(1-h)t]}{t + t_c}, v > S_{il} + f_c t \end{cases} \quad (13)$$

where Q_p is the peak flow (mm/hr); v is the rainfall event volume (mm); S_{di} is the depression storage of the impervious area (mm); h is the fraction of impervious area (unit-less); t is the rainfall event duration (hr); t_c is the time of concentration (hr); S_{il} is the initial losses of the pervious areas (mm); f_c is ultimate infiltration capacity (mm/hr); and S_d is the area weighted depression storage of a catchment (mm). The rainfall event volume (v) and duration (t) is a user-defined parameter and values can be taken from historic records, intensity duration frequency curves, or design storms. The various depression storage values (S_d, S_{di}, S_{il}) can be obtained from Table 3-1. The fraction of impervious area in a catchment can be found from the land use or existing inventory data of a catchment. Infiltration of water into the soil is measured by using Horton's equations and infiltration rates (Bedient & Huber, 2008). The ultimate infiltration capacity is described as the infiltration rate once the soil has been saturated with water and typical values are shown in Table 3-4. The soil type varies over a catchment and can be determined from soil maps for various regions.

Table 3-4: Values for Ultimate Infiltration Capacity (Bedient & Huber, 2008)

Soil Type	f_c (mm/hr)
Alphalpha loamy sand	35.6
Carnegie sandy loam	50.0
Dothan loamy sand	66.8
Fuquay pebbly loamy sand	61.5
Leefield loamy sand	43.9
Tooup sand	45.7

From the first relation in Equation 13, no flow from the catchment is expected if the rainfall intensity does not exceed the depression storage of the impervious area. This represents a small rainfall where all of the water is caught in pools and other depression storage. Once this depth is exceeded, flow from the catchment is observed from the remainder of the expressions in Equation 13. Depending on the amount of rainfall, the pervious and/or impervious areas may contribute to the peak flow. The boundaries of the second line of Equation 13 show a situation where the rainfall event has not exceeded the depression storage and the infiltration capacity of the soil. In this situation the pervious areas are not contributing to the peak flow. Finally, the last expression in Equation 13 shows the scenario when the rainfall event has exceeded a value when both pervious and impervious areas are contributing to peak flow. Further information concerning the probability of peak flow can be found in research by Guo (1998).

Using Equation 13 and the calibrated parameters determined earlier, the peak flow from the Highland Creek was determined. The peak flow was calculated for the base case (no green roofs), 50% and 100% green roof scenarios based on the input parameters. The reduction in peak flow from the analytical model was compared with other findings. Aquafor Beech (2004) provided a hydrology update report for the Highland Creek to develop a flood management strategy. This document included peak flow analysis for a variety of storms and was used as a comparison for the analytical model shown in Equation 13. The analytical model was not be calibrated to fit the data found in the Highland Creek hydrology report update.

3.1.4 Limitations

Certain limitations are inherent to the development of the analytical model. Rainfall characteristics must be treated as a sample of events from a parent population. This requires a long-term coherent history of rainfall data to approximate. Another assumption is that the rainfall events are independent of one another and stationary. Although rainfall events do depend on weather patterns and are hardly stationary, these assumptions are acceptable and their impacts are small and difficult to quantify (Adams & Papa, 2000). The analytical model and rainfall parameters only predict the runoff during non-winter months. To account for the runoff during non-winter months, another methodology must be used. Since the analytical model is based on statistics, the runoff calculated from Equations 9 and 9b represents an average value. This method is best suited for applications requiring long-term data as opposed to determining extreme scenarios.

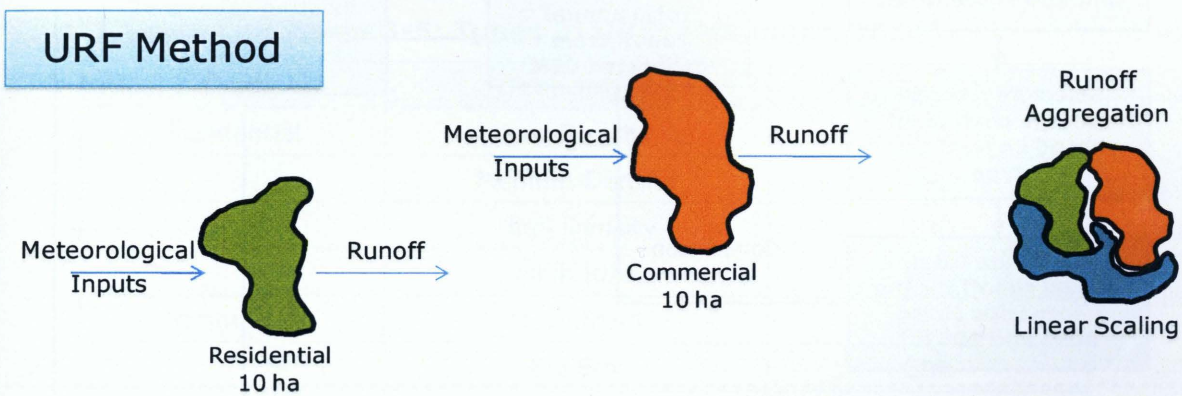
Peak flow limitations arise from the development of a hydrograph. In reality a hydrograph is a complex and unique curve for a specific catchment. The triangular hydrograph also assumes that rainfall intensity is constant over the storm and that the spatial distribution of rainfall over the catchment is uniform. Extrapolating this method over a large watershed area may increase some of the errors. Increasing the number of individual catchments in the same area may reduce the impact of the uniform assumption.

3.2 URF Method

Although the analytical model can determine the total runoff from a catchment, it would have difficulty modelling a multi-land use catchment. This occurs because the analytical model requires area-averaged input parameters and does not consider hydraulic mechanics inside the catchment. Analysis is best done considering single land uses. The URF method or approach adopted by Banerjee (2004), uses a CSM (HSP-F) to determine the hydrological response of a 10 ha catchment representing a single homogeneous land use type (high density residential, commercial, industrial etc.). The URFs also simulate different implementation magnitudes of green roof technology (50% and 100%). Overall, each land use type has three corresponding URFs for different scenarios (0% or base, 50% and 100%). The total annual runoff volume of a watershed can then be determined from the aggregation of the different URFs based on the land use areas.

This total runoff aggregation method can be performed with data from the case study (Highland Creek watershed) as provided by Banerjee (2004) and Maunder (2004). The URF method is linear and assumes that a parcel of land reacts the same from one watershed to another. Developing the URFs can be accomplished by using a CSM or an analytical model. Since the method is simple to use, the applied study has adopted the URF method to determine the hydrological response. Figure 3-4 shows a graphical representation of the URF method and runoff aggregation method.

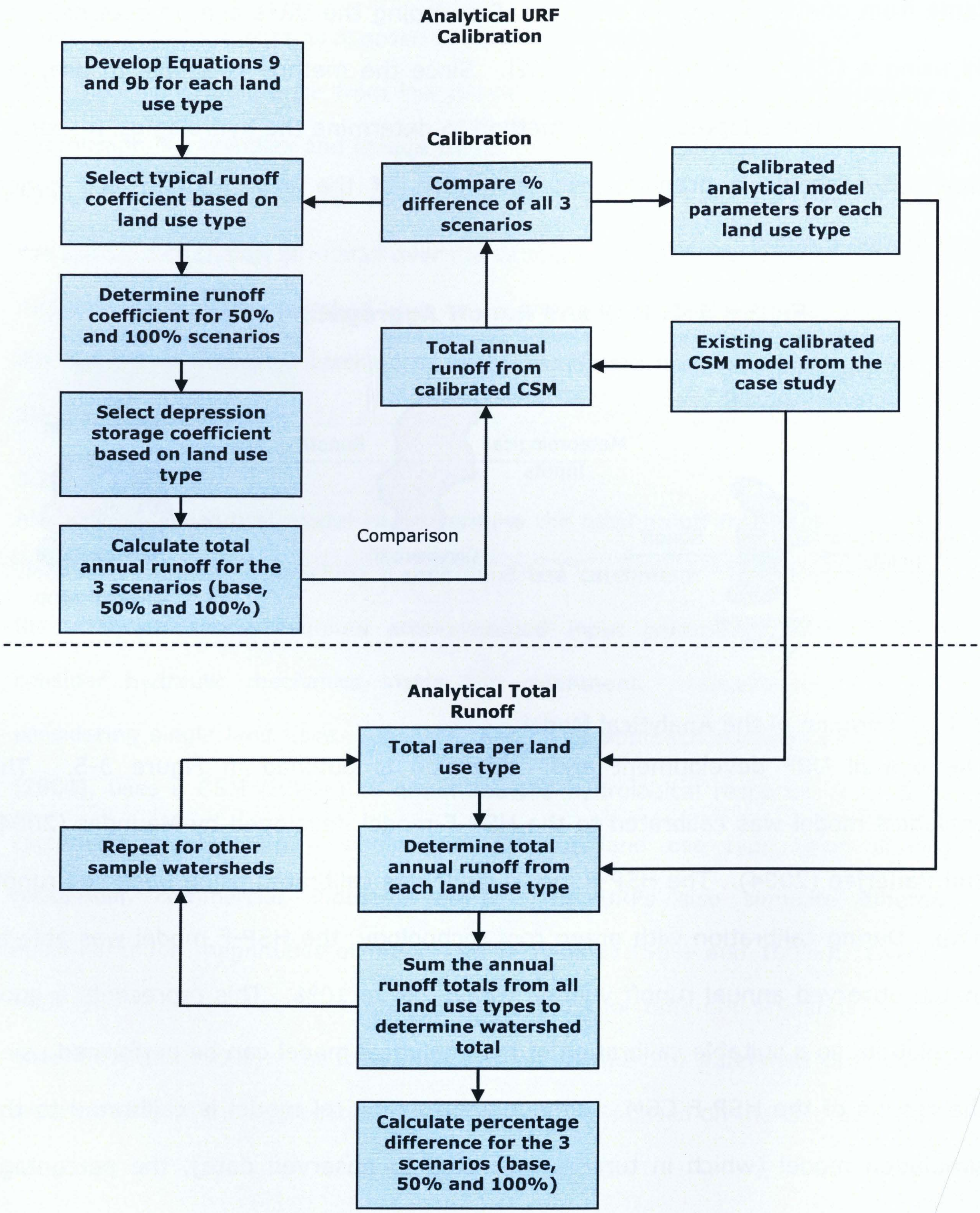
Figure 3-4: URF and Runoff Aggregation Method



3.3 Calibration of the Analytical Model

The overall URF development and calibration is outlined in Figure 3-5. The analytical model was calibrated to the HSP-F model developed by Maunder (2004) and Banerjee (2004). The HSP-F model itself was calibrated using observed runoff data. During calibration with green roof technology, the HSP-F model was able to match observed annual runoff volume within 2% to 10%. This represents a good correlation, so a suitable calibration of the analytical model can be performed using the results of the HSP-F CSM. Although the analytical model is calibrated to the simulation model (which in turn is calibrated to observed data), the percentage error in matching observed runoff values is not as important as the percentage reduction in runoff from using green roof technology.

Figure 3-5: URF Development and Calibration



The URFs developed for the HSP-F model of the Highland Creek are divided into land use types with their own corresponding characteristics. They are defined as the hydrological response of a hypothetical homogeneous 10 ha test catchment, representing each land use type, soil and connectivity configurations associated with the known set of meteorological conditions. They vary based on soil type, roof leader connection type, footing drains, etc. The types of URFs are listed in Table 3-5 (see Appendix B for full details of the URFs). The original URF modelling also provides details concerning water quality parameters; however they are not considered in this research.

Table 3-5: Types of URFs (Maunder, 2004)

Type	Description	Code
Residential	Low Density	RLD
	Medium Density	RMD
	High Density	RHD
	High Rise	RHR
Commercial	Downtown	CDT
	Big Box	CBB
	Strip Mall	CSM
	Educational/Institutional	EIS
Open Space	Park lands, hydro	OPL
	Valley lands, golf/cemetery	OVL
Transportation		THC
Industrial	Prestige	IPR
	Big Box	IBB

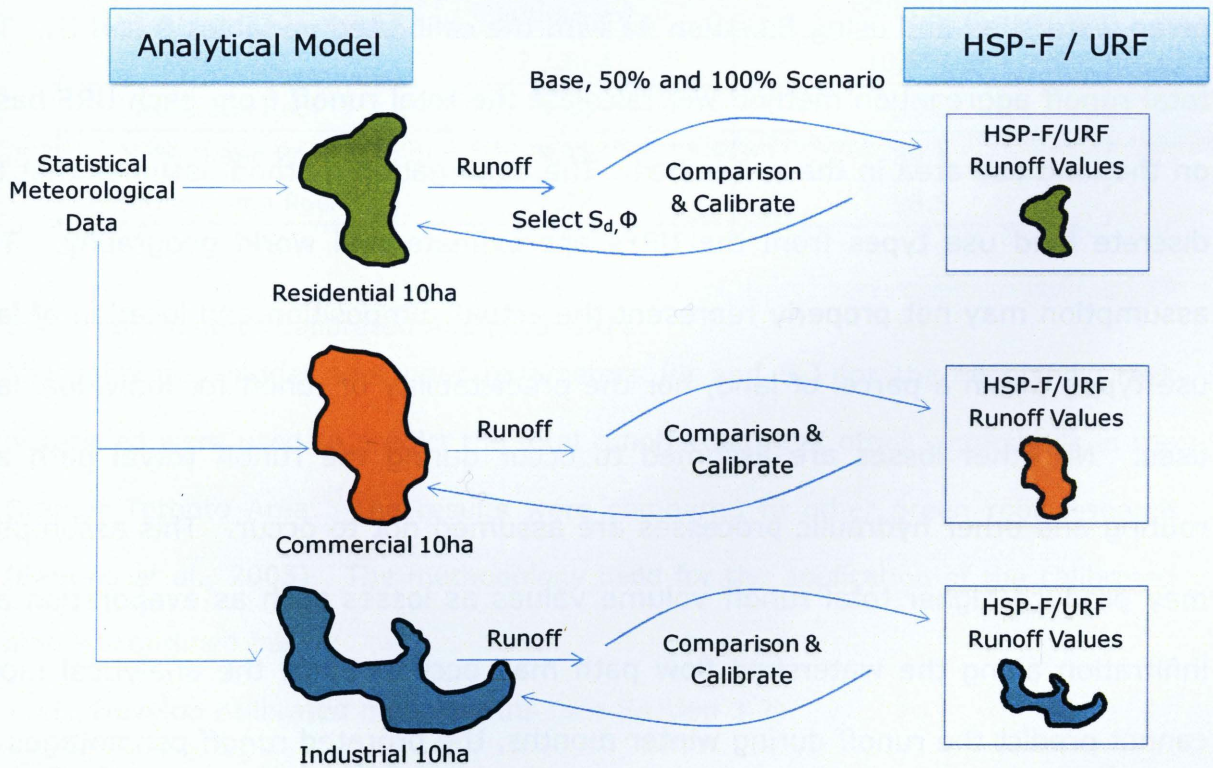
The existing land use data and watershed catchment plan are provided Appendix B. Each URF, shown in Table 3-5, has an average annual runoff with respect to three different scenarios based on the practical level of implementation on the roof area. The three scenarios include:

- no green roofs
- 50% green roofs
- 100% green roofs

Each scenario is generated with 6 years of annual runoff volume (m^3) for each URF, however only the runoff volume for the non-winter months were extracted from the HSP-F model. The analytical model (Equation 9) calculates a depth of runoff and when multiplied by an area (Equation 9a) produces the total runoff volume. The URF model used a uniform area catchment of 10 ha. Using Equation 9b, the total runoff volume for each URF was calculated by varying the runoff coefficient and depression storage. Two runoff coefficients and two depression storage values were first selected, representing the pervious and impervious components. The parameters were selected from a list of appropriate values corresponding to the catchment and land use type as outlined in Table 3-1 and Table 3-2. The pervious and impervious parameters were averaged based on the percentage of impervious and pervious area. Once the area weighted runoff coefficient and depression storage (Φ and S_d) were calculated for the base scenario (no green roofs), the other two scenarios were automatically calculated by the inherent change of the roof area (impervious) being converted to a pervious area. This change in pervious area simulates the roof's conversion into a green roof. The method used to determine the change in pervious area is the same as the HSP-F model and assumes that only 75% of roof areas are capable of supporting green roof technology. This represents a conversion of 37.5% and 75% respectively of the total roof area to a pervious area. Using this method, the total runoff volume of all three scenarios is generated at once. The calibration requires that all three scenarios be within a reasonable range of the original URF volume. The calibration process is illustrated in Figure 3-6 and performed following the general steps:

1. Select a typical runoff coefficient for the specific URF based on land use
2. Calculate the corresponding runoff coefficients for the 50% and 100% green roof cases based on the change in impervious area
3. Select a typical depression storage for the specific URF based on land use
4. Calculated total runoff volume and compare to URF for the 3 scenarios (base, 50% and 100% green roof)
5. Using best judgment, modify runoff coefficient and depression storage values to obtain better match with all scenarios

Figure 3-6: Calibration of Analytical URF to HSP-F/URF Data



The analytical rainfall parameters (Appendix A) for the Highland Creek only predict the runoff volume during the months of March to November (inclusive). Therefore the runoff volumes from the HSP-F/URF model were extracted on a monthly basis and the months of January, February and December were removed from the total. This procedure allowed the total runoff volume from the analytical model to be properly calibrated to the URFs with the same time period. Once the calibration is complete, the percentages of runoff during the months of January, February and December were added back to each analytical URF to generate the final annual total runoff.

3.3.1 Total Annual Runoff Volume

Once all of the URFs have a corresponding calibrated analytical URF model, the calibrated parameters (Φ and S_d) can be used to determine the total runoff volume from a watershed. This can be accomplished by obtaining the land use areas for a given watershed and using Equation 9a with the calibrated variables θ and S_d. The total runoff aggregation method will calculate the total runoff from each URF based on the land use area in the watershed. The aggregation method assumes that the discrete land use types from the URFs approximate real world geography. This assumption may not properly represent the actual composition and location of land use types within a parcel of land, nor the predictability of runoff for individual land uses. No other losses are assumed to occur during the runoff travel path and routing and other hydraulic processes are assumed not to occur. This assumption may produce higher total runoff volume values as losses such as evaporation and infiltration along the watershed flow path may occur. Since the analytical model cannot predict the runoff during winter months, the prorated runoff percentages for the winter months were added. The analytical model cannot estimate the groundwater or stream flow of the hydrological cycle. Baseflow data from the TRCA was obtained and used to determine the final total annual runoff volume.

With the total annual runoff volume predicted by the analytical URFs for all three scenarios and the baseflow for the watershed, the percentage reduction due to implementing green roofs with the various scenarios was calculated. Maunder (2004) used the HSP-F model to predict runoff leaving the Markham Branch and the entire Highland Creek watershed with various levels of green roof implementation. The total runoff volume is summarized in Table 3-6 and was used for comparison to the analytical model.

Table 3-6: HSP-F Predicted Runoff

	Highland Creek – Markham Branch Million m^3	**Highland Creek Million m^3**
Area (ha)	2,124.4	10,574.5
No Green Roof	8.34	39.6
50% Green Roof	8.27	39.1
100% Green Roof	8.09	38.5

3.4 Application of Calibrated Analytical URFs

The calibrated model and input parameters (Φ and S_d) for the Highland Creek watershed were used to predict the total runoff volume of other watersheds in the Greater Toronto Area. The results were compared to other green roof research (Banting et al., 2005). The methodology used for the application of the calibrated model is outlined below:

1. Develop calibrated model inputs (see Section 3.3)
2. Obtain runoff volumes and land use composition data for various watersheds in the GTA (Banting et al., 2005)

3. If required, remap the land use codes to appropriate calibrated model land use codes by averaging similar land use categories
4. Using Equations 9 and 9b, determine total aggregate runoff with and without green roofs by inputting the area quantities directly into the calibrated model for each watershed
5. Calculate percentage differences of total runoff volume and runoff volume reduction due to green roof technology

The calibrated model inputs were used with Equation 13 to determine the peak flow of the Highland Creek watershed. These results were compared to TRCA studies and findings. The methodology used to determine the peak flow is outlined below:

1. Develop calibrated model inputs (Section 3.3)
2. Calculate the fraction of impervious (h) area from the land use data provided with the HSP-F model.
3. Calculate area weighted parameters for depression storage (S_d, S_{di}, S_{il}) and ultimate infiltration capacity (f_c) from land use data and calibrated inputs.
4. Calculate the catchment time of concentration (t_c) using Uplands Velocity Method and the sub-catchment data provide by TRCA.
5. Select a rainfall event volume and duration based on the peak flow data provided by the TRCA.
6. Use Equation 13 and calculated variables to determine the peak flow.

The determination of peak flow was not subjected to calibration and was intended for comparison purposes. The HSP-F model performed a brief peak flow analysis over a six year period. One of the difficulties in validating the analytical model for peak flow was the scarcity of observed historic peak discharge data for comparison (Guo, 1998).

CHAPTER 4

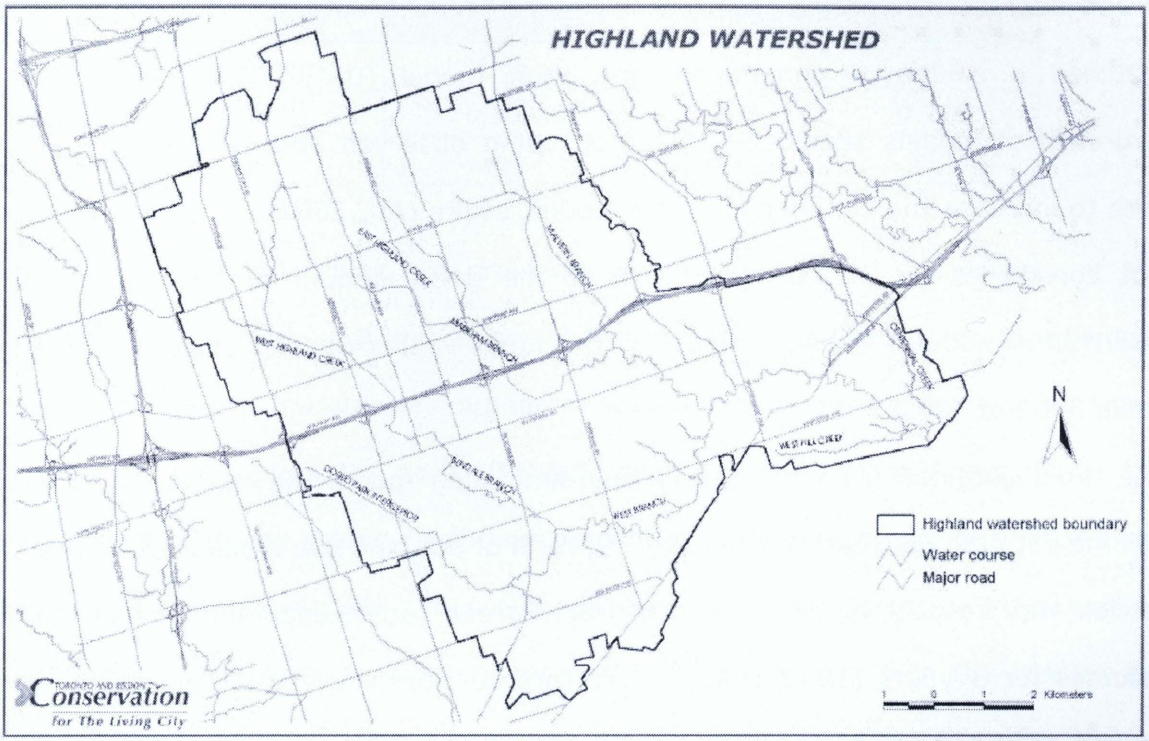
4.0 CASE STUDY AND RESULTS

This Chapter outlines the case study and calibration of the analytical model to the data of the Highland Creek watershed. The first series of calibrations were completed to match the URFs and are described in Section 4.1.1. Calculations and comparisons of the annual runoff volume and volume reduction by green roof technology from the calibrated analytical model and HSP-F are outlined in Sections 4.1.2 & 4.1.3. Results using the calibrated model to predict total annual runoff volume from other watersheds are shown in Section 4.2. Finally, a simple exercise to calculate the peak flow of the Highland Creek was performed and results are shown in Section 4.3. Discussion of the results is included in each section.

4.1 Case Study: Highland Creek Watershed

The Highland Creek watershed is described as an "urban creek" by the TRCA (TRCA, 1999). Approximately 85% of the land area is considered urban, making the watershed the most developed in the TRCA's jurisdiction (TRCA, 1999). With over 75 km of watercourses, the Highland Creek watershed drains an area of 102 km^2. The watershed boundaries are shown in Figure 4-1.

Figure 4-1: Map of the Highland Creek Watershed (TRCA, 1999)



The Highland Creek watershed was chosen as the case study because a CSM had already been calibrated and developed. The CSM also incorporated the implementation of green roof technology. Using the results from the Highland Creek CSM, an analytical model was calibrated. The various calculations and comparisons were performed using a spreadsheet program with area-based determinations from GIS. The calibrated analytical model was used to calculate the total runoff volume and runoff volume reduction from green roof technology implementation on a watershed basis. The results in this chapter are based on the analytical model and tools developed by Adams & Papa (2000) and Guo (1998) and focus on three (3) parameters of interest in a hydrologic system: total annual runoff, peak flow and total runoff volume reduction.

4.1.1 Calibration of URFs

The calibration consisted of changing the values of model inputs (runoff coefficient Φ and depression storage, S_d) while trying to produce outputs (total runoff) that matched a calibrated continuous simulation model (URF/HSP-F) within 15%. Hydrological models should be calibrated using observed data or post-calibrated data to increase the confidence of the model results (Au, 2007). A simple method was considered for the calibration due to the small amount of field data in the URF/HSP-F model. Typical ranges for the input values (Φ, S_d) were provided in Table 3-1 and Table 3-2.

The URFs obtained from the continuous simulation model URF/HSP-F had runoff volume data for the years 1990-1996. Several of the land use types within the URF model, with respect to the 50% and 100% green roof scenario, only had runoff volumes for 3 years (1990-1992). The Toronto Downsview weather station was chosen as it had more than 20 years of collected data, forming a reliable rainfall data set. The rainfall parameters used are summarized in Table 4-1. Parameters from the Toronto Bloor Street and Ellesmere weather stations were also used with the calibrated model to determine the sensitivity of the parameters. The IETD duration was selected as 1 hour because the URFs are based on a catchment size of 10 ha, which was calculated to have a time of concentration less than 1 hour.

Table 4-1: Statistical Rainfall Parameters for Analytical Modelling (Adams & Papa, 2000)

Rainfall Statistics IETD = 1h			
Parameter	**Downsview**	**Bloor Street**	**Ellesmere**
$V_{average}$ (mm)	3.85	4.31	4.07
ζ (mm^{-1})	0.260	0.232	0.246
θ	114	107	117

Complete calibration tables are provided in Appendix D and a summary of the calibrated parameters of Φ and S_d are shown in Table 4-2. It is important to note that the calibrated parameters are area-weighted averages of the pervious and impervious parameters for each URF land use. At the top of Appendix D, the parameters used are stated, including percentage impervious/pervious, roof area, depression storage and soil types (AB, BC and CD). As stated in the described methodology, the base parameters for each URF are taken from the master list found in Appendix B. The runoff was then calculated using Equation 9 and multiplied by the sample area size of 10 ha to produce the annual runoff in cubic metres.

Table 4-2: Calibrated Parameters of Φ and S_d

URF Type	Runoff Coefficient Φ			Depression Storage S_d		
	Base	50%	100%	Base	50%	100%
Low Density Residential	0.44-0.50	0.4-0.47	0.37-0.44	0.85	0.87	0.9
Med. Density Residential	0.61-0.65	0.54-0.6	0.48-0.54	0.25	0.25	0.25
High Density Residential	0.76-0.79	0.68-0.72	0.60-0.65	0.15	0.17	0.19
High Rise Residential	0.58-0.6	0.56-0.6	0.53-0.85	0.38	0.38	0.39
Commercial	0.99	0.92-0.98	0.85-0.97	0.03	0.2	0.2
Institutional & Educational	0.46-0.52	0.44-0.51	0.42-0.49	1.18	1.21	1.25
Open Space	0.13-0.36			2.9-4.9		
Transportation Corridor	0.3-0.91			3.25		
Industrial	0.83-0.89	0.78-0.89		0.1	0.1	0.1

The URF model assumed that no green roofs could be implemented in areas designated as "Open Space" and "Transportation Corridor." For these URFs, the analytical model was only calibrated for the base case. Overall, the calibrated runoff coefficients increased in value with increased impervious land use type. The low-density residential runoff coefficients ranged from 0.54 to 0.66 while the high-density area ranged from 0.91 to 0.97. The URFs representing open green space required the lowest coefficients ranging from 0.13 to 0.43. The calibrated runoff coefficient was higher than expected for the commercial area (base case) and was paired with a small depression storage value. The highest runoff value using the analytical model occurs if the runoff coefficient was 1.0 and the depression storage was 0. Substituting these two values, the maximum runoff volume was 440 mm per year or 44,000 m^3 of total runoff volume on a 10 ha catchment. The average runoff volume predicted by the HSP-F/URF model (Banerjee, 2004) (commercial base case) ranged from 45,222-46,731 m^3 per 10 ha, representing values impossible to obtain using the analytical model. This may have occurred because the analytical parameters for rainfall are statistical long-term averages, obtained from a larger dataset. Since the data in the URF/HSP-F model was based on six years, the years 1990-1996 may have had above average rainfall. Reviewing rainfall data from TRCA, the amount of precipitation during the years 1990 to 1996 was 709 mm (TRCA, 2005). This value was higher than average value predicted by the analytical model parameter of 585 mm, thereby increasing the total annual runoff volume in the HSP-F/URF model. This highlights the importance of ensuring an average dataset is available when using the analytical model.

Each URF has additional characteristics such as roof leader type, soil type, foundation drainage and ditches. The analytical model is not capable of specifically incorporating these parameters. This is a recognized deficiency of using an analytical model, but the goal is to keep the calculations simple. Three different soil types, used in the URF model, are accounted for by using different runoff coefficients. The soil types are classified as AB, BC and CD and lead to three different total runoff volumes as the soils become progressively more resistant to infiltration. Soil AB is a mix of deep sand, deep/shallow loess, aggregated silts, BC is sandy clay, shallow sandy loam and CD soils have significant portions of clay. This amount of detail is appropriate for planning level purposes.

Depression storage followed the same pattern as the runoff coefficients. The less developed land use types such as open space had higher values ranging from 2-5 mm, while commercial and industrial areas had almost no depression storage. As can be seen in Table 4-2, the depression storage had a range of values, representing different soil and surface conditions. Most of the calibrated depression storage values were lower than typical values seen in Table 4-1. During the calibration process, preference was given to selecting the proper runoff coefficient because of the more sensitive relationship of the variable, based on the results of the sensitivity analysis (Section 4.1.4). The runoff coefficient was given calibration priority by having more precision (up to one decimal place). It also represents the physical change in green roof technology and soil conditions and was determined to be more sensitive.

The average absolute percentage difference between the calibrated analytical runoff model and the URF runoff is summarized in Table 4-3 for each general land use type. Percentage differences can be seen in the calibration worksheets in Appendix D.

Table 4-3: % Difference of URFs and Calibrated Analytical Model

URF Type	No Green Roof %	50% Green Roof %	100% Green Roof %
Low Density Residential	2.9	6.1	2.8
Med. Density Residential	3.4	4.7	6.1
High Density Residential	4.0	4.0	7.9
High Rise Residential	3.0	4.8	3.2
Commercial	6.5	4.3	5.9
Institutional & Educational	5.9	6.2	5.5
Open Space	1.9	N/A	N/A
Transportation Corridor	0.3	N/A	N/A
Industrial	8.7	5.9	10.1

A good match can be found for all URF types. When calibrating, a near perfect match can be made for one of the scenarios, however, the goal was to balance the percentage difference among the three scenarios. The commercial and industrial runoff values from the URF model are larger than the maximum that the analytical model could predict. This occurred because the precipitation data used during 1990 to 1996 was higher than average. This should not greatly impact the overall runoff volume aggregation due to the smaller percentages of commercial and industrial areas in the Highland Creek watershed.

During the calibration process, it was found that the analytical model under-predicted the annual runoff volume when no green roof technology was implemented, and over-predicted the annual runoff volume when green roofs were implemented. This suggests that changing the roof area to a pervious area, to represent the implementation of a green roof does not fully account for all the benefits. Factors that might account for this trend include increased infiltration and evaporation from green roofs. The under-prediction produces conservative estimates when quantifying the runoff reduction when using the analytical model. Changes to the model would be required to account for some of these additional benefits of green roofs.

In addition, the CSM has its own inherent differences when modelling flow patterns and paths. Examples include the residential URFs that had roof leaders disconnected or use of roadside ditches without storm sewers. These URFs produced runoff values less than half of their counterparts (with roof leaders connected to a storm sewer) when using the same runoff characteristics. For example, URF #1001 (low density residential) had a runoff of about 18,200 m^3

compared to URF #1019 (low density residential) with a runoff of about 2,645 m^3 in 1990. Both URFs are categorized as low-density residential with an area of 10 hectares, but URF #1019 includes ditches and disconnected roof leaders. It could be reasoned that much higher depression storage occurs with ditches and that the runoff coefficients are lower due to the increased flow paths over pervious areas. URFs with ditches and roof leaders disconnected were not included in the calibrated due to the large difference in runoff coefficient and depression storage. Their calibration was omitted for this applied study because no areas in the Highland Creek HSP-F model were categorized as such and thus they have no impact on the total annual runoff calculation. The Highland Creek also contains the land use types described as AGR, TRY and EIU (agricultural, transportation, educational land uses); however, the URF/HSP-F models did not use this land type. The analytical model was not calibrated for these land use types and they account for a small percentage of the land use (<3%).

4.1.2 Total Runoff Volume

Land use in the Highland Creek watershed is broken down by smaller watersheds and outlined in Appendix B. The Highland Creek watershed has about 10,574.5 ha according to the original data used in the HSP-F model (Banerjee, 2004). The total runoff volume aggregation method ignores the land use areas that have not been calibrated (described above). Since one of the objectives is to determine the relative percentage difference in the reduction of runoff due to green roofs, the small amount of land left un-calibrated does not have a major impact. The percentage of area unaccounted for is 5.6% and assumed as a small amount.

The total annual runoff determined from the analytical model is summarized in Table 4-4. The calibrated model parameters were combined with the quantities of land use to determine the runoff. This runoff value does not include the runoff during the months of January, February and December, because the analytical URFs were originally calibrated excluding those months. Therefore, the runoff values were prorated accordingly by the percentage calculated earlier in Section 4.1.1, Calibration of URFs. The HSP-F model included a component of flow described as subsurface flow or groundwater flow, which is part of the final total runoff volume at the most downstream part of the watershed. As described earlier, the analytical model (Equations 9 and 9b) does provide a methodology to model the groundwater component of the hydrological cycle. To overcome this shortcoming, average baseflow data for the Highland Creek from the TRCA was included with the analytical model to determine the final outflows of the watershed. Analytical rainfall parameters from the Toronto Bloor and Ellesmere weather station were also used with the calibrated model to determine total flow.

Table 4-4: Total Runoff Volume for the Analytical and HSP-F Models

Parameter	Calibrated Area (ha)	Scenario 1: No Green Roofs Million m^3	Scenario 2: 50% Green Roofs Million m^3	Scenario 3: 100% Green Roofs Million m^3
HSP-F Model	10,574.5	39.6	39.1	38.5
Analytical Model w/baseflow	9,986	42.0	40.3	38.7
% Difference		6%	3%	0.5%
Analytical Model (Bloor Street) w/baseflow		43.9	42	40.3
Analytical Model (Ellesmere) w/baseflow		44.5	42.6	40.9

The total outflow from the analytical model and HSP-F model show a good match. For comparison purposes, streamflow data from the TRCA for the past 10 years has recorded 35-45 million m^3 of total flow from the Highland Creek Watershed. The percentage difference between the HSP-F and analytical model range from 0.5% to 6% across the 3 green roof scenarios. These values could be refined by examining how to determine and account for the runoff during winter. Although the original calibration was performed for a period excluding the winter months, the total outflow includes all months. As stated earlier, the runoff during winter months is simply prorated from the total runoff volume. The runoff volume predicted by the analytical model may also be skewed to higher runoff values, since the initial calibration with the URFs was completed with higher than average rainfall data spanning over 6 years. Ensuring that the URFs are calibrated over a more representative time period would increase the confidence of the results. Using the rainfall parameters from other near-by locations, the total annual runoff volume differs by ~5%. Although this difference is small, the rainfall parameters should be reviewed to ensure they reflect the geographic location since rainfall can differ greatly within a small region.

4.1.3 Runoff Reduction

The runoff reduction of implementing green roofs is shown in Table 4-5. Although there were a few concerns in developing the total runoff volume (unknown URFs, industrial under-prediction), the calculation of runoff reduction should diminish most of the issues because we are examining the relative differences.

Table 4-5: Runoff Reduction (Analytical and HSP-F Models)

Parameter	Scenario 2: 50% Green Roofs	Scenario 3: 100% Green Roofs
HSP-F Model	1.3%	2.8%
Analytical Model	4.2%	8.0%

The analytical model shows a higher percentage of runoff volume reduction. Additional work by Banting et al. (2005) found that the total runoff volume was reduced by 4.12-12.3% in a variety of watersheds in the GTA using the URFs developed for Toronto's Wet Weather Flow Study (City of Toronto, 2003). Maunder (2004) performed an HSP-F model on the Markham Branch of the Highland Creek and found that the runoff was reduced by 4% with green roof technology. The Green Build-out Model found that their modeled intensive green roof scenario prevented 10% of total annual stormwater from entering the system (Casey Trees & Limno Tech, 2007). Although others have found that individual green roofs can retain 32-100% of runoff (Kohler et al., 2002; Moran et al., 2003; Moran et al., 2004; Perry, 2003; Sherman, 2005), the overall watershed effect is lower because of the small amount of land green roofs occupy in a watershed. Although the analytical model does not match well with the HSP-F model for runoff reduction, comparison with other research has shown better matches.

4.1.4 Sensitivity Analysis

A simple sensitivity analysis was performed on the analytical model used to predict runoff volumes. The purpose of the analysis was to estimate the rate of change of the model outputs (runoff) with respect to changes in inputs (runoff coefficient Φ and depression storage, S_d). The method used was the most common sensitivity analysis, a sampling based method that involves running the original model for a set of input parameter combinations and determining the sensitivity from the model outputs (Saltelli, 2004). The analytical model or Equation 9 is shown below;

$$R = \theta \frac{\phi}{\zeta} e^{-\zeta S_d} \tag{9}$$

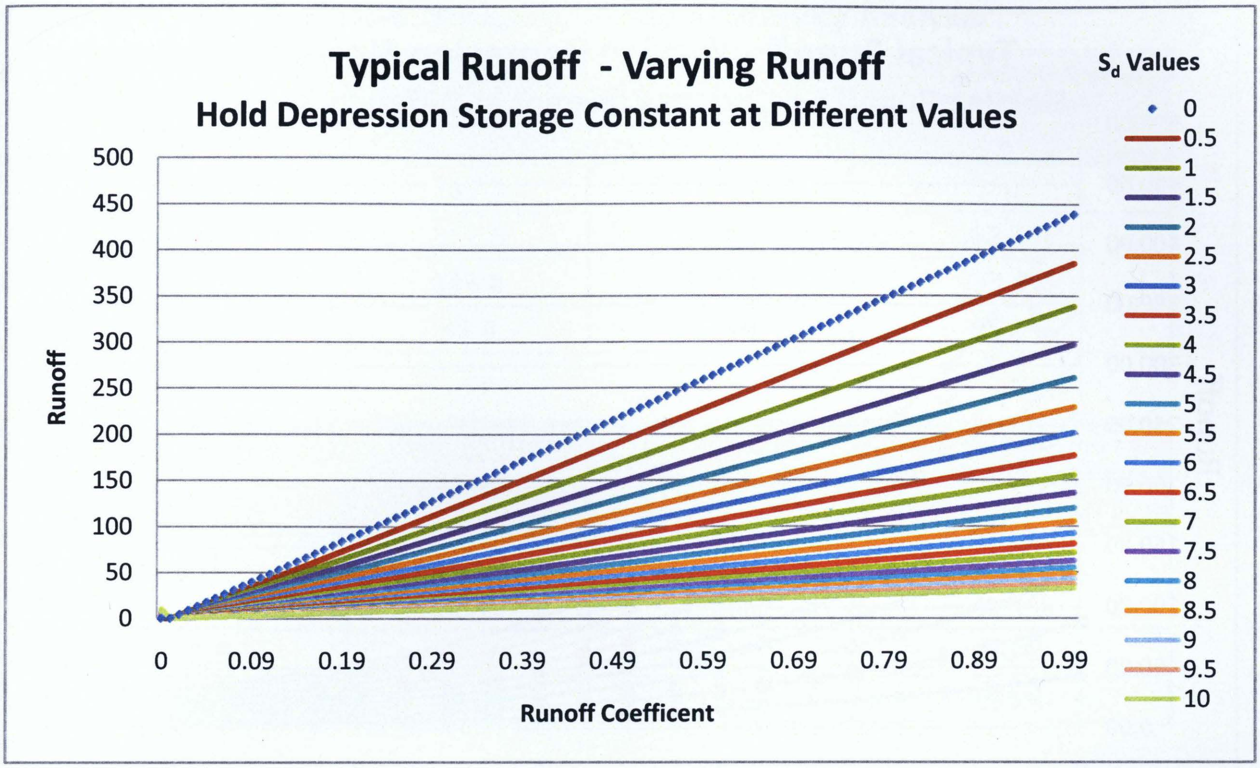
The variables that were calibrated are S_d (depression storage) and Φ (runoff coefficient), which are dependent on the catchment. The rainfall characteristics ζ and θ are constants, which have been tabulated for many major cities and areas in Canada. Due to the simplicity of the model, the sensitivity analysis was not complex and incorporated a minimum, maximum and sampling analysis while holding one of the variables constant.

The runoff coefficient is a unit less measure of the amount of rainfall, in excess of depression storage, that is converted into runoff. Typical values are shown in Table 3-2 and the coefficient has a range from 0 to 1. Assuming that depression storage is a constant over the watershed, the rate of change for the total runoff volume is:

$$\frac{dR}{d\phi} = \frac{\theta}{\zeta} e^{-\zeta S_d} \tag{11}$$

which is a constant value dependent on the statistical rainfall parameters. Figure 4-2 shows the total runoff volume, R, and the effect of varying the runoff coefficient, while holding the depression storage constant (for a range of values). The rate of change is constant as shown in the linearity of the resulting curves. The result is a direct relationship between the runoff coefficient and total runoff volume; if the runoff coefficient doubles, so does the total runoff volume. Therefore the runoff coefficient is not more sensitive at any value.

Figure 4-2: Sensitivity Analysis: Variation of Runoff

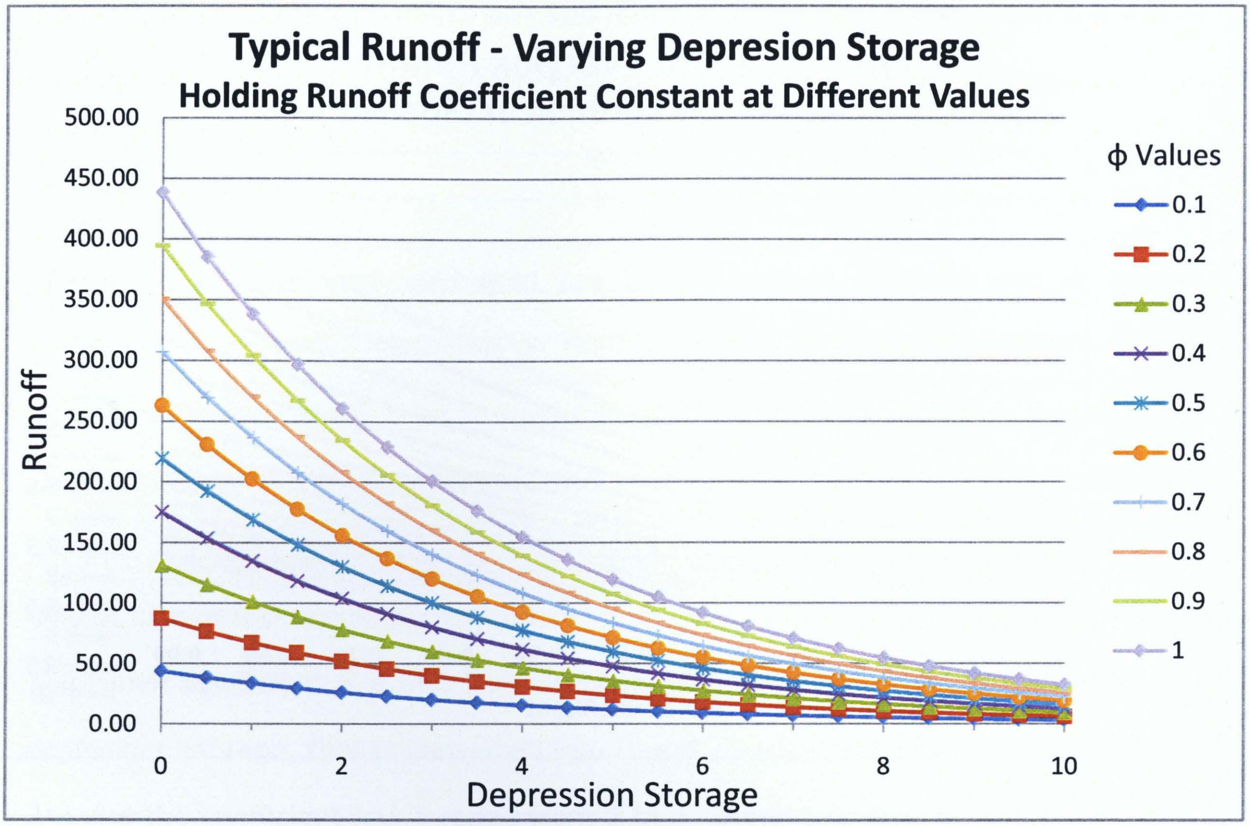


Depression storage cannot be negative and the typical range is 0-7.5 mm as shown in Table 3-1. Taking Equation (9) and assuming that the runoff coefficient is a constant, the rate of change for the total runoff volume dR is:

$$\frac{dR}{dS_d} = \left(\theta \frac{\phi}{\zeta}\right)(-\zeta)\, e^{-\zeta S_d} \tag{12}$$

The rate of change is exponentially decaying. Figure 4-3 shows the total runoff volume, R, and the effect of varying the depression storage. The rate of change has a higher magnitude when the depression storage is low, such as between the values of 0 and 3.

Figure 4-3: Sensitivity Analysis: Variation of Depression Storage



Sampling analysis was performed using a residential high density catchment, 50% green roof scenario (S_d=0.17, Φ=0.68). The results of the analysis are shown Table 4-6.

Table 4-6: Sampling Based Sensitivity Analysis

Runoff Coefficient S_d=0.17	Total Runoff Volume	% Difference Total Runoff	% Difference Runoff Coefficient
0.68	285.3	0	0
0.9	377.6	32.4%	32.4%
0.45	188.8	33.8%	33.8%
0.1	42.0	85.3%	85.3%

Depression Storage Φ=0.68	Total Runoff Volume	% Difference Total Runoff	% Difference Depression Storage
0.17	285.3	0	0
1	229.9	19.4%	47.1%
2.5	155.6	45.4%	267%
5	81.3	71.5%	635%

The results from the sampling analysis show that a change in runoff coefficient results in a greater change in the total runoff volume than the depression storage. As shown in the rate of change equation for the runoff coefficient, the derivative is a constant value. A 50% change in the runoff coefficient results in a 50% change in the total runoff volume. The relationship with depression storage is different. A much larger change in depression storage must occur before an equal change in total runoff volume is observed.

4.2 Application of Calibrated Model

Using Toronto's WWFMMP data and the developed URFs, the reduction of runoff from the implementation of green roof technology was estimated by others (Banting et al., 2005). The predicted runoff with and without green roof technology is summarized in Table 4-7.

Table 4-7: Runoff Reduction of Various Watersheds (Banting et al., 2005)

Watershed	No Green Roofs (m^3)	100% Implementation of Green Roof (m^3)	Runoff Reduction (m^3)	Runoff Reduction (%)
Don River	34,039,315	31,712,567	2,326,748	6.84%
Don River Main	8,828,582	8,341,255	487,327	5.52%
Don River West	2,335,424	2,067,991	267,433	11.45%
Eastern Beaches Tunnel	1,248,587	1,193,737	54,851	4.39%
Etobicoke Creek	4,672,633	4,220,926	451,708	9.67%
Highland Creek	28,169,911	25,976,604	2,193,308	7.79%
Humber River	28,938,192	26,585,595	2,352,597	8.13%
Inner Harbour & Coatsworth Cut	10,774,454	9,449,024	1,325,430	12.30%
Lake Ontario	6,864,077	6,245,024	619,053	9.02%
Massey Creek	5,670,812	5,262,666	408,145	7.20%
Mimico Creek	9,200,720	8,366,329	834,391	9.07%
Rouge	5,893,065	5,319,632	573,433	9.73%
Waterfront	3,356,652	3,218,297	138,355	4.12%
Western Beaches Tunnel	7,641,430	6,993,439	647,991	8.48%

The runoff reduction potential of green roofs from this study ranges from 4% to 12%. Using the analytical model, the runoff reduction of the Highland Creek was estimated at 4% (50% green roofs) and 8% (100% green roofs) which is within the range of the values developed by Banting et al. (2005) using the 100% green roof scenario. The calibrated parameters and the analytical model discussed in this report were used to predict the total runoff volume and runoff volume reduction from the same watersheds as shown in Table 4-7. The final results of this comparison are shown in Table 4-8. A complete list of values, including the land area of the basins, for total runoff volume without green roof technology is shown in Appendix E.

Table 4-8: Comparison of Runoff Reduction from Using Green Roofs

Watershed	% Runoff Reduction (Banting et al., 2005)	% Runoff Reduction Analytical Model
Don River	6.84%	15.02%
Don River Main	5.52%	9.39%
Don River West	11.45%	13.17%
Eastern Beaches Tunnel	4.39%	9.05%
Etobicoke Creek	9.67%	10.90%
Highland Creek	7.79%	8%
Humber River	8.13%	11.60%
Inner Harbour & Coatsworth Cut	12.30%	11.11%
Lake Ontario	9.02%	10.50%
Massey Creek	7.20%	12.94%
Mimico Creek	9.07%	11.17%
Rouge	9.73%	10.58%
Waterfront	4.12%	8.36%
Western Beaches Tunnel	8.48%	10.02%
Average Reduction	8%	11%

The results show that the runoff reduction values generated from the calibrated models exceed the data generated for the GTA watersheds. Relatively good matches were found for the Etobicoke Creek, Inner Harbour & Coatsworth Cut, Lake Ontario, and Rouge watersheds. In general, the analytical model predicted a greater runoff reduction (11%) than the work performed by Banting et al. (2005) (8%). This finding is similar to the initial calibration and comparison in Section 4.1.3.

The reduction percentage for the watersheds of the Don River, Eastern Beaches Tunnel and Waterfront showed a significant difference. It was expected that the difference in runoff reduction would be smaller, because of the averaging effect of large watersheds in the HSP-F/URF models. One hectare of light residential area in one watershed should behave similar to another one in a nearby watershed. The remapping of land use codes is one source of error because of the uncertainty of the exact land use designation from that source. In addition, the calibrated analytical model has built-in parameters that reflect the characteristics of the Highland Creek Watershed. Applying these characteristics to other watersheds may produce results that do not match well. Since there are no other documented continuous simulations of the other watersheds with green roofs, the comparison of these results should not validate or invalidate the methodology of using an analytical model. As can be seen from the results, both methods are based or calibrated to the HSP-F/URF model of the Highland Creek and produced different results.

4.3 Peak Flow Analytical Model

To calculate the peak flow from the Highland Creek watershed, the time of concentration (t_c) was first determined. Using Equations 11 & 12 and the methodology described earlier, the t_c of the Highland Creek was found to be 8.2 hours. The corresponding peak flows from the analytical model (Equation 13) were then determined for all the storm events provided in the Hydrology Update by Aquafor Beech (2004) (Appendix G). The results from Equation 13 are shown in Table 4-9.

Table 4-9: Results of Analytical Peak Flow

Storm ID	Peak Flow Analytical Model m^3/s	Peak Flow Measured Storm m^3/s (Aquafor Beech Ltd., 2004)	% Difference Analytical/Measured %
1	47.8	123.0	61%
2	44.9	87.0	48%
3	66.6	114.0	42%
4	83.1	18.0	362%
5	44.0	22.0	100%
6	33.9	30.0	13%
7	36.2	48.0	25%

The analytical model used to predict peak flow shows a poor correlation to the measured peak flow events of the Highland Creek. The results show a large range of difference due to the crude development of the input parameters and methodology used in Equation 13. The depression storage and ultimate infiltration capacity are calculated from the area weighted average of the entire catchment. This method does capture how the catchment reacts to peak flow because it is treated as a homogenous parcel of land. The analytical model assumes uniform rainfall intensity, however none of the rainfall events were uniform (Appendix G). During real storms the rainfall intensity varies over time and space. Several of these issues could be resolved by further dividing the sub-catchment of the Highland Creek into smaller and finer catchments with specific input parameters; however, this increases the complexity of using the analytical model. Hydraulic routing of the storm flow is not accounted for in the analytical model; but plays a large role in peak flow determination. Although most of the storms were not closely matched by the analytical model, peak flow for Storm ID 6 and 7 were relatively close. Analyzing those two storms, the peak flow reduction of green roof implementation was calculated to range from 11 to 20%.

The peak flow reduction using the analytical model is higher than the 3% and 4% as predicted by Maunder (2004). Research is limited on the overall peak flow reduction on a watershed basis. Other studies have found peak flow reductions ranging from 46-90% from individual green roofs (Moran et al., 2003; Moran et al., 2004; TRCA, 2005). The underlying basis of the analytical model was to vary the runoff coefficient or the impervious area assuming that available roof area could be switched to a pervious area. Not enough data from other studies are available to validate or compare the results obtained from the peak flow runoff reduction. The results of the peak flow may not be accurate results, however the exercise was easy to complete and may still provide a first estimate of peak flow reduction for planning purposes if additional and long-term data is available for calibration.

CHAPTER 5

5.0 SUMMARY AND CONCLUSION

Urbanization has greatly changed the hydrological cycle and stormwater flow patterns, requiring mitigation measures to accommodate excess runoff from rainwater, flooding, erosion and water pollution. The design of urban storm water management systems have greatly evolved with the aid of computerized assistance and models. The design process typically involves running continuous simulation models to predict outputs such as storm runoff volumes, peak flow, water quality parameters, combined sewer overflows etc. During the early stages of urban stormwater design, the final details of the drainage system have yet to be determined. The amount of effort required to generate a continuous simulation model based on unknown variables may not be cost effective. An alternative type of modelling can be used for such instances when a preliminary characterization is required for planning purposes. Based primarily on statistics, analytical modelling can be used during the planning stage of the design. Important parameters during the planning stages for stormwater design include total runoff volume and peak flow for a given catchment.

Green roof technology has been identified as a BMP and increased the use of green roofs within urban drainage systems. Various studies on green roofs have found that they retain and delay stormwater and offer filtering effects to improve water quality. Significant non-hydrological benefits have been studied and identified such as energy savings, air quality improvement and psychological effects, thus providing further support for usefulness of green roofs. Green roof research has mainly focused on evaluating the hydrological reaction of a single green roof to rain events. The research is limited on how a series of green roofs performs over a watershed. This study models the hydrological benefits of green roofs over a watershed.

Using the Highland Creek Watershed as a case study, an analytical URF model was developed and calibrated to a CSM (HSP-F) developed by Banerjee (2004). The original work by Banerjee (2004) also included developing URFs for land use types with green roofs. The URF calibration process involved changing the catchment parameters of runoff coefficient and depression storage to match total runoff volume. The analytical URF calibrations were successful, with an overall agreement of less than 8% difference between the HSP-F model. The calibrated parameters were close to typical values for their corresponding land use. The average percentage difference of annual runoff (not including industrial land use) between the HSP-F URFs and analytical URF model ranged from 3.7% to 7.8%. A near perfect match was made for the runoff scenario of High Density Residential land (50% green roof implementation); however, the goal was to balance the percentage difference among the three scenarios: base case (no green roof), 50% green roofs and 100% green roofs.

The calibrated analytical URF model and the land use area data of the Highland Creek watershed were used to calculate the annual total runoff volume. Using the aggregation method a good match was obtained when comparing the aggregate runoff volume of the HSP-F and analytical URF model. The percentage difference between the analytical and HSP-F model for total annual runoff (including base flow) from the watershed was 0.5%, 3% and 6% for the three scenarios. For the total annual runoff volume reduction, the analytical model showed a 4.2% and

8.0% annual runoff reduction with 50% and 100% green roof implementation, respectively. The corresponding runoff reductions from the HSP-F model were 1.3% and 2.8%. Since the annual runoff volume reduction determines the relative differences between the scenarios, the error and inaccuracies are diminished. Using the calibrated analytical URF parameters, the runoff reductions from additional watersheds across the GTA were calculated, resulting in a range of 8% to 15% reduction for the entire region. Other studies have produced values comparable to the analytical model results. For example, Banting et al. (2005) found that the total runoff volume was reduced by 4.12%-12.3% when implementing green roofs in a variety of watersheds in the GTA, and Aquafor Beech (2000) found that the runoff was reduced by 4% with green roofs within the Markham Branch of the Highland Creek. A conclusive statement concerning the accuracy of the analytical model for runoff volume reduction could not be provided. As indentified earlier, the research on quantifying watershed hydrological benefits of green roofs remains limited.

The additional exercise of determining peak flow using analytical tools did not produce results that agreed well with previous studies. This may be due to the area-averaged parameters used in the analytical peak flow model. This method does not capture how the catchment reacts to peak flow since the catchment is treated as a homogenous parcel of land. Unlike the runoff estimate, which was independent of the routing mechanics, the peak flow estimation using analytical models may suffer from averaging catchment properties, uniform rainfall intensity and lack of routing mechanisms. Using observed data and a calibrated simulation model produced for the Highland Creek Watershed (Aquafor Beech, 2004) as a basis for comparison, the analytical peak flow model showed peak flow reduction of 13-363%. Maunder (2004), using the HSP-F model, determined the instantaneous peak flow volume reduction to be approximately 3% and 4% using green roof technology. However, the number of available observations was insufficient to provide rigorous evaluation of the analytical model's results for peak flow reduction. Several key findings of this applied study are presented below:

- The analytical model is simple and does not include all the details of the HSP-F/URF model, such as roof leaders and road side ditches.
- The percentage difference between the analytical and HSP-F model for total annual runoff (including base flow) from the watershed was 0.5%, 3% and 6% for the three scenarios
- The total annual runoff volume reduction, as predicted by the analytical model showed a 4.2% and 8.0% annual runoff reduction with 50% and 100% green roof implementation
- The original URF model was based on 6 years of rainfall/runoff data which is not sufficient for long term statistical analysis of average rainfall events.
- The routing mechanics of the HSP-F model and the analytical model differ. Since the analytical model directly transforms the rainfall into runoff, water losses and gains within a watershed is ignored. This impact was minimized in this study by comparing the total runoff total volume over a year and not per event. Routing does not play a significant role when determining the annual runoff; however, it plays a large role during peak flow determination.

- The sensitivity of the analytical model shows that a much larger change in the depression storage parameter must occur before an equal change in total runoff volume is observed. As such, the runoff coefficient was given calibration priority which may lead to selecting depression storage values outside their normal range.
- Results using the peak flow analytical model did not provide good results. There is a lack of observed long-term peak flow data to perform a calibration.

This study attempted to calibrate an analytical model based on a CSM to produce results for total runoff volume with reasonable accuracy. After successful calibration, the model was then used in two applications to determine the total runoff volume and runoff volume reduction due to green roofs. The results indicate that green roof technology could play a role in stormwater management at the watershed level, although the current research is somewhat limited to provide an adequate comparison. To assist future work and research the following recommendations are provided:

- Refinement and/or modification to the analytical model and tools such as incorporating additional details, additional land use types and ensuring all of the area and land use types are included
- Future use of the analytical URF model should ensure that the original calibration dataset represents a statistically average sample with sufficient long-term data

- Although the difference in total runoff by selecting analytical rainfall parameters from different geographic locations is small, rainfall can vary greatly within a small region

The analytical model was simple to use, contained within a spreadsheet program. It was designed for quick recalibration and analysis of multiple watersheds. The analytical URF approach provides reasonable, high-level estimates of the hydrologic benefits. Analytical URFs can be generated for any watershed by changing a few parameters. With additional refinements and research, improvements can be made. Therefore, this analytical tool is an effective means for studying the watershed-level effects of implementing green roof technology and other stormwater management practices. The existing green roof projects in North America are mainly isolated, single building efforts within large urban areas. If planners are able to determine the benefits of green roofs under different scenarios, the cities, regions and municipalities may be able to enact policies to encourage the use of green roofs. With further study and refinement of the methods in this study, calibrated analytical URF models can achieve a pivotal role in the development of stormwater management policy.

APPENDIX A: STATISTICAL RAINFALL DATA (IETD 1HR)

(ADAMS & PAPA, 2004)

Table B.1 Rainfall Statistics of Rain Season (IETD = 1 h)

AES ID	Location	Months	Years of Record	$\bar{t}$ (h)	λ (h^{-1})	$\bar{b}$ (h)	ψ^a (h^{-1})	ψ^b (h^{-1})	$\bar{v}$ (mm)	ζ (mm^{-1})	$\bar{i}$ (mm/h)	β (h/mm)	θ (#/yr)
1018610	Victoria Gonzales Hts.	1–12	1960–83	2.69	0.372	34.3	0.0291	0.0300	2.52	0.397	0.693	1.44	236
1018620	Victoria Int'l Airport	1–12	1964–83	3.03	0.330	29.0	0.0373	0.0357	2.88	0.348	0.670	1.49	274
1108447	Vancouver Int'l Airport	1–12	1960–83	3.47	0.288	26.8	0.0373	0.0388	3.70	0.271	0.764	1.31	289
1108487	Vancouver UBC	1–12	1960–83	3.49	0.278	25.1	0.0398	0.0415	3.94	0.254	0.772	1.30	305
1123970	Kelowna Airport	1–12	1968–83	2.25	0.444	64.9	0.0154	0.0156	1.83	0.546	0.664	1.51	130
3012205	Edmonton Airport	4–10	1961–83	2.54	0.394	47.7	0.0210	0.0214	3.15	0.317	0.992	1.01	104
3031093	Calgary Airport	5–10	1960–83	2.42	0.413	50.4	0.0198	0.0202	3.04	0.329	1.05	0.953	84.8
3033880	Lethbridge Airport	4–10	1960–83	2.68	0.373	71.2	0.0141	0.0142	3.53	0.283	1.05	0.951	70.3
4015320	Moose Jaw Airport	4–11	1960–83	2.38	0.421	65.0	0.0154	0.0156	3.20	0.313	1.10	0.909	77.9
4016560	Regina Airport	4–10	1960–83	2.33	0.430	60.3	0.0166	0.0169	3.14	0.319	1.12	0.895	83.7
4057120	Saskatoon Airport	4–10	1960–83	2.24	0.446	61.1	0.0164	0.0166	2.89	0.346	1.06	0.941	82.8
5023222	Winnipeg Int'l Airport	4–10	1960–83	2.40	0.416	49.9	0.0201	0.0204	3.84	0.261	1.29	0.778	100
6048261	Thunder Bay Airport	4–10	1960–83	2.61	0.384	41.2	0.0243	0.0249	4.01	0.249	1.23	0.810	120
6057592	Sault Ste Marie Airport	4–10	1961–83	2.60	0.385	37.0	0.0270	0.0278	3.70	0.270	1.13	0.881	131
6104175	Kingston Pumping Stn.	3–11	1960–83	2.75	0.363	46.3	0.0216	0.0221	4.04	0.247	1.21	0.829	135
6106000	Ottawa Int'l Airport	3–11	1967–83	2.81	0.356	41.0	0.0244	0.0250	4.01	0.249	1.23	0.812	152
6135638	Niagara Falls	3–11	1965–83	2.68	0.374	46.3	0.0216	0.0221	4.18	0.239	1.37	0.732	136
6139525	Windsor Airport	3–11	1960–83	2.69	0.371	45.0	0.0222	0.0227	4.61	0.217	1.53	0.651	140
6140954	Brantford MOE	3–11	1961–83	2.62	0.381	47.8	0.0209	0.0214	4.17	0.240	1.36	0.735	121
6144475	London Airport	3–11	1960–83	2.68	0.373	40.3	0.0248	0.0254	3.96	0.253	1.27	0.785	155
6153194	Hamilton Airport	3–11	1970–83	2.87	0.348	40.5	0.0247	0.0253	4.19	0.239	1.26	0.794	153
6153300	Hamilton RBG	3–11	1962–83	2.65	0.378	58.3	0.0171	0.0175	4.38	0.228	1.46	0.683	109
6155878	Oshawa WPCP	3–11	1960–83	2.47	0.405	54.5	0.0184	0.0187	3.74	0.267	1.21	0.823	114
6158350	Toronto Bloor Street	3–11	1937–83	2.73	0.367	58.5	0.0170	0.0174	4.31	0.232	1.38	0.724	107
6158443	Toronto Downsview	3–11	1964–82	2.50	0.400	55.9	0.0179	0.0182	3.85	0.260	1.36	0.735	114
6158520	Toronto Ellesmere	3–11	1966–83	2.63	0.380	54.0	0.0185	0.0189	4.07	0.246	1.33	0.751	117
6158525	Toronto Etobicoke	3–11	1963–80	2.64	0.379	53.7	0.0186	0.0190	4.07	0.245	1.33	0.752	119
6158733	Toronto Int'l Airport	3–11	1960–92	2.69	0.372	34.9	0.0287	0.0295	4.05	0.247	1.31	0.763	126
6158740	Toronto Met. Res. Stn.	3–11	1965–83	2.56	0.391	54.8	0.0183	0.0186	3.74	0.267	1.23	0.813	118
6158875	Trenton Airport	3–11	1964–83	2.75	0.363	50.3	0.0199	0.0203	4.09	0.245	1.24	0.808	126
6166450	Peterborough STP	4–11	1964–83	2.61	0.383	42.5	0.0235	0.0241	3.83	0.261	1.27	0.790	130
7016294	Quebec Airport	4–11	1961–83	2.96	0.338	35.7	0.0280	0.0228	4.68	0.214	1.32	0.756	154
7025250	Montreal Int'l Airport	3–11	1943–83	2.74	0.365	37.7	0.0265	0.0272	3.69	0.271	1.12	0.895	164
7025280	Montreal McGill	3–11	1960–83	2.86	0.350	39.0	0.0257	0.0263	4.15	0.241	1.27	0.786	157
8101600	Fredericton CDA	4–11	1960–83	2.96	0.338	40.1	0.0250	0.0256	4.36	0.229	1.12	0.890	139
8104900	Saint John Airport	4–11	1960–83	3.09	0.323	34.7	0.0288	0.0297	5.39	0.185	1.13	0.888	158
8202200	Halifax	3–12	1960–74	3.03	0.330	38.2	0.0216	0.0269	4.47	0.224	1.01	0.992	178
8300400	Charlottetown CDA	4–11	1960–83	2.36	0.424	37.4	0.0268	0.0275	4.04	0.247	0.961	1.04	145
	Maximum Value			3.49	0.446	71.2	0.0398	0.0415	5.39	0.546	1.53	1.51	305
	Minimum Value			2.24	0.278	25.1	0.0141	0.0142	1.83	0.185	0.664	0.651	70.3

Table B.2 Rainfall Statistics of Rain Season (IETD = 2 h)

AES ID	Location	Months	Years of Record	$\bar{t}$ (h)	λ (h^{-1})	$\bar{b}$ (h)	ψ^a (h^{-1})	ψ^b (h^{-1})	$\bar{v}$ (mm)	ζ (mm^{-1}	$\bar{i}$ (mm/h)	β (h/mm)	θ (#/yr)
1018610	Victoria Gonzales Hts.	1–12	1960–83	3.71	0.269	43.6	0.0229	0.0240	3.22	0.331	0.675	1.48	185
1018620	Victoria Int'l Airport	1–12	1964–83	4.27	0.234	37.7	0.0265	0.0280	3.77	0.265	0.667	1.50	209
1108447	Vancouver Int'l Airport	1–12	1960–83	4.86	0.206	34.9	0.0287	0.0304	4.85	0.206	0.763	1.31	220
1108487	Vancouver UBC	1–12	1960–83	5.16	0.194	33.3	0.0300	0.0319	5.29	0.189	0.771	1.30	228
1123970	Kelowna Airport	1–12	1968–83	2.90	0.345	77.6	0.0129	0.0132	2.19	0.456	0.665	1.53	109
3012205	Edmonton Airport	4–10	1961–83	3.30	0.303	57.7	0.0173	0.0180	3.83	0.261	0.991	1.01	85.3
3031093	Calgary Airport	5–10	1960–83	3.08	0.325	59.8	0.0167	0.0173	3.62	0.276	1.04	0.957	71.1
3033880	Lethbridge Airport	4–10	1960–83	3.47	0.288	86.3	0.0116	0.0119	4.29	0.233	1.04	0.961	57.8
4015320	Moose Jaw Airport	4–11	1960–83	2.97	0.337	76.2	0.0131	0.0135	3.76	0.266	1.11	0.898	66.3
4016560	Regina Airport	4–10	1960–83	3.03	0.330	72.8	0.0137	0.0141	3.80	0.263	1.13	0.881	69.1
4057120	Saskatoon Airport	4–10	1960–83	2.86	0.350	72.5	0.0138	0.0142	3.44	0.291	1.06	0.944	69.6
5023222	Winnipeg Int'l Airport	4–10	1960–83	3.12	0.321	60.1	0.0166	0.0172	4.64	0.215	1.27	0.786	82.9
6048261	Thunder Bay Airport	4–10	1960–83	3.38	0.295	49.9	0.0200	0.0209	4.88	0.205	1.23	0.816	98.5
6057592	Sault Ste Marie Airport	4–10	1961–83	3.53	0.283	46.3	0.0216	0.0226	4.67	0.214	1.15	0.868	104
6104175	Kingston Pumping Stn.	3–11	1960–83	3.68	0.272	57.5	0.0174	0.0180	5.04	0.198	1.22	0.820	108
6106000	Ottawa Int'l Airport	3–11	1967–83	3.73	0.268	50.8	0.0197	0.0205	4.99	0.200	1.26	0.794	122
6135638	Niagara Falls	3–11	1965–83	3.49	0.286	56.3	0.0178	0.0184	5.11	0.196	1.38	0.724	111
6139525	Windsor Airport	3–11	1960–83	3.52	0.284	54.9	0.0182	0.0189	5.65	0.177	1.57	0.636	114
6140954	Brantford MOE	3–11	1961–83	3.45	0.290	58.4	0.0171	0.0177	5.12	0.195	1.35	0.741	98.3
6144475	London Airport	3–11	1960–83	3.58	0.280	49.8	0.0201	0.0209	4.92	0.203	1.28	0.782	125
6153194	Hamilton Airport	3–11	1970–83	3.84	0.260	50.4	0.0198	0.0207	5.24	0.191	1.27	0.788	122
6153300	Hamilton RBG	3–11	1962–83	3.45	0.290	70.9	0.0141	0.0145	5.34	0.187	1.47	0.680	89.0
6155878	Oshawa WPCP	3–11	1960–83	3.19	0.313	65.7	0.0152	0.0157	4.52	0.221	1.22	0.817	94.0
6158350	Toronto Bloor Street	3–11	1937–83	3.48	0.288	70.4	0.0142	0.0146	5.17	0.193	1.40	0.716	89.4
6158443	Toronto Downsview	3–11	1964–82	3.25	0.308	67.7	0.0148	0.0152	4.67	0.214	1.40	0.716	93.3
6158520	Toronto Ellesmere	3–11	1966–83	3.47	0.288	66.3	0.0151	0.0156	5.01	0.200	1.34	0.748	95.4
6158525	Toronto Etobicoke	3–11	1963–80	3.46	0.289	65.7	0.0152	0.0157	5.00	0.200	1.34	0.744	96.6
6158733	Toronto Int'l Airport	3–11	1960–92	3.55	0.282	43.4	0.0230	0.0236	5.00	0.200	1.32	0.758	104
6158740	Toronto Met. Res. Stn.	3–11	1965–83	3.39	0.295	67.3	0.0149	0.0153	4.62	0.217	1.22	0.817	95.8
6158875	Trenton Airport	3–11	1964–83	3.64	0.274	[illegible]	0.0161	0.0167	5.06	0.198	1.26	0.791	102
6166450	Peterborough STP	4–11	1964–83	3.48	0.287	[illegible]	0.0191	0.0198	4.75	0.211	1.27	0.785	105
7016294	Quebec Airport	4–11	1961–83	3.89	0.257	[illegible]	0.0227	0.0238	5.79	0.173	1.36	0.735	124
7025250	Montreal Int'l Airport	3–11	1943–83	3.66	0.273	46.7	0.0214	0.0240	4.60	0.217	1.12	0.896	132
7025280	Montreal McGill	3–11	1960–83	3.82	0.262	48.4	0.0206	0.0216	5.18	0.193	1.29	0.774	126
8101600	Fredericton CDA	4–11	1960–83	4.09	0.244	51.3	0.0195	0.0203	5.62	0.178	1.14	0.878	108
8104900	Saint John Airport	4–11	1960–83	4.20	0.238	43.9	0.0228	0.0239	6.86	0.146	1.14	0.877	124
8202200	Halifax	3–12	1960–74	4.23	0.236	49.4	0.0203	0.0211	5.81	0.172	1.02	0.977	137

76

Appendix B: URFs Developed for the HSP-F Model (Maunder, 2004)

URF LIST and WDM Slot Numbering

Common HSP-F Unit-Area Response Function Listing

Land-Use					WDM Slot Number (DSN)	Roof Options		Connectivity						Soil Classifications			Measured Land Surface-Type Breakdown									Timeseries Units	Timeseries Consituent
								Roof Leaders		Footing Drains			Roadside Ditches	SCS Soil Types			Impervious Category					Pervious Category		Measured Totals			
Class	Category	Flow Component	Code	SubCode		Peaked	Flat	Connected	Disconnected	Connected to Sanitary	Disconnected	Connected to Storm	(No Storm Sewer)	A,AB	B,BC	C-D	Roofs (%)	Roads (%)	Parking (%)	Driveways (%)	Walks/Patio (%)	Lawns (%)	Open Space (%)	Impervious TIMP (%)	Pervious TPER (%)		
Residential	Low-Density Residential	Surface	RLD	1ab	1001	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1bc	1002	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1cd	1003	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2ab	1004	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2bc	1005	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2cd	1006	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3ab	1007	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3bc	1008	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3cd	1009	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4ab	1010	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4bc	1011	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4cd	1012	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5ab	1013	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5bc	1014	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5cd	1015	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6ab	1016	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6bc	1017	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6cd	1018	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7ab	1019	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7bc	1020	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7cd	1021	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8ab	1022	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8bc	1023	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8cd	1024	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
		Subsurface	RLD	1abx	1501	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1bcx	1502	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1cdx	1503	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2abx	1504	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2bcx	1505	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2cdx	1506	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3abx	1507	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3bcx	1508	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3cdx	1509	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4abx	1510	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4bcx	1511	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4cdx	1512	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5abx	1513	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5bcx	1514	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5cdx	1515	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6abx	1516	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6bcx	1517	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6cdx	1518	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7abx	1519	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7bcx	1520	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7cdx	1521	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8abx	1522	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8bcx	1523	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8cdx	1524	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
	Medium-Density Residential	Surface	RMD	1ab	1101	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1bc	1102	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1cd	1103	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2ab	1104	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2bc	1105	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2cd	1106	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3ab	1107	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3bc	1108	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3cd	1109	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4ab	1110	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4bc	1111	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4cd	1112	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5ab	1113	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5bc	1114	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5cd	1115	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6ab	1116	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6bc	1117	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6cd	1118	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7ab	1119	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7bc	1120	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7cd	1121	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8ab	1122	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8bc	1123	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8cd	1124	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
		Subsurface	RMD	1abx	1601	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1bcx	1602	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1cdx	1603	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2abx	1604	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2bcx	1605	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2cdx	1606	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3abx	1607	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3bcx	1608	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3cdx	1609	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4abx	1610	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4bcx	1611	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4cdx	1612	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5abx	1613	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW

URF LIST and WDM Slot Numbering

Common HSP-F Unit-Area Response Function Listing

Land-Use					WDM Slot Number	Roof Options		Connectivity						Soil Classifications			Measured Land Surface-Type Breakdown									Timeseries Units	Timeseries Consituent
								Roof Leaders		Footing Drains			Roadside Ditches	SCS Soil Types			Impervious Category					Pervious Category		Measured Totals			
Class	Category	Flow Component	Code	SubCode	(DSN)	Peaked	Flat	Connected	Disconnected	Connected to Sanitary	Disconnected	Connected to Storm	(No Storm Sewer)	A,AB	B,BC	C-D	Roofs (%)	Roads (%)	Parking (%)	Driveways (%)	Walks/Patio (%)	Lawns (%)	Open Space (%)	Impervious TIMP (%)	Pervious TPER (%)		
Residential	Low-Density Residential	Surface	RLD	1ab	1001	✓	×	✓	×	✓	×	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1bc	1002	✓	×	✓	×	✓	×	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1cd	1003	✓	×	✓	×	✓	×	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2ab	1004	✓	×	✓	×	×	✓	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2bc	1005	✓	×	✓	×	×	✓	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2cd	1006	✓	×	✓	×	×	✓	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3ab	1007	✓	×	×	✓	✓	×	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3bc	1008	✓	×	×	✓	✓	×	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3cd	1009	✓	×	×	✓	✓	×	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4ab	1010	✓	×	×	✓	×	✓	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4bc	1011	✓	×	×	✓	×	✓	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4cd	1012	✓	×	×	✓	×	✓	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5ab	1013	✓	×	✓	×	×	×	✓	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5bc	1014	✓	×	✓	×	×	×	✓	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5cd	1015	✓	×	✓	×	×	×	✓	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6ab	1016	✓	×	×	✓	×	×	✓	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6bc	1017	✓	×	×	✓	×	×	✓	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6cd	1018	✓	×	×	✓	×	×	✓	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7ab	1019	✓	×	×	✓	✓	×	×	✓	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7bc	1020	✓	×	×	✓	✓	×	×	✓	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7cd	1021	✓	×	×	✓	✓	×	×	✓	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8ab	1022	✓	×	×	✓	×	✓	×	✓	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8bc	1023	✓	×	×	✓	×	✓	×	✓	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8cd	1024	✓	×	×	✓	×	✓	×	✓	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
		Subsurface	RLD	1abx	1501	✓	×	✓	×	✓	×	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1bcx	1502	✓	×	✓	×	✓	×	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1cdx	1503	✓	×	✓	×	✓	×	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2abx	1504	✓	×	✓	×	×	✓	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2bcx	1505	✓	×	✓	×	×	✓	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2cdx	1506	✓	×	✓	×	×	✓	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3abx	1507	✓	×	×	✓	✓	×	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3bcx	1508	✓	×	×	✓	✓	×	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3cdx	1509	✓	×	×	✓	✓	×	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4abx	1510	✓	×	×	✓	×	✓	×	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4bcx	1511	✓	×	×	✓	×	✓	×	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	4cdx	1512	✓	×	×	✓	×	✓	×	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5abx	1513	✓	×	✓	×	×	×	✓	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5bcx	1514	✓	×	✓	×	×	×	✓	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	5cdx	1515	✓	×	✓	×	×	×	✓	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6abx	1516	✓	×	×	✓	×	×	✓	×	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6bcx	1517	✓	×	×	✓	×	×	✓	×	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6cdx	1518	✓	×	×	✓	×	×	✓	×	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7abx	1519	✓	×	×	✓	✓	×	×	✓	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7bcx	1520	✓	×	×	✓	✓	×	×	✓	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7cdx	1521	✓	×	×	✓	✓	×	×	✓	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8abx	1522	✓	×	×	✓	×	✓	×	✓	✓	×	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8bcx	1523	✓	×	×	✓	×	✓	×	✓	×	✓	×	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8cdx	1524	✓	×	×	✓	×	✓	×	✓	×	×	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
	Medium-Density Residential	Surface	RMD	1ab	1101	✓	×	✓	×	✓	×	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1bc	1102	✓	×	✓	×	✓	×	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1cd	1103	✓	×	✓	×	✓	×	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2ab	1104	✓	×	✓	×	×	✓	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2bc	1105	✓	×	✓	×	×	✓	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2cd	1106	✓	×	✓	×	×	✓	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3ab	1107	✓	×	×	✓	✓	×	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3bc	1108	✓	×	×	✓	✓	×	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3cd	1109	✓	×	×	✓	✓	×	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4ab	1110	✓	×	×	✓	×	✓	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4bc	1111	✓	×	×	✓	×	✓	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4cd	1112	✓	×	×	✓	×	✓	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5ab	1113	✓	×	✓	×	×	×	✓	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5bc	1114	✓	×	✓	×	×	×	✓	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5cd	1115	✓	×	✓	×	×	×	✓	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6ab	1116	✓	×	×	✓	×	×	✓	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6bc	1117	✓	×	×	✓	×	×	✓	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6cd	1118	✓	×	×	✓	×	×	✓	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7ab	1119	✓	×	×	✓	✓	×	×	✓	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7bc	1120	✓	×	×	✓	✓	×	×	✓	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7cd	1121	✓	×	×	✓	✓	×	×	✓	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8ab	1122	✓	×	×	✓	×	✓	×	✓	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8bc	1123	✓	×	×	✓	×	✓	×	✓	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8cd	1124	✓	×	×	✓	×	✓	×	✓	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
		Subsurface	RMD	1abx	1601	✓	×	✓	×	✓	×	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1bcx	1602	✓	×	✓	×	✓	×	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1cdx	1603	✓	×	✓	×	✓	×	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2abx	1604	✓	×	✓	×	×	✓	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2bcx	1605	✓	×	✓	×	×	✓	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2cdx	1606	✓	×	✓	×	×	✓	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3abx	1607	✓	×	×	✓	✓	×	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3bcx	1608	✓	×	×	✓	✓	×	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3cdx	1609	✓	×	×	✓	✓	×	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4abx	1610	✓	×	×	✓	×	✓	×	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4bcx	1611	✓	×	×	✓	×	✓	×	×	×	✓	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4cdx	1612	✓	×	×	✓	×	✓	×	×	×	×	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5abx	1613	✓	×	✓	×	×	×	✓	×	✓	×	×	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW

Land-Use					WDM Slot Number (DSN)	Roof Options		Connectivity: Roof Leaders		Connectivity: Footing Drains			Connectivity: Roadside Ditches	Soil Classifications: SCS Soil Types			Measured Land Surface-Type Breakdown: Impervious Category					Pervious Category		Measured Totals		Timeseries Units	Timeseries Consituent
Class	Category	Flow Component	Code	SubCode		Peaked	Flat	Connected	Disconnected	Connected to Sanitary	Disconnected	Connected to Storm	(No Storm Sewer)	A,AB	B,BC	C-D	Roofs (%)	Roads (%)	Parking (%)	Driveways (%)	Walks/Patio (%)	Lawns (%)	Open Space (%)	Impervious TIMP (%)	Pervious TPER (%)		
Open Space	Valley Lands, Golf / Cemetery	Surface	OVL	0ab	4101	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0bc	4102	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0cd	4103	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
		Subsurface	OVL	0abx	4601	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0bcx	4602	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0cdx	4603	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
Transportation	Highway Corridors	Surface	THC	0ab	5001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0bc	5002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0cd	5003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
		Subsurface	THC	0abx	5501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0bcx	5502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0cdx	5503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
Industrial	Prestige Industrial	Surface	IPR	1ab	6001	×	✓	✓	×	✓	×	n/a	n/a	✓	×	×	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1bc	6002	×	✓	✓	×	✓	×	n/a	n/a	×	✓	×	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1cd	6003	×	✓	✓	×	✓	×	n/a	n/a	×	×	✓	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
		Subsurface	IPR	1abx	6501	×	✓	✓	×	✓	×	n/a	n/a	✓	×	×	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1bcx	6502	×	✓	✓	×	✓	×	n/a	n/a	×	✓	×	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1cdx	6503	×	✓	✓	×	✓	×	n/a	n/a	×	×	✓	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
	Big Box Industrial	Surface	IBB	1bc	6101	×	✓	✓	×	✓	×	n/a	n/a	×	✓	×	45	6	42	0	0	7	0	93	7	cu.m/hr	FLOW
		Subsurface	IBB	1bcx	6601	×	✓	✓	×	✓	×	n/a	n/a	×	✓	×	45	6	42	0	0	7	0	93	7	cu.m/hr	FLOW
Agricultural	Tilled	Surface	AGT	0ab	7001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0bc	7002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0cd	7003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
		Subsurface	AGT	0abx	7501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0bcx	7502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0cdx	7503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
	Posture/Fallow	Surface	AGP	0ab	7101	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0bc	7102	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0cd	7103	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
		Subsurface	AGP	0abx	7601	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0bcx	7602	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0cdx	7603	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
Special	PERLND Soils AB	Surface	PER	0ab	8001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	0	0	0	0	0	100	0	100	mm/hr	SAB
	PERLND Soils BC		PER	0bc	8002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	0	0	0	0	0	100	0	100	mm/hr	SBC
	PERLND Soils CD		PER	0cd	8003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	0	0	0	0	0	100	0	100	mm/hr	SCD
	PERLND Soils AB	Subsurface	PER	0abx	8501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	×	×	0	0	0	0	0	0	100	0	100	mm/hr	GWAB
	PERLND Soils BC		PER	0bcx	8502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	✓	×	0	0	0	0	0	0	100	0	100	mm/hr	GWBC
	PERLND Soils CD		PER	0cdx	8503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	×	×	✓	0	0	0	0	0	0	100	0	100	mm/hr	GWCD
	IMPLND (Road)	Surface	IMP	0	8004	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	100	0	0	0	0	0	100	0	mm/hr	ROAD
Total number of URFs					213																						

Notes: The Transportation Highway Corridors will be created as a simple IMPLND-PERLND-RCHRES connection but the ratios of pavement to ROW may be altered by the individual consultants.
A Special category was added for the ultimate in flexibility. This will allow the user to create complex areas with these elements. Note that the IMPLND 8004 is the same as the road elements used in all other URFs.
Eventhough the runs will be executed with a 15 minute timestep, the resulting data will be stored in hourly format. Thus TSCODE=3, TSTEP=1, TSFORM=2. TGROUP has been set to 6 (yrs).

APPENDIX C: HIGHLAND CREEK LAND USE & WATERSHED CATCHMENT PLAN (MAUNDER, 2004)

EXISTING LAND USE BREAKDOWN (circa 1995)
Highland Creek Watershed within the City

Catchment ID / Area	100	101	102	103	104	105	200	201	202	203	204
Land Use Category	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]	[ha]
RLD5ab	69.0	38.7	14.0	3.8	17.1	0.0	34.6	0.0	0.0	0.0	0.0
RLD5bc	6.1	14.5	20.6	3.3	17.9	0.0	24.6	0.0	0.0	36.4	16.1
RLD5cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RLD8ab											
RLD8bc											9.9
RMD8ab											
RMD5ab	86.7	22.5	25.0	19.8	28.4	0.0	114.4	0.0	0.0	0.0	0.0
RMD5bc	21.1	26.9	56.6	8.0	40.4	2.3	63.0	0.0	0.0	91.3	22.5
RMD5cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RHD5ab	17.4	3.8	0.0	3.8	0.0	0.0	10.0	0.0	0.0	0.0	0.0
RHD5bc	0.0	0.0	7.5	0.0	11.9	0.0	7.1	7.6	0.0	25.9	2.2
RHD5cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RHR2ab	9.2	3.3	0.0	9.1	0.0	0.0	6.3	4.1	0.0	0.0	0.0
RHR2bc	4.6	19.5	13.6	3.3	5.2	0.0	0.0	6.1	0.0	19.3	1.7
RHR2cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CBBbc	4.0	4.7	3.3	6.3	0.0	4.7	0.0	13.3	9.3	7.4	12.1
CSMbc	6.7	11.0	12.8	22.5	25.1	0.0	10.0	8.2	4.3	6.8	7.3
EISab	9.5	6.3	7.1	17.6	4.7	0.0	23.8	0.0	0.0	0.0	0.0
EISbc	7.0	3.6	14.9	11.5	10.9	5.3	11.3	12.9	0.0	22.2	9.6
EIScd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EIUab	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EIUbc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OPLab	27.8	19.7	15.1	30.5	6.4	0.0	57.6	3.3	0.6	0.0	0.0
OPLbc	19.9	48.0	13.0	15.7	9.5	26.8	0.0	33.9	0.0	40.7	17.7
OPLcd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OVLab	0.0	0.0	0.0	0.0	0.0	0.0	30.9	0.0	0.0	0.0	0.0
OVLbc	9.8	0.0	0.0	0.0	0.0	0.0	23.8	0.0	0.0	0.0	0.0
THCab	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
THCbc	0.0	0.0	0.0	0.0	0.0	10.0	0.0	3.1	2.6	34.4	19.1
THCcd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRYbc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRYcd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IPRab	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IPRbc	0.0	11.2	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	9.8
IPRcd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBBbc	2.4	40.6	0.0	119.5	16.9	73.6	0.0	103.3	0.0	0.0	27.1
AGRab	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AGRbc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	305.4	274.2	203.5	274.8	194.3	130.3	417.4	196.0	16.8	284.3	154.9

Impervious Area	120.7	126.5	88.5	178.1	102.0	91.6	149.2	137.3	15.2	132.2	91.5
Percent Impervious	39.5%	46.1%	43.5%	64.8%	52.5%	70.3%	35.7%	70.1%	90.6%	46.5%	59.1%

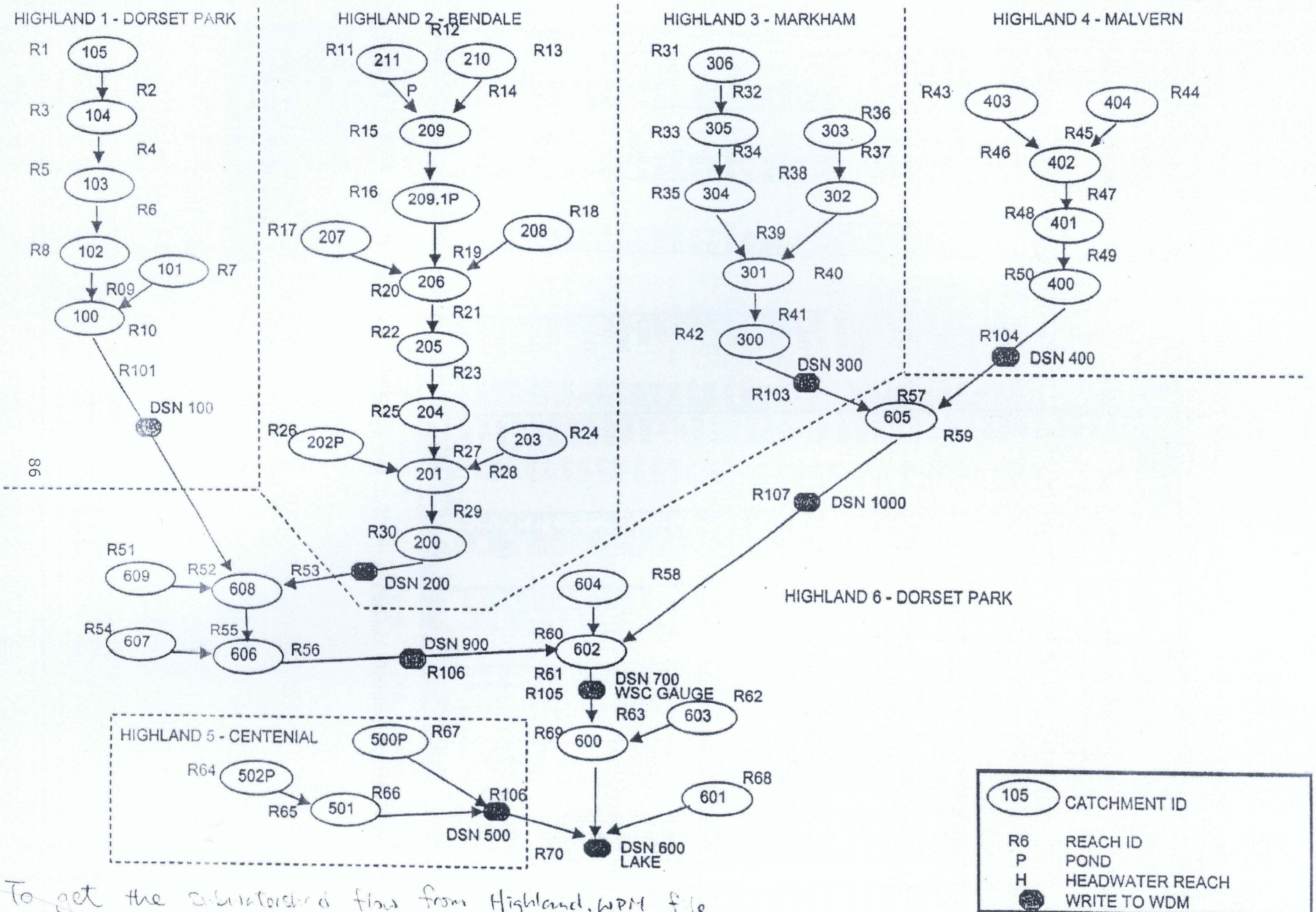
Flow Location	Total Area	Catchments	
Dorset Park Interceptor	1382.4	100-105	
Bendale Branch	2533.4	200-211	
Markham Branch	2124.3	300-306	
Malvern Branch	1411.1	400-404	
Centennial Creek	519.0	500-502	
To RAP Gauge	9473.5	100-404, 602,603, 604,605,606,607,608,609	
To WSC Gauge	9379.2	100-404, 602,604,605,606,607,608,609	
Total	10574.5	100-609	
Areas using "north" preci	1254.5	208, 210, 211, 305, 306, 403	11.9%
Areas using "south" prec	9320.1		88.1%

5 [ha]	206 [ha]	207 [ha]	208 [ha]	209 [ha]	210 [ha]	211 [ha]	300 [ha]	301 [ha]	302 [ha]	303 [ha]	304 [ha]	305 [ha]
0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7	0.0	0.0	0.0	0.0	0.0
38.7	3.6	15.6	11.5	1.5	3.6	6.8	0.0	29.2	66.7	16.8	19.9	11.8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.1									2.4			
0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.8	0.0	0.0	0.0	0.0	0.0
60.7	53.3	91.4	89.7	5.9	31.5	59.3	0.0	52.8	87.6	44.0	91.9	76.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	0.0	0.0	0.0	0.0
19.1	26.3	59.5	59.1	13.5	29.2	55.0	0.0	20.3	17.9	28.0	43.4	24.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.4	17.3	30.2	24.3	3.2	0.0	0.0	20.2	8.9	0.0	0.0	13.6	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	3.6	4.7	7.7	0.0	7.9	18.1	43.8	22.2	0.0	17.1	15.1	0.0
19.7	5.3	14.0	0.0	0.0	0.0	0.0	10.7	22.9	7.4	3.4	0.0	1.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.5	0.0	0.0	0.0	0.0	0.0
10.6	26.1	27.9	37.7	8.1	17.5	7.3	15.0	18.5	31.5	13.4	32.4	7.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.5	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.5	0.0	0.0	0.0	0.0	0.0
76.6	16.2	58.8	42.9	53.8	67.3	21.9	43.4	49.1	40.1	86.0	54.4	30.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.9	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.0	14.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	69.9	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0	0.0	0.0	0.0
0.0	0.0	16.6	0.0	0.0	16.7	0.0	0.0	39.9	9.9	11.2	9.2	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0
0.0	0.0	13.6	0.0	0.0	24.8	2.4	77.3	59.9	45.0	46.5	18.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7	0.0	0.0
251.9	151.8	332.3	272.9	85.9	198.4	170.9	429.6	369.5	308.5	280.2	367.7	151.9
97.6	72.2	163.2	122.7	21.7	92.3	92.0	245.9	222.1	147.3	130.4	190.5	64.4
38.7%	47.6%	49.1%	45.0%	25.3%	46.5%	53.8%	57.2%	60.1%	47.7%	46.5%	51.8%	42.4%

306 [ha]	400 [ha]	401 [ha]	402 [ha]	403 [ha]	404 [ha]	500 [ha]	501 [ha]	502 [ha]	600 [ha]	601 [ha]	602 [ha]	603 [ha]
0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.3	27.7	4.3	0.9	20.2	27.0
15.8	64.0	24.5	7.9	4.4	0.0	0.0	39.5	17.1	2.2	20.5	0.0	9.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
							31.2	34.5		59.0	17.3	30.0
							31.2	17.3		29.6		10.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.2	9.8	0.0	8.5	15.1	32.4
101.8	38.2	29.5	0.0	63.3	16.6	16.0	50.3	3.1	0.0	22.3	0.0	7.9
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.3	13.1	0.0	17.6	10.9	25.8
32.5	25.5	18.5	0.0	60.1	0.0	4.6	11.3	2.6	0.0	0.0	0.0	5.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	8.1	0.0
0.0	13.3	3.6	0.0	15.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	6.1	0.0	6.8	5.8	7.7	0.0	0.0	4.0	0.0	5.1	16.9	0.0
0.0	7.0	11.3	0.0	0.0	4.3	0.0	0.0	2.4	0.0	5.7	9.1	11.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	5.4	0.0	8.6	18.7	20.2
8.7	15.6	26.0	0.0	18.0	8.6	0.0	12.9	0.0	0.0	13.7	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.8	7.0
0.0	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	14.3	2.1	22.6	12.5	78.7
58.1	26.9	55.8	64.9	70.9	68.9	7.7	12.3	9.0	7.8	18.5	0.0	5.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	32.2	8.3	27.2	0.0
0.0	18.5	0.0	0.0	0.0	0.0	0.7	17.5	0.0	42.9	22.6	7.9	9.8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4	0.0	0.0	0.0	0.0
0.0	36.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	6.9	73.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0
0.0	7.2	0.0	0.0	0.0	4.9	0.0	0.0	0.0	0.0	4.2	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	25.5	122.4	135.7	5.8	167.7	11.0	0.0	0.0	6.2	15.5	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	4.7	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
217.0	**289.7**	**298.4**	**293.7**	**243.5**	**285.7**	**39.9**	**306.4**	**172.7**	**97.6**	**297.8**	**201.4**	**280.9**
85.4	139.4	179.5	193.3	103.6	189.5	22.0	111.2	68.1	10.9	114.8	75.7	94.3
39.4%	48.1%	60.2%	65.8%	42.6%	66.3%	55.0%	36.3%	39.4%	11.2%	38.5%	37.6%	33.6%

604 [ha]	605 [ha]	606 [ha]	607 [ha]	608 [ha]	609 [ha]	Total Area	Modelled Percent Imp.	Impervious Area
0.0	0.0	1.4	16.2	39.6	90.7	443.4	30%	133.0
13.0	31.5	6.0	20.0	0.0	0.0	641.1	30%	192.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	30%	0.0
				9.0	20.4	201.4	30%	60.4
						14.4	30%	4.3
						88.4	50%	44.2
6.7	0.0	4.0	111.2	64.7	55.1	677.3	50%	338.7
19.4	65.4	8.0	96.5	5.2	7.0	1626.8	50%	813.4
0.0	0.0	0.0	0.0	0.0	0.0	8.1	50%	4.1
7.7	0.0	1.9	9.0	10.8	9.0	163.2	65%	106.1
15.8	12.5	0.0	7.9	0.0	0.0	655.0	65%	425.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	65%	0.0
0.0	0.0	2.8	7.2	26.2	24.2	110.7	50%	55.3
14.1	0.0	0.0	11.7	0.0	0.0	273.3	50%	136.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	50%	0.0
0.0	0.0	0.0	0.0	0.0	6.2	263.7	98%	258.4
9.9	0.0	1.0	19.6	25.8	21.9	329.1	98%	322.5
16.2	0.0	0.0	15.1	21.7	15.2	211.3	32%	67.6
0.0	28.6	1.4	12.1	7.9	0.0	516.0	32%	165.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	32%	0.0
25.7	0.0	0.0	0.0	0.0	0.0	67.6	32%	21.6
26.0	0.0	0.0	0.0	0.0	0.0	52.3	32%	16.7
38.4	0.0	3.2	29.4	92.0	28.1	524.2	10%	52.4
29.6	35.0	0.0	0.0	21.3	0.0	1358.1	10%	135.8
0.0	0.0	0.0	0.0	0.0	0.0	7.8	10%	0.8
0.0	0.0	16.6	0.0	33.6	0.0	154.1	3%	4.6
86.6	89.7	29.1	21.1	16.1	3.4	418.3	3%	12.5
30.3	0.0	0.0	0.0	0.0	0.0	52.1	70%	36.5
12.7	4.3	0.0	0.0	0.0	0.0	201.8	70%	141.2
0.0	0.0	0.0	0.0	0.0	0.0	0.0	70%	0.0
0.0	0.0	0.0	0.0	0.0	0.0	157.1	70%	110.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	70%	0.0
0.0	0.0	0.0	0.0	0.0	0.0	15.3	80%	12.3
0.0	0.0	0.0	0.0	0.0	0.0	148.2	80%	118.5
0.0	0.0	0.0	0.0	0.0	0.0	8.5	80%	6.8
0.0	0.0	0.0	0.0	0.0	0.0	1160.8	93%	1079.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0.0
0.0	0.0	0.0	0.0	0.0	0.0	25.6	0%	0.0
							Weighted %Imp	
352.0	267.0	75.3	377.1	373.9	281.2	10574.5	46.1%	4877.1
110.2	68.6	13.9	166.7	117.2	117.7			
31.3%	25.7%	18.5%	44.2%	31.4%	41.8%			

Landuse Breakdown		
Landuse	Total Area	Percentage
RLD	1300.3	12.3%
RMD	2400.6	22.7%
RHD	818.1	7.7%
RHR	384.0	3.6%
CBB	263.7	2.5%
CSM	329.1	3.1%
EIS	727.3	6.9%
EIU	119.8	1.1%
OPL	1890.0	17.9%
OVL	572.3	5.4%
THC	253.9	2.4%
TRY	157.1	1.5%
IPR	172.0	1.6%
IBB	1160.8	11.0%
AGP	25.6	0.2%
Total	10574.5	



To get the subwatershed flow from Highland.WDM file, please refer the DSN number

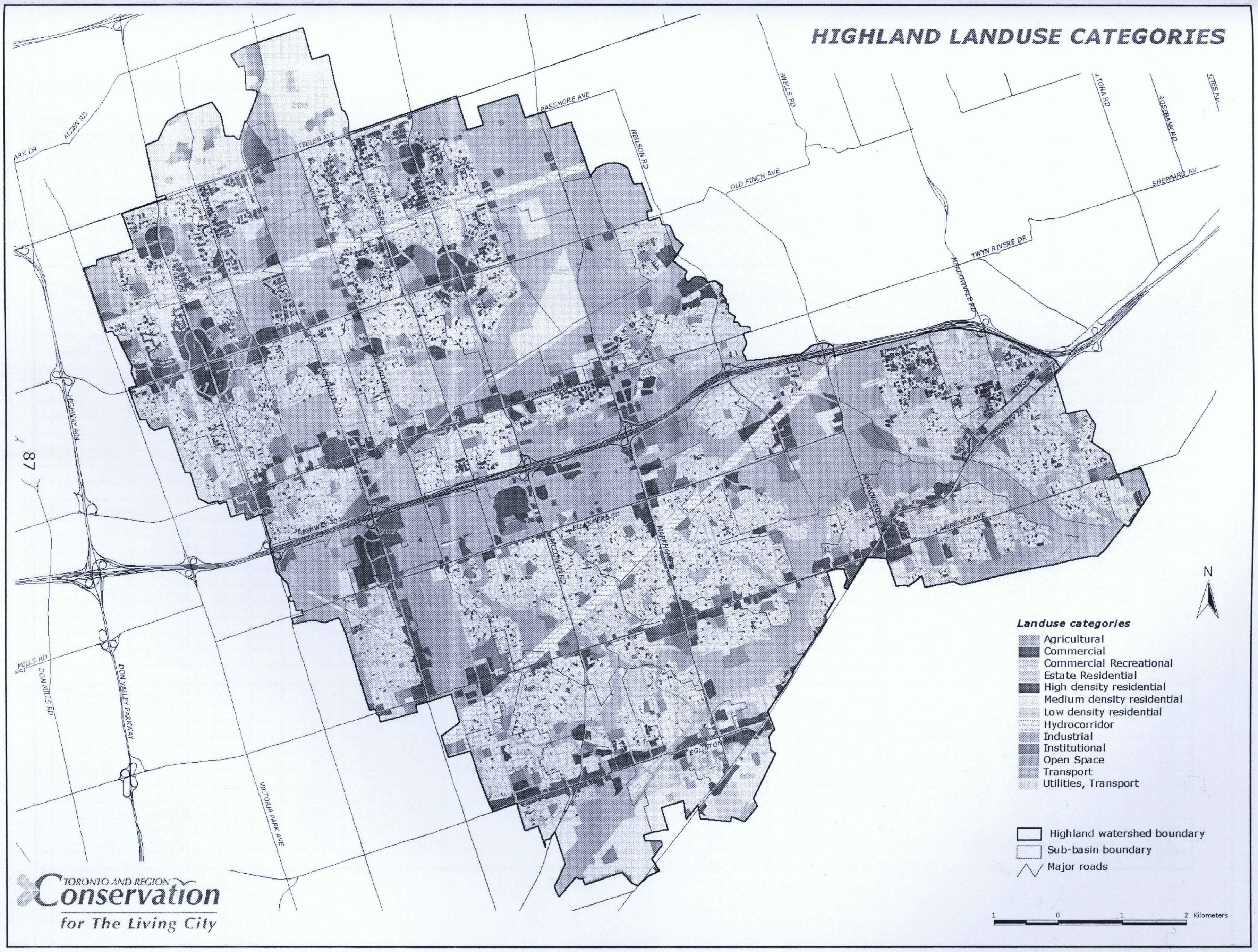


Figure A.2 *Existing Landuses*

APPENDIX D: CALIBRATION AND RUNOFF TABLES USING THE ANALYTICAL MODEL

Low Density Residential

Data

Impervious Area							
Impervious %	30%	Roof %	13%	Runoff Coefficient	0.95	Depression (mm)	0.5
50% GF	25%						
100% GF	20%						

Pervious Area							
Pervious %	70%	Runoff Coefficient wrt soil	A	B	C	Depression (mm)	1
50% GF	75%						
100% GF	80%		0.22	0.25	0.31		

= User Input
= Calibrating User Input

Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Constituent	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression Storage	Runoff (mm)	Runoff m3	Percent Difference	Absolute
1001	m3/yr	A	11980	11833	16255.3	15274	12722	15968	19755	14826.8	0.44	0.85	154.3181	15431.8	4%	4.1%
1002	m3/yr	B	12570	11843	17625.3	15772	13952	16008	20898	15524	0.46	0.85	161.7001	16170	4%	4.2%
1003	m3/yr	C	13880	12174	21075.3	18423	16663	17308	24086	17658.5	0.50	0.85	176.464	17646.4	0%	0.1%
1004	m3/yr	A	11980	11833	16255.3	15274	12722	15968	19755	14826.8	0.44	0.85	154.3181	15431.8	4%	4.1%
1005	m3/yr	B	12570	11843	17625.3	15772	13952	16008	20898	15524	0.46	0.85	161.7001	16170	4%	4.2%
1006	m3/yr	C	13880	12174	21075.3	18423	16663	17308	24086	17658.5	0.50	0.85	176.464	17646.4	0%	0.1%
1013	m3/yr	A	11980	11833	16255.3	15274	12722	15968	19755	14826.8	0.44	0.85	154.3181	15431.8	4%	4.1%
1014	m3/yr	B	12570	11843	17625.3	15772	13952	16008	20898	15524	0.46	0.85	161.7001	16170	4%	4.2%
1015	m3/yr	C	13760	12144	20735.3	18093	16232	17078	23635	17382.5	0.50	0.85	176.464	17646.4	2%	1.5%
															Average =	2.9%
50% Greenroofs			1990	1991	1992	1993	1994	1995	1996							
1001	m3/yr	A	11980	11478	16185.3	-	-	-	-	13214.4	0.40	0.87	140.9125	14091.2	7%	6.6%
1002	m3/yr	B	12570	11491	17535.3	-	-	-	-	13865.4	0.43	0.87	148.7586	14875.9	7%	7.3%
1003	m3/yr	C	13880	12204	21045.3	-	-	-	-	15709.8	0.47	0.87	164.451	16445.1	5%	4.7%
1004	m3/yr	A	11980	11478	16185.3	-	-	-	-	13214.4	0.40	0.87	140.9125	14091.2	7%	6.6%
1005	m3/yr	B	12570	11491	17535.3	-	-	-	-	13865.4	0.43	0.87	148.7586	14875.9	7%	7.3%
1006	m3/yr	C	13880	12204	21045.3	-	-	-	-	15709.8	0.47	0.87	164.451	16445.1	5%	4.7%
1013	m3/yr	A	11980	11833	16255.3	-	-	-	-	13356.1	0.40	0.87	140.9125	14091.2	6%	5.5%
1014	m3/yr	B	12570	11843	17625.3	-	-	-	-	14012.8	0.43	0.87	148.7586	14875.9	6%	6.2%
1015	m3/yr	C	13760	12144	20735.3	-	-	-	-	15546.4	0.47	0.87	164.451	16445.1	6%	5.8%
															Average =	6.1%
100% Greenroofs			1990	1991	1992	1993	1994	1995	1996							
1001	m3/yr	A	11980	11478	16185.3	-	-	-	-	13214.4	0.37	0.90	127.67	12767	-3%	3.4%
1002	m3/yr	B	12570	11491	17535.3	-	-	-	-	13865.4	0.39	0.90	135.9743	13597.4	-2%	1.9%
1003	m3/yr	C	13880	12204	21045.3	-	-	-	-	15709.8	0.44	0.90	152.5827	15258.3	-3%	2.9%
1004	m3/yr	A	11980	11478	16185.3	-	-	-	-	13214.4	0.37	0.90	127.67	12767	-3%	3.4%
1005	m3/yr	B	12570	11491	17535.3	-	-	-	-	13865.4	0.39	0.90	135.9743	13597.4	-2%	1.9%
1006	m3/yr	C	13880	12204	21045.3	-	-	-	-	15709.8	0.44	0.90	152.5827	15258.3	-3%	2.9%
1013	m3/yr	A	11980	11833	16255.3	-	-	-	-	13356.1	0.37	0.90	127.67	12767	-4%	4.4%
1014	m3/yr	B	12570	11843	17625.3	-	-	-	-	14012.8	0.39	0.90	135.9743	13597.4	-3%	3.0%
1015	m3/yr	C	13760	12144	20735.3	-	-	-	-	15546.4	0.44	0.90	152.5827	15258.3	-2%	1.9%
															Average =	2.8%

Medium Density Residential

Data

Impervious Area								
Impervious %	50%	Roof %	24%	Runoff Coefficient	0.95		Depression (mm)	0.25
50% GF	41%							
100% GF	32%							
Pervious Area								
Pervious %	50%	Runoff Coefficient wrt soil		A	B	C	Depression (mm)	0.25
50% GF	59%							
100% GF	68%			0.26	0.3	0.35		

= User Input
= Calibrating User Input

Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Constituent	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
1101	m3/yr	A	19474	19251	26299.4	24815	20446	25952	31820	24008.2	0.61	0.25	248.5752	24857.52	4%	3.5%
1102	m3/yr	B	19904	19261	27349.4	25255	21426	25992	32730	24559.6	0.63	0.25	256.7925	25679.25	5%	4.6%
1103	m3/yr	C	20914	19581	30019.4	27325	23516	27112	35250	26245.3	0.65	0.25	267.0642	26706.42	2%	1.8%
1104	m3/yr	A	19474	19251	26299.4	24815	20446	25952	31820	24008.2	0.61	0.25	248.5752	24857.52	4%	3.5%
1105	m3/yr	B	19904	19261	27349.4	25255	21426	25992	32730	24559.6	0.63	0.25	256.7925	25679.25	5%	4.6%
1106	m3/yr	C	20914	19581	30019.4	27325	23516	27112	35250	26245.3	0.65	0.25	267.0642	26706.42	2%	1.8%
1113	m3/yr	A	19474	19251	26299.4	24815	20446	25952	31820	24008.2	0.61	0.25	248.5752	24857.52	4%	3.5%
1114	m3/yr	B	19904	19261	27349.4	25255	21426	25992	32720	24558.2	0.63	0.25	256.7925	25679.25	5%	4.6%
1115	m3/yr	C	20814	19541	29739.4	27075	23186	26953	34900	26029.8	0.65	0.25	267.0642	26706.42	3%	2.6%
															Average =	3.4%
50% Greenroofs			1990	1991	1992	1993	1994	1995	1996							
1101	m3/yr	A	19474	18661	26219.4	-	-	-	-	21451.5	0.54	0.25	223.0603	22306.03	4%	4.0%
1102	m3/yr	B	19904	18671	27289.4	-	-	-	-	21954.8	0.57	0.25	232.7567	23275.67	6%	6.0%
1103	m3/yr	C	20914	19231	29999.4	-	-	-	-	23381.5	0.60	0.25	244.8774	24487.74	5%	4.7%
1104	m3/yr	A	19474	18661	26219.4	-	-	-	-	21451.5	0.54	0.25	223.0603	22306.03	4%	4.0%
1105	m3/yr	B	19904	18671	27289.4	-	-	-	-	21954.8	0.57	0.25	232.7567	23275.67	6%	6.0%
1106	m3/yr	C	20914	19231	29999.4	-	-	-	-	23381.5	0.60	0.25	244.8774	24487.74	5%	4.7%
1113	m3/yr	A	19474	19251	26299.4	-	-	-	-	21674.8	0.54	0.25	223.0603	22306.03	3%	2.9%
1114	m3/yr	B	19904	19261	27349.4	-	-	-	-	22171.5	0.57	0.25	232.7567	23275.67	5%	5.0%
1115	m3/yr	C	20814	19541	29739.4	-	-	-	-	23364.8	0.60	0.25	244.8774	24487.74	5%	4.8%
															Average =	4.7%
100% Greenroofs			1990	1991	1992	1993	1994	1995	1996							
1101	m3/yr	A	19474	18661	26219.4	-	-	-	-	21451.5	0.48	0.25	197.5454	19754.54	-8%	7.9%
1102	m3/yr	B	19904	18671	27289.4	-	-	-	-	21954.8	0.51	0.25	208.721	20872.1	-5%	4.9%
1103	m3/yr	C	20914	19231	29999.4	-	-	-	-	23381.5	0.54	0.25	222.6905	22269.05	-5%	4.8%
1104	m3/yr	A	19474	18661	26219.4	-	-	-	-	21451.5	0.48	0.25	197.5454	19754.54	-8%	7.9%
1105	m3/yr	B	19904	18671	27289.4	-	-	-	-	21954.8	0.51	0.25	208.721	20872.1	-5%	4.9%
1106	m3/yr	C	20914	19231	29999.4	-	-	-	-	23381.5	0.54	0.25	222.6905	22269.05	-5%	4.8%
1113	m3/yr	A	19474	19251	26299.4	-	-	-	-	21674.8	0.48	0.25	197.5454	19754.54	-9%	8.9%
1114	m3/yr	B	19904	19261	27349.4	-	-	-	-	22171.5	0.51	0.25	208.721	20872.1	-6%	5.9%
1115	m3/yr	C	20814	19541	29739.4	-	-	-	-	23364.8	0.54	0.25	222.6905	22269.05	-5%	4.7%
															Average =	6.1%

High Density Residential

Data

Impervious Area							
Impervious %	65%	Roof %	32%	Runoff Coefficient	1	Depression (mm)	0.1
50% GF	53%						
100% GF	41%						

Pervious Area							
Pervious %	35%	Runoff Coefficient wrt soil	A	B	C	Depression (mm)	0.25
50% GF	47%						
100% GF	59%		0.32	0.35	0.4		

= User Input
= Calibrating User Input

Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Constituent	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
1201	m3/yr	A	24878	24600	33613.5	31695	26080	33150	40560	30653.8	0.76	0.15	321.1195	32111.95	5%	4.8%
1202	m3/yr	B	25208	24630	34413.5	32125	26880	33220	41340	31116.6	0.77	0.15	325.5444	32554.44	5%	4.6%
1203	m3/yr	C	26008	24940	36523.5	33815	28540	34310	43410	32506.6	0.79	0.15	332.9192	33291.92	2%	2.4%
1204	m3/yr	A	24878	24600	33613.5	31695	26080	33150	40560	30653.8	0.76	0.15	321.1195	32111.95	5%	4.8%
1205	m3/yr	B	25208	24630	34413.5	32125	26880	33220	41340	31116.6	0.77	0.15	325.5444	32554.44	5%	4.6%
1206	m3/yr	C	26008	24940	36523.5	33815	28540	34310	43410	32506.6	0.79	0.15	332.9192	33291.92	2%	2.4%
1213	m3/yr	A	24878	24600	33613.5	31695	26080	33150	40560	30653.8	0.76	0.15	321.1195	32111.95	5%	4.8%
1214	m3/yr	B	25208	24630	34413.5	32125	26880	33220	41340	31116.6	0.77	0.15	325.5444	32554.44	5%	4.6%
1215	m3/yr	C	25928	24910	36313.5	33645	28290	34150	43140	32339.5	0.79	0.15	332.9192	33291.92	3%	2.9%
															Average =	4.0%
50% Greenroofs			1990	1991	1992	1993	1994	1995	1996							
1201	m3/yr	A	24878	23830	33533.5	-	-	-	-	27413.8	0.68	0.17	285.3931	28539.31	4%	4.1%
1202	m3/yr	B	25208	23860	34353.5	-	-	-	-	27807.2	0.69	0.17	291.3074	29130.74	5%	4.8%
1203	m3/yr	C	26008	24340	36523.5	-	-	-	-	28957.2	0.72	0.17	301.1644	30116.44	4%	4.0%
1204	m3/yr	A	24878	23830	33533.5	-	-	-	-	27413.8	0.68	0.17	285.3931	28539.31	4%	4.1%
1205	m3/yr	B	25208	23860	34353.5	-	-	-	-	27807.2	0.69	0.17	291.3074	29130.74	5%	4.8%
1206	m3/yr	C	26008	24340	36523.5	-	-	-	-	28957.2	0.72	0.17	301.1644	30116.44	4%	4.0%
1213	m3/yr	A	24878	24600	33613.5	-	-	-	-	27697.2	0.68	0.17	285.3931	28539.31	3%	3.0%
1214	m3/yr	B	25208	24630	34413.5	-	-	-	-	28083.8	0.69	0.17	291.3074	29130.74	4%	3.7%
1215	m3/yr	C	25928	24910	36313.5	-	-	-	-	29050.5	0.72	0.17	301.1644	30116.44	4%	3.7%
															Average =	4.0%
100% Greenroofs			1990	1991	1992	1993	1994	1995	1996							
1201	m3/yr	A	24878	23830	33533.5	-	-	-	-	27413.8	0.60	0.19	249.9934	24999.34	-9%	8.8%
1202	m3/yr	B	25208	23860	34353.5	-	-	-	-	27807.2	0.62	0.19	257.383	25738.3	-7%	7.4%
1203	m3/yr	C	26008	24340	36523.5	-	-	-	-	28957.2	0.65	0.19	269.6989	26969.89	-7%	6.9%
1204	m3/yr	A	24878	23830	33533.5	-	-	-	-	27413.8	0.60	0.19	249.9934	24999.34	-9%	8.8%
1205	m3/yr	B	25208	23860	34353.5	-	-	-	-	27807.2	0.62	0.19	257.383	25738.3	-7%	7.4%
1206	m3/yr	C	26008	24340	36523.5	-	-	-	-	28957.2	0.65	0.19	269.6989	26969.89	-7%	6.9%
1213	m3/yr	A	24878	24600	33613.5	-	-	-	-	27697.2	0.60	0.19	249.9934	24999.34	-10%	9.7%
1214	m3/yr	B	25208	24630	34413.5	-	-	-	-	28083.8	0.62	0.19	257.383	25738.3	-8%	8.4%
1215	m3/yr	C	25928	24910	36313.5	-	-	-	-	29050.5	0.65	0.19	269.6989	26969.89	-7%	7.2%
															Average =	7.9%

High Rise Residential

Data

Impervious Area							
No Green Roof	50%	Roof %	9%	Runoff Coefficient	0.95	Depression (mm)	0.25
50% GF	47%						
100% GF	43%						

Pervious Area							
No Green Roof	50%	Runoff Coefficient wrt soil	A	B	C	Depression (mm)	0.5
50% GF	53%						
100% GF	57%		0.21	0.24	0.3		

= User Input
= Calibrating User Input
Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Constituent	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
1301	m3/yr	A	19193	19176	26523.7	24913	19940	25920	31980	23949.4	0.58	0.38	230.683	23068.31	-4%	3.7%
1302	m3/yr	B	19493	19186	27313.7	25123	20630	25940	32590	24325.1	0.60	0.38	236.649	23664.9	-3%	2.7%
1303	m3/yr	C	20393	19266	29593.7	26683	22341	26430	34430	25591	0.63	0.38	248.581	24858.09	-3%	2.9%
1304	m3/yr	A	19193	19176	26523.7	24923	19940	25920	31980	23950.8	0.58	0.38	230.683	23068.31	-4%	3.7%
1305	m3/yr	B	19493	19186	27313.7	25123	20630	25950	32590	24326.5	0.60	0.38	236.649	23664.9	-3%	2.7%
1306	m3/yr	C	20313	19256	29373.7	26493	22111	26330	34150	25432.4	0.63	0.38	248.581	24858.09	-2%	2.3%
															Average =	3.0%
50% Green Roofs			1990	1991	1992	1993	1994	1995	1996	Average						
1301	m3/yr	A	19193	17724.6	25576.7	-	-	-	-	20831.4	0.56	0.38	220.266	22026.61	6%	5.7%
1302	m3/yr	B	19493	17744.6	26316.7	-	-	-	-	21184.8	0.57	0.38	226.621	22662.08	7%	7.0%
1303	m3/yr	C	20393	18084.6	28626.7	-	-	-	-	22368.1	0.60	0.38	239.33	23933.01	7%	7.0%
1304	m3/yr	A	19193	19176	26523.7	-	-	-	-	21630.9	0.56	0.38	220.266	22026.61	2%	1.8%
1305	m3/yr	B	19493	19186	27313.7	-	-	-	-	21997.6	0.57	0.38	226.621	22662.08	3%	3.0%
1306	m3/yr	C	20313	19256	29373.7	-	-	-	-	22980.9	0.60	0.38	239.33	23933.01	4%	4.1%
															Average =	4.8%
100% Green Roofs			1990	1991	1992	1993	1994	1995	1996	Average						
1301	m3/yr	A	19193	16944.3	24630.6	-	-	-	-	20256	0.53	0.39	209.894	20989.36	4%	3.6%
1302	m3/yr	B	19493	16944.3	25380.6	-	-	-	-	20606	0.55	0.39	216.635	21663.53	5%	5.1%
1303	m3/yr	C	20393	17304.3	27680.6	-	-	-	-	21792.6	0.58	0.39	230.119	23011.87	6%	5.6%
1304	m3/yr	A	19193	19176	26523.7	-	-	-	-	21630.9	0.53	0.39	209.894	20989.36	-3%	3.0%
1305	m3/yr	B	19493	19186	27313.7	-	-	-	-	21997.6	0.55	0.39	216.635	21663.53	-2%	1.5%
1306	m3/yr	C	20313	19256	29373.7	-	-	-	-	22980.9	0.58	0.39	230.119	23011.87	0%	0.1%
															Average =	3.2%

Commercial

Data

Impervious Area						
	Downtown	Big Box	Strip Mall	Runoff Coefficient	1	Depression (mm) 0
Roof %	95%	29%	17%			
No Green Roof	95%	96%	96%			
50% GF	59%	85%	90%			
100% GF	24%	74%	83%			

Pervious Area					
	Downtown	Big Box	Strip Mall	Soil Type	Depression (mm) 0.5
No Green Roof	5%	4%	4%	B	
50% GF	41%	15%	10%		
100% GF	76%	26%	17%	0.8	

= User Input
= Calibrating User Input

Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Type	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
2001	Downtown	B	36261	36230	50207.7	47045	37510	48940	60360	45222	0.99	0.03	431.265	43126.5	-5%	4.6%
2101	Big Box	B	37608.1	37550	51841.5	48779	38860	50770	62420	46832.7	0.99	0.02	432.698	43269.8	-8%	7.6%
2201	Strip Mall	B	37513.1	37460	51731.7	48659	38760	50650	62340	46730.5	0.99	0.02	432.698	43269.8	-7%	7.4%
															Average =	6.5%
50% Green Roofs			1990	1991	1992	1993	1994	1995	1996	Average						
2001	Downtown	B	36261	29510	42189.6	-	-	-	-	35986.9	0.92	0.20	382.114	38211.4	6%	6.2%
2101	Big Box	B	37608.1	35049	51969.7	-	-	-	-	41542.3	0.97	0.20	403.533	40353.3	-3%	2.9%
2201	Strip Mall	B	37513.1	32584	47531.7	-	-	-	-	39209.6	0.98	0.20	407.276	40727.6	4%	3.9%
															Average =	4.3%
100% Green Roofs			1990	1991	1992	1993	1994	1995	1996	Average						
2001	Downtown	B	36261	28419	42415.8	-	-	-	-	35698.6	0.85	0.20	352.48	35248	-1%	1.3%
2101	Big Box	B	37608.1	29249	43601.5	-	-	-	-	36819.5	0.95	0.20	394.487	39448.7	7%	7.1%
2201	Strip Mall	B	37513.1	29219	43677.7	-	-	-	-	36803.3	0.97	0.20	401.973	40197.3	9%	9.2%
															Average =	5.9%

Educational/Institutional

Data

Impervious Area							
No Green Roof	32%	Roof %	9%	Runoff Coefficient	0.85	Depression (mm)	0.5
50% GF	29%						
100% GF	25%						

Pervious Area							
No Green Roof	68%	Runoff Coefficient wrt soil	A	B	C	Depression (mm)	1.5
50% GF	71%						
100% GF	75%		0.27	0.29	0.37		

= User Input
= Calibrating User Input

Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Constituent	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
3001	m3/yr	A	14048.1	12249	17013.6	15921	12839	16566	20551	15598.2	0.46	1.18	146.985	14698.5	-6%	5.8%
3002	m3/yr	B	14478.1	12259	18113.6	16241	13819	16606	21400	16131	0.47	1.18	151.373	15137.3	-6%	6.2%
3003	m3/yr	C	15908.1	12409	21243.6	18472	16230	17376	24041	17954.2	0.52	1.18	168.923	16892.3	-6%	5.9%
															Average =	5.9%
50% Green Roofs			1990	1991	1992	1993	1994	1995	1996	Average						
3001	m3/yr	A	12288.1	11031.6	16005.5	-	-	-	-	13108.4	0.44	1.21	139.441	13944.1	6%	6.4%
3002	m3/yr	B	12718.1	11032.6	17075.5	-	-	-	-	13608.7	0.45	1.21	144.006	14400.6	6%	5.8%
3003	m3/yr	C	13958.1	11552.6	20245.5	-	-	-	-	15252.1	0.51	1.21	162.267	16226.7	6%	6.4%
															Average =	6.2%
100% Green Roofs			1990	1991	1992	1993	1994	1995	1996	Average						
3001	m3/yr	A	12288.1	10222.3	15070.5	-	-	-	-	12527	0.42	1.25	132.017	13201.7	5%	5.4%
3002	m3/yr	B	12718.1	10233.3	16140.5	-	-	-	-	13030.6	0.43	1.25	136.757	13675.7	5%	5.0%
3003	m3/yr	C	13958.1	10744.3	19310.5	-	-	-	-	14671	0.49	1.25	155.714	15571.4	6%	6.1%
															Average =	5.5%

Open Space

Data

= User Input
= Calibrating User Input

Comparison Data

Impervious Area							
	1	2	Runoff Coefficient			Depression (mm)	
Roof %	5%	3%	Type 1	0.8		Type 1	2
No Green Roof	10%	3%	Type 2	0.8		Type 2	2
50% GF	8%	2%	1 = Parks, Hydro, Golf, Cemetery				
100% GF	6%	1%	2 = Valley Lands, Golf/Cemetery				

Pervious Area								
	1	2	Runoff Coefficient and Soil Type				Depression (mm)	
				A	B	C		
No Green Roof	90%	97%						
50% GF	92%	98%	Type 1	0.17	0.2	0.315	Type 1	3
100% GF	94%	99%	Type 2	0.105	0.155	0.35	Type 2	5

No Green Roofs Scenario	Type	Soil Type	HSPF DATA 1990	1991	1992	1993	1994	1995	1996	Average	ANALYTICAL MODEL DATA Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
4001	1-A	FLOW	3950.6	3904	5452.2	5077.6	4195	5279	6630	4926.91	0.23	2.90	48.065	4806.5	-2%	2.4%
4002	1-B	FLOW	4464.6	3910	6756.2	5360.6	5299	5321	7611	5531.77	0.26	2.90	53.6348	5363.48	-3%	3.0%
4003	1-C	FLOW	6126.6	4031	10758.2	7940.6	8236	6039	10669	7685.77	0.36	2.90	74.9856	7498.56	-2%	2.4%
4101	2-A	FLOW	1258	1199.6	1693.8	1586.5	1347.7	1624.7	2114.8	1546.44	0.13	4.91	15.3945	1539.45	0%	0.5%
4102	2-B	FLOW	1913	1206.6	2960.8	1813.3	2407.5	1652.9	3139.8	2156.27	0.17	4.91	21.3272	2132.72	-1%	1.1%
4103	2-C	FLOW	3711	1390.5	7403.8	4632.8	5414.5	2470.6	6681.6	4529.26	0.36	4.91	44.4647	4446.47	-2%	1.8%
															Average =	1.9%
50% Green Roofs																
4001	1-A	FLOW	3950.6	3801	5430.2	-	-	-	-	4393.93	0.22	2.92	45.4064	4540.64	3%	3.3%
4002	1-B	FLOW	4464.6	3803	6682.2	-	-	-	-	4983.27	0.25	2.92	51.0645	5106.45	2%	2.5%
4003	1-C	FLOW	6126.6	4334	10734.2	-	-	-	-	7064.93	0.35	2.92	72.7541	7275.41	3%	3.0%
4101	2-A	FLOW	1258	1192.6	1689.8	-	-	-	-	1380.13	0.12	4.94	14.3119	1431.19	4%	3.7%
4102	2-B	FLOW	1913	1200.6	2939.8	-	-	-	-	2017.8	0.17	4.94	20.261	2026.1	0%	0.4%
4103	2-C	FLOW	3711	1871.5	7403.8	-	-	-	-	4328.77	0.36	4.94	43.4624	4346.24	0%	0.4%
															Average =	2.2%
100% Green Roofs																
4001	1-A	FLOW	3950.6	3801	5430.2	-	-	-	-	4393.93	0.21	2.94	42.7724	4277.24	-3%	2.7%
4002	1-B	FLOW	4464.6	3803	6682.2	-	-	-	-	4983.27	0.24	2.94	48.518	4851.8	-3%	2.6%
4003	1-C	FLOW	6126.6	4334	10734.2	-	-	-	-	7064.93	0.35	2.94	70.5426	7054.26	0%	0.2%
4101	2-A	FLOW	1258	1192.6	1689.8	-	-	-	-	1380.13	0.11	4.98	13.2471	1324.71	-4%	4.0%
4102	2-B	FLOW	1913	1200.6	2939.8	-	-	-	-	2017.8	0.16	4.98	19.2118	1921.18	-5%	4.8%
4103	2-C	FLOW	3711	1871.5	7403.8	-	-	-	-	4328.77	0.35	4.98	42.4742	4247.42	-2%	1.9%
															Average =	2.7%

Transportation Corridor

Data

Impervious Area							
No Green Roof	25%	Roof %	0%	Runoff Coefficient	0.95	Depression (mm)	1
50% GF	25%						
100% GF	25%						

Pervious Area							
No Green Roof	75%	Runoff Coefficient wrt soil	A	B	C	Depression (mm)	4
50% GF	75%						
100% GF	75%		0.08	0.41	0.9		

= User Input
= Calibrating User Input

Comparison Data

No Green Roofs			HSPF DATA								ANALYTICAL MODEL DATA					
Scenario	Type	Soil Type	1990	1991	1992	1993	1994	1995	1996	Average	Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
5001	A	A	1026.3	908.6	8072.5	5108.4	8320.2	5087.8	10871.8	5627.94	0.30	3.25	56.0325	5603.25	0%	0.4%
5002	B	B	4360	3614	13361.5	10526.2	11853.5	10547.3	17745.7	10286.9	0.55	3.25	102.648	10264.8	0%	0.2%
5003	C	C	10150.4	8994.4	20455.8	19085.4	16459.7	18089.4	27259.2	17213.5	0.91	3.25	171.864	17186.4	0%	0.2%
															Average =	0.3%
50% Green Roofs																
5001	A	A	1026.3	349.1	7607.8	-	-	-	-	2994.4	0.30	3.25	56.0325	5603.25	87%	87.1%
5002	B	B	4360	2752.6	13135.3	-	-	-	-	6749.3	0.55	3.25	102.648	10264.8	52%	52.1%
5003	C	C	10150.4	9499.6	20444.8	-	-	-	-	13364.9	0.91	3.25	171.864	17186.4	29%	28.6%
															Average =	55.9%
100% Green Roofs																
5001	A	A	1026.3	349.1	7607.8	-	-	-	-	2994.4	0.30	3.25	56.0325	5603.25	87%	87.1%
5002	B	B	4360	2752.6	13135.3	-	-	-	-	6749.3	0.55	3.25	102.648	10264.8	52%	52.1%
5003	C	C	10150.4	9499.6	20444.8	-	-	-	-	13364.9	0.91	3.25	171.864	17186.4	29%	28.6%
															Average =	55.9%

Industrial

Data

Impervious Area						
	Prestige	Big Box				
Roof %	30%	7%	Runoff Coefficient	0.9	Depression (mm)	0.1
No Green Roof	80%	93%				
50% GF	69%	90%				
100% GF	58%	88%				

Pervious Area									
	Prestige	Big Box	Big Box	Soil Type			Depression (mm)	0.1
			B	A	B	C		
No Green Roof	20%	7%						
50% GF	31%	10%						
100% GF	43%	12%	0.8	0.53	0.55	0.59		

= User Input
= Calibrating User Input

Comparison Data

Scenario	Type	Soil Type	HSPF DATA 1990	1991	1992	1993	1994	1995	1996	Average	ANALYTICAL MODEL DATA Runoff Coefficient	Depression	Runoff (mm)	Runoff m3	Percent Difference	Absolute
No Green Roofs																
6001	Prestige-A	FLOW	30327	30320	42063.2	39485	31470	41007	50650	37903.2	0.83	0.10	352.874	35287.4	-7%	6.9%
6002	Prestige-B	FLOW	30517	30330	42523.2	39675	31840	41057	51130	38153.2	0.83	0.10	354.583	35458.3	-7%	7.1%
6003	Prestige-C	FLOW	30897	30500	43573.2	40495	32590	41557	52070	38811.7	0.84	0.10	358.001	35800.1	-8%	7.8%
6101	BigBox-B	FLOW	35139	35110	48837.3	45791	36400	47520	58690	43926.8	0.89	0.10	381.497	38149.7	-13%	13.2%
															Average =	8.7%
50% Green Roofs																
6001	Prestige-A	FLOW	30327	25788	37970.2	-	-	-	-	31361.7	0.78	0.10	335.092	33509.2	7%	6.8%
6002	Prestige-B	FLOW	30517	25808	38430.2	-	-	-	-	31585.1	0.79	0.10	337.762	33776.2	7%	6.9%
6003	Prestige-C	FLOW	30897	26098	39460.2	-	-	-	-	32151.7	0.80	0.10	343.102	34310.2	7%	6.7%
6101	BigBox-B	FLOW	35139	30584	44947.3	-	-	-	-	36890.1	0.89	0.10	380.376	38037.6	3%	3.1%
															Average =	5.9%
100% Green Roofs																
6001	Prestige-A	FLOW	30327	22427	34035.2	-	-	-	-	28929.7	0.74	0.10	317.309	31730.9	10%	9.7%
6002	Prestige-B	FLOW	30517	22437	34475.2	-	-	-	-	29143.1	0.75	0.10	320.94	32094	10%	10.1%
6003	Prestige-C	FLOW	30897	22757	35505.2	-	-	-	-	29719.7	0.77	0.10	328.203	32820.3	10%	10.4%
6101	BigBox-B	FLOW	35139	27209	40942.4	-	-	-	-	34430.1	0.89	0.10	379.254	37925.4	10%	10.2%
															Average =	10.1%

Total Annual Runoff - Highland Creek Watershed

	Code	Sub Code	WDM ID	Total Area (ha)	No Green Roof: Analytical Calibration: Runoff Coefficient	No Green Roof: Analytical Calibration: Depression Storage (mm)	No Green Roof: Analytical Predicted Runoff (m3)	% Increase Non-runoff Months	50% Green Roof: Analytical Calibration: Runoff Coefficient	50% Green Roof: Analytical Calibration: Depression Storage (mm)	50% Green Roof: Analytical Predicted Runoff (m3)	100% Green Roof: Analytical Calibration: Runoff Coefficient	100% Green Roof: Analytical Calibration: Depression Storage (mm)	100% Green Roof: Analytical Predicted Runoff (m3)
Residential														
Low Density	RLD	1ab	1001	0	0.44	0.85	0	31%	0.40	0.87	0	0.37	0.90	0
	RLD	1bc	1002	0	0.46	0.85	0	35%	0.43	0.87	0	0.39	0.90	0
	RLD	1cd	1003	0	0.50	0.85	0	39%	0.47	0.87	0	0.44	0.90	0
	RLD	2ab	1004	0	0.44	0.85	0	31%	0.40	0.87	0	0.37	0.90	0
	RLD	2bc	1005	0	0.46	0.85	0	35%	0.43	0.87	0	0.39	0.90	0
	RLD	2cd	1006	0	0.50	0.85	0	39%	0.47	0.87	0	0.44	0.90	0
	RLD	5ab	1013	443.4	0.44	0.85	684,247	31%	0.40	0.87	624,806	0.37	0.90	566,089
	RLD	5bc	1014	641.1	0.46	0.85	1,036,659	35%	0.43	0.87	953,692	0.39	0.90	871,731
	RLD	5cd	1015	0	0.50	0.85	0	39%	0.47	0.87	0	0.44	0.90	0
Medium Density	RMD	1ab	1101	0	0.61	0.25	0	31%	0.54	0.25	0	0.48	0.25	0
	RMD	1bc	1102	0	0.63	0.25	0	33%	0.57	0.25	0	0.51	0.25	0
	RMD	1cd	1103	0	0.65	0.25	0	35%	0.60	0.25	0	0.54	0.25	0
	RMD	2ab	1104	0	0.61	0.25	0	31%	0.54	0.25	0	0.48	0.25	0
	RMD	2bc	1105	0	0.63	0.25	0	33%	0.57	0.25	0	0.51	0.25	0
	RMD	2cd	1106	0	0.65	0.25	0	35%	0.60	0.25	0	0.54	0.25	0
	RMD	5ab	1113	677.3	0.61	0.25	1,683,600	31%	0.54	0.25	1,510,787	0.48	0.25	1,337,975
	RMD	5bc	1114	1626.8	0.63	0.25	4,177,501	33%	0.57	0.25	3,786,487	0.51	0.25	3,395,473
	RMD	5cd	1115	8.1	0.65	0.25	21,632	35%	0.60	0.25	19,835	0.54	0.25	18,038
High Density	RHD	1ab	1201	0	0.76	0.15	0	31%	0.68	0.17	0	0.60	0.19	0
	RHD	1bc	1202	0	0.77	0.15	0	32%	0.69	0.17	0	0.62	0.19	0
	RHD	1cd	1203	0	0.79	0.15	0	34%	0.72	0.17	0	0.65	0.19	0
	RHD	2ab	1204	0	0.76	0.15	0	31%	0.68	0.17	0	0.60	0.19	0
	RHD	2bc	1205	0	0.77	0.15	0	32%	0.69	0.17	0	0.62	0.19	0
	RHD	2cd	1206	0	0.79	0.15	0	34%	0.72	0.17	0	0.65	0.19	0
	RHD	5ab	1213	163.2	0.76	0.15	524,067	31%	0.68	0.17	465,762	0.60	0.19	407,989
	RHD	5bc	1214	655	0.77	0.15	2,132,316	32%	0.69	0.17	1,908,063	0.62	0.19	1,685,858
	RHD	5cd	1215	0	0.79	0.15	0	33%	0.72	0.17	0	0.65	0.19	0
High Rise	RHR	1ab	1301	0	0.58	0.38	0	33%	0.56	0.38	0	0.53	0.39	0
	RHR	1bc	1302	0	0.60	0.38	0	34%	0.57	0.38	0	0.55	0.39	0
	RHR	1cd	1303	0	0.63	0.38	0	36%	0.60	0.38	0	0.58	0.39	0
	RHR	2ab	1304	110.7	0.58	0.38	255,366	33%	0.56	0.38	243,835	0.53	0.39	232,352
	RHR	2bc	1305	273.3	0.60	0.38	646,762	34%	0.57	0.38	619,355	0.55	0.39	592,064
	RHR	2cd	1306	0	0.63	0.38	0	36%	0.60	0.38	0	0.58	0.39	0
Commercial														
Down Town	CDT	1bc	2001	0	0.99	0.03	0	33%	0.92	0.20	0	0.85	0.20	0
Big Box	CBB	1bc	2101	263.7	0.99	0.02	1,141,025	33%	0.97	0.20	1,064,116	0.95	0.20	1,040,262
Strip Mall	CSM	1bc	2201	329.1	0.99	0.02	1,424,009	33%	0.98	0.20	1,340,346	0.97	0.20	1,322,894
Educational/Institutional	EIS	1ab	3001	211.3	0.46	1.18	310,580	31%	0.44	1.21	294,639	0.42	1.25	278,953
	EIS	1bc	3002	516	0.47	1.18	781,084	33%	0.45	1.21	743,072	0.43	1.25	705,664
	EIS	1cd	3003	0	0.52	1.18	0	38%	0.51	1.21	0	0.49	1.25	0
Open Space														
Park lands, hydro, golf/cemetary	OPL	0ab	4001	524.2	0.23	2.90	251,957	33%	0.22	2.92	238,020	0.21	2.94	224,213
	OPL	0bc	4002	1358.1	0.26	2.90	728,414	41%	0.25	2.92	693,507	0.24	2.94	658,923
	OPL	0cd	4003	7.8	0.36	2.90	5,849	55%	0.35	2.92	5,675	0.35	2.94	5,502
Valley lands, golf/cemetary	OVL	0ab	4101	154.1	0.13	4.91	23,723	32%	0.12	4.94	22,055	0.11	4.98	20,414
	OVL	0bc	4102	418.3	0.17	4.91	89,212	45%	0.17	4.94	84,752	0.16	4.98	80,363
	OVL	0cd	4103	0	0.36	4.91	0	71%	0.36	4.94	0	0.35	4.98	0
Transportation	THC	0ab	5001	52.1	0.30	3.25	29,193	54%	0.30	3.25	29,193	0.30	3.25	29,193
	THC	0bc	5002	201.8	0.55	3.25	207,143	43%	0.55	3.25	207,143	0.55	3.25	207,143
	THC	0cd	5003	0	0.91	3.25	0	35%	0.91	3.25	0	0.91	3.25	0
Industrial														
Prestige	IPR	1ab	6001	15.3	0.83	0.10	53,990	19%	0.78	0.10	51,269	0.74	0.10	48,548
	IPR	1bc	6002	148.2	0.83	0.10	525,492	19%	0.79	0.10	500,563	0.75	0.10	475,634
	IPR	1cd	6003	8.5	0.84	0.10	30,430	20%	0.80	0.10	29,164	0.77	0.10	27,897
Big Box	IBB	1bc	6101	1160.8	0.89	0.10	4,428,419	20%	0.89	0.10	4,415,402	0.89	0.10	4,402,384
Runoff from Jan, Nov, Dec.								6,350,105			5,917,355			5,525,771
TOTALS				**9968.2**			**27,542,773**				**25,768,890**			**24,161,328**
RUNOFF REDUCTION							**N/A**				**6.44%**			**12.28%**

Total Annual Runoff - Markham Branch

	Code	Sub Code	WDM ID	Total Area (ha)	No Green Roof – Analytical Calibration – Runoff Coefficient	No Green Roof – Analytical Calibration – Depression Storage (mm)	No Green Roof – Analytical Predicted Runoff (m3)	% Increase Non-runoff Months	50% Green Roof – Analytical Calibration – Runoff Coefficient	50% Green Roof – Analytical Calibration – Depression Storage (mm)	50% Green Roof – Analytical Predicted Runoff (m3)	100% Green Roof – Analytical Calibration – Runoff Coefficient	100% Green Roof – Analytical Calibration – Depression Storage (mm)	100% Green Roof – Analytical Predicted Runoff (m3)
Residential														
Low Density	RLD	1ab	1001		0.44	0.85	0	31%	0.40	0.87	0	0.37	0.90	0
	RLD	1bc	1002		0.46	0.85	0	35%	0.43	0.87	0	0.39	0.90	0
	RLD	1cd	1003		0.50	0.85	0	39%	0.47	0.87	0	0.44	0.90	0
	RLD	2ab	1004		0.44	0.85	0	31%	0.40	0.87	0	0.37	0.90	0
	RLD	2bc	1005		0.46	0.85	0	35%	0.43	0.87	0	0.39	0.90	0
	RLD	2cd	1006		0.50	0.85	0	39%	0.47	0.87	0	0.44	0.90	0
	RLD	5ab	1013	10.7	0.44	0.85	16,512	31%	0.40	0.87	15,078	0.37	0.90	13,661
	RLD	5bc	1014	160.2	0.46	0.85	259,044	35%	0.43	0.87	238,311	0.39	0.90	217,831
	RLD	5cd	1015		0.50	0.85	0	39%	0.47	0.87	0	0.44	0.90	0
Medium Density	RMD	1ab	1101		0.61	0.25	0	31%	0.54	0.25	0	0.48	0.25	0
	RMD	1bc	1102		0.63	0.25	0	33%	0.57	0.25	0	0.51	0.25	0
	RMD	1cd	1103		0.65	0.25	0	35%	0.60	0.25	0	0.54	0.25	0
	RMD	2ab	1104		0.61	0.25	0	31%	0.54	0.25	0	0.48	0.25	0
	RMD	2bc	1105		0.63	0.25	0	33%	0.57	0.25	0	0.51	0.25	0
	RMD	2cd	1106		0.65	0.25	0	35%	0.60	0.25	0	0.54	0.25	0
	RMD	5ab	1113	40.8	0.61	0.25	101,419	31%	0.54	0.25	91,009	0.48	0.25	80,599
	RMD	5bc	1114	454.2	0.63	0.25	1,166,352	33%	0.57	0.25	1,057,181	0.51	0.25	948,011
	RMD	5cd	1115	8.1	0.65	0.25	21,632	35%	0.60	0.25	19,835	0.54	0.25	18,038
High Density	RHD	1ab	1201		0.76	0.15	0	31%	0.68	0.17	0	0.60	0.19	0
	RHD	1bc	1202		0.77	0.15	0	32%	0.69	0.17	0	0.62	0.19	0
	RHD	1cd	1203		0.79	0.15	0	34%	0.72	0.17	0	0.65	0.19	0
	RHD	2ab	1204		0.76	0.15	0	31%	0.68	0.17	0	0.60	0.19	0
	RHD	2bc	1205		0.77	0.15	0	32%	0.69	0.17	0	0.62	0.19	0
	RHD	2cd	1206		0.79	0.15	0	34%	0.72	0.17	0	0.65	0.19	0
	RHD	5ab	1213	9.9	0.76	0.15	31,791	31%	0.68	0.17	28,254	0.60	0.19	24,749
	RHD	5bc	1214	166.6	0.77	0.15	542,357	32%	0.69	0.17	485,318	0.62	0.19	428,800
	RHD	5cd	1215		0.79	0.15	0	33%	0.72	0.17	0	0.65	0.19	0
High Rise	RHR	1ab	1301		0.58	0.38	0	33%	0.56	0.38	0	0.53	0.39	0
	RHR	1bc	1302		0.60	0.38	0	34%	0.57	0.38	0	0.55	0.39	0
	RHR	1cd	1303		0.63	0.38	0	36%	0.60	0.38	0	0.58	0.39	0
	RHR	2ab	1304		0.58	0.38	0	33%	0.56	0.38	0	0.53	0.39	0
	RHR	2bc	1305	42.7	0.60	0.38	101,049	34%	0.57	0.38	96,767	0.55	0.39	92,503
	RHR	2cd	1306		0.63	0.38	0	36%	0.60	0.38	0	0.58	0.39	0
Commercial														
Down Town	CDT	1bc	2001		0.99	0.03	0	33%	0.92	0.20	0	0.85	0.20	0
Big Box	CBB	1bc	2101	98.2	0.99	0.02	424,909	33%	0.97	0.20	396,269	0.95	0.20	387,386
Strip Mall	CSM	1bc	2201	45.9	0.99	0.02	198,608	33%	0.98	0.20	186,940	0.97	0.20	184,506
Educational/Institutional	EIS	1ab	3001	15.5	0.46	1.18	22,783	31%	0.44	1.21	21,613	0.42	1.25	20,463
	EIS	1bc	3002	126.9	0.47	1.18	192,092	33%	0.45	1.21	182,744	0.43	1.25	173,544
	EIS	1cd	3003		0.52	1.18	0	38%	0.51	1.21	0	0.49	1.25	0
Open Space														
Park lands, hydro, golf/cemetary	OPL	0ab	4001	24.5	0.23	2.90	11,776	33%	0.22	2.92	11,125	0.21	2.94	10,479
	OPL	0bc	4002	361.6	0.26	2.90	193,944	41%	0.25	2.92	184,649	0.24	2.94	175,441
	OPL	0cd	4003	7.8	0.36	2.90	5,849	55%	0.35	2.92	5,675	0.35	2.94	5,502
Valley lands, golf/cemetary	OVL	0ab	4101		0.13	4.91	0	32%	0.12	4.94	0	0.11	4.98	0
	OVL	0bc	4102	18.9	0.17	4.91	4,031	45%	0.17	4.94	3,829	0.16	4.98	3,631
	OVL	0cd	4103		0.36	4.91	0	71%	0.36	4.94	0	0.35	4.98	0
Transportation	THC	0ab	5001	5.2	0.30	3.25	2,914	54%	0.30	3.25	2,914	0.30	3.25	2,914
	THC	0bc	5002	78.8	0.55	3.25	80,886	43%	0.55	3.25	80,886	0.55	3.25	80,886
	THC	0cd	5003		0.91	3.25	0	35%	0.91	3.25	0	0.91	3.25	0
Industrial														
Prestige	IPR	1ab	6001	11.2	0.83	0.10	39,522	19%	0.78	0.10	37,530	0.74	0.10	35,539
	IPR	1bc	6002	70.2	0.83	0.10	248,917	19%	0.79	0.10	237,109	0.75	0.10	225,300
	IPR	1cd	6003	8.5	0.84	0.10	30,430	20%	0.80	0.10	29,164	0.77	0.10	27,897
Big Box	IBB	1bc	6101	246.7	0.89	0.10	941,153	20%	0.89	0.10	938,387	0.89	0.10	935,620
								1,383,530			1,290,951			1,208,276
TOTALS				2013.1			6,021,500				5,641,538			5,301,576
PERCENT DIFFERENCE							25.76%				35.20%			31.74%

Appendix E: Additional Watershed Land Use Data and Runoff Tables (Banting et al., 2005)

Land Area by Basin and Landuse Code (Banting et al. 2005)

		Watershed														
Land Use Code	Description	Don River	Don River Main	Don River West	Eastern Beaches Tunnel	Etobicoke Creek	Highland Creek	Humber River	Inner Harbour & Coatsworth Cut	Lake Ontario	Massey Creek	Mimico Creek	Rouge	waterfront	Western Beaches Tunnel	**Grand Total**
C	Commercial	752.12	218.29	59.20	13.45	31.41	755.78	5.23	579.36	6.11	68.65	3.34	24.58	30.75	225.02	**2,773.29**
CBB	Commercial Bigbox					9.04		272.20		7.18		72.85			4.20	**365.47**
CI	Commercial Downtown	1,467.47	25.50	154.23		0.05	1,197.84	13.70	299.49	125.95	268.34	0.48	18.09		91.15	**3,662.28**
CR	commercial-industrial	399.37	316.66	97.55	67.95	0.01	381.90	11.78	565.66	558.40	99.05	0.04	9.51	58.05	446.20	**3,012.14**
CSM	commercial-residential		0.16			58.76		271.10		54.33		146.45			0.15	**530.95**
EIS	Commercial Strip Mall	26.97	52.45	2.68	2.16	73.30	16.25	819.05	168.19	2.43	13.70	46.51			21.22	**1,244.90**
EIU	Educational/Institutional							218.81								**218.81**
GC	Golf Course												134.10			**134.10**
GS	Greenspace: parks						12.37						1,261.43			**1,273.80**
I	industrial	31.40		30.65			119.72	0.02	22.63	85.75	26.48	0.07	2.16	131.88	36.93	**487.70**
IBB	Industrial Bigbox					155.39		1,408.56		1.99		591.70			19.43	**2,177.08**
IN	Resource-Industrial	6.04	2.72			225.41	64.90		50.96	0.43	12.72	0.25	524.40	0.99	4.78	**893.61**
IPR	Prestige Industrial	0.11				68.63		286.29		102.46		327.69			1.00	**786.19**
IR	Resource-Industrial	11.06					40.67	0.01		0.46	18.74				9.85	**80.80**
MIX	Mixed						1.56			38.97		0.00	6.89		26.97	**74.39**
OGC	Open Space -golf							443.47							0.08	**443.54**
OHC	Open hydro corridor							173.10								**173.10**
OPL	Open Space/Park Land	99.74	140.20	10.05	0.81	579.86	169.63	1,128.99	55.10	30.35	147.20	669.48	28.97	27.76	59.83	**3,147.99**
OVL	Open Valley Lands							869.46								**869.46**
PK	Park						9.73						359.75	0.93		**370.41**
R	residential	10,054.55	3,068.07	275.18	467.40	173.60	7,266.20	95.66	1,318.14	1,236.84	1,532.72	7.96	251.71	1,164.11	1,791.05	**28,703.18**
RES	residential, open area					718.63		7.27		48.11		1,896.03				**2,670.04**
RHD	Residential High Density		1.44					585.45				0.70			1.56	**589.14**
RHR	Residential High Rise		0.94					592.09							0.44	**593.47**
RLD	Residential Low Density		0.47					1,337.65				1.52			0.33	**1,339.96**
RMD	Residential Medium Density		0.67					2,241.05				6.76			1.72	**2,250.20**
RS	residential, open area						44.12						492.33	3.65		**540.09**
RT	commercial						2.80						2.14			**4.94**
SC	Government-Institutional						1.18						8.52			**9.70**
SPC	STP, Park, commercial-indus							161.39								**161.39**
TA	Government-Institutional, z												417.33			**417.33**
TAP	Downsview airport	0.02						174.78								**174.80**
THC	Highway Corridors	21.27	3.03			0.03	85.80	2,714.73		0.00		97.27	5.38		11.12	**2,938.65**
TRY	roadways							15.75								**15.75**
W	Water	0.00	13.33	0.03		0.84	3.44	0.90	12.51	3.37	1.01		0.05	9.63	1.17	**46.28**
Totals		12,870.12	3,843.94	629.58	551.77	2,094.94	10,173.91	13,848.50	3,072.04	2,303.13	2,188.61	3,869.11	3,547.34	1,427.75	2,754.19	**63,174.95**

Total Annual Runoff - Calibrated Analytical URF Model using Input From Banting et al. (2005)

				No Green Roof			50% Green Roof		100% Green Roof		Don River				Don River Main				Don River West				Eastern Beaches Tunnel		
				Analytical Calibration		% Increase	Analytical Calibration		Analytical Calibration		Land Use	No GRT	50% GRT	100% GRT		No GRT	50% GRT	100% GRT		No GRT	50% GRT	100% GRT		No GRT	50% GRT
	Code	Sub Code	WDM ID	Runoff Coefficient	Storage (mm)	Non-runoff Months	Runoff Coefficient	Storage (mm)	Runoff Coefficient	Storage (mm)	Area (ha)	Volume	Volume	Volume		Volume	Volume	Volume		Volume	Volume	Volume		Volume	Volume
Residential																									
	RLD	1ab	1001	0.44	0.85	31%	0.40	0.87	0.37	0.90	**310.73433**	479,519	437,863	396,715	**0.099172**	153	140	127	**0**	0	0	0	**0**	0	0
	RLD	1bc	1002	0.46	0.85	35%	0.43	0.87	0.39	0.90	**310.73433**	502,458	462,244	422,519	**0.099172**	160	148	135	**0**	0	0	0	**0**	0	0
	RLD	1cd	1003	0.50	0.85	39%	0.47	0.87	0.44	0.90	**310.73433**	548,334	511,006	474,127	**0.099172**	175	163	151	**0**	0	0	0	**0**	0	0
	RLD	2ab	1004	0.44	0.85	31%	0.40	0.87	0.37	0.90	**310.73433**	479,519	437,863	396,715	**0.099172**	153	140	127	**0**	0	0	0	**0**	0	0
Low Density	RLD	2bc	1005	0.46	0.85	35%	0.43	0.87	0.39	0.90	**310.73433**	502,458	462,244	422,519	**0.099172**	160	148	135	**0**	0	0	0	**0**	0	0
	RLD	2cd	1006	0.50	0.85	39%	0.47	0.87	0.44	0.90	**310.73433**	548,334	511,006	474,127	**0.099172**	175	163	151	**0**	0	0	0	**0**	0	0
	RLD	5ab	1013	0.44	0.85	31%	0.40	0.87	0.37	0.90	**310.73433**	479,519	437,863	396,715	**0.099172**	153	140	127	**0**	0	0	0	**0**	0	0
	RLD	5bc	1014	0.46	0.85	35%	0.43	0.87	0.39	0.90	**310.73433**	502,458	462,244	422,519	**0.099172**	160	148	135	**0**	0	0	0	**0**	0	0
	RLD	5cd	1015	0.50	0.85	39%	0.47	0.87	0.44	0.90	**310.73433**	548,334	511,006	474,127	**0.099172**	175	163	151	**0**	0	0	0	**0**	0	0
	RMD	1ab	1101	0.61	0.25	31%	0.54	0.25	0.48	0.25	**310.73433**	772,408	693,125	613,841	**0.0242994**	60	54	48	**0**	0	0	0	**0**	0	0
	RMD	1bc	1102	0.63	0.25	33%	0.57	0.25	0.51	0.25	**310.73433**	797,943	723,255	648,568	**0.0242994**	62	57	51	**0**	0	0	0	**0**	0	0
	RMD	1cd	1103	0.65	0.25	35%	0.60	0.25	0.54	0.25	**310.73433**	829,860	760,918	691,976	**0.0242994**	65	60	54	**0**	0	0	0	**0**	0	0
	RMD	2ab	1104	0.61	0.25	31%	0.54	0.25	0.48	0.25	**310.73433**	772,408	693,125	613,841	**0.0242994**	60	54	48	**0**	0	0	0	**0**	0	0
Medium Density	RMD	2bc	1105	0.63	0.25	33%	0.57	0.25	0.51	0.25	**310.73433**	797,943	723,255	648,568	**0.0242994**	62	57	51	**0**	0	0	0	**0**	0	0
	RMD	2cd	1106	0.65	0.25	35%	0.60	0.25	0.54	0.25	**310.73433**	829,860	760,918	691,976	**0.0242994**	65	60	54	**0**	0	0	0	**0**	0	0
	RMD	5ab	1113	0.61	0.25	31%	0.54	0.25	0.48	0.25	**310.73433**	772,408	693,125	613,841	**0.0242994**	60	54	48	**0**	0	0	0	**0**	0	0
	RMD	5bc	1114	0.63	0.25	33%	0.57	0.25	0.51	0.25	**310.73433**	797,943	723,255	648,568	**0.0242994**	62	57	51	**0**	0	0	0	**0**	0	0
	RMD	5cd	1115	0.65	0.25	35%	0.60	0.25	0.54	0.25	**310.73433**	829,860	760,918	691,976	**0.0242994**	65	60	54	**0**	0	0	0	**0**	0	0
	RHD	1ab	1201	0.76	0.15	31%	0.68	0.17	0.60	0.19	**310.73433**	997,829	886,814	776,815	**0.1292764**	415	369	323	**0**	0	0	0	**0**	0	0
	RHD	1bc	1202	0.77	0.15	32%	0.69	0.17	0.62	0.19	**310.73433**	1,011,578	905,192	799,777	**0.1292764**	421	377	333	**0**	0	0	0	**0**	0	0
	RHD	1cd	1203	0.79	0.15	34%	0.72	0.17	0.65	0.19	**310.73433**	1,034,494	935,821	838,047	**0.1292764**	430	389	349	**0**	0	0	0	**0**	0	0
	RHD	2ab	1204	0.76	0.15	31%	0.68	0.17	0.60	0.19	**310.73433**	997,829	886,814	776,815	**0.1292764**	415	369	323	**0**	0	0	0	**0**	0	0
High Density	RHD	2bc	1205	0.77	0.15	32%	0.69	0.17	0.62	0.19	**310.73433**	1,011,578	905,192	799,777	**0.1292764**	421	377	333	**0**	0	0	0	**0**	0	0
	RHD	2cd	1206	0.79	0.15	34%	0.72	0.17	0.65	0.19	**310.73433**	1,034,494	935,821	838,047	**0.1292764**	430	389	349	**0**	0	0	0	**0**	0	0
	RHD	5ab	1213	0.76	0.15	31%	0.68	0.17	0.60	0.19	**310.73433**	997,829	886,814	776,815	**0.1292764**	415	369	323	**0**	0	0	0	**0**	0	0
	RHD	5bc	1214	0.77	0.15	32%	0.69	0.17	0.62	0.19	**310.73433**	1,011,578	905,192	799,777	**0.1292764**	421	377	333	**0**	0	0	0	**0**	0	0
	RHD	5cd	1215	0.79	0.15	33%	0.72	0.17	0.65	0.19	**310.73433**	1,034,494	935,821	838,047	**0.1292764**	430	389	349	**0**	0	0	0	**0**	0	0
	RHR	1ab	1301	0.58	0.38	33%	0.56	0.38	0.53	0.39	**310.73433**	716,812	684,442	652,211	**0.1025421**	237	226	215	**0**	0	0	0	**0**	0	0
	RHR	1bc	1302	0.60	0.38	34%	0.57	0.38	0.55	0.39	**310.73433**	735,350	704,188	673,160	**0.1025421**	243	232	222	**0**	0	0	0	**0**	0	0
High Rise	RHR	1cd	1303	0.63	0.38	36%	0.60	0.38	0.58	0.39	**310.73433**	772,426	743,681	715,058	**0.1025421**	255	245	236	**0**	0	0	0	**0**	0	0
	RHR	2ab	1304	0.58	0.38	33%	0.56	0.38	0.53	0.39	**310.73433**	716,812	684,442	652,211	**0.1025421**	237	226	215	**0**	0	0	0	**0**	0	0
	RHR	2bc	1305	0.60	0.38	34%	0.57	0.38	0.55	0.39	**310.73433**	735,350	704,188	673,160	**0.1025421**	243	232	222	**0**	0	0	0	**0**	0	0
	RHR	2cd	1306	0.63	0.38	36%	0.60	0.38	0.58	0.39	**310.73433**	772,426	743,681	715,058	**0.1025421**	255	245	236	**0**	0	0	0	**0**	0	0
Commercial																									
Down Town	CDT	1bc	2001	0.99	0.03	33%	0.92	0.20	0.85	0.20	**561.84723**	2,423,048	2,146,896	1,980,402	**151.0648**	651,489	577,239	532,474	**190.22607**	820,378	726,880	670,510	**15.808437**	68,176	60,406
Big Box	CBB	1bc	2101	0.99	0.02	33%	0.97	0.20	0.95	0.20	**561.84723**	2,431,101	2,267,239	2,216,414	**125.56779**	543,329	506,707	495,349	**35.993181**	155,742	145,244	141,988	**15.808437**	68,403	63,792
Strip Mall	CSM	1bc	2201	0.99	0.02	33%	0.98	0.20	0.97	0.20	**561.84723**	2,431,101	2,288,269	2,258,476	**178.02161**	770,296	725,039	715,599	**38.676119**	167,351	157,519	155,468	**17.966547**	77,741	73,173
Educational/Institutional	EIS	1ab	3001	0.46	1.18	31%	0.44	1.21	0.42	1.25	**8.9899563**	13,214	12,536	11,868	**0**	0	0	0	**0**	0	0	0	**0**	0	0
	EIS	1bc	3002	0.47	1.18	33%	0.45	1.21	0.43	1.25	**8.9899563**	13,608	12,946	12,294	**0**	0	0	0	**0**	0	0	0	**0**	0	0
	EIS	1cd	3003	0.52	1.18	38%	0.51	1.21	0.49	1.25	**8.9899563**	15,186	14,588	13,999	**0**	0	0	0	**0**	0	0	0	**0**	0	0
Open Space																									
	OPL	0ab	4001	0.23	2.90	33%	0.22	2.92	0.21	2.94	**36.932445**	17,752	16,770	15,797	**1069.6621**	514,134	485,695	457,520	**95.075872**	45,698	43,171	40,666	**156.06999**	75,015	70,866
Park lands, hydro, golf/cemetary	OPL	0bc	4002	0.26	2.90	41%	0.25	2.92	0.24	2.94	**36.932445**	19,809	18,859	17,919	**1069.6621**	573,711	546,218	518,978	**95.075872**	50,994	48,550	46,129	**156.06999**	83,708	79,696
	OPL	0cd	4003	0.36	2.90	55%	0.35	2.92	0.35	2.94	**36.932445**	27,694	26,870	26,053	**1069.6621**	802,093	778,223	754,567	**95.075872**	71,293	69,172	67,069	**156.06999**	117,030	113,547
	OVL	0ab	4101	0.13	4.91	32%	0.12	4.94	0.11	4.98	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0
Valley lands, golf/cemetary	OVL	0bc	4102	0.17	4.91	45%	0.17	4.94	0.16	4.98	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0
	OVL	0cd	4103	0.36	4.91	71%	0.36	4.94	0.35	4.98	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0
Transportation	THC	0ab	5001	0.30	3.25	54%	0.30	3.25	0.30	3.25	**7.0903948**	3,973	3,973	3,973	**0**	0	0	0	**0**	0	0	0	**0**	0	0
	THC	0bc	5002	0.55	3.25	43%	0.55	3.25	0.55	3.25	**7.0903948**	7,278	7,278	7,278	**13.330018**	13,683	13,683	13,683	**0.0303565**	31	31	31	**0**	0	0
	THC	0cd	5003	0.91	3.25	35%	0.91	3.25	0.91	3.25	**7.1068113**	12,214	12,214	12,214	**3.0255799**	5,200	5,200	5,200	**0**	0	0	0	**0**	0	0
Industrial																									
	IPR	1ab	6001	0.83	0.10	19%	0.78	0.10	0.74	0.10	**185.47487**	654,493	621,511	588,529	**40.262825**	142,077	134,917	127,758	**19.857066**	70,070	66,539	63,008	**8.4937287**	29,972	28,462
Prestige	IPR	1bc	6002	0.83	0.10	19%	0.79	0.10	0.75	0.10	**185.47487**	657,662	626,463	595,264	**40.262825**	142,765	135,992	129,220	**19.857066**	70,410	67,070	63,729	**8.4937287**	30,117	28,689
	IPR	1cd	6003	0.84	0.10	20%	0.80	0.10	0.77	0.10	**185.47487**	664,001	636,368	608,734	**40.262825**	144,141	138,142	132,144	**19.857066**	71,088	68,130	65,171	**8.4937287**	30,408	29,142
Big Box	IBB	1bc	6101	0.89	0.10	20%	0.89	0.10	0.89	0.10	**214.8646**	819,702	817,293	814,883	**40.262825**	153,602	153,150	152,699	**19.857066**	75,754	75,531	75,309	**8.4937287**	32,403	32,308
Jan, Nov, **Dec Runoff Months**												11,462,300	10,537,535	9,727,977		1,617,036	1,527,613	1,468,341		508,864	466,291	440,970		217,974	206,623
TOTAL RUNOFF												47,046,583	43,280,947	39,980,087		6,080,851	5,734,494	5,509,588		2,107,674	1,934,128	1,830,049		830,947	786,705

Total Annual Runoff - Calibrated Analytical URF Model using Input From Banting et al. (2005)

					Etobicoke Creek				Humber River				Inner Harbour & Coatsworth Cut				Lake Ontario				Massey Creek				Mimico Creek
				100% GRT		No GRT	50% GRT	100% GRT		No GRT	50% GRT	100% GRT		No GRT	50% GRT	100% GRT		No GRT	50% GRT	100% GRT		No GRT	50% GRT	100% GRT	
	Code	Sub Code	WDM ID	Volume		Volume	Volume	Volume		Volume	Volume	Volume		Volume	Volume	Volume		Volume	Volume	Volume		Volume	Volume	Volume	
Residential																									
	RLD	1ab	1001	0	**22.666961**	34,979	31,941	28,939	**151.81519**	234,278	213,927	193,823	**0**	0	0	0	**2.2808643**	3,520	3,214	2,912	**0**	0	0	0	**60.436441**
	RLD	1bc	1002	0	**22.666961**	36,652	33,719	30,821	**151.81519**	245,485	225,838	206,430	**0**	0	0	0	**2.2808643**	3,688	3,393	3,101	**0**	0	0	0	**60.436441**
	RLD	1cd	1003	0	**22.666961**	39,999	37,276	34,586	**151.81519**	267,899	249,662	231,644	**0**	0	0	0	**2.2808643**	4,025	3,751	3,480	**0**	0	0	0	**60.436441**
	RLD	2ab	1004	0	**22.666961**	34,979	31,941	28,939	**151.81519**	234,278	213,927	193,823	**0**	0	0	0	**2.2808643**	3,520	3,214	2,912	**0**	0	0	0	**60.436441**
Low Density	RLD	2bc	1005	0	**22.666961**	36,652	33,719	30,821	**151.81519**	245,485	225,838	206,430	**0**	0	0	0	**2.2808643**	3,688	3,393	3,101	**0**	0	0	0	**60.436441**
	RLD	2cd	1006	0	**22.666961**	39,999	37,276	34,586	**151.81519**	267,899	249,662	231,644	**0**	0	0	0	**2.2808643**	4,025	3,751	3,480	**0**	0	0	0	**60.436441**
	RLD	5ab	1013	0	**22.666961**	34,979	31,941	28,939	**151.81519**	234,278	213,927	193,823	**0**	0	0	0	**2.2808643**	3,520	3,214	2,912	**0**	0	0	0	**60.436441**
	RLD	5bc	1014	0	**22.666961**	36,652	33,719	30,821	**151.81519**	245,485	225,838	206,430	**0**	0	0	0	**2.2808643**	3,688	3,393	3,101	**0**	0	0	0	**60.436441**
	RLD	5cd	1015	0	**22.666961**	39,999	37,276	34,586	**151.81519**	267,899	249,662	231,644	**0**	0	0	0	**2.2808643**	4,025	3,751	3,480	**0**	0	0	0	**60.436441**
	RMD	1ab	1101	0	**22.666961**	56,344	50,561	44,778	**252.19249**	626,888	562,541	498,195	**0**	0	0	0	**2.2808643**	5,670	5,088	4,506	**0**	0	0	0	**59.684945**
	RMD	1bc	1102	0	**22.666961**	58,207	52,759	47,311	**252.19249**	647,611	586,995	526,379	**0**	0	0	0	**2.2808643**	5,857	5,309	4,761	**0**	0	0	0	**59.684945**
	RMD	1cd	1103	0	**22.666961**	60,535	55,506	50,477	**252.19249**	673,516	617,562	561,609	**0**	0	0	0	**2.2808643**	6,091	5,585	5,079	**0**	0	0	0	**59.684945**
	RMD	2ab	1104	0	**22.666961**	56,344	50,561	44,778	**252.19249**	626,888	562,541	498,195	**0**	0	0	0	**2.2808643**	5,670	5,088	4,506	**0**	0	0	0	**59.684945**
Medium Density	RMD	2bc	1105	0	**22.666961**	58,207	52,759	47,311	**252.19249**	647,611	586,995	526,379	**0**	0	0	0	**2.2808643**	5,857	5,309	4,761	**0**	0	0	0	**59.684945**
	RMD	2cd	1106	0	**22.666961**	60,535	55,506	50,477	**252.19249**	673,516	617,562	561,609	**0**	0	0	0	**2.2808643**	6,091	5,585	5,079	**0**	0	0	0	**59.684945**
	RMD	5ab	1113	0	**22.666961**	56,344	50,561	44,778	**252.19249**	626,888	562,541	498,195	**0**	0	0	0	**2.2808643**	5,670	5,088	4,506	**0**	0	0	0	**59.684945**
	RMD	5bc	1114	0	**22.666961**	58,207	52,759	47,311	**252.19249**	647,611	586,995	526,379	**0**	0	0	0	**2.2808643**	5,857	5,309	4,761	**0**	0	0	0	**59.684945**
	RMD	5cd	1115	0	**22.666961**	60,535	55,506	50,477	**252.19249**	673,516	617,562	561,609	**0**	0	0	0	**2.2808643**	6,091	5,585	5,079	**0**	0	0	0	**59.684945**
	RHD	1ab	1201	0	**22.666961**	72,788	64,690	56,666	**68.237018**	219,122	194,744	170,588	**0**	0	0	0	**2.2808643**	7,324	6,509	5,702	**0**	0	0	0	**59.684945**
	RHD	1bc	1202	0	**22.666961**	73,791	66,031	58,341	**68.237018**	222,142	198,779	175,630	**0**	0	0	0	**2.2808643**	7,425	6,644	5,871	**0**	0	0	0	**59.684945**
	RHD	1cd	1203	0	**22.666961**	75,463	68,265	61,133	**68.237018**	227,174	205,506	184,035	**0**	0	0	0	**2.2808643**	7,593	6,869	6,151	**0**	0	0	0	**59.684945**
	RHD	2ab	1204	0	**22.666961**	72,788	64,690	56,666	**68.237018**	219,122	194,744	170,588	**0**	0	0	0	**2.2808643**	7,324	6,509	5,702	**0**	0	0	0	**59.684945**
High Density	RHD	2bc	1205	0	**22.666961**	73,791	66,031	58,341	**68.237018**	222,142	198,779	175,630	**0**	0	0	0	**2.2808643**	7,425	6,644	5,871	**0**	0	0	0	**59.684945**
	RHD	2cd	1206	0	**22.666961**	75,463	68,265	61,133	**68.237018**	227,174	205,506	184,035	**0**	0	0	0	**2.2808643**	7,593	6,869	6,151	**0**	0	0	0	**59.684945**
	RHD	5ab	1213	0	**22.666961**	72,788	64,690	56,666	**68.237018**	219,122	194,744	170,588	**0**	0	0	0	**2.2808643**	7,324	6,509	5,702	**0**	0	0	0	**59.684945**
	RHD	5bc	1214	0	**22.666961**	73,791	66,031	58,341	**68.237018**	222,142	198,779	175,630	**0**	0	0	0	**2.2808643**	7,425	6,644	5,871	**0**	0	0	0	**59.684945**
	RHD	5cd	1215	0	**22.666961**	75,463	68,265	61,133	**68.237018**	227,174	205,506	184,035	**0**	0	0	0	**2.2808643**	7,593	6,869	6,151	**0**	0	0	0	**59.684945**
	RHR	1ab	1301	0	**22.666961**	52,289	49,928	47,576	**101.86864**	234,994	224,382	213,816	**0**	0	0	0	**2.2808643**	5,262	5,024	4,787	**0**	0	0	0	**59.937918**
	RHR	1bc	1302	0	**22.666961**	53,641	51,368	49,105	**101.86864**	241,071	230,855	220,683	**0**	0	0	0	**2.2808643**	5,398	5,169	4,941	**0**	0	0	0	**59.937918**
High Rise	RHR	1cd	1303	0	**22.666961**	56,346	54,249	52,161	**101.86864**	253,226	243,802	234,419	**0**	0	0	0	**2.2808643**	5,670	5,459	5,249	**0**	0	0	0	**59.937918**
	RHR	2ab	1304	0	**22.666961**	52,289	49,928	47,576	**101.86864**	234,994	224,382	213,816	**0**	0	0	0	**2.2808643**	5,262	5,024	4,787	**0**	0	0	0	**59.937918**
	RHR	2bc	1305	0	**22.666961**	53,641	51,368	49,105	**101.86864**	241,071	230,855	220,683	**0**	0	0	0	**2.2808643**	5,398	5,169	4,941	**0**	0	0	0	**59.937918**
	RHR	2cd	1306	0	**22.666961**	56,346	54,249	52,161	**101.86864**	253,226	243,802	234,419	**0**	0	0	0	**2.2808643**	5,670	5,459	5,249	**0**	0	0	0	**59.937918**
Commercial																									
Down Town	CDT	1bc	2001	55,722	**20.308417**	87,583	77,601	71,583	**32.888658**	141,837	125,672	115,926	**586.88847**	2,531,042	2,242,582	2,068,667	**230.10659**	992,368	879,269	811,081	**307.72658**	1,327,116	1,175,866	1,084,676	**26.008818**
Big Box	CBB	1bc	2101	62,362	**29.303942**	126,798	118,251	115,600	**305.08837**	1,320,111	1,231,132	1,203,534	**287.3968**	1,243,560	1,159,741	1,133,743	**111.33702**	481,753	449,282	439,210	**39.390945**	170,444	158,955	155,392	**98.384308**
Strip Mall	CSM	1bc	2201	72,221	**93.557726**	404,822	381,038	376,077	**303.98413**	1,315,333	1,238,055	1,221,935	**455.58645**	1,971,313	1,855,495	1,831,336	**106.58799**	461,204	434,107	428,455	**53.089583**	229,718	216,221	213,406	**72.041772**
Educational/Institutional	EIS	1ab	3001	0	**0**	0	0	0	**345.95227**	508,499	482,399	456,717	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
	EIS	1bc	3002	0	**0**	0	0	0	**345.95227**	523,678	498,192	473,112	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
	EIS	1cd	3003	0	**0**	0	0	0	**345.95227**	584,394	561,365	538,695	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Open Space																									
	OPL	0ab	4001	66,755	**251.15309**	120,717	114,040	107,424	**513.27894**	246,708	233,061	219,542	**457.74672**	220,016	207,846	195,789	**435.38604**	209,269	197,693	186,225	**559.9729**	269,151	254,263	239,514	**225.93314**
Park lands, hydro, golf/cemetary	OPL	0bc	4002	75,722	**251.15309**	134,706	128,250	121,854	**513.27894**	275,296	262,103	249,033	**457.74672**	245,512	233,746	222,089	**435.38604**	233,519	222,328	211,241	**559.9729**	300,340	285,948	271,688	**225.93314**
	OPL	0cd	4003	110,096	**251.15309**	188,329	182,724	177,170	**513.27894**	384,885	373,432	362,080	**457.74672**	343,244	333,030	322,906	**435.38604**	326,477	316,761	307,133	**559.9729**	419,899	407,403	395,019	**225.93314**
	OVL	0ab	4101	0	**0**	0	0	0	**363.72974**	55,994	52,057	48,184	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Valley lands, golf/cemetary	OVL	0bc	4102	0	**0**	0	0	0	**363.72974**	77,573	73,695	69,879	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
	OVL	0cd	4103	0	**0**	0	0	0	**363.72974**	161,731	158,086	154,491	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Transportation	THC	0ab	5001	0	**0**	0	0	0	**904.9108**	507,044	507,044	507,044	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
	THC	0bc	5002	0	**0.8377733**	860	860	860	**920.66561**	945,042	945,042	945,042	**12.510244**	12,841	12,841	12,841	**3.3670375**	3,456	3,456	3,456	**1.0081828**	1,035	1,035	1,035	**0**
	THC	0cd	5003	0	**0.0332561**	57	57	57	**1079.6953**	1,855,610	1,855,610	1,855,610	**0**	0	0	0	**0.0021906**	4	4	4	**0**	0	0	0	**97.274856**
Industrial																									
	IPR	1ab	6001	26,951	**79.229611**	279,581	265,492	251,403	**78.211896**	275,990	262,082	248,173	**89.105253**	314,429	298,584	282,739	**125.61715**	443,270	420,933	398,595	**0**	0	0	0	**109.31348**
Prestige	IPR	1bc	6002	27,260	**79.229611**	280,935	267,607	254,280	**78.211896**	277,326	264,170	251,014	**89.105253**	315,952	300,963	285,975	**125.61715**	445,417	424,287	403,156	**0**	0	0	0	**109.31348**
	IPR	1cd	6003	27,877	**79.229611**	283,643	271,838	260,034	**78.211896**	279,999	268,346	256,694	**89.105253**	318,997	305,722	292,446	**125.61715**	449,710	430,995	412,279	**0**	0	0	0	**109.31348**
Big Box	IBB	1bc	6101	32,213	**211.74413**	807,798	805,423	803,049	**78.211896**	298,376	297,499	296,622	**89.105253**	339,934	338,935	337,936	**93.455494**	356,530	355,482	354,434	**0**	0	0	0	**591.78053**
Jan, Nov, Dec Runoff Months				198,573		1,343,327	1,261,423	1,189,364		7,460,268	7,018,667	6,621,552		2,513,301	2,329,006	2,231,901		1,376,158	1,287,915	1,229,108		1,013,992	938,047	888,255	
TOTAL RUNOFF				755,751		5,909,983	5,567,935	5,265,592		29,046,627	27,272,451	25,677,706		10,370,143	9,618,491	9,218,369		5,965,374	5,592,902	5,339,021		3,731,695	3,437,738	3,248,985	

Total Annual Runoff - Calibrated Analytical URF Model using Input From Banting et al. (2005)

	Code	Sub Code	WDM ID	No GRT Volume	50% GRT Volume	100% GRT Volume	rouge	No GRT Volume	50% GRT Volume	100% GRT Volume	waterfront	No GRT Volume	50% GRT Volume	100% GRT Volume	Western Beaches Tunnel	No GRT Volume	50% GRT Volume	100% GRT Volume
Residential																		
Low Density	RLD	1ab	1001	93,264	85,162	77,159	**0.0323749**	50	46	41	**0**	0	0	0	**0.2165496**	334	305	276
	RLD	1bc	1002	97,726	89,904	82,178	**0.0323749**	52	48	44	**0**	0	0	0	**0.2165496**	350	322	294
	RLD	1cd	1003	106,649	99,388	92,216	**0.0323749**	57	53	49	**0**	0	0	0	**0.2165496**	382	356	330
	RLD	2ab	1004	93,264	85,162	77,159	**0.0323749**	50	46	41	**0**	0	0	0	**0.2165496**	334	305	276
	RLD	2bc	1005	97,726	89,904	82,178	**0.0323749**	52	48	44	**0**	0	0	0	**0.2165496**	350	322	294
	RLD	2cd	1006	106,649	99,388	92,216	**0.0323749**	57	53	49	**0**	0	0	0	**0.2165496**	382	356	330
	RLD	5ab	1013	93,264	85,162	77,159	**0.0323749**	50	46	41	**0**	0	0	0	**0.2165496**	334	305	276
	RLD	5bc	1014	97,726	89,904	82,178	**0.0323749**	52	48	44	**0**	0	0	0	**0.2165496**	350	322	294
	RLD	5cd	1015	106,649	99,388	92,216	**0.0323749**	57	53	49	**0**	0	0	0	**0.2165496**	382	356	330
Medium Density	RMD	1ab	1101	148,362	133,133	117,905	**54.735356**	136,059	122,093	108,127	**0.4052449**	1,007	904	801	**0.0259196**	64	58	51
	RMD	1bc	1102	153,266	138,921	124,575	**54.735356**	140,556	127,400	114,244	**0.4052449**	1,041	943	846	**0.0259196**	67	60	54
	RMD	1cd	1103	159,397	146,155	132,913	**54.735356**	146,179	134,034	121,890	**0.4052449**	1,082	992	902	**0.0259196**	69	63	58
	RMD	2ab	1104	148,362	133,133	117,905	**54.735356**	136,059	122,093	108,127	**0.4052449**	1,007	904	801	**0.0259196**	64	58	51
	RMD	2bc	1105	153,266	138,921	124,575	**54.735356**	140,556	127,400	114,244	**0.4052449**	1,041	943	846	**0.0259196**	67	60	54
	RMD	2cd	1106	159,397	146,155	132,913	**54.735356**	146,179	134,034	121,890	**0.4052449**	1,082	992	902	**0.0259196**	69	63	58
	RMD	5ab	1113	148,362	133,133	117,905	**54.735356**	136,059	122,093	108,127	**0.4052449**	1,007	904	801	**0.0259196**	64	58	51
	RMD	5bc	1114	153,266	138,921	124,575	**54.735356**	140,556	127,400	114,244	**0.4052449**	1,041	943	846	**0.0259196**	67	60	54
	RMD	5cd	1115	159,397	146,155	132,913	**54.735356**	146,179	134,034	121,890	**0.4052449**	1,082	992	902	**0.0259196**	69	63	58
High Density	RHD	1ab	1201	191,660	170,337	149,208	**0.0323749**	104	92	81	**0**	0	0	0	**0.0750948**	241	214	188
	RHD	1bc	1202	194,301	173,867	153,619	**0.0323749**	105	94	83	**0**	0	0	0	**0.0750948**	244	219	193
	RHD	1cd	1203	198,703	179,750	160,970	**0.0323749**	108	98	87	**0**	0	0	0	**0.0750948**	250	226	203
	RHD	2ab	1204	191,660	170,337	149,208	**0.0323749**	104	92	81	**0**	0	0	0	**0.0750948**	241	214	188
	RHD	2bc	1205	194,301	173,867	153,619	**0.0323749**	105	94	83	**0**	0	0	0	**0.0750948**	244	219	193
	RHD	2cd	1206	198,703	179,750	160,970	**0.0323749**	108	98	87	**0**	0	0	0	**0.0750948**	250	226	203
	RHD	5ab	1213	191,660	170,337	149,208	**0.0323749**	104	92	81	**0**	0	0	0	**0.0750948**	241	214	188
	RHD	5bc	1214	194,301	173,867	153,619	**0.0323749**	105	94	83	**0**	0	0	0	**0.0750948**	244	219	193
	RHD	5cd	1215	198,703	179,750	160,970	**0.0323749**	108	98	87	**0**	0	0	0	**0.0750948**	250	226	203
High Rise	RHR	1ab	1301	138,267	132,023	125,806	**0.0323749**	75	71	68	**0**	0	0	0	**0.0801726**	185	177	168
	RHR	1bc	1302	141,843	135,832	129,847	**0.0323749**	77	73	70	**0**	0	0	0	**0.0801726**	190	182	174
	RHR	1cd	1303	148,994	143,449	137,928	**0.0323749**	80	77	75	**0**	0	0	0	**0.0801726**	199	192	184
	RHR	2ab	1304	138,267	132,023	125,806	**0.0323749**	75	71	68	**0**	0	0	0	**0.0801726**	185	177	168
	RHR	2bc	1305	141,843	135,832	129,847	**0.0323749**	77	73	70	**0**	0	0	0	**0.0801726**	190	182	174
	RHR	2cd	1306	148,994	143,449	137,928	**0.0323749**	80	77	75	**0**	0	0	0	**0.0801726**	199	192	184
Commercial																		
Down Town	CDT	1bc	2001	112,167	99,383	91,676	**100.25843**	432,379	383,101	353,391	**19.926171**	85,935	76,141	70,236	**240.54536**	1,037,387	919,157	847,875
Big Box	CBB	1bc	2101	425,707	397,013	388,113	**82.173206**	355,562	331,596	324,163	**19.926171**	86,220	80,409	78,606	**153.59958**	664,622	619,825	605,930
Strip Mall	CSM	1bc	2201	311,723	293,409	289,589	**82.173206**	355,562	334,672	330,314	**19.926171**	86,220	81,155	80,098	**170.6205**	738,271	694,896	685,849
Educational/Institutional	EIS	1ab	3001	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
	EIS	1bc	3002	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
	EIS	1cd	3003	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
Open Space																		
Park lands, hydro, golf/cemetary	OPL	0ab	4001	108,595	102,588	96,637	**539.04143**	259,091	244,759	230,561	**397.29203**	190,959	180,396	169,931	**626.2232**	300,994	284,345	267,851
	OPL	0bc	4002	121,179	115,372	109,618	**539.04143**	289,114	275,259	261,532	**397.29203**	213,087	202,875	192,758	**626.2232**	335,874	319,778	303,831
	OPL	0cd	4003	169,417	164,376	159,379	**539.04143**	404,203	392,175	380,254	**397.29203**	297,912	289,046	280,260	**626.2232**	469,577	455,603	441,754
Valley lands, golf/cemetary	OVL	0ab	4101	0	0	0	**142.26863**	21,901	20,361	18,846	**0.308664**	48	44	41	**0.0129884**	2	2	2
	OVL	0bc	4102	0	0	0	**142.26863**	30,342	28,825	27,332	**0.308664**	66	63	59	**0.0129884**	3	3	2
	OVL	0cd	4103	0	0	0	**142.26863**	63,259	61,833	60,427	**0.308664**	137	134	131	**0.0129884**	6	6	6
Transportation	THC	0ab	5001	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0
	THC	0bc	5002	0	0	0	**0.0482955**	50	50	50	**9.6292569**	9,884	9,884	9,884	**1.1675023**	1,198	1,198	1,198
	THC	0cd	5003	167,181	167,181	167,181	**5.3832502**	9,252	9,252	9,252	**0**	0	0	0	**11.119914**	19,111	19,111	19,111
Industrial																		
Prestige	IPR	1ab	6001	385,739	366,300	346,862	**184.99539**	652,801	619,904	587,007	**40.473975**	142,822	135,625	128,428	**68.997667**	243,475	231,205	218,936
	IPR	1bc	6002	387,607	369,219	350,831	**184.99539**	655,962	624,844	593,725	**40.473975**	143,514	136,706	129,897	**68.997667**	244,654	233,048	221,441
	IPR	1cd	6003	391,343	375,057	358,770	**184.99539**	662,285	634,722	607,160	**40.473975**	144,897	138,867	132,837	**68.997667**	247,012	236,732	226,452
Big Box	IBB	1bc	6101	2,257,626	2,250,990	2,244,353	**184.99539**	705,752	703,678	701,603	**40.473975**	154,407	153,953	153,499	**88.096667**	336,086	335,098	334,110
Jan, Nov, **Dec Runoff Months**				2,819,832	2,644,018	2,482,104		1,812,791	1,705,613	1,615,972		520,864	497,239	477,652		1,518,358	1,423,462	1,365,733
TOTAL RUNOFF				12,546,306	11,817,366	11,144,501		7,980,579	7,522,965	7,135,960		2,086,362	1,991,055	1,911,964		6,163,786	5,780,043	5,546,079

APPENDIX F: HIGHLAND CREEK SUB-CATCHMENT PARAMETERS (AQUAFOR BEECH LTD., 2004)

Table A.1
EXISTING LANDUSE SCENARIO

URBAN COMPONENT PARAMETERS

CATCHMENT ID	TOTAL AREA (hectares)	CATCHEMNT SLOPE (mean)	STREAM SLOPE (%)	MAX STREAM LENGTH (metres)	UNADJUSTED CN*_URBAN (from GIS)	DESIGN CN*_URBAN AMC II	DESIGN CN*_URBAN AMC III	IA_perv (mm)	DPI (IA_imp) (mm)	% IMPERVIOUS (%)	IMPERVIOUS LENGTH (m)	PERVIOUS LENGTH (m)	IMPERVIOUS n	PERVIOUS n
100	305.27	5.12	0.55	2310	61	61	78	5.0	2.0	47.7%	1427	40	0.013	0.250
101	274.20	3.00	0.68	2780	65	65	82	5.0	2.0	49.4%	1352	40	0.013	0.250
102	203.50	3.61	0.53	990	68	68	84	5.0	2.0	49.9%	1165	40	0.013	0.250
103	274.79	3.71	0.60	2090	62	62	79	5.0	2.0	63.7%	1354	40	0.013	0.250
104	194.23	3.13	0.49	1250	67	67	84	5.0	2.0	54.6%	1138	40	0.013	0.250
105	130.21	3.56	0.77	1030	73	73	88	5.0	2.0	68.3%	932	40	0.013	0.250
200	417.39	6.42	0.42	3790	62	62	79	5.0	2.0	44.1%	1668	40	0.013	0.250
201	195.99	5.79	0.46	1800	69	69	84	5.0	2.0	66.5%	1143	40	0.013	0.250
202	16.78	3.41	0.38	440	72	72	86	5.0	2.0	93.8%	335	40	0.013	0.250
203	284.36	3.32	0.67	1880	73	73	87	5.0	2.0	53.2%	1377	40	0.013	0.250
204	154.74	4.02	0.52	1040	73	73	87	5.0	2.0	59.2%	1016	40	0.013	0.250
205	251.87	3.47	0.35	1640	72	72	86	5.0	2.0	46.9%	1296	40	0.013	0.250
206	151.79	2.68	0.51	1720	73	73	87	5.0	2.0	53.4%	1006	40	0.013	0.250
207	332.28	2.10	0.51	2290	74	74	88	5.0	2.0	56.4%	1735	40	0.013	0.250
208	273.36	2.02	0.46	2360	73	73	87	5.0	2.0	50.9%	1350	40	0.013	0.250
209	85.82	3.22	0.21	1080	70	70	85	5.0	2.0	33.8%	756	40	0.013	0.250
210	198.36	2.51	1.26	1720	73	73	87	5.0	2.0	54.0%	1150	40	0.013	0.250
211	170.84	2.60	0.85	1270	73	73	87	5.0	2.0	49.9%	1067	40	0.013	0.250
300	429.52	6.45	0.70	3220	62	62	79	5.0	2.0	56.3%	1692	40	0.013	0.250
301	369.48	4.34	1.12	1710	74	74	88	5.0	2.0	61.2%	1570	40	0.013	0.250
302	308.50	3.45	0.69	3150	73	73	87	5.0	2.0	51.9%	1434	40	0.013	0.250
303	280.20	2.47	0.87	1860	73	73	87	5.0	2.0	49.5%	1367	40	0.013	0.250
304	367.59	3.05	0.76	2970	73	73	87	5.0	2.0	55.3%	1565	40	0.013	0.250
305	151.87	1.96	0.81	1770	73	73	87	5.0	2.0	50.2%	1006	40	0.013	0.250
306	217.53	2.41	0.98	1810	72	72	86	5.0	2.0	40.2%	1204	40	0.013	0.250
400	289.75	5.03	0.78	1450	73	73	87	5.0	2.0	53.2%	1390	40	0.013	0.250
401	298.37	3.64	0.95	900	73	73	86	5.0	2.0	55.3%	1410	40	0.013	0.250
402	293.65	3.05	0.56	2170	73	73	88	5.0	2.0	61.8%	1399	40	0.013	0.250
403	243.43	2.88	0.85	3120	72	72	86	5.0	2.0	49.8%	1274	40	0.013	0.250
404	285.65	2.82	0.51	1610	72	72	86	5.0	2.0	60.1%	1380	40	0.013	0.250
500	39.95	2.74	1.11	900	72	72	86	5.0	2.0	42.1%	516	40	0.013	0.250
501	306.25	5.04	0.97	3000	65	65	85	5.0	2.0	44.9%	1429	40	0.013	0.250
502	172.77	3.26	0.95	1750	61	61	78	5.0	2.0	45.2%	1073	40	0.013	0.250
600	97.65	10.72	0.27	3480	60	60	78	5.0	2.0	17.6%	807	40	0.013	0.250
601	297.76	4.86	1.28	3590	63	63	80	5.0	2.0	43.9%	1409	40	0.013	0.250
602	201.44	7.53	0.52	3090	56	56	74	5.0	2.0	41.0%	1512	40	0.013	0.250
603	280.82	3.76	0.44	830	58	58	76	5.0	2.0	39.5%	1368	40	0.013	0.250
604	351.99	8.18	2.45	2480	49	49	68	5.0	2.0	33.8%	1532	40	0.013	0.250
605	266.95	10.32	0.63	3410	70	70	85	5.0	2.0	35.1%	1334	40	0.013	0.250
606	75.33	12.93	0.43	1280	63	63	80	5.0	2.0	28.4%	709	40	0.013	0.250
607	377.11	3.91	1.37	3640	65	65	82	5.0	2.0	51.7%	1586	40	0.013	0.250
608	373.88	9.58	0.44	5390	57	57	75	5.0	2.0	38.5%	1579	40	0.013	0.250
609	281.25	4.35	0.58	2480	59	59	77	5.0	2.0	50.5%	1369	40	0.013	0.250
TOTALS =	10574.47													

Table A.2
FUTURE LANDUSE SCENARIO

URBAN COMPONENT PARAMETERS

CATCHMENT ID	TOTAL AREA (hectares)	CATCHEMNT SLOPE (mean)	STREAM SLOPE (%)	MAX STREAM LENGTH (metres)	UNADJUSTED CN*_URBAN (from GIS)	DESIGN CN*_URBAN AMC II	DESIGN CN*_URBAN AMC III	IA_perv (mm)	DPI (IA_imp) (mm)	% IMPERVIOUS (%)	IMPERIVOUS LENGTH (m)	PERVIOUS LENGTH (m)	IMPERIVOUS n	PERVIOUS n
100	287.2	5.12	0.55	2310	61	61	78	5.0	2.0	46.0%	1384	40	0.013	0.250
100.1	18.18	5.12	0.55	2310	59	59	77	5.0	2.0	90.0%	348	40	0.013	0.250
101	185.26	3.00	0.68	2780	65	65	82	5.0	2.0	43.8%	1111	40	0.013	0.250
101.1	88.92	3.00	0.68	2780	70	70	85	5.0	2.0	90.0%	770	40	0.013	0.250
102	185.31	3.61	0.53	990	68	68	84	5.0	2.0	46.9%	1111	40	0.013	0.250
102.1	18.07	3.61	0.53	990	69	69	84	5.0	2.0	90.0%	347	40	0.013	0.250
103	115.05	3.71	0.60	2090	62	62	79	5.0	2.0	44.5%	876	40	0.013	0.250
103.1	159.8	3.71	0.60	2090	62	62	79	5.0	2.0	90.0%	1032	40	0.013	0.250
104	150.9	3.13	0.49	1250	68	68	84	5.0	2.0	47.9%	1003	40	0.013	0.250
104.1	43.37	3.13	0.49	1250	66	66	82	5.0	2.0	90.0%	538	40	0.013	0.250
105	20.5	3.56	0.77	1030	74	74	88	5.0	2.0	55.9%	370	40	0.013	0.250
105.1	109.71	3.56	0.77	1030	73	73	87	5.0	2.0	90.0%	855	40	0.013	0.250
200	409.83	6.42	0.42	3790	62	62	79	5.0	2.0	43.5%	1653	40	0.013	0.250
200.1	7.6	6.42	0.42	3790	59	59	77	5.0	2.0	90.0%	225	40	0.013	0.250
201	34.94	5.79	0.46	1800	68	68	84	5.0	2.0	59.9%	483	40	0.013	0.250
201.1	161.1	5.79	0.46	1800	70	70	85	5.0	2.0	90.0%	1036	40	0.013	0.250
202	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
202.1	16.78	3.41	0.38	440	72	72	86	5.0	2.0	90.0%	334	40	0.013	0.250
203	244.09	3.32	0.67	1880	73	73	87	5.0	2.0	51.9%	1276	40	0.013	0.250
203.1	40.2	3.32	0.67	1880	73	73	87	5.0	2.0	90.0%	518	40	0.013	0.250
204	80.55	4.02	0.52	1040	73	73	87	5.0	2.0	46.5%	733	40	0.013	0.250
204.1	74.4	4.02	0.52	1040	73	73	87	5.0	2.0	90.0%	704	40	0.013	0.250
205	229.05	3.47	0.35	1640	72	72	86	5.0	2.0	42.8%	1236	40	0.013	0.250
205.1	22.9	3.47	0.35	1640	74	74	88	5.0	2.0	90.0%	391	40	0.013	0.250
206	143.78	2.68	0.51	1720	73	73	87	5.0	2.0	51.8%	979	40	0.013	0.250
206.1	8	2.68	0.51	1720	74	74	88	5.0	2.0	90.0%	231	40	0.013	0.250
207	321.11	2.10	0.51	2290	74	74	88	5.0	2.0	55.3%	1463	40	0.013	0.250
207.1	11	2.10	0.51	2290	74	74	88	5.0	2.0	90.0%	271	40	0.013	0.250
208	268.6	2.02	0.46	2360	73	73	87	5.0	2.0	50.3%	1338	40	0.013	0.250
208.1	4.7	2.02	0.46	2360	74	74	88	5.0	2.0	90.0%	177	40	0.013	0.250
209	84.81	3.22	0.21	1080	70	70	85	5.0	2.0	33.4%	752	40	0.013	0.250
209.1	1	3.22	0.21	1080	74	74	88	5.0	2.0	90.0%	82	40	0.013	0.250
210	128.92	2.51	1.26	1720	73	73	87	5.0	2.0	47.8%	927	40	0.013	0.250
210.1	69.5	2.51	1.26	1720	73	73	87	5.0	2.0	90.0%	681	40	0.013	0.250
211	170.81	2.60	0.85	1270	73	73	87	5.0	2.0	49.9%	1067	40	0.013	0.250
211.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
300	168.58	6.45	0.70	3220	62	62	79	5.0	2.0	41.5%	1060	40	0.013	0.250
300.1	261.06	6.45	0.70	3220	70	70	85	5.0	2.0	90.0%	1319	40	0.013	0.250
301	172.46	4.34	1.12	1710	74	74	88	5.0	2.0	50.6%	1072	40	0.013	0.250
301.1	197	4.34	1.12	1710	75	75	88	5.0	2.0	90.0%	1146	40	0.013	0.250
302	247.48	3.45	0.69	3150	73	73	87	5.0	2.0	46.6%	1284	40	0.013	0.250
302.1	61	3.45	0.69	3150	73	73	87	5.0	2.0	90.0%	638	40	0.013	0.250
303	132.15	2.47	0.87	1860	73	73	87	5.0	2.0	52.6%	939	40	0.013	0.250
303.1	148.00	2.47	0.87	1860	72	72	86	5.0	2.0	90.0%	993	40	0.013	0.250

Table A.2 (Continued ...)

FUTURE LANDUSE SCENARIO

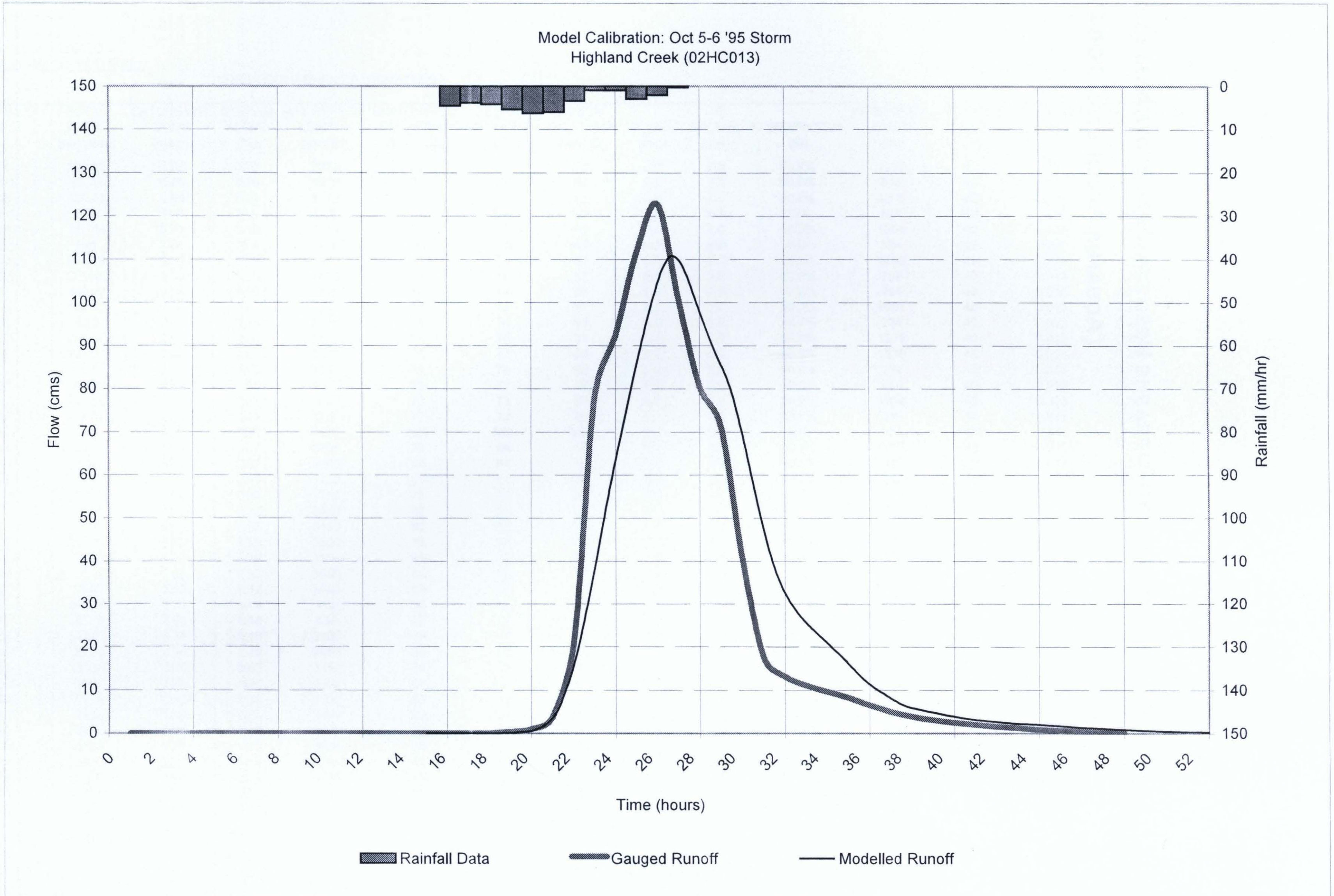
URBAN COMPONENT PARAMETERS

CATCHMENT ID	TOTAL AREA (hectares)	CATCHEMNT SLOPE (mean)	STREAM SLOPE (%)	MAX STREAM LENGTH (metres)	UNADJUSTED CN*_URBAN (from GIS)	DESIGN CN*_URBAN AMC II	DESIGN CN*_URBAN AMC III	IA_perv (mm)	DPI (IA_imp) (mm)	% IMPERVIOUS (%)	IMPERIVOUS LENGTH (m)	PERVIOUS LENGTH (m)	IMPERIVOUS n	PERVIOUS n
304	267.82	3.05	0.76	2970	73	73	87	5.0	2.0	50.2%	1336	40	0.013	0.250
304.1	99.70	3.05	0.76	2970	73	73	87	5.0	2.0	90.0%	815	40	0.013	0.250
305	151.86	1.96	0.81	1770	73	73	87	5.0	2.0	50.2%	1006	40	0.013	0.250
305.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
306	217.54	2.41	0.98	1810	72	72	86	5.0	2.0	40.2%	1204	40	0.013	0.250
306.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
400	214.73	5.03	0.78	1450	73	73	87	5.0	2.0	48.8%	1196	40	0.013	0.250
400.1	75.00	5.03	0.78	1450	73	73	87	5.0	2.0	90.0%	707	40	0.013	0.250
401	148.17	3.64	0.95	900	72	72	86	5.0	2.0	42.2%	994	40	0.013	0.250
401.1	150.30	3.64	0.95	900	73	73	87	5.0	2.0	90.0%	1001	40	0.013	0.250
402	8.20	3.05	0.56	2170	74	74	88	5.0	2.0	48.7%	234	40	0.013	0.250
402.1	285.40	3.05	0.56	2170	73	73	87	5.0	2.0	90.0%	1379	40	0.013	0.250
403	230.37	2.88	0.85	3120	72	72	86	5.0	2.0	48.5%	1239	40	0.013	0.250
403.1	13.00	2.88	0.85	3120	74	74	88	5.0	2.0	90.0%	294	40	0.013	0.250
404	36.92	2.82	0.51	1610	71	71	86	5.0	2.0	39.0%	496	40	0.013	0.250
404.1	248.80	2.82	0.51	1610	73	73	87	5.0	2.0	90.0%	1288	40	0.013	0.250
500	39.95	2.74	1.11	900	72	72	86	5.0	2.0	42.1%	516	40	0.013	0.250
500.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
501	303.55	5.04	0.97	3000	65	65	85	5.0	2.0	44.6%	1423	40	0.013	0.250
501.1	2.90	5.04	0.97	3000	64	64	81	5.0	2.0	90.0%	139	40	0.013	0.250
502	167.51	3.26	0.95	1750	61	61	78	5.0	2.0	44.2%	1057	40	0.013	0.250
502.1	5.10	3.26	0.95	1750	73	73	87	5.0	2.0	90.0%	184	40	0.013	0.250
600	85.41	10.72	0.27	3480	60	60	78	5.0	2.0	13.8%	755	40	0.013	0.250
600.1	12.20	10.72	0.27	3480	62	62	79	5.0	2.0	90.0%	285	40	0.013	0.250
601	256.63	4.86	1.28	3590	63	63	80	5.0	2.0	40.6%	1308	40	0.013	0.250
601.1	41.10	4.86	1.28	3590	65	65	82	5.0	2.0	90.0%	523	40	0.013	0.250
602	162.48	7.53	0.52	3090	55	55	74	5.0	2.0	31.6%	1041	40	0.013	0.250
602.1	38.80	7.53	0.52	3090	59	59	77	5.0	2.0	90.0%	509	40	0.013	0.250
603	258.36	3.76	0.44	830	58	58	76	5.0	2.0	38.3%	1312	40	0.013	0.250
603.1	22.56	3.76	0.44	830	55	55	74	5.0	2.0	90.0%	388	40	0.013	0.250
604	323.23	8.18	2.45	2480	48	48	68	5.0	2.0	30.5%	1468	40	0.013	0.250
604.1	28.70	8.18	2.45	2480	66	66	82	5.0	2.0	90.0%	437	40	0.013	0.250
605	266.92	10.32	0.63	3410	70	70	85	5.0	2.0	35.1%	1334	40	0.013	0.250
605.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
606	75.28	12.93	0.43	1280	63	63	80	5.0	2.0	28.4%	708	40	0.013	0.250
606.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
607	354.52	3.91	1.37	3640	65	65	82	5.0	2.0	49.8%	1537	40	0.013	0.250
607.1	22.52	3.91	1.37	3640	62	62	79	5.0	2.0	90.0%	387	40	0.013	0.250
608	338.98	9.58	0.44	5390	57	57	75	5.0	2.0	33.9%	1503	40	0.013	0.250
608.1	35.00	9.58	0.44	5390	59	59	77	5.0	2.0	90.0%	483	40	0.013	0.250
609	231.26	4.35	0.58	2480	59	59	77	5.0	2.0	46.1%	1242	40	0.013	0.250
609.1	49.9	4.35	0.58	2480	58	58	76	5.0	2.0	90.0%	577	40	0.013	0.250
TOTALS =	10574.34													

Appendix G: Storm Hydrographs Used for Peak Flow Analysis

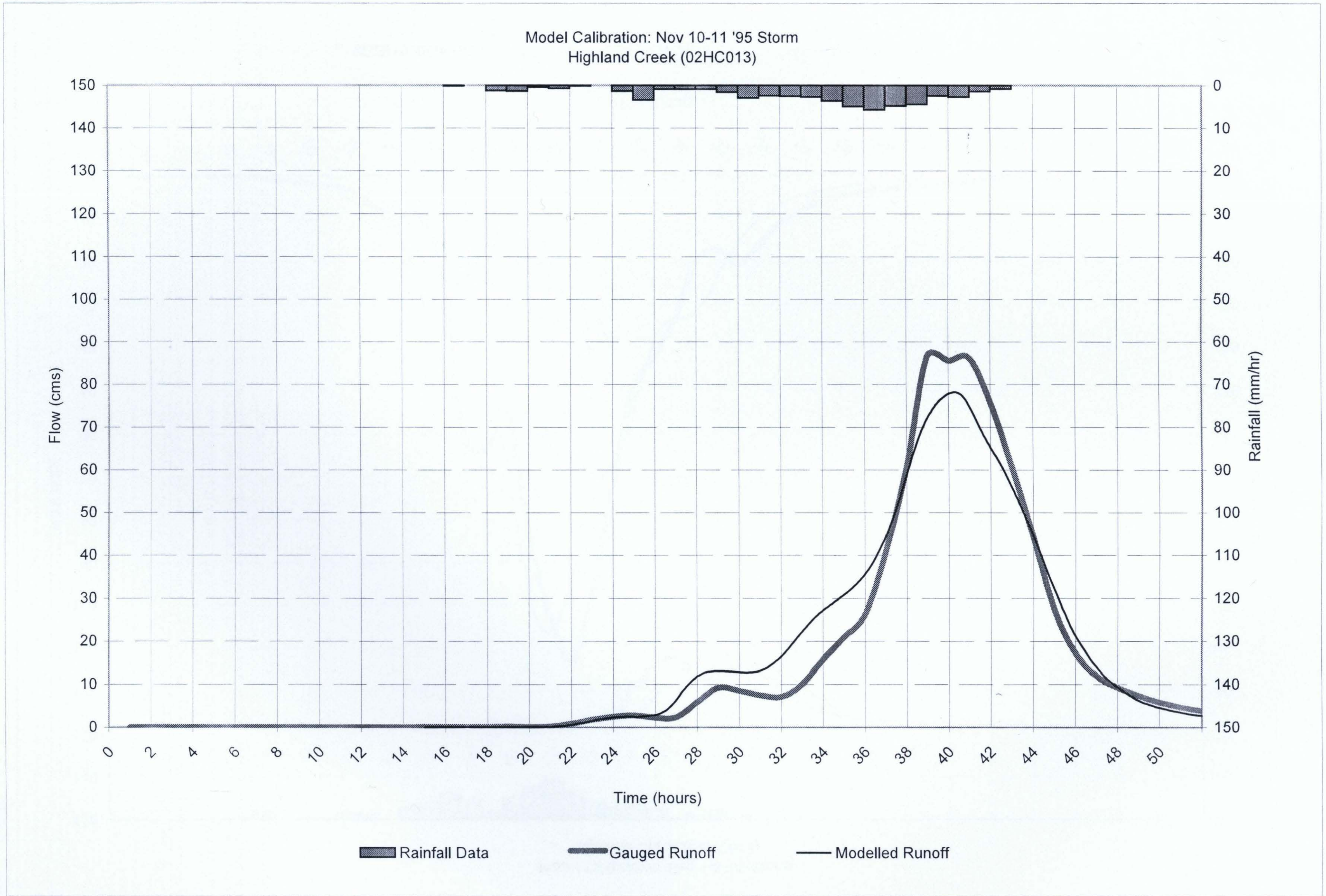
(Aquafor Beech Ltd., 2004)

Storm Hydrograph Used for Peak Flow Analysis - Storm ID 1



(Aquafor Beech Limited, 2004)

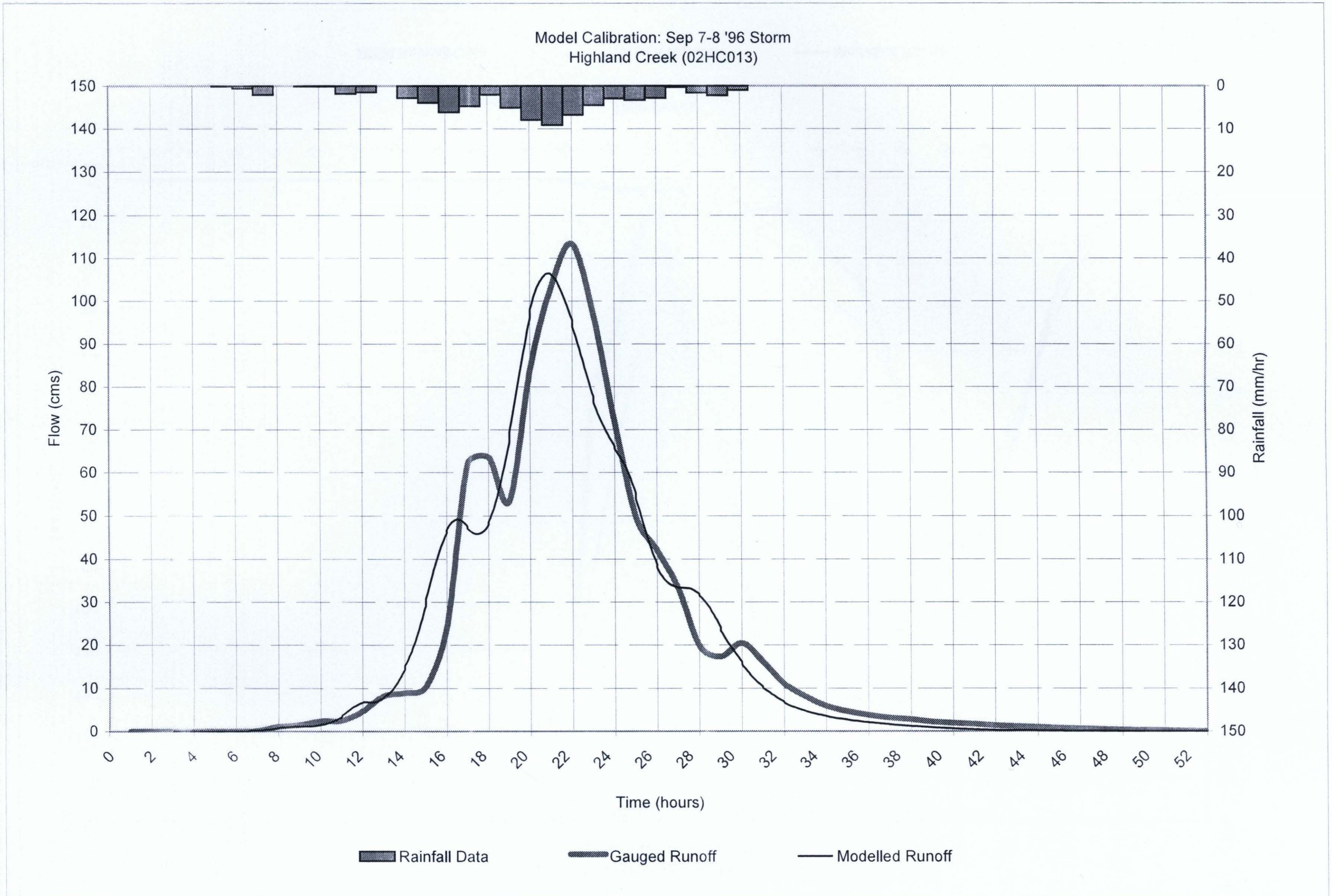
Storm Hydrograph Used for Peak Flow Analysis - Storm ID 2



(Aquafor Beech Limited, 2004)

Appendix G

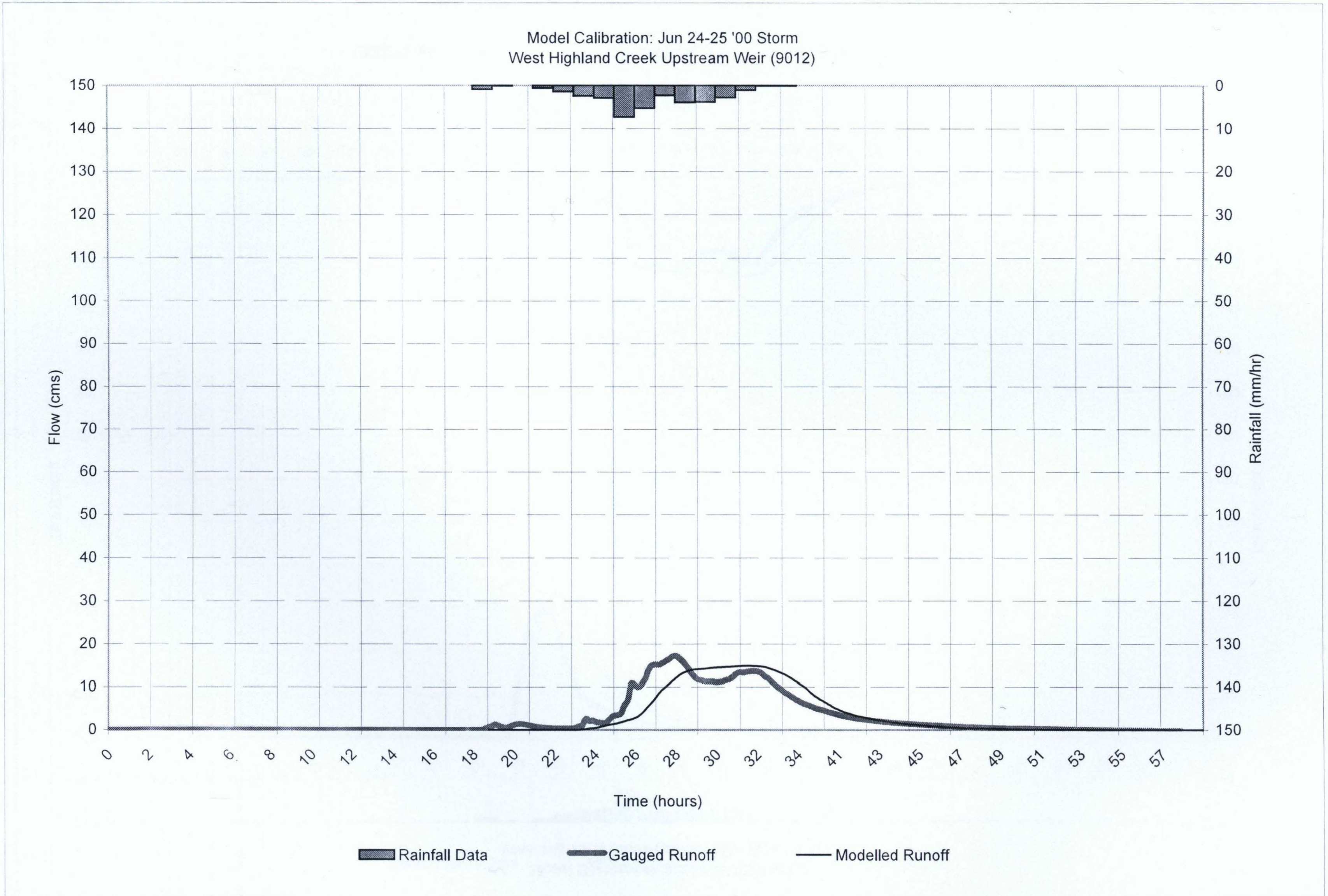
Storm Hydrograph Used for Peak Flow Analysis - Storm ID 3



(Aquafor Beech Limited, 2004)

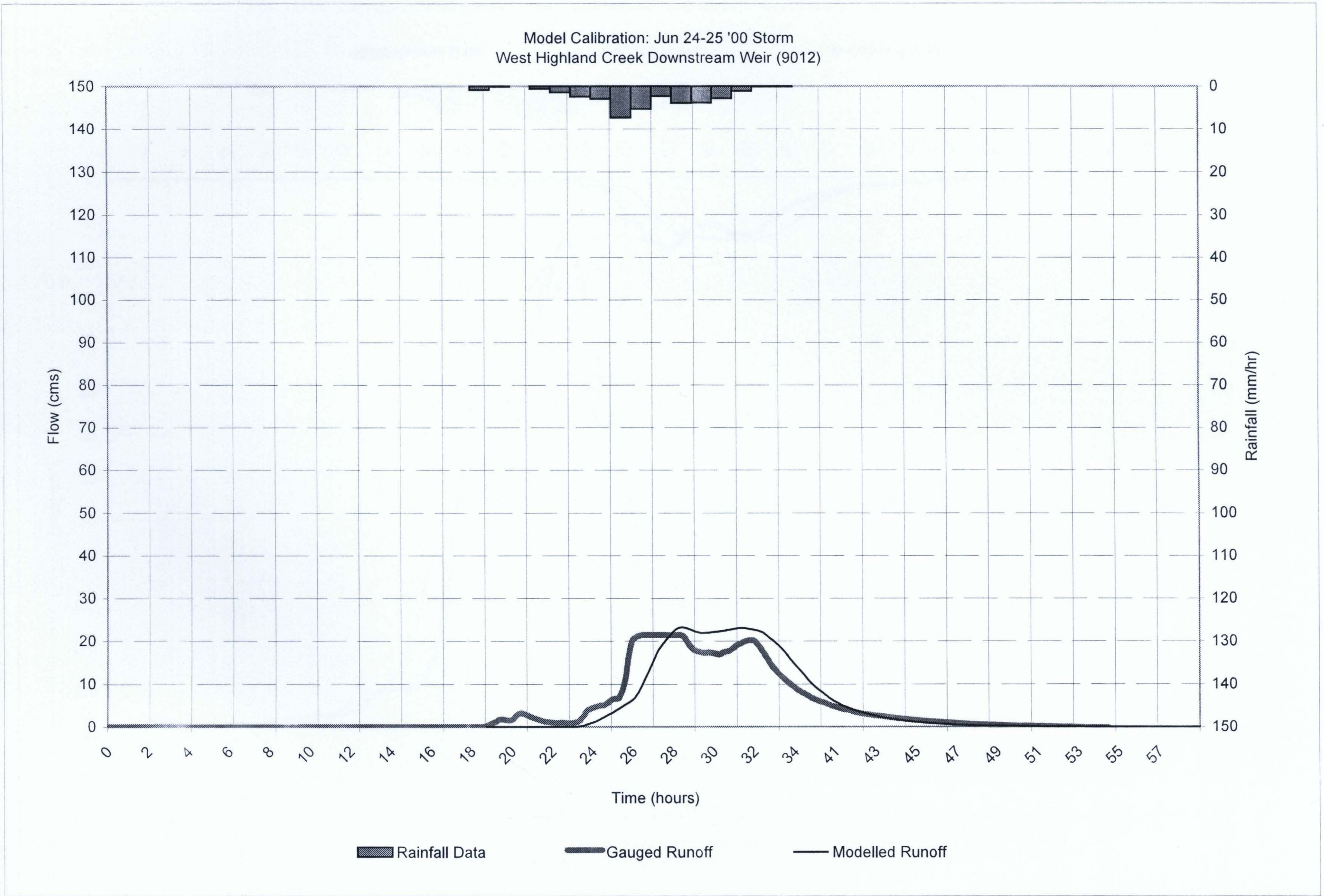
Appendix G

Storm Hydrograph Used for Peak Flow Analysis - Storm ID 4



(Aquafor Beech Limited, 2004)

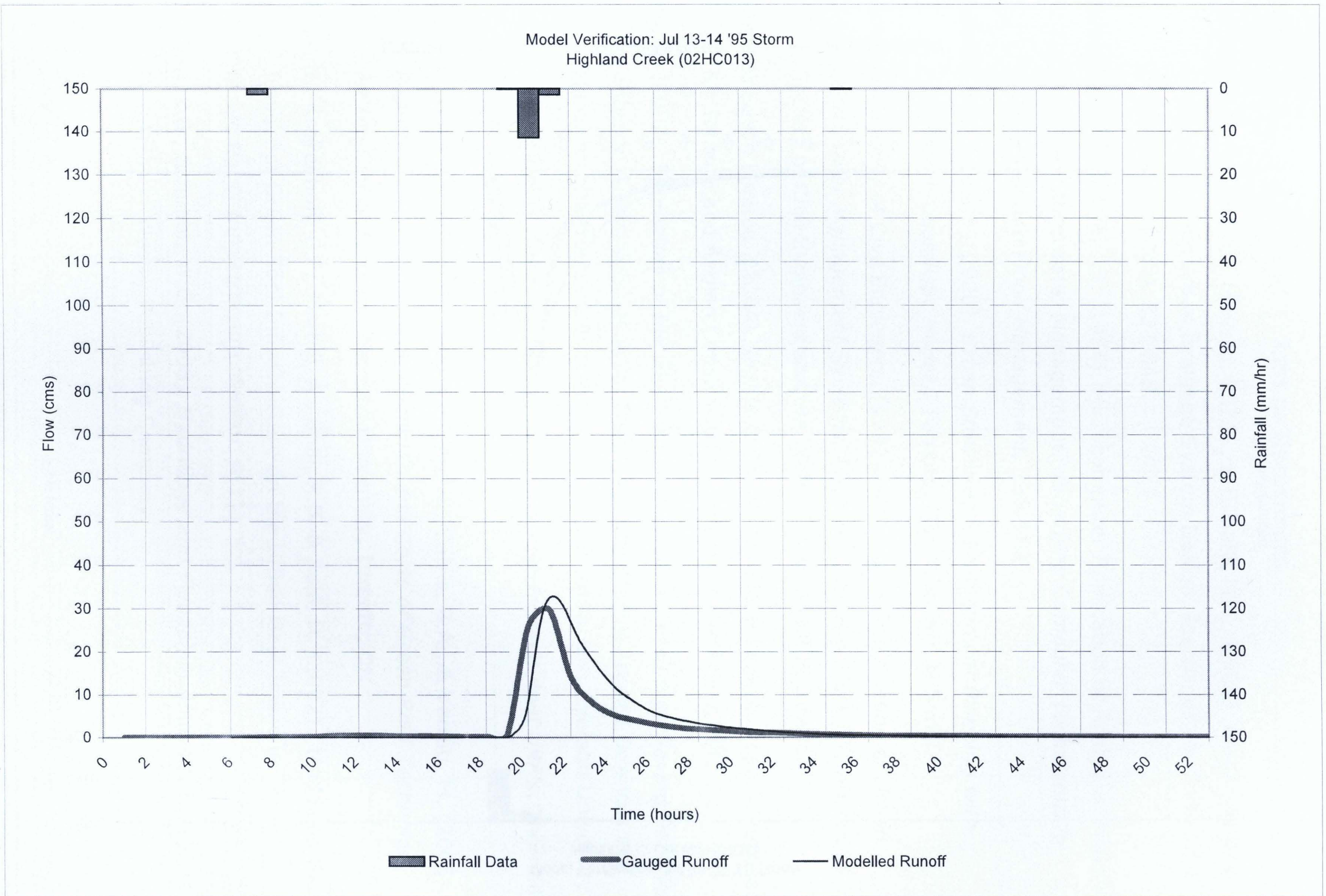
Storm Hydrograph Used for Peak Flow Analysis - Storm ID 5



(Aquafor Beech Limited, 2004)

Appendix G

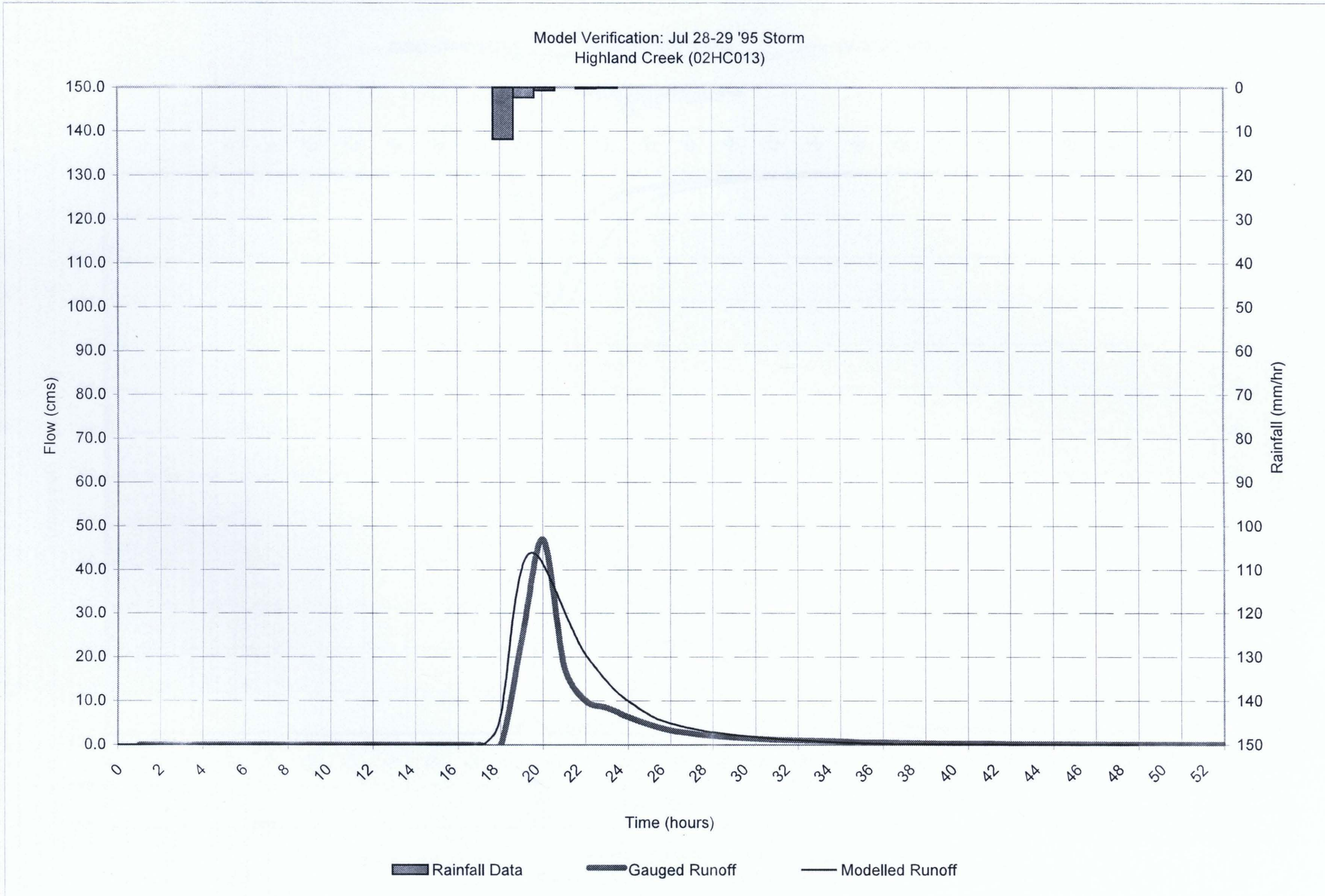
Storm Hydrograph Used for Peak Flow Analysis - Storm ID 6



(Aquafor Beech Limited, 2004)

Appendix G

Storm Hydrograph Used for Peak Flow Analysis - Storm ID 7



(Aquafor Beech Limited, 2004)

Appendix G

List of References

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List of Acronyms

BMP	Best Management Practice
BOD	Biological Oxygen Demand
CSM	Continuous Simulation Model
CSO	Combined Sewer Overflow
GTA	Greater Toronto Area
HSP-F	Hydrological Simulation Program - Fortran
IETD	Interevent Time Definition
NRCS	Natural Resources Conservation Service
PAH	Poly Aromatic Hydrocarbons
pdf	Probability Distribution Function
QQS	Quantity-Quality Simulation
STORM	Storage, Treatment, Overflow, Runoff Model
SUDS	Sustainable Urban Drainage Systems
TRCA	Toronto and Region Conservation Authority
UFORE	Urban Forest Effects
UARF	Unit-area Reduction Factors
URF	Unit Response Function
WWFMMP	Wet Weather Flow Management Master Plan