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Water Resources Group

MEMORANUM

Date: January 27, 2005
From: Tham Saravanapavan
Andrew Parker
To: Mark Voorhees, US EPA-New England
Re: Model Calibration – Vermont Stormwater Analysis

Numerous Vermont watersheds are not meeting Vermont's aquatic life standards because of storm water runoff from suburban and urban drainages. In an effort to identify appropriate targets and corresponding wasteload and load allocations that are necessary to attain applicable water quality standards, the present study involves defining hydrologic conditions of impaired and attained watersheds using relatively simple hydrologic modeling. The P8 UCM model was selected to estimate time-series flow values for small watersheds that are impaired by storm water runoff, as well as for attainment watersheds that are presently supporting aquatic life uses. Flow-duration curves will be developed using the model output for all impaired and selected attainment watersheds.

A technical memo, dated April 30, 2004, detailed the review of models and modeling recommendations. After careful consideration of project objectives and the availability of data and other resources, P8 UCM was selected for the following capabilities:

- Continuous simulation with hourly output
- Simulates snow melt
- Urban stormwater BMPs and wetland simulation
- Data needs can be filled with available information
- Requires moderate effort to set up, calibrate, and validate the model

A technical memo, dated July 16, detailed the procedures of model set up, calibration, and validation. Initial model calibration was performed using daily flow observations from selected USGS gauges. The calibration focused on evaluating the accuracy of representing watershed characteristics in model parameters, especially percent imperviousness, runoff curve number, and time of concentration. A technical memo, dated September 24, was developed to present the results of initial calibration. The results were reviewed in a study group meeting at DEC on September 29, 2004. With a specific focus on stormwater and its impacts in small watersheds, the study group decided to make use of the hourly flow data collected by the University of Vermont (UVM) during the summer 2004 for detailed calibration of model parameters. This memo presents the procedures and results of calibration using flow data collected by the University of Vermont (UVM) at six locations during the summer of 2004. It also demonstrates the application of model results in developing flow duration curves for selected impaired and attainment watersheds.

1. Calibration Data

UVM collected flow measurements at 15 minute intervals during the summer of 2004 at six locations. Table 1 presents the details about the drainage areas for UVM gauges. For comparison to P8-UCM's hourly predictions, the 15 minute flow measurements were aggregated to hourly values.

Table 1. (a) Drainage characteristics for UVM gages: land use and soil

		Total Area	Land Use (% by area)								Hydrology Group (% by area)			
	Watersheds	(Acres)	Residential	Commercial	Industrial	Transportation	Other Urban	Forest	Wetland/Water	Agri. Related	A	B	C	D
1	Johnnie	2517	5%	0%	0%	3%	0%	76%	5%	11%	2%	1%	46%	52%
2	Potash	4587	21%	10%	1%	19%	3%	10%	7%	29%	29%	10%	18%	43%
3	Indian	4476	17%	3%	0%	11%	11%	32%	7%	19%	15%	7%	17%	60%
4	Mill	10275	4%	0%	0%	4%	1%	73%	8%	10%	16%	6%	41%	37%
5	Munroe	3373	16%	2%	1%	6%	3%	26%	38%	8%	5%	11%	18%	66%
6	Patrick	4114	19%	0%	0%	6%	0%	46%	12%	17%	11%	1%	33%	55%

Table 1. (b) Drainage characteristics of UVM gages: percent imperviousness, SCS curve number, and average slope

			Percent Imperviousness		Pervious Curve Number	Average Slope
	Watersheds	Total Area (Acres)	Estimated[1]	Measured[2]		
1	Johnnie	2517	2	5*	76	14%
2	Potash	4587	22	20	69	5%
3	Indian	4476	16	8	73	7%
4	Mill	10275	3	5*	70	18%
5	Munroe	3373	9	4	77	6%
6	Patrick	4114	6	6*	74	11%

[1] Percent Imperviousness estimated using the coefficients developed by Center for Watershed Protection for VCGI Land use Data (Table 2 on page 4).
[2] Percent Imperviousness were measured by DEC.
* Measured PI is not available and the regression equation (Eq. 1 on page 5) was used to estimate.

2. Model Parameters and Estimation

Inputs to P8-UCM for hydrologic simulation include climatological data, percent imperviousness (PI), pervious curve number (PCN), and times of concentration for ground water base flow (TC-BF) and surface runoff (TC-SR). This section details the estimation of these parameters.

2.1. Climatological Data

Hourly time-series data for the Burlington International Airport, Burlington, VT station were downloaded from the National Oceanic and Atmospheric Administration (NOAA) and the National Climatic Data Center (NCDC) Unedited Local Climatological Data (ULCD) system for Oct. 2003 – Sep. 2004. The data include hourly precipitation and temperature, which are the major climate inputs for P8-UCM. As all the gauges were located within the ten-miles radius of the Burlington Airport, the same weather data was used in all UVM gauged watersheds.

2.2. Percent Imperviousness

P8-UCM estimates runoff for pervious and impervious portions of a watershed separately. To determine the pervious and impervious areas of each watershed, percent imperviousness (PI) values were used (based on land use in the watershed). PI was estimated using a previously developed relationship (CWP et al., 1999) for the Vermont Center for Geographic Information (VCGI) land use data layer. Table 2 presents the estimated vales of PI for various land use categories.

Table 2. Relationship between VCGI Land Use and Percent Imperviousness

VCGI Land Use Code	Land Use Name	Percent Impervious Cover
3	Brush/Transitional	0%
5	Water	0%
7	Barren Land	0%
11	Residential	14%
12	Commercial	80%
13	Industrial	60%
14	Transportation	41%
17	Other Urban	60%
24	Agriculture/Mixed Open	2%
41	Deciduous Forest	0%
42	Coniferous Forest	0%
43	Mixed Forest	0%
62	Non-Forested Wetland	0%
211	Row Crops	2%
212	Hay/Pasture	2%

Land use based estimation is the only means available to estimate PI for all impaired and attained watersheds at this time. It should be noted that VT DEC has measured PI on several selected watersheds using a detailed evaluation of land cover at the lot scale. These measured PIs are expected to be more accurate than that of land use based estimations, however they are not available at all locations. In order to improve the accuracy of estimating PI, a relationship between land use based PI estimation and measured PI (Figure 1) was developed and can be explained by the following equation.

Measured PI = Land use based PI (estimated) * 0.43 + 3.62 [$R^2 = 0.55$]……(Eq. 1)

This relationship is a useful tool to estimate the equivalent measure PI of watersheds, for which measured PI values are not available. VT DEC plans to expand the procedure of measuring PI for all impaired and attained watersheds. This will help to improve the representation of PI in the model.

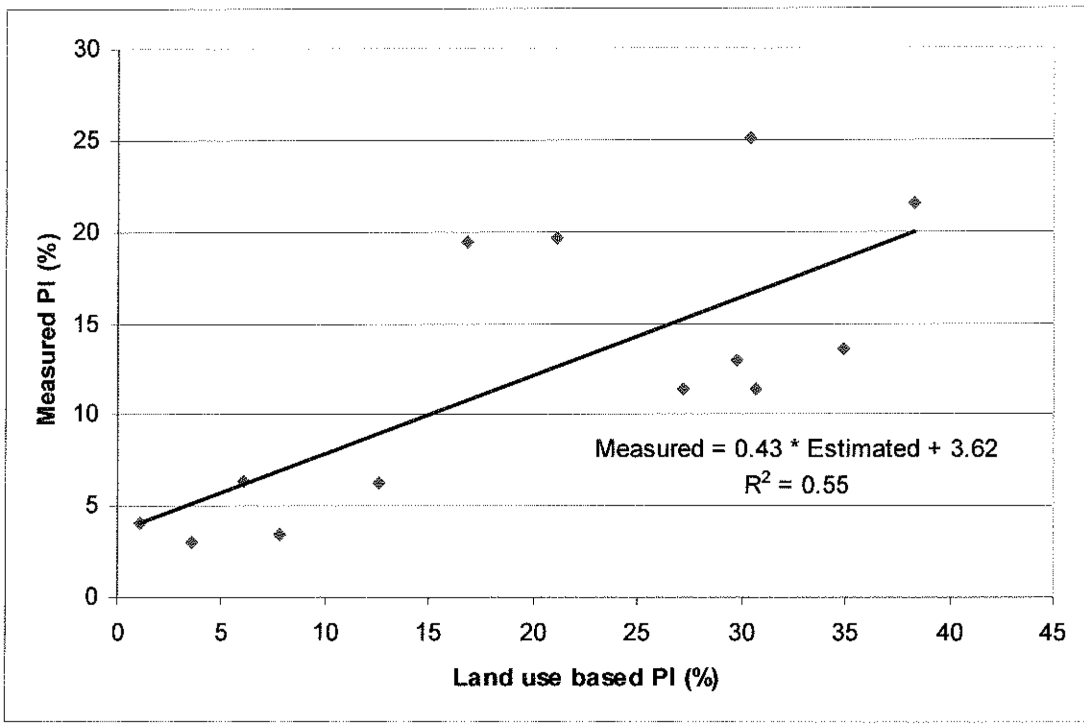

Figure 1. Relationship between measured PI (by VT DEC) and estimated PI using VCGI land use.

2.3. Pervious Curve Number

P8-UCM uses the curve number (CN) approach for hydrologic simulation of pervious areas. As such, weighted CNs for the pervious portions of each modeled watershed were estimated using VCGI land use and detailed SSURGO soils data (Natural Resources Conservation Services, United States Department of Agriculture). Table 3 presents the CNs that were used for each land use/soil group combination for each UVM watershed. Weighted CNs for the pervious portions of each UVM watershed are presented in Table 1 (b).

Table 3. CNs for Land Uses (Source: USDA, 1986)

Land Use	CN for hydrology soil group			
	A	B	C	D
Pervious portion of urban land uses (Residential, Commercial, Industrial, Transportation, etc.) – Urban Open Space in good condition	39	61	74	80
Brush/Transitional (Assuming Fair Condition)	35	56	70	77
Barren Land (Assuming Natural Desert Landscaping)	63	77	85	88
Agriculture/Mixed Open	30	58	71	78
Forest (All types in Fair Condition)	36	60	73	79
Non Forested Wetland (as per MA NRCS)	78	78	78	78
Row Crops (Assuming Contoured + Crop residue Cover in Good Condition)	64	74	81	85
Hay/Pasture (Assuming Fair Condition)	49	69	79	84

2.4. Time of Concentration

Two different times of concentration were used for this application of P8-UCM. One is for the ground water base flow (TC-BF) and the other is for the surface runoff (TC-SR). TC-BF can be defined as the time between infiltration and the time the stream is reached (and is thus different from the traditional hydrological definition for TC). TC-SR is the same as the traditional definition of hydrological TC, i.e., the time runoff takes to travel from the farthest point in the watershed to the watershed outlet.

During the meeting on September 29, 2004, the study team evaluated the flow simulations for several USGS gauged watersheds, compared the model simulations of stream flow using different TC-BF values, and recommended using 1,000 hours as an initial estimate for all watersheds since modeled stream flow following rainfall events in each of the calibration watersheds agreed reasonably well with observed stream flow data.

It was revealed during the comparison of model simulations with hourly flow observations at the UVM gauges that TC-SF was a sensitive model parameter, especially in the hourly flow estimations. Therefore, it was considered one of the calibration parameters. The detailed evaluation of TC-SR is presented in the following sections.

3. Model Calibration

Among the six UVM watersheds, Potash, Indian, and Munroe Brooks are impaired watersheds. Patrick Brook was excluded in the calibration process as it includes large water impoundments, such as lakes, ponds, and wetlands that are believed to strongly affect stream flow responses to rainfall events.

Each watershed was represented in P8-UCM using a simple framework as portrayed in Figure 2. Although P8-UCM is capable of simulating impoundments such as pond, reservoirs, wetlands, etc., the present analysis excluded the detailed representation of impoundments for two reasons. One is that the objective of the project is to develop hydrological targets for impaired watersheds in relation to attainment watersheds. This comparative exercise can eliminate the errors associated with the exclusion of impoundments if the selection of an attainment watershed for each impaired watershed is carefully conducted. The other reason for exclusion of impoundments is due to the lack of site-specific data.

Among the UVM gauges, Potash Brook was selected for detailed calibration. Potash Brook is one of the impaired watersheds with substantial urban development. Therefore evaluating the sensitivity of percent imperviousness is appropriate. Potash Brook has the least influence from water impoundments in the watershed among the UVM gauged watersheds. Thus it is a suitable watershed to evaluate the impact of other model parameters. Also, Potash Brook is in close proximity to the Burlington Airport rainfall gauge.

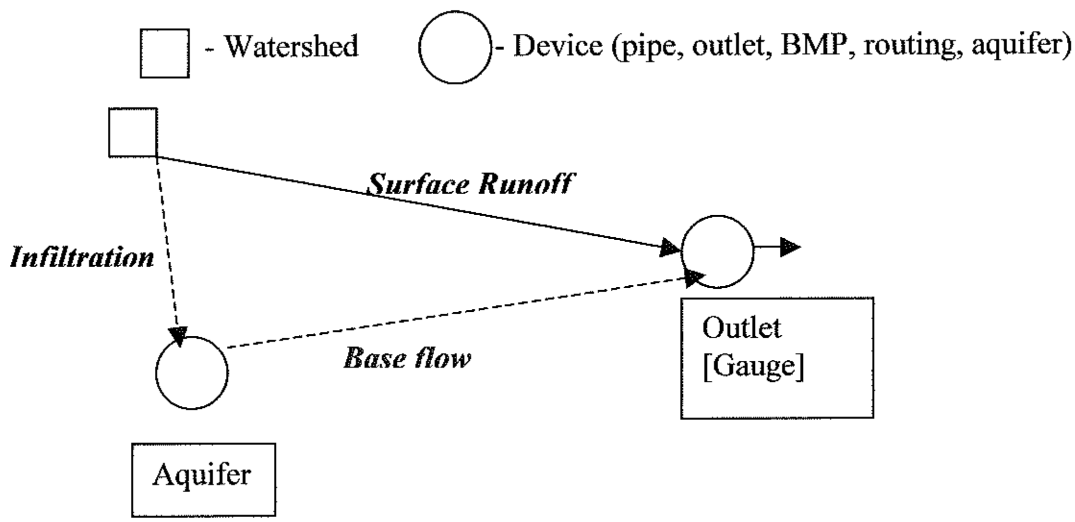

Figure 2. Sample schematic diagram for a selected gauge station

3.1. Watershed Percent Imperviousness

In the SCS CN approach (SCS, USDA, 1969) runoff starts after an initial abstraction (Ia) of surface has been completed. This abstraction consists principally of interception, surface storage, and infiltration. SCS expressed Ia = 0.2 * (1000/CN – 10); CN – Curve Number. In Potash Brook, Pervious Curve Number (PCN: Average weighted CN for the pervious portion of the watershed) is 69 and the initial abstraction is 0.9 inches. In this watershed we can assume that the runoff generated by the storms, with a rainfall amount of less than 0.9 inches, is primarily generated by the impervious portion of the watershed. Therefore, a storm of 0.75 inches between 1:00 PM – 6:00 PM on 7/1/2004 was selected to examine PI.

P8-UCM has two input parameters that specifically relate to surface runoff from impervious areas, percent imperviousness (PI) and the Imperviousness Runoff Coefficient (IC). The IC parameter is used to translate total watershed impervious area into directly connected or effective impervious area. Directly connected or effective impervious area represents the portion of watershed impervious area that drains directly to the stream. As part of the model calibration process, these parameters were evaluated to identify the most suitable values to be used in this study.The following are the values used for Potash Brook.

- Measured PI = 20
- Imperviousness runoff Coefficient (IC) = 0.76 (for a mixed residential watershed following Lincoln Creek study in Wisconsin)
- Imperviousness runoff Coefficient (IC) = 0.54 (for a residential watershed following Monroe street study in Wisconsin)

Figure 3 compares predicted hydrographs with observed during the 7/1 storm. The combination of measured PI with IC of 0.0.54 represents the condition in Potash Brook appropriately Figure 4.

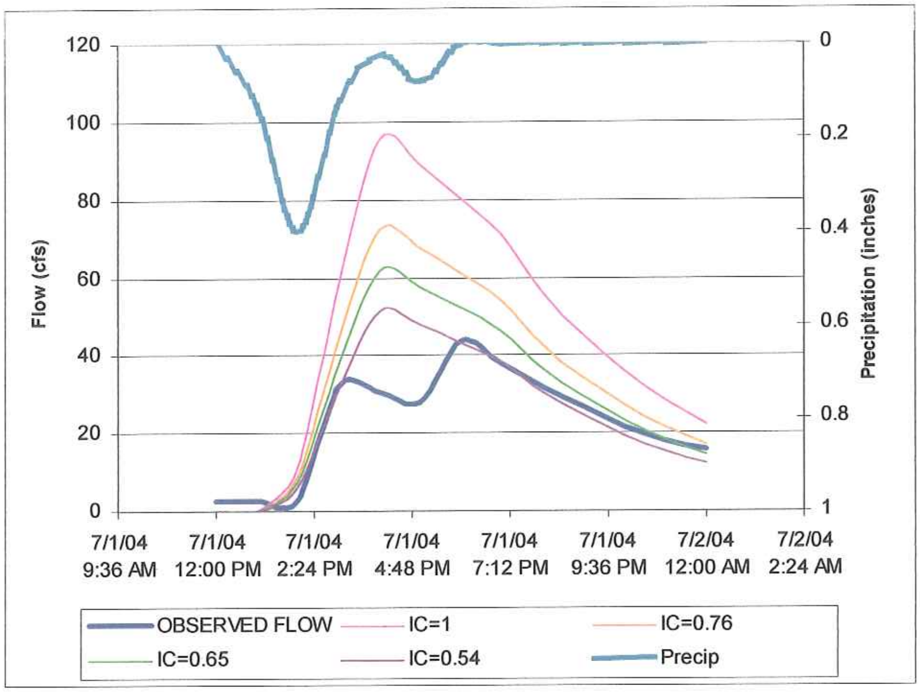

Figure 3. Precipitation and stream flow during the storm on 7/1.

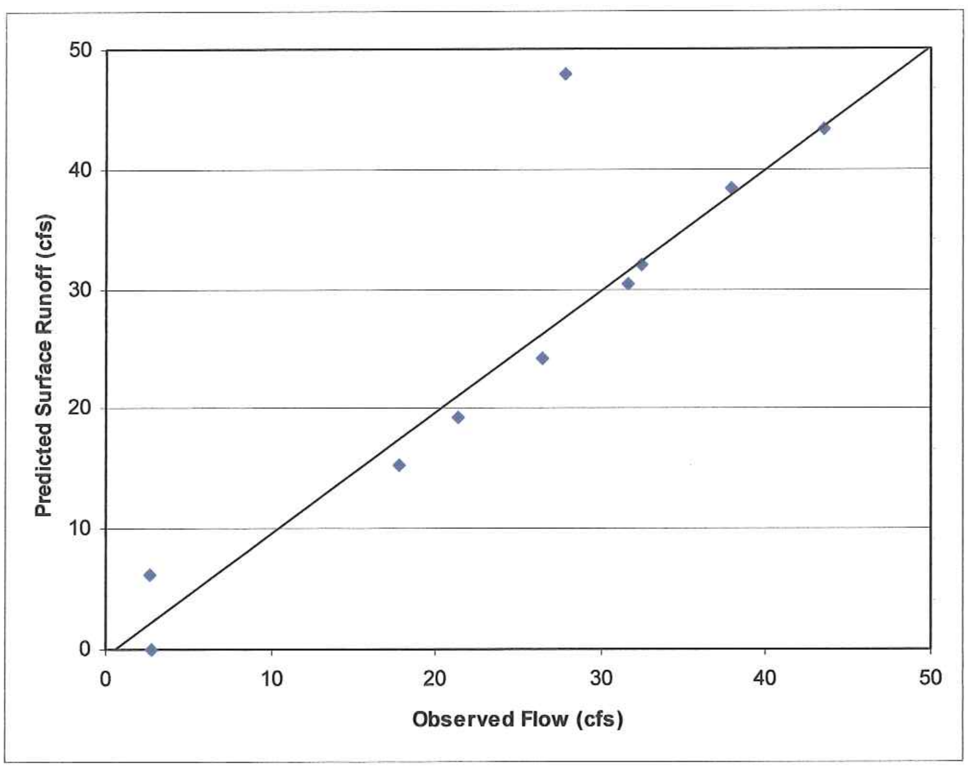

Figure 4. Predicted flow (PI = 20, IC = 0.54, R^2=0.78) and observed flow during the storm on 7/1.An ideal fit line also plotted for an easy comparison.

To further understand the accuracy of IC, the peak flow for all storm events during July and August 2004 were compared with observed peak flow (Figure 5) and found that IC of 0.54 is well representing the conditions in Potash Brook.

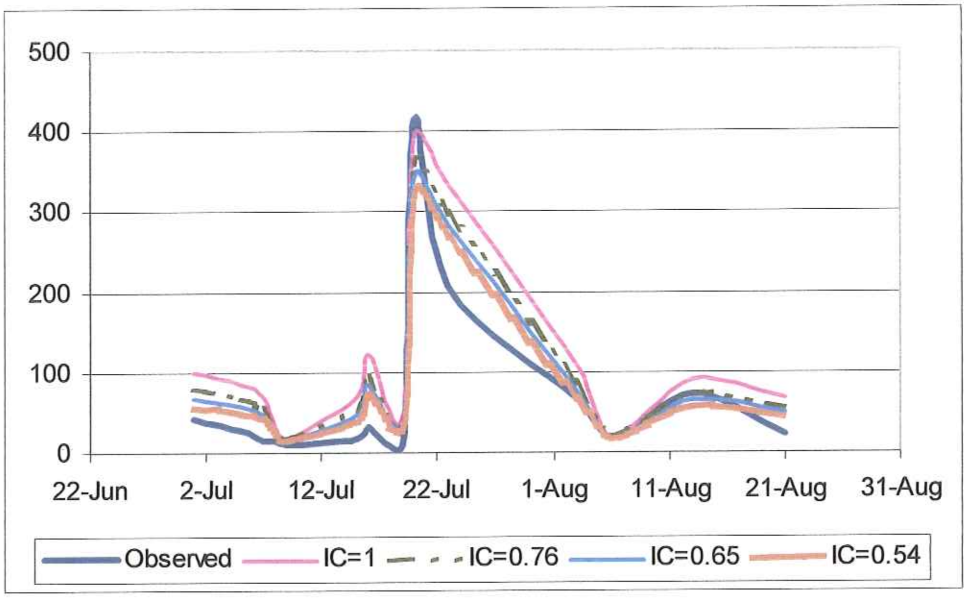

Figure 5. Predicted peak flow and observed flow for all storm events during July and August 2004.

3.2.Pervious Curve Number

In order to evaluate the importance of PCN, three different values of PCNs were considered: estimated PCN based on soil, and PCNs ± 5 of estimated one. Predicted flow during two storms in July 2004 (1.68 inches –7/20 & 1.25 inches 7/22 – 7/23) was closely compared with observed flow and found that the estimated curve number predicts better than the others (Figure 6). In this evaluation, PI and IC were kept the same for all three cases as 20 and 0.54 respectively.

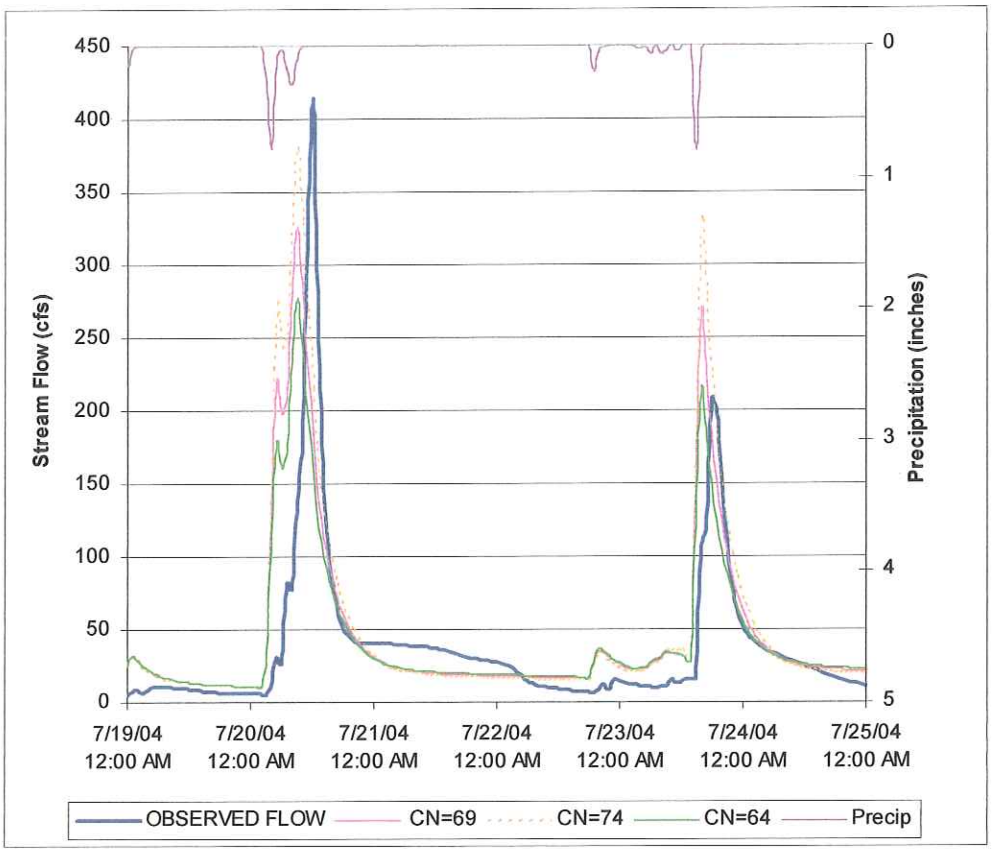

Figure 6. Predicted and observed flow during 7/19 – 7/25.

3.3 Surface Runoff Time of Concentration

TC-SR of 5, 10, and 15 hours were evaluated while the rest of the model parameters were kept the same. Comparison of simulatedpeak flow resulted in the coefficient of determinations (R^2) of 0.85, 0.92, and 0.95 respectively. Although TC-SR of 5 hrs predicted the observed maximum flow well, it generally over-predicts the peak flow. On the other hand, TC-SR of 15 hrs predicted well during many small storms and under-predicted peak flows during the large storms. It was observed that the TC-SR of 10 hrs fits well in representing Potash Brook's conditions as presented in Figure 7. Predicted flow and observed flow with all calibrated parameters are plotted in Figure 8.

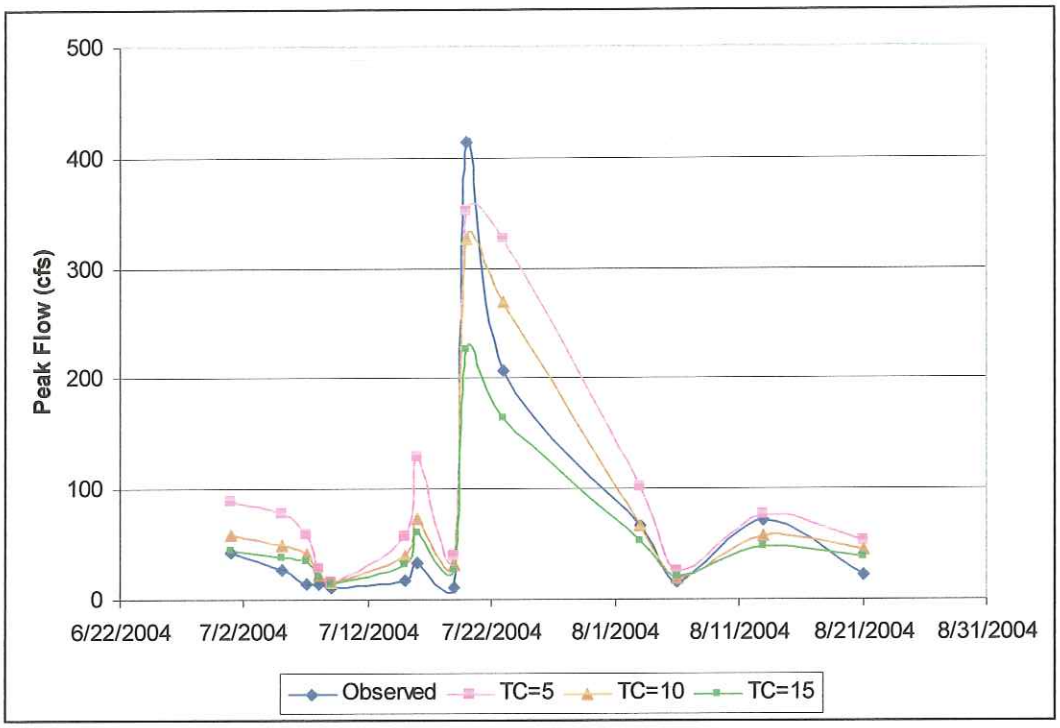

Figure 7. Observed and modeled peak flow (magnitude) at Potash Brook during storm events in July and August 2004.

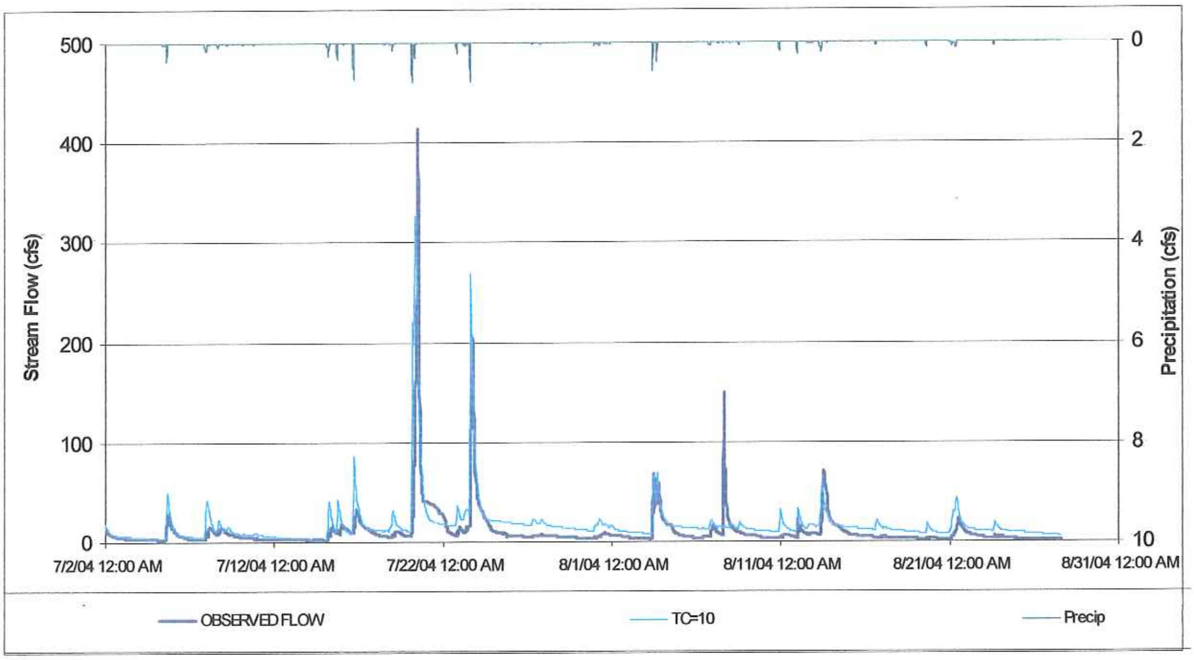

Figure 8. Predicted flow and observed flow during July and August 2004 (TC=10, PI = 20, IC=0.54, PCN=69)

A similar procedure was repeated for the rest of the UVM gauged watersheds and the results are presented in the following sub sections.

3.4. *Johnnie Brook*

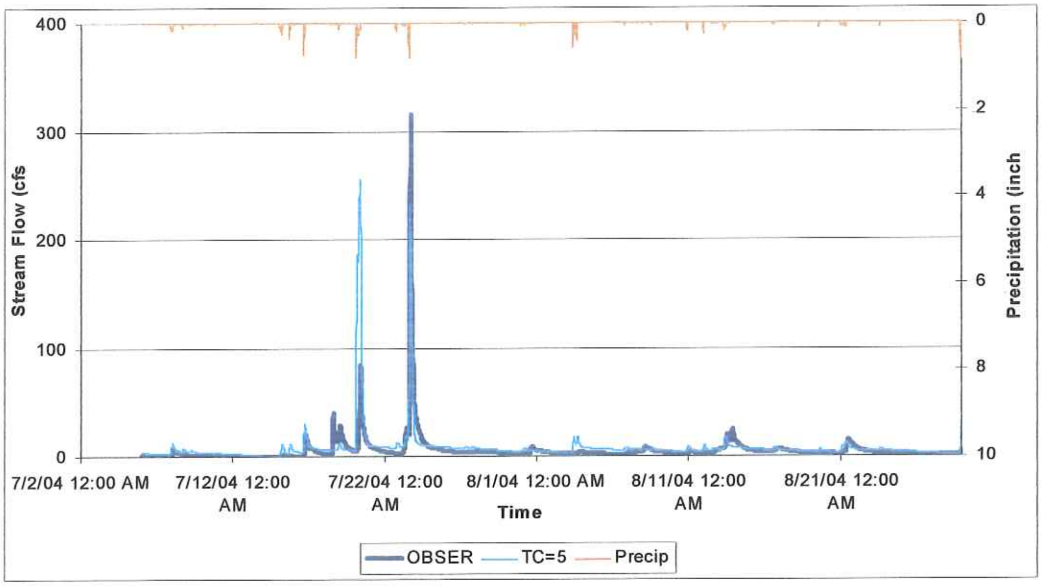

Figure 9. Predicted flow and observed flow during July and August 2004 (Johnnie Brook: TC=5, PI = 5, IC=0.54, PCN=76)

3.5. *Monroe Brook*

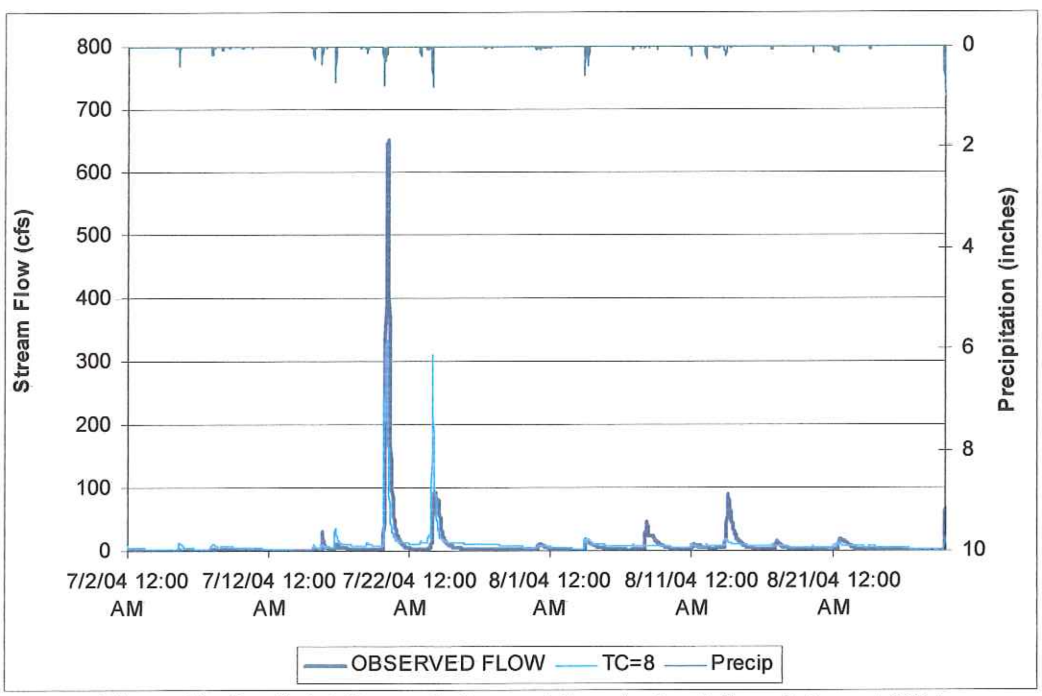

Figure 10. Predicted flow and observed flow during July and August 2004 (Monroe Brook: TC=8, PI = 7, IC=0.54, PCN=77)

3.5.Mill Brook

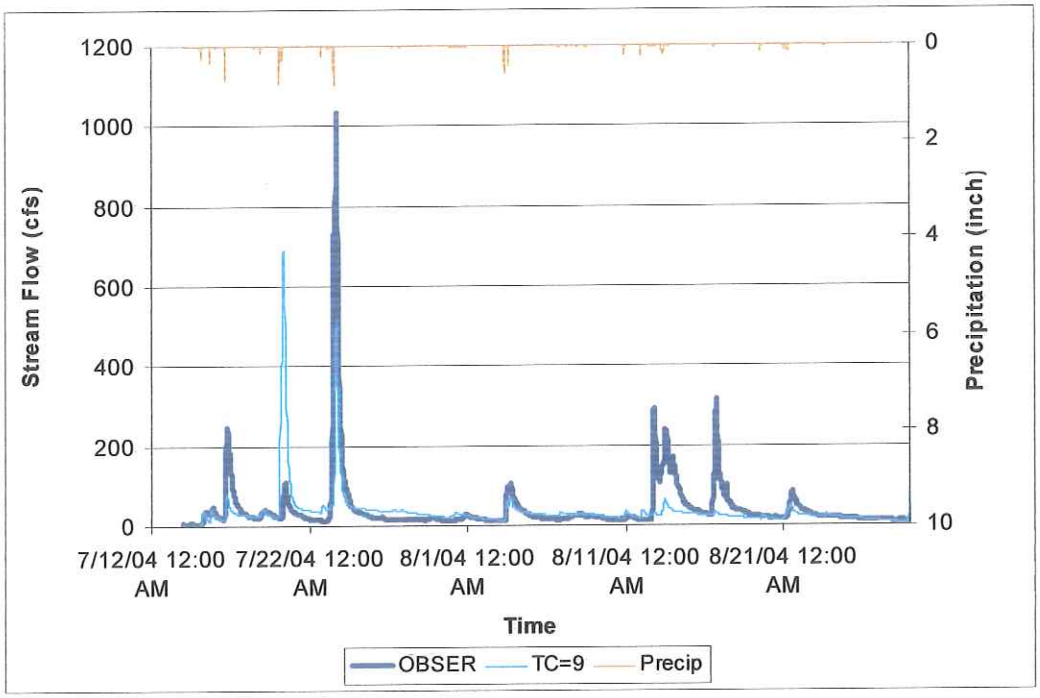

Figure 11. Predicted flow and observed flow during July and August 2004 (Mill Brook: TC=9, PI = 5, IC=0.54, PCN=70)

3.6. Indian Brook

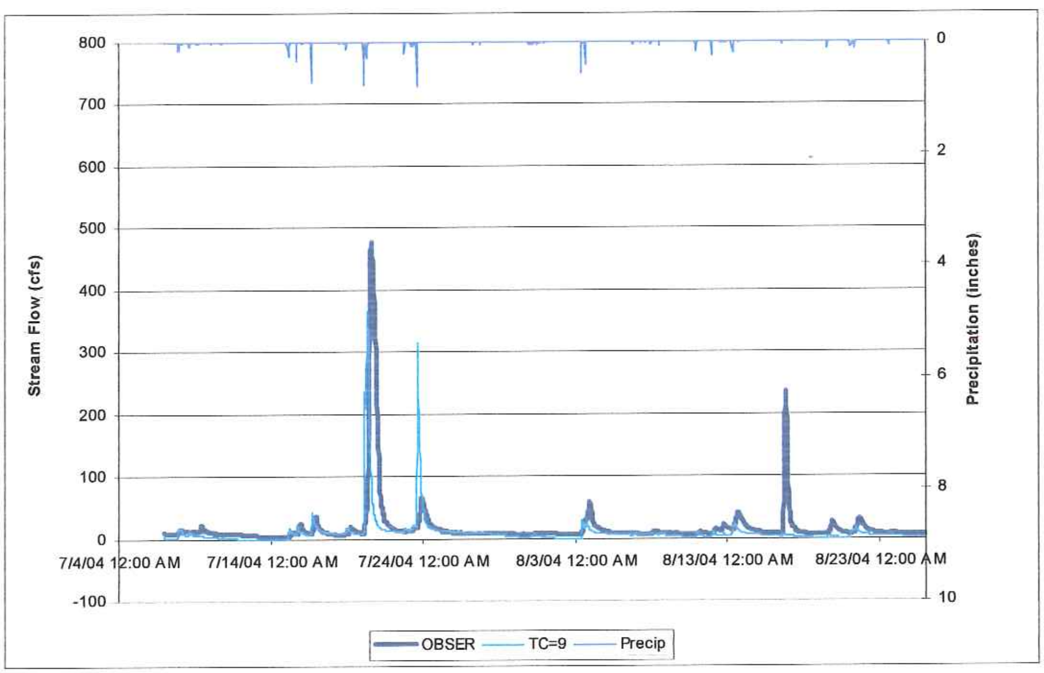

Figure 12. Predicted flow and observed flow during July and August 2004 (Indian Brook: TC=9, PI = 11, IC=0.54, PCN=73)

3.7 Spatial Variation of Precipitation

In general, the comparison of model predictions and observations yield a favorable outcome given the complexity in the watersheds and the simple representation using P8-UCM model. However, it is important to notice the spatial variation of precipitation and its influence on model predictions. Due to the limited availability of continuous hourly precipitation data, data from Burlington airport was employed in simulating the flow for all UVM watersheds. All UVM watersheds are located within approximately 12 miles radius of Burlington airport weather station (Figure 13).

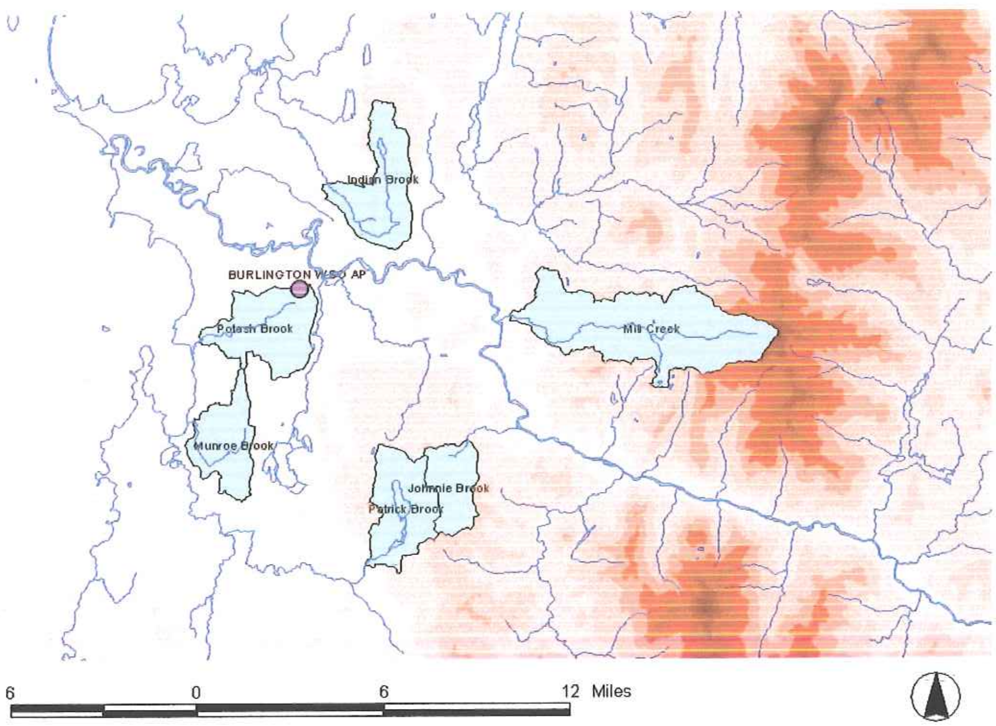

Figure 13. Burlington airport weather station and University of Vermont gauged watersheds are plotted on a digital elevation map. The dark color represents higher elevation and the light color represents lower elevations.

UVM recorded precipitation values for 3 gauged watersheds - Potash Brook, Mill Brook, and Patrick Brook. The UVM observations vary from Burlington airport observations for many storm events. Table 4 presents the total precipitation amounts recorded at the four rain gages for storm events during the summer of 2004 when stream flow data was being collected by UVM. As indicated, precipitation amount varied considerably for certain storm events while for other events the precipitation amounts varied only slightly. Although the variation in precipitation exists, the calibrations were conducted using Burlington airport data due to the limited continuous precipitation data available at the

UVM gauge at Mill Brook. One can infer that the accuracy of model prediction would have been improved if continuous precipitation data from Mill Brook were employed.

Table 4. Total event rainfall recorded at four gauges for storm events during the summer 2004.

Date	Precipitation at Gauge (inches)			
	Burlington Airport	**Potash Brook**	**Mill Brook**	**Patrick Brook**
July 20, 2004	1.68	NR	2.08	NR
July 23, 2004	1.09	NR	2.71	1.05
July 31, 2004	0.28	NR	1.43	0.31
August 7, 2004	0.10	NR	2.12	0.43
August 13, 2004	0.63	0.74	0.90	0.63
August 21, 2004	0.66	0.84	1.56	0.67

NR –No record available

4. Estimation of Time of Concentration for Un-gauged Watersheds

Appropriate TC-SR values for each UVM watershed were estimated through the calibration process. Unlike PCN and PI, there is no direct way of estimating TC-SR for un-gauged watersheds. Therefore, it is important to develop a methodology for estimating TC. In general, TC is proportional to the watershed area. Thus the relationship between TC and watershed area for the UVM watersheds were examined. Although TC increases with an increase in area, it exhibits relatively a poor correlation (Figure 14).

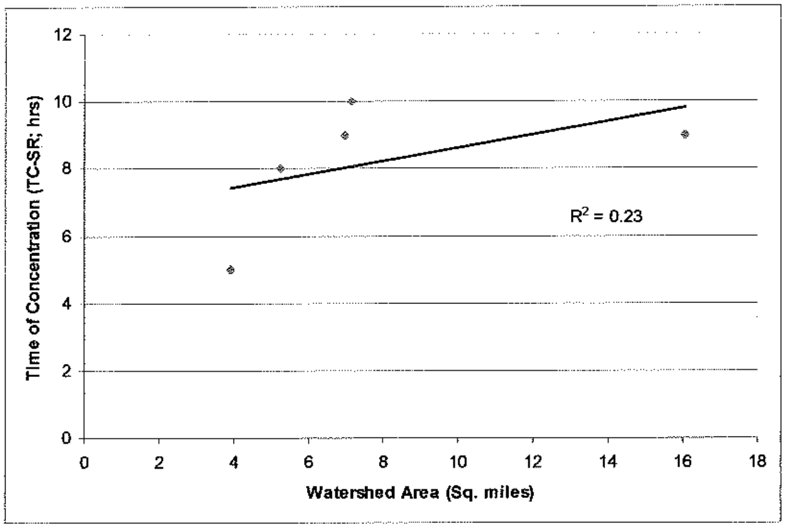

Figure 14. Relationship between TC-SR and watershed area.

Another watershed feature that influences TC is watershed slope. The relationship between TC and average watershed slope is presented in Figure 15. Although TC decreases with the increase in watershed slope, it also exhibits a poor correlation.

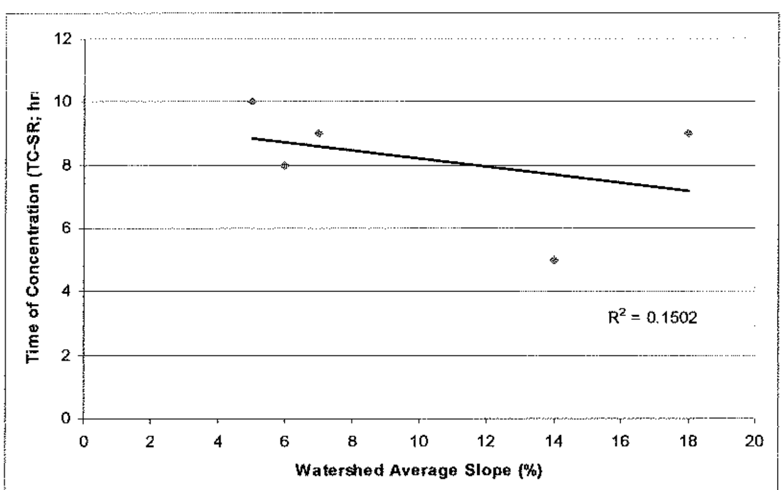

Figure 15. Relationship between TC and watershed average slope.

Since TC shows an increase with watershed area and a decrease with watershed slope, the relationship between TC and the ratio between area and slope (Area/Slope), was further examined and results in a satisfactory correlation (Figure 16).

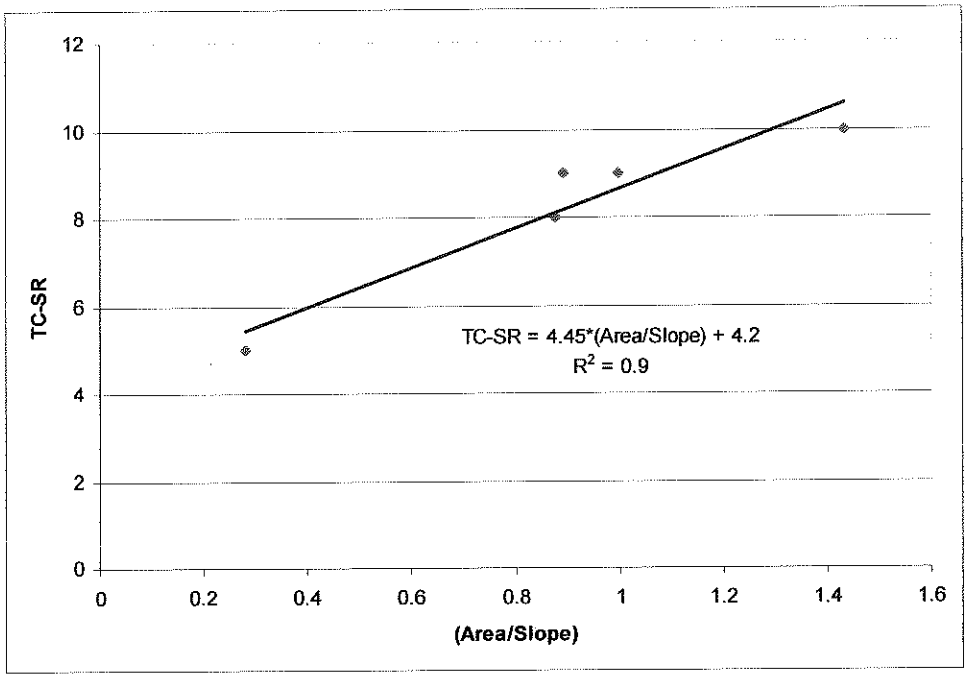

Figure 16. Relationship between TC and area-slope ratio.

The relationship [TC=4.45*(Area/Slope) + 4.2; Eq. 2] can be used to estimate TC for un-gauged watersheds.

5. Summary on Model Simulation Procedures

Based on the calibration process, a standard procedure for model set up and simulation was developed as follows.

- Estimate the Percent Imperviousness using VCGI land use data using the coefficients given in Table 2.
- Adjust the estimated Percent Imperviousness using Eq. 1.

The two procedures mentioned above can be eliminated if the measured PI are available for all impaired and attained watersheds.

- Estimate Pervious Curve Number using VCGI land use data and VCGI SSURGO soil data.
- Estimate Surface Runoff Time of Concentration using Eq. 2. Watershed area and average watershed slope can be estimated using VCGI slope24 data.
- The rest of the model parameters are set to the same values as calibrated ones, such as impervious runoff coefficient (0.54), depression storage (0.014 inches) and groundwater time of concentration (1,000 hrs).
- Use observed hourly precipitation and daily temperature data for the model.

One should note that the procedures and recommendations were made by carefully considering the project objectives and the available data and resources.

6. Model Application: Development of Flow Duration Curves

The objective of the modeling exercise is to estimate time-series flow values for small watersheds (impaired and attainment) and to develop flow-duration curves (FDC). FDC will be employed to identify necessary storm water control targets for each impaired watershed by comparing to an appropriate attainment watershed. Although the model being employed is not extremely detailed, it is expected to reasonably predict the relative variability of stream flow among watersheds. Given the complexity of the watershed features and processes, it is apparent from modeling to this point that a simple representation of P8-UCM simulates the stream flow reasonably well. The development of FDC and relative hydrological targets, especially the relative variability of stream flow between impaired and attained watersheds, can be carried out with reasonable confidence.

One of the important aspects in using FDC to identify necessary storm water control targets is to identify an appropriate attainment watershed (s) for each impaired watershed. Therefore the following guidelines were followed in two phases.

Initial Phase (Using watershed characteristics from available GIS Data)

- Eco-region (high/moderate gradient and precipitation zone)
- Slope
- Curve Number Factors
- Land use, soils, impervious cover
- Drainage Area

Second Phase (maps/orthophotos)

- Wetlands/Dams
- Watershed Shape

Considering the guidelines mentioned above, two pairs of watersheds (Potash Brook & Youngman Brook, Moon Brook & Mallets Creek) were selected to demonstrate the application of the calibrated model in developing FDC. A brief summary of the watershed characteristics of the selected watersheds is given in Table 5, and FDCs are presented in Figures 17 and 18.

Table 5. Summary of watershed characteristics (major model variables)

Watershed Characteristics	Potash Brook	Youngman Brook	Moon Brook	Mallets Creek
Area (acres)	4556	672	5546	9318
Average Slope (%)	5	5	13	10
Percent Imperviousness (%)	20	3	13	4
Pervious Curve Number	70	57	68	74
Surface Runoff – Time of Concentration (Hour)	10.5	5.1	7.2	10.7

Potash Brook and Youngman Brook

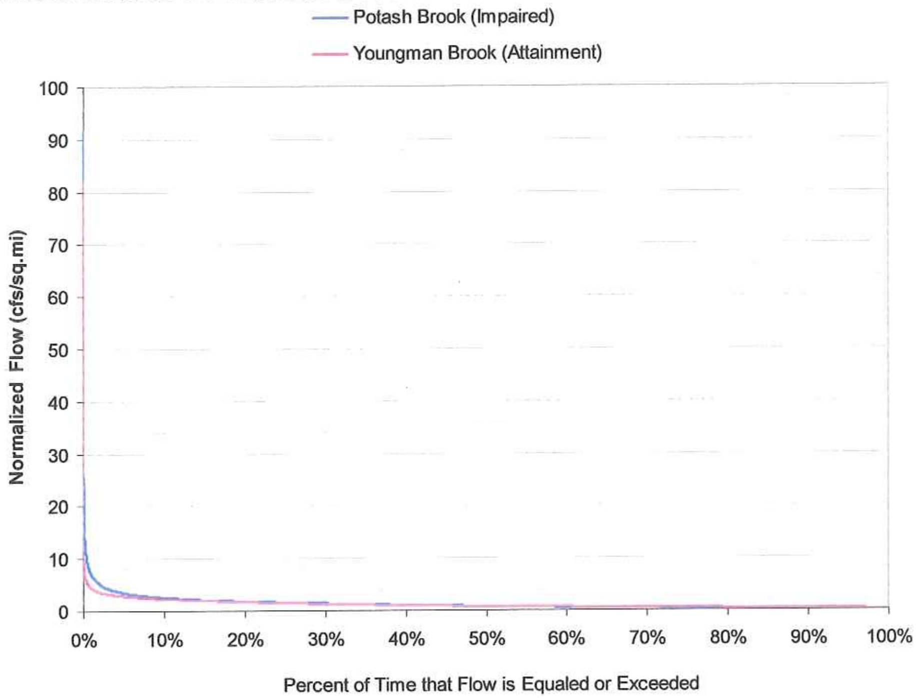

Figure 17a. FDCs for Potash Brook and Youngman Brook.

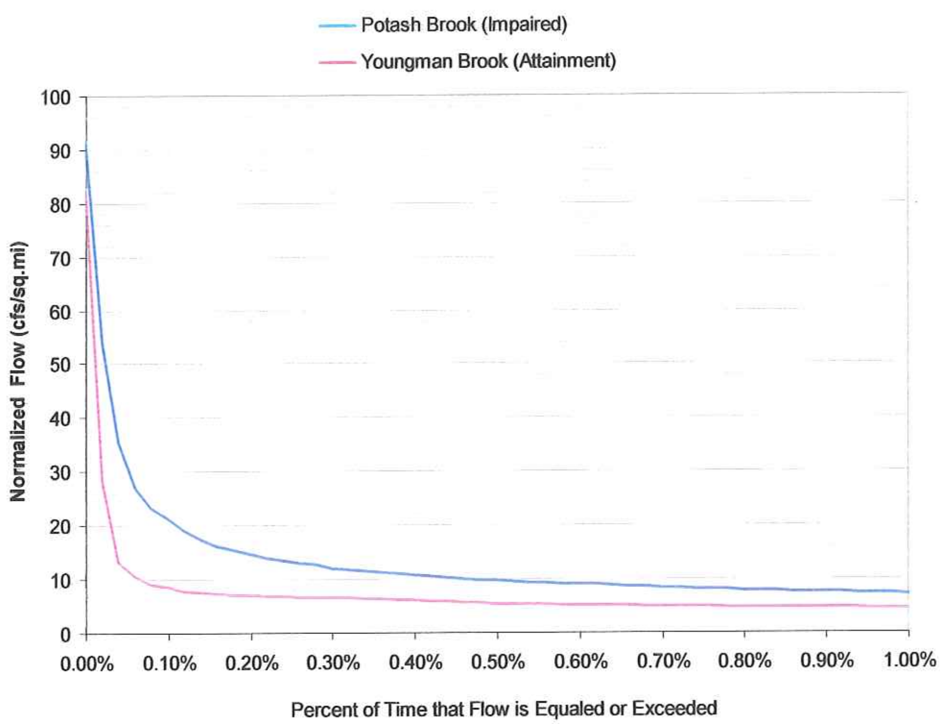

Figure 17b. FDC at high flow for Potash and Youngman Brooks.

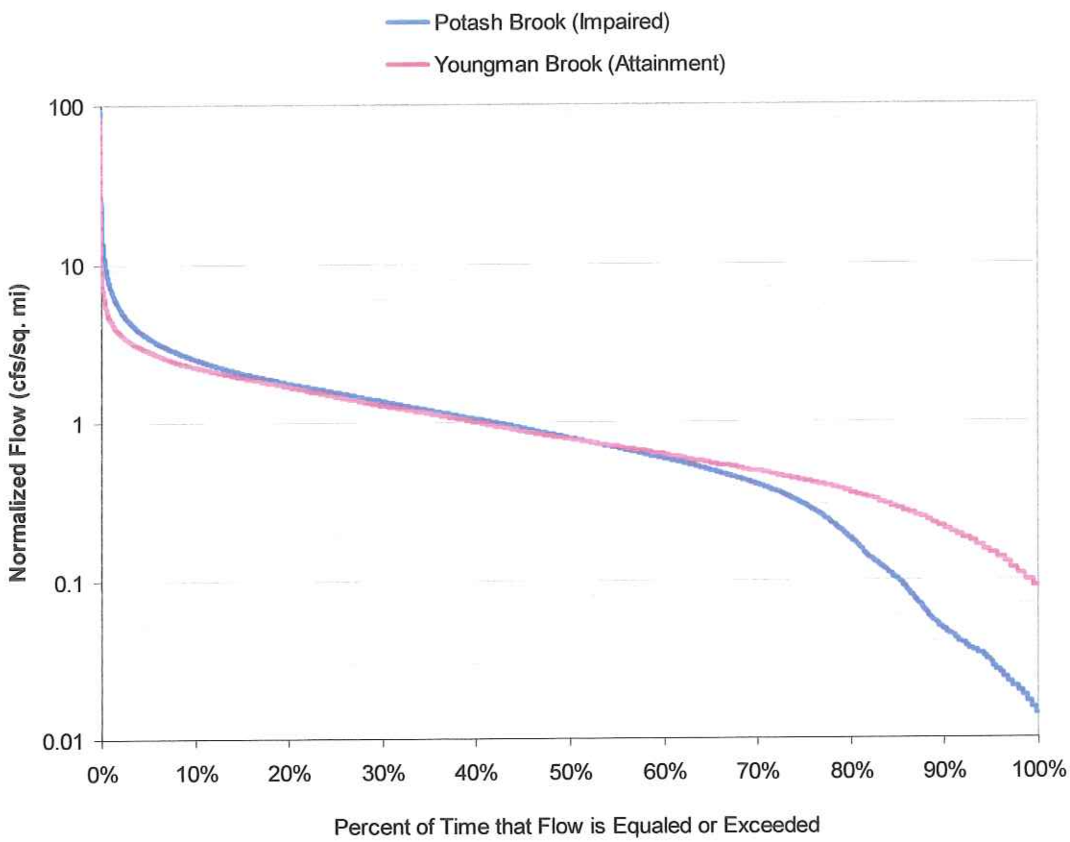

Figure 17c. FDC in log scale for Potash and Youngman Brooks.

Moon Brook and Mallets Creek

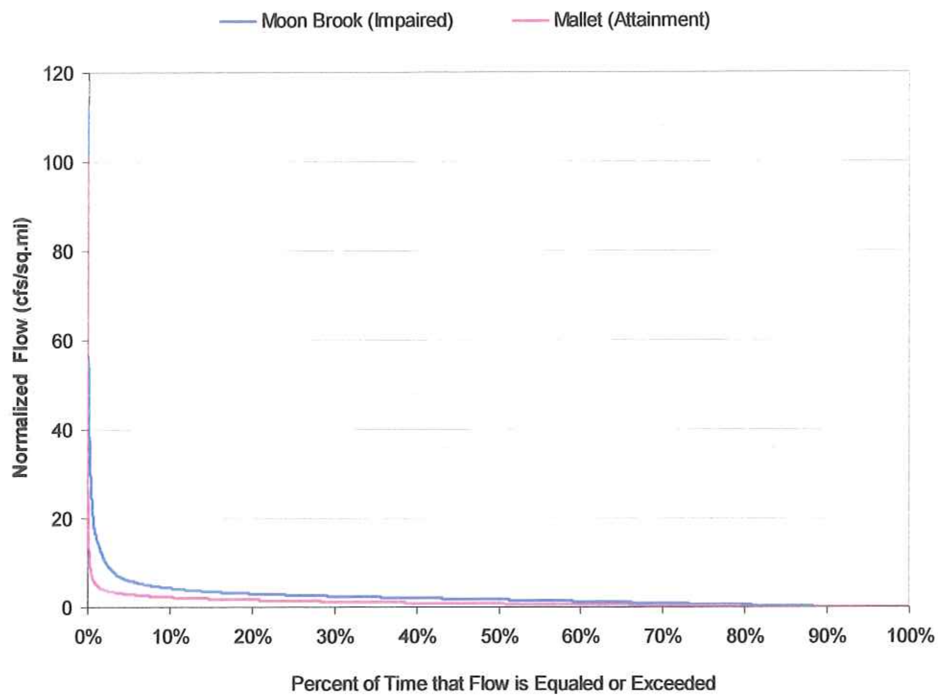

Figure 18a. FDCs for Moon Brook and Mallets Creek.

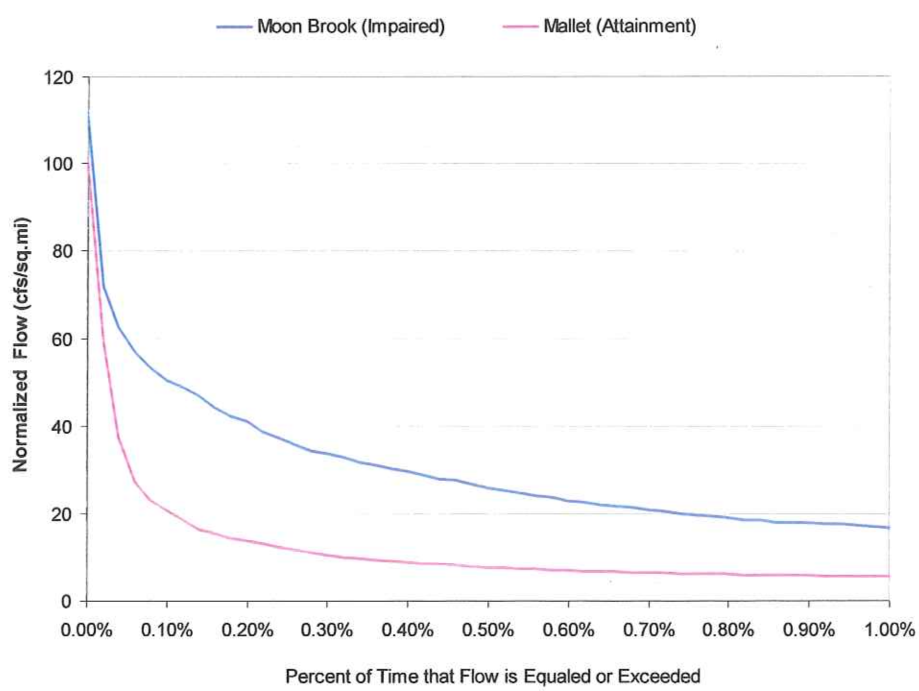

Figure 18b. FDC at high flow for Moon Brook and Mallets Creek.

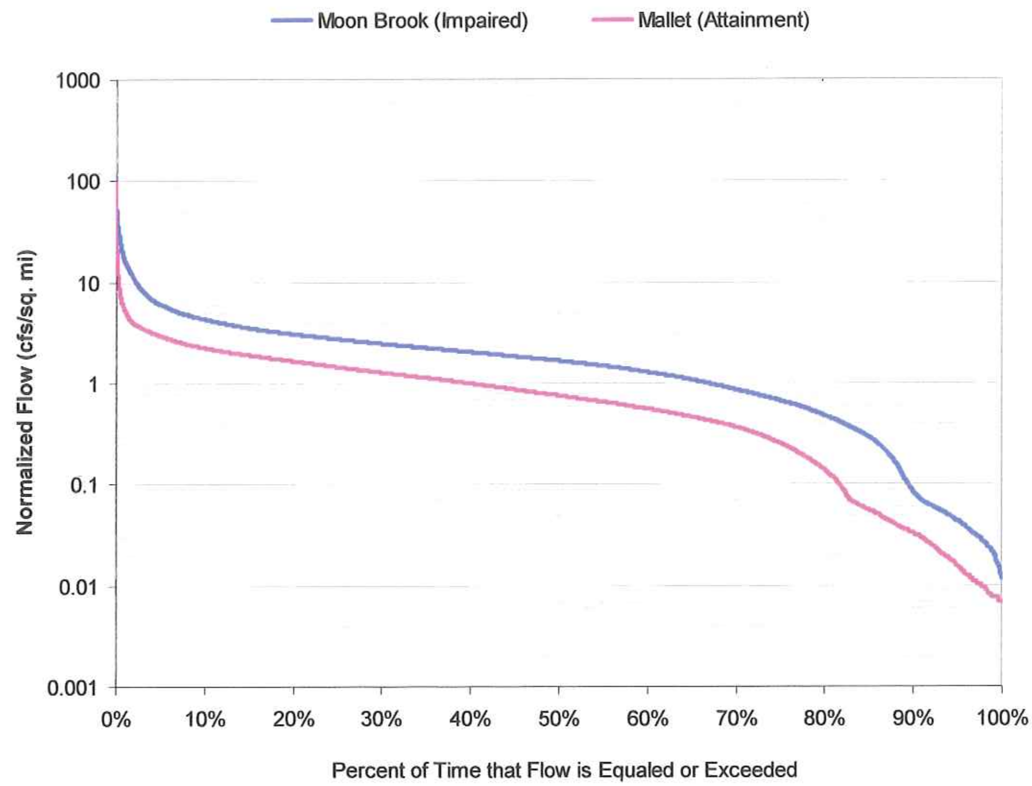

Figure 18c. FDC in log scale for Moon Brook and Mallets Creek.

In order to further understand the sensitivity of percent imperviousness (PI) in FDC, the model simulations of Potash Brook were made for PIs of 10%, 20% (existing condition), 30%, 40%, and 50%. The results of the sensitivity analysis are presented in Figure 19.

Sensitivity Analysis: Potash Brook

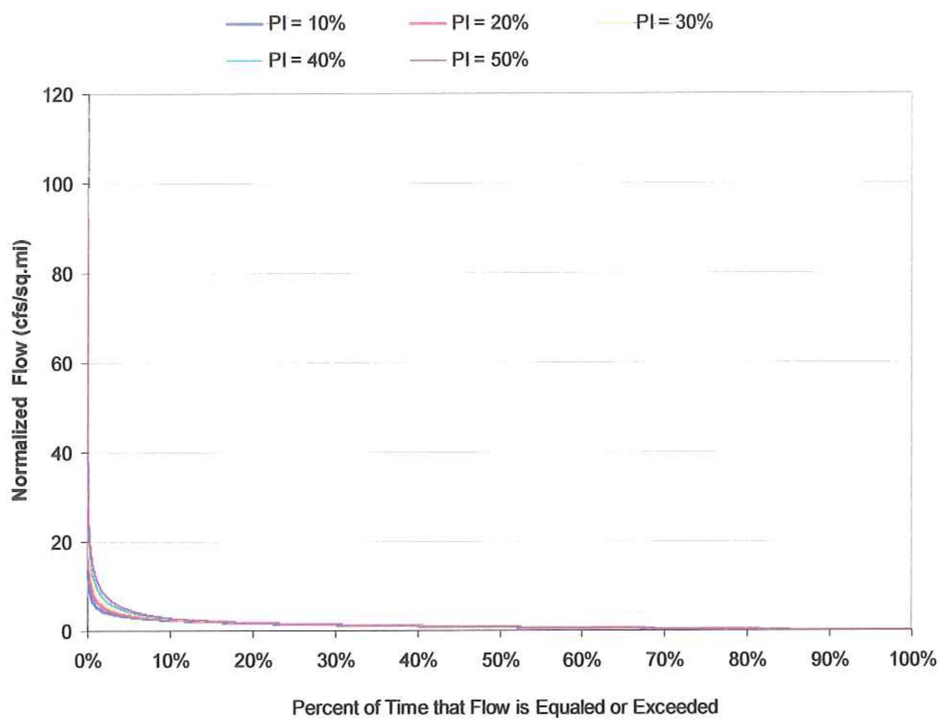

Figure 19a. Flow Duration Curves for Potash Brook.

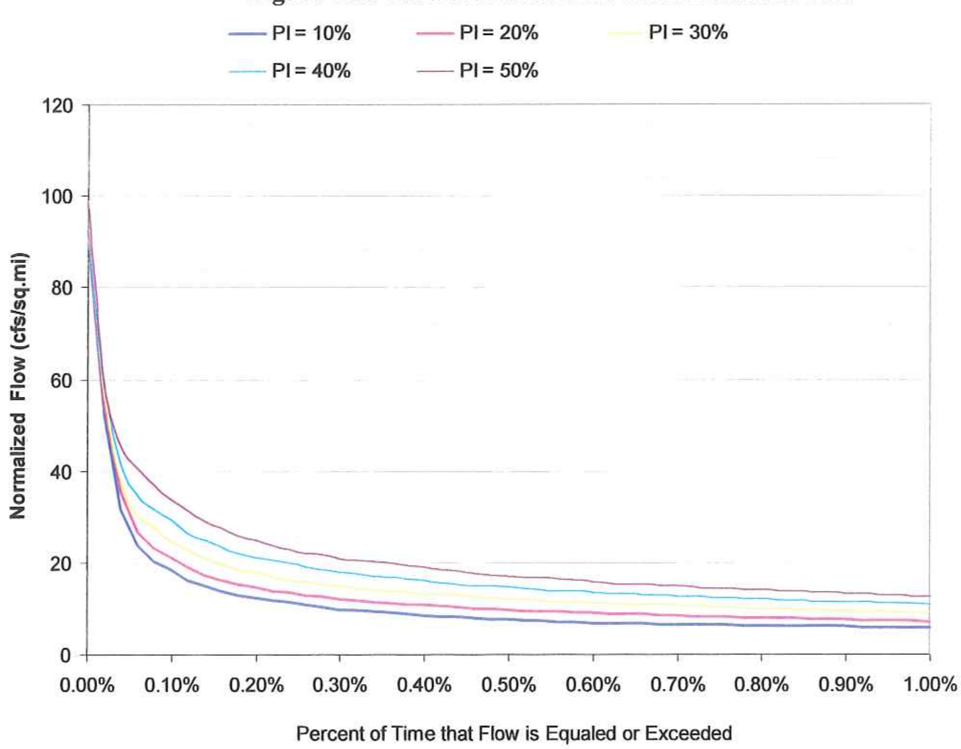

Figure 19b. FDCs at high flow for Potash Brook.

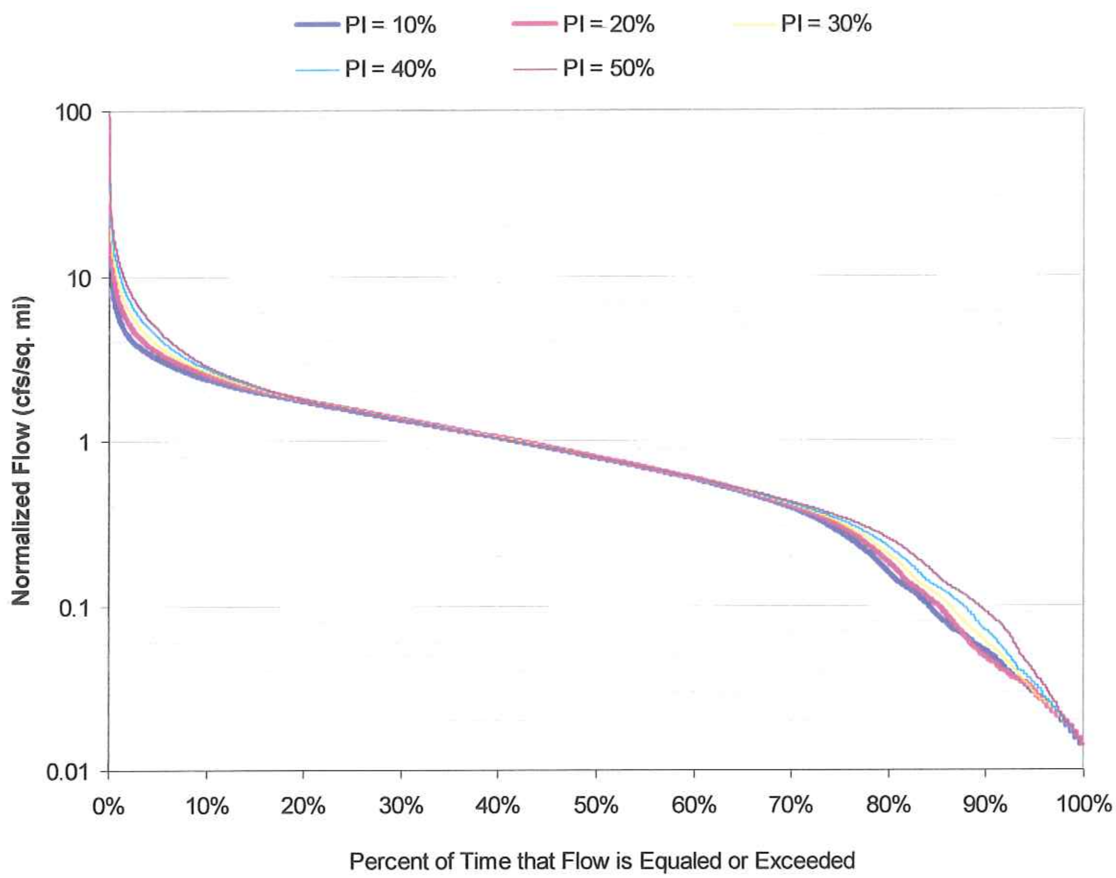

Figure 19c. FDCs in log scale for Potash Brook.