

MEMORANDUM

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FROM: Dr. Harold Schroeter, P.Eng.,

Signature: _____

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PROJECT: 13-12

SUBJECT: 1200 King Road – Hydrologic Modelling

Pages: 75

This memo report provides a summary of the activities under taken for the hydrologic modelling portion for the ongoing 1200 King Road Development Project in Burlington, Ontario. There are eight main activities or tasks reported herein:

1. Background information review,
2. Data collection activities (processing flow data),
3. Watershed Modelling (setup, calibration/validation) for existing conditions, and
4. Model Applications for Impact Assessment.
 - a) Return Period and Regional Storm Applications
 - b) Long-term simulations for Water Balance
 - c) Flood Flow Comparisons
 - d) Post-Development Applications
 - e) Erosion Assessment

Each of these activities or tasks is summarized in a separate section of this memo. Most of the discussion that follows is given in point form, with adequate references noted where more detailed information is available. Table and figure numbers are assigned as they are referenced in the text by first occurrence, although most of the relevant tables and figures are found following the references. Some of the smaller tables have been inserted directly in the text.

The detailed hydrologic model developed for this study utilized the GAWSER (Guelph All-Weather Sequential-Events Runoff model) program throughout. This program, based upon the original HYMO platform, has physically-based computational procedures that have seen wide application in more than 90 watershed studies in Ontario, and has evolved over the past 35 years as one of the best available 'Canadian-made' hydrologic modelling tools for water management, planning and operations. It is fully described elsewhere (e.g. LPRCA, 2004; PEI, 2002; Schroeter and Boyd, 1998; Schroeter et al., 2000a, 2003; Schroeter & Associates, 1999; 2004; 2005, 2014), and is capable of computing long-term water balances and high/low flows for more than 50 plus years.

1.0 BACKGROUND INFORMATION REVIEW

When the original terms of reference for this project were formulated, it was thought that the existing models developed by Valdor Engineering Ltd. (2011) for Falcon Creek, and AMEC (2011) for Indian Creek would be used directly. However, upon closer review of these models it was decided to make use of the full hydrologic models developed during the South Waterdown Subwatershed Study (Ecoplans, 2004, 2010) and subsequent applications for the Waterdown Bay Functional Servicing and Stormwater Management Plans (Metropolitan, 2014), and revising them to include Indian Creek for the following reasons:

1. these models are already formulated using the physically-based GAWSER program,
2. the existing condition models have undergone significant peer review and revisions as the result of two OMB hearings (2007 and 2014, need references),
3. parts of the Grindstone Creek Tributary 3 (or GS-3 for short) have been calibrated against monitoring data supplied by SNC-Lavalin (2008),
4. Grindstone Creek has been modelled numerous times using GAWSER in the 1990s (e.g. Schroeter & Associates, 1993; Cosburn Pattern Wardman Ltd., 1995; EWRG Ltd., 1997), and peak flow estimates were comparable to those estimated by other Grindstone Creek models (e.g. Philips Planning and Engineering Ltd., 1985; Dillon, 1988; Ecoplans, 1996)
5. peak flow estimates for Falcon Creek are comparable to those reported by Valdor Engineering Ltd. (2011) as noted in a peer review study conducted by Schroeter & Associates (2011),
6. Indian Creek has been modelled using GAWSER in an earlier study by Schroeter & Associates (1993) for Conservation Halton, and peak flow estimates from that model were comparable to others developed at that time by Philips Planning and Engineering Ltd. (1991) for the Federal/Provincial Flood Damage Reduction Program, and
7. the ongoing Stage 3 portion of the South Waterdown Subwatershed Study will supply additional monitoring data to further validate the GS-3 and Falcon Creek parts of the model over the next 3 to 5 years.

Figure 1 shows the subcatchment boundaries for the current GS-3 and Falcon Creek models formulated during the South Waterdown Subwatershed Study (SWSS) and the 1200 King Road project site. The development site falls within GS-3 subcatchment 1312 and Falcon Creek subcatchment 3509. Figure 2 gives the subcatchment boundaries for Indian Creek that have been delineated by AMEC (2011), and re-numbered as subcatchments 1601, 1602, 1605 and 1607. The subcatchment boundaries for the three watercourses on the 1200 King Road development site were delineated by staff at Metropolitan Consulting Ltd. and are presented in Figure 3.

For the remainder of this report, the following acronyms will be used to reference certain reoccurring items:

SWSS = South Waterdown Subwatershed Study (also referred to as Waterdown Bay)
TKR = 1200 King Road, the 'development' site that this project is centered around.
GS-3 = Grindstone Tributary 3
AES = Atmospheric Environment Service
PGI = Short-form reference for Parish Geomorphic Inc.
TDL = Terra Dynamics Ltd.
MCL = Metropolitan Consulting Ltd.
S&A = Schroeter & Associates

2.0 DATA COLLECTION ACTIVITIES

This section briefly outlines two main data collection activities:

- Input data required to set-up and validate the continuous hydrologic model, and
- Water level data and estimating discharges for seven gauges on the TKR site.

1. Staff at Metropolitan Consulting Ltd (MCL). supplied all the revised input data required by the hydrologic model for the TKR site including: subcatchment boundaries and drainage areas, subcatchment and channel lengths and slopes, estimates of impervious area and land cover. The subcatchment boundaries (see Figure 3) on the TKR site were delineated to isolate the drainage areas for the seven water level recording gauges installed and maintained by Terra Dynamics Ltd. (TDL).

Stream cross-section information (distance-elevation tables) for the three watercourses on the TKR site were supplied by Parish Geomorphic Inc. (PGI). These sections were extended to include flood plain areas for the Regional Storm applications.

All meteorological input data required to run the continuous hydrologic model for 60+ year simulations were supplied by Environment Canada through the AES website. These data included daily maximum and minimum air temperatures, and daily rainfall and snowfall amounts, and hourly rainfall amounts. Some specific event periods, 15 minute rainfall data were available from the ongoing Stage 3 monitoring portion of the SWSS.

Dr. Schroeter of Schroeter & Associates (S &A) and Kevin Slaine of TDL visited the TKR site on August 13, 2014. The purpose of the field trip was show Dr. Schroeter the general layout of the development site, in terms of topography, drainage patterns and land cover, but also to visit the locations of each of surface water level recorder, and the online pond in GS-3.

2. As noted earlier, TDL, the ground water specialists for this TKR Study, installed and maintained water level recorders at 7 locations for the purpose of developing time-series discharge information (e.g. hydrographs) that could be used to calibrate/validate the continuous hydrologic models. The

gauge locations are also noted in the model schematics exhibited in Figures 6 to 9. A complete description of the gauge station installations and the development of stage-discharge relationships (e.g. rating curves) are outlined in the Ground water report by TDL. (2014).

For the period September 27-28, 2013 and July 16-7, 2014, TDL supplied fifteen minute water level information to S & A for the 7 gauge locations, where three of the gauges are located in Indian Creek, two in Falcon Creek, and two in GS-3. An eighth gauge measured water level only in the online pond in GS-3. Using computer software developed in-house, S & A applied the rating curve information (stage-discharge data) to the times-series of water levels supplied by TDL. to estimate 15 minute or hourly discharges. Table 1 is a sample of the mean daily flow table that can be estimated for all 7 gauge locations. The complete record of the mean daily flows with tables like Table 1 for all 7 gauges are located in Appendix A. Figure 10 illustrates the mean monthly flows for the September 2013 to July 2014 period at all seven gauges. As will be noted in the model validation work, the flow data for these gauges is questionable, especially during the winter period (December to April) as noted below. The pattern of mean monthly flows does not match other gauges maintained by the Water Survey of Canada (WSC) in the surrounding area.

The harsh winter of 2013-2014 produced numerous anomalies in the water level measurements, and these are noted in the TDL report. In particular, the atmospheric pressure reference dataloggers were subjected to great air temperature fluctuations, rendering some of these data as questionable. Consequently, TDL utilized the hourly atmospheric pressure data available at the AES website for the Hamilton RBG (6153301) climate station. Similar effects caused by temperature fluctuations were noticeable in the loggers measuring water and atmospheric pressure, whenever these loggers had no water covering them. Comments about the impact of these difficulties will be further discussed in the model validation activities.

3.0 WATERSHED MODELLING

This task has two main components, model set-up and calibration/validation. Each of these will be discussed in separate subsections.

3.1 Model Set-up

1. The procedures for setting-up GAWSER for a particular watershed or site application are described in numerous watershed studies (e.g. LPRCA, 2004; PEI, 2002; Schroeter and Boyd, 1998; Schroeter et al., 2000a, 2003; Schroeter & Associates, 1999; 2004; 2005, 2014). These procedures, especially those documented in the SWSS (Ecoplans, 2004; 2010), were applied directly in the present work.
2. As noted in the background information review (see Figure 1), the existing GS-3 and Falcon Creek models developed during the SWSS were modified to account for the TKR site. Input data from the existing AMEC model for Indian Creek watershed (see Figure 2) was modified as well to account for the TKR site. Figure 3 depicts the subcatchment breakdown for the three watercourses across the TKR site. Figures 4 and 5 shows the schematic representation for the

current GS-3 and Falcon Creek models to illustrate what parts of those models were modified to account for the TKR site. Figures 6 to 9 summarize the arrangement of linked subcatchment, channel, and reservoir elements in the schematic representations of the three watercourse models across the TKR site. Notice that there are modelling nodes (e.g. 3610, 3611, 3612, 3591, 3592, 2356 and 5322) at each of the 7 stream gauge locations.

- Table 2 gives some information outlining the level of modelling detail provided by the three watercourse models. The total drainage area considered in the hydrologic model is 521.52 ha, of which 70.94 ha (14%) represents the development site, and 450.59 ha (or 86%) are the external drainage areas upstream of the project site. The overall mean subcatchment size is 7.56 ha, but for the development area, the mean size is 7.09 ha. Eleven channel routing reaches having an average length of 218 m were modelled. One reservoir (or wetland) element with considerable storage was identified and considered in the model. This level of modelling detail, in terms of mean subcatchment size and channel lengths, is comparable to other GAWSER applications (see S & A, 2004; 2005).

Table 2 Level of modelling detail in the three watercourse models

Modelling Elements	Grindstone Creek (or rather GS-3)	Falcon Creek	Indian Creek	Totals Modelled Areas
External Drainage (ha) (or upstream areas)	71.33	253.68	125.58	450.59
Subcatchments	26	28	5	59
Channels	16	15	1	32
Storage/Wetlands	2	4	None	6
TKR Site Models				
Site drainage (ha)	13.08	15.67	42.19	70.94
Subcatchments	3	3	4	10
Channels	5	3	3	11
Storage/Wetlands	1	None	None	1
Total Drainage (ha)	84.41	269.35	167.76	521.52
Total subcatchments	29	31	9	69
Total channels	21	18	4	43
Total Wetlands	3	4	None	7

- To account for the wide variation in runoff generation response attributed to the different land cover features and soil types (e.g. source areas), the subcatchment elements are further subdivided into nine 'hydrologic response units' (HRUs); one impervious, and eight pervious. The HRUs defined in Table 3 below were originally established in the *Bronte Creek Hydrology*

and *Geomorphology Study* (PEI, 2002), and adopted for use in the SWSS (S & A, 2005). These same definitions are applied here.

Table 3 Hydrological response units considered in the hydrologic model

Hydrologic Response Unit (RU)	Description (vegetation/soil type)
1	Impervious Surfaces (includes open water & exposed bedrock areas)
2	Wetland areas
	<i>Low Vegetative Cover (includes pasture and row crops)</i>
3	Peat and muck (not in wetlands) contributes to SS
4	Silt Till, Silty Clays (Halton Till) contributes to SS
5	Silty sands (Wentworth Till) contributes to SS
6	Sand Contributes to GW
7	Gravel Contributes to GW
	<i>High Vegetative Cover (Forests)</i>
8	Low infiltration (includes soils in response units 3 to 5)
9	High infiltration (includes soils in response units 6 and 7)

5. The selected values for the response unit drainage characteristics applied in the SWSS were used directly in the present study and are summarized in Table 4 below. These values represent mid-summer (around July 30th) conditions.
6. The general characteristics of the 10 subcatchment elements used in the TKR site model are listed in Table 5, and they include: drainage areas, subcatchment length and width, response unit percentages (see Table 3 for definitions), and the FTB parameter used in the overland routing procedures. Notice that more than 65% of the soils in the three watercourses comprise silty-clays, and more than 40% of GS-3 and Falcon Creek lie in forest blocks. Moreover, because highway 403 straddles the three watercourses, the amount of impervious area is (more than 20%) very high for the subcatchments immediately adjacent the roadway easement. We can expect that most of the surface runoff will be generated by response units 1, 3, 4 and 5, leaving response units 6, 7, 8 and 9 to contribute to subsurface flow or groundwater storage.

Outflows from subsurface and groundwater storage are modelled in GAWSER using a linear reservoir procedure, which requires two recession constants to be specified; KGW for discharge from groundwater storage and KSS for subsurface flow. These constants are estimated from observed hydrograph data or hydrogeologic studies, when available. Nevertheless, previous values were deemed to be acceptable here, and so KSS=5 h, and KGW=384 h for each subcatchment (see *GAWSER Training Guide*, Lesson 5 and 7).

The groundwater factor, GWFACT, which tells the program how much infiltrated water generated will not return as baseflow at the subcatchment outlet, is usually set to zero for most applications. If the computed baseflow is to leave the watershed totally, and not be available for

re-entry at some downstream location, then the GWON parameter would be set to zero (otherwise it would be set to 1.0). From consultation with other members of the study team, GWFACT was set to zero for the 11 subcatchments considered on the TKR site.

During previous field visits to the TKR site in 2013 and 2014, TDL noticed that there was an area downstream of GS-3 Gauge 7 within channel 2320 (see Figure 6) that acted like a sink, where runoff from smaller rainfall events would be captured and directed to subsurface or groundwater storage. During the August 13, 2014 field visit to the TKR site, the sink area (in Channel 2320) was reviewed by S & A, and it was not operating as a sink, but significant water ponding was noticed. This means the sink area does not have that much capacity to re-direct runoff water, as a small amount of rainfall (about 13 mm) over the previous two days caused the area to saturate, with significant ponding. Consequently, the model was not adjusted to account for the sink, as it was decided that it would have a minimal influence of flood flows generated by return period events and the Regional Storm.

7. Stream channel data are necessary inputs to both the overland flow (runoff) and channel routing calculations in GAWSER. Consequently, representative cross-sections are required inputs to the routing procedures, where the parameters are computed directly by the program using the channel length, bed slope and a characteristic rating curve developed for the section.

Typical off-channel sections were developed for rural and urban subcatchments in previous studies (e.g. PEI, 2002; S & A, 2005; 2014). Additional field measurements collected by PGI supplied cross-sections for specific locations in the three watercourses across the TKR site. Table 6 summarizes the characteristics for the channel routing reaches (elements) considered in the TKR models.

8. Distinct hydraulic features within the watercourses were isolated, and considered as diversion of flow, or reservoir (pond) elements. In GAWSER, storage-outflow information for reservoirs (as well as ponds, lakes and wetlands) can be entered as tables computed by other means (e.g. HEC-2, HEC-RAS), standard equations representing flow through different parts of the control structure (e.g. weir, gates, valves or turbines) and the storage in the reservoir as a function of water level, or a combination of tables (e.g. elevation-storage) and discharge equations. These procedures are fully described in Lesson 6 of the *GAWSER Training Guide and Reference Manual* (S & A, 2014).

Elevation-outflow-storage characteristics were established in this study for the GS-3 online pond in the same manner as utilized in the SWSS (S & A, 2005; Ecoplans, 2010). Elevation storage tables were created using elevation-surface area data measured from detailed topographic information for the site. In that regard, each pond was assumed to have a maximum depth of 0.5 m. Above this depth, all inflow to the ponds will be 'spilled'.

9. Snow accumulation and melt in different land cover units within a watershed are accounted for in GAWSER by defining 'blocks of equivalent accumulation' (BEAs). For the study watersheds, six EABs were identified and considered: two types of field blocks (ploughed and grass/pasture/grains), forests, and three edge blocks (e.g. road easements, fence lines and forest edges). Edge blocks are areas with significant capacity to store snow during blowing snow

conditions. Schroeter and Whiteley (1986) and Burkart et al. (1991) provide further information about snow accumulation characteristics among differing landscape units in southern Ontario.

The BEAs were determined from land cover information available in Table 5 using similar relationships between blocks found in other parts of southern Ontario. The snowmelt model parameters listed in Table 7 were taken directly from EWRG (1997) for Grindstone Creek, and the SWSS (see S & A, 2005).

10. In GAWSER, there are two evapotranspiration models, one using a set daily potential for each month (the climatology approach) developed from available lake evaporation estimates, and the Linacre (1977) formula, which uses daily mean air temperatures, the elevation and latitude of a watershed to compute daily potential evaporation rates. The first method is well described in Appendix A of the GAWSER Training Guide and Reference Manual (Schroeter & Associates, 2014), but the second approach has now seen wide application in most GAWSER applications in recent years (see S & A, 2004; 2005; 2006; 2008; 2010), and so it is well documented in those study reports.
11. To account for seasonal variations in the parameters, the GAWSER program adjusts the specified parameters for all response units and subcatchments in a similar manner, as shown here for the effective hydraulic conductivity (KEFF).

$$[1] \quad KEFF(i)_{used} = FKEFF * KEFF(i)_{specified}$$

where FKEFF is the effective hydraulic conductivity adjustment factor, the subscript ‘used’ denotes the value of KEFF actually used in the runoff calculations for response unit (i), and the subscript ‘specified’ represents the value of the parameter (e.g. KEFF in Table 4) for response unit (i) actually entered in the input files during model set-up.

The monthly parameter adjustment factor table (see Table 8 below) was originally calibrated in the *Eramosa River Watershed Study* (Schroeter & Boyd, 1998), but later completely validated in the *Credit Valley Subwatershed 16 and 18 Study* (Schroeter & Associates, 1999). This parameter adjustment table was applied directly in the present study, and is remarkably robust, having been utilized with essentially the same values in more than 50 hydrology studies in the past 25 years (see Schroeter et al., 2003). The parameter adjustment factors are defined below.

Symbol	Definition
FDS	Maximum depth of depression storage factor
FKEFF	Effective hydraulic conductivity factor (for surface infiltration)
FCS	Maximum seepage rate (movement of water from layer 1 to 2)
FD	Maximum percolation rate (movement of water out of layer 2)
FKO	Overland runoff lag factor
FKMF	Combined refreeze/snowmelt factor
FIMCI	Initial soil-water content adjustment factor for soil layer 1
FIMCII	Initial soil-water content adjustment factor for soil layer 2
FEVAP	Potential evapotranspiration adjustment factor
FNEW	Relative density of new snow factor
FDINS	Interception storage adjustment factor

Table 8 Monthly parameter adjustment factors applied in this study

GAWSER Parameter Adjustment Table Generated From: SWS5006.DAT												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FDS	0.50	0.50	0.50	0.50	1.20	1.15	1.15	1.50	1.50	1.00	1.00	0.75
FKEFF	0.02	0.02	0.02	0.10	0.40	0.70	0.80	0.90	0.65	0.25	0.20	0.02
FCS	0.03	0.02	0.02	0.09	0.40	0.50	0.60	0.75	0.35	0.30	0.13	0.06
FD	0.04	0.03	0.03	0.05	0.05	0.06	0.10	0.11	0.09	0.08	0.07	0.05
FKO	3.50	4.00	3.50	4.00	3.00	4.50	5.50	6.00	5.00	4.00	3.50	3.00
FKSS	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
FKMF	0.25	0.33	1.10	1.40	1.50	1.00	1.00	1.00	1.00	1.00	0.25	0.15
FNEW	1.00	1.00	1.10	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.10	1.10
FEVAP	0.00	0.00	0.00	2.33	3.23	3.83	4.52	3.61	2.40	1.35	1.00	0.00
FDINS	0.20	0.20	0.20	0.50	0.70	1.20	1.50	1.50	1.20	0.70	0.20	0.20

12. Long-term meteorological datasets for input to the TKR models were prepared using a methodology developed by Schroeter et al. (2000b) that was applied for the entire province as part of the Drinking Water Source Water Protection (SWP) program (see S & A, 2007) in preparing more than 350 meteorological datasets. For this study, a 57-year meteorological dataset (1950 to 2006) comprising daily maximum and minimum air temperatures, daily snowfall, and hourly rainfall amounts was available from the SWSS (see Ecoplans, 2010; S & A, 2005) for Millgrove (6155183). This dataset was modified to add data for 2007 to 2014 using records from Hamilton RBG (6153300; 6153301), Hamilton Airport (6153194; 6153193) and Oakville TWN (6155750) climate stations, all of which are maintained through the AES.

3.2 Model Calibration/Validation

1. In any hydrologic modelling exercise, it is generally assumed that if a given model reproduces an observed or measured sequence of quantities (e.g. streamflow volume, reservoir water levels) that ‘confidence’ can be placed in its predictive capability, from which management options or decisions are often made. Obviously, if additional comparisons between model output and measured quantities are made and their agreement is deemed to be ‘acceptable’, then more confidence can be placed in predictions from the model, particularly for impact analyses. Consequently, an important step in any hydrologic modelling exercise is to establish the ‘level of confidence’ in the predictive results, or ‘validating the model’.

This important confidence building or ‘validation’ step in the modelling procedures is often referred to as ‘calibration’, although the term ‘calibration’ has been used interchangeably with ‘verification’, ‘validation’ and ‘confirmation’. This is unfortunate, because ‘calibration’ is a unique step in the modelling procedures, apart from ‘validation’, ‘verification’ or ‘confirmation’.

Model *calibration* is a process of adjusting model parameters, variables or other inputs in order to reduce the differences between simulated and observed flows (or other hydrologic quantities) to levels that are deemed acceptable (see Watt et al., 1989; James and Burgess, 1982). The ‘adjusted’ or ‘calibrated’ parameters or variables are then ‘verified’ or ‘validated’ by applying the model to an independent data set that was not used for calibration.

According to James and Burgess (1982), model *calibration* involves a trial-and-error procedure to achieve optimum parameter levels that produce a reasonably good match between model results and observed data. The parameters, whose values are based on field measurements or are well-established from previous studies, *remain fixed*. Those to be calibrated are adjusted based on a goodness of fit criterion using visual or statistical comparisons between measured and simulated results (see James and Burgess, 1982; Schroeter and Boyd, 1998). A model is said to be ‘robust’ if its parameter settings can be transferred from one watershed to another (Schroeter and Watt, 1989).

A simple comparison of model output with any measured values does not constitute a ‘calibration’ exercise, unless the parameters are adjusted to improve the agreement between observed and simulated results. On the whole, any comparison between measured and modelled results is always considered part of the model ‘confirmation’ or ‘validation’ procedures.

In summary then, the 1200 King Road (TKR) watershed models have been adequately ‘confirmed’ or ‘validated’, because the following validation checks have been made.

The GAWSER (Guelph All-Weather Sequential-Events Runoff) model has been extensively calibrated, verified and validated in more than 40 watershed modelling studies within the last 25 years were conducted for Ontario watersheds. These applications constitute model comparisons with observed flow data from more than 150 gauges for more than 1800 gauge-events. For continuous simulation work, the model has been compared with long-term streamflow data from more than 50 gauges for some 750 gauge-years of application. For urban

runoff modelling, the model has been tested with data from more than 15 gauges for more than 70 gauge-events. This massive amount of experience gained in applying the model in Ontario over the last 25 years was utilized directly in formulating the TKR hydrologic models. The monthly parameter adjustment table has proved to be an extremely 'robust' tool in applying GAWSER throughout Ontario.

Of particular relevance to the present work, GAWSER was applied in *Halton Region Integrated Flood Forecast System (HRIFFS) set-up Study* (Schroeter & Associates, 1993), the *Grindstone Creek Water Resources Support Study* (EWRG, 1997), the *Bronte Creek Hydrology and Geomorphology Study* (PEI, 2002), *South Waterdown Subwatershed Study* (Ecoplans, 2010). The monthly parameter adjustment table applied in those applications was utilized directly in the present study with no alterations.

Mean annual evapotranspiration amounts estimated by the physically-based GAWSER model were well within acceptable ranges reported in numerous southern Ontario climatology documents and maps (e.g. Brown et al., 1974; OMNR, 1984), as well as those estimated in the EWRG (1997) and Ecoplans (1996) studies.

The modelling results were reviewed by other members of the study team and the computed numbers were found to 'make sense', or 'reasonable'. Hence, the collective experience of the entire study team helped to validate the results of the hydrologic modelling.

In this study, the main objective of the 'validation' procedures was to ensure that the level of performance provided by the models presented here were consistent with previous modelling exercises in Grindstone, Falcon and Indian Creeks, as well as elsewhere in southern Ontario. 'Readily' available meteorological data were used for 'validating' the hydrology model where ever possible.

The model validation procedures were divided into four parts. First, the model was applied in continuous simulation mode for the period 1950 to 2013 as a check on long-term water balance quantities compared with watersheds in the surrounding area. Secondly, the models were applied for the 9 month period (September 2013 to July 2014) that corresponds with the available streamflow information from the 7 gauge locations maintained by TDL. This exercise was primarily to see how reliable the stream flow data were and to generally confirm the monthly parameter adjustment table through comparison between the observed and simulated hydrographs. The third part involved a comparison of measured and modelled hydrographs for individual event periods to ascertain how well the model reproduces the hydrograph shape and timing.

The fourth and final part involved applying the return period 4 hour Chicago Storms, the Regional Storm, and a 60+ year meteorological input data sequence to the model to produce estimates of flood flows, and comparing them with those made in other studies or by alternative methods. These types of comparisons allowed the routing calculations in the different hydrologic elements (e.g. overland flow, channel and reservoir) to be assessed, in terms of hydrograph timing and peak flow estimates. For this report, the fourth model validation check will be discussed in the next subsection 4.3 dealing with model applications.

2. The hydrologic model was applied for the period November 1, 1950 to October 31, 2013, a period of about 64 years. Because the model was applied using the water year concept, the initial snow pack depth and equivalent water contents on November 1, 1950 were assumed to be zero.

A first check on the results for the 64 year simulation is a rather comprehensive ('one-stop shopping') table, an example of which is given in Table 10 for Falcon Creek at the CNR Tracks (or Node 3593) under existing conditions (see also Figure 11). The top part of Table 10 gives the mean monthly water balance, and the middle portion lists a return period extreme flow summary (high and 7-day lows), and the bottom part provides flow duration information. These water balance quantities represent the areal average for the entire drainage area (269.35 ha) upstream of Falcon Creek Node 3593.

The individual quantities for the top part of Table 10 can be expressed in a water balance

$$[2] \quad \text{Precip} = \text{ET} + \text{Runoff} + \text{Baseflow} + \text{Losses (or net storage)}$$

where 'Precip' represents the total precipitation (rainfall plus snowfall), ET is the combined evapotranspiration and sublimation total, 'Runoff' is the mean annual runoff, 'Baseflow' is the portion of the infiltrated water that returns to the stream, and 'Losses' signifies the amount of infiltrated water that does not return to the receiving stream. The 'Losses' total also includes water stored in the system, and is often referred to as the 'net storage' term. For instance, the positive totals for 'Losses' during the winter months (e.g. December to March) represents snow on the ground, whereas the negative values during the summer months (e.g. April to August) denotes water pulled from soil-water storage by evapotranspiration. Water present in all controllable lakes or reservoirs will also influence the value of the 'net storage term'. 'Total Flow' is the sum of the 'Runoff' and 'Baseflow' components. Tables like 10 can be prepared for any point of interest noted in the watershed model (see schematics in Figures 6 to 9) for both measured (when available) and modelled flows. Water balance quantities for other points of interest will be shown in the next section on Model Application.

From Table 10, one can see that the mean annual precipitation for the 1950 to 2013 water year period is about 873.8 mm. The average annual actual evapotranspiration (ET) plus sublimation total is about 511.4 mm, a reasonable value for this part of Ontario according to Brown et al. (1974) and OMNR (1984). The mean annual runoff is about 179.8 mm, of which 37% is generated during the months of March to May. The mean annual total streamflow is 309.1 mm, of which 42% appears as baseflow, and is a comparable to other watersheds below the Niagara Escarpment.

3. As a second check on model performance, the meteorological input dataset for the period September 28, 2013 to July 17, 2014 was applied to the three watercourses, and the resulting mean monthly flow diagrams are given in Figure 12. Compare these mean monthly flows in Figure 12 with the observed values given in Figure 10. In general, there is very little similarity between the mean monthly flows given in Figure 10 with those given in Figure 12. The general pattern of the simulated flows in Figure 12 is consistent with flows measured by the WSC in

the surrounding area. The lack of similarity, especially during the winter months (December to March), between the plots in Figure 10 and 12 suggests that the measured flows are of questionable accuracy. The flows measured during the summer are probably more representative of the watercourses on the project site.

4. A third check on model performance involves applying the model for specific or individual event periods, and comparing the observed and simulated hydrographs. In that regard, measured and modelled hydrographs for the three watercourses are given in Figures 13, 14 and 15 for the period April 1 to 6, 2014. Because the measured flows are of questionable accuracy, these hydrograph comparisons focused on hydrograph shape and timing. In general, the models are reproducing the hydrograph shape in every instance. The pattern of the baseflow recessions are matched very well. The questionable accuracy of the measured flows is illustrated by the pairing of Gauge 4 and 5 in Falcon Creek. The simulated hydrograph at Gauge 4 and 5 are almost the identical, but the model greatly over predicts the flows at Gauge 5. Because Gauge 5 is downstream of Gauge 4, the flows at Gauge 5 should be higher than those recorded at Gauge 4. The best overall simulated hydrograph in terms of matching the observed flows was for the main event on April 4th for Gauge 1 in Indian Creek. Measured and modelled event period hydrographs could be shown for other periods. However, in many instances the order of magnitude of the observed flows renders hydrograph comparisons as useless, especially for winter events. However, as mentioned earlier, the models are reproducing the shape of the measured curves. For future monitoring work, efforts should be directed toward warm water periods, and more stage-discharge measurements.

4.0 MODEL APPLICATION FOR IMPACT ANALYSIS

The formulated hydrologic model of the 1200 King Road area (TKR), once validated, was ready for use in assessing the hydrologic response of the three watercourses under existing conditions, and post-development with controls. Flood flow estimates are made by applying return period and Regional Storm events to the model. A 64 year meteorological data sequence was applied to the model for determining long-term water balance quantities, low flows, flow duration information, and erosion assessment.

4.1 Return period and regional storm applications

The validated watershed model was used to generate flood flow estimates resulting from return period events and the Regional Storm. The 4 hour Burlington Chicago Storm (with R=0.400) was used to generate the return period flood flows. The intensity-duration-frequency (IDF) curves were fitted to the following relationship:

$$[3] \quad I=A/(B+T)^C$$

where I is intensity in mm/h, T is storm duration in minutes, A, B and C are regression constants. IDF parameters (A, B and C) for the Burlington storms were obtained from City staff, and are summarized in Table 10. The IDF constants for the 25 mm storm were created from the 2 year Storm, with the A

parameter was adjusted to give a 25 mm 4 hour volume. For comparison with storm volumes for longer events, the return period 12 and 24 hour volumes are given in Table 11 for two climate stations, Hamilton A and Hamilton RBG.

Table 12 gives the temporal distribution patterns for a representative Chicago Storm (here, the 100 year), SCS Type II (24 hour, 100 year volume) and the Regional Storm. No reduction factors to account for spatial variations in rainfall volume were applied to the Chicago and Regional storms. As in previous applications (e.g. Schroeter & Boyd, 1998), the parameter adjustment factors were set for an early autumn event, with initial soil-water conditions set at field capacity (normal for a mid-October event). Flood flows generated for each storm pattern under existing conditions are given in Table 13.

4.2 Long-term simulations water balance and peak flows

A 64 year time-series (November 1, 1950 to October 31, 2013) of meteorological inputs (e.g. daily maximum and minimum air temperatures, daily rainfall and snowfall depths, and hourly rainfall depths) prepared for the Milgrove climate station (6155183) was applied to the hydrologic model for existing conditions. These applications provided estimates of water balance quantities for 16 selected locations in the study area, as well as return period extreme flows (e.g. high and 7-day lows), and flow duration information. All of these are summarized herein. The return period and Regional storm estimates generated from the event modelling are given in the previous section.

The results of the long-term (64 year) water balance simulations are summarized in Table 14 for existing conditions at the selected locations within the TKR area. Recall, that Eq. [2] gives the balance formula used to compute the infiltration ‘losses’ (also known as the net storage term) noted in the tables. The quantities shown in Table 14 are what would be expected for watersheds in the surrounding area. Any location with mean actual evapotranspiration totals less than 500 mm are areas with higher imperviousness.

Table 15 gives a complete summary of the mean annual flow, the 2, 20 and 100 year return period high and 7-day low flows, and key duration flows (20%, 50%, and 80%) for the same selected locations noted in Table 14. This flow duration information should be interpreted as follows. The 20% flow means that 20% of the time (during the entire 64 year simulation period, or about 73 days in any given year), the mean daily flow is greater than or equal to the value indicated. Conversely, it also means that 80% of the time (or about 292 days in any given year) the mean daily flow is less than this amount. Generally speaking, the annual maximum flows are much higher than the 20% duration flow, and the annual minimum 1 day to 30 day low flows are much less than the 80% duration flow. Because the time-series of annual streamflow extremes (e.g. high and low flows) are highly skewed quantities, statistically, the mean annual flow is usually higher than the 50% (or median) duration flow. This is occurring for all locations noted in Table 15. Moreover, often the 50 to 60% duration flows are used to ‘define’ the baseflow (LPRCA, 2004). Notice that the 2, 20 and 100 year 7-day low flows are all zero for the locations considered here.

The return period high flows summarized in Table 15 are compared with other estimates in the next section.

4.3 Flood Flow Comparisons

The 'reasonableness' or credibility of the flood flows generated in this study for existing conditions was established by comparing the results with previous estimates and regional analyses (Moin and Shaw, 1985; 1986; CCL, 2000) for eight locations in the three watercourses considered in this study (see Figures 6, 7, and 9). The various estimates for the 2, 5, 10, 25, 50, and 100 year and Regional Storm flood flows are summarized in Tables 16 and 17. The steps taken to produce these two tables are listed below.

1. Index Flood Method 1: Moin and Shaw (1985; 1986) developed regional flood flow estimates based on regression analyses of observed index floods (e.g. 2 year) for the whole province. For their Region 7, which contains the Grindstone, Falcon and Indian Creek watersheds, the index flood is computed as:

$$Q_2 = C (\text{drainage area})^N$$

where Q_2 is the index flood (in m^3/s), the drainage area is in km^2 , $C=0.40$ and $N=0.696$. For Region 7, the mean C value was found to be 1.13, with a minimum of 0.40, and a maximum of 1.61. The remaining return period flood flows (5 through 100 year) are taken as ratios of the Index Flood. The applicable ratios for Region 7 are given below.

<i>Index</i>	<i>Q2</i>	<i>Q5</i>	<i>Q10</i>	<i>Q25</i>	<i>Q50</i>	<i>Q100</i>
Ratio	1.00	1.32	1.58	1.91	2.15	2.41

Note: Moin and Shaw did not actually show 25 year flows in their work, but rather the 20 year values, where the applicable ratio for Region 7 was found to be 1.82. From experience we have found that the 25 year flood flow is typically about 5% higher than the 20 year flow, and so the computed ratio for the 25 year flow was found to be 1.91.

As noted by S & A (1993), the ratio of Regional Storm to 100 year flood flows is in the range of 2 to 5, depending on the size of storm or procedure for generating the 100 year flow. For this application, a factor of 4.5 was applied to the 100 year flows to get an estimate of the Regional Storm flood flows by this method.

The results for the Index Flood Method 1 are given at the top of Table 16.

2. Index Flood Method 2: In 2000, Cumming Cockburn Ltd. (CCL) was commissioned by the Ontario Ministry of Natural Resources to update the regional analysis undertaken by Moin and Shaw (1985). For their Region 1, which includes all of southwestern Ontario from Windsor to Oshawa and north to Lake Simcoe, the index flood is computed using:

$$Q_2 = 0.757 (\text{drainage area})^{0.7649}$$

where Q2 is the index flood (in m³/s) and the drainage area is in km². The remaining return period flood flows (5 through 100 year) are taken as ratios of the Index Flood. The applicable ratios for CCL’s Region 1 are given below.

<i>Index</i>	<i>Q2</i>	<i>Q5</i>	<i>Q10</i>	<i>Q25</i>	<i>Q50</i>	<i>Q100</i>
Ratio	1.000	1.464	1.757	2.136	2.393	2.664

Note: Like Moin & Shaw (1985), CCL (2000) did not actually show 25 year flows in their work, but rather the 20 year values, where the applicable ratio for their Region 1 was found to be 2.034. As mentioned earlier, the 25 year flood flow is typically about 5% higher than the 20 year flow, and so the computed ratio for the 25 year flood flow was found to be 2.136.

For this application, a factor of 4.5 was applied to the 100 year flows to get an estimate of the Regional Storm flood flows by this method.

The results for the Index Flood Method 2 are given in the bottom part of Table 16.

- Return period flood flows for eight locations were established by conducting a frequency analyses of the annual maximum flow time-series generated by applying a 64 year meteorological data sequence to the model. The three parameter lognormal distribution (LN3P) fitted by a regression procedure provided the most stable return period flood flow estimates. Comparative estimates for the 2, 5, 10, 20, 25, 50 and 100 year flood flows are given in Table 17.

For completeness in Table 17, the Regional Storm flood flows were taken from Table 13.

- Return period flood flows generated through computer application of a specified storm pattern (e.g. Chicago 4 hour) and return period rainfall volumes established by frequency analysis (IDF information, see Table 10) using the model developed for existing conditions in this study are summarized in Table 13 for all points of interest. For this comparison in this section, the flood flows generated by this method have been extracted from Table 13 for selected points of interest are given at the bottom of Table 17.

For comparison with the flood flows recorded in Table 13, additional results from other studies (here Valdor, 2011 and AMEC, 2011) are summarized in Tables 18 and 19. Table 18 was taken from the peer review report by Schroeter & Associates (2011) where flood flows for Falcon Creek were estimated by two different models in two separate studies (e.g. Valdor, and SWSS). Selected results from the present study (see Table 13) were added to Table 18. Similarly, Table 19 gives flood flows estimated in the AMEC study (2011) for Indian Creek, and these are compared with results from the present study (taken from Table 13). In comparing flood flow results from various studies, we have tried to line up the different modelling nodes by drainage area as best as possible.

From a brief glance at Tables 16, 17, 18 and 19, one can see that there is acceptable agreement (less than ±25%) for many flows, particularly when the event modelled flows are compared with those computed for the two index flood methods or continuous simulation. In general, the return period

estimates from the two index flood methods are not comparable with the flows generated by the study model. This is due to the fact that the index flood methods were developed using actual flow data from much larger watersheds. Overall, the computations for Regional Storm flood flows are comparable between studies (e.g. Valdor, AMEC, and S & A), but the differences in the return period flood flows (e.g. 2 to 100 year) are associated with computational time step, and storm duration (e.g. 3, 4 or 24 hours), which have a greater influence on the results. Recall, that for the continuous simulation estimates, the computational time step is 60 minutes, whereas for the individual event modelling the computational time step is 5 minutes for the return period events and 15 minutes for the Regional Storm. Remember that the Regional Storm is specified in 60 minute time steps, and so a 15 minute application would have four computational steps for each rainfall step.

According to Watt and Paine (1992), who describe uncertainty considerations in flood risk mapping, some of the discrepancies noted above are not surprising. Watt and Paine suggest that hydrologic uncertainty for 100 year flood estimates using single station frequency analyses or calibrated watershed models are about 25 to 40%. Using an uncalibrated model, this range of uncertainties widens to 50%. For the Regional Storm, the uncertainty can be as high as 55%. Therefore, it is likely that variations less than the normal or typical uncertainty may be difficult to explain, because they proceed as a natural consequence of accepted practice in available methodology. Nevertheless, where the differences are much higher than the normal uncertainty, logical explanations may be possible. Any noted differences are primarily attributed to variations/differences in the methodology that produced each estimate, as shown here for the more frequent flows (2 and 5 year) generated by event modelling as compared to those made from continuous simulation.

In general, the results from this study (both event and continuous modelling) are in good agreement with previous studies and regional analysis, which suggests that the formulated model predicts flood flows in the 1200 King Road watersheds reasonably well. With good agreement in the peak flow estimates and the general water balance, we now turn our attention to modelling the post-development conditions.

4.4 Post-development conditions

The hydrologic model for existing conditions described in the previous sections was modified to account for post-development conditions on the TKR site. Figure 16 shows the proposed storm drainage plan for the Indian Creek portion of the development site, and indicates which areas within Falcon Creek will likely be developed. At present, there is no specific plan for Falcon Creek, but it will be fully developed likely with a mix of high density residential and commercial areas. The GS-3 portion of the TKR site will eventually be developed, but not within the next few years. Consequently, the GS-3 land will not be included in any post-development scenarios.

Post-development conditions are represented in the hydrological model primarily through changes to the following input variables.

- a) Changes to response units: Recall that these response units (see Table 3) represent the different land cover features and soil-types in each subcatchment element. For new urban developments, generally the impervious surface areas are increased, with corresponding decreases in pervious area (including forests).
- b) Changes to the drainage network Part 1: In general, the drainage network in a watershed model is represented by different stream cross-sections and channel lengths/slopes, as well as subcatchment length and widths, and representative main and off-channel sections. The particular arrangement of these items for each subcatchment and channel element will reflect the particular land use planning scenario being considered. Some historical scenarios required modifications to channel routing reaches to represent 'channelization' efforts or replacement by significant conduits (e.g. pipes). However, recent trends in 'natural' approaches in watershed management have left existing channel routing reaches unaltered. No changes were made to subcatchment overland flow routing procedures unless the imperviousness for the subcatchment was greater than 10%.
- c) Changes to the drainage network Part 2: The drainage network is further represented by the presence or absence of certain storage elements, such as mill ponds, lakes, impoundments caused by railroad embankments, stormwater management (SWM) ponds, as well as hummocky topography. In areas with significant hummocky topography, the development of residential or industrial land usually results in the removal of these natural depressions because of lot grading regulations.
- d) Changes to the drainage network Part 3: For scenarios that require the insertion of stormwater management (SWM) ponds, typical pond volumes and outflow controls are based upon the current practice in the applicable municipality. These ponds are usually sized using the 3 or 4 hour Chicago Storm for six return intervals (2, 5, 10, 25, 50 and 100 year) and the Regional Storm. These ponds are required to control the post-development flows to pre-development levels, and include an extended detention volume based upon capturing the runoff volume for impervious surfaces from a 25 mm storm, and releasing this volume over a 48 hour period. The permanent pool volumes for 'wet ponds' are usually set equal to the extended detention volume. Infiltration/recharge are considered in these ponds where the soil-types have high hydraulic conductivity. In that case, the infiltration or recharge rate is taken as one-fourth of the hydraulic conductivity for the dominant soil-type within a particular subcatchment element.

- e) Changes to the drainage network Part 4: To account for some infiltration of runoff water draining to residential backyards, 15% of the directly connected impervious areas are assigned to the response unit representing the dominate soil-group within the subcatchment.

In the present applications, the subcatchments undergoing development were modified for increased imperviousness, changes to account for an urban drainage network, insertion of SWM ponds, and some infiltration of backyard drainage. The low hydraulic conductivity for the dominant soil-type (e.g. Response Unit 4, silty-clays of Halton Till) in the area precluded further consideration of infiltration/recharge in the proposed SWM ponds. Table 20 and 21 outline the impervious area calculations for the two SWM ponds considered in Indian Creek, and two in Falcon Creek. About 0.85 ha of drainage on the east side of Falcon Creek now drains to Indian Creek as part of the drainage for SWM Pond 2. The drainage areas to each pond resulted in the insertion of four new subcatchment elements (e.g. 1595, 1596, 1621, and 1622), as shown by the revised model schematics for the Indian and Falcon Creek parts of the TKR site given in Figures 17 and 18, respectively. The insert of these new 'urban' subcatchments results in adjustments to exist condition subcatchments 1591, 1592, 1593, 1610, 1611, 1612 and 1613. Subcatchment 1615 is a new element that accounts for the remaining not-developed portions of subcatchment 1613 that are not part of the main stream buffered areas. The revised subcatchment characteristics are noted in Table 22.

The release rates for the four SWM ponds were determined from unit area flood flows computed for the existing condition subcatchments that would be under going significant development, namely 1592, 1593, 1612 and 1613. Table 23A lists the unit area return period and Regional Storm flood flows for these subcatchment elements. Recall, that the existing condition return period and Regional Storm flood flows are summarized in Table 13 for selected points of interest, including the aforementioned subcatchments. The return period & Regional Storm outflows were determined by applying the drainage areas for the four SWM ponds to the unit area flood flows in Table 23A. The proposed SWM pond outflows are listed in Table 23B. Following an iterative process of multiple model runs, the resulting return period and Regional Storm SWM pond volumes are presented in Table 24.

The return period and Regional Storms were applied to post-development with controls model, and the resulting flood flows are given in Table 25. For key points of interest in Falcon and Indian Creek (e.g. Node 3593 and 3613), the agreement between pre and post-development flood flows are within the range of 1.2% to 7% for the return period storms, and -0.5 to 2.8% for the Regional Storm.

The 64 year meteorological input data sequence was applied to the post-development with controls model to see if the SWM controls had any influence on the water balance (see Table 26) and long-term extreme flows (high and low). These results are presented in Tables 26 and 27, and should be compared with the values in Tables 14 and 15 for existing conditions. For mean annual total flow, the pre and post-development results agree to within 7%. In general, there is good agreement between the pre and post-development return period flood flows (e.g. 2, 20 and 100 year).

In conclusion, the modelled SWM ponds (1, 2, 3 and 4) are successful in controlling post-development flood flows to pre-development (or existing conditions) levels.

4.5 Erosion Assessment

Once the pre and post development hydrology models were set-up for continuous simulation purposes by applying the 64 year meteorological input data sequence noted earlier, they were now available for erosion assessment. The erosion assessment involves counting the number of hours that simulated flows, mean velocities or shear stresses at a given location (or modelling node) are above specific critical values over the continuous simulation period. In order to do these exceedance counts, the critical flows, velocities and shear stresses need to be established through geomorphology field surveys. In reviewing the Parish (2014) geomorphology report for the TKR site, no references to erosion thresholds (or critical values) were noted for the three watercourses. However, Parish did reference a 2012 erosion assessment of Falcon Creek that they did for Validor Engineering Ltd. (2011) as part of a floodplain mapping study. In that study, threshold flows, critical shear stress and velocity were established for the entire Falcon Creek reach across the TKR site, comprising modelling channels 2592 and 2593 (See Figures 7 and 17). For this analysis, we produced the exceedance counts for Falcon Creek Node 3593, the most downstream location on the TKR site. The available erosion thresholds for Node 3593 are given in Table 33.

To do the actual exceedance counts, one needs the hydraulics of a stream cross-section to find the critical shear stress and velocity as function of discharge. For this purpose, we chose Falcon Creek cross-section 35.921 (or Parish FC-XS3) at Node 3593 for determining the shear stress and velocity as a function of discharge. Using this cross-section, and a threshold of $1.55 \text{ m}^3/\text{s}$, we could not exactly match the critical shear stress and velocity given in Table 33. The values that were determined using the threshold flow of $1.55 \text{ m}^3/\text{s}$ and cross-section FC-XS3 are also given in Table 33.

As was done in the MCL Waterdown Bay study (2014), the exceedance counts were made for the three thresholds (discharge, shear stress and velocity) so that three erosion indicators, outlined in Appendix B, could be computed and compared with values for the pre and post-development conditions. Upon application of the continuous simulation model for existing conditions, the modelled hourly flows were used to produce the exceedance counts for 64 years (or 552264 hours). Samples of the detailed results are given in Tables 28, 29, 30, 31 and 32.

Table 28 shows the complete summary of discharge exceedance counts as monthly totals, as well as the 64 year grand total. The second discharge threshold of $13.35 \text{ m}^3/\text{s}$ is not required in this analysis, but it represents the bankfull discharge estimated by the PGI study team. Notice that over 64 years, that the critical discharge of $1.55 \text{ m}^3/\text{s}$ was exceeded for only 179 hours under existing conditions.

The complete summary of critical shear stress exceedance counts is presented in Table 29, giving monthly totals as well as the overall total. Notice that the critical shear stress of 45.71 Pa was exceeded for only 99 hours in the simulation period under existing conditions. Moreover, this table gives the value for Erosion Index No 1, which for this application is about 36.5 Pa-days.

The critical velocity exceedance counts summary is given in Table 30. This table uses the average critical velocity of 1.17 m/s determined by PGI (2012) from field surveys. However, the total number of hours that the critical velocity is exceeded was found to be 671 hours, more than 3 to 6 times higher than for critical discharge and shear stress. This is not reasonable, as the exceedance counts for all three indicators (discharge, shear stress and velocity) are usually within the same order of magnitude or

within $\pm 50\%$ of each other. Consequently, we used the critical discharge of $1.55 \text{ m}^3/\text{s}$ and the hydraulic characteristics of cross-section FC-XS3 to find the corresponding critical velocity, that was found to be 1.44 m/s . Applying this velocity to the exceedance counts, it was found that the critical velocity was exceeded for 172 hours in the entire simulation as summarized in Table 31. This total exceedance count is reasonable when compared to the discharge counts in Table 28. Tables 30 and 31 illustrate the values for Erosion Index No. 2, which for this application, is 1.33 m/s-days for existing conditions (when critical velocity is 1.44 m/s).

Table 32 gives the shear stress exceedance counts as was done in Table 29, however, Table 32 shows the values for Erosion Index No. 3 (the Effective Work index) for existing conditions. Here the value for Index No. 3 is 5996 kJ/m^2 .

Tables 28 to 32 give the exceedance counts and erosion index values for existing conditions. The 64 year meteorological input data set was applied again to the post-development model, and the results for those computations are given in Table 33. In general, the post-development exceedance counts for discharge, shear stress and velocity are about 2 to 5% less than those given for existing conditions. The post-development values for the three Erosion Indices are within 0 to 2% of those for existing conditions. In summary, future development will have minimal impact on the erosion aspects of Falcon Creek on the TKR site

5.0 CONCLUSIONS

1. Hydrologic models of three watercourses crossing the 1200 King Road development site have been formulated using the GAWSER (Guelph All-Weather Sequential-Events Runoff model) program. Two of these models (GS-3 and Falcon Creek) were adapted from those applied in the South Waterdown Subwatershed Study (SWSS), whereas the Indian Creek model was a new set-up making use of data supplied by AMEC. Overall, the three watercourse models have a total drainage area of 521.52 ha, and comprising 69 subcatchment elements, 43 channels, and 7 wetlands. On the 1200 King Road development site, the three models contribute 70.94 ha of drainage area (about 14% for the total area modelled), and consist of 10 subcatchment elements, 11 stream channels, and only one wetland. The mean subcatchment size on the development site is 7.1 ha, and the average channel routing length was 218 m.
2. More than 65% of the drainage area on the 1200 King Road site is composed of silt Till and silty-clay soils, that can produce significant amounts of runoff on a mean annual basis. About 30 to 35% of the area in GS-3 and Falcon Creek lie in forest blocks. Because Highway 403 straddles the three watercourses, the amount of impervious area is very high (more than 20%) for the subcatchments immediately adjacent to the roadway easement. We would expect that most of the surface runoff will be generated by response units 1, 3, 4 and 5, leaving response units 6, 7, 8 and 9 to contribute to subsurface flow or groundwater storage.
3. Water level data were recorded and available from 7 gauges on the development site for the period September 27, 2013 to July 17, 2014. Using stage-discharge relationships for the 7 gauges, the time-series of water level data was used to estimate discharges. Because of significant temperature fluctuations during the winter of 2013-2014, much of the flow data has questionable accuracy. However, the available discharge data were used to successfully validate the timing and hydrograph shape for simulated curves for the existing conditions models at the 7 gauge locations during warm weather periods (like September to October, and April to July). Further work to improve the discharge measurements should focus on the warm weather periods.
4. The monthly model parameter adjustment factor table established in previous applications of GAWSER for southern Ontario was used directly in this study. The use of this adjustment table was confirmed by comparing the mean annual water balance quantities under existing conditions to estimates given in previous studies. In this regard, the agreement between the various estimates was very good. Additional performance testing was made by comparing the model estimates of Regional Storm and return period flood flows from event and continuous simulation modelling with those computed in previous studies, or using alternative methods (e.g. Index Flood). These performance tests revealed that the three watercourse models on the 1200 King Road development site have been validated for use in assessing impacts for future development.
5. A 64 year meteorological data set comprising daily maximum and minimum temperatures, daily rainfall and snowfall depths, as well as hourly rainfall depths, was prepared for using data collected at the Atmospheric Environment Service (AES) station at Millgrove (6155183). From these computations (for Indian Creek for example), the mean annual precipitation in the area is about 873.8 mm, of which 479.0 mm (or 55%) is returned to the atmosphere through

evapotranspiration/sublimation. About 45% of the mean annual precipitation appears as total flow, of which 79% appears as runoff, and 21% as baseflow. About 0.2% of the mean annual precipitation is lost to the various storages in the system.

6. Using a proposed development plan for Indian Creek, and rough initial plan for Falcon Creek, a post-development model of the 1200 King Road site was formulated with four SWM Ponds. Each of these ponds was sized to control post-development flows to existing condition levels. These ponds were shown to minimize the impact of post-development flood flows over existing conditions.
7. An erosion assessment was done for Falcon Creek by applying the continuous simulation model for 64 years and counting how many times certain critical flows, mean velocities or shear stresses were exceeded, and comparing those numbers for pre and post-development conditions. In order to do these exceedance counts, the critical flows, velocities and shear stresses needed to be established through geomorphology field surveys. For Falcon Creek, these critical values were supplied by PGI. For the exceedance counts procedures, three erosion indices were computed for pre and post-development conditions. From these analyses, the proposed post-development will have minimal impact on the erosion aspects of Falcon Creek on the TKR site

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Figures

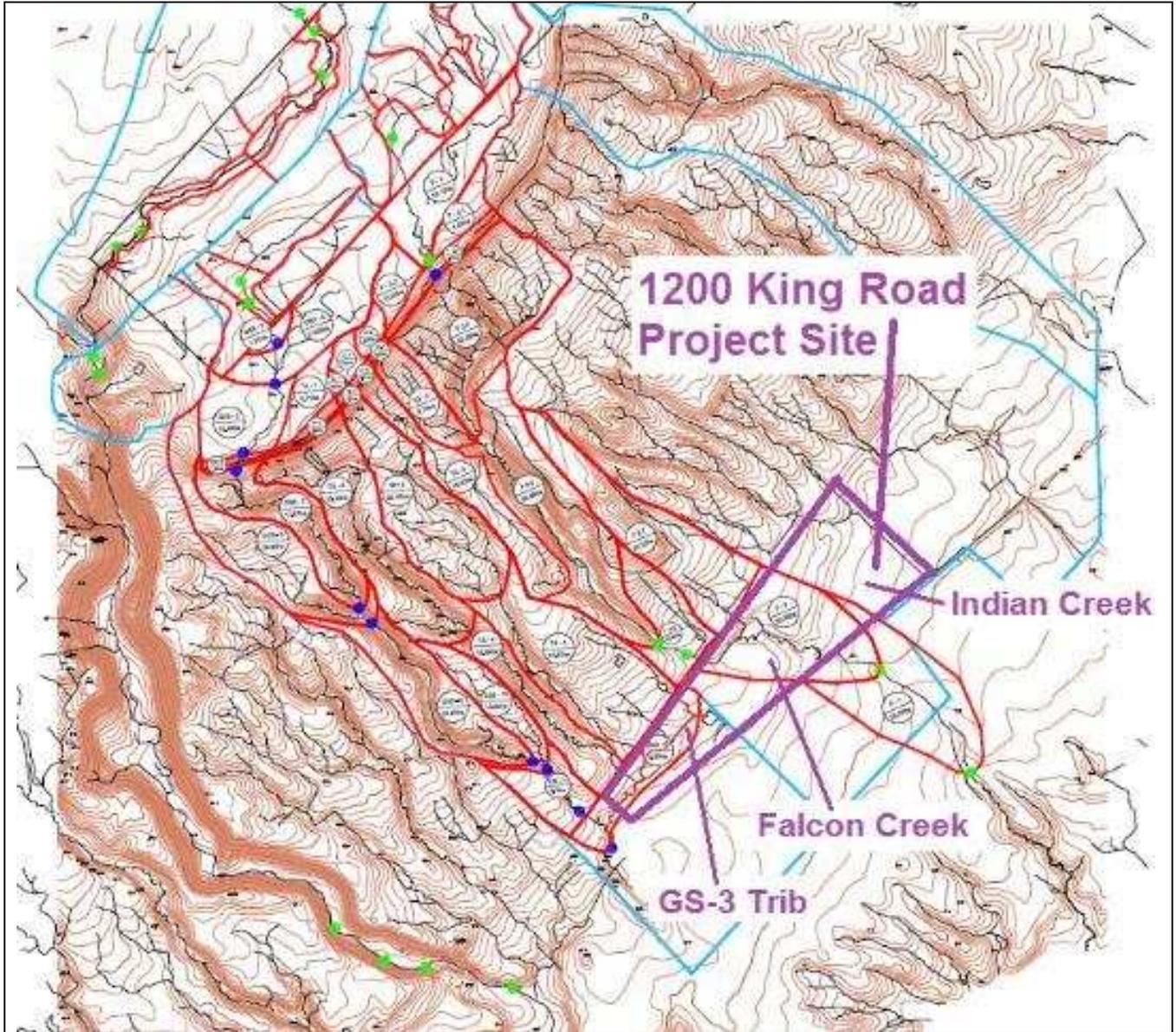


Figure 1 Subcatchment boundaries for existing GS-3 and Falcon Creek models from the South Waterdown Subwatershed Study

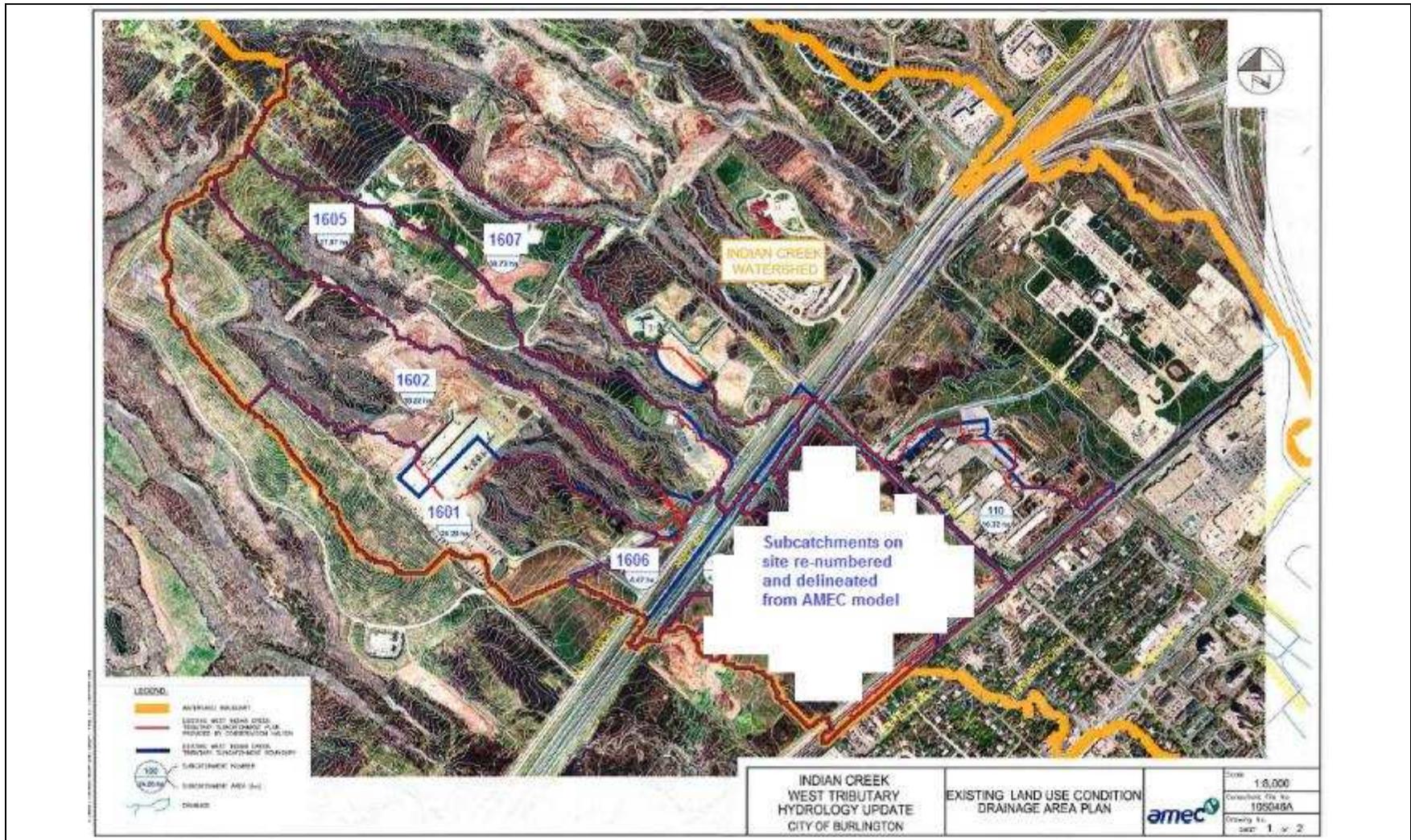


Figure 2 Subcatchment boundaries for existing Indian Creek model according to AMEC (2011)

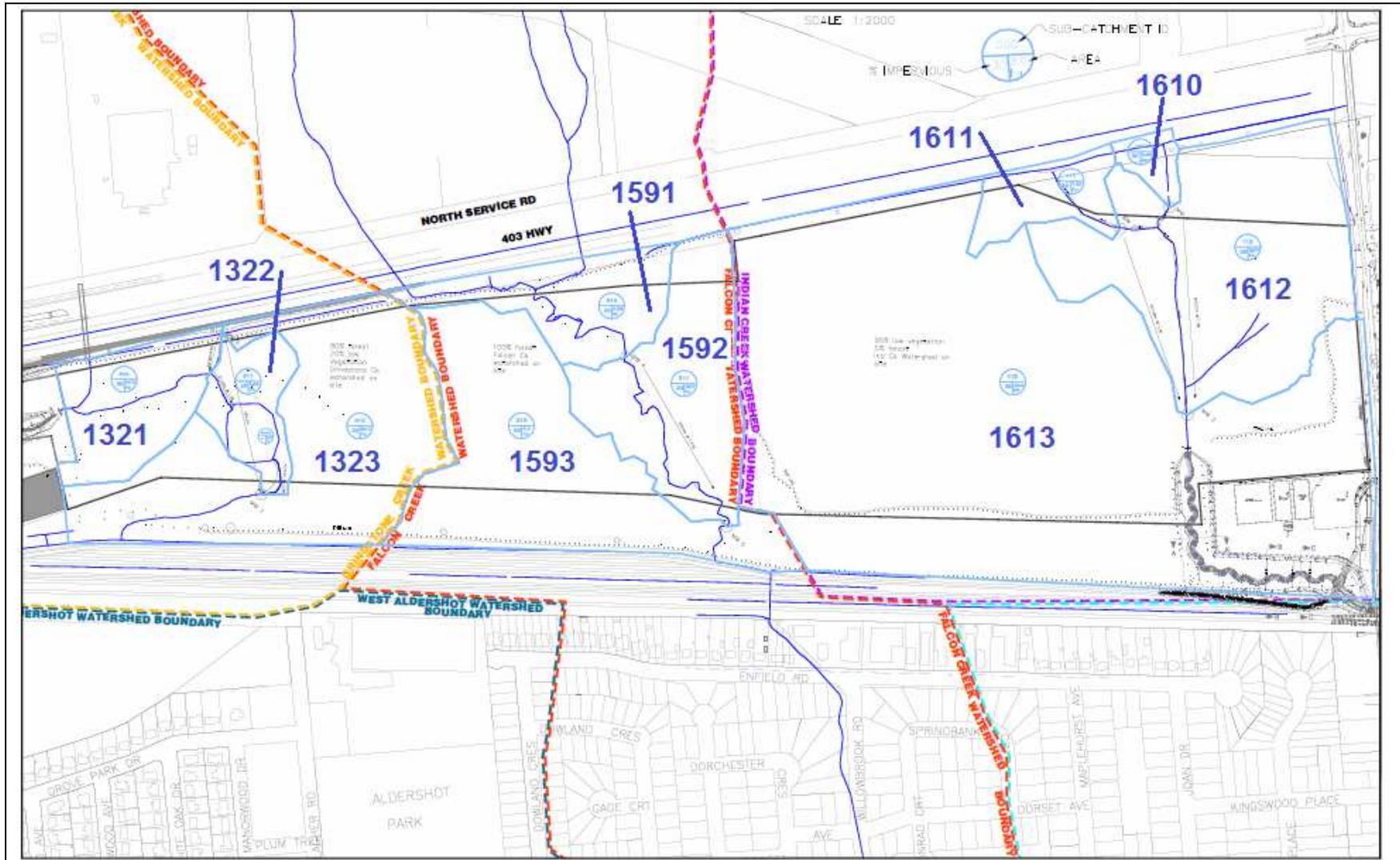


Figure 3 Subcatchment boundaries for three watercourses on the 1200 King Street project Site

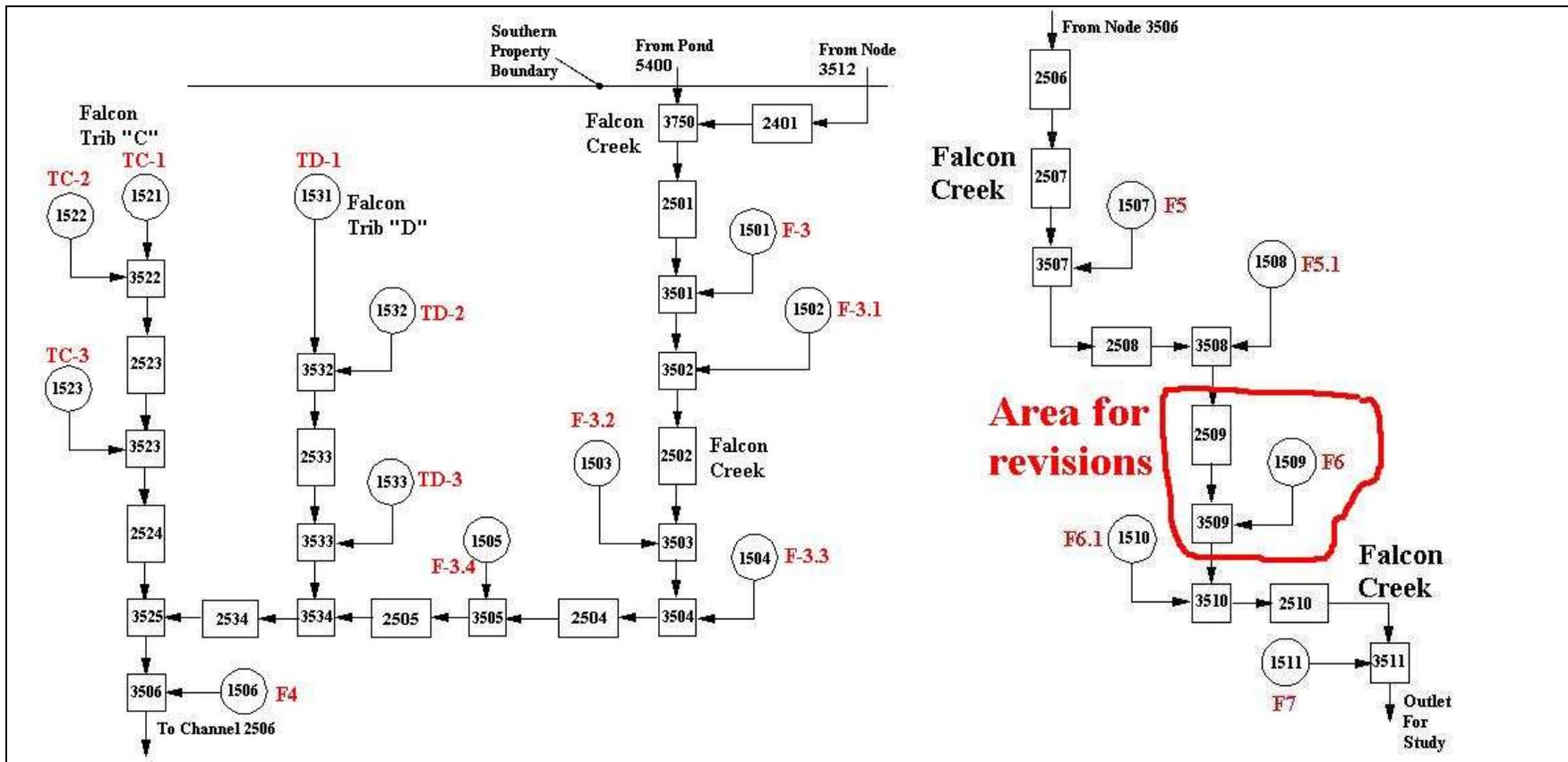


Figure 5 Schematic for existing Falcon Creek model from the Southwaterdown Subwatershed Study

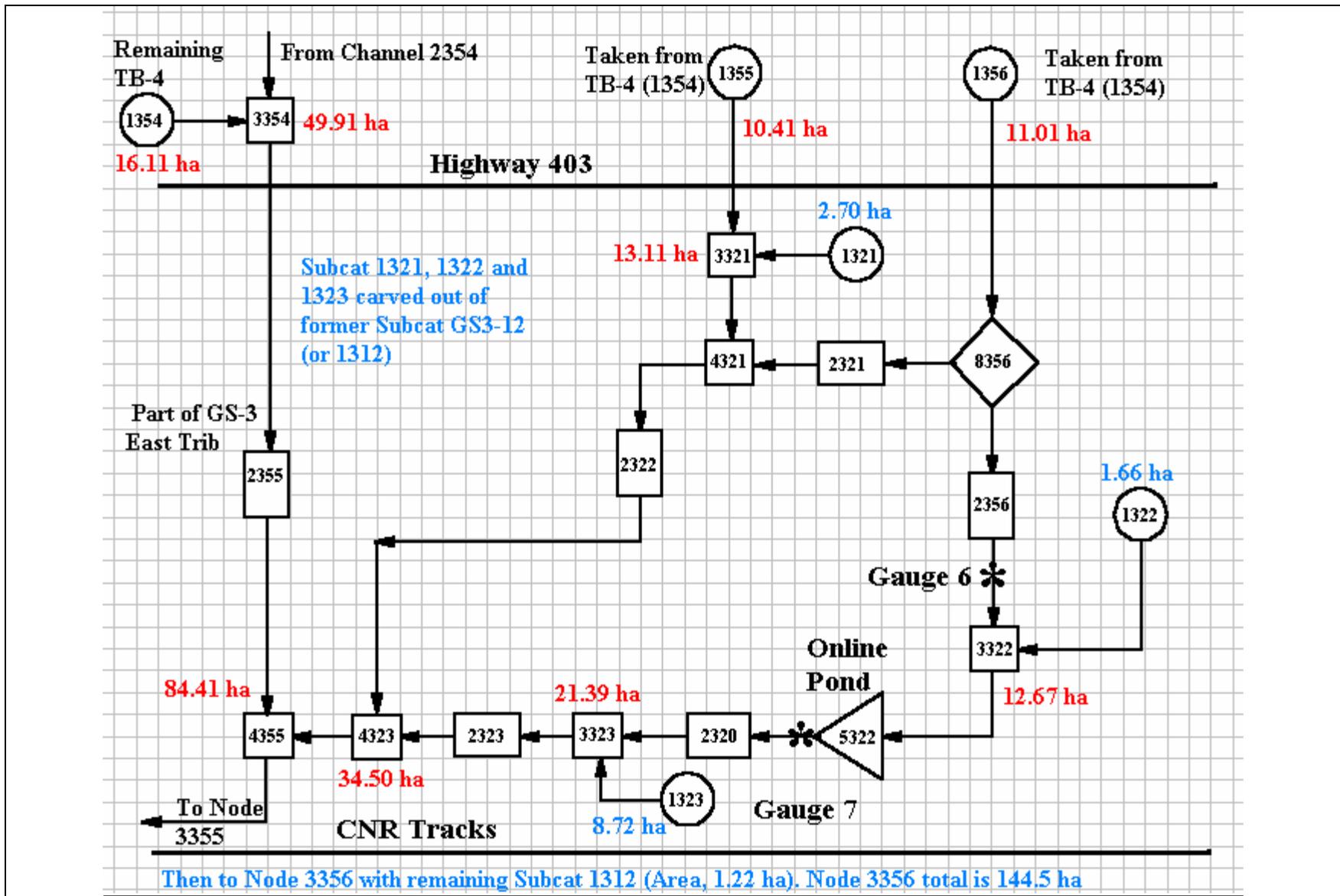


Figure 6 Schematic representation of GS-3 model on 1200 King Road Site for existing conditions

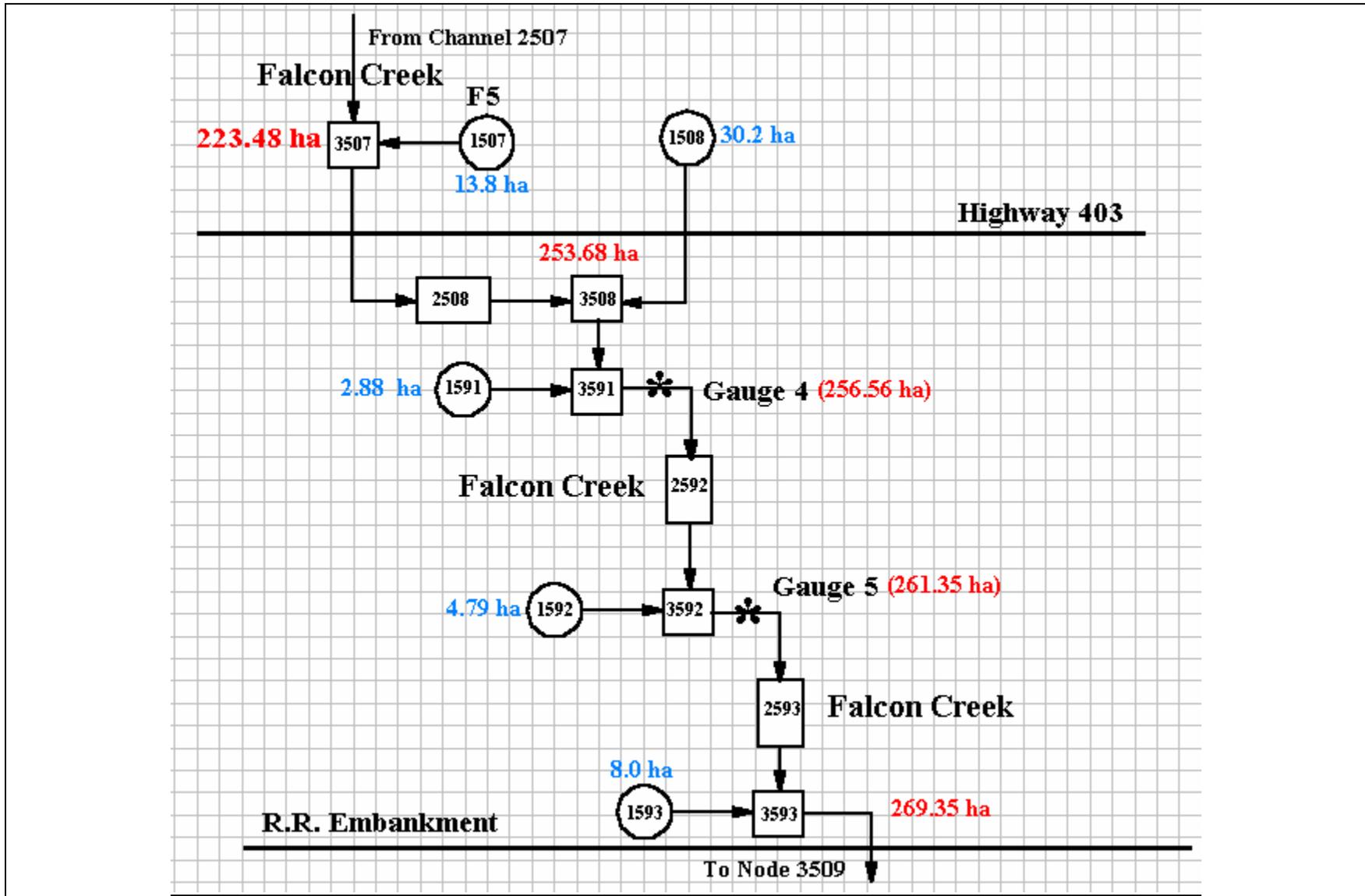


Figure 7 Schematic representation of Falcon Creek model on 1200 King Road Site for existing conditions

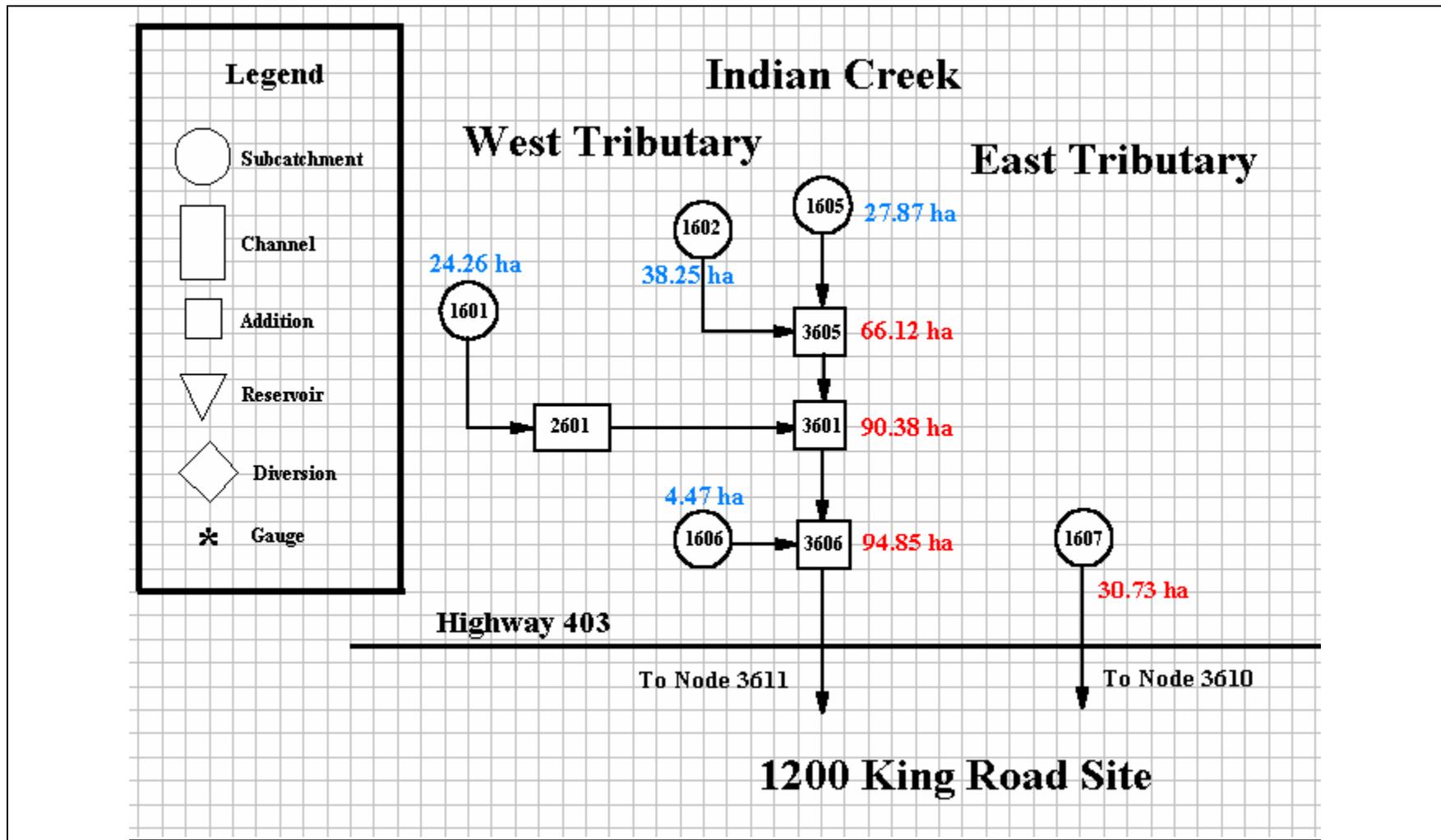


Figure 8 Schematic representation of Indian Creek model north of Highway 403 for existing conditions

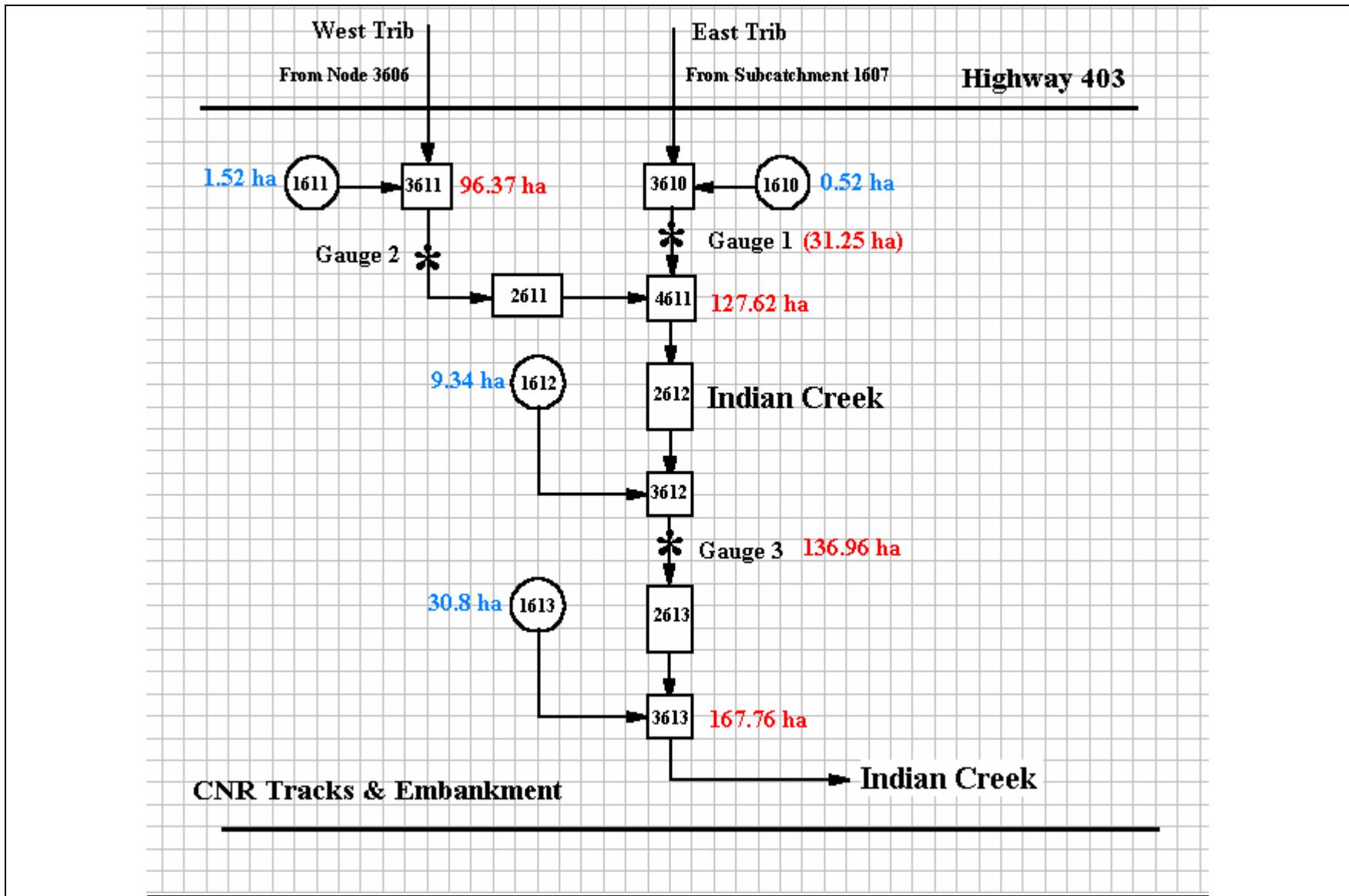


Figure 9 Schematic representation of Indian Creek model on 1200 King Road Site for existing conditions

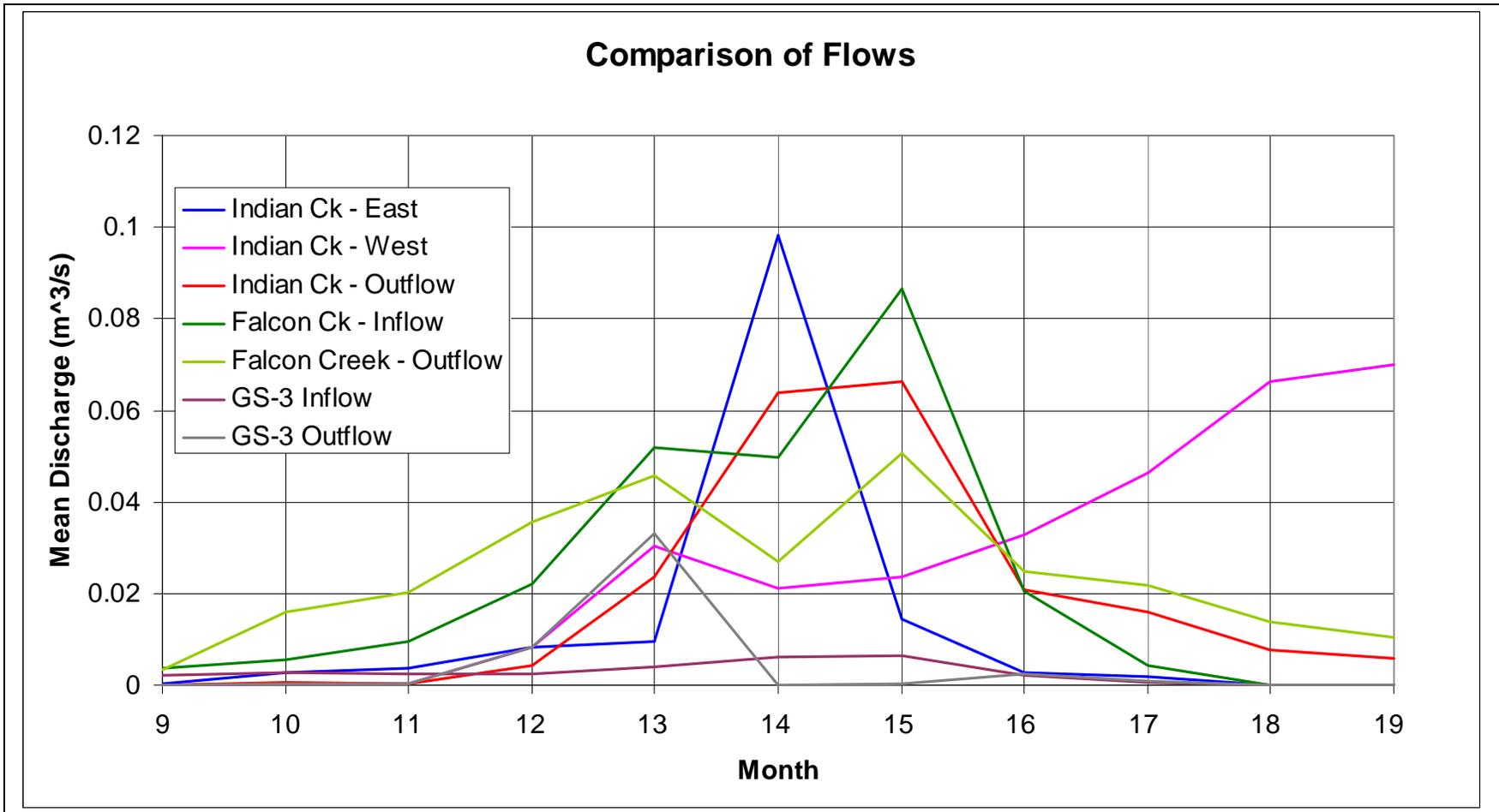


Figure 10 Measured flows at seven locations on 1200 King Road Site (Sept. 2013 to July 2014)

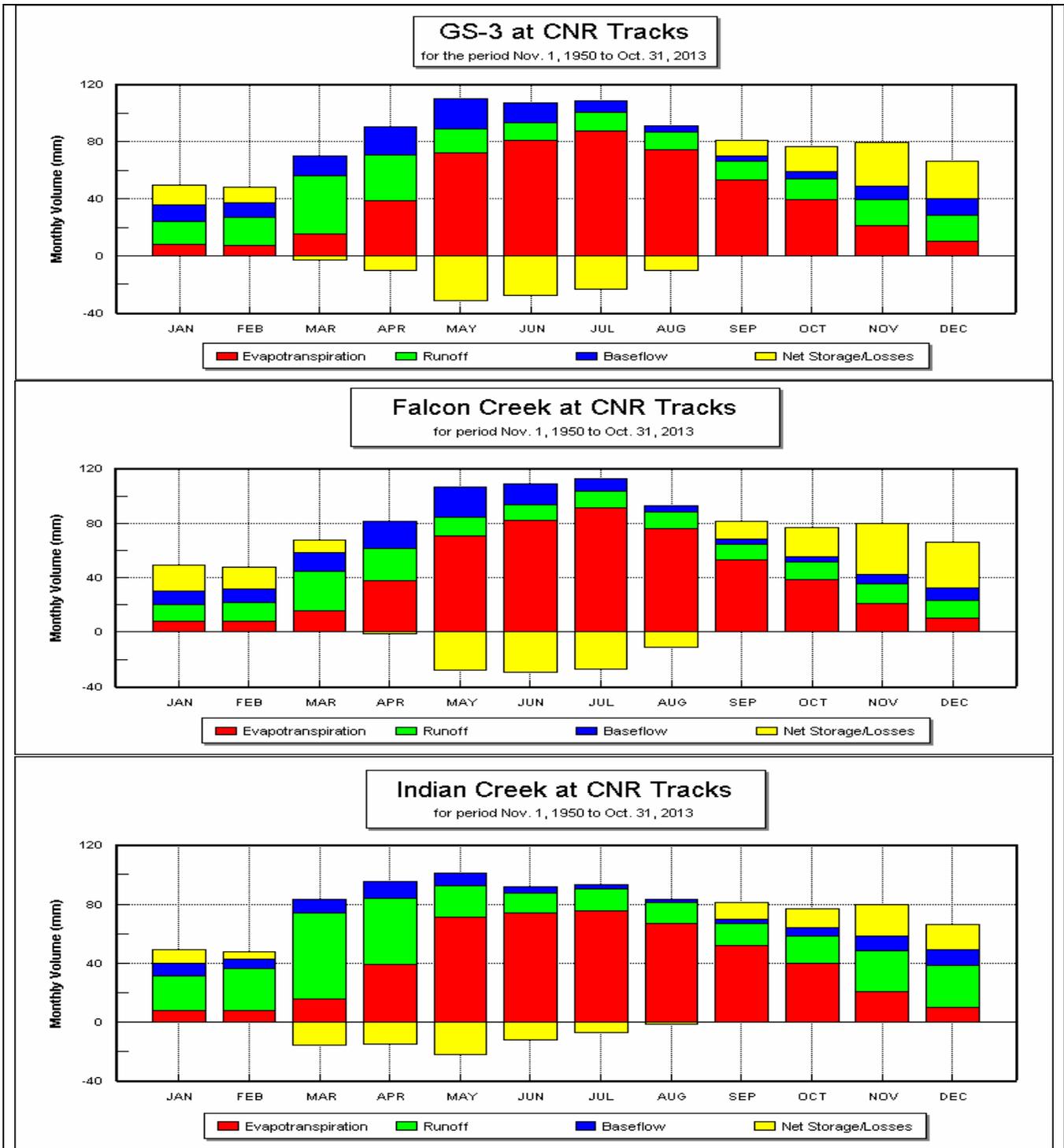


Figure 11 Monthly distribution of mean water balance quantities at key locations on the 1200 King Road (for Nov. 1950 to Oct. 2013)

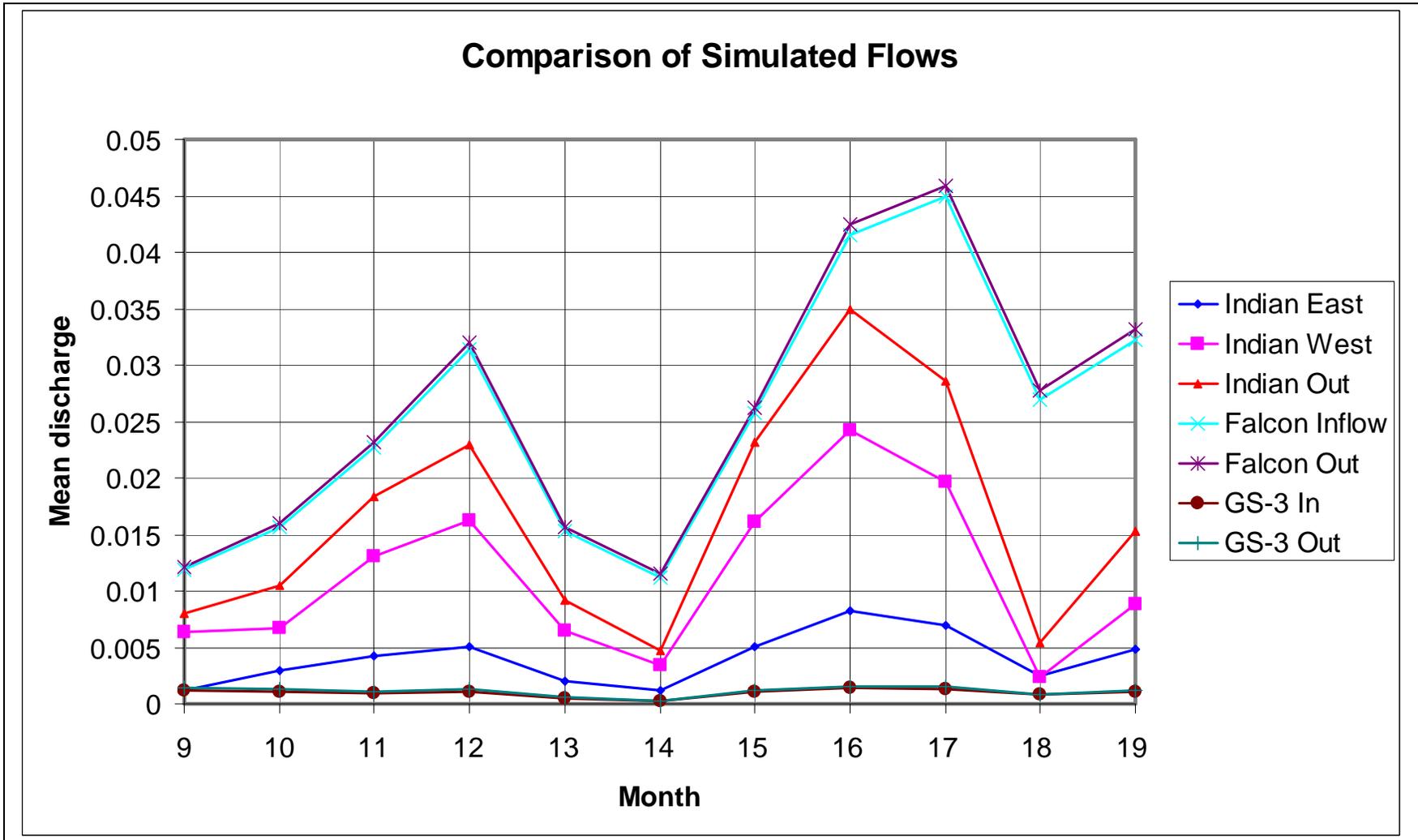


Figure 12 Modelled flows at seven locations on 1200 King Road Site (Sept. 2013 to July 2014)

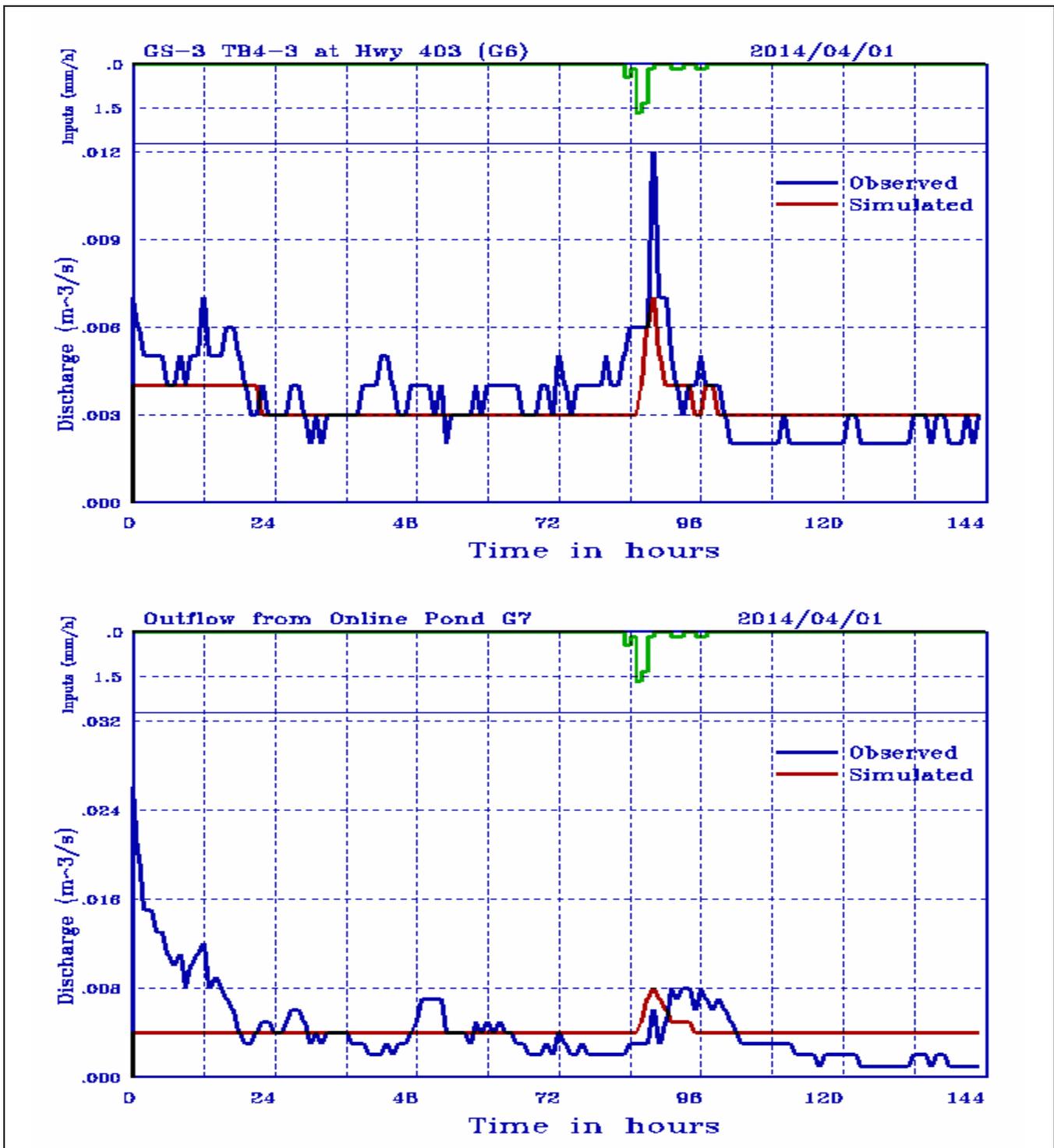


Figure 13 Observed and simulated hydrographs for GS-3 (Gauge 6 & 7) for April 1-6, 2014

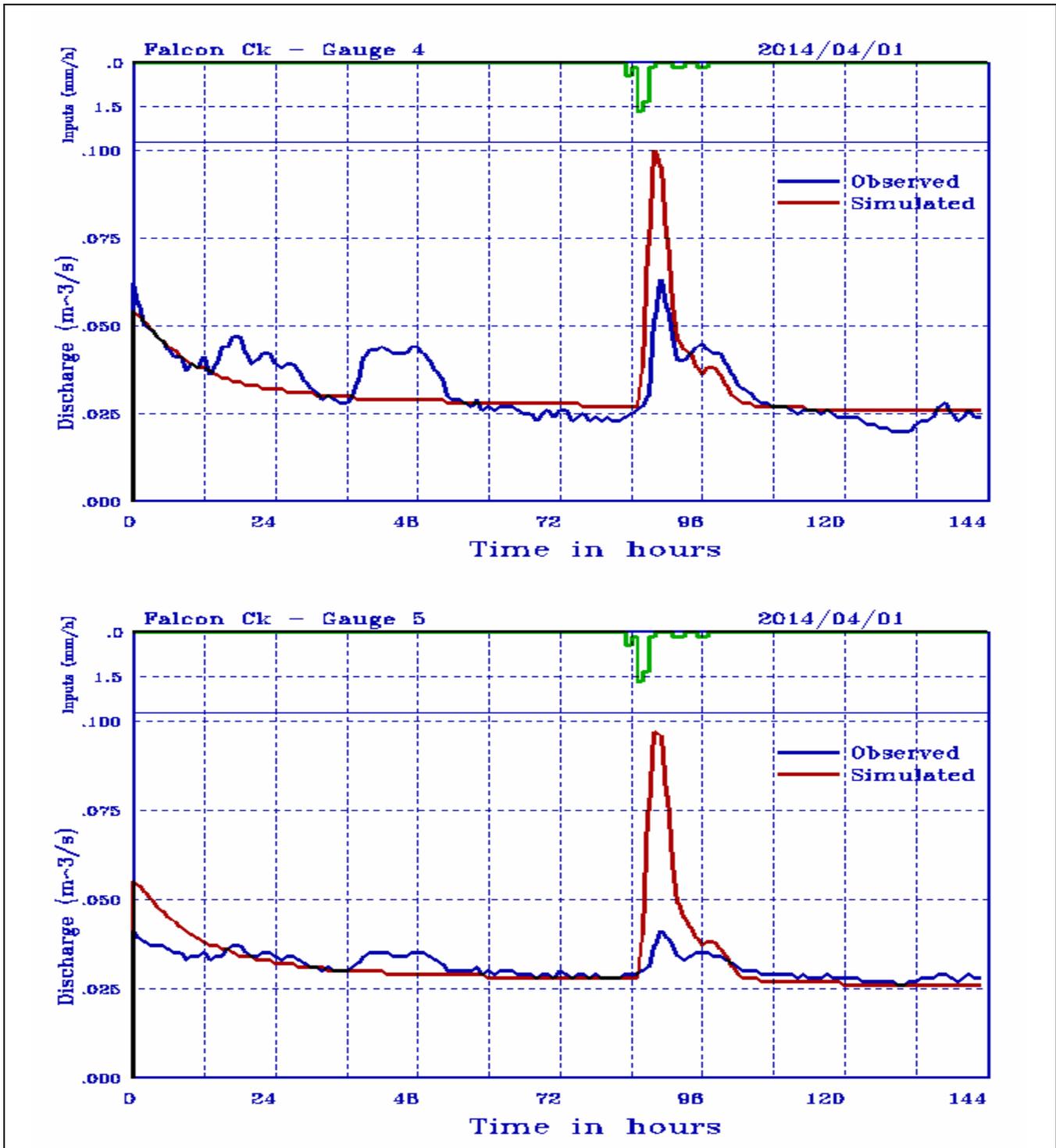


Figure 14 Measured and modelled hydrographs for Falcon Creek (Gauge 4 & 5) for April 1-6, 2014

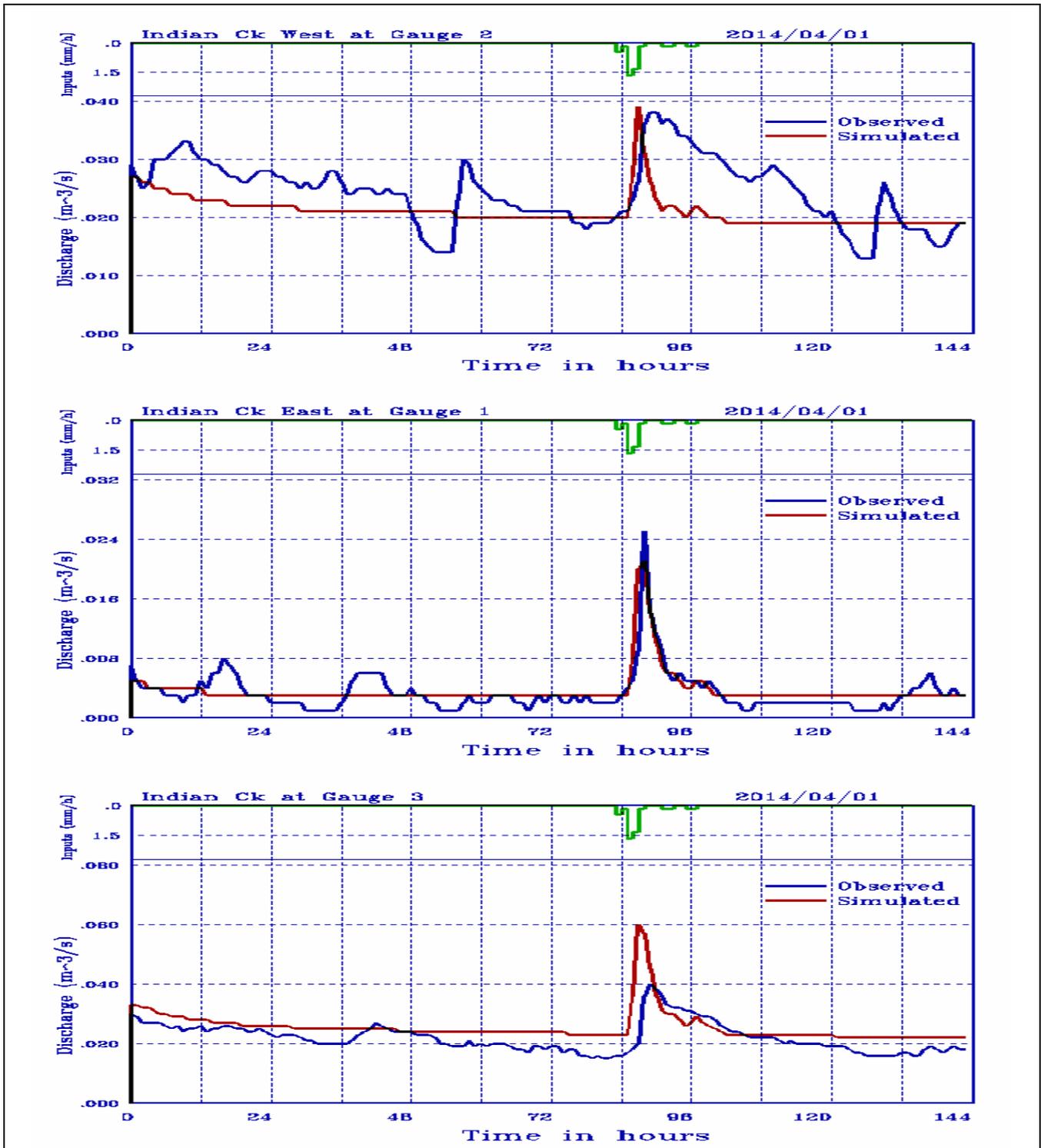


Figure 15 Observed and simulated hydrographs for Indian Creek (Gauges 1, 2 & 3) for April 1-6, 2014

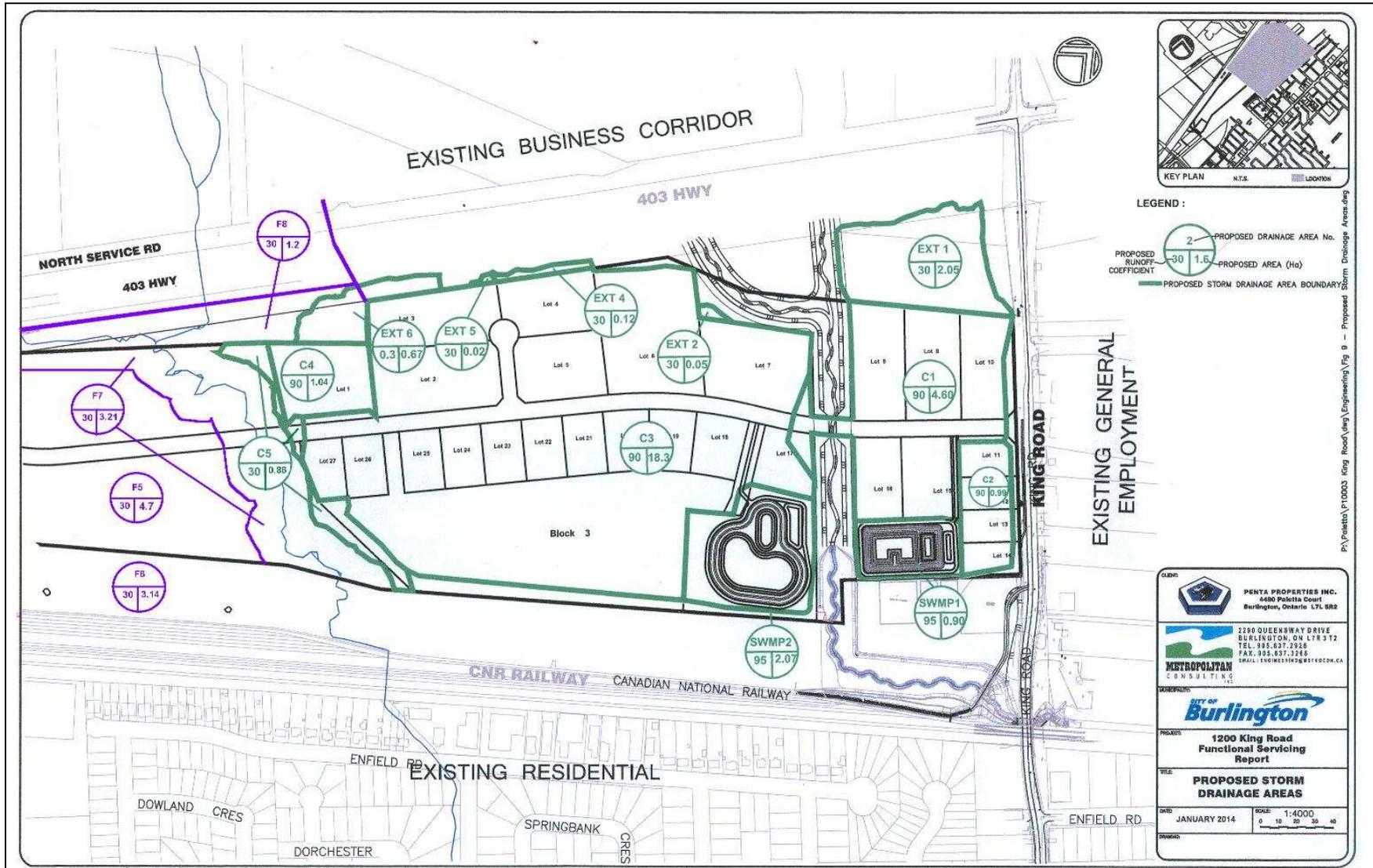


Figure 16 Proposed development plan for the 1200 King Road site

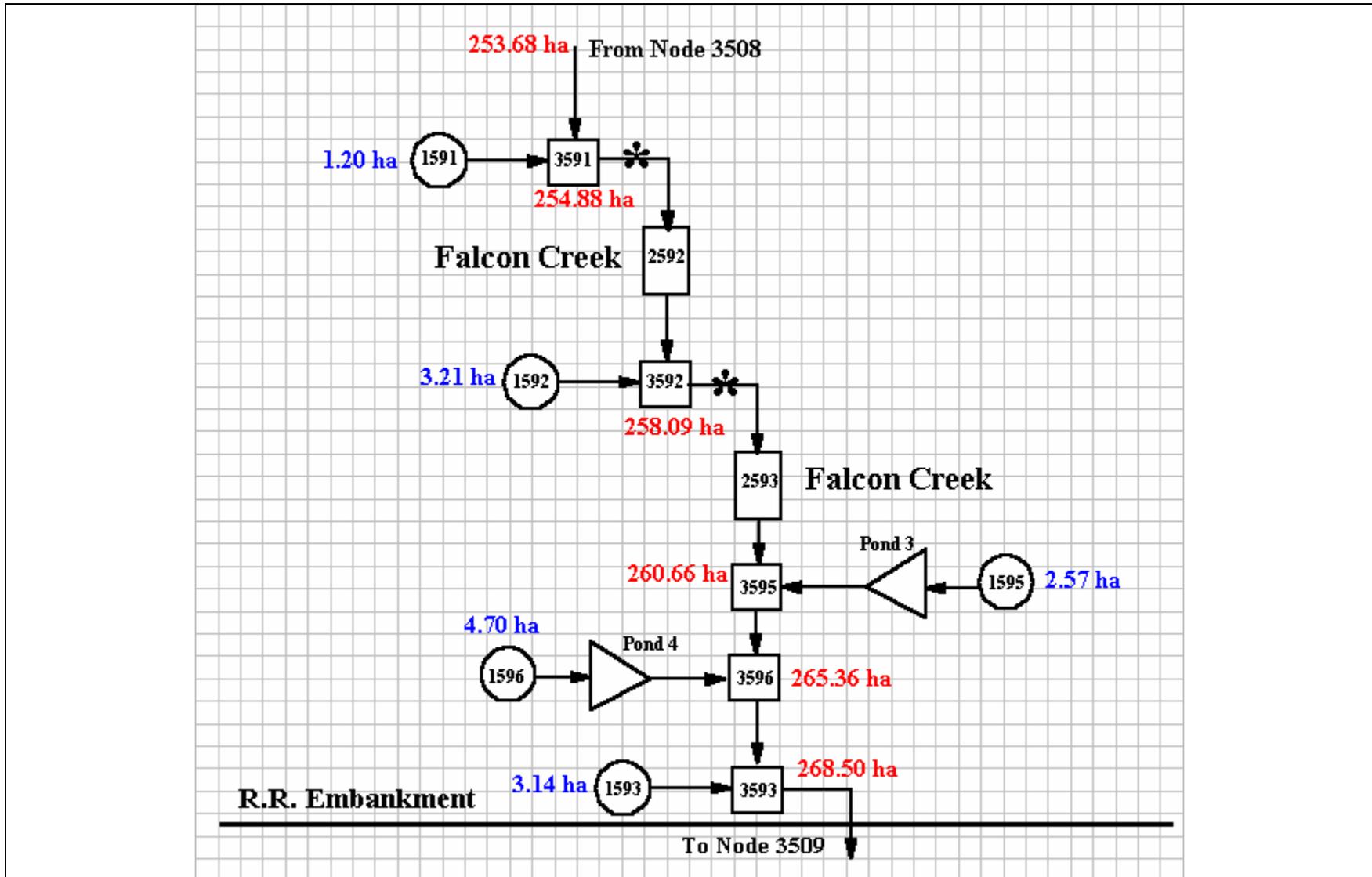


Figure 17 Revised schematic for Falcon Creek model for post-development conditions (SWM Pond 3 and 4)

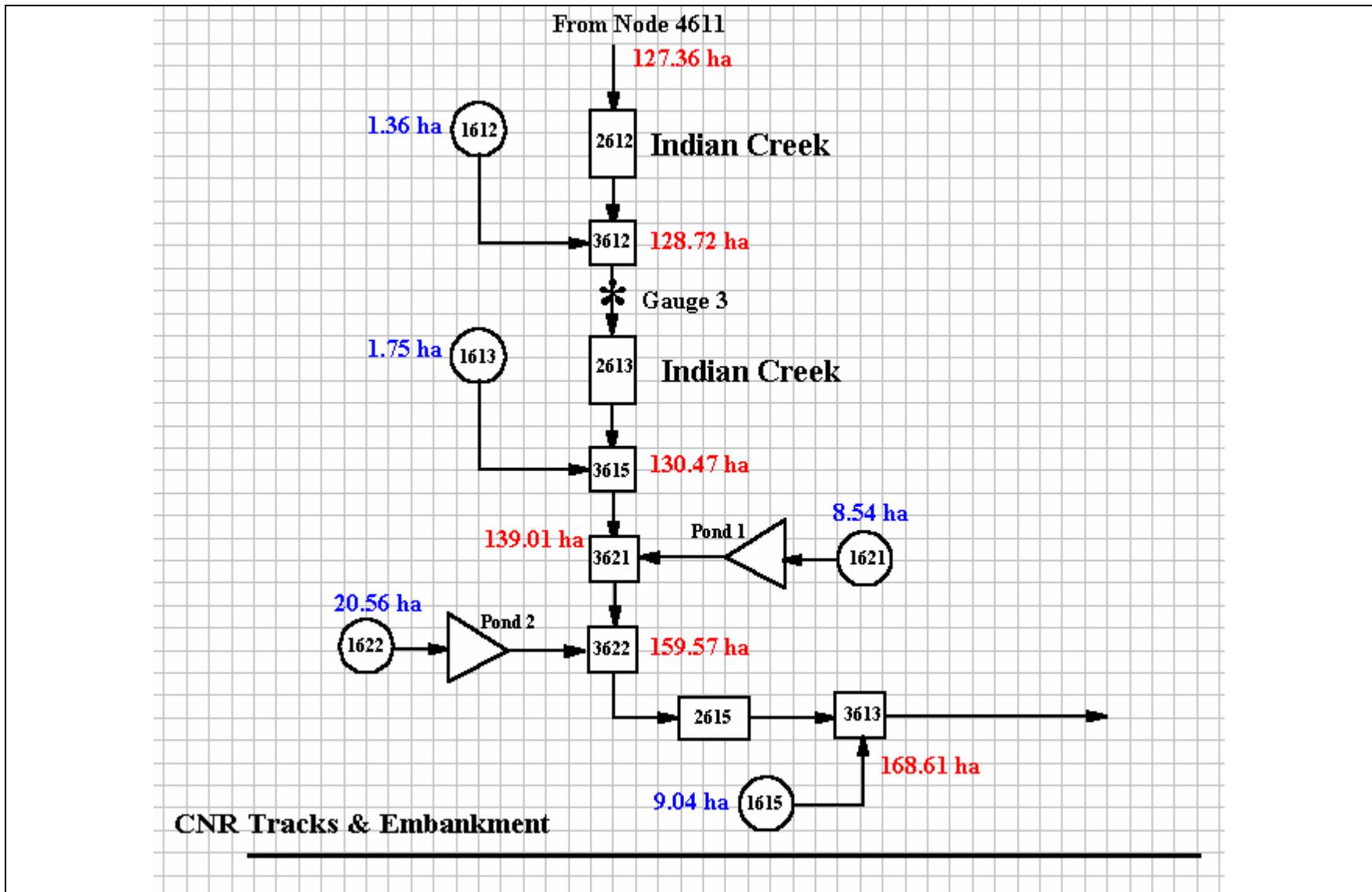


Figure 18 Revised schematic for Indian Creek model for post-development conditions (SWM Pond 1 and 2)

Tables

Table 1 Sample Mean daily flow table for one gauge on the 1200 King Road Site

Falcon Creek Outflow													FALCONO
DAILY DISCHARGE IN CUBIC METRES PER SECOND FOR 2014													
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	0.0380	0.0195	0.0207	0.0352	0.0317	0.0149	0.0118	---	---	---	---	---	1
2	0.0304	0.0196	0.0200	0.0329	0.0251	0.0150	0.0112	---	---	---	---	---	2
3	0.0257	0.0189	0.0193	0.0301	0.0232	0.0174	0.0112	---	---	---	---	---	3
4	0.0244	0.0190	0.0192	0.0315	0.0210	0.0150	0.0098	---	---	---	---	---	4
5	0.0264	0.0189	0.0186	0.0298	0.0201	0.0141	0.0040	---	---	---	---	---	5
6	0.0850	0.0186	0.0193	0.0274	0.0189	0.0138	0.0002	---	---	---	---	---	6
7	0.0563	0.0182	0.0205	0.0303	0.0185	0.0138	0.0146	---	---	---	---	---	7
8	0.0259	0.0183	0.0199	0.0354	0.0183	0.0141	0.0152	---	---	---	---	---	8
9	0.0236	0.0182	0.0200	0.0269	0.0182	0.0141	0.0127	---	---	---	---	---	9
10	0.0244	0.0176	0.0265	0.0248	0.0169	0.0139	0.0113	---	---	---	---	---	10
11	0.0860	0.0173	0.0770	0.0229	0.0166	0.0145	0.0110	---	---	---	---	---	11
12	0.119	0.0178	0.0843	0.0220	0.0166	0.0202	0.0109	---	---	---	---	---	12
13	0.125	0.0187	0.0384	0.0233	0.0500	0.0155	0.0106	---	---	---	---	---	13
14	0.128	0.0177	0.0609	0.0284	0.0339	0.0140	0.0099	---	---	---	---	---	14
15	0.114	0.0170	0.122	0.0332	0.0357	0.0140	0.0111	---	---	---	---	---	15
16	0.101	0.0169	0.0975	0.0256	0.0357	0.0140	0.0095	---	---	---	---	---	16
17	0.0664	0.0178	0.0649	0.0219	0.0250	0.0155	0.0092#	---	---	---	---	---	17
18	0.0377	0.0174	0.0533	0.0138	0.0228	0.0143	---	---	---	---	---	---	18
19	0.0297	0.0176	0.0570	0.0178	0.0213	0.0134	---	---	---	---	---	---	19
20	0.0259	0.0190	0.117	0.0137	0.0211	0.0130	---	---	---	---	---	---	20
21	0.0223	0.0992	0.108	0.0209	0.0207	0.0126	---	---	---	---	---	---	21
22	0.0203	0.125	0.0935	0.0200	0.0190	0.0124	---	---	---	---	---	---	22
23	0.0197	0.0430	0.0579	0.0188	0.0184	0.0129	---	---	---	---	---	---	23
24	0.0201	0.0283	0.0409	0.0189	0.0179	0.0132	---	---	---	---	---	---	24
25	0.0194	0.0266	0.0321	0.0195	0.0172	0.0129	---	---	---	---	---	---	25
26	0.0217	0.0247	0.0261	0.0192	0.0167	0.0122	---	---	---	---	---	---	26
27	0.0197	0.0219	0.0275	0.0185	0.0166	0.0115	---	---	---	---	---	---	27
28	0.0196	0.0209	0.0715	0.0185	0.0159	0.0114	---	---	---	---	---	---	28
29	0.0191		0.0637	0.0340	0.0156	0.0124	---	---	---	---	---	---	29
30	0.0194		0.0360	0.0342	0.0153	0.0126	---	---	---	---	---	---	30
31	0.0187		0.0371		0.0148		---	---	---	---	---	---	31
TOTAL	1.41	0.753	1.57	0.750	0.679	0.419	0.174#	0 #	0 #	0 #	0 #	0 #	TOTAL
MEAN	0.0460	0.0270	0.0510	0.0250	0.0220	0.0140	0.0100#	---	---	---	---	---	MEAN
MINDAY	0.0187	0.0169	0.0186	0.0137	0.0148	0.0114	0.0002#	---	---	---	---	---	MIND
MAXDAY	0.128	0.125	0.122	0.0354	0.0500	0.0202	0.0152#	---	---	---	---	---	MAXD
PEAK	0.141	0.167	0.140	0.0654	0.0911	0.0353	0.0246#	---	---	---	---	---	PEAK
@DD:HH	13:24	21:17	15:01	29:15	13:06	12:02	7:07	0:00	30:15	4:05	17:23	25:09	@DD:HH

NOTE: Amounts given in m³/s , # Incomplete total, + <0.00005 TOTAL VOLUME FOR YEAR, 498 dam³
 Drainage Area, 2.614 km²

Maximum Hourly Value, 0.167 on FEB 21 at 17:00

Table 4 Hydrologic response unit drainage characteristics

<i>Symbol</i>	<i>Description</i>	<i>Units</i>	<i>Imp</i>	<i>Wet Lands</i>	<i>Low Veg. Peat Muk</i>	<i>Low Veg. Silty Clay</i>	<i>Low Veg. Silty Sands</i>	<i>Low Veg. Sand</i>	<i>Low Veg. Gravl</i>	<i>High Veg. Low Infiltr</i>	<i>High Veg. High Infiltr</i>
	Response Unit Number		1	2	3	4	5	6	7	8	9
DS	Maximum depth of depression Storage	(mm)	2	100	5	5	5	5	5	15	15
KEFF	Infiltration into 1 st soil layer	(mm/h)	0	0.20	2	3	8	16	30	16	50
CS	Infiltration into 2 nd soil layer	(mm/h)	0	0.10	1.5	2	6	12	23	12	38
D	Infiltration out of 2 nd layer	(mm/h)	0	0.05	0.5	0.3	0.8	2	3	2	5
SAV	Average suction at the wetting front	(mm)	0	200	200	200	200	250	250	200	250
X	Groundwater Contribution Indicator: 1=SS, 0=GW		0	1	1	1	1	0	0	0	0
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	0	3	1	1	1	1	1	5	5
First Soil Layer											
HI	Soil layer thickness	(mm)	0	0.01	100	100	100	150	150	200	200
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0	0.56	0.56	0.54	0.5	0.4	0.4	0.5	0.4
IMCI	Initial soil-water content	(vol/vol)	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
FCAPI	Field capacity soil-water content	(vol/vol)	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
WILTI	Wilting point soil-water content	(vol/vol)	0	0.27	0.27	0.19	0.13	0.04	0.04	0.13	0.04
Second Soil Layer											
HII	Soil layer thickness	(mm)	0	0.01	150	250	300	600	600	500	600
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0	0.56	0.56	0.54	0.5	0.4	0.4	0.5	0.4
IMCII	Initial soil-water content	(vol/vol)	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
FACPII	Field capacity soil-water content	(vol/vol)	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
WILTII	Wilting point soil-water content	(vol/vol)	0	0.27	0.27	0.19	0.13	0.04	0.04	0.13	0.04

Background Sources: Hydrology of Floods in Canada (Watt et al., 1989), Bronte Creek Hydrology and Geomorphology Study (PEI, 2002)

Table 5 Subcatchment characteristics for existing conditions at 1200 King Road Site

<i>Subcat No.</i>	<i>Area (ha)</i>	<i>L (m)</i>	<i>W (m)</i>	<i>Imp RU 1</i>	<i>RU 2</i>	<i>RU 3</i>	<i>RU 4</i>	<i>RU 5</i>	<i>RU 6</i>	<i>RU 7</i>	<i>RU 8</i>	<i>RU 9</i>	<i>FTB</i>
1354	16.11	351	356	24	0	0	0	35	5	0	36	0	2.0
1355	10.41	856	1220	24	0	0	0	35	5	0	36	0	2.0
1356	11.01	967	114	24	0	0	0	35	5	0	36	0	2.0
1321	2.7	201	134	30	0	0	14	0	0	0	56	0	2.0
1322	1.66	147	98	30	0	0	14	0	0	0	56	0	2.0
1323	8.72	436	291	30	0	0	14	0	0	0	56	0	2.0
1312	1.28	150	320	70	0	0	0	0	0	0	30	0	2.0
1507	13.8	616	184	15	0	0	0	0	0	0	85	0	2.0
1508	30.2	588	268	17	0	0	0	10	10	0	63	0	2.0
1591	2.88	145	97	30	0	0	0	0	0	0	70	0	2.0
1592	4.79	232	155	30	0	0	0	0	0	0	70	0	2.0
1593	8.00	594	135	30	0	0	0	0	0	0	70	0	2.0
1509	15.01	588	268	17	0	0	0	10	10	0	63	0	2.0
1601	24.26	1074	227	0	0	43	0	57	0	0	0	0	2.0
1602	38.25	1360	281	13	0	13	0	74	0	0	0	0	2.0
1605	27.87	1564	178	0	0	30	0	70	0	0	0	0	2.0
1606	4.47	393	114	36	0	0	0	64	0	0	0	0	2.0
1607	30.73	1724	178	30	0	0	0	65	0	0	5	0	2.0
1610	0.52	55	37	30	0	0	65	0	0	0	5	0	2.0
1611	1.52	172	115	30	0	0	65	0	0	0	5	0	2.0
1612	9.34	470	313	30	0	0	65	0	0	0	5	0	2.0
1613	30.8	681	452	30	0	0	65	0	0	0	5	0	2.0

Table 6 Channel routing characteristics for existing and post-development conditions

<i>Number</i>	<i>Length (m)</i>	<i>Slope (m/m)</i>	<i>Cross-Section Number</i>	<i>Comment/Remarks</i>
2321	193	0.017	23.21	GS-3 Tributary
2356	115	0.0095	13.56	
2320	67	0.022	13.56	
2323	202	0.022	33.23	
2322	400	0.013	33.22	
2508	243	0.012	25.08	Falcon Creek
2591	238	0.004	35.91	
2592	349	0.0127	35.92	
2601	393	0.012	26.01	Indian Creek
2611	72	0.024	16.11	
2612	290	0.0133	36.12	
2613	409	0.0035	36.13	
2613	200	0.0035	36.13	Indian Creek - Post-development
2615	209	0.0035	36.13	Indian Creek - Post-development

Table 7 Model parameters for each block of equivalent snow accumulation

<i>Parameter</i>	<i>Symbol</i>	<i>Units</i>	<i>Fields Ploughed</i>	<i>Fields Grass</i>	<i>Forest</i>	<i>Roadway Easements</i>	<i>Fence Lines</i>	<i>Forest Edges</i>
Constant melt factor	KMI	(mm/d-C°)	0.3	2.0	0.2	4	4	0.2
Variable melt factor	KMII	(mm/d-C°)	32	29	22	24	24	23
Refreeze factor	KF	(mm/d-C°)	16	16	11	16	12	11
Base Temperature	TBAS	(C°)	0	0	0	0	0	0
Sublimation rate	SUBLIM	(mm/d)	0.33	0.33	0.33	0.33	0.33	0.33
Threshold density	MRHO	(vol/vol)	0.40	0.37	0.35	0.40	0.70	0.37
Compaction Constant:	A	(hours)	0.10	0.10	0.10	0.10	0.10	0.10
Compaction Constant:	B	(1/C°)	7.0	7.0	7.0	7.0	7.0	7.0
Holding Capacity	HCAP	(cm)	9.5	17	44	35	55	2000
Percentage of Area	AREA	(%)	17.2	52.7	8.1	3.8	13.2	4.8

General Parameters Applied to All Blocks

Parameter	Symbol	Units	Value
New snow density	NEWDEN	(vol/vol)	0.100
Eroded snow density	RHOE	(vol/vol)	0.120
Irreducible water saturation	SWI	(vol/vol)	0.07
Initial liquid water content	ILWC	(mm)	0.00

Table 9

WATER BALANCE SUMMARY FOR HYDROGRAPH 3593

=====

Location: Falcon Ck at CNR Tracks
 Scenario File: wbexl.dat (Existing Conditions)
 Period: 1950/11/01 to 2013/10/31 Area: 2.6935 km²

Month	Precip	ET	Runoff	Infiltration		Total Flow
				(Baseflow)	(Losses)	
JAN	49.2	8.0	11.8	10.6	18.8	22.5
FEB	47.8	7.6	14.4	9.8	16.0	24.2
MAR	67.8	15.5	29.1	13.8	9.4	42.9
APR	80.3	37.7	23.6	19.8	-0.9	43.4
MAY	78.6	70.5	13.8	22.2	-27.9	36.0
JUN	79.5	82.3	11.1	15.7	-29.6	26.8
JUL	85.5	91.3	12.1	9.2	-27.0	21.2
AUG	81.4	76.1	11.8	4.9	-11.3	16.6
SEP	81.2	52.9	11.9	3.2	13.2	15.1
OCT	76.8	38.9	12.7	3.8	21.4	16.4
NOV	79.5	20.6	14.7	6.9	37.3	21.6
DEC	66.2	10.0	12.9	9.4	33.8	22.4
Total	873.8	511.4	179.8	129.2	53.3	309.1

Extreme Flows Summary

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Return Period (Years)	High Flows (m ³ /s)	Low Flows (m ³ /s)
1.25	0.960	0.0023
2.00	1.500	0.0005
5.00	2.460	0.0001
10.00	3.250	0.0000
20.00	4.100	0.0000
25.00	4.390	0.0000
50.00	5.360	0.0000
100.00	6.420	0.0000
200.00	7.590	0.0000
500.00	9.300	0.0000

Flow-Duration Summary

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PCT%	Time	Flow (m ³ /s)	PCT%	Time	Flow (m ³ /s)
98.0		0.00002	50.0		0.01300
90.0		0.00100	40.0		0.01800
80.0		0.00300	30.0		0.02300
70.0		0.00600	20.0		0.03000
60.0		0.00900	10.0		0.05600

Table 10 City of Burlington rainfall IDF parameters for the return period events

<i>Return Period (Years) or Event</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>Four Hour Volume (mm)</i>
<i>25 mm</i>	457.8	6.0	0.780	25.0
2	592.6	6.0	0.780	32.4
5	697.4	5.0	0.764	41.7
10	798.5	5.0	0.763	48.0
25	926.9	5.0	0.762	56.1
50	1019.4	5.0	0.761	62.0
100	1114.2	5.0	0.761	67.8

NOTE: IDF parameters supplied City of Burlington Staff

Table 11 Return period rainfall volumes for longer durations in the general study area

<i>Return Period (Years)</i>	<i>Hamilton RBG (6153300) 12 h</i>	<i>Hamilton RBG (6153300) 24 h</i>	<i>Hamilton A (6153194) 12 h</i>	<i>Hamilton A (6153194) 24 h</i>
2	42.2	49.1	44.1	51.3
5	57.3	64.3	60.5	69.2
10	67.3	74.4	71.3	81.1
25	80.0	87.2	85.0	95.1
50	89.3	96.6	95.1	107.1
100	98.7	106.0	105.2	118.2

NOTE: Data to 2003.

Data obtained from Environment Canada, Atmospheric Environment Service

Table 12 Temporal Rainfall Distribution Patterns used in this Study

<i>Event</i>	<i>Time Step (min)</i>	Rainfall amounts (mm) for time step ending at											<i>Total Rain (mm)</i>		
		<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>		<i>12</i>	
Regional	60	2	2	2	2	2	2	2	2	2	2	2	2	2	285
		2	2	2	2	2	2	2	2	2	2	2	2		
		2	2	2	2	2	2	2	2	2	2	2	2		
		6	4	6	13	17	13	23	13	13	53	38	13		
Chicago (4 hour)	10	0.76	0.84	0.94	1.07	1.25	1.52	1.97	2.90	6.24	23.65	7.24	3.81	67.76	
		2.65	2.06	1.71	1.46	1.29	1.15	1.05	0.96	0.89	0.83	0.78	0.73		
SCS Type II (24 hour)	15	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	106.0	
		0.30	0.30	0.30	0.30	0.30	0.30	0.54	0.54	0.54	0.54	0.54	0.54		
		0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54		
		0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	1.43	1.43	1.43		
		2.15	4.27	11.10	26.69	4.77	2.86	2.23	1.70	1.32	1.32	1.32	1.32		
		0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.54	0.54	0.54		
		0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54		
		0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.30	0.30	0.30		
		0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30		

Table 13 Summary of Flood Flow Estimates: Return Period Events & Regional Storm for 1200 King Road
Revised Existing Conditions

No. Point of Interest	Area km ²	Peak Flows (m ³ /s)							
		25 mm	1:2 yr	1:5	1:10	1:25	1:50	1:100	Reg 1.00
3354 GS-3 TB Trib at Hwy 403	0.4991	0.325	0.594	0.916	1.160	1.550	1.850	2.140	4.600
1355 GS-3 TB4-2 at Hwy 403	0.1041	0.084	0.134	0.197	0.247	0.334	0.398	0.462	0.969
3321 GS-3 TB4-2 d/s Hwy 403	0.1311	0.123	0.187	0.267	0.335	0.458	0.548	0.638	1.240
1356 GS-3 TB4-3 at Hwy 403 (G6)	0.1101	0.098	0.144	0.203	0.251	0.331	0.391	0.449	0.973
8356 Divert flows to West Trib	0.1101	0.039	0.057	0.081	0.100	0.132	0.156	0.180	0.389
4321 First E/W summation	0.1311	0.158	0.240	0.343	0.429	0.582	0.694	0.802	1.630
3322 Inflow to Online Pond G6	0.1267	0.084	0.122	0.169	0.208	0.278	0.332	0.384	0.750
5322 Outflow from Online Pond G7	0.1267	0.000	0.000	0.000	0.000	0.050	0.091	0.130	0.703
4323 Sum East & West Tributary.	0.3450	0.235	0.346	0.484	0.605	0.829	0.994	1.150	3.070
4355 GS-3 TB Tributary	0.8441	0.540	0.919	1.380	1.740	2.350	2.820	3.270	7.660
3355 GS-3 Sum TA & TB Tribs	1.4331	0.867	1.440	2.140	2.730	3.770	4.560	5.340	12.700
3356 GS-3 add remaining 1312	1.4459	0.887	1.470	2.180	2.770	3.830	4.620	5.400	12.900
3312 GS-3 Outlet (for SWSS)	3.1909	1.940	3.110	4.570	5.840	8.070	9.740	11.400	28.100
3750 Falcon Ck at boundary	0.9058	0.054	0.117	0.207	0.287	0.498	0.714	1.010	7.560
3507 Falcon Creek at Hwy 403	2.2348	0.981	1.450	2.030	2.550	3.510	4.270	4.940	17.500
3508 Falcon Ck d/s Hwy 403	2.5368	1.070	1.590	2.240	2.810	3.910	4.770	5.530	19.500
1591 Subcatchment 1591	0.0288	0.027	0.035	0.045	0.058	0.088	0.111	0.133	0.273
3591 Falcon Ck - Gauge 4	2.5656	1.090	1.610	2.260	2.850	3.960	4.820	5.590	19.600
1592 Subcatchment 1592	0.0479	0.054	0.071	0.092	0.116	0.179	0.225	0.270	0.494
3592 Falcon Ck - Gauge 5	2.6135	1.120	1.650	2.310	2.900	4.030	4.910	5.690	19.900
1593 Subcatchment 1593	0.0800	0.073	0.095	0.123	0.156	0.239	0.299	0.359	0.752
3593 Falcon Ck at CNR Tracks	2.6935	1.170	1.710	2.390	3.000	4.160	5.070	5.880	20.500
3510 Falcon Ck at Sub F6.1	2.9376	1.280	1.860	2.590	3.260	4.520	5.490	6.380	22.000
3511 Falcon Ck Outlet (for SWSS)	3.2286	1.590	2.320	3.180	3.910	5.230	6.280	7.200	23.900
3606 Indian Ck West at 403	0.9485	0.777	1.450	2.270	2.840	3.570	4.100	4.630	9.040
3611 Indian Ck West at Gauge 2	0.9637	0.815	1.510	2.350	2.930	3.680	4.230	4.770	9.210
1607 Indian Ck East at 403	0.3073	0.266	0.441	0.652	0.801	1.000	1.140	1.290	2.740
3610 Indian Ck East at Gauge 1	0.3125	0.284	0.466	0.684	0.838	1.040	1.190	1.340	2.800
4611 Indian Ck Sum East & West	1.2762	1.100	1.970	3.030	3.760	4.720	5.420	6.110	12.000
1612 Subcatchment 1612	0.0934	0.071	0.106	0.150	0.180	0.220	0.250	0.279	0.680
3612 Indian Ck at Gauge 3	1.3696	1.160	2.070	3.170	3.930	4.920	5.650	6.370	12.600
1613 Subcatchment 1613	0.3080	0.167	0.251	0.354	0.426	0.521	0.592	0.661	1.860
3613 Indian Ck at CNR Tracks	1.6776	1.310	2.290	3.480	4.310	5.390	6.170	6.950	14.400

NOTE: * Storage/outflow table exceeded Event File: region.dat
Channel rating curve exceeded .WAT File: exist9.wat

Table 14

WATER BALANCE SUMMARY FOR WATERSHED
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Scenario File: wbex2.dat (Existing Conditions)
 Period: 1950/11/01 to 2013/10/31

Number	Location	Drainage Area (km ²)	Precip	Water Balance Quantities (in mm)				Total Flow
				ET/SUB	Runoff	Infiltration (Baseflow)	Losses	
3354	GS-3 TB Trib at Hwy 403	0.499	873.8	522.0	209.0	141.3	1.4	350.4
1355	GS-3 TB4-2 at Hwy 403	0.104	873.8	490.0	243.9	139.0	0.9	382.9
1356	GS-3 TB4-3 at Hwy 403 (G6)	0.110	873.8	490.6	274.9	107.6	0.6	382.5
4323	Sum East & West Tributary.	0.345	873.8	490.4	254.2	122.6	6.6	376.8
4355	GS-3 TB Tributary	0.844	873.8	509.1	227.5	133.6	3.6	361.1
3508	Falcon Ck d/s Hwy 403	2.537	873.8	512.3	177.1	127.8	56.5	304.9
3591	Falcon Ck - Gauge 4	2.566	873.8	512.1	177.6	128.1	55.9	305.7
3592	Falcon Ck - Gauge 5	2.614	873.8	511.9	178.5	128.5	54.9	307.0
3593	Falcon Ck at CNR Tracks	2.694	873.8	511.4	179.8	129.2	53.3	309.1
3606	Indian Ck West at 403	0.948	873.8	508.4	265.5	97.7	2.1	363.3
3611	Indian Ck West at Gauge 2	0.964	873.8	507.3	267.5	96.8	2.2	364.3
1607	Indian Ck East at 403	0.307	873.8	440.0	333.5	98.8	1.5	432.3
3610	Indian Ck East at Gauge 1	0.313	873.8	440.0	334.4	97.7	1.7	432.1
4611	Indian Ck Sum East & West	1.276	873.8	490.9	283.9	96.9	2.1	380.9
3612	Indian Ck at Gauge 3	1.370	873.8	487.5	291.1	93.1	2.1	384.3
3613	Indian Ck at CNR Tracks	1.678	873.8	479.0	309.4	83.4	2.0	392.9

Table 15

EXTREME FLOW AND DURATION SUMMARY
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Scenario File: wbex2.dat (Existing conditions)
 Period: 1950/11/01 to 2013/10/31

Number	Location	Drainage Area (km ²)	Mean Annual Flow	Return Period Flows (in Years)						Flow-Duration (% Time)		
				High Flows (Max Inst)			Low Flows (7 Day)			20%	50%	80%
				2	20	100	2	20	100			
3354	GS-3 TB Trib at Hwy 403	0.499	0.006	0.540	1.210	1.660	0.000	0.000	0.000	0.010	0.003	0.001
1355	GS-3 TB4-2 at Hwy 403	0.104	0.001	0.110	0.270	0.380	0.000	0.000	0.000	0.003	0.001	0.000
1356	GS-3 TB4-3 at Hwy 403 (G6)	0.110	0.001	0.120	0.270	0.370	0.000	0.000	0.000	0.003	0.001	0.000
4323	Sum East & West Tributary.	0.345	0.004	0.350	0.790	1.110	0.000	0.000	0.000	0.010	0.002	0.001
4355	GS-3 TB Tributary	0.844	0.010	0.870	2.000	2.780	0.000	0.000	0.000	0.020	0.006	0.002
3508	Falcon Ck d/s Hwy 403	2.537	0.025	1.420	3.880	6.040	0.000	0.000	0.000	0.052	0.017	0.006
3591	Falcon Ck - Gauge 4	2.566	0.025	1.430	3.900	6.070	0.000	0.000	0.000	0.053	0.017	0.006
3592	Falcon Ck - Gauge 5	2.614	0.025	1.440	3.940	6.150	0.000	0.000	0.000	0.054	0.017	0.006
3593	Falcon Ck at CNR Tracks	2.694	0.026	1.500	4.100	6.420	0.000	0.000	0.000	0.056	0.018	0.006
3606	Indian Ck West at 403	0.948	0.011	1.360	2.820	3.720	0.000	0.000	0.000	0.018	0.005	0.001
3611	Indian Ck West at Gauge 2	0.964	0.011	1.380	2.860	3.760	0.000	0.000	0.000	0.019	0.005	0.001
1607	Indian Ck East at 403	0.307	0.004	0.400	0.880	1.200	0.000	0.000	0.000	0.010	0.002	0.001
3610	Indian Ck East at Gauge 1	0.313	0.004	0.410	0.880	1.200	0.000	0.000	0.000	0.010	0.002	0.001
4611	Indian Ck Sum East & West	1.276	0.015	1.790	3.720	4.920	0.000	0.000	0.000	0.029	0.007	0.002
3612	Indian Ck at Gauge 3	1.370	0.017	1.880	3.900	5.160	0.000	0.000	0.000	0.033	0.007	0.002
3613	Indian Ck at CNR Tracks	1.678	0.021	2.100	4.370	5.790	0.000	0.000	0.000	0.044	0.008	0.003

Note: All flows in m³/s

Table 16

Index Flood Comparisons for the 1200 King Road Area											
Moin & Shaw Index (1985, 1986) - Region 7 (Average)											
Water Course	Model Hyd No	Drainage Area (ha)	Return Period Peak Flows (in m³/s)							Regional Storm	Regional Factor
			2	5	10	20	25	50	100		
Grindstone	3354	49.91	0.70	0.92	1.10	1.27	1.33	1.50	1.68	7.56	
	4355	84.41	1.00	1.33	1.59	1.83	1.92	2.16	2.42	10.89	
Falcon Creek	3508	253.68	2.16	2.85	3.41	3.93	4.13	4.64	5.21	23.43	
	3593	269.35	2.25	2.97	3.56	4.10	4.30	4.84	5.43	24.42	
Indian Creek	3606	94.85	1.09	1.44	1.72	1.98	2.08	2.34	2.62	11.81	
	1607	30.73	0.50	0.66	0.79	0.90	0.95	1.07	1.20	5.39	
	4611	127.62	1.34	1.77	2.12	2.44	2.56	2.88	3.23	14.52	
	3613	167.75	1.62	2.14	2.56	2.95	3.09	3.48	3.90	17.57	
	QX/Q2	Ratios	1.00	1.32	1.58	1.82	1.91	2.15	2.41	10.85	4.50
Cumming Cockburn Ltd (CCL) (2000) - Region 1											
Water Course	Model Hyd No	Drainage Area (ha)	Return Period Peak Flows (in m³/s)							Regional Storm	Regional Factor
			2	5	10	20	25	50	100		
Grindstone	3354	49.91	0.44	0.65	0.78	0.90	0.95	1.06	1.19	5.33	
	4355	84.41	0.66	0.97	1.17	1.35	1.42	1.59	1.77	7.97	
Falcon Creek	3508	253.68	1.54	2.26	2.71	3.14	3.30	3.69	4.11	18.50	
	3593	269.35	1.62	2.36	2.84	3.29	3.45	3.87	4.30	19.36	
Indian Creek	3606	94.85	0.73	1.06	1.28	1.48	1.55	1.74	1.94	8.72	
	1607	30.73	0.31	0.45	0.54	0.62	0.66	0.73	0.82	3.68	
	4611	127.62	0.91	1.34	1.60	1.86	1.95	2.18	2.43	10.94	
	3613	167.75	1.12	1.65	1.98	2.29	2.40	2.69	3.00	13.48	
	QX/Q2	Ratios	1.000	1.464	1.757	2.034	2.136	2.393	2.664	11.988	4.50

Table 17

Peak flow comparisons for the 1200 King Road Area from event and continuous modelling											
Model Generated, 64 year Simulation plus frequency analysis											
Water Course	Model Hyd No	Drainage Area (ha)	Return Period Peak Flows (in m ³ /s)							Regional Storm	Qreg/Q100 Ratio
			2	5	10	20	25	50	100		
Grindstone	3354	49.91	0.54	0.83	1.02	1.21	1.27	1.46	1.66	4.600	2.771
	4355	84.41	0.87	1.34	1.67	2.00	2.10	2.44	2.78	7.660	2.755
Falcon Creek	3508	253.68	1.42	2.35	3.08	3.88	4.16	5.06	6.04	19.500	3.228
	3593	269.35	1.50	2.46	3.25	4.10	4.39	5.36	6.42	20.500	3.193
Indian Creek	3606	94.85	1.36	2.00	2.42	2.82	2.95	3.33	3.72	9.040	2.430
	1607	30.73	0.40	0.60	0.74	0.88	0.92	1.06	1.20	2.740	2.283
	4611	127.62	1.79	2.64	3.20	3.72	3.89	4.41	4.92	12.000	2.439
	3613	167.75	2.10	3.09	3.75	4.37	4.57	5.18	5.79	14.400	2.487
											2.698
Model Generated using Chicago 4 hour Storm, return interval rainfall volumes, plus Regional Storm											
Water Course	Model Hyd No	Drainage Area (ha)	Return Period Peak Flows (in m ³ /s)							Regional Storm	Qreg/Q100 Ratio
			2	5	10	20	25	50	100		
Grindstone	3354	49.91	0.594	0.916	1.160		1.550	1.850	2.140	4.600	2.150
	4355	84.41	0.919	1.380	1.740		2.350	2.820	3.270	7.660	2.343
Falcon Creek	3508	253.68	1.590	2.240	2.810		3.910	4.770	5.530	19.500	3.526
	3593	269.35	1.710	2.390	3.000		4.160	5.070	5.880	20.500	3.486
Indian Creek	3606	94.85	1.450	2.270	2.840		3.570	4.100	4.630	9.040	1.952
	1607	30.73	0.441	0.652	0.801		1.000	1.140	1.290	2.740	2.124
	4611	127.62	1.970	3.030	3.760		4.720	5.420	6.110	12.000	1.964
	3613	167.75	2.290	3.480	4.310		5.390	6.170	6.950	14.400	2.072
											2.452
	4 hour Rain	Volume (mm)	32.4	41.7	48.0		56.1	62.0	67.8	285.0	4.206

Table 18 Falcon Creek flood flow comparison between Valdor, SWSS and WB/KR studies

<i>Valdor Node</i>	<i>Valdor Drainage Area (ha)</i>	<i>Valdor 100 year Storm Flow (m³/s)</i>	<i>Valdor Regional Storm Flow (m³/s)</i>	<i>SWSS and WB/KR Node</i>	<i>SWSS Drainage Area (ha)</i>	<i>SWSS 100 year Storm Flow (m³/s)</i>	<i>SWSS 100 Year Flow (Cont.)* (m³/s)</i>	<i>SWSS Regional Storm Flow (m³/s)</i>	<i>WB/KR Drainage Area (ha)</i>	<i>WB/KR 100 year Storm Flow (m³/s)</i>	<i>WB/KR 100 Year Flow (Cont.)* (m³/s)</i>	<i>WB/KR Regional Storm Flow (m³/s)</i>
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
n/a				3512	63.1	1.85	1.95	5.59	63.8	1.39	1.19	5.40
n/a				3750	89.8	2.50	2.74	7.76	90.6	2.34	1.62	7.56
100	107.0	2.23	6.20	3501	109.5	2.66	3.48	9.43	110.3	2.60	2.24	9.11
802	174.1	8.94	13.1	3525	172.3	4.62	5.27	14.4	173.1	4.49	3.99	14.1
808	226.6	11.6	18.5	3507	222.7	5.71	6.67	18.2	223.5	5.53	5.18	17.5
909	255.6	13.9	21.5	2509	252.9	6.41	7.32	20.3	n/a			
809	291.3	14.1	23.8	3509	283.6	7.36	8.22	22.5	284.4	6.87	6.80	21.4
811	319.8	15.7	26.2	3511	322.1	9.21	8.74	26.1	322.9	8.00	7.37	23.9
815	379.1	19.0	32.6	n/a					n/a			

Notes: SWSS = South Waterdown Subwatersheds Study (Ecoplans, 2005, 2007 and 2009)

WB/KR=Waterdown Bay & 1200 King Road (2014)

SCS Type II 24 hour storm pattern applied for results in Columns [3], [7] and [10].

* Three parameter lognormal distributed used in the SSFA.

Table 19 Indian Creek flood flow comparison between AMEC and present study

<i>Present Study WB/KR Node</i>	<i>Drainage Area (ha)</i>	<i>100 Year Chicago 4 h (m³/s)</i>	<i>100 Year SCS 24 h (m³/s)</i>	<i>Regional Storm Flow (m³/s)</i>	<i>AMEC Node</i>	<i>Drainage Area (ha)</i>	<i>100 Year Chicago 3 h (m³/s)</i>	<i>100 Year SCS 24 h (m³/s)</i>	<i>Regional Storm Flow (m³/s)</i>
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
3606	94.9	4.63	5.45	9.04	504	92.8	2.06	3.76	9.95
3611	96.4	4.77	5.60	9.21	505	97.2	2.11	3.8	10.4
1607	30.7	1.29	1.53	2.74	103	30.7	2.17	2.08	3.39
3610	31.3	1.34	1.55	2.80	503	32.1	1.14	2.12	3.52
4611	127.6	6.11	7.15	12.0	506	129.2	3.12	5.62	13.9
3613	167.8	6.95	8.07	14.4	509	165.1	3.85	6.79	17.1

Notes:

Table 20

Pond 1: Post Development Impervious Area Computations				
		Total Area	Runoff	Impervious Area
Description	Contributing Area	(ha)	Coefficient, C	(ha)
Hydro Land	EXT1	2.05	0.30	0.615
Pond	SWMP1	0.9	0.95	0.855
Development Area	C1, C2	5.59	0.90	5.031
	TOTAL AREAS	8.54		6.50
Subcatchment 1621	Percent Impervious		76%	
Pond 2: Post Development Impervious Area Computations				
		Total Area	Runoff	Impervious Area
Description	Contributing Area	(ha)	Coefficient, C	(ha)
Off Lot	EXT2	0.05	0.30	0.015
	EXT4	0.12	0.30	0.036
	EXT5	0.02	0.30	0.006
Pond	SWMP2	2.07	0.95	1.9665
Development Area	C3	18.3	0.90	16.47
	TOTAL AREAS	20.56		18.49
Subcatchment 1622	Percent Impervious		90%	

Table 21

Pond 3: Post Development Impervious Area Computations				
		Total Area	Runoff	Impervious Area
Description	Contributing Area	(ha)	Coefficient, C	(ha)
Development Area	C5, C6, EXT6, (Includes SWMP3)	2.57	0.90	2.313
	TOTAL AREAS	2.57		2.31
Subcatchment 1595	Percent Impervious		90%	
Pond 4: Post Development Impervious Area Computations				
		Total Area	Runoff	Impervious Area
Description	Contributing Area	(ha)	Coefficient, C	(ha)
Development Area	F5 (includes SWMP4)	4.70	0.90	4.23
	TOTAL AREAS	4.70		4.23
Subcatchment 1596	Percent Impervious		90%	

Table 22 Subcatchment characteristics for Post-development conditions at 1200 King Road Site

<i>Subcat No.</i>	<i>Area (ha)</i>	<i>L (m)</i>	<i>W (m)</i>	<i>Imp RU 1</i>	<i>RU 2</i>	<i>RU 3</i>	<i>RU 4</i>	<i>RU 5</i>	<i>RU 6</i>	<i>RU 7</i>	<i>RU 8</i>	<i>RU 9</i>	<i>FTB</i>
1354	16.11	351	356	24	0	0	0	35	5	0	36	0	2.0
1355	10.41	856	1220	24	0	0	0	35	5	0	36	0	2.0
1356	11.01	967	114	24	0	0	0	35	5	0	36	0	2.0
1321	2.7	201	134	30	0	0	14	0	0	0	56	0	2.0
1322	1.66	147	98	30	0	0	14	0	0	0	56	0	2.0
1323	8.72	436	291	30	0	0	14	0	0	0	56	0	2.0
1312	1.28	150	320	70	0	0	0	0	0	0	30	0	2.0
1507	13.8	616	184	15	0	0	0	0	0	0	85	0	2.0
1508	30.2	588	268	17	0	0	0	10	10	0	63	0	2.0
1591	1.20	60	40	30	0	0	0	0	0	0	70	0	2.0
1592	3.21	155	104	30	0	0	0	0	0	0	70	0	2.0
1593	3.14	233	53	30	0	0	0	0	0	0	70	0	2.0
1595	2.57	100	25	76.5	0	0	23.5	0	0	0	0	0	1.2
1596	4.70	100	25	76.5	0	0	23.5	0	0	0	0	0	1.2
1509	15.01	588	268	17	0	0	0	10	10	0	63	0	2.0
1601	24.26	1074	227	0	0	43	0	57	0	0	0	0	2.0
1602	38.25	1360	281	13	0	13	0	74	0	0	0	0	2.0
1605	27.87	1564	178	0	0	30	0	70	0	0	0	0	2.0
1606	4.47	393	114	36	0	0	0	64	0	0	0	0	2.0
1607	30.73	1724	178	30	0	0	0	65	0	0	5	0	2.0
1610	0.44	55	37	30	0	0	65	0	0	0	5	0	2.0
1611	1.34	172	115	30	0	0	65	0	0	0	5	0	2.0
1612	1.36	68	46	30	0	0	65	0	0	0	5	0	2.0
1613	1.75	39	26	30	0	0	65	0	0	0	5	0	2.0
1615	9.04	200	133	30	0	0	65	0	0	0	5	0	2.0
1621	8.54	100	25	64.7	0	0	35.3	0	0	0	0	0	1.2
1622	20.56	100	25	76.5	0	0	23.5	0	0	0	0	0	1.2

Table 23 Unit area flood flows for post-development SWM pond release rates

A - Existing condition unit area flood flows for selected subcatchments in Falcon and Indian Creek

Return Period (Years)	Falcon Creek 1592 (m³/s/km²)	Falcon Creek 1593 (m³/s/km²)	Indian Creek 1612 (m³/s/km²)	Indian Creek 1613 (m³/s/km²)
2	1.48	1.19	1.13	0.815
5	1.92	1.54	1.61	1.15
10	2.42	1.95	1.93	1.38
25	3.73	2.99	2.36	1.69
50	4.70	3.74	2.68	1.92
100	5.64	4.49	2.99	2.15
Regional	10.3	9.40	7.28	6.04

Note: Peak flows taken from Table 13

B - Existing condition return period flood outflows for SWM Ponds 1 & 2 in Indian Creek, and Ponds 3 & 4 in Falcon Creek

Return Period (Years)	Falcon Creek 1595 Pond 3 (m³/s)	Falcon Creek 1596 Pond 4 (m³/s)	Indian Creek 1621 Pond 1 (m³/s)	Indian Creek 1622 Pond 2 (m³/s)
4 h 25 mm Storm	0.004	0.006	0.020	0.129
2	0.0381	0.0558	0.0969	0.168
5	0.0494	0.0723	0.137	0.236
10	0.0622	0.0917	0.165	0.284
25	0.0960	0.140	0.201	0.348
50	0.121	0.176	0.229	0.395
100	0.145	0.211	0.255	0.441
Regional	0.265	0.442	0.622	1.24
Drainage Area (ha)	2.57	4.70	8.54	20.56

Table 24 Return period and Regional Storm SWM Pond Volumes for Ponds 1, 2, 3 and 4

Return Period (Years)	Falcon Creek 1595 Pond 3 (m³)	Falcon Creek 1596 Pond 4 (m³)	Indian Creek 1621 Pond 1 (m³)	Indian Creek 1622 Pond 2 (m³)
Permanent Pool	643	1058	1664	4766
Extended Detention	1284	2116	3000	7451
2	1284	2124	3024	9063
5	1334	2327	3729	10461
10	1408	2499	4083	11399
25	1499	2690	4532	12584
50	1558	2829	4860	13452
100	1621	2950	5182	14300
Regional	2149	4322	9660	28934
Drainage Area (ha)	2.57	4.70	8.54	20.56

Table 25 Summary of Flood Flow Estimates: Return Period Events & Regional Storm for 1200 King Road Post Development with Controls (Chicago storms)

No. Point of Interest	Area km ²	Peak Flows (m ³ /s)							
		25 mm	1:2 yr	1:5	1:10	1:25	1:50	1:100	Reg 1.00
3354 Main Trib GS-3 at Hwy 403	0.4991	0.325	0.594	0.916	1.160	1.550	1.850	2.140	4.600
1355 West Trib at Hwy 403	0.1041	0.084	0.134	0.197	0.247	0.334	0.398	0.462	0.969
3321 West Trib S of Hwy 403	0.1311	0.123	0.187	0.267	0.335	0.458	0.548	0.638	1.240
1356 East Trib at Hwy 403 (G6)	0.1101	0.098	0.144	0.203	0.251	0.331	0.391	0.449	0.973
8356 Divert flows to West Trib	0.1101	0.039	0.057	0.081	0.100	0.132	0.156	0.180	0.389
4321 First E/W summation	0.1311	0.158	0.240	0.343	0.429	0.582	0.694	0.802	1.630
3322 Inflow to Online Pond G6	0.1267	0.084	0.122	0.169	0.208	0.278	0.332	0.384	0.750
5322 Outflow from Online Pond G7	0.1267	0.000	0.000	0.000	0.000	0.050	0.091	0.130	0.703
4323 Sum East & West Tributary.	0.3450	0.235	0.346	0.484	0.605	0.829	0.994	1.150	3.070
3356 GS-3 at CNR tracks	1.4459	0.887	1.470	2.180	2.770	3.830	4.620	5.400	12.900
3507 Falcon Creek at Hwy 403	2.2348	0.981	1.450	2.030	2.540	3.500	4.250	4.930	17.500
3508 Falcon Ck d/s Hwy 403	2.5368	1.070	1.590	2.230	2.810	3.900	4.750	5.520	19.400
3591 Falcon Ck - Gauge 4	2.5488	1.080	1.590	2.240	2.820	3.910	4.760	5.530	19.500
3592 Falcon Ck - Gauge 5	2.5809	1.100	1.620	2.270	2.850	3.950	4.810	5.580	19.600
1595 Outflows SWM Pond 3	0.0257	0.004	0.006	0.049	0.062	0.096	0.121	0.145	0.265
3595 Falcon Ck Pond 3 Additions	2.6066	1.100	1.620	2.320	2.910	4.030	4.900	5.690	19.800
1596 Outflows SWM Pond 4	0.0470	0.006	0.053	0.072	0.092	0.140	0.176	0.211	0.442
3596 Falcon Ck Pond 4 Additions	2.6536	1.110	1.650	2.390	3.000	4.170	5.060	5.870	20.200
3593 Falcon Ck at CNR Tracks	2.6850	1.120	1.670	2.410	3.030	4.210	5.100	5.920	20.400
3606 Indian Ck West at 403	0.9485	0.777	1.450	2.270	2.840	3.570	4.100	4.630	9.040
3611 Indian Ck West at Gauge 2	0.9619	0.811	1.500	2.340	2.920	3.670	4.220	4.760	9.190
1607 Indian Ck East at 403	0.3073	0.266	0.441	0.652	0.801	1.000	1.140	1.290	2.740
3610 Indian Ck East at Gauge 1	0.3117	0.281	0.462	0.679	0.832	1.040	1.180	1.330	2.790
4611 Indian Ck Sum East & West	1.2736	1.090	1.960	3.020	3.750	4.700	5.400	6.090	12.000
3612 Indian Ck at Gauge 3	1.2872	1.120	2.000	3.080	3.820	4.800	5.510	6.210	12.100
3615 Indian Ck u/s Pond 1 outlet	1.3047	1.160	2.060	3.160	3.920	4.920	5.640	6.360	12.200
1621 Outflows SWM Pond 1	0.0854	0.026	0.103	0.141	0.168	0.204	0.232	0.258	0.626
3621 Indian Ck Pond 1 Additions	1.3901	1.180	2.120	3.280	4.070	5.090	5.840	6.580	12.800
1622 Outflows SWM Pond 2	0.2056	0.138	0.167	0.234	0.282	0.346	0.393	0.439	1.230
3622 Indian Ck Pond 2 Additions	1.5957	1.300	2.270	3.470	4.290	5.370	6.150	6.930	14.000
3613 Indian Ck at CNR Tracks	1.6861	1.430	2.450	3.730	4.610	5.750	6.590	7.420	14.800

NOTE: * Storage/outflow table exceeded
 # Channel rating curve exceeded

Event File: region.dat
 .WAT File: post2wc.wat

Table 26

WATER BALANCE SUMMARY FOR WATERSHED
 =====

Scenario File: wbfut2.dat (Post-Development)
 Period: 1950/11/01 to 2013/10/31

Number	Location	Drainage Area (km ²)	Precip	Water Balance Quantities (in mm)				Total Flow
				ET/SUB	Runoff	Infiltration (Baseflow)	Losses	
3508	Falcon Ck d/s Hwy 403	2.537	873.8	512.3	177.2	127.8	56.5	305.0
3591	Falcon Ck - Gauge 4	2.549	873.8	512.2	177.4	127.9	56.3	305.3
3592	Falcon Ck - Gauge 5	2.581	873.8	512.0	177.9	128.2	55.6	306.1
3595	Falcon Ck Pond 3 Additions	2.607	873.8	509.6	181.1	127.9	55.3	308.9
3596	Falcon Ck Pond 4 Additions	2.654	873.8	505.2	186.5	127.4	54.6	314.0
3593	Falcon Ck at CNR Tracks	2.685	873.8	505.1	187.0	127.7	54.0	314.7
3606	Indian Ck West at 403	0.948	873.8	508.4	265.5	97.7	2.1	363.3
3611	Indian Ck West at Gauge 2	0.962	873.8	507.4	267.2	96.9	2.2	364.2
1607	Indian Ck East at 403	0.307	873.8	440.0	333.5	98.8	1.5	432.3
3610	Indian Ck East at Gauge 1	0.312	873.8	440.0	334.2	97.9	1.7	432.1
4611	Indian Ck Sum East & West	1.274	873.8	491.0	283.7	97.1	2.1	380.8
3612	Indian Ck at Gauge 3	1.287	873.8	490.4	284.7	96.5	2.1	381.3
3615	Indian Ck u/s Pond 1 outlet	1.305	873.8	489.8	286.2	95.7	2.1	382.0
3621	Indian Ck Pond 1 Additions	1.390	873.8	478.5	297.4	94.6	3.2	392.1
3622	Indian Ck Pond 2 Additions	1.596	873.8	450.7	329.0	88.7	5.3	417.9
3613	Indian Ck at CNR Tracks	1.686	873.8	450.2	298.1	120.4	5.1	418.7

Table 27

EXTREME FLOW AND DURATION SUMMARY
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Scenario File: wbfut2.dat (Post-Development)
 Period: 1950/11/01 to 2013/10/31

Number	Location	Drainage Area (km^2)	Mean Annual Flow	Return Period Flows (in Years)						Flow-Duration (% Time)		
				High Flows (Max Inst)			Low Flows (7 Day)			20%	50%	80%
				2	20	100	2	20	100			
3508	Falcon Ck d/s Hwy 403	2.537	0.025	1.420	3.890	6.040	0.000	0.000	0.000	0.052	0.017	0.006
3591	Falcon Ck - Gauge 4	2.549	0.025	1.420	3.860	6.000	0.000	0.000	0.000	0.052	0.017	0.006
3592	Falcon Ck - Gauge 5	2.581	0.025	1.420	3.860	6.000	0.000	0.000	0.000	0.053	0.017	0.006
3595	Falcon Ck Pond 3 Additions	2.607	0.026	1.450	3.930	6.080	0.000	0.000	0.000	0.055	0.017	0.006
3596	Falcon Ck Pond 4 Additions	2.654	0.026	1.500	4.060	6.220	0.000	0.000	0.000	0.058	0.017	0.006
3593	Falcon Ck at CNR Tracks	2.685	0.027	1.510	4.090	6.290	0.000	0.000	0.000	0.059	0.018	0.006
3606	Indian Ck West at 403	0.948	0.011	1.360	2.820	3.720	0.000	0.000	0.000	0.018	0.005	0.001
3611	Indian Ck West at Gauge 2	0.962	0.011	1.380	2.850	3.750	0.000	0.000	0.000	0.019	0.005	0.001
1607	Indian Ck East at 403	0.307	0.004	0.400	0.880	1.200	0.000	0.000	0.000	0.010	0.002	0.001
3610	Indian Ck East at Gauge 1	0.312	0.004	0.410	0.880	1.200	0.000	0.000	0.000	0.010	0.002	0.001
4611	Indian Ck Sum East & West	1.274	0.015	1.790	3.720	4.920	0.000	0.000	0.000	0.029	0.007	0.002
3612	Indian Ck at Gauge 3	1.287	0.016	1.790	3.710	4.900	0.000	0.000	0.000	0.030	0.007	0.002
3615	Indian Ck u/s Pond 1 outlet	1.305	0.016	1.800	3.700	4.880	0.000	0.000	0.000	0.030	0.007	0.002
3621	Indian Ck Pond 1 Additions	1.390	0.017	1.880	3.940	5.220	0.000	0.000	0.000	0.035	0.008	0.002
3622	Indian Ck Pond 2 Additions	1.596	0.021	2.040	4.320	5.790	0.000	0.000	0.000	0.049	0.008	0.003
3613	Indian Ck at CNR Tracks	1.686	0.022	2.170	4.600	6.170	0.000	0.000	0.000	0.052	0.008	0.003

Table 28

STREAM DISCHARGE EXCEEDANCE SUMMARY FOR 3593

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Location: Falcon Ck at CNR Tracks (Existing Conditions)
 Period: 1950/11/ 1 to 2013/10/31

Month	Mean Flow (m ³ /s)	Flow Extremes		Total Hours	Threshold 1: Flow: 1.55 (m ³ /s)				Threshold 2: Flow: 13.35 (m ³ /s)			
		Highest (m ³ /s)	Lowest (m ³ /s)		Hours	PCT	Pulses	Duration	Hours	PCT	Pulses	Duration
JAN	0.02327	3.59800	0.00000	46872.	18.	0.0	4.	4.5	0.	0.0	0.	0.0
FEB	0.02669	2.62850	0.00000	42720.	23.	0.1	6.	3.8	0.	0.0	0.	0.0
MAR	0.04310	4.84100	0.00000	46872.	57.	0.1	20.	2.8	0.	0.0	0.	0.0
APR	0.0451	2.2272	0.0032	45360.	8.	0.0	4.	2.0	0.	0.0	0.	0.0
MAY	0.0362	2.5935	0.0012	46872.	18.	0.0	6.	3.0	0.	0.0	0.	0.0
JUN	0.02781	1.61380	0.00049	45360.	2.	0.0	1.	2.0	0.	0.0	0.	0.0
JUL	0.02137	2.35240	0.00017	46872.	5.	0.0	2.	2.5	0.	0.0	0.	0.0
AUG	0.01673	2.54850	0.00004	46872.	16.	0.0	5.	3.2	0.	0.0	0.	0.0
SEP	0.01569	2.35410	0.00000	45360.	4.	0.0	1.	4.0	0.	0.0	0.	0.0
OCT	0.01653	5.34100	0.00000	46872.	15.	0.0	3.	5.0	0.	0.0	0.	0.0
NOV	0.02240	2.73710	0.00000	45360.	10.	0.0	4.	2.5	0.	0.0	0.	0.0
DEC	0.02251	2.17880	0.00000	46872.	3.	0.0	1.	3.0	0.	0.0	0.	0.0
Annual	0.02644	5.34100	0.00000	552264.	179.	0.0	57.	3.1	0.	0.0	0.	0.0

Table 29

STREAM DISCHARGE EXCEEDANCE SUMMARY FOR 3593

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Location: Falcon Ck at CNR Tracks (Existing Conditions)
 Period: 1950/11/ 1 to 2013/10/31

Month	Total Hours	Critical Shear Stress (Pa)	Exceedances Hours	PCT	Erosion Impulse (Stress X Time) (Pa-days)
JAN	46872.	45.710	13.	0.0	5.073
FEB	42720.	45.710	11.	0.0	1.668
MAR	46872.	45.710	33.	0.1	15.811
APR	45360.	45.710	2.	0.0	0.214
MAY	46872.	45.710	11.	0.0	2.307
JUN	45360.	45.710	0.	0.0	0.000
JUL	46872.	45.710	2.	0.0	0.391
AUG	46872.	45.710	8.	0.0	1.546
SEP	45360.	45.710	3.	0.0	0.526
OCT	46872.	45.710	10.	0.0	7.817
NOV	45360.	45.710	4.	0.0	0.889
DEC	46872.	45.710	2.	0.0	0.228
Total	552264.	45.710	99.	0.0	36.470

Table 30

STREAM DISCHARGE EXCEEDANCE SUMMARY FOR 3593

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Location: Falcon Ck at CNR Tracks (Existing Conditions)
 Period: 1950/11/ 1 to 2013/10/31

Month	Total Hours	Critical Velocity (m/s)	Exceedances Hours	PCT	Erosion Index (Vel. X Time) (m/s X day)
JAN	46872.	1.170	67.	0.1	0.579
FEB	42720.	1.170	87.	0.2	0.591
MAR	46872.	1.170	181.	0.4	1.734
APR	45360.	1.170	60.	0.1	0.305
MAY	46872.	1.170	47.	0.1	0.416
JUN	45360.	1.170	17.	0.0	0.084
JUL	46872.	1.170	42.	0.1	0.197
AUG	46872.	1.170	43.	0.1	0.389
SEP	45360.	1.170	18.	0.0	0.133
OCT	46872.	1.170	32.	0.1	0.451
NOV	45360.	1.170	53.	0.1	0.330
DEC	46872.	1.170	24.	0.1	0.137
Total	552264.	1.170	671.	0.1	5.346

Table 31

STREAM DISCHARGE EXCEEDANCE SUMMARY FOR 3593
 =====

Location: Falcon Ck at CNR Tracks (Existing Conditions)
 Period: 1950/11/ 1 to 2013/10/31

Month	Total Hours	Critical Velocity (m/s)	Exceedances Hours	PCT	Erosion Index (Vel. X Time) (m/s X day)
JAN	46872.	1.440	17.	0.0	0.170
FEB	42720.	1.440	23.	0.1	0.108
MAR	46872.	1.440	55.	0.1	0.522
APR	45360.	1.440	7.	0.0	0.019
MAY	46872.	1.440	17.	0.0	0.111
JUN	45360.	1.440	2.	0.0	0.001
JUL	46872.	1.440	5.	0.0	0.021
AUG	46872.	1.440	16.	0.0	0.082
SEP	45360.	1.440	4.	0.0	0.026
OCT	46872.	1.440	15.	0.0	0.214
NOV	45360.	1.440	8.	0.0	0.041
DEC	46872.	1.440	3.	0.0	0.014
Total	552264.	1.440	172.	0.0	1.328

Note: Adjusted velocity

Table 32

STREAM DISCHARGE EXCEEDANCE SUMMARY FOR 3593
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Location: Falcon Ck at CNR Tracks (Existing Conditions)
 Period: 1950/11/ 1 to 2013/10/31

Month	Total Hours	Critical Shear Stress (Pa)	Exceedances Hours	PCT	Effective Work (Pa m/s X Time) (kJ/Sq m)
JAN	46872.	45.710	13.	0.0	811.706
FEB	42720.	45.710	11.	0.0	240.757
MAR	46872.	45.710	33.	0.1	2659.281
APR	45360.	45.710	2.	0.0	30.118
MAY	46872.	45.710	11.	0.0	333.694
JUN	45360.	45.710	0.	0.0	0.000
JUL	46872.	45.710	2.	0.0	55.827
AUG	46872.	45.710	8.	0.0	223.089
SEP	45360.	45.710	3.	0.0	75.330
OCT	46872.	45.710	10.	0.0	1402.707
NOV	45360.	45.710	4.	0.0	131.279
DEC	46872.	45.710	2.	0.0	31.773
Total	552264.	45.710	99.	0.0	5995.561

**Table 33 Comparison of erosion indices for pre and post-development conditions
In Falcon Creek Node 3593**

<i>Erosion Indicator</i>	<i>Existing Conditions</i>	<i>Post-Development</i>
Threshold Flow (m ³ /s)	1.55	1.55
Critical Shear Stress (Pa)	45.71 (40.88)	45.71 (40.88)
Critical Velocity 1 (m/s)	1.17	1.17
Critical Velocity 2 (m/s)	1.44	1.44
Total hours in Simulation:	552264	552264
Cross-section used:	FC-XS3 or 35.921	FC-XS3 or 35.921
Exceedance Counts (h)		
Critical/threshold flow	179	175 (-2.2%)
Critical shear stress	99	94 (-5%)
Critical velocity 1	671	651 (-3%)
Critical velocity 2	172	167 (-3%)
Erosion Indices		
Index 1 (Pa-days)	36.5	37.0 (+1.4%)
Index 2 (m/s-days) - 1	5.35	5.30 (-1%)
- 2	1.33	1.33 (0%)
Index 3 (kJ/m ²)	5996	6079 (+1.4%)

Note: