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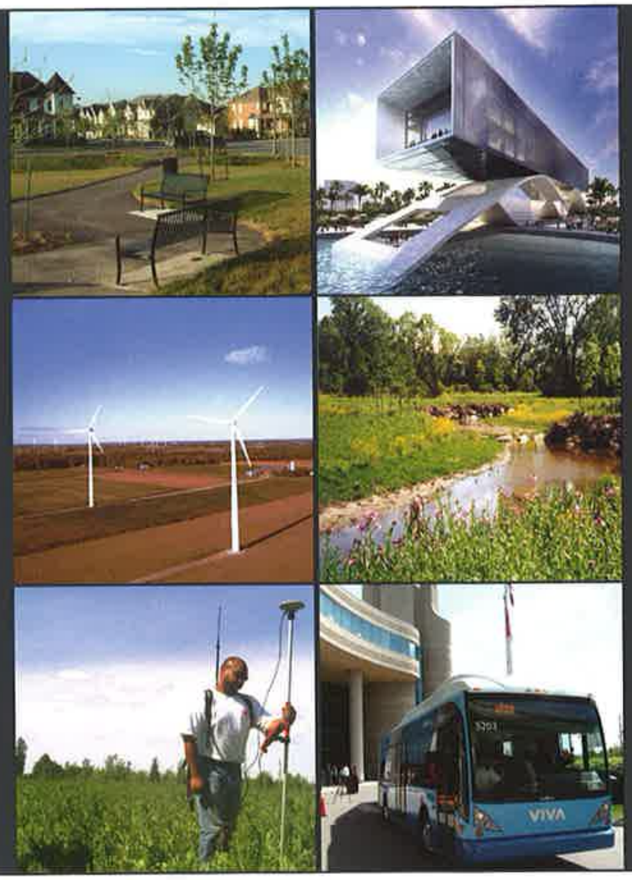

Final Report
Hydrologic Modelling
Mimico Creek

for Toronto Region Conservation Authority
14-04089-001-I01

COMMUNITIES
TRANSPORTATION
BUILDINGS
INFRASTRUCTURE

MMM GROUP

December 2009

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1. INTRODUCTION

1.1 BACKGROUND

MMM Group Limited was retained by the Toronto and Region Conservation Authority (TRCA) to update the hydrologic model for the Mimico Creek watershed. The model was originally formulated in the late 1970s. TRCA determined that it was necessary to update the model for the following reasons:

- The model was based on the HYMO computer program, which is outdated at present, and seldom used for current watershed modelling. Hence, the previous model needed to be updated to Visual OTTHYMO, which is the latest transformation of the HYMO model.
- There has been extensive development in the Mimico Creek watershed over the last 25 years. It was necessary to update the model to reflect the current development condition in the watershed. The City of Toronto completed their Wet Weather Flow Management study, during which, current land use data and statistics were collected for the watershed. Hence this data could be used to update the TRCA hydrologic model.
- In May 2000 and August 2005, there were significant storm events, which resulted in rainfalls that ranged from a 5 year to over a 100 year event depending on the location in the Greater Toronto Area. This provided an opportunity to calibrate and validate the updated model to these relatively rare events.

1.2 SCOPE OF WORK

The following Scope of Work was identified for the Mimico Creek hydrologic update:

- Conversion of the HYMO model from the previous update to Visual OTTHYMO Version 2.0 (VO_2);
- Model update based on the current development condition in the watershed from the information available on existing land use from the City of Toronto Wet Weather Flow Management Plan information south of Steeles, and 2002 orthophotography north of Steeles. All existing SWM ponds in the watershed should be incorporated in the updated watershed model using a "lumped" catchment approach;
- Calibration and verification of the model based recent storm events;
- Update of model based on areas of future land use identified in municipal and Regional OP's and OPA's;

- Simulation of appropriate 25 mm, 2, 5, 10, 25, 50 and 100 year design events, and the Regional Storm using the updated and verified models, and documentation of results;
- Identification of areas affected by significant changes in flow conditions, including flood vulnerable areas and sites, active valley land use, and any other critical areas identified by the TRCA;
- Provision of a summary of SWM quantity control recommendations;
- Preparation of a report documenting the results of the hydrologic update, including all supporting calculations, conclusions and recommendations;
- Preparing a "user's guide" and a detailed protocol for future updates of the model.

1.3 RELEVANT PREVIOUS STUDIES

A review of relevant studies was conducted for the present hydrologic update. The reviewed documents are summarized below:

- *Hydrologic Model Study, Etobicoke and Mimico Creeks, James F. MacLaren Limited (March 1978);*
- *Existing Conditions Report, Etobicoke and Mimico Watersheds, WWFMP, TSH Limited, January 2001;*
- *Summary of Rainfall Analysis Completed for the August 19, 2005 Event Over the TRCA, Clarifica, November 2005.*

1.4 ORGANIZATION OF REPORT

Section 2 describes the methodology adopted for the development of the VO_2 model for the Mimico Creek watershed. Section 2.1 focuses on model development while Section 2.2 describes the calibration and validation of the model. Section 3 discusses the selection of appropriate 2 to 100-year design storms for the watershed, and the results obtained from the design storm and Regional Storm simulations performed using the validated models. Section 4 discusses the stormwater management issues in the Mimico Creek watershed related to the present update. Section 5 summarizes the conclusions and recommendations of the present hydrologic update. The "user's guide" and technical memorandum prepared to provide assistance for future updates of the watershed model are included as Appendix A.

2. MODEL UPDATE

The HYMO model for the Mimico Creek watershed was updated to Visual OTTHYMO V2 (VO_2) and modified to reflect the current land use in the watershed. Because of the need to provide additional flow points within the watershed, the number of subcatchments modelled was also increased substantially. The future conditions model is identical to the existing conditions model as the watershed is essentially fully developed or actively in the latter stages of infilling areas not completed.

The model was calibrated and validated using a unique procedure which permitted the most significant model parameters to be determined automatically based upon observed precipitation and stream flow data. This procedure required direct access to the input and output files of the OTTHYMO model. Since this is not available for the VO_2 model, an intermediate step involving the development of an OTTHYMO-89 model was required. Once this had been calibrated, it was converted to the VO_2 format.

The following sections provide a brief discussion on the methodology used for completing the model update.

2.1 MODEL DEVELOPMENT

2.1.1 Watershed Discretization

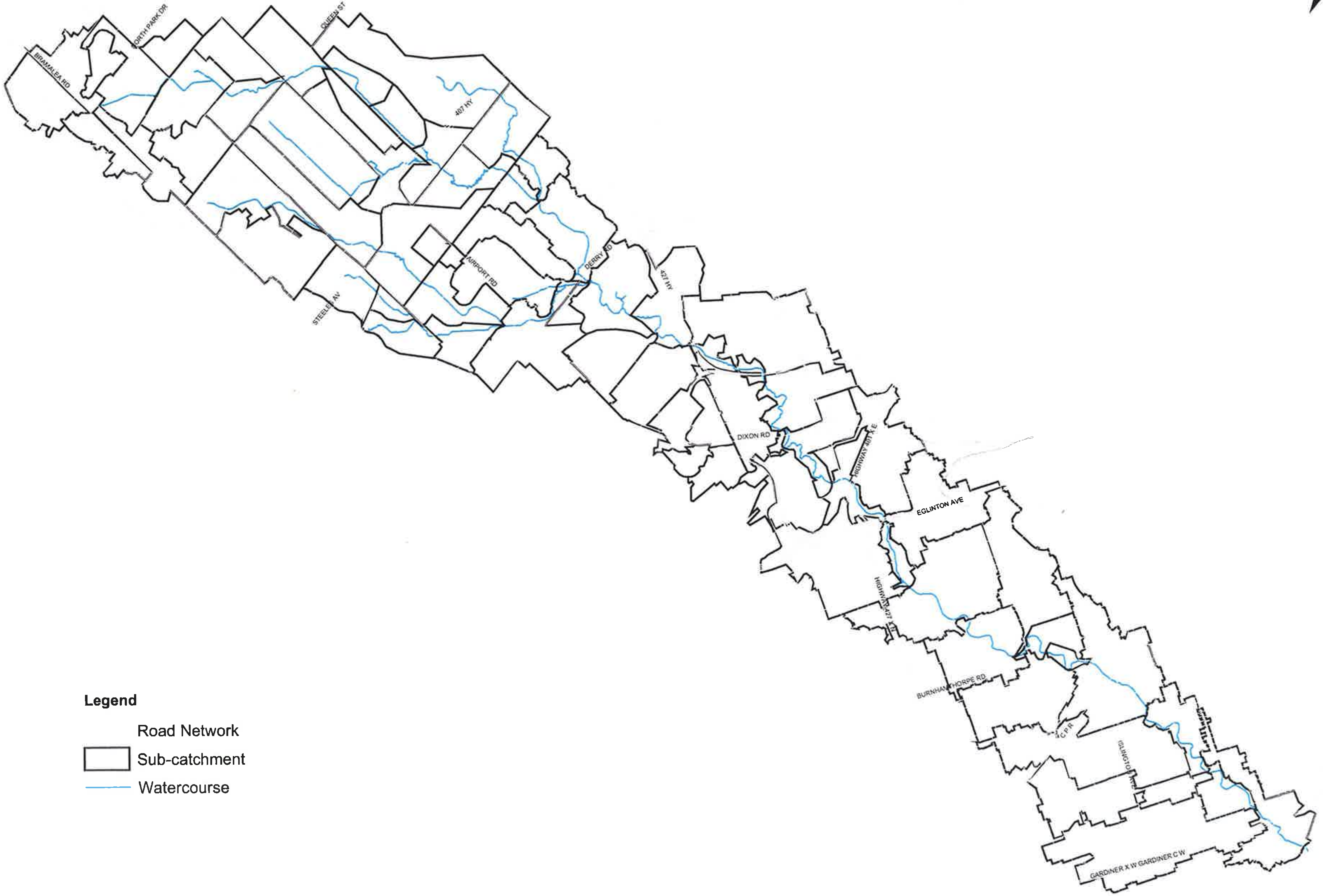
Base data was provided by TRCA in the form of air photos, GIS layers, stormwater management reports and planning information. This was used to develop a sub-basin discretization for the model. Establishing the final model schematic/discretization took several iterations and contacts with the City of Brampton to define current drainage pathways. Figure 2.1, "Study Area," shows the final subcatchment delineation. The model has a total of 67 subcatchments in contrast to the 1979 model which had only 10 subcatchments.

2.1.2 Land Use

Using ARCVIEW, a base land use map was prepared. This also took many iterations to fill in gaps in the information which was originally anticipated to be available from the City of Toronto WWFMMP study. Figure 2.2 shows the final map with the land use categories indicated on the figure.

MIMICO CREEK HYDROLOGY STUDY

Study Area



N

Legend

Road Network

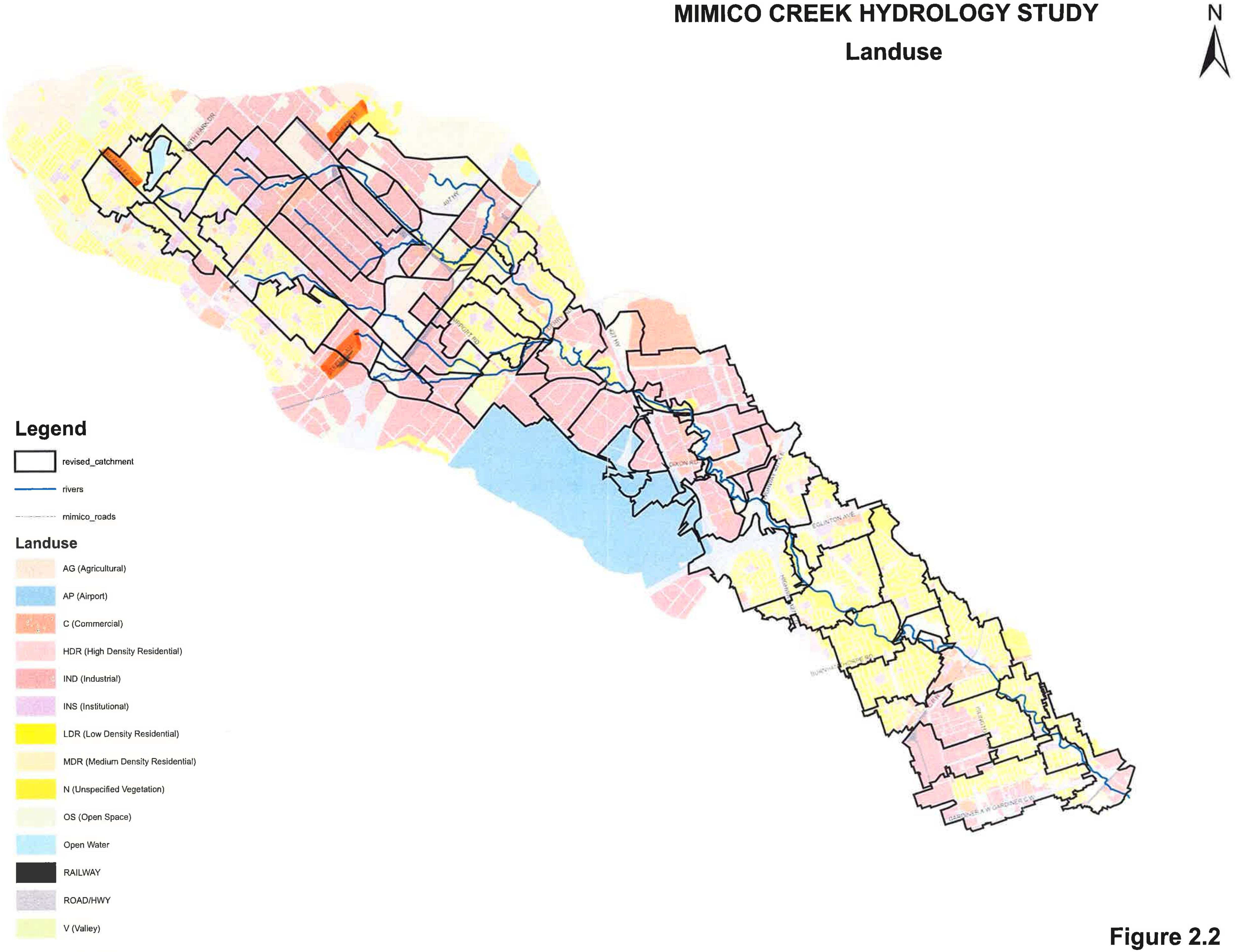
▭ Sub-catchment

— Watercourse

Data Source: TRCA (2005)

Figure 2.1

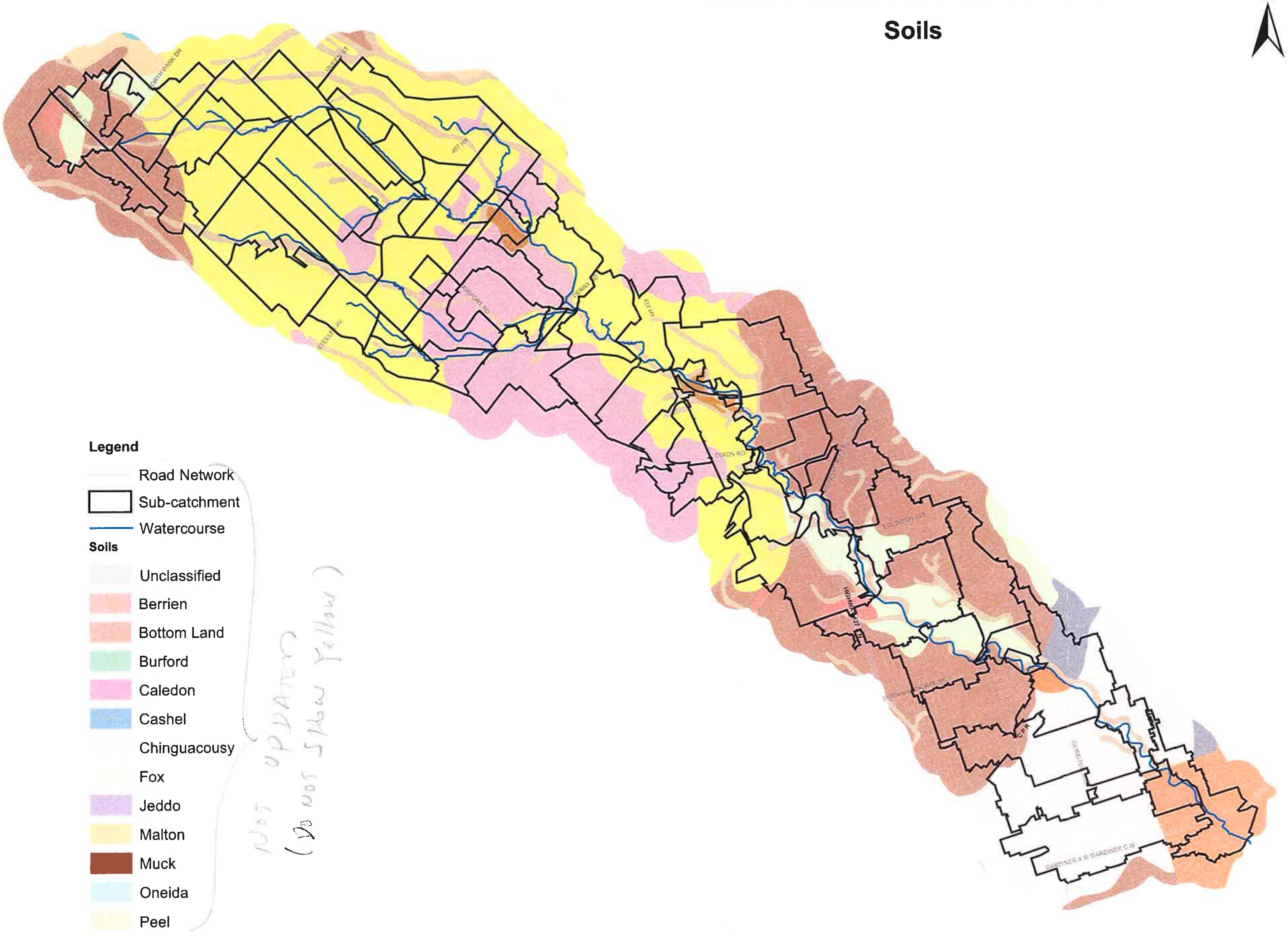
MIMICO CREEK HYDROLOGY STUDY
Landuse



Data Source: TRCA (2005)

Figure 2.2

MIMICO CREEK HYDROLOGY STUDY
Soils



NOT UPDATED
(DO NOT SHOW Yellow)

Data Source: TRCA (2005)

Figure 2.3

2.1.3 Soils

Soils information was obtained from the City of Toronto WWFMP study. That data was originally extracted from Ontario Soil Survey documents (outside the City of Toronto) and a database of soils in boreholes created in association with construction projects within the City. Figure 2.3 shows the distribution of soils within the watershed. Soils are predominantly of an impermeable nature such as clays or clay loams.

2.1.4 Model Preparation

As noted earlier, the initial model of Mimico Creek was developed using the OTTHYMO-89 version. Based upon the subcatchment discretization and the stream reaches which connect them, a model schematic was developed. Using the model schematic, land use information, soils information and topographic information, a base OTTHYMO model was established by overlaying the different layers of data in ARCVIEW. The model contains a total 67 subcatchments and 34 routing reaches. In addition, based upon TRCA's stormwater management facility database and information from SWM reports, a total of 21 reservoir routing components were added to the model to represent existing stormwater management facilities and on-site controls. In cases where more than one facility is located within a subcatchment, they were lumped together into a single route reservoir command. This provides a functional representation of the facilities with equivalent performance to the individual facilities. The approach used is documented in Appendix A. It should be noted that these SWM facilities were removed from the model version used to simulate the Regional Storm but are essential for simulations representing current conditions and design storm simulations up to the 1 in 100 year storm. Existing SWM facilities information was derived from various earlier studies which were received from TRCA and different sources. A summary of these SWM pond studies are documented in Appendix B. The final model schematic for the VO2 version is presented as Drawing No. 1 in the back pocket of this report.

2.1.5 Initial Parameter Values

Although the main model parameters were obtained through the calibration/validation process, initial values were required to begin that process. The subwatersheds within the study area are predominantly "urban" based on the land-use mapping, and generally have more than 20% impervious cover. Such areas are normally modelled in VO2 and OTTHYMO-89 using the STANDHYD command, which has as input parameters: Area, Total Imperviousness (TIMP), Directly Connected Impervious Area (XIMP), Storage Coefficient (SC), slope of pervious and impervious areas (SLPP% and SLPI%) and CN values for the pervious areas. For any areas with less than 20% imperviousness, the

NASHYD command was used. Relevant parameters are: Area, N (number of linear reservoir), CN value, IA and Time to Peak (Tp).

The geophysical parameters (Area and Slope) were obtained directly from the GIS data using ARCVIEW. TIMP and XIMP were based upon weighted imperviousness values for the land uses obtained from a GIS overlay of subcatchment boundaries. CN values for pervious areas were obtained for AMCII conditions based upon weighted values for the soils identified in each subcatchment. SC values were obtained from the formula: S = (25400/CN) – 10. For the NASHYD command, the initial value of N was 3, IA was 0.1*S and Tp was estimated from the Williams Formula. Table C-1 in Appendix C shows the initial parameter values for each subcatchment.

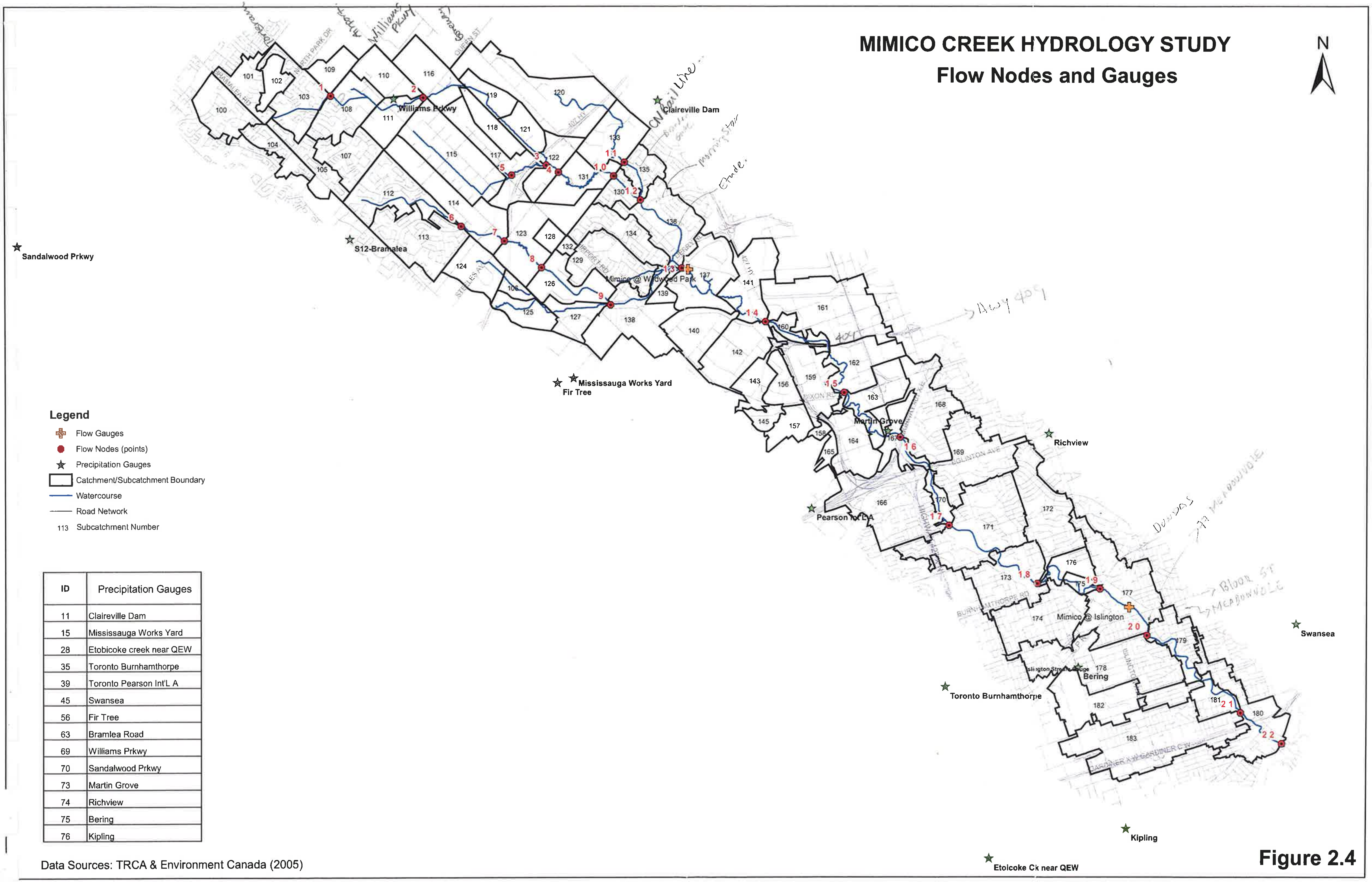
2.2 CALIBRATION AND VALIDATION

The calibration and validation process used consisted of two main steps: a) an automated optimization process was used to identify model parameters which gave a best fit to a series of observed events, and b) a common set of parameters was identified which gave an overall best fit to the set of events. As part of the process, some events were used in calibration and others were reserved for the validation of the parameters. As a final check, a simulation of the August 19, 2005 storm event was completed since this severe event occurred during the completion of this study.

The available streamflow and precipitation data was screened to identify events suitable for calibration/validation. Figure 2.4 indicates the locations of available stream flow and precipitation gauges relevant to the study area. This proved to be somewhat more difficult than anticipated as the data from precipitation gauges not operated by the Meteorological Service of Canada was incomplete. Similarly, the streamflow data from the upstream gauge at Goreway Road was not always consistent with that from the long term gauge operated by Water Survey of Canada at Islington Avenue near the mouth of the basin. Ultimately, nine events were identified for the Islington gauge and four events for the Goreway gauge. Precipitation for each event is listed in Table 2.1.

MIMICO CREEK HYDROLOGY STUDY

Flow Nodes and Gauges



ID	Precipitation Gauges
11	Claireville Dam
15	Mississauga Works Yard
28	Etobicoke creek near QEW
35	Toronto Burnhamthorpe
39	Toronto Pearson Int'L A
45	Swansea
56	Fir Tree
63	Bramlea Road
69	Williams Prkwy
70	Sandalwood Prkwy
73	Martin Grove
74	Richview
75	Bering
76	Kipling

Data Sources: TRCA & Environment Canada (2005)

Figure 2.4

Table 2.1: Storm Events Identified for Calibration/Validation

Time	Gauge Location	Rainfall Depth (mm)
April 20, 2000	Pearson Airport	46.9
May 11, 2000	Pearson Airport	62.9
June 12, 2000	Pearson Airport	54.3
June 24, 2000	Pearson Airport	30.7
July 21, 2002	Pearson Airport	12.5
May 23, 2003	Pearson Airport	35.1
Aug 11, 2003	Pearson Airport	29.3
June 13, 2004	Peel S12	15.4
July 14, 2004	Peel S8	12.5

The following sections describe the use of these events in the calibration/validation process.

2.2.1 Automated Model Parameter Estimation

The automated calibration procedure used a technique referred to as Shuffled Complex Evolution method. This is described in Appendix D but essentially, it searches through a multi-dimensional parameter space to find the minimum value of an "objective error function." The latter is defined, in this case, as the sum of squares of the difference between the observed and simulated flows. The SCE method avoids the pitfalls of earlier automated optimization procedures such as finding only local minima in the search space. Its application involved the following steps:

- For each event, the runoff volume was calculated from the streamflow data at the gauges. The rainfall for the event was identified. The appropriate initial value of the SCS Curve Number for each sub-basin was calculated to ensure that the modeled runoff volume would be close to that observed. This is achieved by estimating a basin wide value and prorating back to each sub-basin by comparing the calculated value to the basin wide average AMC II value. Since OTTHYMO is a single event simulation model there is no other way of establishing antecedent conditions. In addition, for design event simulations, the initial conditions are prescribed (AMC II or AMC III). Hence there is no need to establish a predictive relationship for antecedent conditions
- Initial values of sub-basin parameters were established as previously discussed
- The automated SCE calibration procedure was initialized and allowed to search a possible range of parameters to find an optimum set for each event. The values optimized were: Tp and N (no. of linear reservoirs) for NASHYDs, SC for STANDHYDs and Manning's n for channel routing sections. The optimization was achieved by applying a multiplication factor (either greater than 1.0 or less than 1.0)

uniformly across all subwatersheds and routing reaches to those parameters until an optimum multiplier was found for each type of parameter. Each optimization run completed the equivalent of dozens of model simulations to identify the optimum parameter set. Table 2.2 shows the multiplier parameter space used.

Table 2.2: Boundaries of Calibration Multiplier Coefficients

	Initial Value	Lower Limit	Upper Limit
SC		0.5	5
N	1	1	2.5
Tp	1	1	3
Manning's n	1	1	2

- The results from the optimization simulations are shown in Table 2.4 and in graphs O1 to O9 in Appendix E. A typical case is shown in Figure 2.5
- It is clear that the optimization of the parameters results in excellent simulations of the observed hydrographs for the majority of the events. Six of the nine events have peak flows within +/- 10% of the observed. Volumes (although essentially forced by the initial CNs) are all within +/- 10%. The hydrograph shapes are also very closely reproduced for the six close calibrations.
- For the three events which are not as well reproduced, the following reasons have been noted:

    1. they are relatively small events (just exceeding the rainfall selection criteria of 12.5 mm) for two of which data for Pearson Airport indicated essentially zero rainfall. Other stations were substituted but in actuality the variation in areal rainfall is very high and affects runoff in a way which cannot be properly predicted.

    2. the parameter optimization procedure results in effectively the same parameters as the initial values because a better fit could not be found within the parameter space boundaries shown in the earlier table. A better fit could be obtained by relaxing the boundaries but this may lead to unrealistic parameters biasing the selection of final parameters based on a very small event.

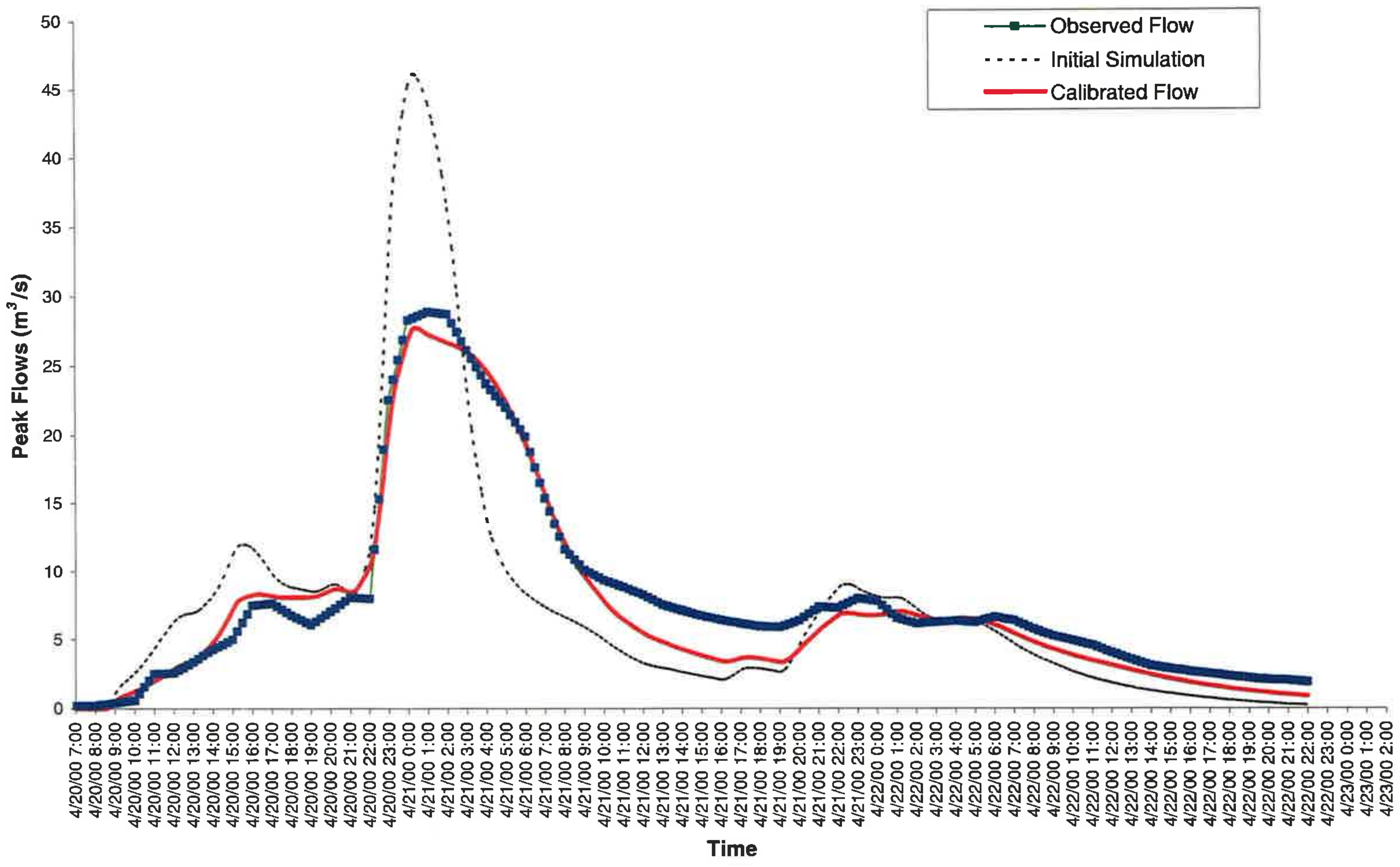
As such, the results from these three events were not relied upon for this part of the process but were reconsidered as part of the simulations with the final set of parameters.

The calibration procedure was also applied at the Goreway gauge. However, it was not feasible to obtain satisfactory results because of inconsistencies between observed runoff volumes and observed rainfalls. In some cases, the volume of runoff was less than or very similar to the observed rainfall.

Table 2.3: Comparison of Observed and Simulated Flows from Automated Calibration Procedure

Location	Rainfall			Runoff Volume (mm)		Volume %Difference	Peak Flow (m³/s)		Peak %Difference	Calibrated Coefficient			
	Time	Gauge Location	Depth (mm)	Observed	Calibrated		Observed	Calibrated		SC	N	TP	n
Islington	June 12,00	Pearson Airport	65.3	24.1	26.2	-8.3	31	32.2	-3.6	0.54	2.49	1	2
Islington	May 11,00	Pearson Airport	62.9	42.3	42.5	-0.5	57.6	64.6	-10.8	1.25	1.02	3	2
Islington	April 20,00	Pearson Airport	46.9	26.0	24.0	8.4	28.8	27.6	4.2	1.1	2.37	1.21	2
Islington	May 23,03	Pearson Airport	35.1	16.5	15.7	5.1	26.9	25.4	5.9	0.5	2.5	1	2
Islington	June 24,00	Pearson Airport	30.7	14.7	13.8	6.6	22.8	23.5	-3.1	1.92	2.5	1	2
Islington	August 11,03	Pearson Airport	29.3	11.2	12.3	-8.4	23.6	22.8	3.4	1.66	2.05	2.4	1.88
Islington	June 12,04	Peel S12	15.4	7.3	7.2	1.2	28.3	22.5	26.0	1.93	2.49	1	1.15
Islington	July 21,02	Pearson Airport	12.5	3.2	3.5	-8.3	21.6	10.6	103.6	0.5	2.48	1.03	1
Islington	July 14,04	Peel S8	12.5	5.0	5.0	0.4	21.8	11.4	90.8	0.58	2.49	1.02	1

Figure 2.5: Simulated and Observed Flows (April 20, 2000) - Calibrated Model



This was not consistent with the relationship of rainfall to runoff anticipated based on land use nor with the relationship in the rest of the basin. In addition, the flows at the upper gauge were in some cases almost the same as at the lower gauge although the latter has a drainage area several times larger than the former. Any attempt to include the calibrated upper portion with the lower portion of the basin resulted in erroneous results at the Islington gauge. As such, the calibration parameters were selected on the basis of the overall basin model ignoring the Goreway results.

2.2.2 Final Model Parameter Selection

Based upon the four well calibrated events, a set of parameters in which the k (SC), N, Tp & Manning's n are multiplied by 1.0, 2.5, 1.0 and 2.0 appeared to be the most promising choice for a common set of multipliers over all events. To verify the final performance of the model with those parameters, a final set of simulations was completed. This set was split into two parts. Four events were used in a "calibration" mode to see whether the proposed set of parameter multipliers was the best available. Three additional events were used in a validation mode where only the final set of multipliers was used. The results from the calibration set showed that the proposed set of multipliers (1.0, 2.5, 1.0 and 2.0) was in fact the best set possible. Hence the validation events were simulated with those multipliers also. Table 2.4 shows comparative observed and simulated peak flows, volumes for this final common set of parameters. Figures F1 to F7 in Appendix F show the final calibrated/validated hydrographs. Figure 2.6 shows a typical case. As indicated, the four calibration events match very closely with no bias. The three validation events are slightly less satisfactory with two events somewhat overestimated. However, with four out of seven events within 10% of the observed peak flow, the model is considered to be very well calibrated and suitable for simulating design events.

As a final check on the model calibration, the August 19, 2005 storm event was simulated. This event caused substantial flood damage within the Greater Toronto Area. It centred in the area north of Steeles Avenue and in some areas was estimated to have a return period well in excess of 1 in 100 years. Information on the rainfall amounts and distribution was obtained from a report commissioned by TRCA (Clarifica, 2005). Using this information and the selected set of model parameters, a simulation was completed with the model. Figure 2.7 shows the resulting hydrograph at Islington Avenue compared to the observed hydrograph. As indicated, the agreement is satisfactory and confirmed the suitability of the selected parameter set. However, despite numerous attempts, it was not feasible to match the observed hydrograph at Goreway Drive. Once again, the observed flows were inconsistent with those at the long term gauge at Islington Avenue and appear unreliable.

Table 2.4: Summary of Results Using Final Parameter Set

Comparison of Observed and Simulated Flows from Calibration									
Flow Location	Rainfall			Runoff Volume (mm)		Volume Difference (%)	Peak Flow (m^3/s)		Peak Difference (%)
	Time	Gauge Location	Depth (mm)	Observed	Calibrated		Observed	Calibrated	
Islington	May 23,03 ✓	Pearson Airport	35.1 ✓	16.5	16.5	0.1	26.9	26.3	-2.4
Islington	April 20,00 ✓	Pearson Airport	46.9 ✓	26	25.2	2.9	28.8	27.6	-4.1
Islington	May 11,00 ✓	Pearson Airport	62.9 ✓	42.3	44.1	-4.2	57.6	65.2	13.2
Islington	Aug 11,03 ✓	Pearson Airport	29.3 ✓	11.2	13.3	-18.3	23.6	21.9	-7.3
Comparison of Observed and Simulated Flows from Validation									
Flow Location	Rainfall			Runoff Volume (mm)		Volume Difference (%)	Peak Flow (m^3/s)		Peak Difference (%)
	Time	Gauge Location	Depth (mm)	Observed	Calibrated		Observed	Simulated	
Islington	June 12,04 ✓	Peel S12	15.4 ?	7.3	8.0	-9.6	28.3	26.3	-7.1
Islington	June 13,00 ✓	Pearson Airport	54.3 ?	24.1	28.0	-16.2	31.0	43.0	38.7
Islington	June 24,00 ✓	Pearson Airport	30.7 ✓	14.7	10.5	28.6	22.8	32.5	42.5

Parameter Multipliers: Sc = 1.0 N =2.5 Tp = 1 Manning's = 2.0

Flow Location	Rainfall			Runoff Volume (mm)		Volume Difference (%)	Peak Flow (m^3/s)		Peak Difference (%)
	Time	Gauge Location	Depth (mm)	Observed	Simulated		Observed	Simulated	
Islington	August 19, 05	Islington	79.2	38.7	34.3	11.4	48.7	60.2	23.5

Figure 2.6: Simulated and Observed Flows (April 20, 2000) - Final Model

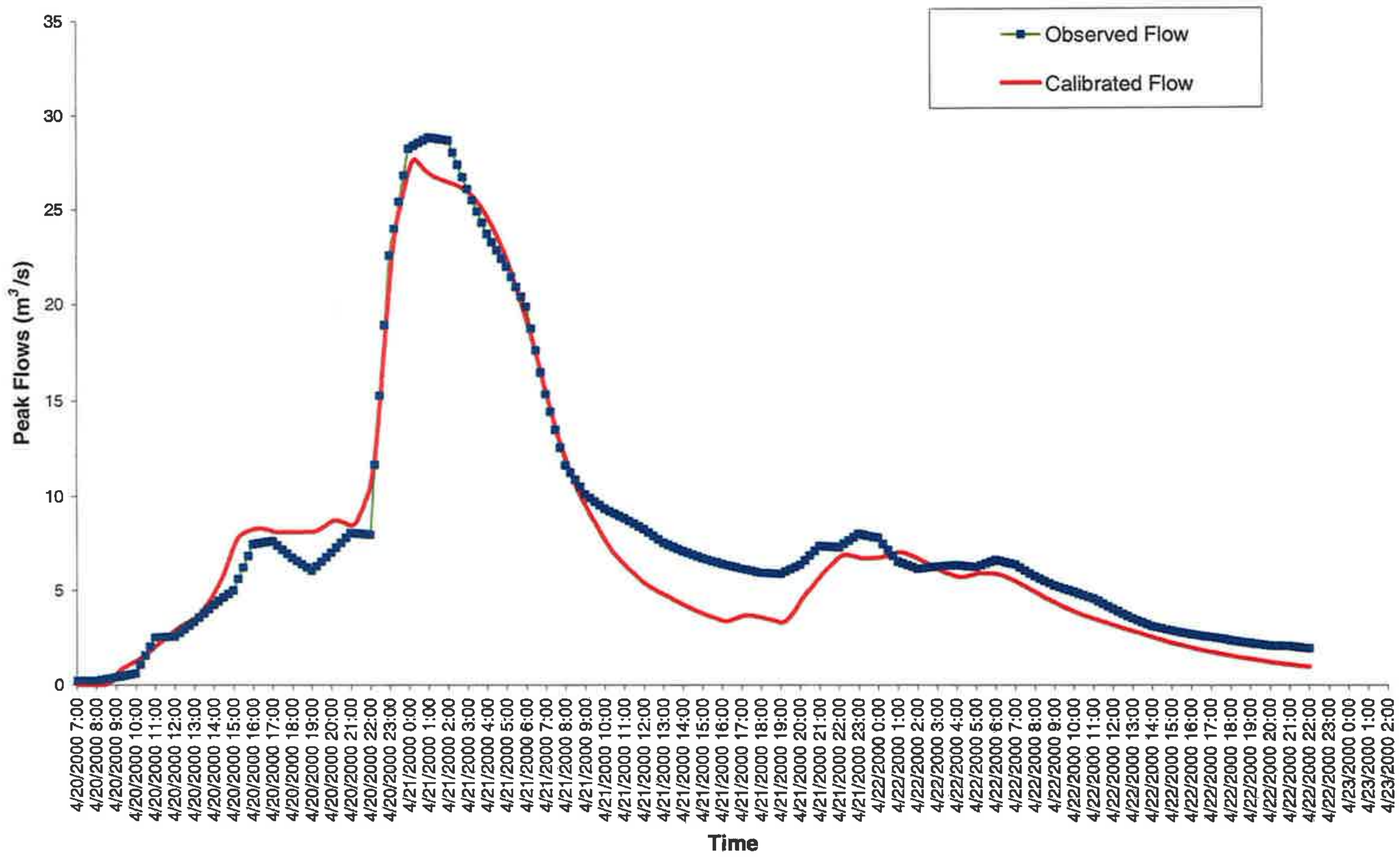
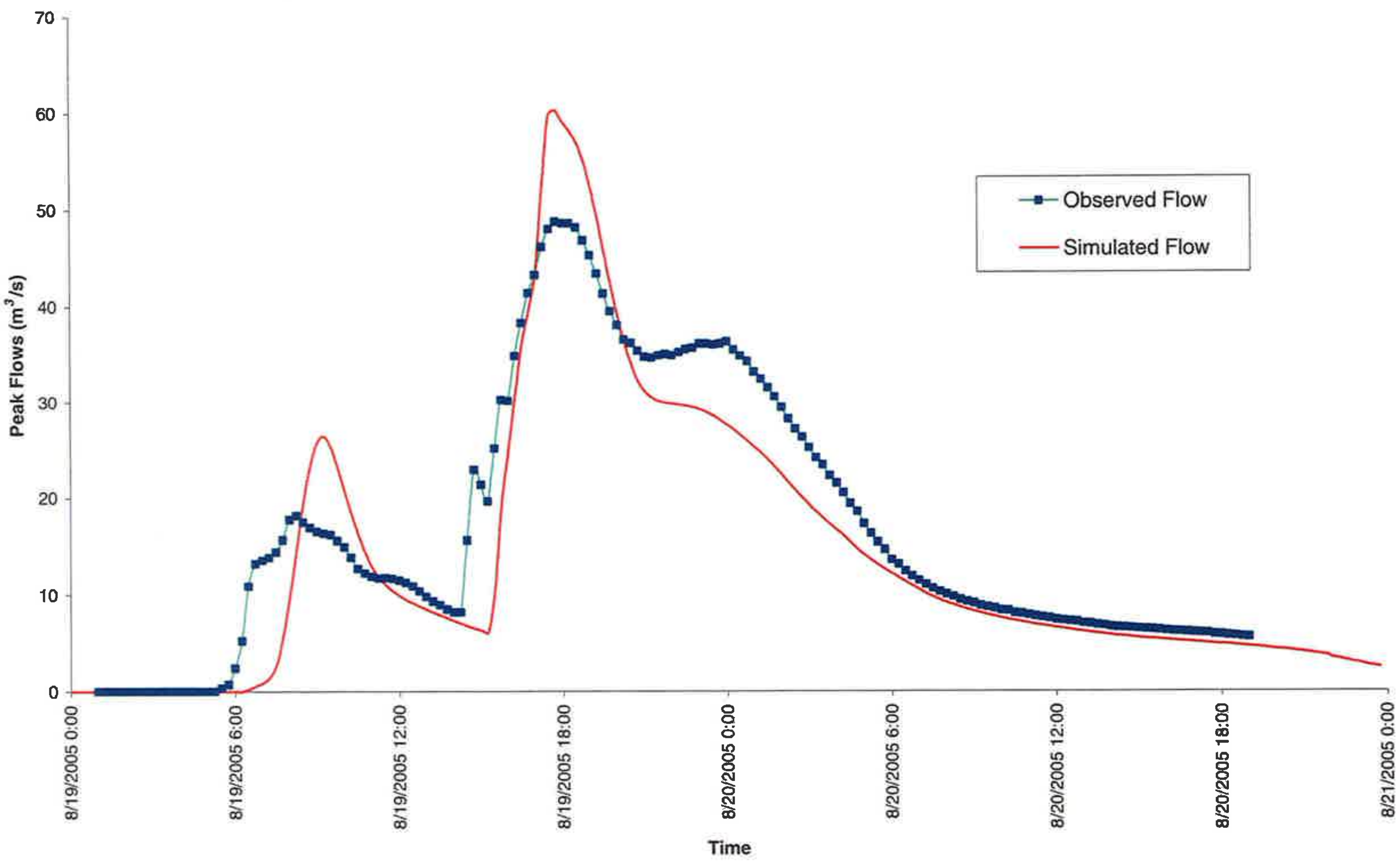


Figure 2.7: Simulated and Observed Flows (Aug 19, 2005) - Final Model



3. DESIGN STORM AND REGIONAL STORM SIMULATIONS

The 2 to 100 year design storms, and Regional Storm peak flows were simulated using the updated and validated model described in the previous sections for both the existing/future conditions scenario. The following sections provide a brief discussion of the modelling procedure and the results obtained from the 2 to 100 year design storms and Regional Storm simulations.

3.1 DESIGN STORM SIMULATIONS

3.1.1 Selection of Appropriate Distribution

Previous hydrologic modelling studies completed for TRCA across the GTA have utilized a variety of design storm distributions. These have included the 4-hour Chicago, 12-hour SCS and 6 and 12-hour AES distributions. Based upon discussion with TRCA staff, it was decided to evaluate the use of the AES 6 and 12 hour design storms for the Mimico Creek watershed. Using AMC II conditions for pervious areas, Visual OTTHYMO simulations were completed with the two storm distributions shown in Table 3.1. Table 3.2 compares the peak flows from these simulations at the Islington gauge. This was time for all nodes ?o through the watersheds. As indicated, the 12 hour storm produces more conservative flows for all return periods.

The design storm simulations for the existing/future conditions model were performed using the 12-hour AES distribution. Rainfall depths based on the IDF data recorded at the Pearson International Airport gauge and 15-minute time steps were used for the simulations.

3.1.2 Discussion of Results

The peak flows from the 2 to 100-year design storm simulations at various flow nodes throughout the watershed (see Figure 2.4) for are summarized in Table 3.3. Table 3.4 compares the 1 in 5 year and 1 in 100 year peak flows with those from the original 1978 model future conditions simulations at nodes where both models provided flows. As indicated, flows in the lower part of the watershed are relatively similar given the length of time that has elapsed. However, flows in the northern part of the watershed are significantly higher than predicted in 1978. This is because significantly more development has occurred in that part of the watershed than the Official Plan suggested at that time. As a result of development pressures, the City's of Brampton and Mississauga have expanded their urban areas well beyond the anticipated areas in 1978.

Table 3.1: 6 and 12 Hour AES Rainfall Distribution

Time (mins)	Rainfall (mm/h)											
	1 in 2 Yr		1 in 5 Yr		1 in 10 Yr		1 in 25 Yr		1 in 50 Yr		1 in 100 Yr	
	6hr	12hr	6hr	12hr	6hr	12hr	6hr	12hr	6hr	12hr	6hr	12hr
15	0.72	0.42	0.96	0.54	0.96	0.63	1.31	0.73	1.46	0.81	1.61	0.89
30	0.72	0.42	0.96	0.54	0.96	0.63	1.31	0.73	1.46	0.81	1.61	0.89
45	0.72	0.42	0.96	0.54	0.96	0.63	1.31	0.73	1.46	0.81	1.61	0.89
60	0.72	0.42	0.96	0.54	0.96	0.63	1.31	0.73	1.46	0.81	1.61	0.89
75	4.32	0.42	5.74	0.54	5.74	0.63	7.87	0.73	8.76	0.81	9.64	0.89
90	4.32	0.42	5.74	0.54	5.74	0.63	7.87	0.73	8.76	0.81	9.64	0.89
105	12.24	0.42	16.25	0.54	16.25	0.63	22.3	0.73	24.82	0.81	27.3	0.89
120	12.24	0.42	16.25	0.54	16.25	0.63	22.3	0.73	24.82	0.81	27.3	0.89
135	33.12	2.52	43.98	3.26	43.98	3.76	60.35	4.39	67.16	4.85	73.88	5.31
150	33.12	2.52	43.98	3.26	43.98	3.76	60.35	4.39	67.16	4.85	73.88	5.31
165	9.36	2.52	12.43	3.26	12.43	3.76	17.06	4.39	18.98	4.85	20.88	5.31
180	9.36	2.52	12.43	3.26	12.43	3.76	17.06	4.39	18.98	4.85	20.88	5.31
195	5.04	7.14	6.69	9.25	6.69	10.66	9.18	12.43	10.22	13.74	11.24	15.05
210	5.04	7.14	6.69	9.25	6.69	10.66	9.18	12.43	10.22	13.74	11.24	15.05
225	2.88	7.14	3.82	9.25	3.82	10.66	5.25	12.43	5.84	13.74	6.42	15.05
240	2.88	7.14	3.82	9.25	3.82	10.66	5.25	12.43	5.84	13.74	6.42	15.05
255	1.44	19.32	1.91	25.02	1.91	28.84	2.62	33.63	2.92	37.17	3.21	40.71
270	1.44	19.32	1.91	25.02	1.91	28.84	2.62	33.63	2.92	37.17	3.21	40.71
285	0.72	19.32	0.96	25.02	0.96	28.84	1.31	33.63	1.46	37.17	1.61	40.71
300	0.72	19.32	0.96	25.02	0.96	28.84	1.31	33.63	1.46	37.17	1.61	40.71
315	0.72	5.46	0.96	7.07	0.96	8.15	1.31	9.5	1.46	10.5	1.61	11.51
330	0.72	5.46	0.96	7.07	0.96	8.15	1.31	9.5	1.46	10.5	1.61	11.51
345	0.72	5.46	0.96	7.07	0.96	8.15	1.31	9.5	1.46	10.5	1.61	11.51
360	0.72	5.46	0.96	7.07	0.96	8.15	1.31	9.5	1.46	10.5	1.61	11.51
375		2.94		3.81		4.39		5.12		5.66		6.2
390		2.94		3.81		4.39		5.12		5.66		6.2
405		2.94		3.81		4.39		5.12		5.66		6.2
420		2.94		3.81		4.39		5.12		5.66		6.2
435		1.68		2.18		2.51		2.92		3.23		3.54
450		1.68		2.18		2.51		2.92		3.23		3.54
465		1.68		2.18		2.51		2.92		3.23		3.54
480		1.68		2.18		2.51		2.92		3.23		3.54
495		0.84		1.09		1.25		1.46		1.62		1.77
510		0.84		1.09		1.25		1.46		1.62		1.77
525		0.84		1.09		1.25		1.46		1.62		1.77
540		0.84		1.09		1.25		1.46		1.62		1.77
555		0.42		0.54		0.63		0.73		0.81		0.89
570		0.42		0.54		0.63		0.73		0.81		0.89
585		0.42		0.54		0.63		0.73		0.81		0.89
600		0.42		0.54		0.63		0.73		0.81		0.89
615		0.42		0.54		0.63		0.73		0.81		0.89
630		0.42		0.54		0.63		0.73		0.81		0.89
645		0.42		0.54		0.63		0.73		0.81		0.89
660		0.42		0.54		0.63		0.73		0.81		0.89
675		0.42		0.54		0.63		0.73		0.81		0.89
690		0.42		0.54		0.63		0.73		0.81		0.89
705		0.42		0.54		0.63		0.73		0.81		0.89
720		0.42		0.54		0.63		0.73		0.81		0.89

Table 3.2: Summary of 6 and 12 Hour AES Peak Flows at Islington

Storm Event (yr)	Peak Flow (m^3/s)		Runoff Volume (mm)	
	6 hr AES	12 hr AES	6 hr AES	12 hr AES
2	35.3	42.3	21.4	26.2
5	52.1	60.4	31.1	36.6
10	65.2	73.9	37.8	43.9
25	81.8	91.6	46.5	53.2
50	96.0	106.0	53.1	60.2
100	110.6	119.6	59.8	67.3

Table 3.3: Return Period Flows - 12 Hour AES Design Storms

Flow Point	VO_2 Id	Drainage Area (ha)	Flow Rates (m^3/s)					
			2 Yr	5 Yr	10 Yr	25 Yr	50 Yr	100 Yr
1	203	341.9	11.1	15.7	18.9	23.1	26.3	29.4
2	207	712.7	5.8	12.1	16.4	23.6	28.2	33.5
3	214	1316.7	22.0	30.0	35.8	43.6	49.6	55.5
4	215	1390.1	25.0	34.1	40.6	49.5	56.2	62.8
5	213	391.5	16.1	21.7	25.7	31.1	35.1	38.9
6	228	467.3	15.4	21.8	26.3	32.0	36.4	40.7
7	229	632.3	20.8	30.1	36.7	44.5	50.2	56.0
8	230	733.8	18.3	29.3	33.8	42.7	47.0	55.0
9	234	1078.5	21.1	32.0	39.7	49.5	56.7	64.0
10	216	1513.4	16.2	23.3	28.3	34.6	39.4	44.4
11	218	382.0	10.3	15.1	18.5	22.9	26.3	29.7
12	219	1992.8	15.5	22.5	27.0	32.7	37.1	41.5
13	233	3745.5	38.2	56.1	67.9	82.1	95.1	104.7
14	223	4129.2	35.1	50.7	60.9	73.3	85.0	93.6
15	254	4997.0	39.7	57.1	68.9	83.4	96.2	107.0
16	245	5488.2	40.6	57.9	69.9	85.5	98.7	110.3
17	249	5959.5	41.7	59.9	72.3	88.6	102.3	114.8
18	253	6582.2	41.9	60.5	73.9	91.3	105.5	118.4
19	260	6829.5	42.3	60.4	73.9	91.6	106.0	119.6 ✓
20	261	7095.0	42.6	60.7	74.4	92.5	107.1	121.0 ✓
21	266	8021.6	43.5	61.8	76.0	95.4	110.4	125.6
22	267	8178.7	43.7	62.0	76.2	96.0	111.3	126.4

Table 3.4: Comparison of Updated (2008) Flows & Original Flows (1978)

Flow Points (Nodes)	VO$_2$ ID #	Drainage Area (ha)	Flow Rates (m^3/s)								
			5 year			100 year			Regional		
			1978	2008	Difference (%)	1978	2008	Difference (%)	1978	2008	Difference (%)
2	207	712.7	6.0	12.1	102	22.0	33.5	52	61.0	84.8	39
4	215	1309.1	11.0	34.1	210	37.0	62.8	70	116.0	148.1	28
7	229	632.3	6.0	30.1	402	22.0	56.0	155	63.0	83.4	32
9	234	1078.5	13.0	32.0	146	55.0	64.0	16	93 116.0	112.3	-3 +20%
12	219	1992.8	19.0	22.5	18	68.0	41.5	-39	200.0	182.5	-9
13	233	3745.5	32.0	56.1	75	123.0	104.7	-15	310.0	321.3	4
16	245	5488.2	43.0	67.9	58	136.0	110.3	-19	340.0	360.9	6
19	260	6829.5	45.0	60.4	34	139.0	119.6	-14	402.0	394.8	-2
22	267	8178.7	50.0	62.0	24	142.0	126.4	-11	442.0	409.0	-7

3.2 REGIONAL STORM SIMULATIONS

3.2.1 Methodology

Regional Storm simulations were performed using the 15-minute rainfall distribution for Hurricane Hazel. The following differences between the Regional Storm simulations and the 2 to 100 year design storm simulations should also be noted:

- In accordance with standard practices, AMC III antecedent conditions, which correspond to saturated ground conditions due to heavy rainfall during the previous 36 hours, were assumed for the simulation. Hence the CN values for AMC III conditions were used for the Regional Storm model;
- As recommended in the *Technical Guidelines for Flood Plain Management in Ontario*, a reduction factor was applied to the total rainfall depth at applicable flow nodes based on the "equivalent circular area" upstream of the flow node. The equivalent circular area upstream of a flow node is defined as the area of the circle drawn with its centre at the centroid of the upstream drainage area, and its radius equal to the distance from the centroid to the flow node. The centroids of the upstream drainage areas for all flow nodes were calculated using the "script" writing capabilities of ARCVIEW. The applicable reduction factor for each flow node was then determined from Table D-3 in the *"Flood Plain Management in Ontario: Technical Guideline (1986)"*. For example, an areal reduction factor of 0.867 was used for the mouth of the creek based on the equivalent circular upstream drainage area of 525.9 sq. km.;

- All SWM ponds were eliminated from the Regional Storm simulations since these facilities were not designed to control a Regional Storm, and hence cannot be considered based on TRCA and MNR policy.

3.2.2 Discussion of Results

The Regional Storm flows at flow nodes throughout the watershed and the applicable reduction factors are summarized in Table 3.5. The flows from the present update have been compared to the future conditions flows from the original model in Table 3.4. The peak flows recorded in Table 3.4 indicate that the future conditions Regional Storm peak flow at the mouth of the Mimico has decreased slightly from 442.0 m^3/s to 409.0 m^3/s, which constitutes a decrease of approximately 7.5%. It appears that this may have occurred because of a more precise application of the equivalent circular area procedure resulting in a lower areal reduction factor. However, the Regional Storm peak flows at some locations (for example, flow nodes 2 and 4) show a significant increase from the previous to the present model. For example, at node 4 the increase is from 116.0 m^3/s to 148.1 m^3/s or 28%. This increase in peak flows may be attributed to the following factors:

- higher levels of imperviousness in many of the catchments in the upstream areas of the watershed. These increase the runoff and result in higher peak flows. The effect is less pronounced than for the design storm events since even undeveloped (pervious) catchment generate high runoff volumes due to AMC III conditions.
- the change from the use of the COMPUTE HYD subroutine to the STANDHYD subroutine to generate runoff hydrographs from the urban catchments result in considerably "peakier" hydrographs for the urban catchments. This difference is responsible for a significant increase in Regional flows at certain locations.

Table 3.5: Regional Storm Flows

Flow Point	VO_2 Id	Watershed Longest Length (km)	Equivalent Circular Area Regional Storm Areal Reduction Factor (km^2)	Regional Storm Areal Reduction Factor	Reduced Total Hazel Storm Depth (mm)	Drainage Area (ha)	Flow Rates (m^3/s)
1	203	2.80	6.1	100.0	212.0	341.9	46.1
2	207	4.80	18.1	100.0	212.0	712.7	84.8
3	214	7.35	42.5	99.2	210.3	1316.7	140.5
4	215	7.62	45.6	99.2	210.3	1390.1	148.1
5	213	6.68	35.0	99.2	210.3	391.5	54.8
6	228	6.05	28.8	99.2	210.3	467.3	61.6
7	229	6.99	38.4	99.2	210.3	632.3	83.4
8	230	7.92	49.3	98.2	208.2	733.8	87.4
→ 9	234	9.49	70.7	97.1	205.9	1078.5	112.3
10	216	8.74	59.9	98.2	208.2	1513.4	138.4
11	218	8.93	62.6	98.2	208.2	382.0	47.1
12	219	9.49	70.7	98.2	208.2	1992.8	184.8
13	233	10.58	87.8	97.1	205.9	3745.5	321.3
14	223	12.60	124.5	95.4	202.2	4129.2	312.5
15	254	14.59	167.0	94.2	199.7	4997.0	349.4
16	245	16.04	202.1	93.5	198.2	5488.2	360.9
17	249	17.78	248.0	92.0	195.0	5959.5	379.7
18	253	19.91	311.1	89.4	189.5	6582.2	386.9
19	260	21.08	348.8	89.4	189.5	6829.5	394.8
20	261	22.40	393.7	89.4	189.5	7095.0	402.8
21	266	24.86	485.0	86.7	183.8	8021.6	405.3
22	267	25.88	525.9	86.7	183.8	8178.7	409.0

← not the same Table 3.4

4. STORMWATER MANAGEMENT

4.1 Quantity Control Criteria

Current stormwater management criteria published by TRCA for Mimico Creek are limited to quantity control for flood related issues. They state that it is necessary to "control post-development peak flows to predevelopment levels for all storms up to and including the 100-year storm (i.e. 2, 5, 10, 25, 50, and 100-year storms)." The watershed is essentially fully developed with only ongoing infilling of new development areas in the upstream areas. Control of flows in the upstream areas of a watershed using storage in SWM facilities tends to delay the upstream hydrograph peak resulting in less coincidence of peaks further downstream. This results in an overall reduction in peak flows in the higher order, downstream water courses. Hence it is recommended that the current policy stay in place in regard to any development proposals which remain to be approved in the future. Other criteria dealing with water quality, erosion control and water balance may also be desirable but are beyond the scope of this study to evaluate.

4.2 Toronto Wet Weather Flow Master Plan Recommendations

The area of Mimico Creek within the boundary of the City of Toronto was studied as part of the *Toronto Wet Weather Flow Management Master Plan (TWWFMMP).* The SWM quantity control recommendations in that plan were developed based on continuous hydrologic modelling using continuous rainfall data from the area, rather than the event based approach used for the current study. The largest storm events in the modelling period considered for the WWF study are in the range of 2-year design storms in the area. As such, the SWM recommendations in the *TWWFMMP* were developed based on providing effective stormwater controls for more frequent storm events. The final "preferred" long-term (100-year) stormwater management strategy for the Mimico watershed was selected after evaluating several strategies against the City's hydrologic, water quality and geomorphic objectives. A detailed 25-year plan, which would be implemented as the first phase of the 100-year plan, was also developed. The stormwater quantity control measures in either of these strategies can be broadly subdivided into three categories:

- **Source Control Measures**-A full range of source control measures were considered for various land uses in the above strategies. The 25-year plan includes a "voluntary" level of "uptake" of source controls, and the preferred strategy includes an "enhanced" level of "uptake" of source controls. These levels of uptake represent the best estimate of the public's willing to implement source control based upon current City programs and additional incentives. The "enhanced" level of source controls will be enforced by the city in areas of land use intensification.

- **Conveyance Controls**-These consist of exfiltration pipe systems in the areas with suitable soils, and filtration systems in all other areas. At the opportunistic level for the 25-year plan, the conveyance controls will be implemented over 25% of the area. At the enhanced level (for the long-term strategy), exfiltration methods were assumed to be implemented in all areas with suitable soils and filtration systems were assumed to be implemented in all other areas.

- **End-of-Pipe Controls**-These consist of "opportunistic" or "green" end-of-pipe facilities above ground to provide erosion and water quality controls for the 25-year plan. Additional underground facilities to provide water quality controls were also included in the "aggressive" approach for the preferred long-term strategy. Quantity control storage for end-of-pipe facilities is not recommended in the WWF Master Plan;

The stormwater management measures described above will assist in improving the overall water management of Mimico Creek but will have little or no effect on flood related flows greater than the 1 in 2 year return period. Hence they are in no way inconsistent or duplicative TRCA's existing stormwater management criteria for Mimico Creek.

5. CONCLUSIONS AND RECOMMENDATIONS

The main conclusions and recommendations of this study may be summarized as follows:

- The HYMO based hydrologic model for the Mimico watershed was converted to a Visual OTTHYMO Version 2.0 (VO2) based model and updated to reflect the current development conditions in the watershed. The updated model was calibrated and validated with a series of storm events from 2002 to 2004. A final check on the model validity was made using the August 19, 2005 event. It was concluded that the updated and validated VO_2 model is an accurate representation of the current hydrologic conditions in the Mimico watershed;
- A total of 21 storm water management ponds was represented in the model using lumped representations where multiple ponds are located in a single catchment.
- Based on the 2 to 100 year design event simulations performed using the updated and validated model, the existing 100-year peak flows near the mouth of the Mimico have decreased somewhat compared to the future flows from the original 1978 model. However, in upstream areas, increases in peak flows are predicted compared to 1978 future flows;
- The Regional Storm simulations were performed without any of the stormwater quantity controls implemented in the watershed, since TRCA and MNR policy does not account for storage not specifically designed to control Regional Storm flows. The future conditions Regional Storm flows in the upstream area of the watershed show significant increases. This is primarily the result of more development in the northern put of the watershed than anticipated in the Official Plan at the time of the 1978 study.
- It is recommended that TRCA continue to employ its existing quantity control stormwater management criteria for Mimico Creek for the limited remaining areas of future infill development.

APPENDIX A: User's Guide

1 INTRODUCTION

The User's Guide has been prepared in accordance with the Terms of Reference to provide supplementary information regarding the modelling procedures adopted during the update and validation of the Don River hydrologic model to assist in future updates of the model. The User's Guide contains detailed discussions on:

- Methodology adopted for the modelling of "lumped" SWM ponds;

2 "LUMPED" SWM POND MODELLING

As discussed in the main report, SWM ponds constructed in the watershed were included in the updated Mimico Creek hydrologic model based on a "lumped" SWM pond modelling procedure. This involved combining all SWM ponds located in a particular subcatchment into one "lumped" pond modelled using a single ROUTE RESERVOIR subroutine. The storage volumes in these "lumped" ponds can be determined by adding the storage volumes in each of the ponds in the catchment, for the 2 to the 100-year design storms. The discharges from the lumped ponds were estimated following the same approach as that adopted in previous studies (e.g.: the *Don River Hydrology Update* and the *Rouge Watershed Study*, *MMM*). Following this approach, the discharges from the lumped ponds are calculated as the sum of the discharges from the individual ponds scales up by a "scaling factor". The discharges of smaller off-line ponds were not considered to contribute significantly to the discharges from the lumped ponds, if larger on-line ponds were present. The scaling factor represents the ratio of the controlled upstream drainage area to the entire catchment, and is calculated based on the Rational Method. It is calculated by equation:

$$\alpha = {\{A_c[0.9 * i_c + 0.2 * (1 - i_c)]\}} \Big/ {\{A_p\ [0.9 * i_p + 0.2 * (1 - i_p)]\}}$$

where

α = scaling factor;

i = imperviousness; and

subscripts 'p' and 'c' denote pond and catchment respectively

It has been established from previous studies that the design flows obtained from these "lumped" ponds at the outlets of the respective catchments are very similar to the flows obtained from the catchments when the SWM ponds are modelled individually. The "lumped" ponds have the added advantage of reducing the size of the hydrologic model. Hence, the "lumped" SWM pond approach is considered be a more efficient approach to SWM pond modelling on a watershed scale, especially when there are a significant number of ponds in a watershed. The "lumped" SWM ponds, and their respective storage-discharge curves, included in the model of the Mimico Creek River watershed, are summarized in Appendix B.

In some cases, the storage-discharge relations include "caps" to avoid unrealistic reductions of post-development flows when the storages are exceeded. Moreover, it was necessary to provide storage-discharge pairs in addition to those shown during application, to avoid increase (rather than attenuation) of post-development flows due to instabilities arising from the abrupt increase in discharges in the "caps".

APPENDIX B:
Details of SWM Facilities Included in Model

SUMMARY OF EXISTING SWM POND

MIMICO CREEK WATERSHED

VO_2 ID	POND NO.	REFERENCES
600	13.1	Brampton Management. Mimico Creek Watershed Project No. 96-405
601	13.5	Functional Servicing and Stormwater Management Report. William Oslar Health Center, Brampton.
611	20.0	Stormwater Detention Facility. Table 1: Stage - Outflow Relationship
9500	20.1	Marathon Lands Park Area 11 for Highway 407
609	20.3	Brampark Management. Mimico Creek Watershed Project No. 96-405
628	267.0	Stormwater Management Report Prepared by Marshall, Macklin, Monaghan for Penereal Development
614	267.1	Magna Magna Training Centre
628	309.0	Stormwater Management Report Prepared by Marshall, Macklin, Monaghan for Penereal Development
620	332.1	Intermodel Drive Extention Stormwater Management Report
620	332.2	Intermodel Drive Extention Stormwater Management Report
620	332.3	Intermodel Drive Extention Stormwater Management Report
623	407.7	
617	407.8	
AIRPORT PONDS		
643	409-2,4	Master Stormwater Implementation Plan from Final Report by Greater Toronto Airports Authority
643	6B	Master Stormwater Implementation Plan from Final Report by Greater Toronto Airports Authority
645	Aeroquay	Master Stormwater Implementation Plan from Final Report by Greater Toronto Airports Authority
657	Carlingview	Master Stormwater Implementation Plan from Final Report by Greater Toronto Airports Authority
658	SWM 16	Master Stormwater Implementation Plan from Final Report by Greater Toronto Airports Authority

APPENDIX C:
Parameter Set for VO_2 Model

STANDHYD								
Catchment #	Parameters							
	XIMP (%)	TIMP (%)	LGP (m)	LGPI (m)	SCP (hrs)	SCPI (hrs)	CN	CN III
100	38	38	40	818	0.325	0.144	56	83
101	30	30	40	702	0.313	0.132	56	83
103	38	38	40	889	0.330	0.152	56	84
109	60	60	40	572	0.290	0.116	58	86
108	53	53	40	900	0.326	0.153	68	86
107	45	45	40	810	0.319	0.143	57	85
111	53	53	40	793	0.311	0.142	58	86
110	60	60	40	613	0.294	0.121	58	86
116	23	23	40	844	0.320	0.147	58	86
119	30	30	40	591	0.291	0.119	58	86
121	45	45	40	596	0.292	0.119	58	86
118	53	53	40	621	0.295	0.122	58	86
117	53	53	40	908	0.326	0.154	58	86
115	53	53	40	1184	0.353	0.180	58	86
122	53	53	40	699	0.304	0.131	58	86
131	23	23	40	907	0.329	0.153	57	85
130	38	38	40	531	0.287	0.111	57	85
120	30	30	40	1341	0.367	0.194	58	86
133	45	45	40	865	0.325	0.149	57	85
135	38	38	40	606	0.302	0.121	56	83
128	30	30	40	631	0.296	0.123	58	86
134	38	38	40	840	0.331	0.147	55	82
136	45	45	40	1021	0.340	0.165	57	85
104	45	45	40	645	0.309	0.125	55	82
105	45	45	40	717	0.314	0.133	56	83
112	38	38	40	1019	0.337	0.165	58	86
113	38	38	40	1072	0.342	0.170	58	86
114	53	53	40	1049	0.343	0.167	57	85
123	23	23	40	822	0.317	0.144	58	86
126	38	38	40	838	0.323	0.146	56	83
124	60	60	40	778	0.313	0.140	58	86
106	23	23	40	398	0.266	0.094	58	86
125	38	38	40	642	0.298	0.125	58	86
127	53	53	40	649	0.307	0.126	56	83
129	45	45	40	990	0.343	0.162	56	83
138	38	38	40	1108	0.354	0.173	56	83
139	53	53	40	376	0.266	0.091	57	85
137	45	45	40	1007	0.336	0.163	58	86
140	60	60	40	841	0.328	0.147	56	83
141	30	30	40	915	0.330	0.154	57	85
142	60	60	40	941	0.335	0.157	56	84
161	53	53	40	1316	0.370	0.192	56	84
160	38	38	40	505	0.281	0.108	58	86
143	60	60	40	654	0.305	0.126	56	84
156	60	60	40	429	0.282	0.098	56	84
145	60	60	40	429	0.282	0.098	55	82
157	60	60	40	591	0.300	0.119	56	83
159	60	60	40	905	0.326	0.153	58	86

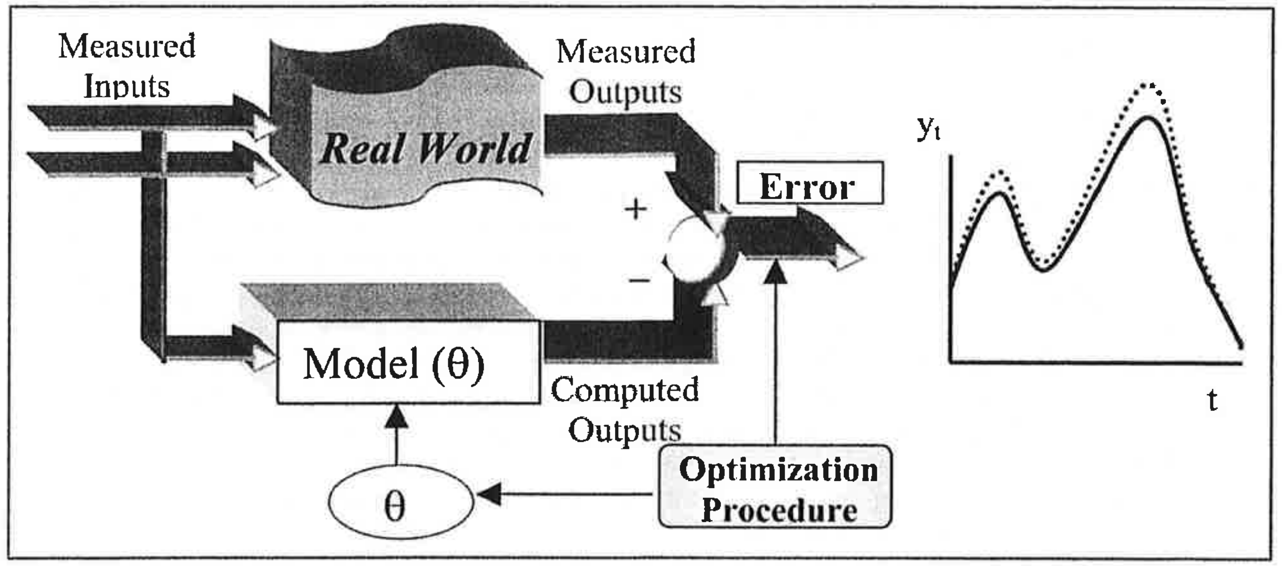
NASHYD				
Catchment #	Parameters			
	CN	CN III	N	TP (hr)
170	57	86	5	0.670
176	57	85	5	1.030
175	55	82	5	0.594

Route Channel				
Catchment #	Parameters			
	Length (m)	Channel Slope (%)	Avg. Floodplain Slope (%)	Channel Roughness
300	1385	1.3	1.3	0.06
301	1252	0.7	0.7	0.06
302	1015	1.1	1.1	0.06
303	737	1.2	1.2	0.07
304	932	0.5	0.5	0.07
305	1375	0.4	0.4	0.06
306	1779	0.2	0.2	0.06
307	934	0.4	0.4	0.06
501	1159	0.4	0.4	0.06
502	850	0.4	0.4	0.06
308	1657	0.2	0.2	0.06
309	2307	1.3	1.3	0.06
310	948	0.8	0.8	0.06
311	965	0.4	0.4	0.06
312	1780	0.4	0.4	0.06
313	937	0.3	0.3	0.06
314	1408	0.7	0.7	0.06
315	1775	0.3	0.3	0.08
316	1310	0.2	0.2	0.06
317	783	0.2	0.2	0.06
318	623	0.4	0.4	0.06
319	1865	0.2	0.2	0.06
320	1289	0.2	0.2	0.06
321	1655	0.3	0.3	0.06
322	1573	0.3	0.3	0.03
323	937	0.3	0.3	0.06
324	1723	0.3	0.3	0.06
325	1163	0.3	0.3	0.08
326	990	0.4	0.4	0.08
327	1110	0.6	0.6	0.08
328	1357	0.5	0.5	0.08
329	2574	0.8	0.8	0.07
330	703	0.7	0.7	0.08
331	632	0.9	0.9	0.06

APPENDIX D:
Documentation of CSE Method

SHUFFLED COMPLEX EVOLUTION METROPOLIS (SCEM-UA) ALGORITHM

MANUAL



Version 1.0
Januari, 2003

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each of the parameters, thereby defining the feasible parameter space (Eq. [2]), and imposing a uniform (noninformative) prior distribution on this rectangle.

Assuming that the residuals are mutually independent, each having the exponential power density E(σ,γ) the likelihood of a parameter set θ for describing the observed data **y** can be computed using [*Box and Tiao*, 1973],

$$p(\theta \mid \mathbf{y},\gamma) = \left[\frac{\omega(\gamma)}{\sigma}\right]^N \exp\left[-c(\gamma)\sum_{j=1}^{N}\left|\frac{e_j(\theta)}{\sigma}\right|^{2/(1+\gamma)}\right] \tag{5}$$

where

$$\omega(\gamma) = \frac{\{\Gamma[3(1+\gamma)/2]\}^{1/2}}{(1+\gamma)\{\Gamma[(1+\gamma)/2]\}^{3/2}}$$

$$c(\gamma) = \left\{\frac{\Gamma[3(1+\gamma)/2]}{\Gamma[(1+\gamma)/2]}\right\}^{1/(1+\gamma)} \tag{6}$$

The parameter γ specifies the error model of the residuals. The residuals are assumed normally distributed when $\gamma = 0$, double exponential when $\gamma = 1$, and tend to a uniform distribution as $\gamma \to -1$. Assuming a noninformative prior of the form $p(\theta,\sigma \mid \gamma) \propto \sigma^{-1}$, Box and Tiao [1973] showed that the influence of σ can be integrated out, leading to the following form of the posterior density of θ,

$$p(\theta \mid \mathbf{y},\gamma) \propto [M(\theta)]^{-N(1+\gamma)/2} \tag{7}$$

where

$$M(\theta) = \sum_{j=1}^{N}\left|e_j(\theta)\right|^{2/(1+\gamma)} \tag{8}$$

For more information about the Bayesian inference scheme, please refer to *Box and Tiao* [1973] and, more recently, to *Thiemann et al.* [2001].

It is not uncommon for the objective function in nonlinear parameter estimation problems to have multiple local optima. However, the standard methods used to solve these problems are local methods that offer no guarantee that the global optimum, and thus the best set of model parameters, has been found. The need for effective and efficient optimization procedures that can help in the identification of a unique and realistic set of optimal parameters have stimulated the research on globally based optimization methods. The theory and practice of global optimization has progresses rapidly during the last decade, and a wide variety of different algorithms are now available. In the development of suitable automatic calibration approaches, we must consider the fact that the model optimization problem usually suffers from the existence of multiple optima in the parameter space (with

APPENDIX E:

Plots of Hydrographs for Automated Calibration Phase

Figure O1: Comparison of Peak Flows (June 12, 2000)

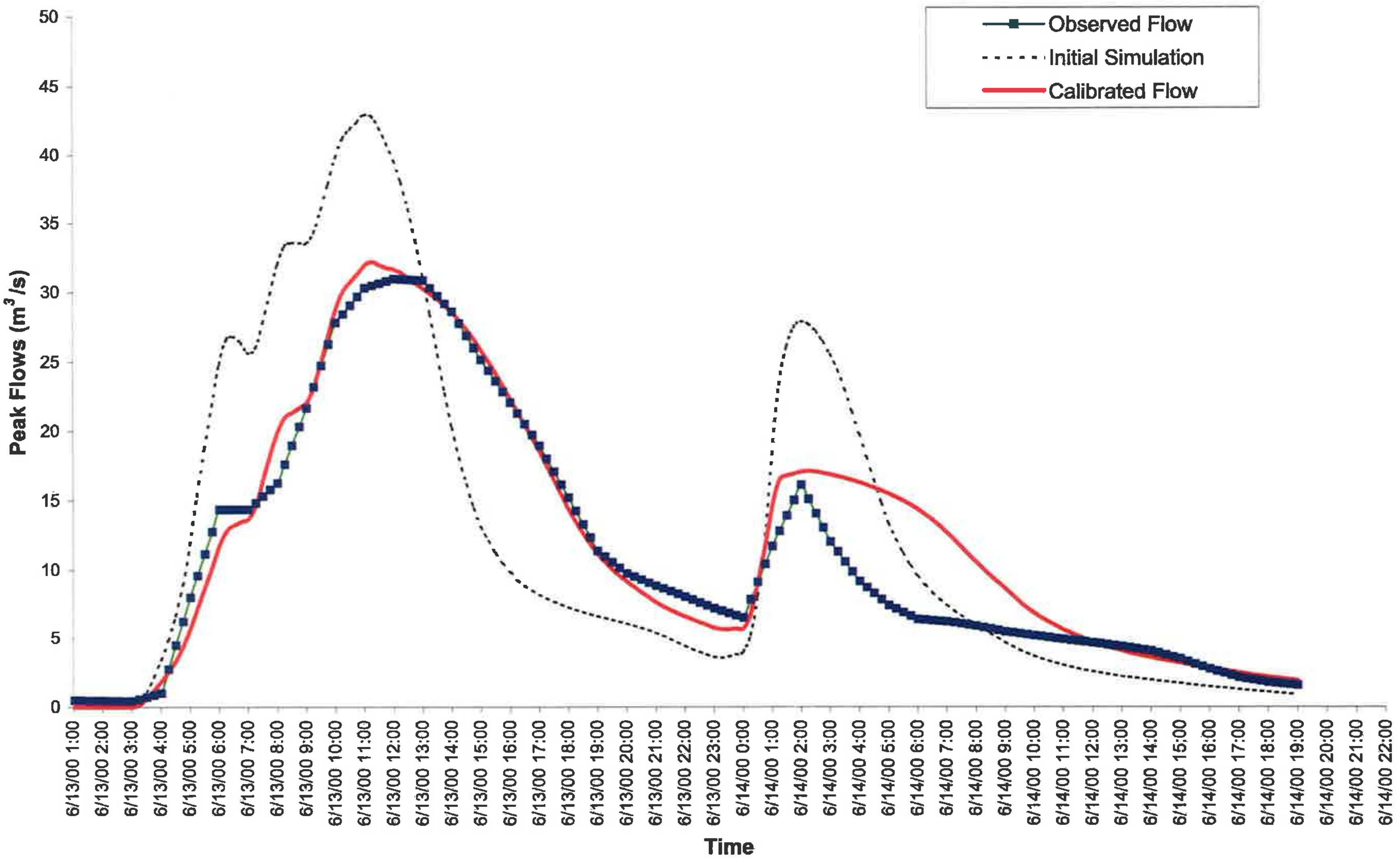


Figure O2: Comparison of Peak Flows (May 11, 2000)

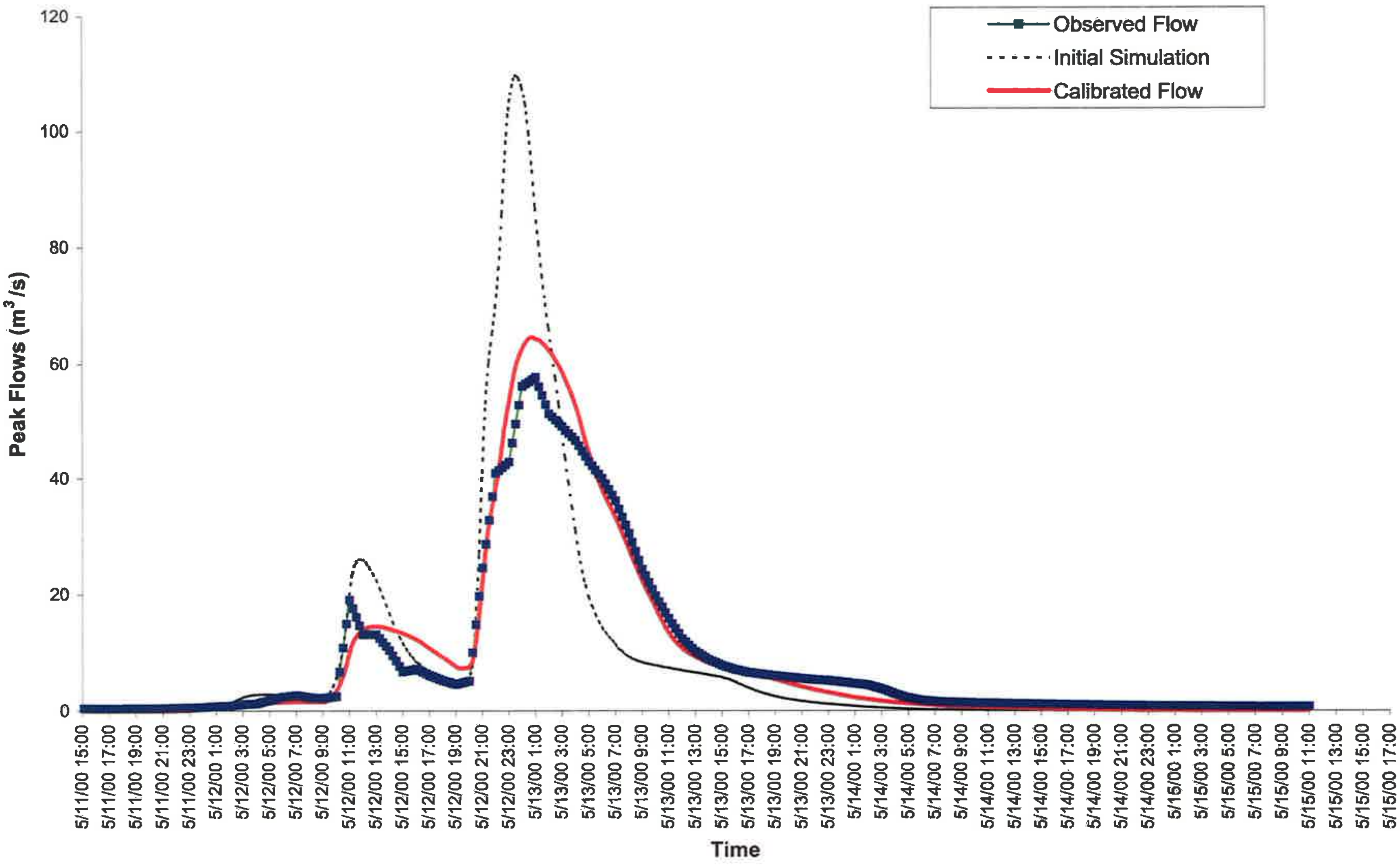


Figure O3: Comparison of Peak Flows (April 20, 2000)

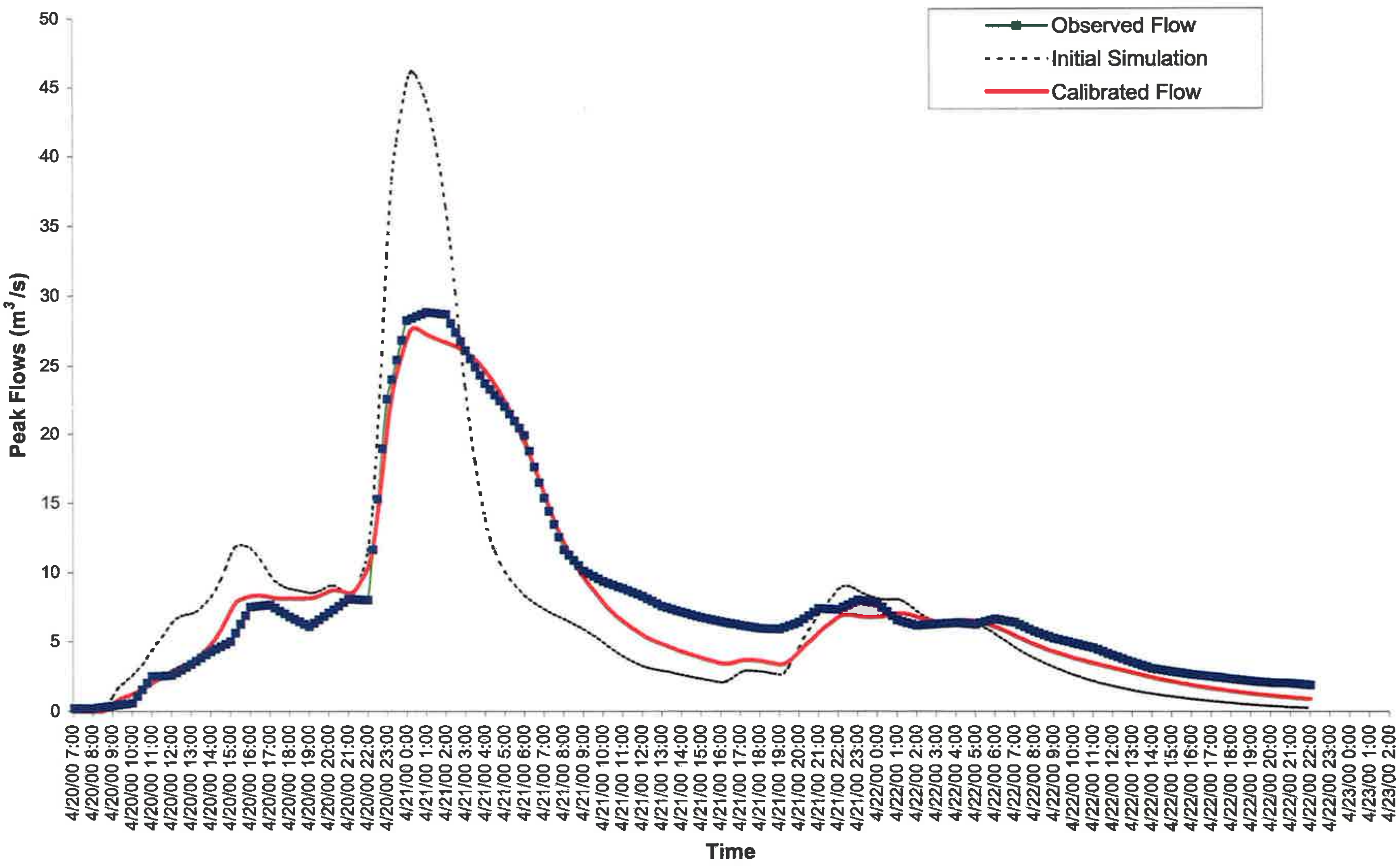


Figure O4: Comparison of Peak Flows (May 23, 2003)

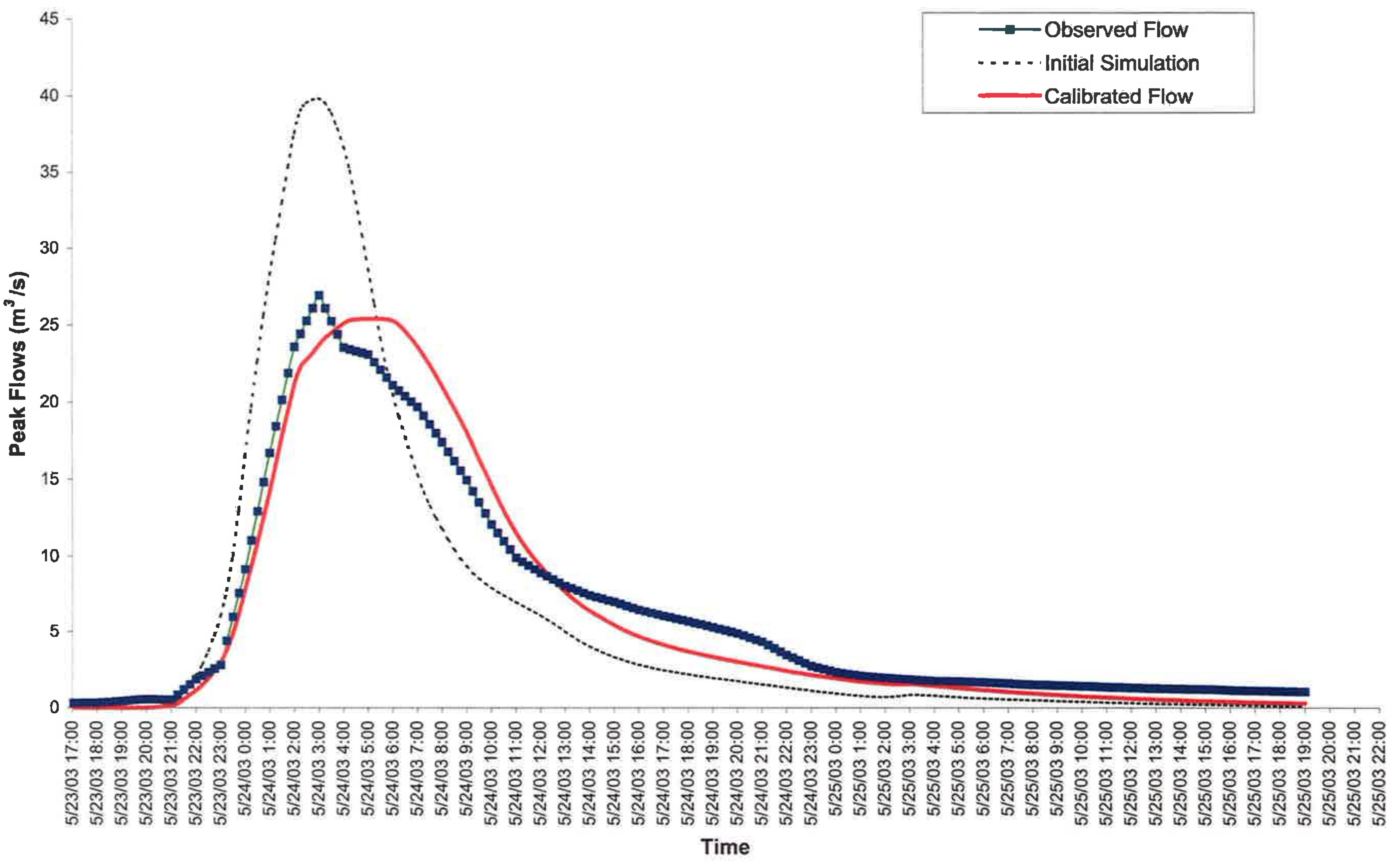


Figure O5: Comparison of Peak Flows (June 24, 2000)

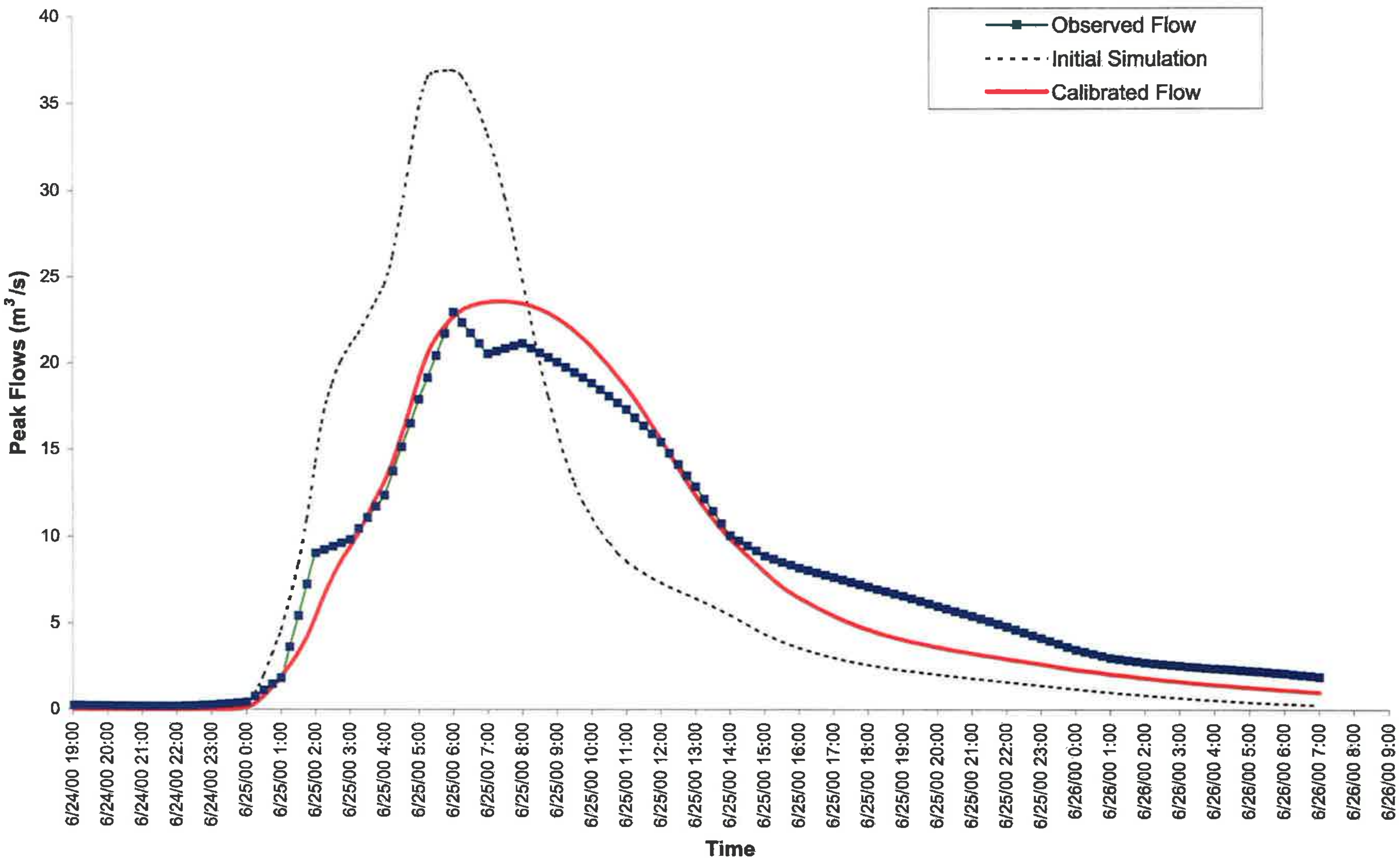


Figure O6: Comparison of Peak Flows (August 11, 2003)

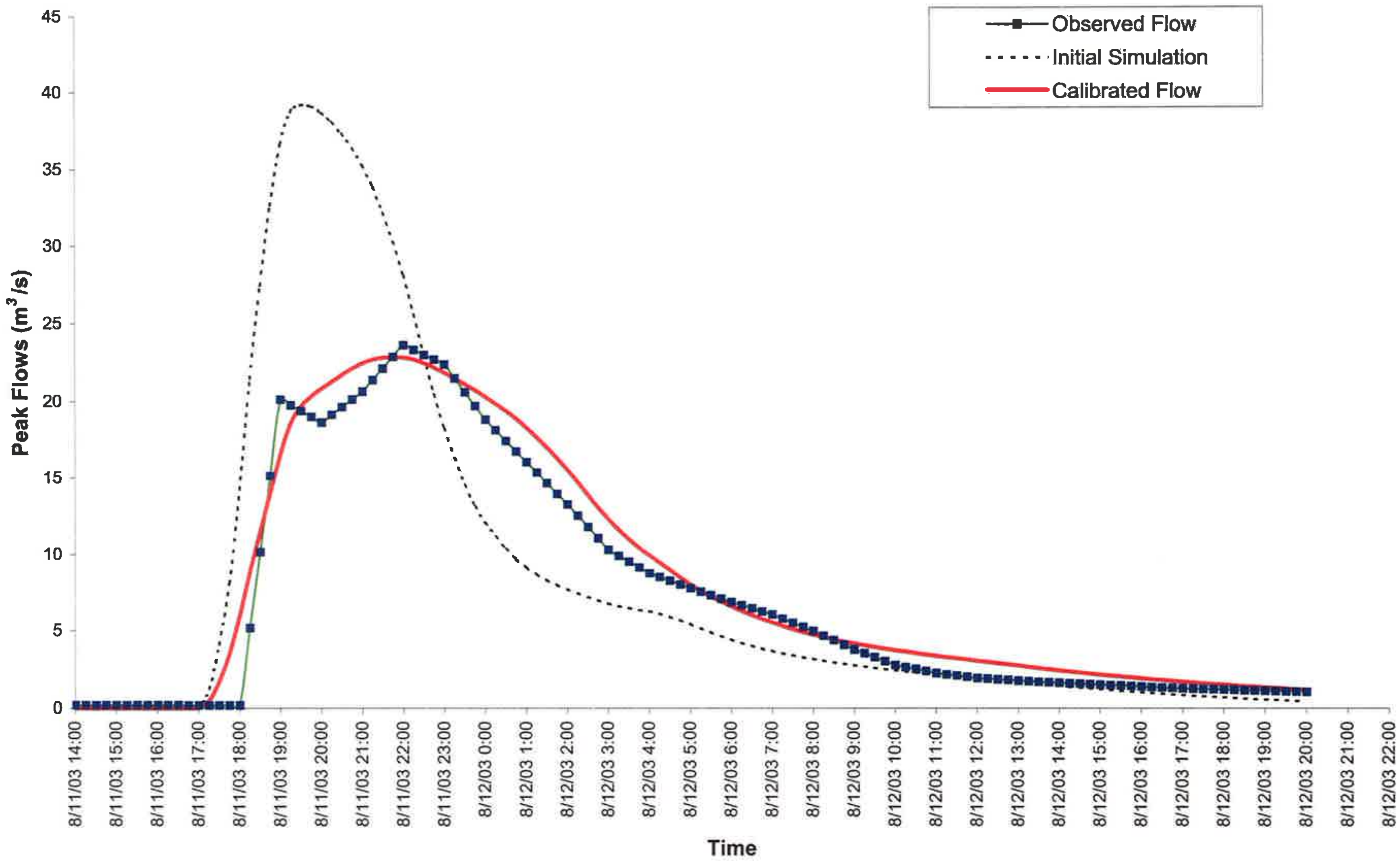


Figure O7: Comparison of Peak Flows (June 13, 2004)

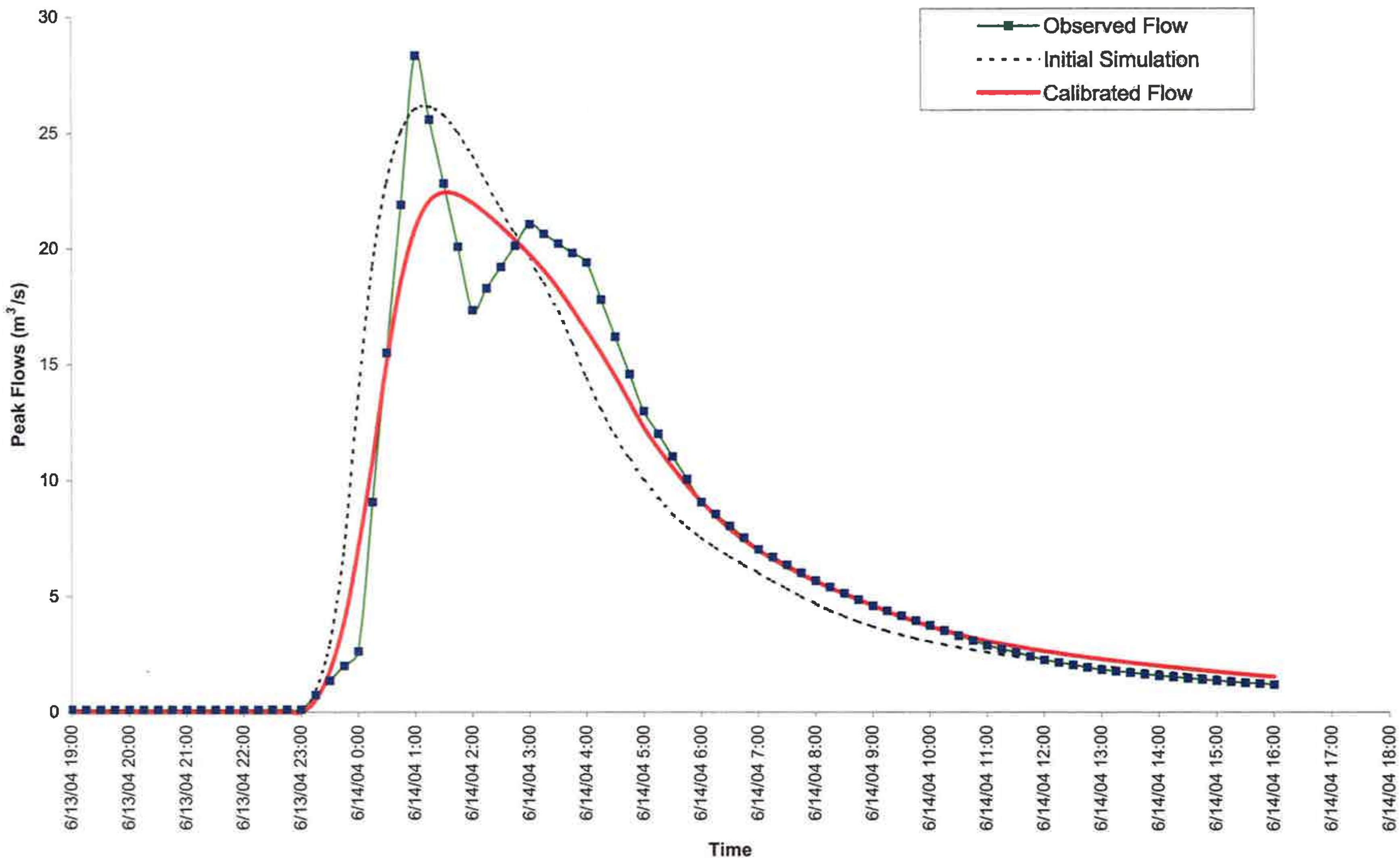


Figure O8: Comparison of Peak Flows (July 21, 2002)

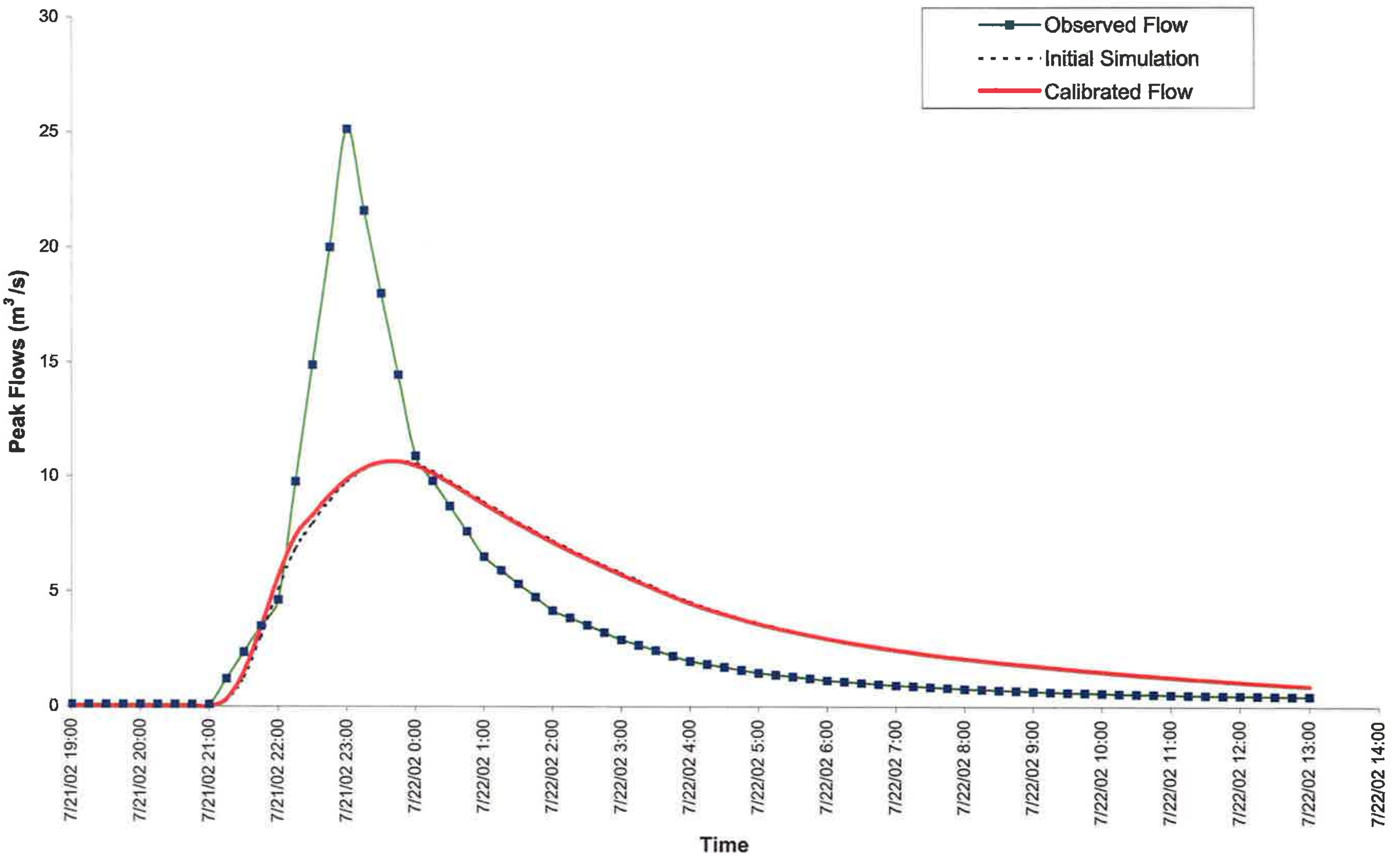
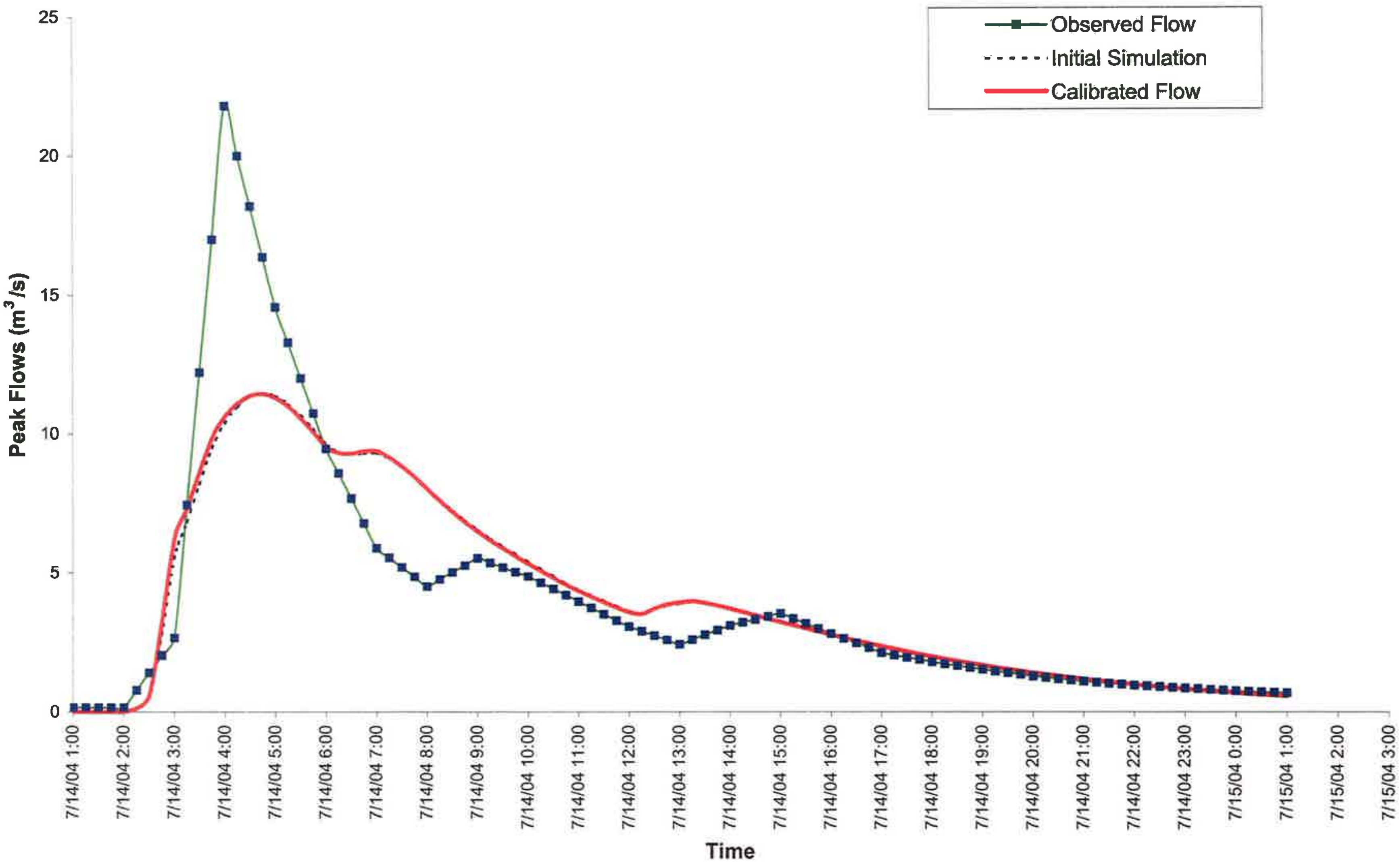


Figure O9: Comparison of Peak Flows (July 14, 2004)



APPENDIX F:
Plots of Hydrographs for Final Model Parameters

Figure F1: Final Comparison of Peak Flows (May 23, 2003)

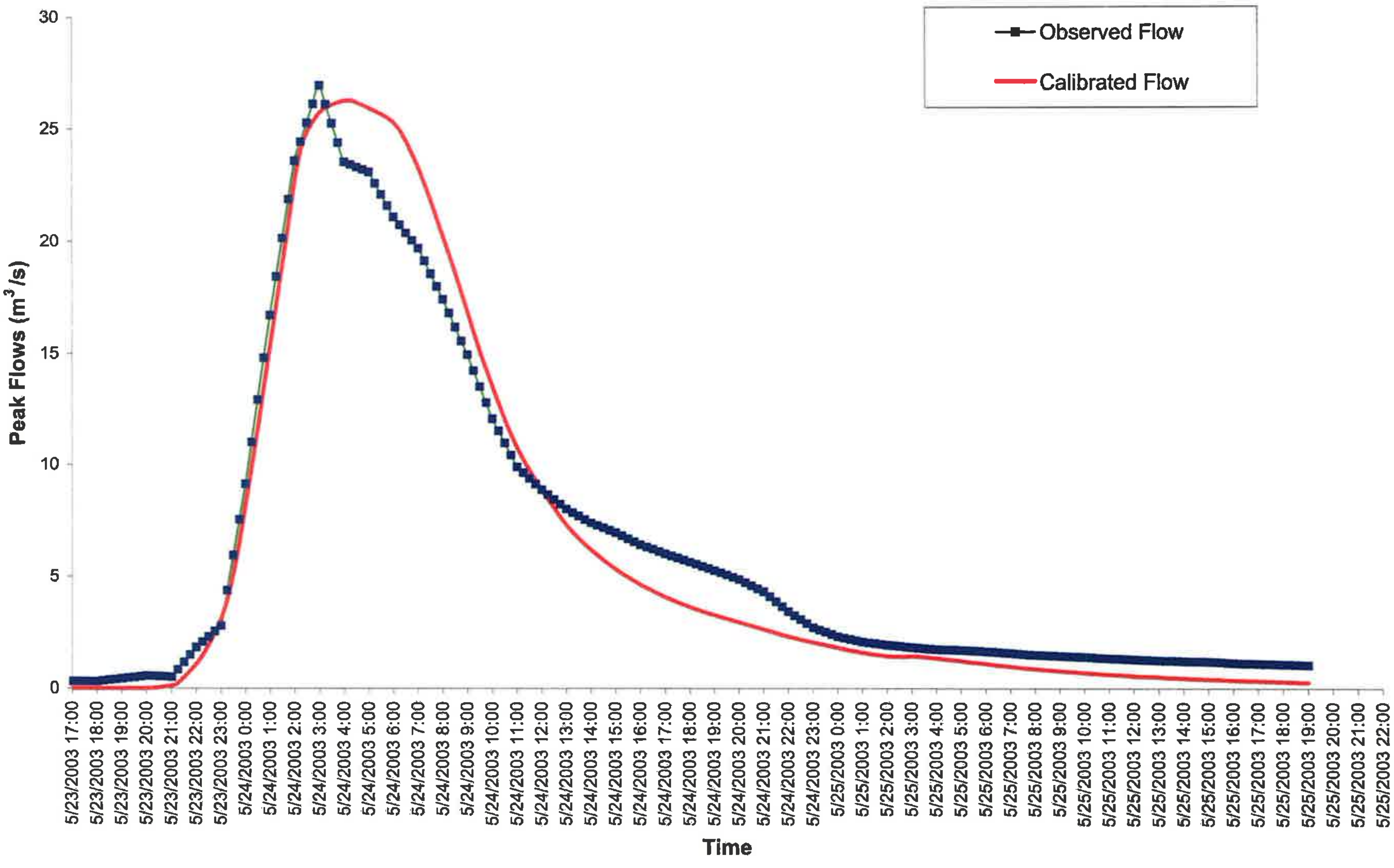


Figure F2: Final Comparison of Peak Flows (April 20, 2000)

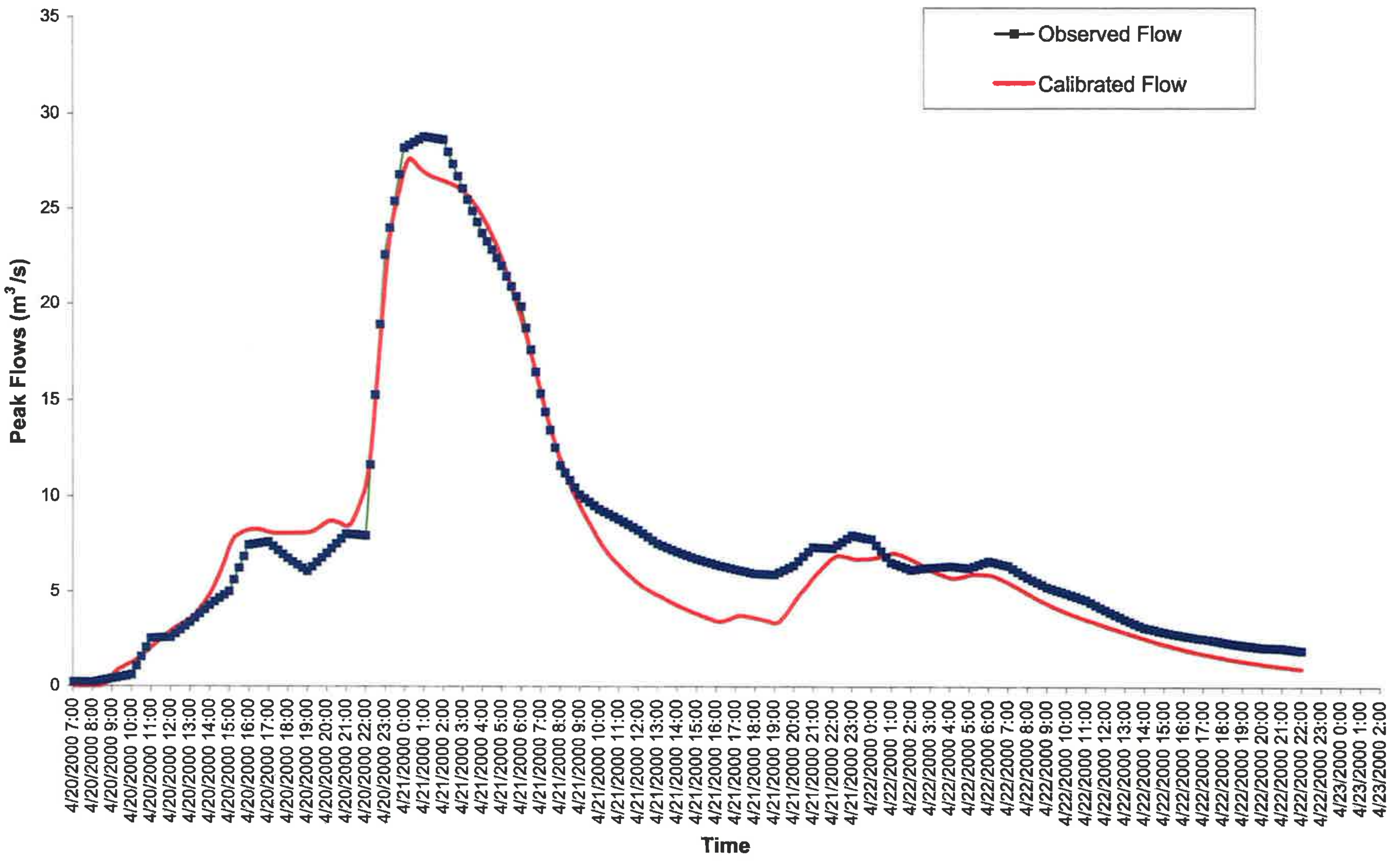


Figure F3: Final Comparison of Peak Flows (May 11, 2000)

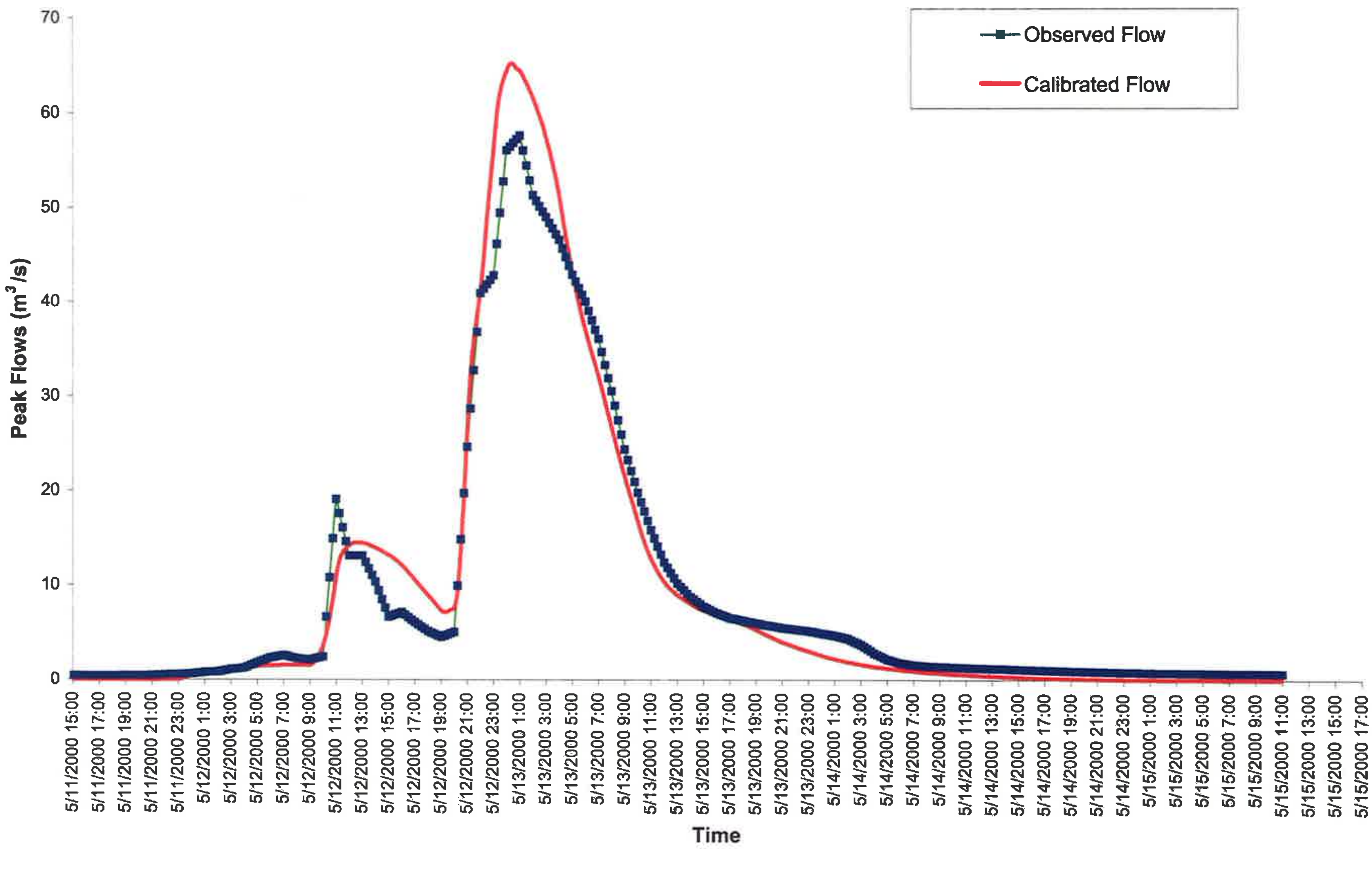


Figure F4: Final Comparison of Peak Flows (August 11, 2003)

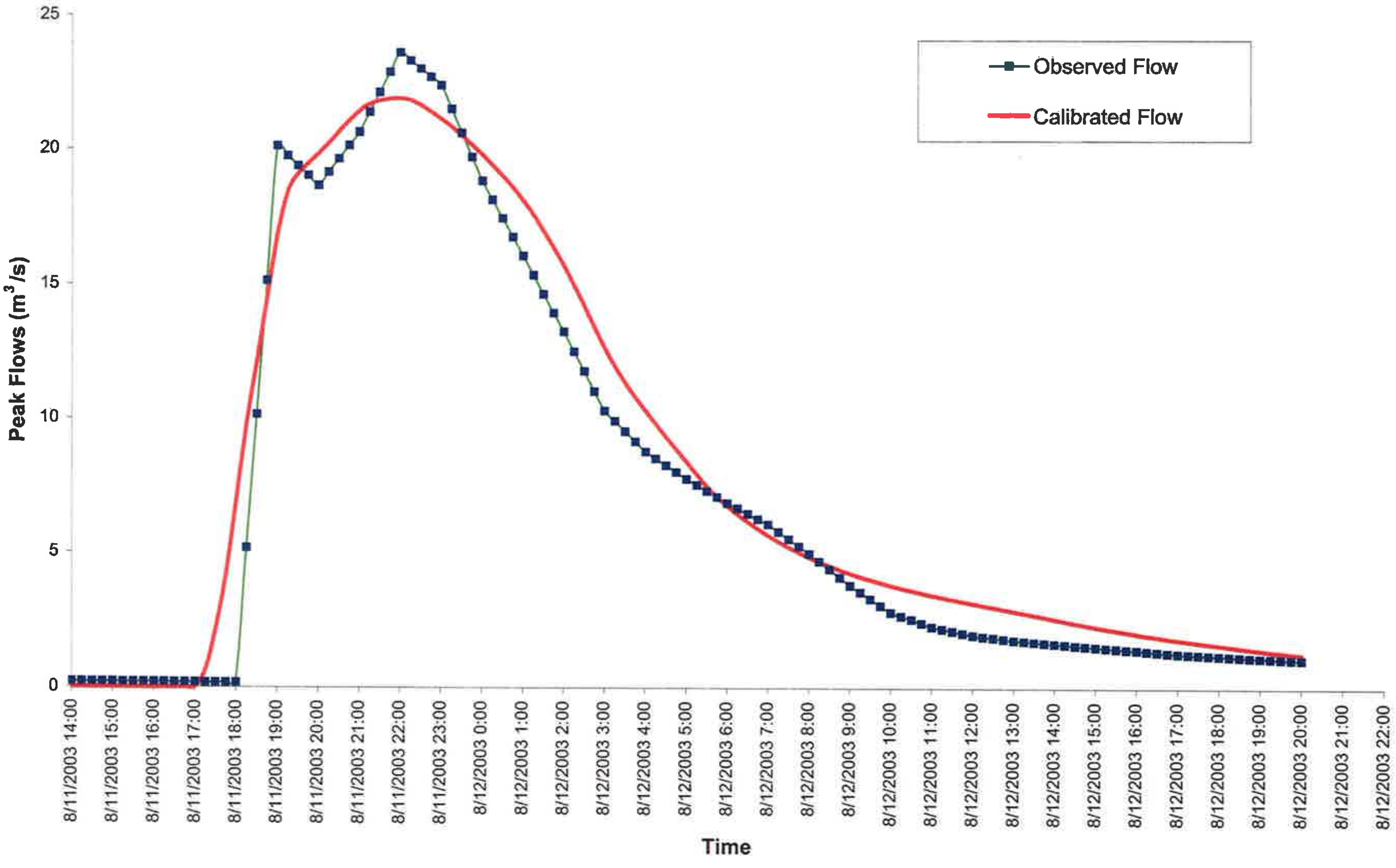


Figure F5: Final Comparison of Peak Flows (June 13, 2004)

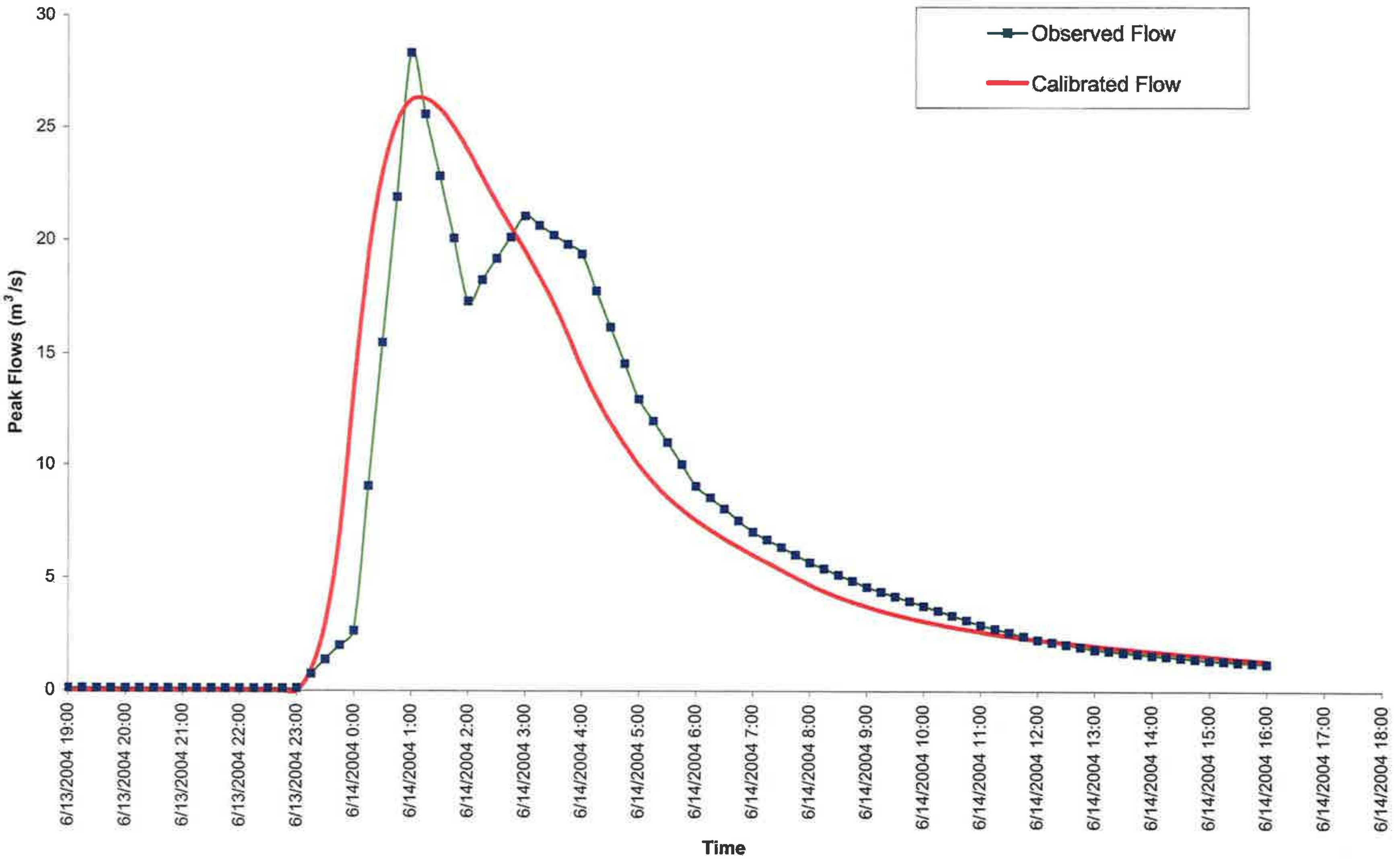


Figure F6: Final Comparison of Peak Flows (June 12, 2000)

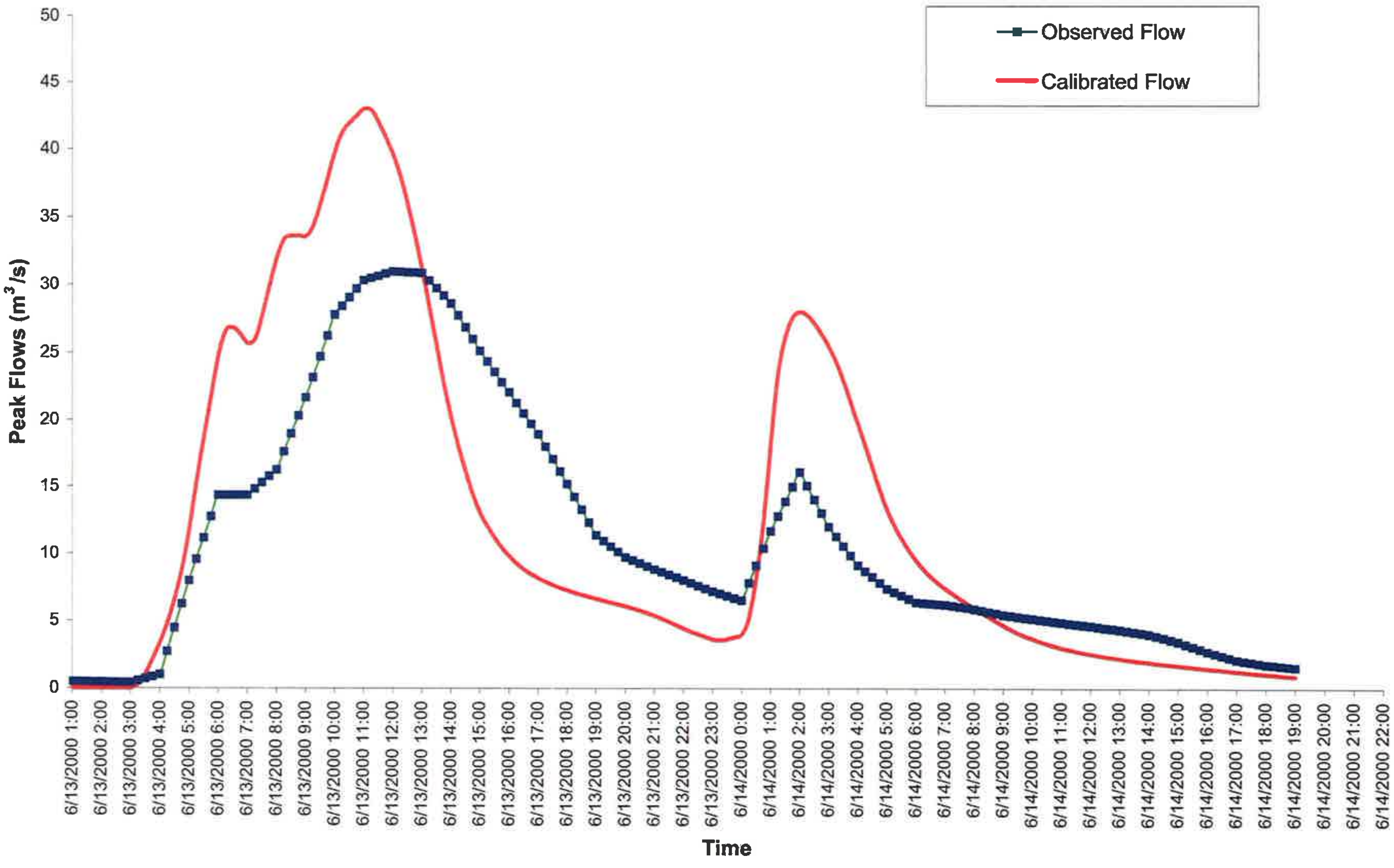


Figure F7: Final Comparison of Peak Flows (June 24, 2000)