TORONTO AND REGION CONSERVATION AUTHORITY:

HSP-F MODELLING OF A GREEN ROOF TECHNOLOGY - HIGHLAND CREEK WATERSHED

FINAL REPORT

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1.0 INTRODUCTION

1.1 General

In March 2004, the Toronto and Region Conservation Authority prepared a report entitled York University Rooftop Garden Stormwater Quantity and Quality Performance Monitoring Report. This project attempted to quantify the benefit of a roof garden, located on the York University Computer Science Building. The benefit was measured by evaluating the effectiveness of the garden roof in removing pollutants and moderating the flow rates from the roof area.

Last summer the Toronto and Region Conservation Authority retained Marshall Macklin Monaghan Limited to develop a Unit Response Function (a Unit Reponse Function is used as input to a computer model in order to define the response to rainfall for a given land use type) to represent a "green roof", i.e., a rooftop garden based on the monitoring program undertaken by TRCA.

Aquafor Beech Limited was then subsequently retained by TRCA to determine the effectiveness of implementing Green Roof Technologies within the Highland Creek Watershed (see Figure1.1).

1.2 Study Objective

The study objective may be defined as follows:

"Determine the effectiveness of implementing a Green Roof Technology within the Highland Creek watershed." Effectiveness will be assessed by considering the impact of the technology on change in water quality, flooding, water balance and erosion.

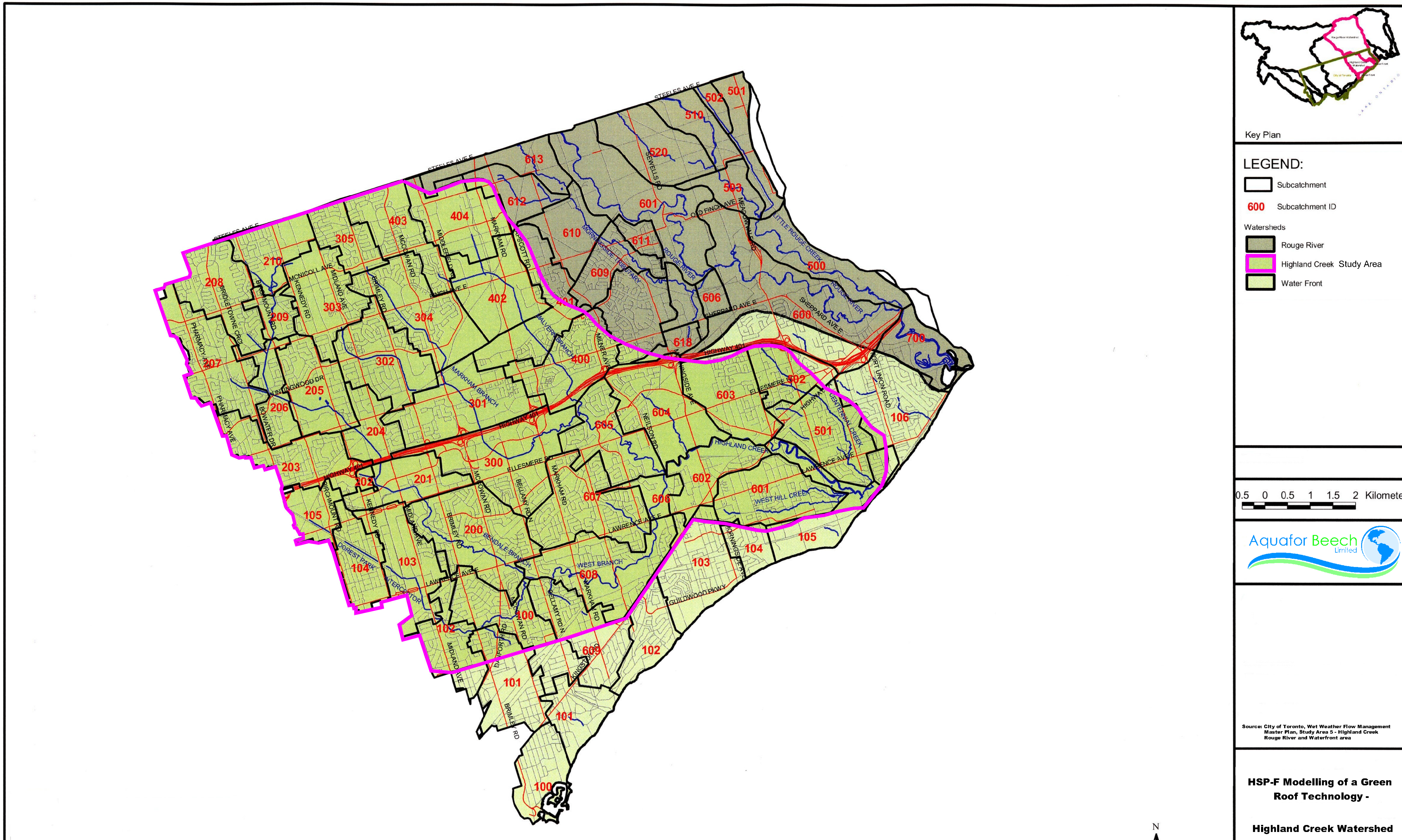

Figure 1.1: Study Area

1.3 Study Area

Highland Creek is situated within the southeastern limits of the City of Toronto (Scarbrough), as is illustrated in figure 1.1. The watershed is fully developed and includes considerable commercial and industrial areas as well as residential landuse. Highland Creek is comprised of the main branch as well as five main tributaries including:

- Dorset Park Interceptor;
- Bendale Branch;
- Markham Branch;
- Malvern Branch; and
- Centennial Creek

2.0 PREVIOUS STUDIES

2.1 General

A considerable amount of work which is of benefit to this study has been undertaken recently . This includes the Monitoring Report by TRCA (TRCA, 2004). The Technical Memorandum by Marshall Macklin Monagham (MMM, 2004) and the Technical Memorandum by Aquafor Beech Limited (Aquafor 2004). Copies of the two Technical Memorandum are provided in Appendix A and B. In addition a study entitled Wet Weather Flow Management Master Plan - Study Area 5 - Highland Creek, Rouge River and Waterfront Area was completed by Aquafor Beech Limited in 2003 (Aquafor 2003). An overview of this study is provided in the following section.

2.2 City of Toronto Wet Wether Flow Master Management Plan

The Wet Weather Flow Master Management Plan (WWFMMP) was a city wide initiative which started in 2001. The City of Toronto initiated the development of a Master Plan to address the impacts of wet weather flow (WWF).

As part of the study a problem statement was defined as was a vision statement, goal statement and a series of thirteen technical objectives. The thirteen technical objectives were establised to ensure that the Plan meets the principles and goals as defined in the study. The technical objective addressed:

- water quality;
- water quantity;
- natural areas and wildlife; and
- sewer systems.

A comprehensive set of targets were also established for each of the thirteen objectives.

A comprehensive computer modelling exercise was also undertaken as part of the process. The objective of developing the watershed model was to provide a tool that defines existing conditions and allows for examining the impacts and benefits of individual control measures, combinations of control measures and overall City-wide pollution control strategies on a number of watershed response indicators including:

- Streamflow regime in Highland Creek, as well as their tributaries within the City of Toronto, where streamflow regime is characterized in terms of peak flows during runoff periods, as well as in terms of low flows or "baseflow" during dry periods.

- Surface water quality in Highland Creek, as well as tributaries within the City of Toronto. Surface water quality is characterized in terms of time-varying concentrations of a set of constituents selected to address the specific objectives of the WWFMMP. These objectives include protection and enhancement of aquatic communities and aquatic habitat, as well as achieving water quality needed to protect public health and safety, and allow for recreational use of local water bodies.

The required modelling platform for the WWFMMP project was set out in the project's Terms of Reference (May 2000) developed by the City. The Terms of Reference required that the watershed model be developed using the Hydrologic Simulation Program - Fortran (HSPF) modelling platform.

HSPF is a comprehensive modelling package capable of simulating hydrologic processes as well as pollutant generation and transport processes within drainage catchment and along watercourse networks. The HSPF software has been developed over a number of decades and is currently maintained and supported by the U.S. Environmental Protection Agency. For the WWFMMP, Version 11 of HSPF was selected for application. Detailed documentation on HSPF is provided by the U.S. EPA (1996).

The HSPF models for the Study Area are structured as follows:

- The watershed is represented as a set of subcatchments. Surface runoff, interflow and groundwater discharge from each subcatchment discharges into the upstream end of a watercourse reach. The watercourse reach may, for example, represent a reach of a tributary of the Highland Creek, or a reach of the Highland Creek itself.

- Each subcatchment is characterized by the land-use, surficial soil types and topography found within the subcatchment. These characteristics are reflected in specific HSPF model input parameters.

- The watercourse network is represented as a set of watercourse reaches. Each of these is characterized using representative stream and valley cross-sections, as well as hydraulic roughness values and channel slopes.

The watersheds were subdivided into a number of subcatchments as follows:

Within the City of Toronto, GIS mapping layers were provided to ABL that provided information on the storm drainage network and storm sewer subcatchment areas. This information was used directly to define 43 urban subcatchments in Highland Creek watershed. Figure 1.1 shows the subcatchments within the City of Toronto.

The HSP-F model was then calibrated using existing meterorological, Provincial Water Quality Monitoring Network data (water quality) and Water Survey of Canada data (flow). The years 1994 to 1996 were used for model calibration while 1991-1993 were used for validation.

Ten water quality parameters were included in the calibration/validation process. The parameters included,

- Total Phosphorus (TP);
- Total Kjedahl Nitrogen (TKN);
- Nitrate & nitrite (Nox);
- Total suspended solids (TSS);
- Copper (Cu);
- Lead (Pb);
- Zinc (Zn);
- Benzo, G,H,I perylene;
- Dieldrin;
- Escherichai Coil (E. Coli) and
- Water Temperature.

Event Mean Concentrations (EMC's) were used in the calibration/validation process.

Upon completion of the calibration/validation process a typical year, 1992 was selected and existing conditions were defined.

The model was also used to evaluate the effectiveness of Five Alternative Strategies. The strategies are define below:

1. "Maintain Status Quo" - this sets out a strategy to maintain existing conditions and ensure no further degradation. It is designed to meet the Status Quo targets. This is essentially the "Do Nothing" alternative of the Class Environmental Assessment.

2. "Opportunistic Best Management Practices" - this sets out a strategy to take adantage of all opportunities for stormwater control such as voluntary implementation of source controls by property owners, opportunistic implementation of "leaky sewers" as in the

above example and "green" end-of-pipe facilities. It is designed to improve over the Status Quo but is not specifically targeted at the higher levels of enhancement.

3. "Striving To Meet Moderate Targets - End-of-Pipe Oriented" - this sets out a strategy to meet the "moderate" targets where feasible using voluntary source controls, opportunistic conveyance controls and emphasizing end-of-pipe facilities both "green" (e.g. wetlands) and "aggressive" measure such as underground tanks.

4. "Striving To Meet Moderate Targets - Source Control Oriented" - this sets out a strategy to meet the "moderate" targets where feasible emphasizing the intensive use of source controls, using intensive application of conveyance contorls and usin gonly opportunistic "green" end-of -pipe facilities.

5. "Striving to Meet Significant Enhancement Targets" - this sets out a strategy to meet "significant" targets and uses intensive levels of source controls, conveyance controls and end-of-pipe facilities.

Upon completion of the evaluation of the strategies a 25-Year Implementation Plan and Long-Term Preferred Strategy were established. Both Plans include a variety of measures including source control measures, conveyance control measures, end of pipe facilities, stream restoration measures, municipal operations and public education and community outreach programs.

As this study progressed, it was concluded that a standard lumped parameter subcatchment based modelling approach would not adequately assess the impact of distributed runoff controls. Hence an innovative "unit response function" method was developed and applied. This was based upon the concept of identifying a set of representative "test catchments" of approximately ten hectares in area covering the range of land uses found within the study areas. For each of the test catchments, a "unit response function" was developed which represented the hydrologic response and water quality response of the area to a predetermined series of meteorologic inputs. A total of sixteen different land use types were identified which when combined with different soil types, with different types of connection to the storm sewer, etc. required a total of just under 100 "unit response functions" (URF) to be created.

For each sewershed within the study area, an analysis was completed using GIS data to identify the proportion of the area covered by each of the URFs. The output from each sewershed was simulated by combining the outputs from the required URFs in appropriate proportions. The outputs from each sewershed were then combined and routed through model elements representing the water courses to simulate the flows and water quality concentrations at points of interest in the watershed, i.e. at the locations where targets had been established.

The concept of a Unit Response Function is illustrated in the figure 2.1.

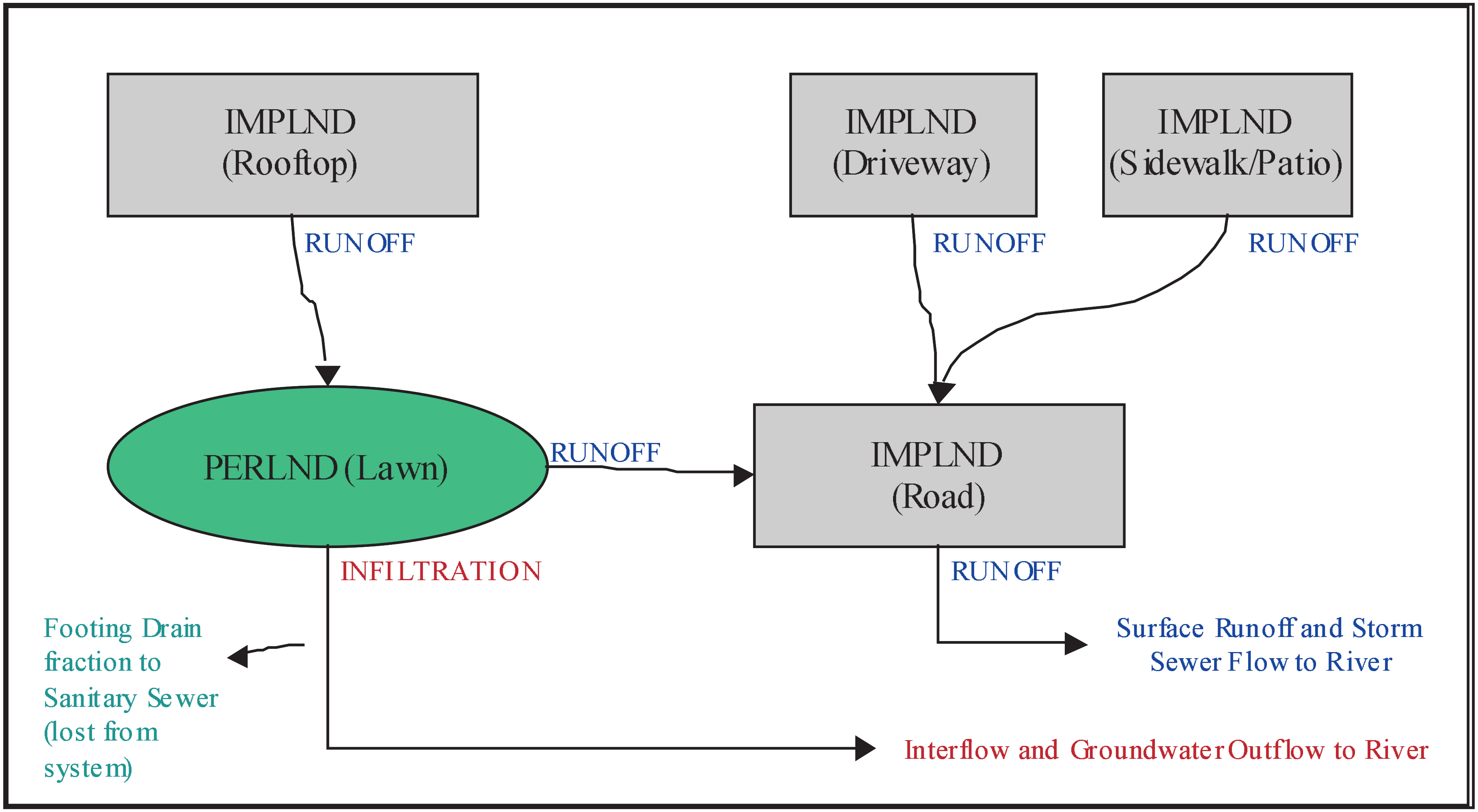

Figure 2.1 Example of HSP-F Sub-Model for Residential Land-Use Unit Response Function

URF LIST and WDM Slot Numbering

Common HSP-F Unit-Area Response Function Listing

Land-Use Class	Land-Use Category	Flow Component	Code	SubCode	WDM Slot Number (DSN)	Roof Options: Peaked	Roof Options: Flat	Connectivity: Roof Leaders: Connected	Connectivity: Roof Leaders: Disconnected	Connectivity: Footing Drains: Connected to Sanitary	Connectivity: Footing Drains: Disconnected	Connectivity: Footing Drains: Connected to Storm	Connectivity: Roadside Ditches (No Storm Sewer)	Soil Classifications (SCS Soil Types): A,AB	Soil Classifications (SCS Soil Types): B,BC	Soil Classifications (SCS Soil Types): C-D	Impervious Category: Roofs (%)	Impervious Category: Roads (%)	Impervious Category: Parking (%)	Impervious Category: Driveways (%)	Impervious Category: Walks/Patio (%)	Pervious Category: Lawns (%)	Pervious Category: Open Spac (%)	Measured Totals: Impervious TIMP (%)	Measured Totals: Pervious TPER (%)	Timeseries Units	Timeseries Consituent
Residential	Low-Density Residential	Surface	RLD	1ab	1001	✓	✗	✓	✗	✓	✗	✗	✗	A,AB	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1bc	1002	✓	✗	✓	✗	✓	✗	✗	✗		✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1cd	1003	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2ab	1004	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2bc	1005	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2cd	1006	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3ab	1007	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	3bc	1008	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
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			RLD	5ab	1013	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
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			RLD	5cd	1015	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	6ab	1016	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
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			RLD	7ab	1019	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7bc	1020	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	7cd	1021	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8ab	1022	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8bc	1023	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	8cd	1024	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
		Subsurface	RLD	1abx	1501	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	1bcx	1502	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
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			RLD	2abx	1504	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
			RLD	2bcx	1505	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
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			RLD	5abx	1513	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	13	9	0	7	1	70	0	30	70	cu.m/hr	FLOW
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	Medium-Density Residential	Surface	RMD	1ab	1101	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
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			RMD	5ab	1113	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5bc	1114	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5cd	1115	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
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			RMD	6bc	1117	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6cd	1118	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7ab	1119	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7bc	1120	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7cd	1121	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8ab	1122	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8bc	1123	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8cd	1124	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
		Subsurface	RMD	1abx	1601	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1bcx	1602	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	1cdx	1603	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2abx	1604	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2bcx	1605	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	2cdx	1606	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3abx	1607	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3bcx	1608	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	3cdx	1609	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4abx	1610	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4bcx	1611	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	4cdx	1612	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5abx	1613	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5bcx	1614	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	5cdx	1615	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6abx	1616	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6bcx	1617	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	6cdx	1618	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7abx	1619	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7bcx	1620	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	7cdx	1621	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8abx	1622	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8bcx	1623	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
			RMD	8cdx	1624	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	24	13	0	10	3	50	0	50	50	cu.m/hr	FLOW
	High-Density Residential	Surface	RHD	1ab	1201	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	1bc	1202	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	1cd	1203	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	2ab	1204	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	2bc	1205	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	2cd	1206	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	3ab	1207	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	3bc	1208	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	3cd	1209	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	4ab	1210	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	4bc	1211	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	4cd	1212	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	5ab	1213	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	5bc	1214	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	5cd	1215	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	6ab	1216	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	6bc	1217	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	6cd	1218	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	7ab	1219	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	7bc	1220	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	7cd	1221	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	8ab	1222	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	8bc	1223	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	8cd	1224	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
		Subsurface	RHD	1abx	1701	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	1bcx	1702	✓	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	1cdx	1703	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	2abx	1704	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	2bcx	1705	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	2cdx	1706	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	3abx	1707	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	3bcx	1708	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	3cdx	1709	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	4abx	1710	✓	✗	✗	✓	✗	✓	✗	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	4bcx	1711	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	4cdx	1712	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	5abx	1713	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	5bcx	1714	✓	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	5cdx	1715	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	6abx	1716	✓	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	6bcx	1717	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	6cdx	1718	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	7abx	1719	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	7bcx	1720	✓	✗	✗	✓	✓	✗	✗	✓	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	7cdx	1721	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	8abx	1722	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	8bcx	1723	✓	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
			RHD	8cdx	1724	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✓	32	17	0	11	5	35	0	65	35	cu.m/hr	FLOW
	High-Rise Residential	Surface	RHR	1ab	1301	✗	✓	✓	✗	✓	✗	✗	✗	✓	✗	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	1bc	1302	✗	✓	✓	✗	✓	✗	✗	✗	✗	✓	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	1cd	1303	✗	✓	✓	✗	✓	✗	✗	✗	✗	✗	✓	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	2ab	1304	✗	✓	✓	✗	✗	✗	✓	✗	✓	✗	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	2bc	1305	✗	✓	✓	✗	✗	✗	✓	✗	✗	✓	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	2cd	1306	✗	✓	✓	✗	✗	✗	✓	✗	✗	✗	✓	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
		Subsurface	RHR	1abx	1801	✗	✓	✓	✗	✓	✗	✗	✗	✓	✗	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	1bcx	1802	✗	✓	✓	✗	✓	✗	✗	✗	✗	✓	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	1cdx	1803	✗	✓	✓	✗	✓	✗	✗	✗	✗	✗	✓	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	2abx	1804	✗	✓	✓	✗	✗	✗	✓	✗	✓	✗	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	2bcx	1805	✗	✓	✓	✗	✗	✗	✓	✗	✗	✓	✗	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW
			RHR	2cdx	1806	✗	✓	✓	✗	✗	✗	✓	✗	✗	✗	✓	9	9	27	5	0	50	0	50	50	cu.m/hr	FLOW

Land-Use					WDM Slot Number	Roof Options		Connectivity						Soil Classifications			Measured Land Surface-Type Breakdown									Timeseries Units	Timeseries Consituent
								Roof Leaders		Footing Drains			Roadside Ditches	SCS Soil Types			Impervious Category					Pervious Category		Measured Totals			
Class	Category	Flow Component	Code	SubCode	(DSN)	Peaked	Flat	Connected	Disconnected	Connected to Sanitary	Disconnected	Connected to Storm	(No Storm Sewer)	A,AB	B,BC	C-D	Roofs (%)	Roads (%)	Parking (%)	Driveways (%)	Walks/Patio (%)	Lawns (%)	Open Space (%)	Impervious TIMP (%)	Pervious TPER (%)		
Commercial	DownTown Commercial	Surface	CDT	1bc	2001	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	52	38	0	5	0	5	0	95	5	cu.m/hr	FLOW
		Subsurface	CDT	1bcx	2501	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	52	38	0	5	0	5	0	95	5	cu.m/hr	FLOW
	Big Box Commercial	Surface	CBB	1bc	2101	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	29	12	57	0	0	4	0	98	4	cu.m/hr	FLOW
		Subsurface	CBB	1bcx	2601	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	29	12	57	0	0	4	0	98	4	cu.m/hr	FLOW
	Strip Mall Commercial	Surface	CSM	1bc	2201	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	17	19	62	0	0	4	0	98	4	cu.m/hr	FLOW
		Subsurface	CSM	1bcx	2701	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	17	19	62	0	0	4	0	98	4	cu.m/hr	FLOW
Educational / Institutional	Local Schools / Churches	Surface	EIS	1ab	3001	✗	✓	✓	✗	✓	✗	n/a	n/a	✓	✗	✗	9	9	14	0	0	63	0	32	63	cu.m/hr	FLOW
			EIS	1bc	3002	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	9	9	14	0	0	63	0	32	63	cu.m/hr	FLOW
			EIS	1cd	3003	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✗	✓	9	9	14	0	0	63	0	32	63	cu.m/hr	FLOW
		Subsurface	EIS	1abx	3501	✗	✓	✓	✗	✓	✗	n/a	n/a	✓	✗	✗	9	9	14	0	0	63	0	32	63	cu.m/hr	FLOW
			EIS	1bcx	3502	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	9	9	14	0	0	63	0	32	63	cu.m/hr	FLOW
			EIS	1cdx	3503	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✗	✓	9	9	14	0	0	63	0	32	63	cu.m/hr	FLOW
Open Space	Park Lands, Hydro, Golf / Cemetery	Surface	OPL	0ab	4001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	5	5	0	0	0	90	10	90	cu.m/hr	FLOW
			OPL	0bc	4002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	5	5	0	0	0	90	10	90	cu.m/hr	FLOW
			OPL	0cd	4003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	5	5	0	0	0	90	10	90	cu.m/hr	FLOW
		Subsurface	OPL	0abx	4501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	5	5	0	0	0	90	10	90	cu.m/hr	FLOW
			OPL	0bcx	4502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	5	5	0	0	0	90	10	90	cu.m/hr	FLOW
			OPL	0cdx	4503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	5	5	0	0	0	90	10	90	cu.m/hr	FLOW
	Valley Lands, Golf / Cemetery	Surface	OVL	0ab	4101	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0bc	4102	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0cd	4103	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
		Subsurface	OVL	0abx	4601	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0bcx	4602	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
			OVL	0cdx	4603	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	3	0	0	0	0	97	3	97	cu.m/hr	FLOW
Transportation	Highway Corridors	Surface	THC	0ab	5001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0bc	5002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0cd	5003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
		Subsurface	THC	0abx	5501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0bcx	5502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
			THC	0cdx	5503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	variable	0	0	0	0	variable	variable	variable	cu.m/hr	FLOW
Industrial	Prestige Industrial	Surface	IPR	1ab	6001	✗	✓	✓	✗	✓	✗	n/a	n/a	✓	✗	✗	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1bc	6002	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1cd	6003	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✗	✓	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
		Subsurface	IPR	1abx	6501	✗	✓	✓	✗	✓	✗	n/a	n/a	✓	✗	✗	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1bcx	6502	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
			IPR	1cdx	6503	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✗	✓	30	7	43	0	0	20	0	80	20	cu.m/hr	FLOW
	Big Box Industrial	Surface	IBB	1bc	6101	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	45	6	42	0	0	7	0	93	7	cu.m/hr	FLOW
		Subsurface	IBB	1bcx	6601	✗	✓	✓	✗	✓	✗	n/a	n/a	✗	✓	✗	45	6	42	0	0	7	0	93	7	cu.m/hr	FLOW
Agricultural	Tilled	Surface	AGT	0ab	7001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0bc	7002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0cd	7003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
		Subsurface	AGT	0abx	7501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0bcx	7502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGT	0cdx	7503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
	Pasture/Fallow	Surface	AGP	0ab	7101	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0bc	7102	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0cd	7103	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
		Subsurface	AGP	0abx	7601	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0bcx	7602	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
			AGP	0cdx	7603	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	0	0	0	0	0	100	0	100	cu.m/hr	FLOW
Special	PERLND Soils AB	Surface	PER	0ab	8001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	0	0	0	0	0	100	0	100	mm/hr	SAB
	PERLND Soils BC		PER	0bc	8002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	0	0	0	0	0	100	0	100	mm/hr	SBC
	PERLND Soils CD		PER	0cd	8003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	0	0	0	0	0	100	0	100	mm/hr	SCD
	PERLND Soils AB	Subsurface	PER	0abx	8501	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✗	✗	0	0	0	0	0	0	100	0	100	mm/hr	GWAB
	PERLND Soils BC		PER	0bcx	8502	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✓	✗	0	0	0	0	0	0	100	0	100	mm/hr	GWBC
	PERLND Soils CD		PER	0cdx	8503	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✗	✗	✓	0	0	0	0	0	0	100	0	100	mm/hr	GWCD
	IMPLND (Road)	Surface	IMP	0	8004	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	100	0	0	0	0	0	100	0	mm/hr	ROAD
Total number of URFs					213																						

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

3.0 STUDY APPROACH

3.1 General

The study objective was defined as; determine the effectiveness of implementing a Green Roof Technology within the Highland Creek Watershed. Effectiveness can be evaluated based on flooding, water balance, water quality and erosion.

3.2 Study Tasks

The study tasks are outlined below.

The initial step involved the collection of background information which included the HSP-F model developed by Aquafor Beech Limited as part of the WWFMMP, the Unit Response Function for the control roof and the URF for the green roof as prepared by MMM.

The existing database was then assessed to define, based on the URFs provided in the WWFMMP, the percentage of land uses where flat roofs could be implemented in the Highland Creek Watershed. Table 3.1 summarizes these data on a subwatershed basis.

The next step involved selecting representative sites in order to determine the percentage of roof area vs. total site area. Eight sites were selected. The results are summarized in Table 3.2. The findings show that for industrial sites the roof area is approximately 42 percent of the site area while for condominium sites the value is approximately 10 percent.

Once the above was complete the HSPF model was run for a number of different scenarios for a

Table 3.1: Flat Roof area simulated in Highland Creek Watershed HSP-F model

Subwatershed	Subwatershed Area (ha)	Landuse with Flat Roof [1] (ha)	Flat Roof area [2] (ha)
Dorset Park Branch	1382.5	544.4	175.5
Bendale Branch	2534.0	715.9	191.3
Markham Branch	2124.4	719.2	209.2
Malven Branch	1411.0	618.4	227.7
Centenial Branch	519.0	41.5	9.7
Main Branch	2604.2	446.9	96.8
Whole watershed	10575.1	3086.3	910.1

[1]- Includes total site area

[2] - Includes roof area only

Table 3.2: % of Roof top area for representative 8 sites

Landuse	Lot size (m2)	Roof top (m2)	% Roof top
Industrial 1	84522	22043	26%
Industrial 2	35548	13071	37%
Industrial 3	39595	17759	45%
Industrial 4	23394	8370	36%
Industrial 5	25039	11168	45%
Industrial 6	30711	18729	61%
		Average	**42%**
Apartment 1	16645	1810	11%
Apartment 2	16709	1450	9%
		Average	**10%**

typical year (1992). The objective was to assess the hydrologic benefit assuming 50 and 100 percent implementation of the green roof technology for suitable land uses (flat roof).

Prior to running the model a couple of adjustments had to made. The percent roof area that was assumed in the WWFMMP study for the representative land uses was changed to reflect the values shown in Table 3.2. Futhermore, for a given roof area it was assumed that only 75 percent of the area would be available for implementing the green roof technology. The minimum size of roof area where green roofs were applied was 100m^2.

3.3 Study Findings

This section presents the findings of the HSPF modelling analysis by assuming 50% and 100% implementation of the green roof technology for the suitable land uses (flat roof). The results are reviewed in terms of flooding, erosion, water quality and water balance.

3.3.1 Reduction of Flow Volume and Peak Flow Rate

Flow Volume Reduction

The monthly and annual runoff volumes at the mouths of the six different subwatersheds are shown in Table 3.3. On an annual basis the flow volume reduces from 48,870,000 m^3 without green roofs to 46,920,000 m^3 with green roofs assuming 100 percent implementation at the mouth of Highland Creek Watershed. This represents approximately a 4.0 precent reduction in runoff volume. If a 50 percent implementation value is assumed then the percent reduction will be 1.7 percent. The volume reductions vary from a high 7.0 percent (Malven Branch) to a low of 0.9 percent (Centennial Branch).

Peak Flow Rate Reduction

Table 3.3: Summary of Montly and Annual runoff volumes for year 1992

Subwatershed	Annual Volume With No Green Roof m3*10E6	Annual Volume With 100% Green Roof m3*10E6	Percentage Reduced	Annual Volume With 50% Green Roof m3*10E6	Percentage Reduced
Mouth of Dorset Park Branch	6.69	6.33	5.3%	6.52	2.5%
Mouth of Bendale Branch	12.03	11.63	3.3%	11.87	1.3%
Mouth of Markham Branch	10.34	9.87	4.5%	10.16	1.7%
Mouth of Malven Branch	7.12	6.62	7.0%	6.89	3.3%
Mouth of Centenial Branch	2.31	2.29	0.9%	2.30	0.4%
Mouth of Highland Creek	48.87	46.92	4.0%	48.06	1.7%

Figure 3.1 - Annual Hydrograph - Mouth of Dorest Park - 1992

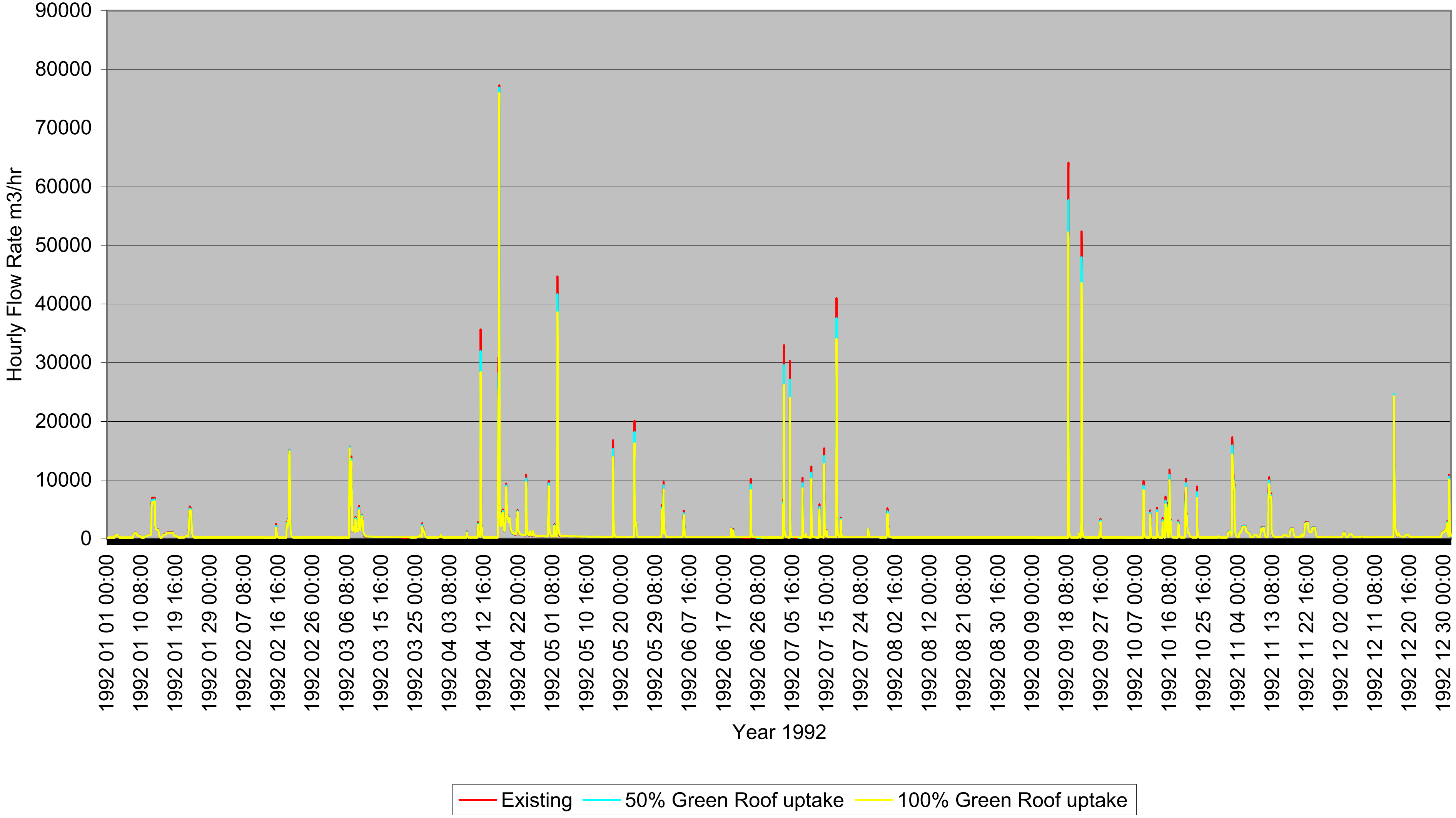


Figure 3.2 - Annual Hydrograph - Mouth of Bendale Branch - 1992

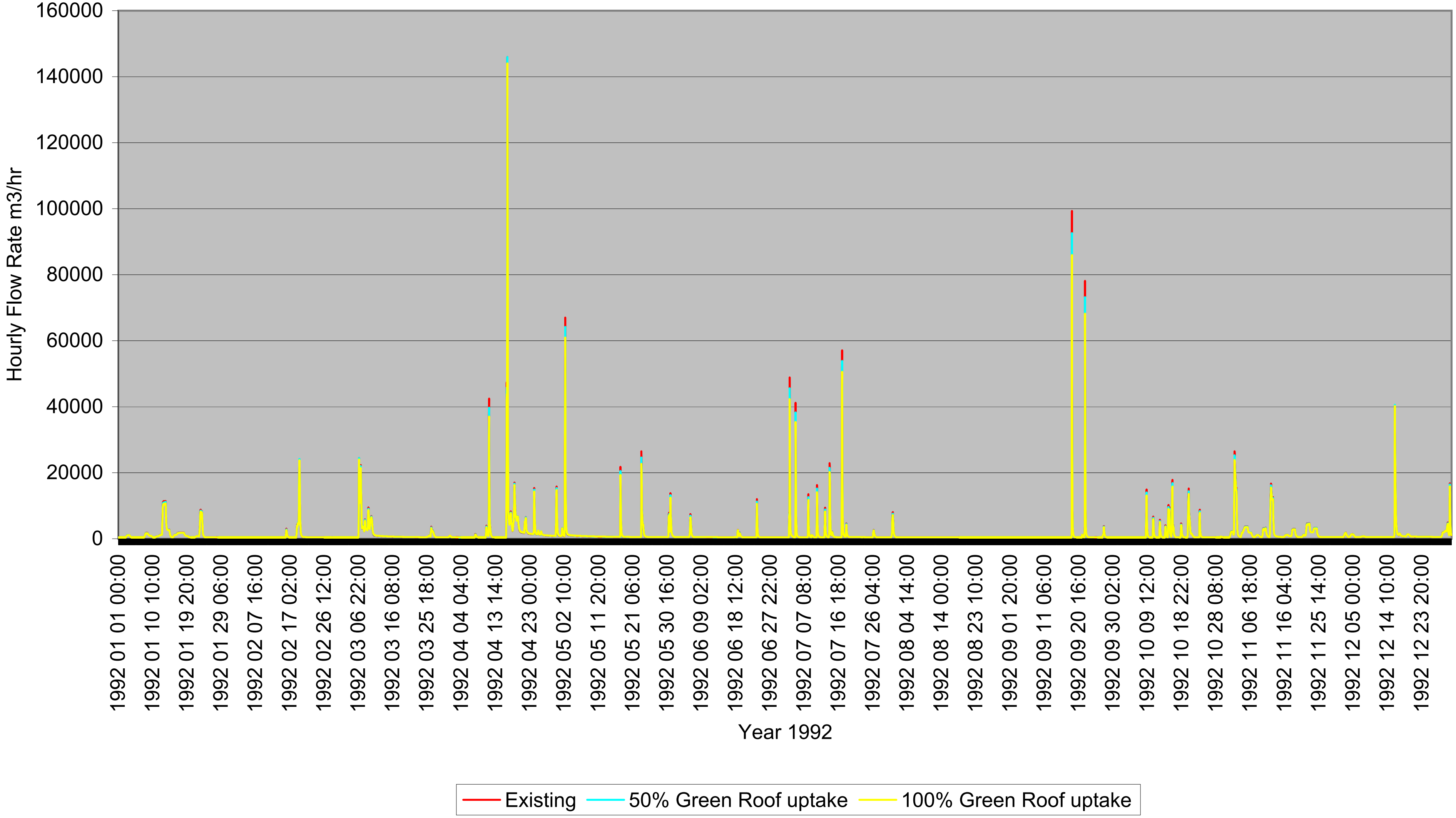


Figure 3.3 - Annual Hydrograph - Mouth of Markham Branch - 1992

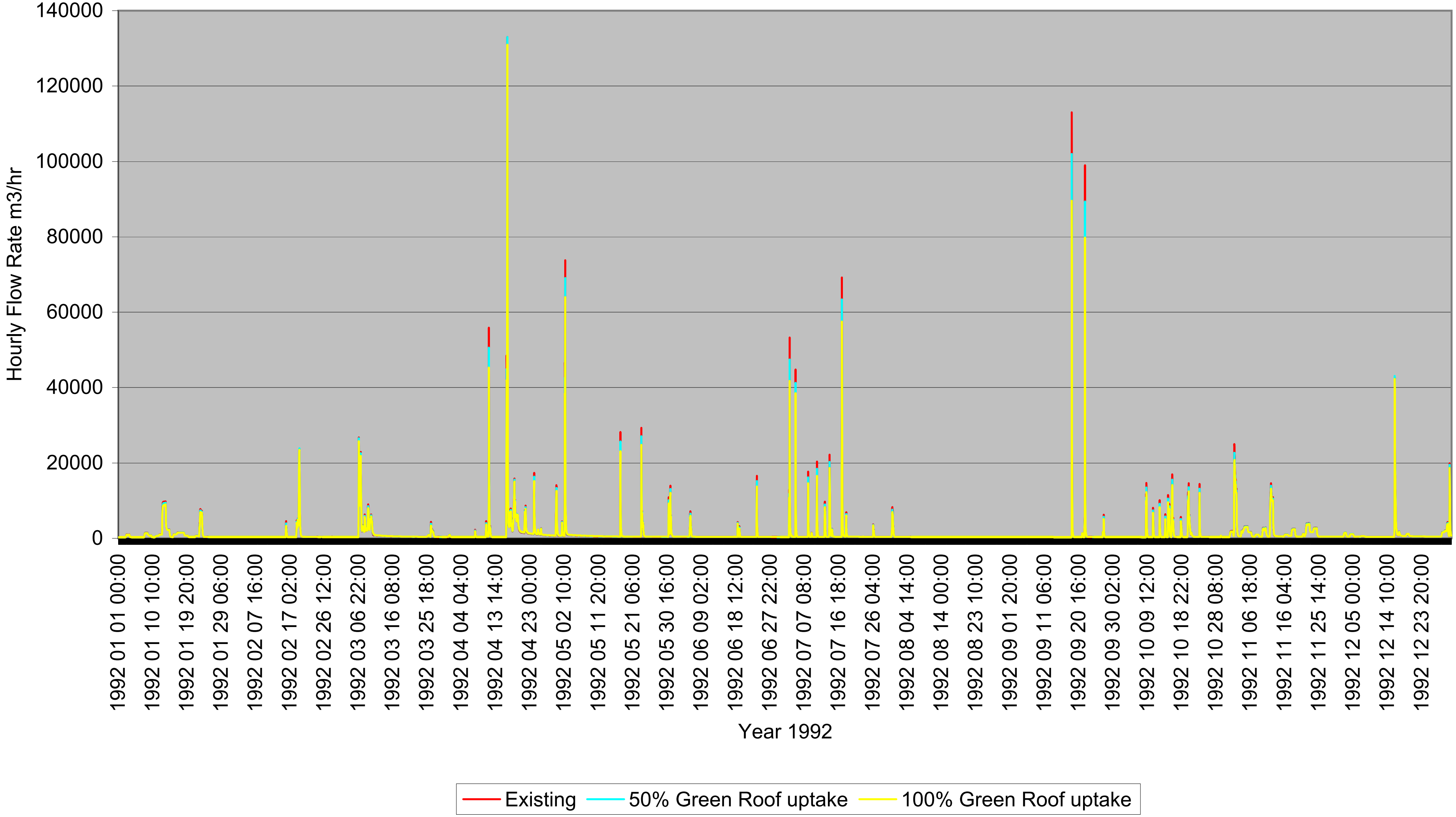


Figure 3.4 - Annual Hydrograph - Mouth of Malvern Branch - 1992

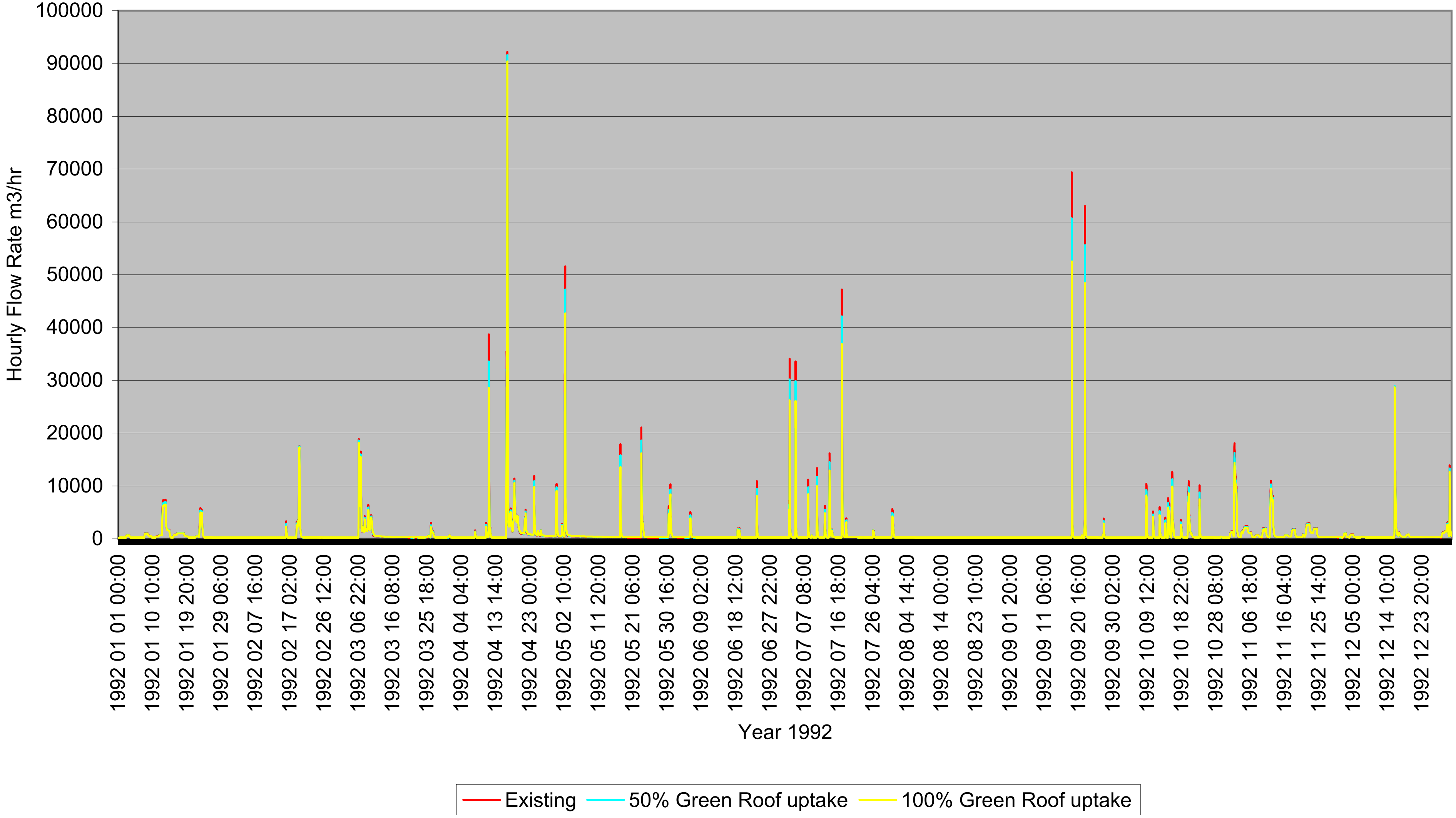


Figure 3.5 - Annual Hydrograph - Mouth of Centenial Branch - 1992

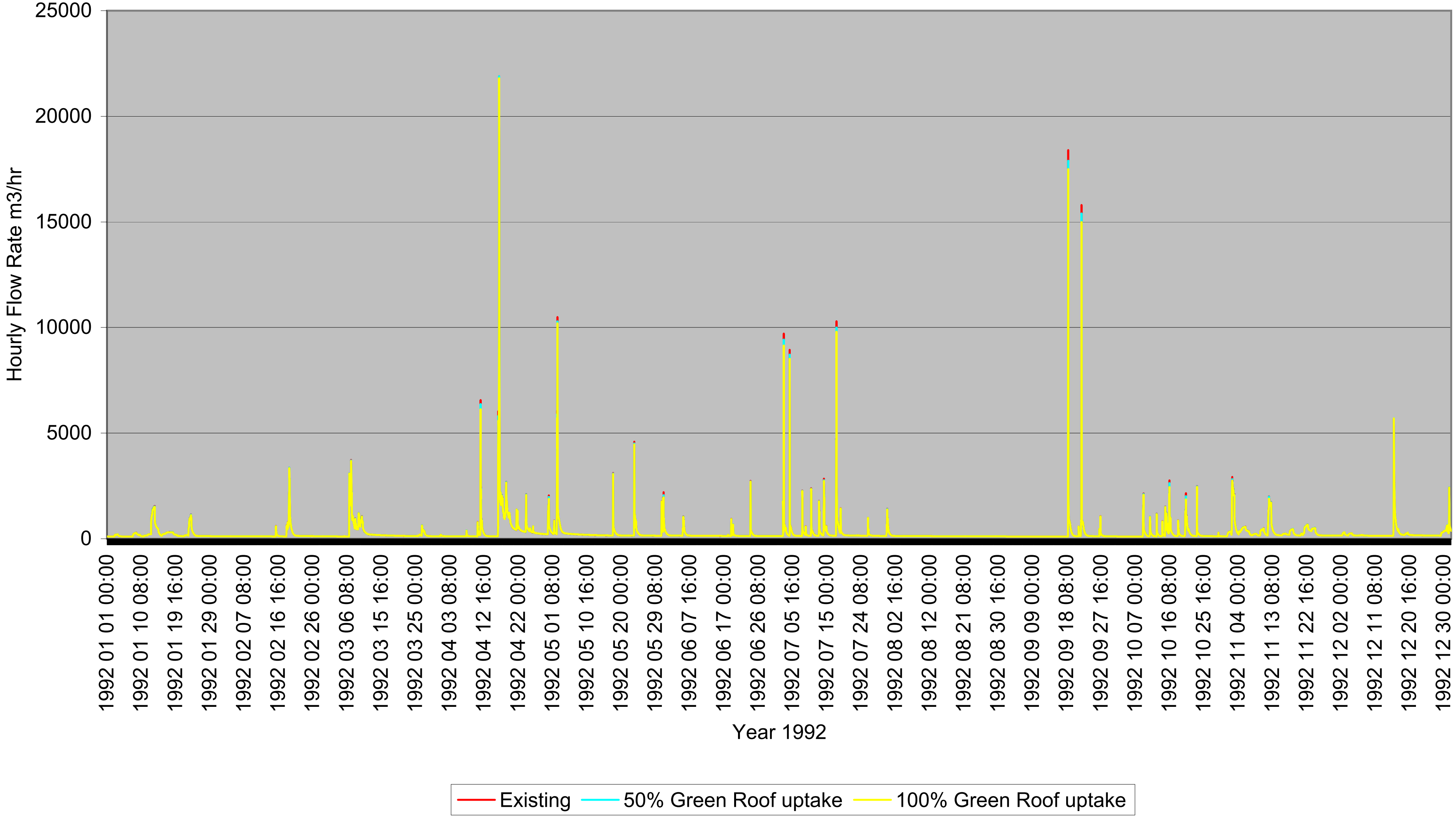
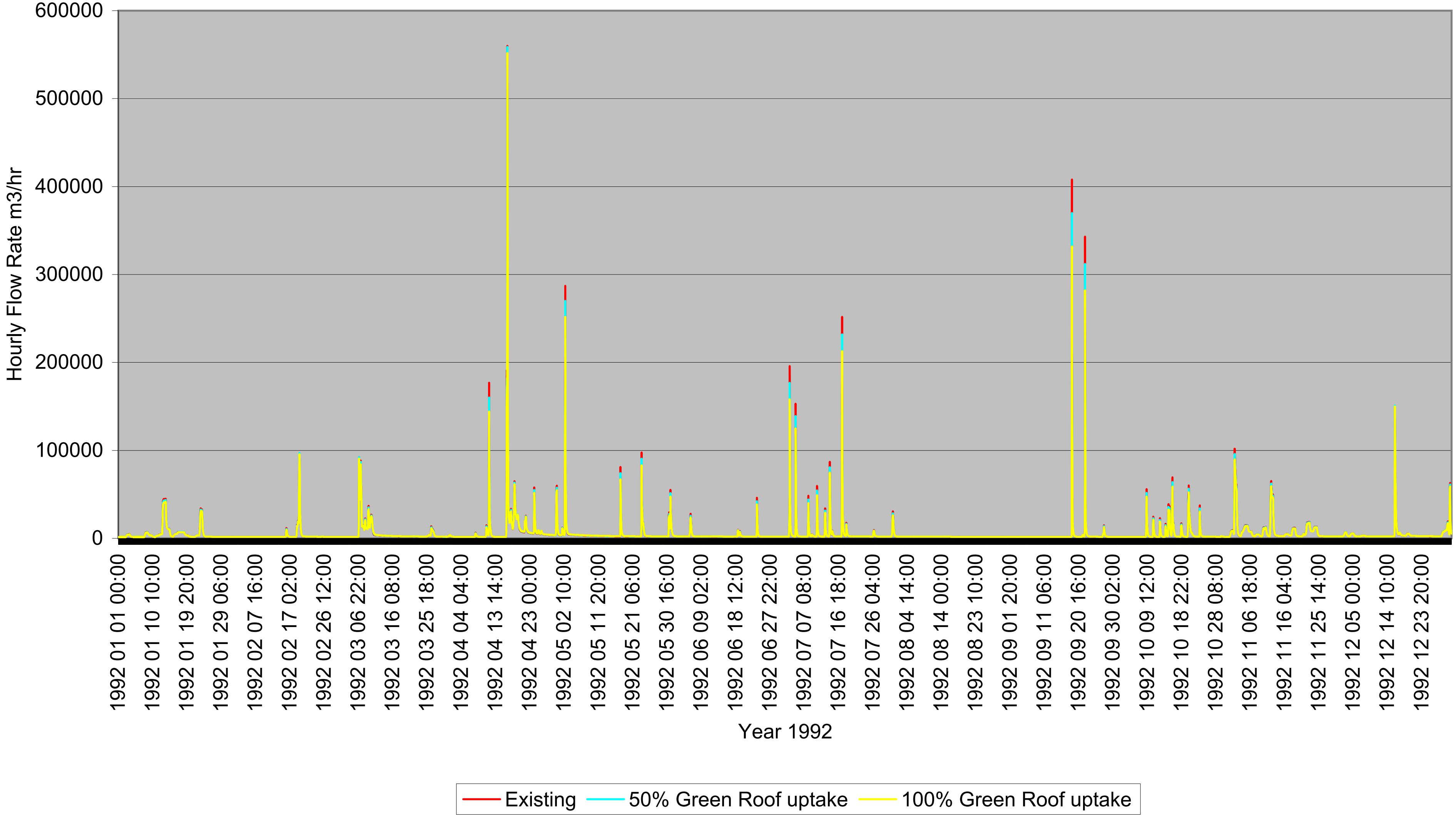


Figure 3.6 - Annual Hydrograph - Mouth of Highland Creek Watershed - 1992



The hydrographs for six different subwatersheds in the year 1992 are shown in Figures 3.1-3.6. Table 3.4 summarizes the date, precipitation volume and peak flows (with and without implementation of the green roof technology) for the six largest events. The results show that the effectiveness varies from subwatershed to subwatershed (depending upon the percentage of land where the technology can be applied) and from event to event (depending upon the type of event and the seasonal effectiveness of the technology). The results show peak flow reductions of approximately 13% and 6% for 100% and 50% implementation of green roof technology respectively at the mouth of Highland Creek Watershed. In the Markham and Malvern Branches peak flow reductions of approximately 21 percent do occur in the summer season.

3.3.2 Flow-duration frequency curves

In order to assess the effectiveness of green roof technology a comprehensive exercise of looking at existing stream conditions, present (without green roof technology) and future (with green roof technology) sediment and flow regimes would need to be determined.

A qualitative assessment can be undertaken by looking at the change in the flow duration frequency curves with and without green roof technology in place. In situations where the stream has excess energy (a majority of the situations within Highland Creek) then a reduction in the flow rate for a given frequency would be of benefit. The results of this simplified assessment are provided below.

The flow duration frequency curves for six different subwatersheds are shown in Figures 3.7-3.12. In a very general sense the benefits of the green roof technology would be found where there is separation between the curves (ie: with and without the green roof technology) for flow rates where the Percent of Time Flow is Exceeded is 10 percent or less. This separation occurs, to a reasonable degree on the Markham, Bendale and Malvern Branches.

Table 3.4: Summary of Precipitation volume and Peak Flow Rates at the Mouth of Highland Creek

Dorset Park Branch

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	9.92	7.89	20%	8.89	10%
April 16-17, 1992	45.70	21.47	21.11	2%	21.36	1%
May 2-3, 1992	27.90	12.48	10.77	14%	11.58	7%
July 16-17, 1992	24.80	11.39	9.47	17%	10.44	8%
September 18-19,1992	27.70	17.81	14.50	19%	16.03	10%
September 21-22,1992	24.20	14.56	12.11	17%	13.33	8%

Bendale Branch

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	11.78	10.28	13%	11.03	6%
April 16-17, 1992	45.70	40.56	40.00	1%	40.56	0%
May 2-3, 1992	27.90	18.61	16.94	9%	17.83	4%
July 16-17, 1992	24.80	15.86	14.06	11%	14.97	6%
September 18-19,1992	27.70	27.58	23.89	13%	25.72	7%
September 21-22,1992	24.20	21.69	18.94	13%	20.33	6%

Markham Branch

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	15.53	12.58	19%	14.06	9%
April 16-17, 1992	45.70	36.94	36.39	2%	39.94	-8%
May 2-3, 1992	27.90	20.50	17.78	13%	19.19	6%
July 16-17, 1992	24.80	19.22	15.97	17%	17.61	8%
September 18-19,1992	27.70	31.39	24.89	21%	28.33	10%
September 21-22,1992	24.20	27.50	22.17	19%	24.83	10%

Malven Branch

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	10.75	7.94	26%	9.33	13%
April 16-17, 1992	45.70	25.61	25.11	2%	25.44	1%
May 2-3, 1992	27.90	14.33	11.86	17%	13.11	9%
July 16-17, 1992	24.80	13.11	10.25	22%	11.69	11%
September 18-19,1992	27.70	19.28	14.58	24%	16.86	13%
September 21-22,1992	24.20	17.50	15.44	12%	13.44	23%

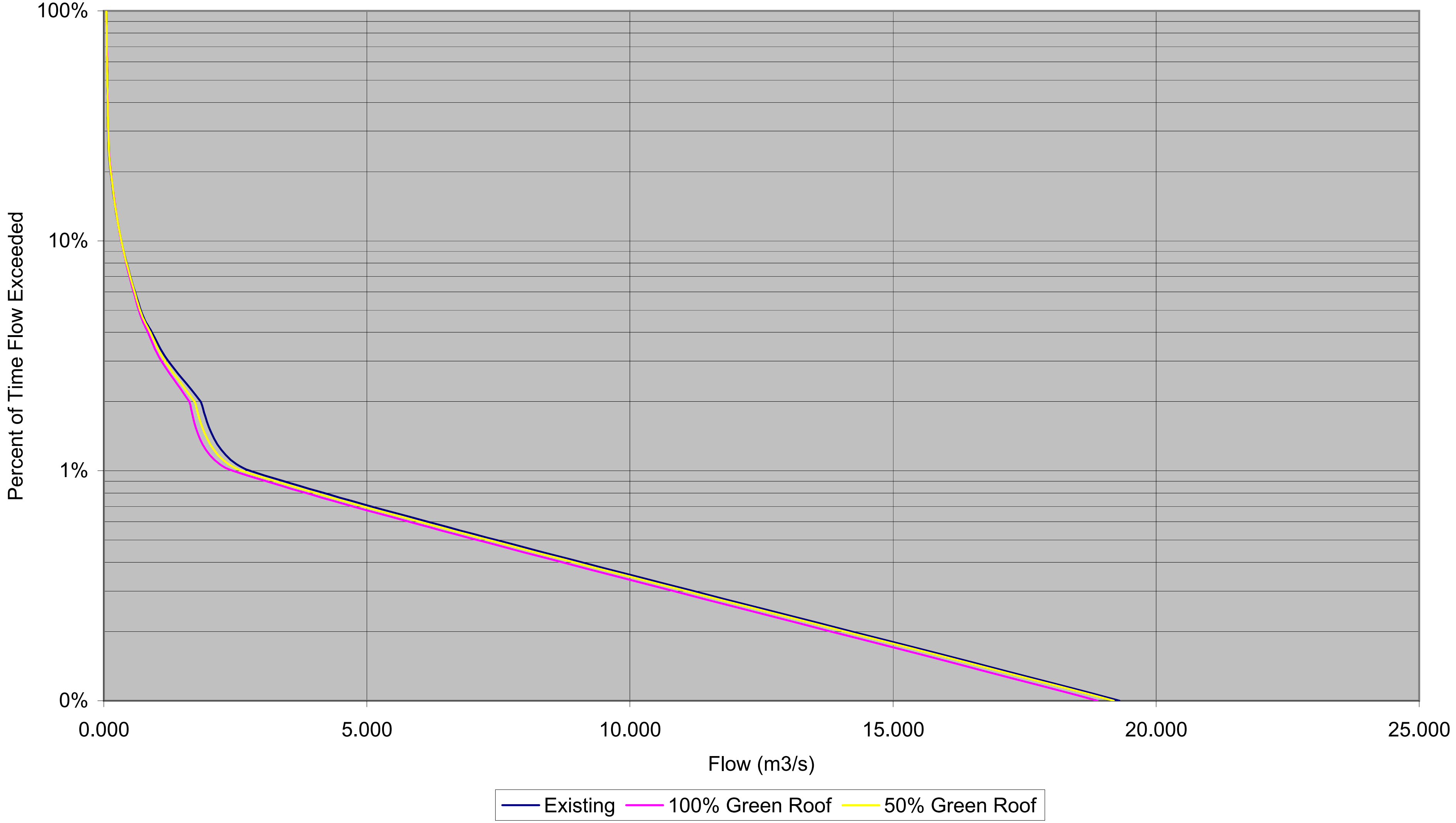
Centenial Branch

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	1.83	1.70	7%	1.77	3%
April 16-17, 1992	45.70	6.08	6.06	0%	6.08	0%
May 2-3, 1992	27.90	2.92	2.88	1%	2.86	2%
July 16-17, 1992	24.80	2.86	2.73	5%	2.77	3%
September 18-19,1992	27.70	5.11	4.86	5%	4.97	3%
September 21-22,1992	24.20	4.39	4.17	5%	4.28	3%

Highland Creek Watershed

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	46.17	40.00	13%	44.44	4%
April 16-17, 1992	45.70	155.28	153.33	1%	155.28	0%
May 2-3, 1992	27.90	79.72	70.00	12%	75.00	6%
July 16-17, 1992	24.80	70.00	59.17	15%	64.44	8%
September 18-19,1992	27.70	113.33	92.22	19%	102.78	9%
September 21-22,1992	24.20	95.28	78.33	18%	86.67	9%

Figure 3.7 - Flow Duration Frequency Curve - Mouth of Dorest Park - 1992



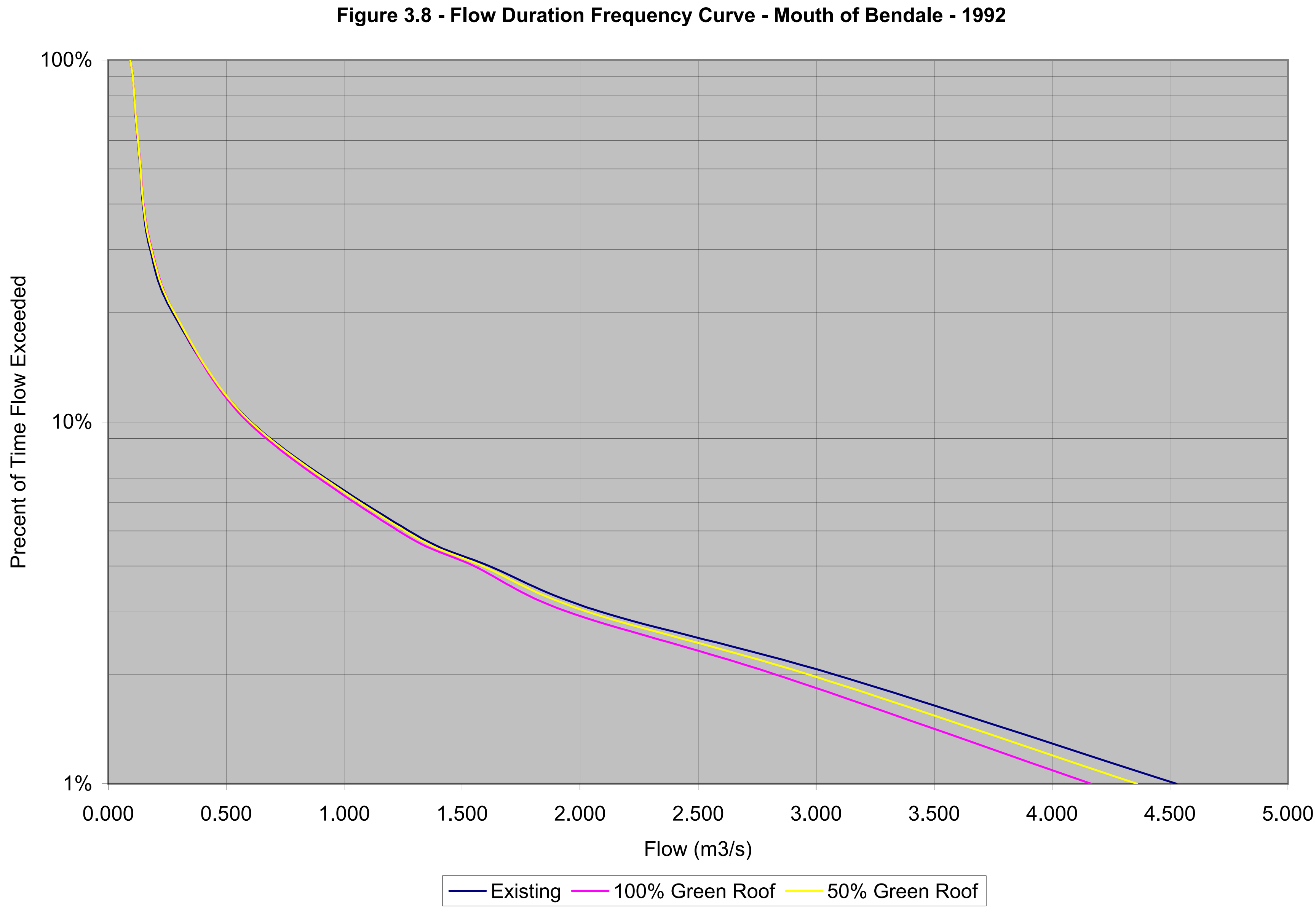


Figure 3.8 - Flow Duration Frequency Curve - Mouth of Bendale - 1992
100%
10%
1%
Precent of Time Flow Exceeded
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
Flow (m3/s)
Existing
100% Green Roof
50% Green Roof

Figure 3.9 - Flow Duration Frequency Curve - Mouth of Markham Branch - 1992

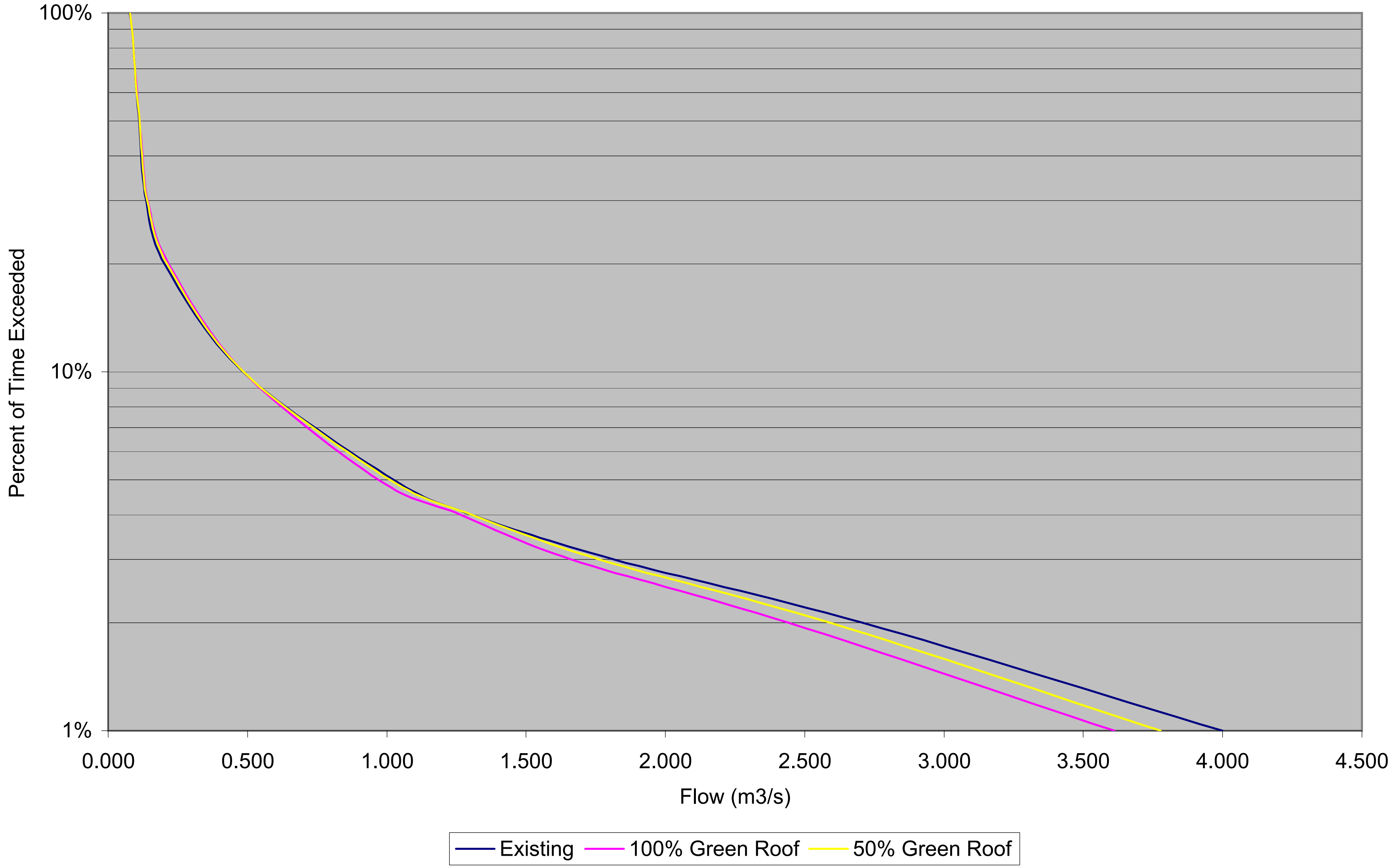


Figure 3.10: Flow Duration Frequency Curve - Mouth of Malvern Branch - 1992

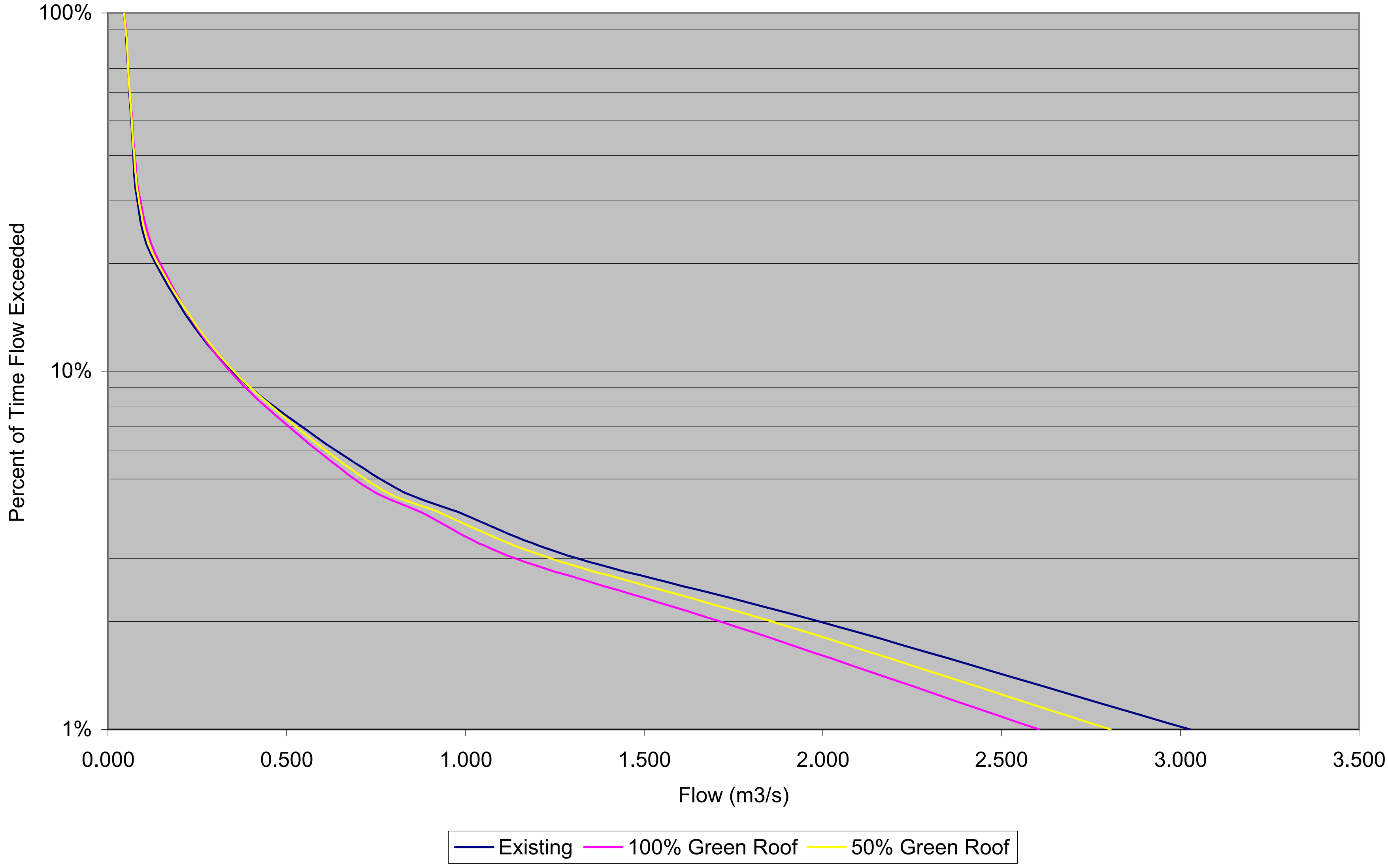


Figure 3.11: Flow Duration Frequency Curve - Mouth of Centenial Branch - 1992

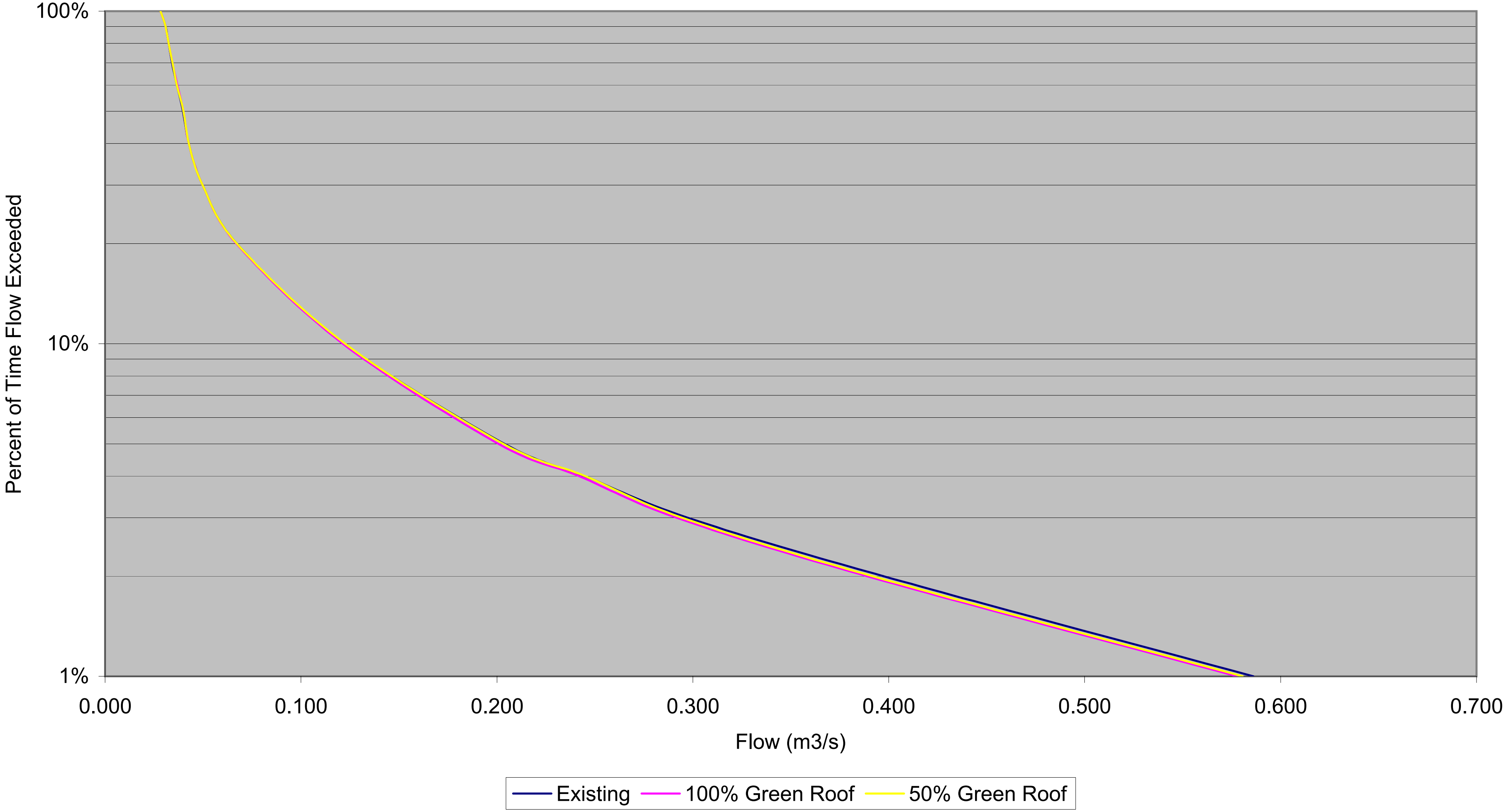
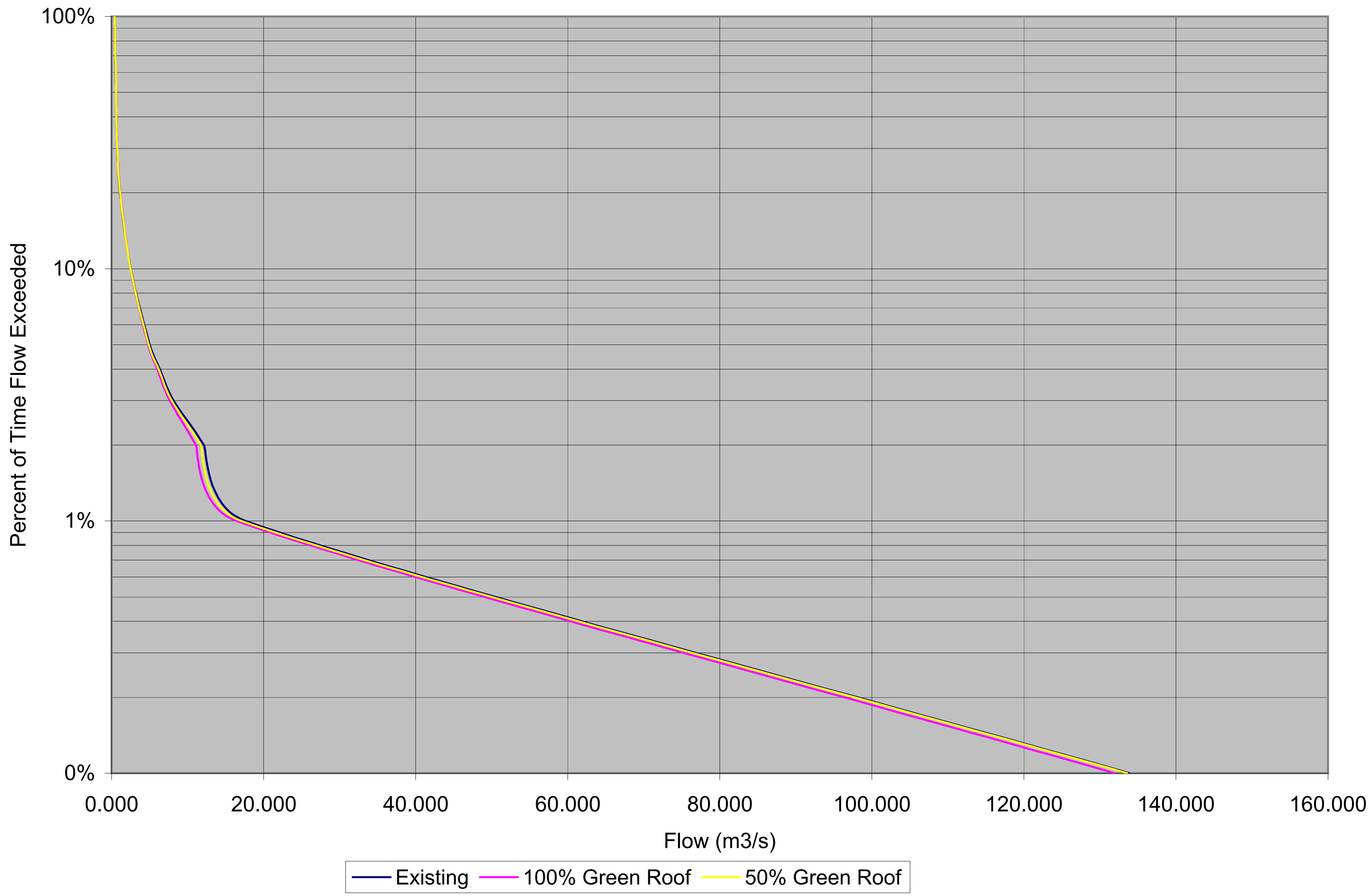


Figure 3.12: Flow Duration Frequency Curve - Mouth of Highland Creek Wastershed - 1992



3.3.3 Water Quality

Table 3.5a summarizes the Event Mean Concentration (EMCs) for a number of parameters. Values are provided for a number of conditions as outlined below.

- WWFMMP: These values represent the average conditions for an industrial site as determined from the WWFMMP study.
- Control Roof: These values represent the average concentration as measured from the discharge location of the control roof.
- Green Roof: Similar to the control roof, values shown here represent the concentrations as measured from the discharge location of the green roof.
- Precipitation: The values as shown represent the product of contaminants atmospherically deposited during dry weather and contaminants in the rain itself.

In order to assess the impact of implementing green roofs on water quality within Highland Creek the HSPF model was run for baseline conditions and for conditions where green roofs were implemented for 100 percent of the eligible land uses. Prior to running the HSPF model several discussions were held with TRCA and City of Toronto staff. Based on these discussions the following was agreed to:

- The comparison between baseline conditions and conditions where the green roofs are implemented would be based on the use of the control roof (baseline) EMCs and green roof (green roofs implemented) EMCs. The precipitation data was not used as some values were high and the concentrations represent the product of contaminants atmospherically deposited during dry weather and contaminants in the rain itself.
- The WWFMMP EMC represents the average concentration from the entire site; ie: roof, parking lots, grassed area and adjacent public right of way. In order to run the model where green roofs are implemented an adjustment to reflect the decrease (or increase) in the site EMC was made. An example of this calculation is provided

Table 3.5a: EMC's for selected water quality parameters

Parameter	Units	EMCs			
		WWFMMP	Control Roof	Green Roof	Precipitation
TSS	mg/L	467	6.3	2.2	6.93
Nitrate/Nitrite	mg/L	1.16	0.52	0.12	0.43
Total Phosphours	mg/L	0.5	0.078	0.577	0.01
TKN	mg/L	1.06	0.711	1.61	0.67
Copper	ug/L	27	111.1	42.9	10.64
Lead	ug/L	16	3.8	4.8	3.47
Zinc	ug/L	242	10.8	8.2	14.5
Benzo(g,h,l)perylene	ng/L	239	68.4	11.8	10
E-coil	#/100L	1138	549	661	19

in Appendix C.

- The model could not be run for copper as the method as described above resulted in a negative EMC being generated for the overall site (See Appendix C).

The results for each subwatershed are provided in Appendix C. Provided below is a summary based on the results as generated at the mouth of Highland Creek. The results at the mouth are representative of the findings on a subwatershed basis.

Table 3.5b illustrates the change in loadings and concentrations for each of the eight parameters. The results show that the impact of implementing the green roof technology is mixed. Loadings, primarily as a result of decreased flow volumes, reduce for all parameters except for Total Phosphorus and Total Kjeldahl Nitogen. Concentrations of Total Phosphorus and Total Kjeldahl Nitorgen increased moderately, while concentrations remain virtually unchanged for Total Suspended Solids, Nitrate/Nitrites, Lead and E-coli. Concentrations reduce for Zinc and Benzo(g,h,l)perylene.

In reviewing the findings several points should be noted:

1. The results are based on a specific type of green roof technology and may not be representative of other green roof technologies.
2. For some parameters, for example Total Suspended Solids, the primary source of the pollutant is from other sources (eg: roads, parking lots). Therefore, even though the difference between the EMC for the control roof and green roof is considerable the overall impact is not.
3. Increases in some concentrations may be from internal sources; eg: soils and/or feces from birds (Total Phosphorus, Total Kjel Nitrogen and E-coli).

Table 3.5b: Change in Loadings and Concentrations at the mouth of Highland Creek as a Result of 100 percent Implementation of Green Roofs for Suitable Land Uses

Parameter	Loading		Percent	Concentrations		Percent
	Baseline	100% implemention	Difference	Baseline	100% implemention	Difference
Total Suspended Solid	kg 14669900	kg 13789100	-6%	mg/L 300.18	mg/L 293.89	-2%
Nitrate/Nitrite	kg 61020	kg 58200	-5%	mg/L 1.25	mg/L 1.24	-1%
Total Phosphorus	kg 13487	kg 15321	12%	mg/L 0.28	mg/L 0.33	15%
Total Kjedahl Nitrogen	kg 53367	kg 56762	6%	mg/L 1.09	mg/L 1.21	10%
Lead	kg 2244.5	kg 2151	-4%	mg/L 0.05	mg/L 0.05	0%
Zinc	kg 5141.3	kg 4771.1	-8%	mg/L 0.11	mg/L 0.1	-10%
Benzo(g,h,l)perylene	g 5828.2	g 5219	-12%	ug/L 0.12	ug/L 0.11	-9%
E-coli	10^11# 60278.5	10^11# 60270	0%	#/100ml 123.34	#/100ml 128.45	4%

3.3.4 Water Balance

In order to quantify the extent to which green roofs may reduce the amount of stormwater runoff, the water balance of the HSP-F model also reviewed. Water balance is a tool often used in water resources management which sums the various components of the hydrologic cycle for a watershed by balancing precipitation input, evaporation and evapotranspiration output, groundwater flow input and output, and surface runoff input and output.

The water balance components employed in the HSP-F concept are presented in Figures 3.14, as per HSP-F Design Manual. The primary components are defined and summarized as follows:

SUPY	The total amount of moisture provided to the land surface (i.e. rain+snowmelt);
SURLI	Surface Lateral Inflow from adjacent impervious areas;
TAET	The total actual evapotranspiration;
SURO	Surface overland runoff to a surface strem;
IFWO	Interflow runoff (from the unsaturated soil zone) to a surface stream;
AGWO	Groundwater runoff to a surface stream;

Precipitation - Evapotranspiration $\pm$ Storage - Runoff = 0
(SUPY+SURLI) - (TAET+IMPEV) $\pm$ Storage - (SURO+IFWO+AGWO) = 0

Table 3.6 shows the annual summary of the water budget components for different landuse URFs, including the green roof URF. The results show that the green roof URF has the highest evapotranspiration and the lowest runoff volume as compared to the other URF's.

Table 3.7 shows the annual depth of evapotranspiration and surface runoff (with and without Green Roof applied) at six different locations. The results show that the evapotranspiration has, at the mouth of Highland Creek, increased by 37% and 18% for 100% and 50% implementation

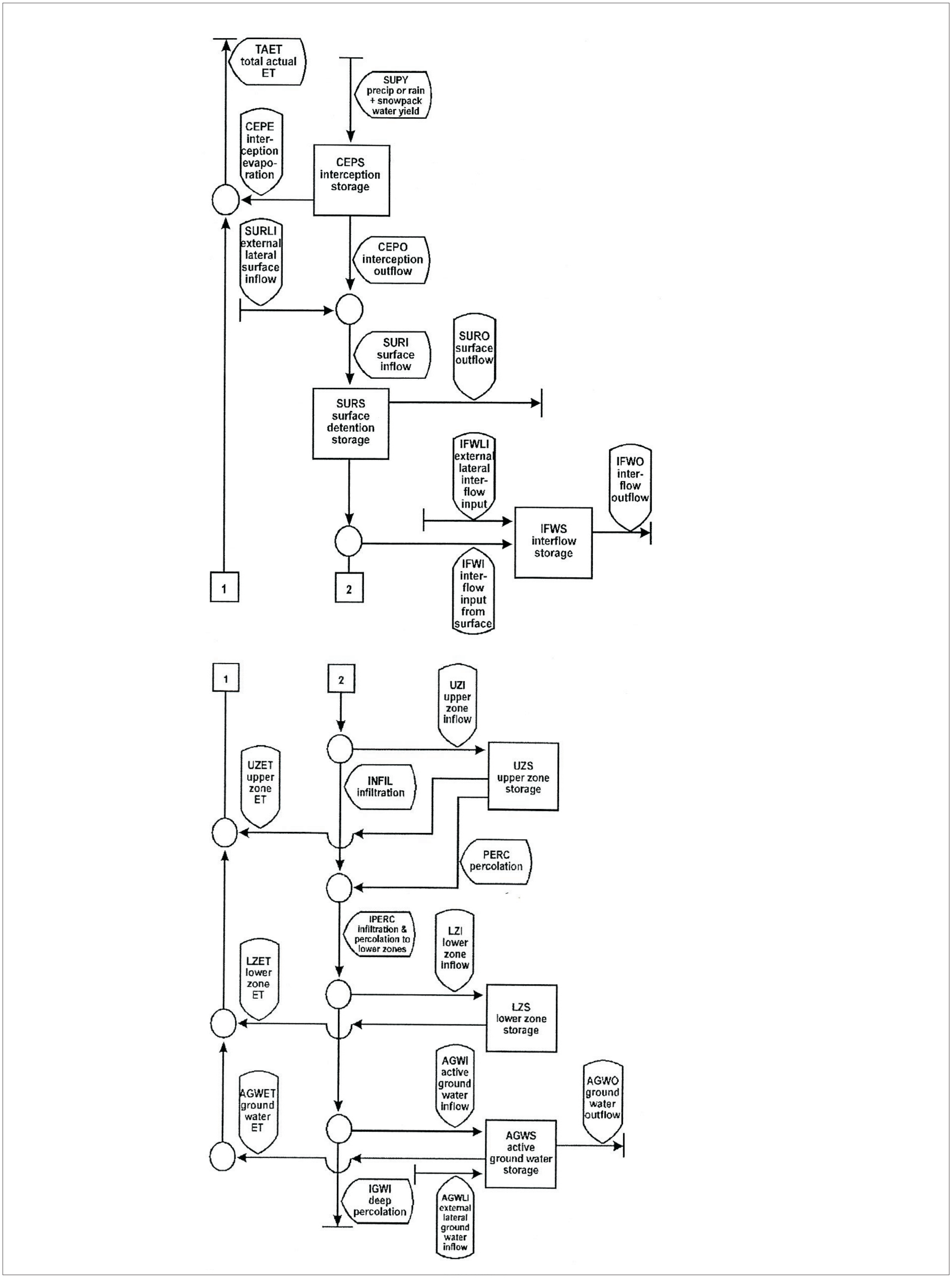


Figure 3.14a Flow Diagram of water movement and storage modeled in the Pervious Land Section

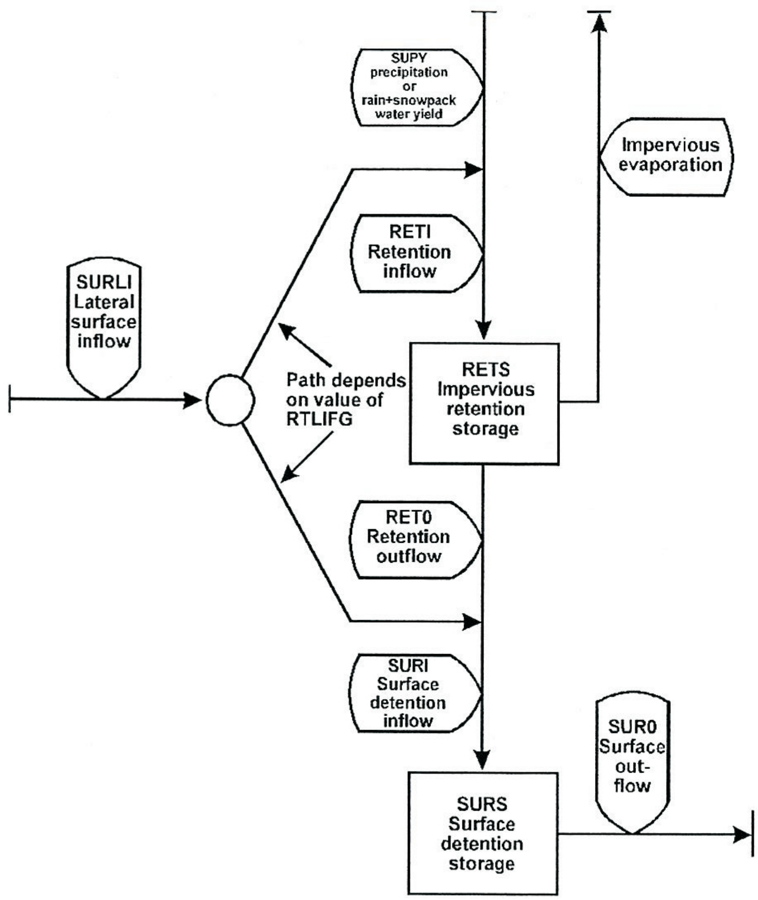


Figure 3.14b Flow Diagram of water movement and storages modeled in the Impervious land section

Table 3.6 ANNUAL SUMMARY OF WATER BUDGET COMPONENTS

Code*	SUPY+SURLI		IMPEV + TAET	AGWO	SURO+IFWO	Sum		Different
	mm		mm	mm	mm			
RHRab	38.8		4.3	2.5	30.0	36.8		2.0
RHRbc	39.7		4.3	2.3	31.3	38.0		1.7
RHRcd	43.1		4.2	2.1	35.6	41.9		1.2
CDTbc	16.4		4.3	2.3	8.2	14.8		1.7
CBBbc	46.5		4.3	2.3	38.2	44.8		1.7
CSMbc	36.8		4.3	2.3	28.5	35.1		1.7
EISab	25.8		4.3	2.5	17.0	23.7		2.0
EISbc	27.1		4.3	2.3	18.7	25.3		1.7
EIScd	31.8		4.2	2.0	24.4	30.6		1.2
IPRab	55.6		4.3	2.4	46.8	53.6		2.0
IPRbc	56.4		4.3	2.3	48.1	54.7		1.7
IPRcd	58.4		4.2	2.0	51.1	57.2		1.2
IBBbc	61.4		4.3	2.3	53.1	59.7		1.7
GreenRoof	15.5		5.1	2.1	7.8	15.0		0.5

* Refer table 2.1 For Landuse Code

Table 3.7a SUMMARY OF EVAPOTRANSPIRATION WITHIN HIGHLAND GREEK WATERSHED

	SUBWATERSHED	DORSET PARK	BENDALE	MARKHAM	MALVERN	CENTENNIAL	WHOLE WATERSHED
Evapotranspiration (mm)	without Green Roof	62.1	51.6	52.3	64.6	16.5	283.9
	50% applied Green Roof	74.5	59.1	62.6	80.6	18.5	336.0
	100% applied Green Roof	87.0	66.7	72.9	96.6	20.4	388.2

Table 3.7b SUMMARY OF SURFACE RUNOFF WITHIN HIGHLAND CREEK WATERSHED

	SUBWATERSHED	DORSET PARK	BENDALE	MARKHAM	MALVERN	CENTENNIAL	WHOLE WATERSHED
Surface Runoff (mm)	without Green Roof	1524.2	969.5	1240.6	2024.4	250.0	6494.0
	50% applied Green Roof	1353.8	878.2	1100.0	1773.3	227.2	5784.7
	100% applied Green Roof	1183.4	786.7	959.3	1522.1	204.5	5075.1

of the green roof technology respectively. The results also show that surface runoff volume has decreased by 21% and 11% assuming 100% and 50% implementation of green roof technology respectively at the mouth of Highland Creek watershed.

4.0 CONCLUSIONS

Aquafor Beech Limited was retained by the Toronto and Region Conservation Authority (TRCA) to determine the effectiveness of implementing green roof technologies within the entire Highland Creek watershed. Conclusions are summarized in the following section.

4.1 Conclusions

1. A considerable amount of work has been carried out within the Highland Creek Watershed. More specifically, three submissions; the WWFMMP, a technical memo by Marshall Macklin Monaghan Limited and a technical memo by Aquafor Beech Limited provided the basis for undertaking this study.

2. The objective of the study was to determine the effectiveness of implementing a Green Roof Technology within the Highland Creek Watershed. Effectiveness was assessed by considering the impact of the technology on the change in flooding, water quality, water balance and erosion.

3. Highland Creek is a good candidate watershed to consider green roofs as approximately 30 percent of the land uses have flat roofs.

4. The findings, for flooding, water balance and erosion were presented assuming the technology was implemented on 100 percent and 50 percent of the flat roofs. Only a 100 percent implementation run was used for assessing the impact on water quality.

5. The results show that the impact on the water balance is modest (approximately a 4 percent reduction in volume at the mouth of Highland Creek assuming a 100 percent

implementation). The percent reduction does vary on a subwatershed basis depending upon land use and thus suitability for implementing the green roof technology.

6. The impact on peak flows is more pronounced, with peak flow reductions as high as 21 percent in the summer for branches (Malvern and Markham) where there is a high percentage of flat roofs. The results show peak flow reductions of approximately 13 percent and 6 percent for 100 and 50 percent implementation at the mouth of Highland Creek.
7. For water quality the results show that the impact of implementing the green roof technology is mixed. Loadings, primarily as a result of decreased flow volumes, reduce for a majority of the parameters which were modelled. Concentrations in the receiving streams show that some parameters increase moderately, several remain virtually unchanged and that some reduce moderately.

8. A qualitative assessment of effectiveness was carried out to determine the impact on erosion. In general, the preliminary results suggest that some benefit may be achieved on the Markham, Bendale and Malvern branches.

9. For water balance, the model results shown the green roof technology will increase the evapotranspiration and reduce the surface runoff with the Highland Creek Watershed.

Respectfully Submitted,
AQUAFOR BEECH LIMITED

Dave Maunder, P.Eng.
Project Manager

REFERENCES

Aquafor Beech Limited. 2004. Technical Memorandum on HSP-F Modelling of Green Roofs - Markham Branch of Highland Creek

Aqua Terra Consultants. 2001. Hydrological simulation program - Fortran. User' Manual

Marshall Macklin Monaghan. 2004. Technical Memorandum on HSP-F Green Roof URF's

The Toronto and Region Conservation Authority. 2003 York University Rooftop Garden Stormwater Quality and Quality Performance Monitoring Report - 2003 Monitoring Season

APPENDIX

APPENDIX A

MARSHALL MACKLIN MONAGHAN TECHNICAL MEMORANDUM

Inter-Office Memo

To:	Sameer Dhalla	Date:	November 18, 2004
From:	Dipanneeta Banerjee	Job No.:	1404091-01-I01
Subject:	Technical Memorandum on HSP-F Green Roof URF's	CC:	Rob Bishop

BACKGROUND

The Toronto and Region Conservation Authority has retained Marshall Macklin Monaghan Ltd to develop a HSP-F (Hydrologic Simulation Program – FORTRAN) Unit Response Function (URF) model representing a "green roof", i.e., a rooftop garden, based on the York University green roof monitoring undertaken by the TRCA in 2003-2004. The objective of this ongoing monitoring program is to assess the effectiveness of green roofs in providing stormwater controls in urban areas.

The methodology adopted for the monitoring and the flow and water quality data collected in 2003 have been documented in the *York University Rooftop Garden Stormwater Quantity and Quality Performance Monitoring Report - 2003 Monitoring Season*. The York University computer science building has been selected as the site of the monitoring. As noted in the report, the roof has a 10% slope, and is divided into two surfaces: shingles (control roof), which represents a normal roof, and garden. The control roof and garden have areas of 131 m^2 and 241 m^2 respectively. The length of overland flow for the control roof is approximately 26.5 m, and that for the garden is approximately 20.5 m. The flows from the two surfaces are isolated and drain to separate eves troughs at the end of the sloped roof, and are piped through two Endress and Hauser Promag 50 flow metres, which determine flow rates and volumes. Detailed descriptions of the flow metres are provided in the *York University Rooftop Garden Stormwater Quantity and Quality Performance Monitoring Report*.

The present memorandum discusses the methodology adopted for developing the HSP-F green roof URF model and the flow calibration results. EMC's for selected water quality parameters are also developed based on the recorded concentrations in 2003.

HSP-F MODEL DEVELOPMENT

Data Collection

The HSP-F *(Hydrologic Simulation Program – FORTRAN)* model was developed and calibrated using continuous meteorological data for the calibration period. Since April 2003, the York University roofs have been monitored continuously for runoff quantity, rainfall, ambient air temperature and relative humidity, soil temperature and moisture. Hence precipitation and air temperature data required as model input, and the flow data used for model calibration were available from the TRCA. The remaining meteorological data required as model input were obtained from Environment Canada.

The meteorological data used in the HSP-F URF model, and the respective sources for the data are summarized below in Table 1:

TABLE 1: METEOROLOGICAL INPUT DATA

PARAMETER	SOURCE	TYPE
Precipitation	TRCA –York University Rooftop	15-minute
Temperature	TRCA –York University Rooftop	15-minute
Wind Speed	Environment Canada – Pearson Airport	Hourly
Dew Point Temperature	Environment Canada – Pearson Airport	Hourly
Solar Radiation	Environment Canada – Toronto Central	Hourly based on Monthly Normals
Potential Evapo-transpiration	Calculated using Penman's Equation	Hourly

Please note that even though continuous flow and meteorological data were available for the entire period from April 15, 2003 -- February 2004 (with a gap from August 26 – September 23, 2003), anomalies were noted in the precipitation and flow data collected in December 2003 – February 2004. Hence, model calibration was only undertaken based on the data collected during April – November 2003.

Methodology

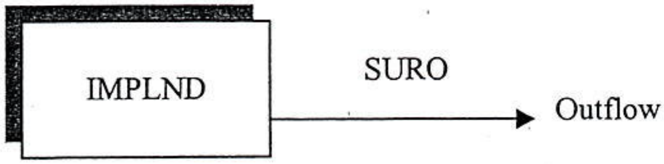
Separate URF's representing the control roof and the roof garden were developed using HSP-F, consistent with the modelling approach adopted for the *City of Toronto Wet Weather Flow Master Plan*. The URF or "Unit Response Function" is the hydrological response of a 10 ha test catchment representing a particular land use type, soil, and connectivity configuration to a set of meteorological conditions. Schematic representations for the URF's developed for the control roof and the garden are provided in Figure 1. As shown on Figure 1, the control roof consists of an impervious land segment represented as an IMPLND in HSP-F. The runoff from the control roof consists entirely of "SURO", which is the net overland flow from a land segment generated in HSP-F.

The roof garden is observed to behave partly as an impervious land segment in that the observed hydrograph shows a very swift response to the rainfall, and has very distinct peaks which clearly follow the peak rainfall intensities during storm events. As shown in Figure 1, the roof garden was therefore simulated in HSP-F using a pervious land segment or a PERLND, and an IMPLND. It was further determined during the calibration procedure (discussed in detail in the following sections), that the best overall agreement between the observed and the simulated flow volumes, and hydrographs for the calibration period is obtained by representing the green roof URF as a 75% pervious, and 25% impervious area. The total runoff from the roof garden consists of SURO, which is the surface runoff, and AGWO + IFWO, which represents the net outflow from the groundwater reservoir, i.e., the net outflow obtained from the infiltrated portion of the precipitation.

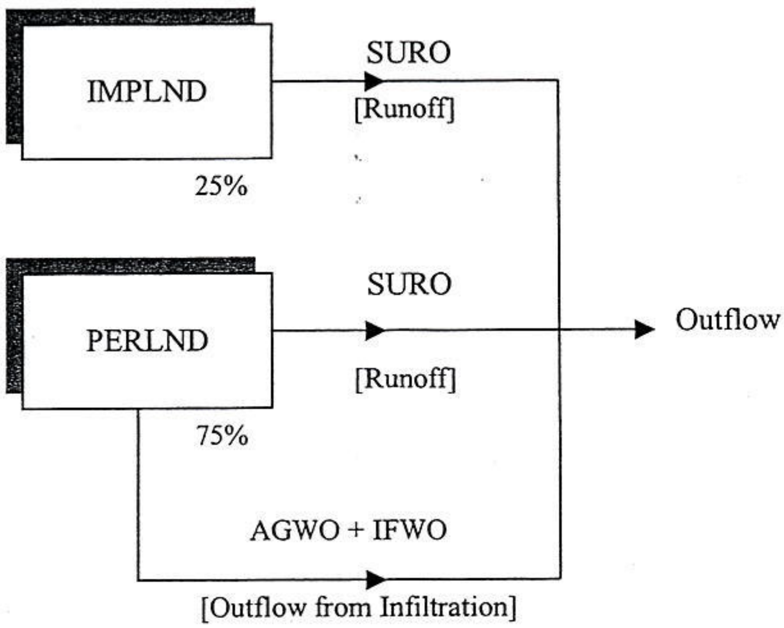
Note that as mentioned in the previous section, the model could not be calibrated for winter or spring conditions due to unavailability of data. The snowmelt subroutine in the model should therefore be regarded as uncalibrated.

FIGURE 1: CONNECTIVITY FOR GREEN ROOF URF's

A. **Control Roof URF Structure**



B. **Roof Garden URF Structure**



MODEL CALIBRATION

Methodology

Model calibration was performed by running the model continuously for April – December 2003 and comparing flow volumes and duration curves for individual months. Internal time steps of 15 minutes were used for all model simulations. Flow hydrographs for selected events were also compared. Please note that the continuous flow hydrographs for the entire period were not compared because the time-to-peak's for both the control roof and the garden during storm events are so short that the actual shapes of the hydrographs will not be evident on a larger time scale. However, note that event based simulations were never performed using the model, i.e., the comparison of hydrographs for individual events presented in Figures 2 – 15 are also derived from continuous model simulations.

The calibration was performed based on the outflows from the actual areas of the control roof and the garden used for the monitoring study, rather than the outflows form the 10 ha URF's. The calibration of the control roof was achieved by a slight adjustment of the retention storage capacity. The garden was calibrated using a number of different parameters, which are summarized in Table 2.

TABLE 2: PARAMETERS USED IN CALIBRATION OF GARDEN URF

PARAMETER	DESCRIPTION
CEPSC	Interception storage capacity of the pervious land segment
UZSN	Upper zone nominal storage of the pervious land segment
LZSN	Lower zone nominal storage of the pervious land segment
LZET	Lower zone evapo-transpiration demand of the pervious land segment
INTERFLW	Interflow inflow parameter of the pervious land segment
RETSC	Retention storage capacity of the impervious land segment

Monthly variations in CEPSC, UZSN, INTERFLW, LZET and RETSC were introduced in the model during calibration based on reasonable seasonal estimates, since significant seasonal variations have been observed in the performance of the garden in 2003.

Results

The simulated flow volumes from the control roof and the garden are compared to the observed volumes for the calibration period of April – December 2003 in Table 3.

TABLE 3: COMPARISON OF OBSERVED AND SIMULATED FLOW VOLUMES

Month	Precipitation (mm)	Garden Volumes				Control Volumes (L)			
		Rainfall (L)	Observed Runoff (L)	Simulated Runoff (L)	Diff (%)	Rainfall (L)	Observed Runoff (L)	Simulated Runoff (L)	Diff (%)
May-03	123.6	29788	12113	12700	5	16192	17470	15940	-9
Jun-03	88.4	21304	2967	3630	22	11580	12224	11460	-6
Jul-03	44.0	10604	1351	1270	-6	5764	5292	5670	7
26-Aug-03	63.6	15328	3419	3610	6	8332	8442	8280	-2
23-Sep-03	72.6	17497	7194	7300	1	9511	5864	5730	-2
Oct-03	59.9	14436	8850	6620	-25	7847	7626	7660	0
Nov-03	149.8	36102	18354	19870	8	19624	17848	19430	9
Dec-03	59.0	14219	9060	9080	0	7729	11873	7420	-38

As evident from the results, good agreement between the observed and simulated volumes is obtained for the control roof for May – November 2003. Further adjustment for December 2003 was not attempted, since the observed runoff for the month appears to be approximately 1.5 times the rainfall volume, which is not realistic. The simulated volume is approximately 96% of the rainfall volume, which is a more reasonable estimate.

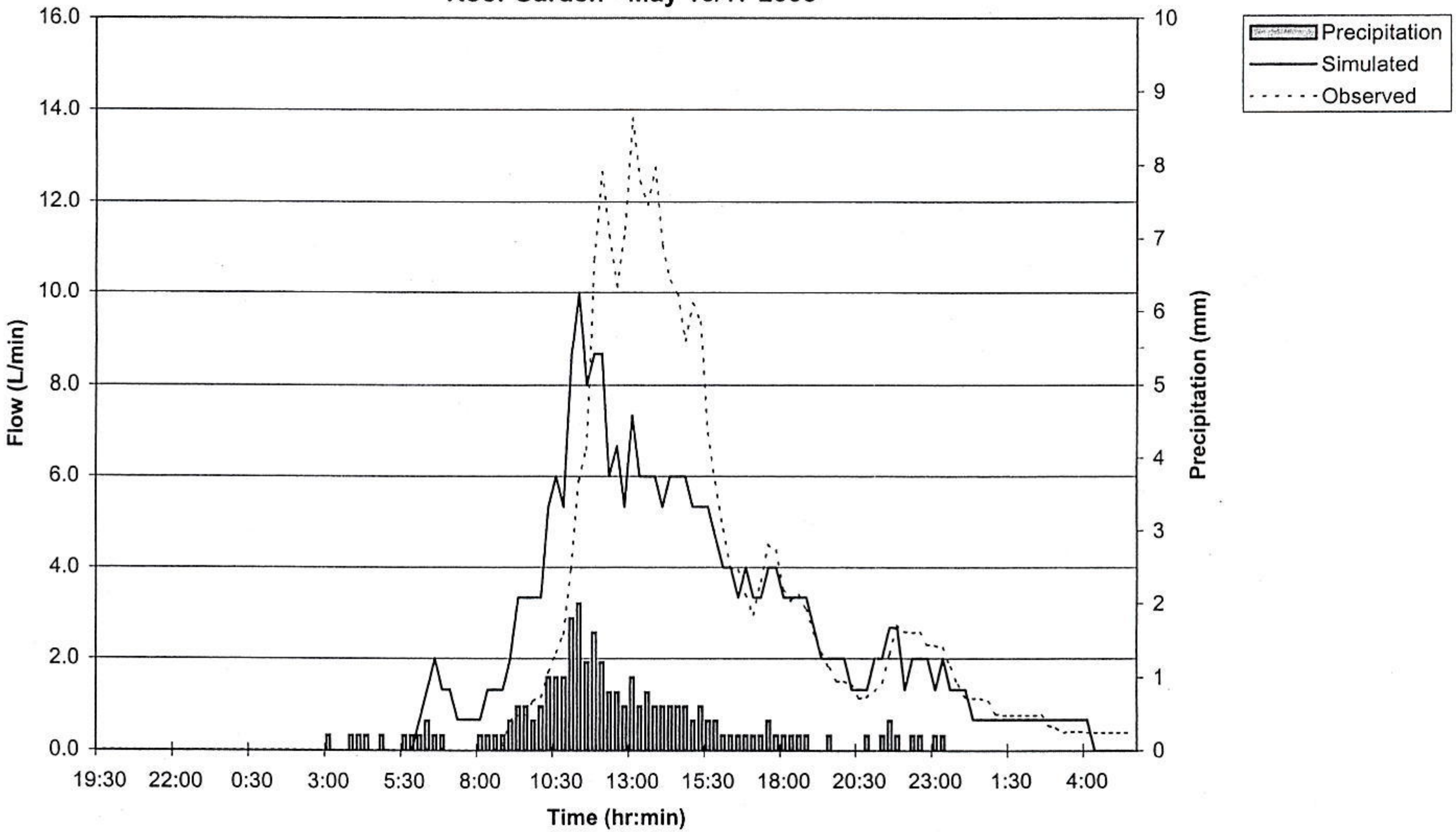
Observed and simulated hydrographs for selected storm events for the control roof are compared in Figures 2-8. The simulated hydrographs for all of the storm events peak approximately 15-30 minutes later than the observed hydrographs. However, further adjustments were not attempted since the simulated hydrographs follow the rainfall peaks (see Figures 2-8).

For the roof garden, good agreement is obtained between the observed and simulated flow for the months of May, July – August 2003, November – December 2003. It was not possible to obtain a better agreement between the flow volumes for June and October 2003 using expected seasonal values for the storage parameters and LZET. The difference observed between the flow volumes in October may be due to the monitored garden reaching its saturation level faster than the modelled garden from irrigation activities, and consequently yielding more runoff than the modelled garden in fall.

Observed and simulated flow hydrographs for selected storm events for the control roof are compared in Figures 9-15. Monthly flow duration curves are compared in Figures 16 - 23. As evident from the figures, the observed and simulated hydrographs show similar response to the events and have similar timings. However, the simulated flows show significantly higher peaks for the events in June, August, and September. Further calibration was not attempted for August and September since the flow volumes for these months show good agreement. As stated earlier, a better calibration for June is not possible using reasonable values of the storage parameters and LZET. The observed and simulated flow duration curves agree reasonably well, although the curves derived from the observed flows generally have a steeper slope than the simulated curves, again suggesting that the soils of the monitored garden reach their saturation level faster than the modelled garden.

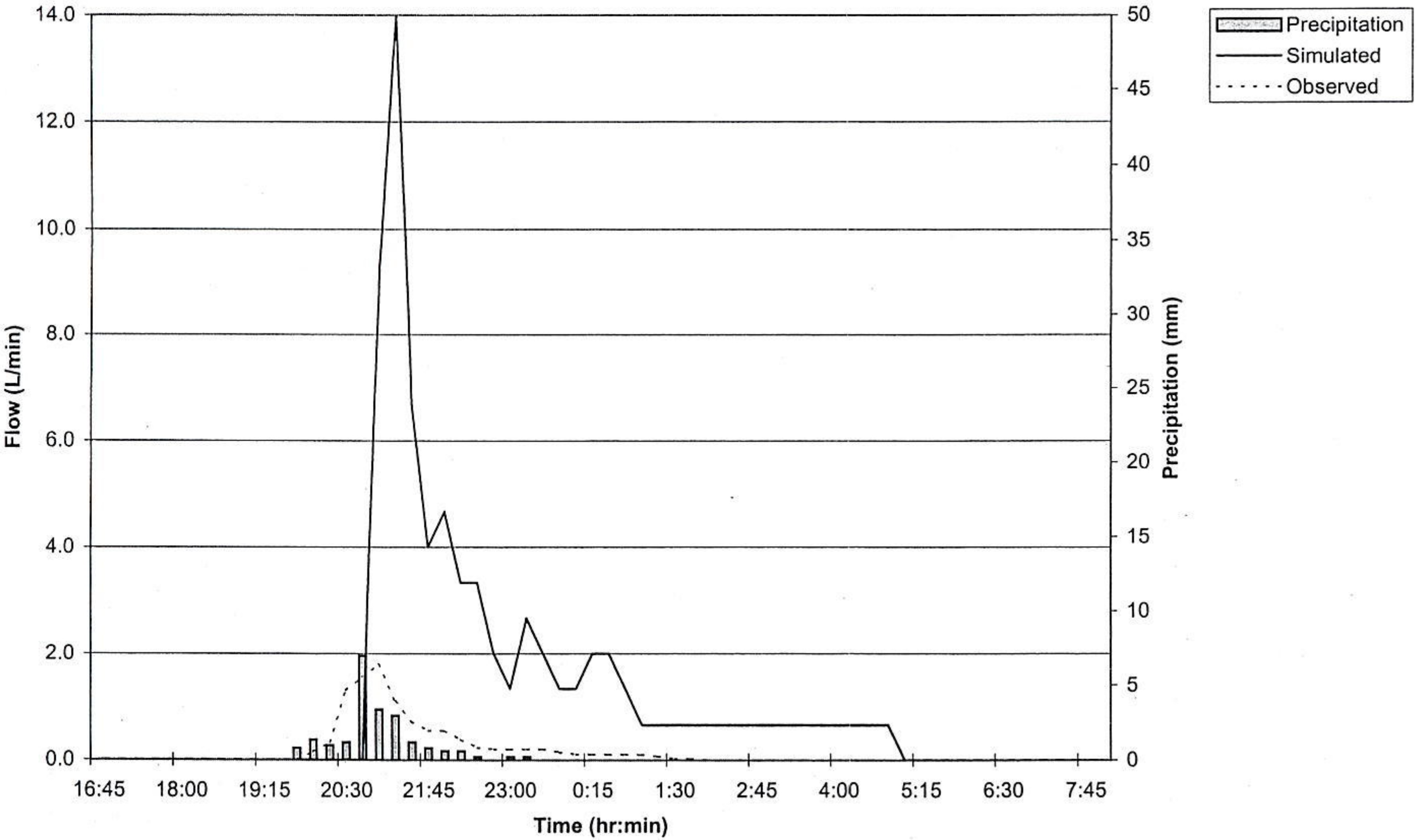
The calibrated model was then used to simulate the average year (1991) used for model simulations in the Toronto Wet Weather Flow Study. The flow series generated from this simulation can be obtained from

Figure 9:
Roof Garden - May 16/17 2003



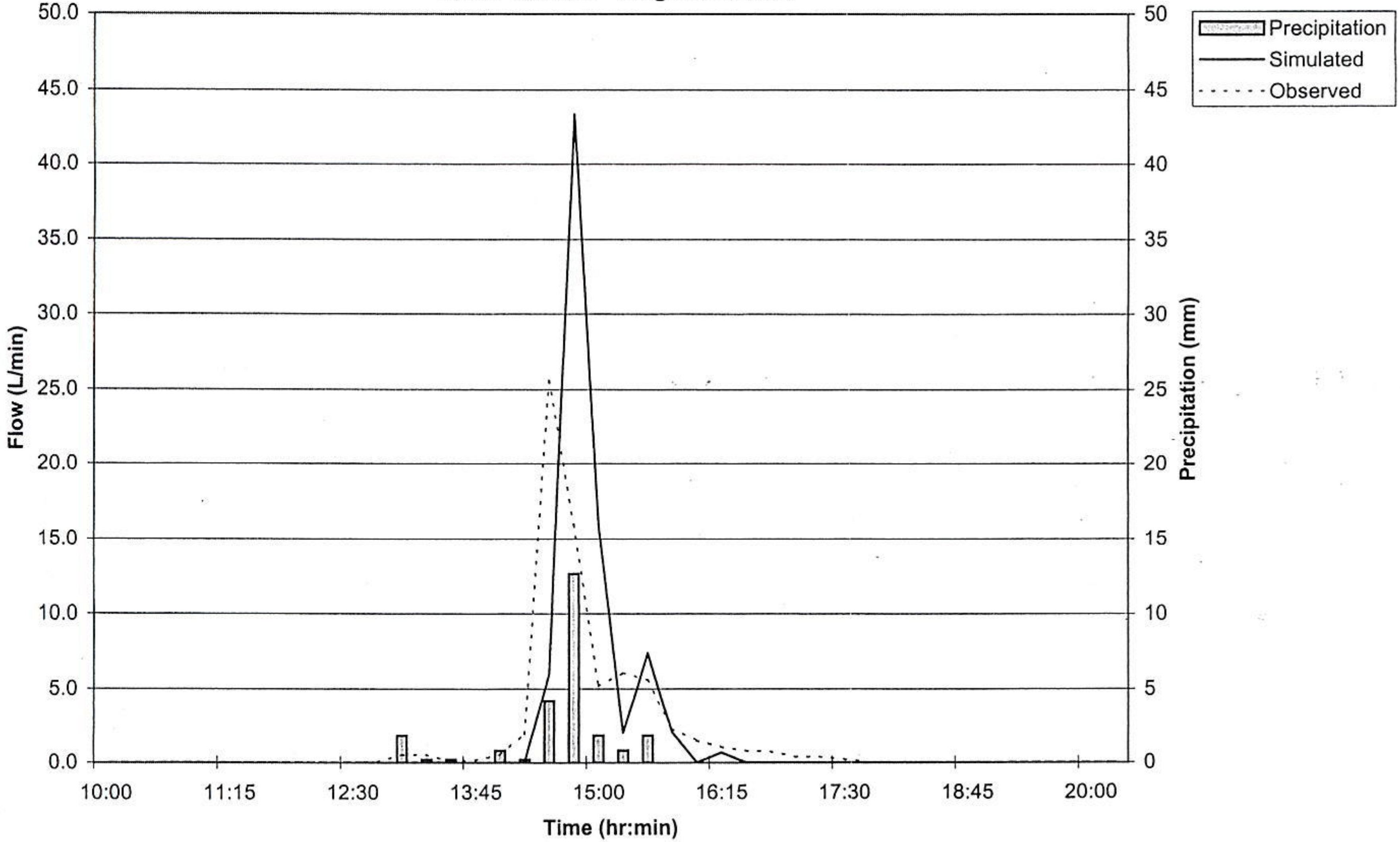
CalibHC.xls

**Figure 10:
Roof Garden - June 8/9 2003**



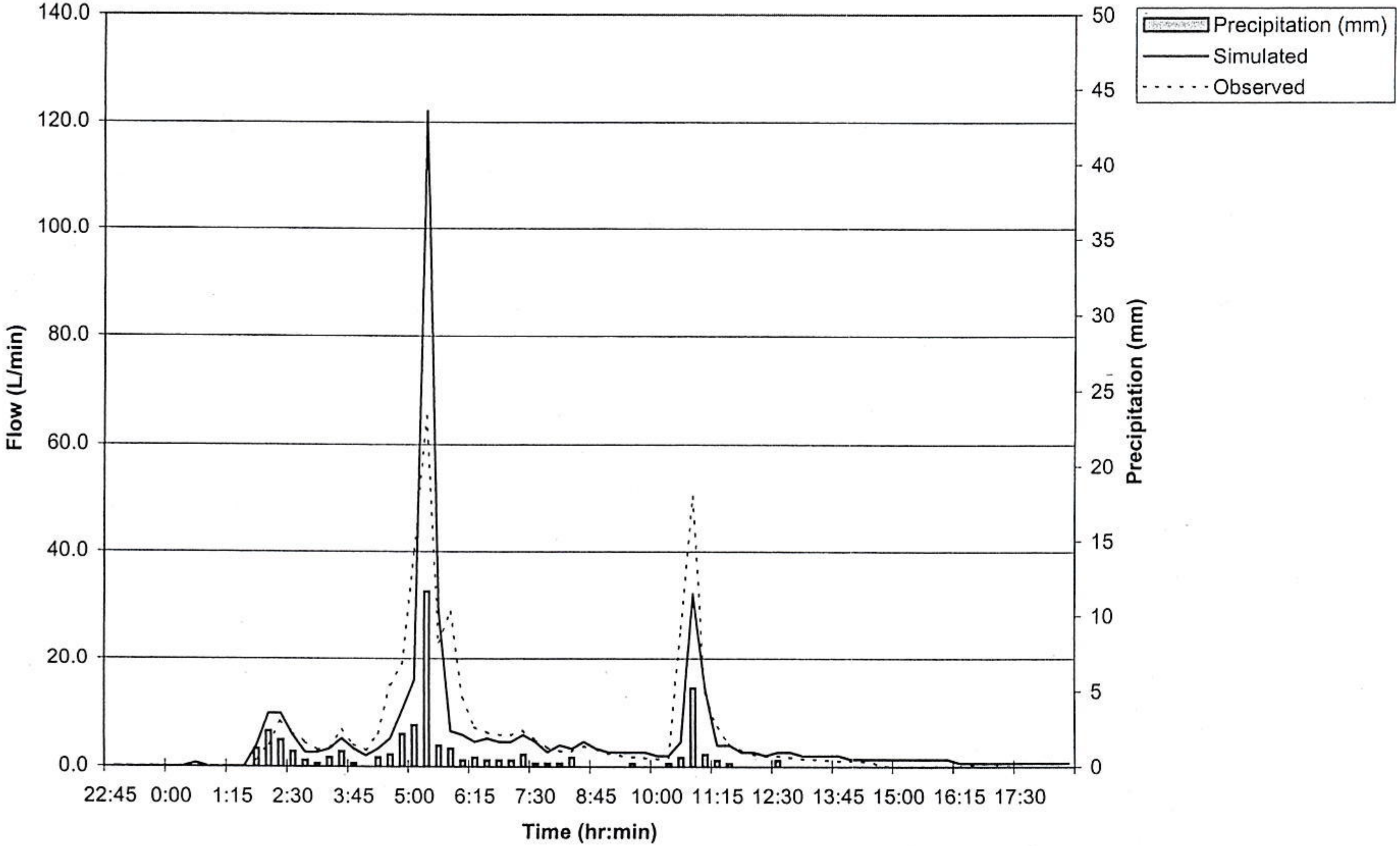
CalibHG2.xls

Figure 11:
Roof Garden - August 2 2003



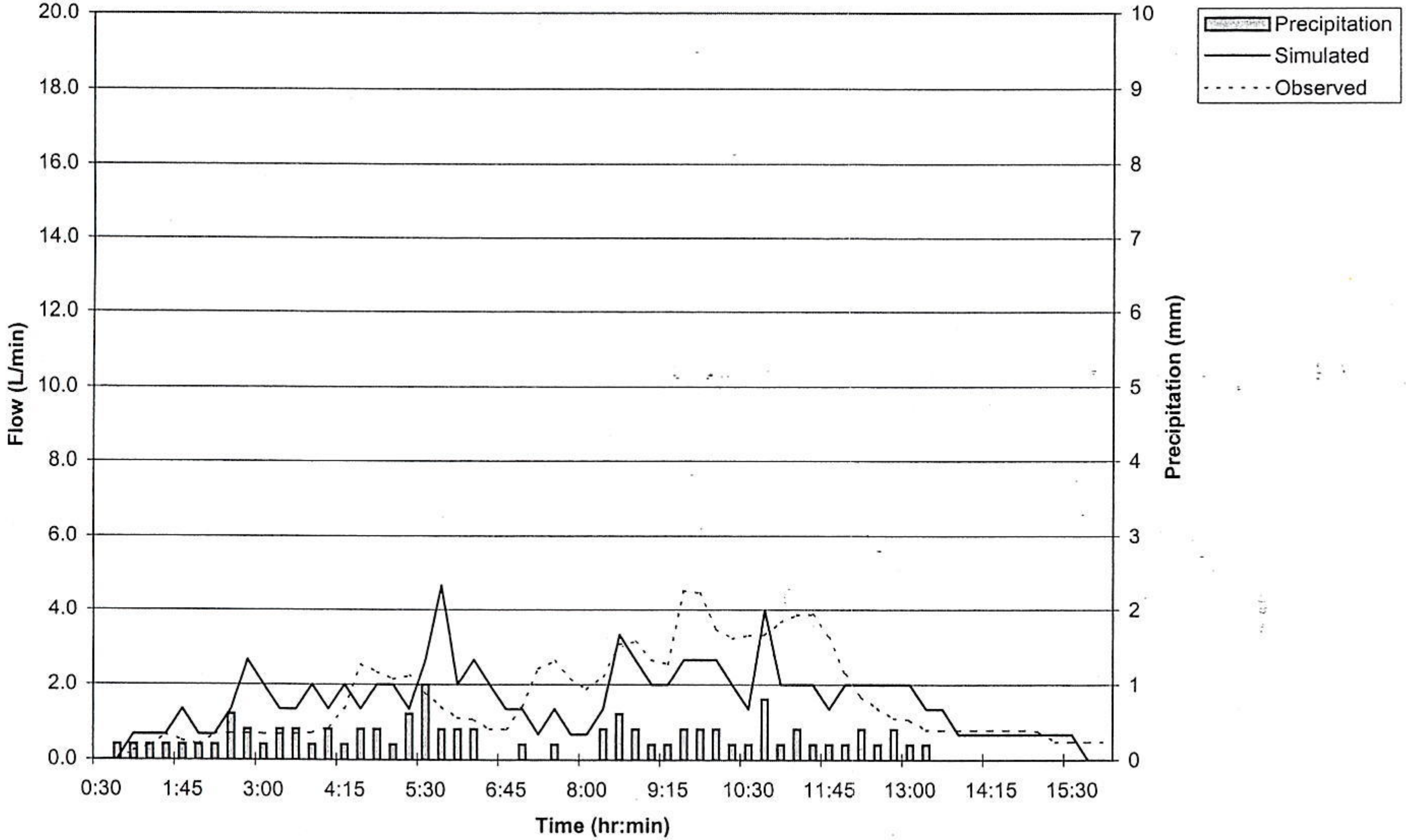
CalibHG2.xls

Figure 12:
Roof Garden - September 27 2003



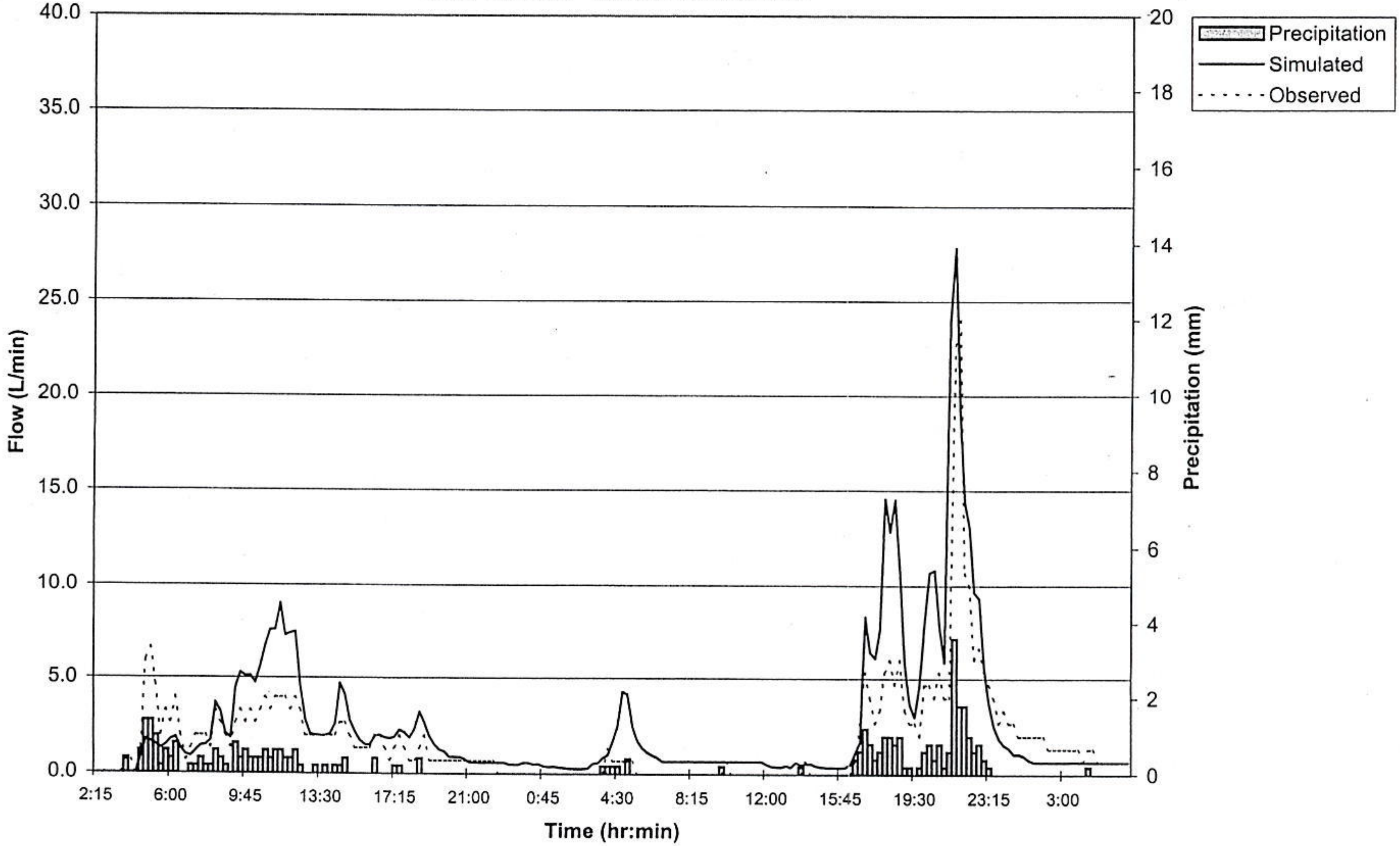
CalibHG2.xls

Figure 13:
Roof Garden - October 26 2003

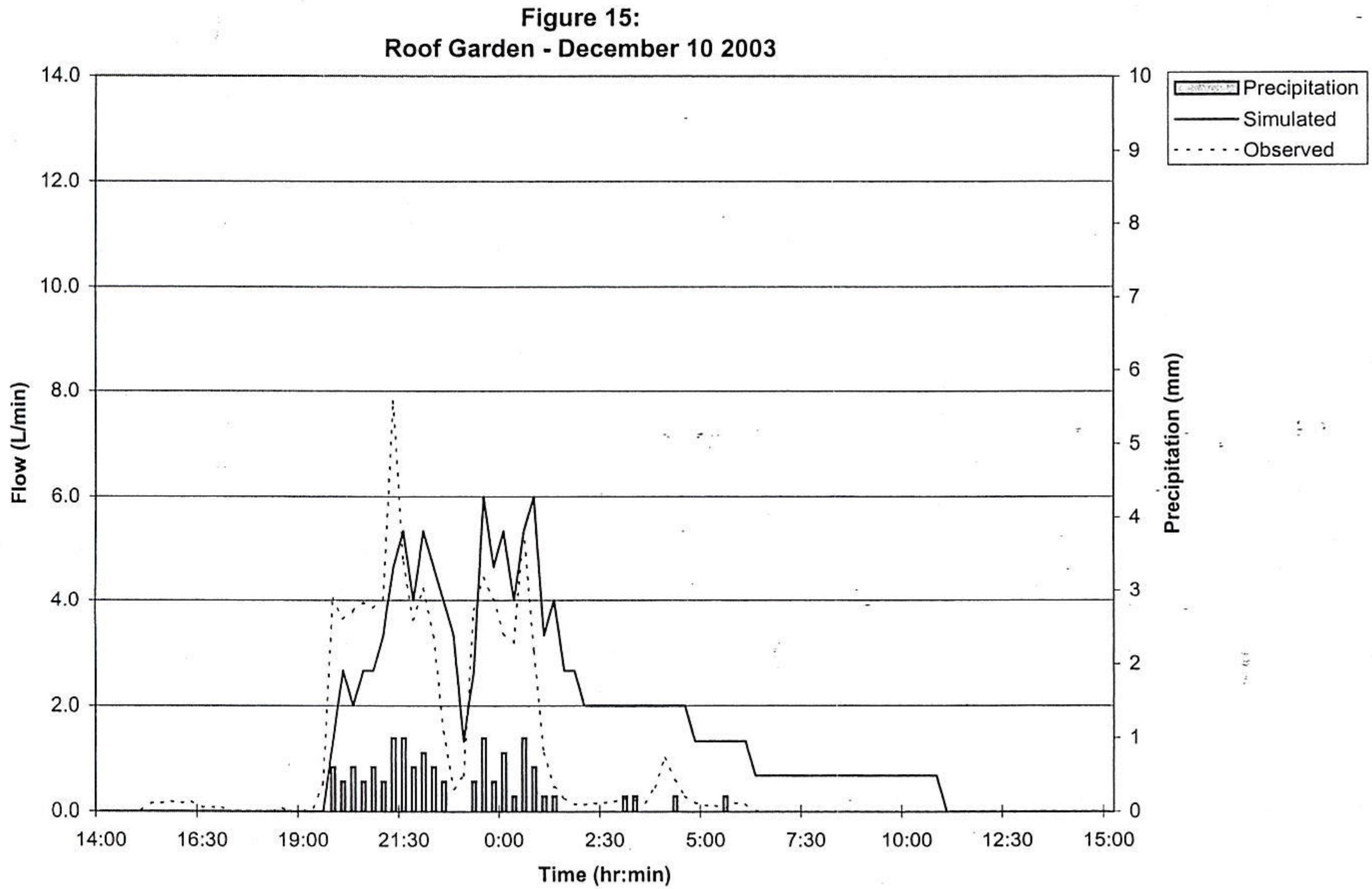


CalibHG2.xls

Figure 14:
Roof Garden - November 2 2003

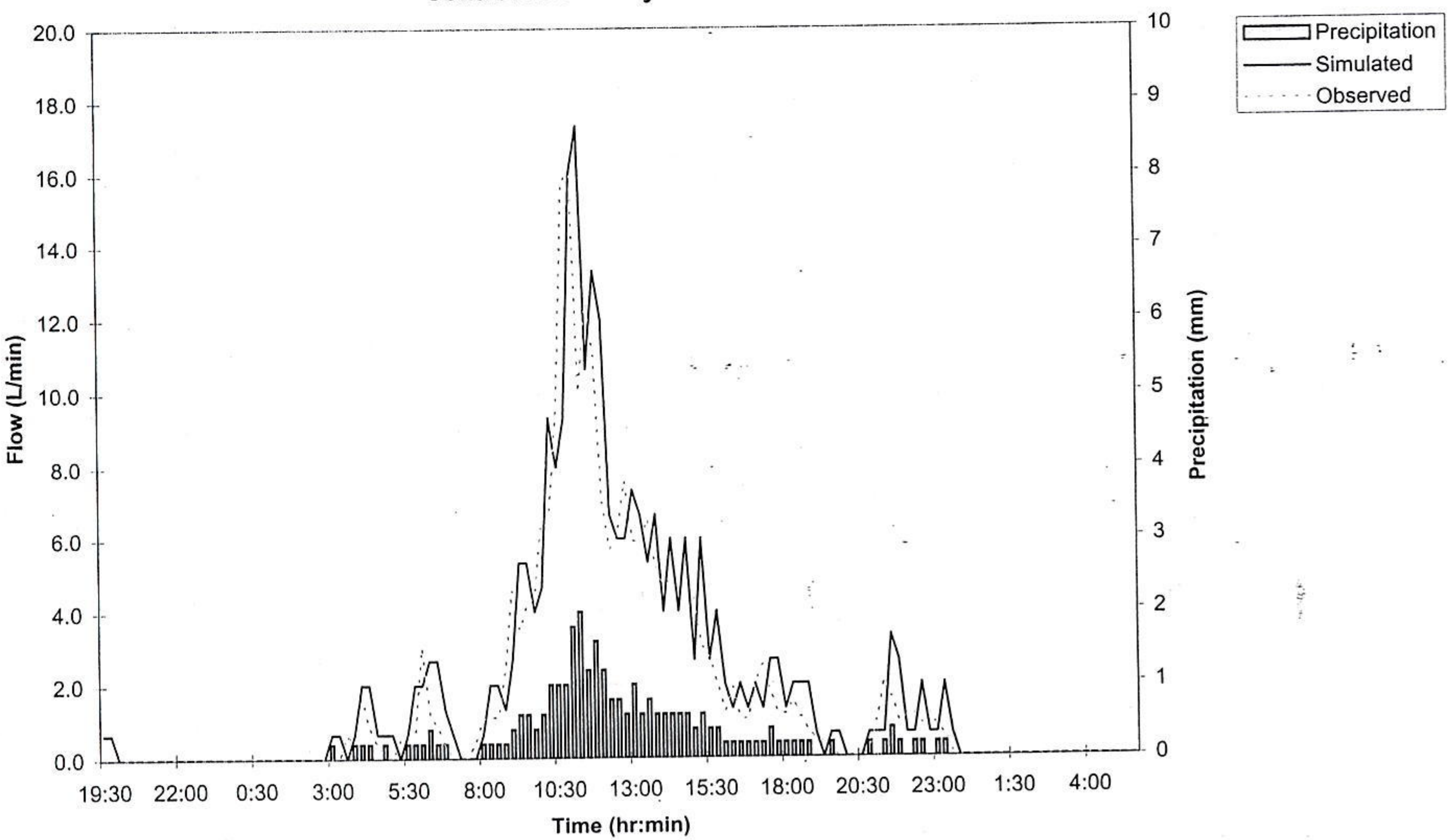


CalibHG2.xls



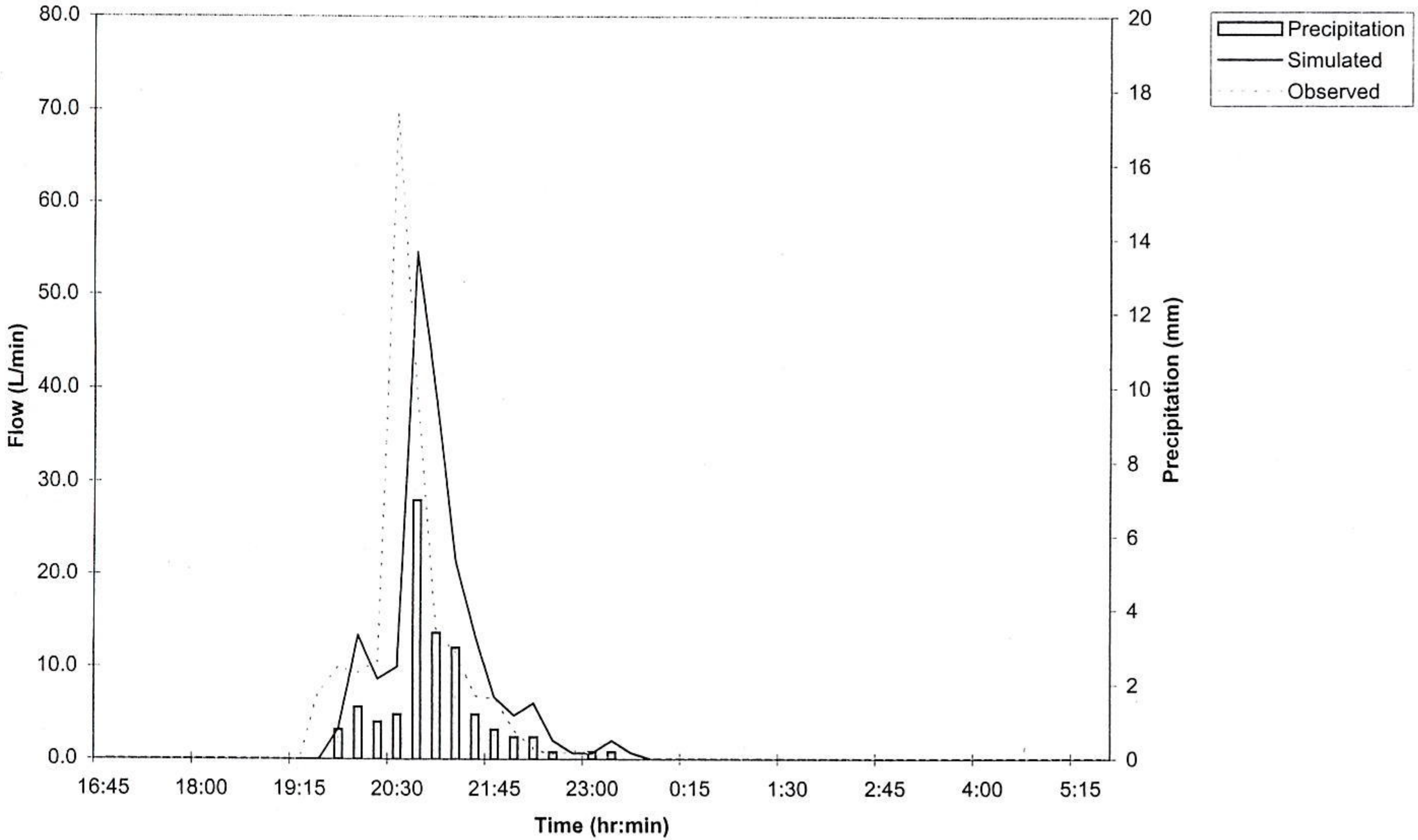
CalibHG2.xls

Figure 2:
Control Roof - May 16/17 2003



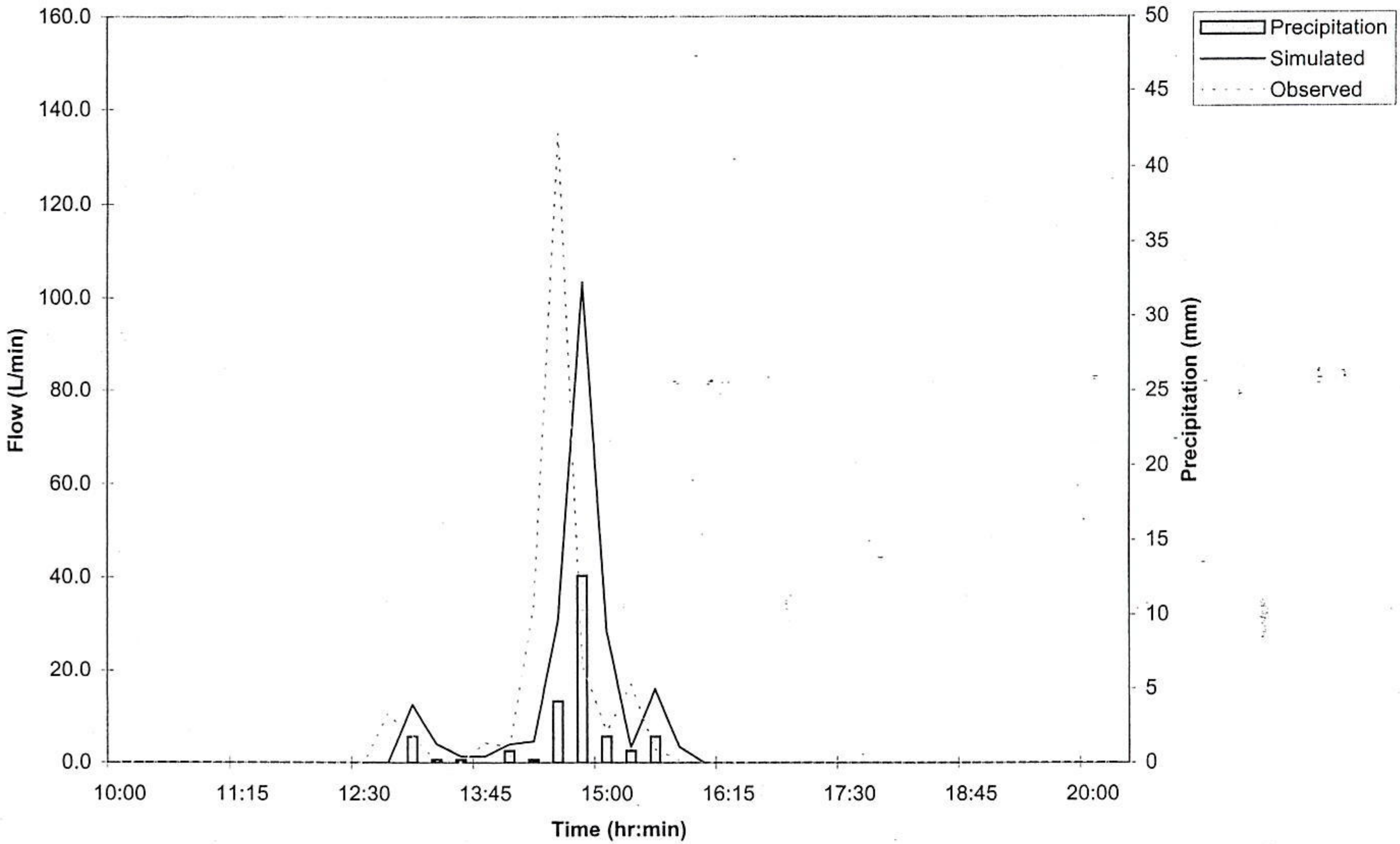
CalibHC.xls

Figure 3:
Control Roof - June 8/9 2003



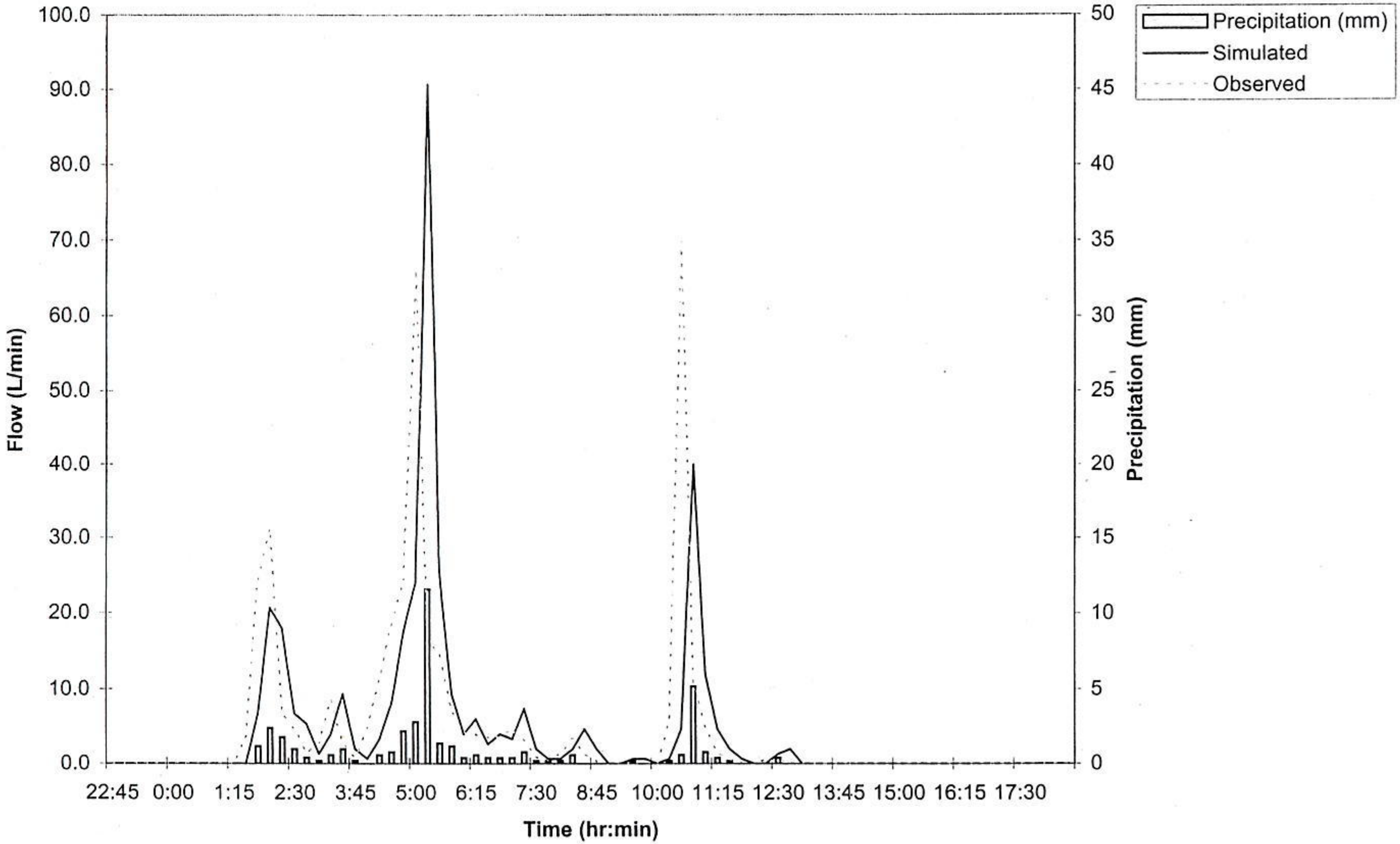
CalibHC.xls

Figure 4:
Control Roof - August 2 2003



CalibHC.xls

Figure 5:
Control Roof - September 27 2003



CalibHCa.xls

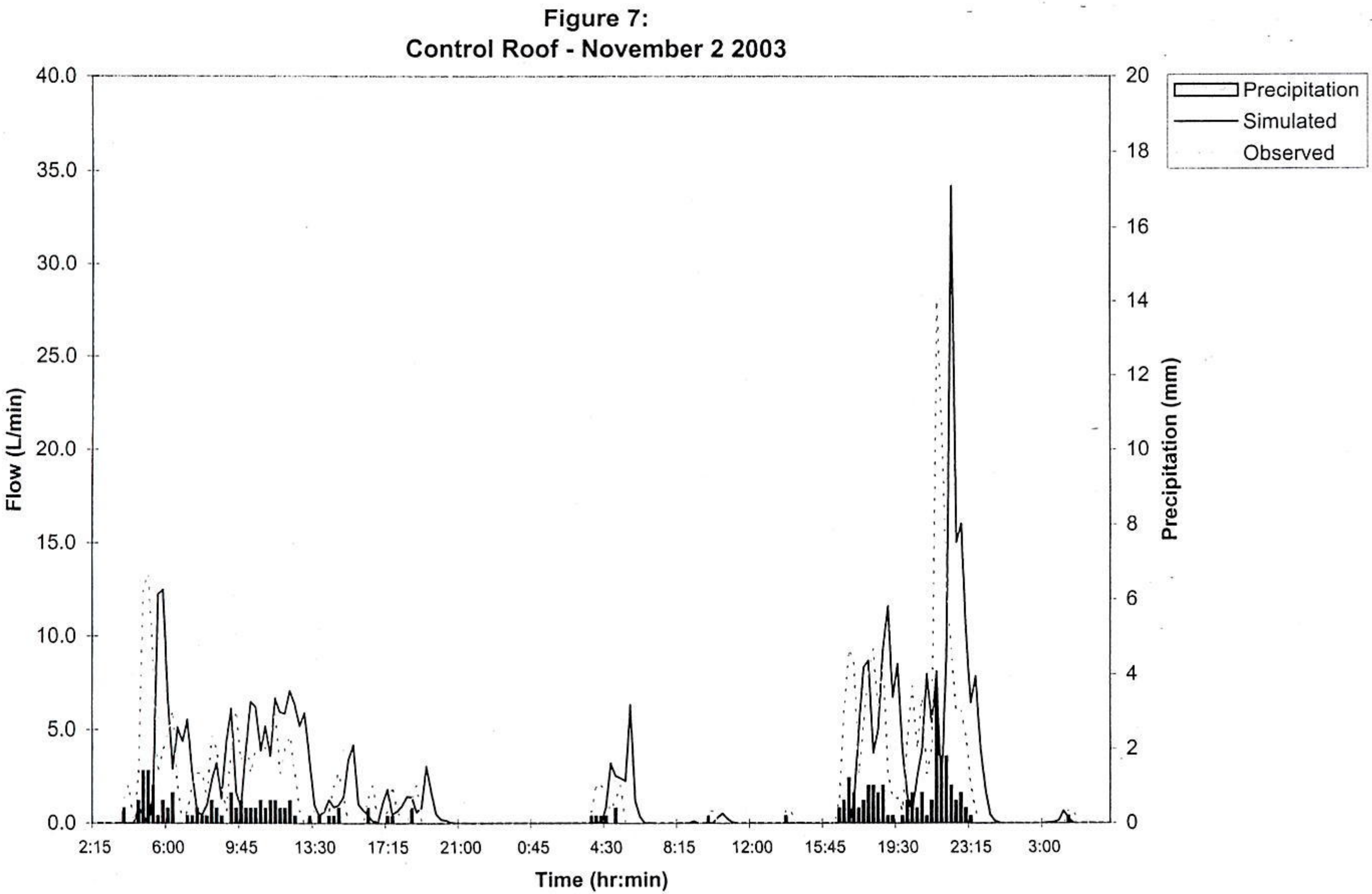
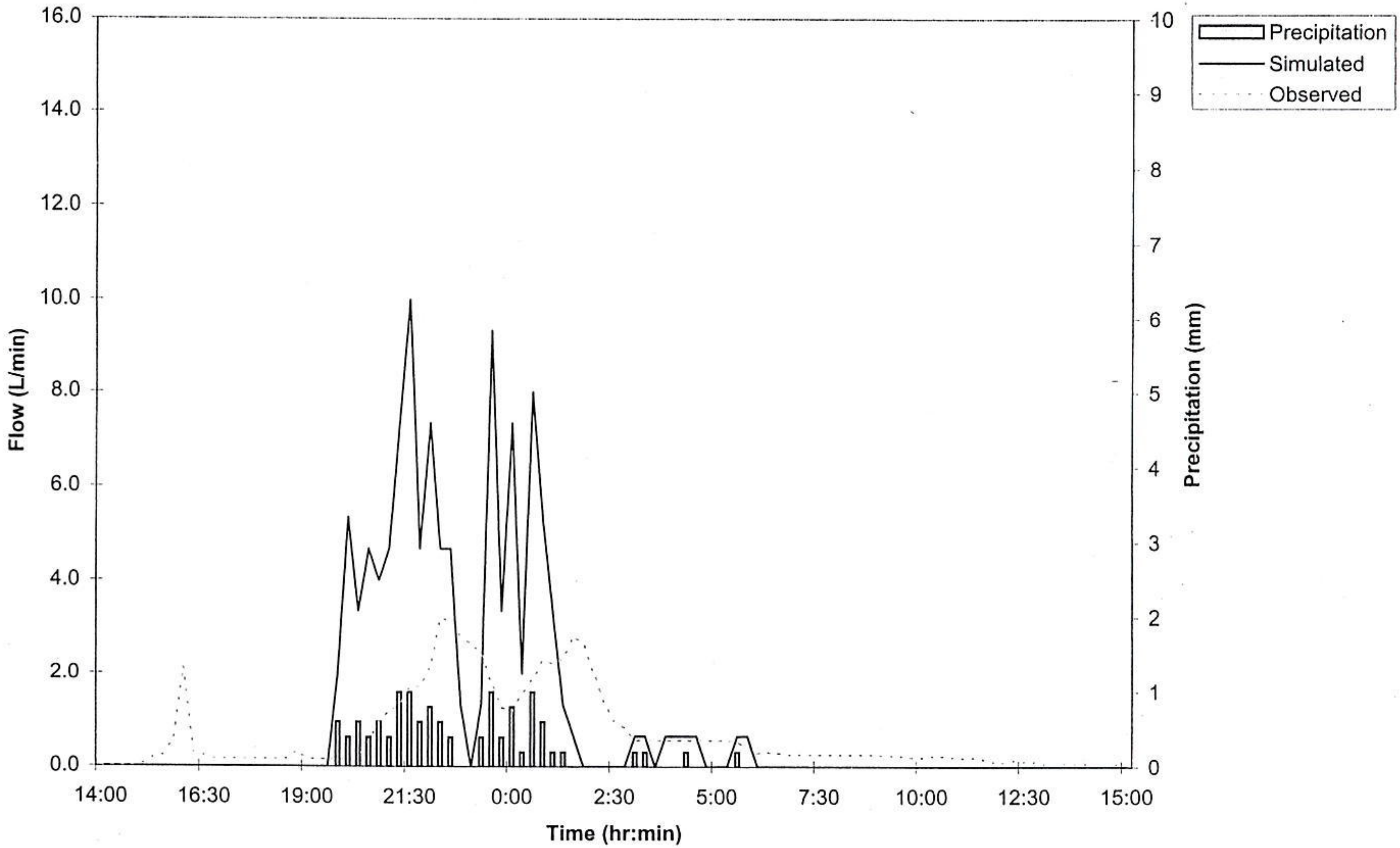


Figure 7:
Control Roof - November 2 2003
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Flow (L/min)
20
18
16
14
12
10
8
6
4
2
0
Precipitation (mm)
Precipitation
Simulated
Observed
2:15
6:00
9:45
13:30
17:15
21:00
0:45
4:30
8:15
12:00
15:45
19:30
23:15
3:00
Time (hr:min)

CalibHC.xls

Figure 8:
Control Roof - December 10 2003



CalibHC.xls

Figure 16:
Flow Duration Curves - May 2003
Roof Garden

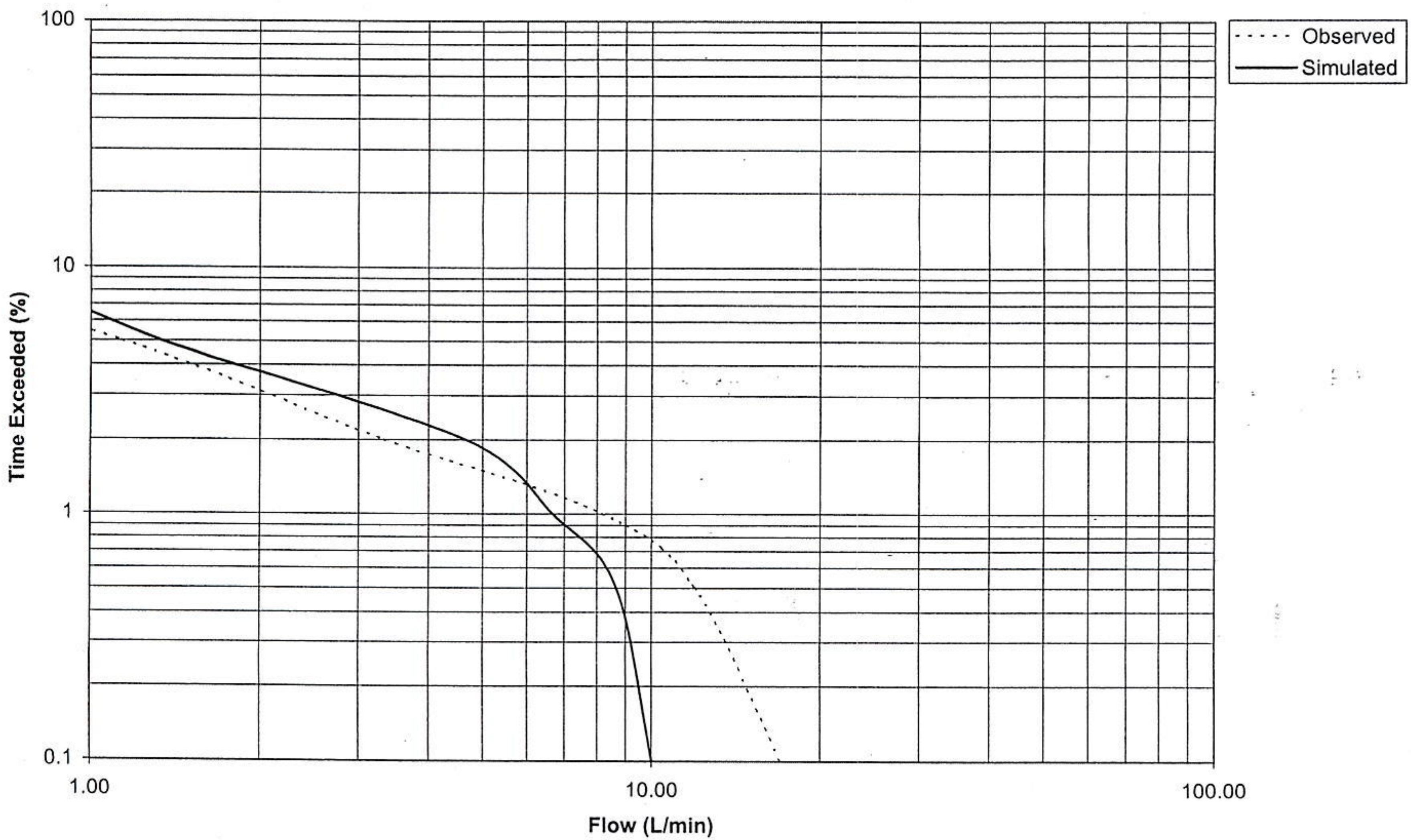


Figure 17:
Flow Duration Curves - June 2003
Roof Garden

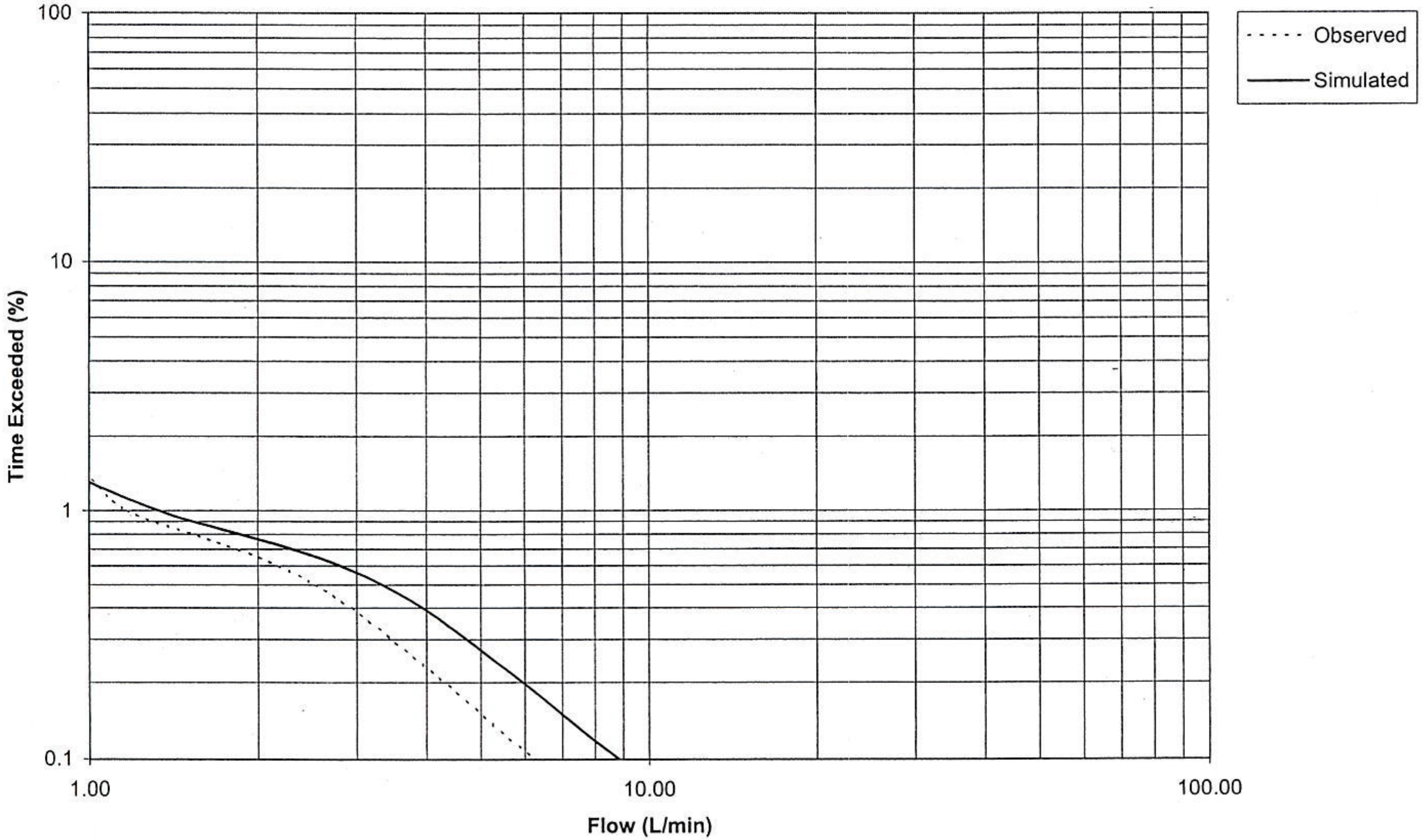


Figure 19:
Flow Duration Curves - August 2003
Roof Garden

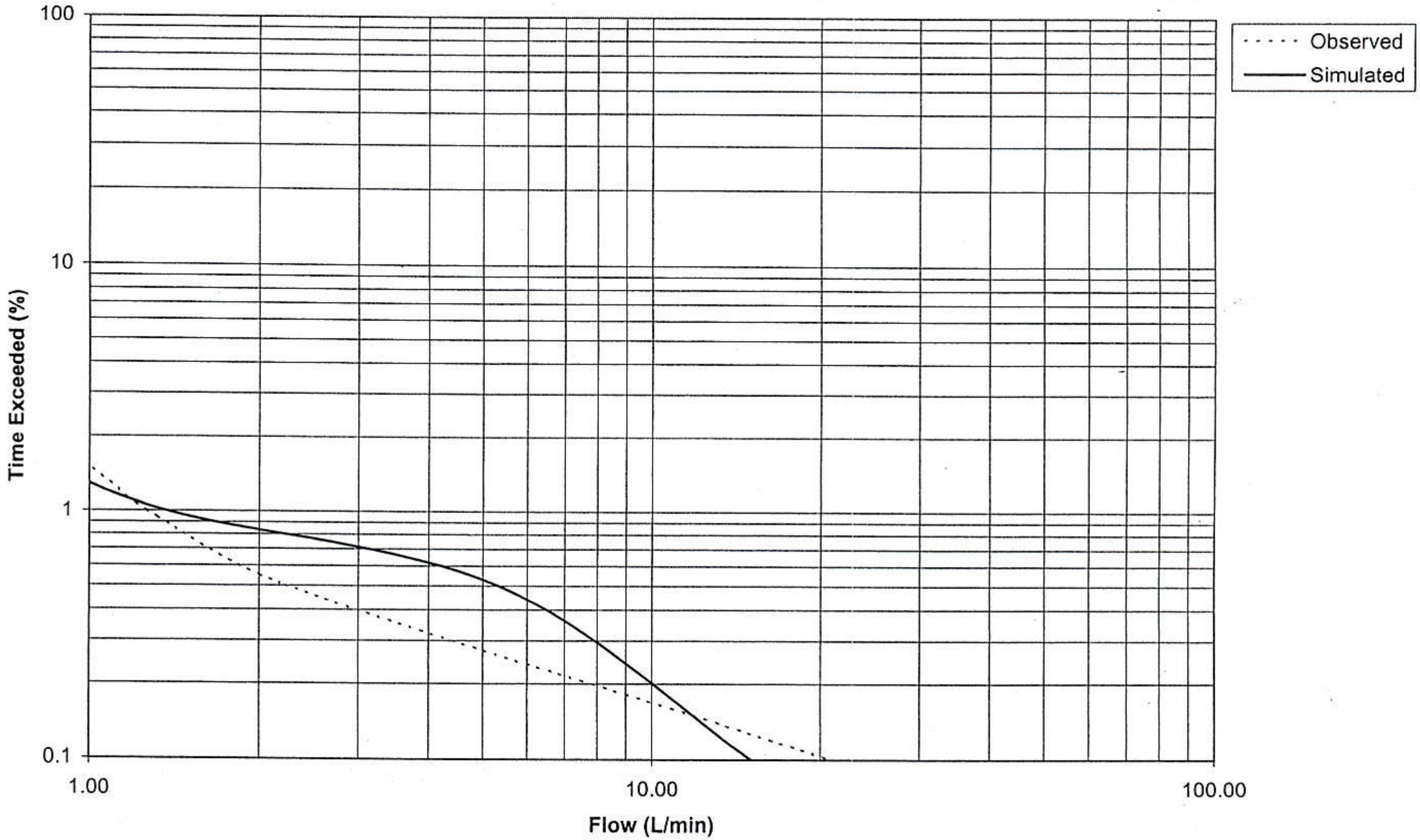


Figure 20:
Flow Duration Curves - September 2003
Roof Garden

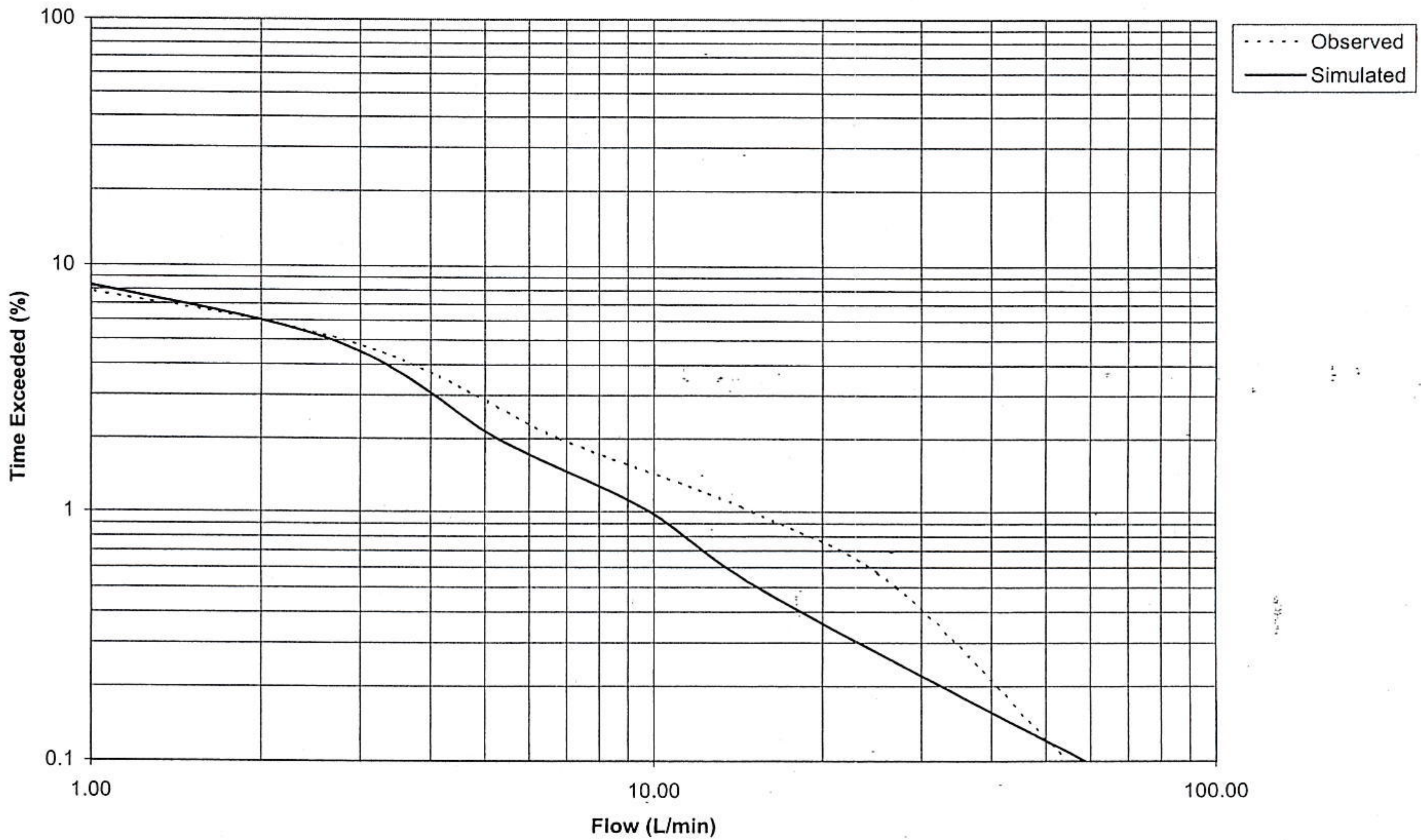


Figure 21:
Flow Duration Curves - October 2003
Roof Garden

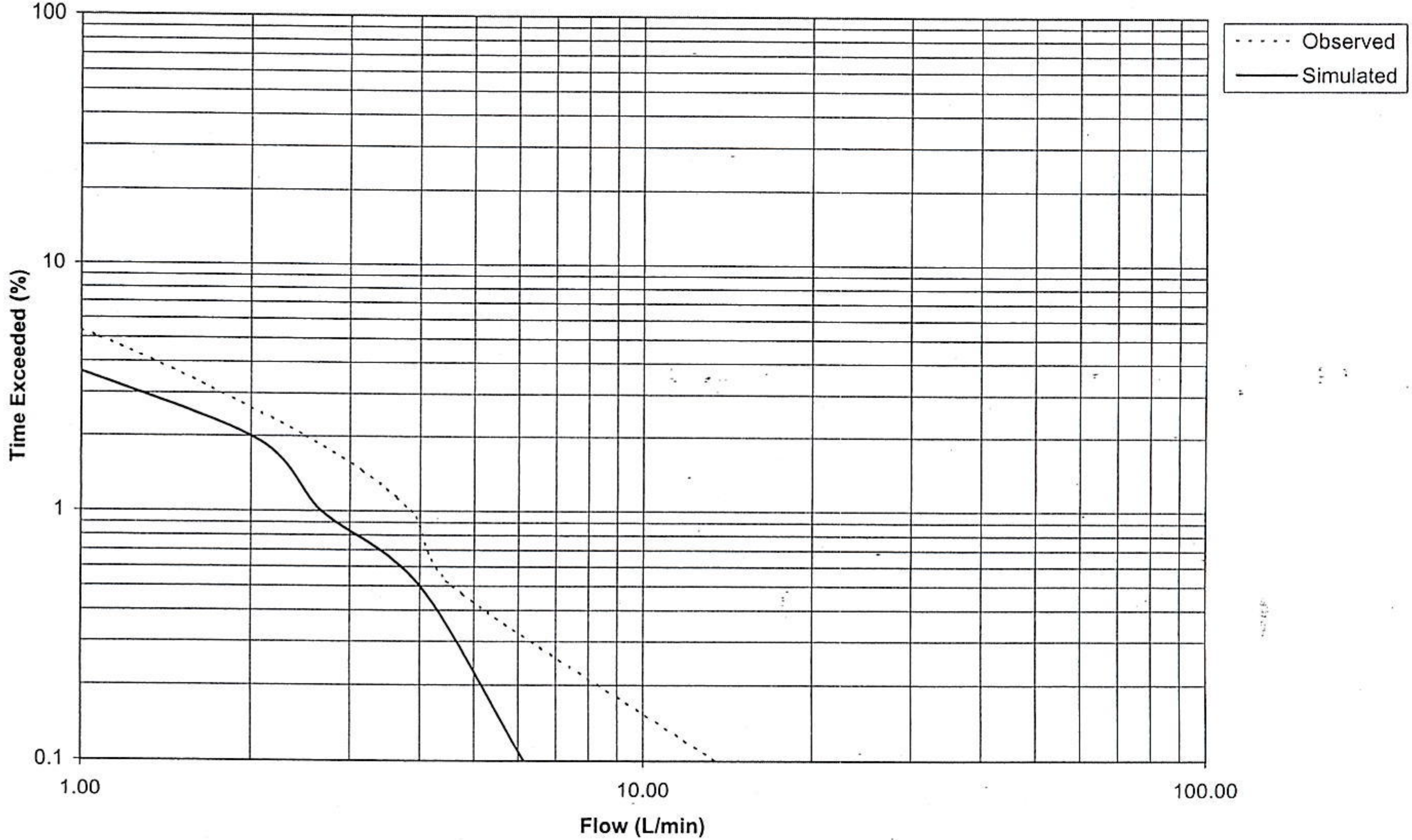


Figure 22:
Flow Duration Curves - November 2003
Roof Garden

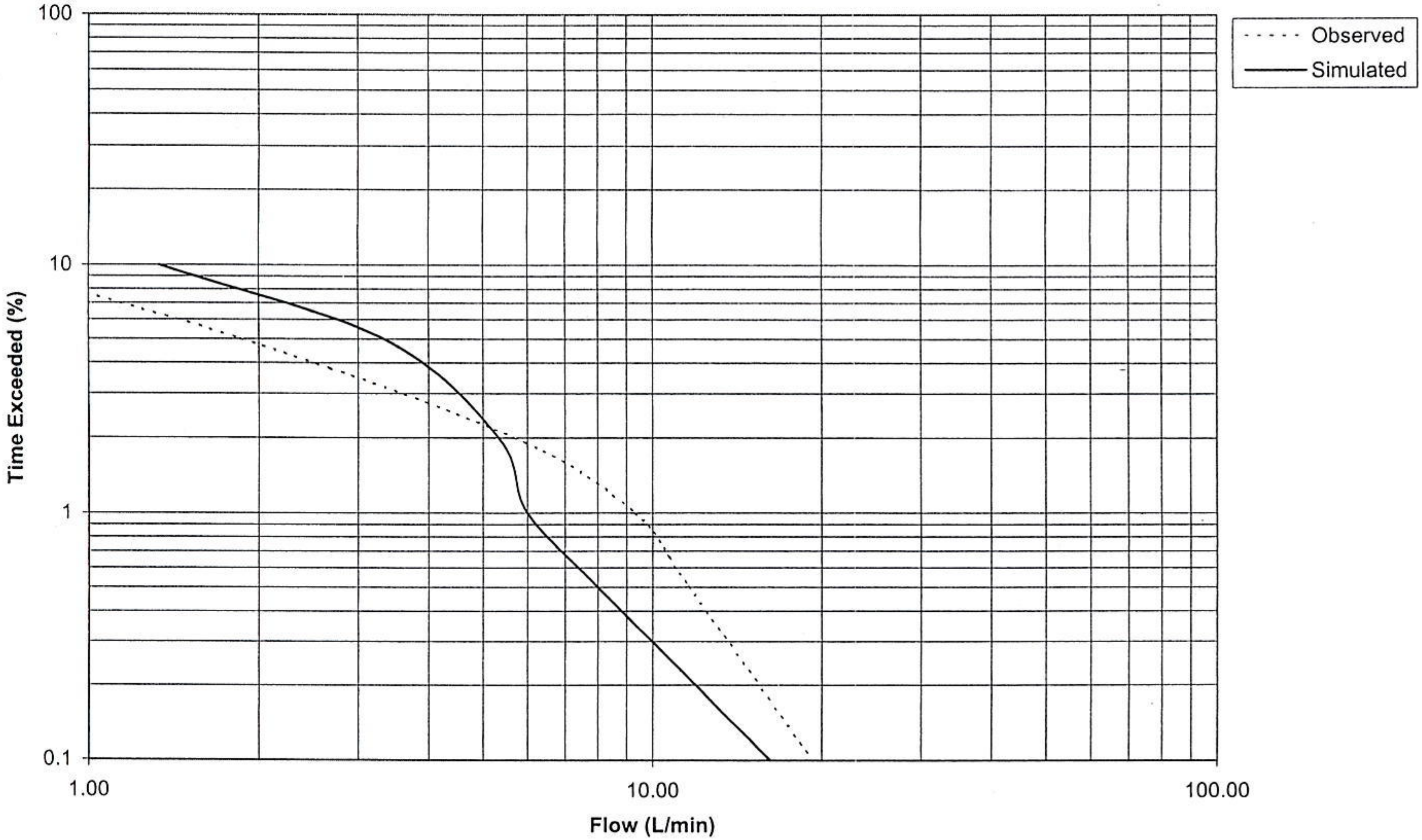
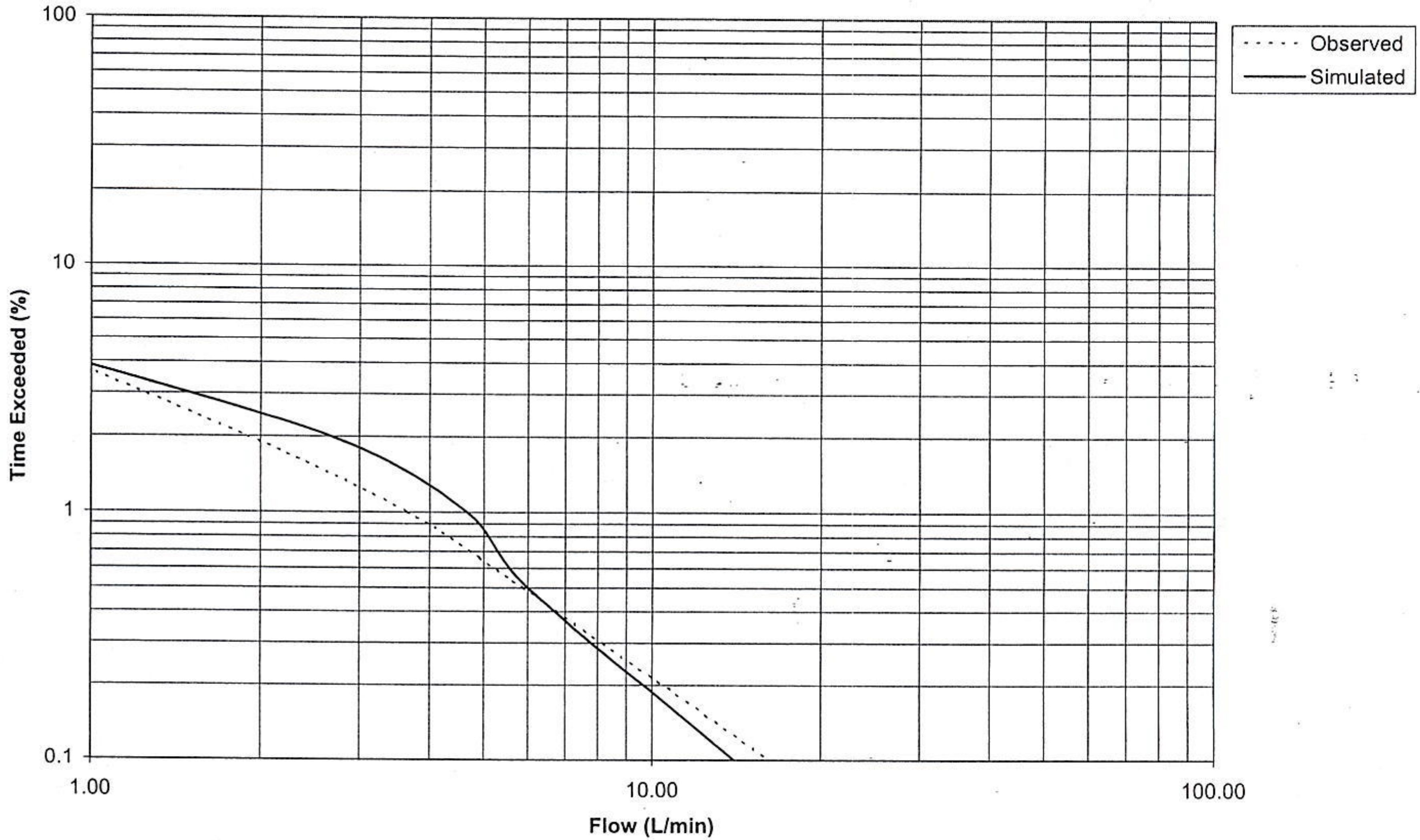


Figure 23:
Flow Duration Curves - December 2003
Roof Garden



the *.wdm results file in the CD enclosed with this memorandum. A summary of all files in the enclosed CD is included in Appendix A.

WATER QUALITY

Water quality parameters were monitored for ten storm events in 2003. The events on September 15, 22, 27, and October 14 and 18 had sufficiently large volumes to be divided into discrete samples for the monitoring of the water quality parameters. Since the flow data for September 27, October 14 and 18 are also available, the average concentrations for the events were calculated using flow proportioning based on the time of collection of each of the discrete samples. Flow data for the events on September 15 and 22 are not available. Hence, the concentrations of the water quality parameters for these events were calculated as simple averages. The events on September 19, and November 2, 3, 12 and 17 were not sufficiently large to be divided into discrete samples. Hence, the concentrations of the composite samples collected during these events represent the average concentrations of the quality constituents for these events. The EMC's for selected water quality parameters calculated based on the average concentrations for these ten individual events for the control roof and the garden are summarized below in Table 4. Please note that the parameters selected here are the same as those selected for the *City of Toronto Wet Weather Flow Master Plan*.

TABLE 4:EMC'S FOR SELECTED WATER QUALITY PARAMETERS

PARAMETER	UNITS	EMC's		% Reduction from Garden
		Control	Garden	
TSS	mg/L	7.23	2.65	63
Nitrate/Nitrite	mg/L	0.53	0.11	79
Total Phosphorus	mg/L	0.09	0.63	-600
TKN	mg/L	0.65	1.48	-128
Copper	ug/L	103.28	29.69	71
Lead	ug/L	5.46	5.33	2
Zinc	ug/L	11.43	9.07	21
Benzo(g,h,i) perylene	ng/L	76.79	20.07	74
E-Coli	ng/L	440.28	5350.47	-1115

As evident from the EMC's summarized in Table 4 and noted in the *Monitoring Report* that the garden effluent concentrations are significantly higher for a number of the water quality constituents including total phosphorus, TKN and E-coli. The garden is also not very effective in reducing concentrations of lead, zinc, although significant reductions are achieved for TSS, nitrate/nitrite, copper and benzo (g,h,i) perylene.

APPENDIX A

SUMMARY OF DIGITAL FILES

SUMMARY OF DIGITAL FILES

1. Technical Memo.doc;
2. Groof27.uci – HSPF User's Control Input file used for calibration;
3. Grooff.uci – HSPF User's Control Input file used for Wet Weather Flow average year simulation;
4. Grmet.wdm – HSPF WDM file containing the meteorological data used for calibration
5. Groof.wdm – HSPF WDM results file. The following flow series are contained in the file:
   2001 – Control roof URF flows for calibration year 2003
   2002 – Control roof flows from actual area used for calibration (using 2003 data)
   2003 – Roof garden URF flows for calibration year 2003
   2004 – Roof garden flows from actual area used for calibration (using 2003 data)
   2011 – Control roof URF flows from Wet Weather Flow average year (1991) simulation
   2013 – Roof garden URF flows from Wet Weather Flow average year (1991) simulation

APPENDIX B

AQUAFOR BEECH LTD TECHNICAL MEMORANDUM

To:	Glenn MacMillan Sameer Dhalla	Date:	December 10, 2004
From:	Dave Maunder	Project No:	64351
Subject:	Technical Memorandum on HSP-F Modelling of Green Roofs – Markham Branch of Highland Creek		

BACKGROUND

The Toronto and Region Conservation Authority retained Marshall Macklin Monaghan Ltd to develop a HSP-F (Hydrologic Simulation Program – FORTRAN) Unit Response Function (URF) model representing a "green roof", i.e., a rooftop garden, based on the York University green roof monitoring undertaken by the TRCA in 2003-2004. The objective of this ongoing monitoring program is to assess the effectiveness of green roofs in providing stormwater controls in urban areas.

Aquafor Beech Limited was then subsequently retained by TRCA to determine the effectiveness of implementing Green Roof Technologies within the Markham Branch of Highland Creek (see figure 1). The Markham Branch was selected as this watershed has a relatively large percentage of sites where green roof technologies may be implemented.

PROJECT APPROACH

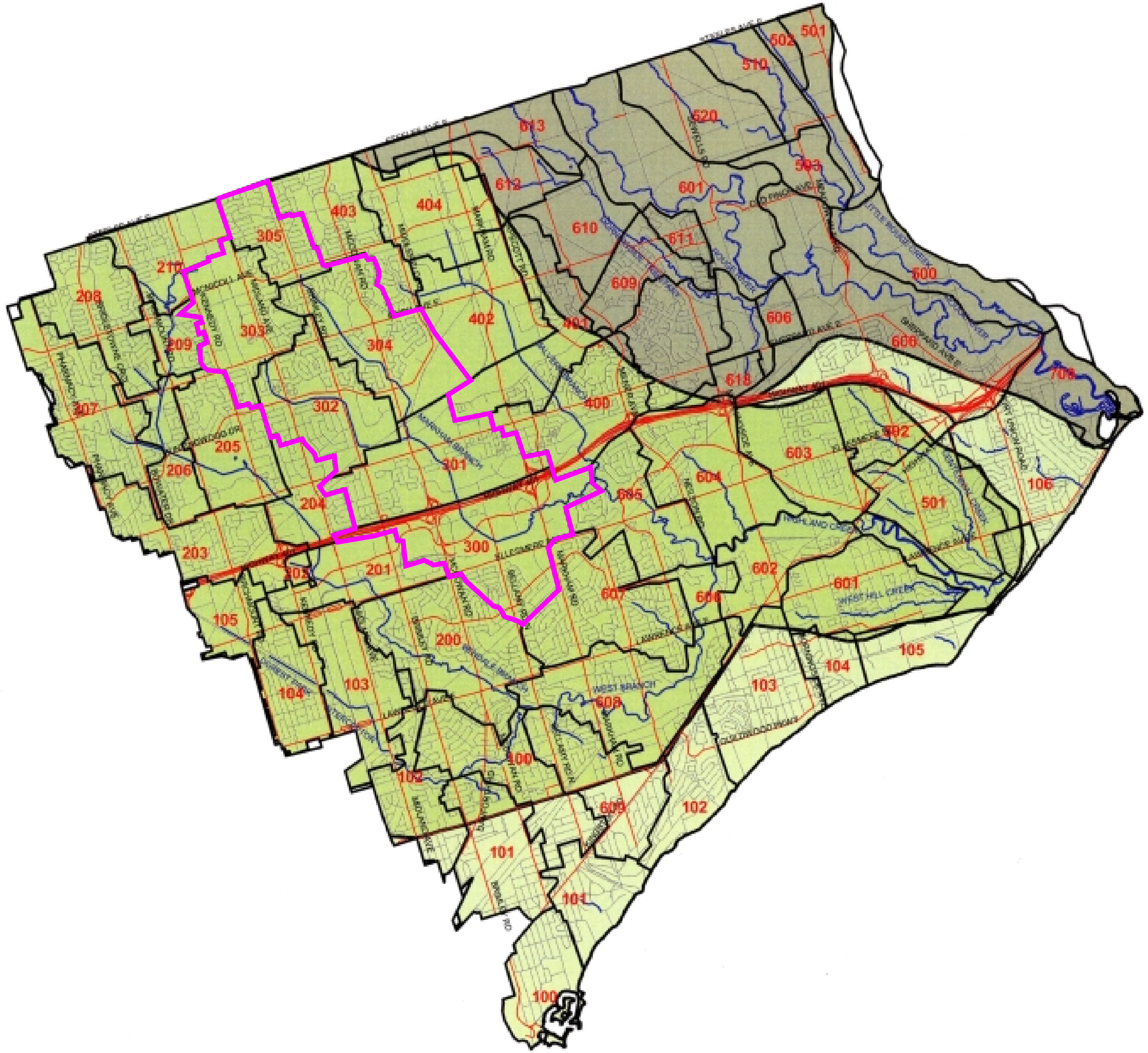
The project approach is outlined below.

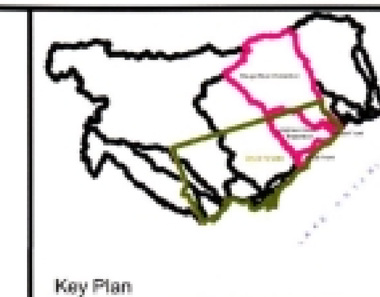
The initial step involved collection of background information which included the HSP-F model developed by Aquafor Beech Limited as part of the WWFMMP. The Technical Memorandum as prepared by MMM was also provided.

The Technical Memorandum provided, among other things, the Event Mean Concentrations (EMCs) for nine water quality parameters. The EMC's are summarized in Table 1 and are the same as those selected for the WWFMMP. Three concentrations are provided for each parameter; these being the EMC as used in the WWFMMP, the EMC for the control roof and the EMC for the roof garden. The EMC as used in the WWFMMP represents the average concentration of runoff from an industrial site (i.e.: the concentration from a combination of grassed areas, parking lots, roads and roof areas). The EMC for the control area is assumed to represent ambient air quality while the EMC for the roof garden represents the effluent concentration after being treated by the roof garden.

Also provided in the Technical Memorandum was the Unit Response Function for the control roof (the typical case where green roofs have not been implemented) and for the green roof.

The next step involved selecting representative sites in order to determine the percentage of roof area vs. total site area. Eight sites were selected. The results are summarized in Table 2. The findings show that for industrial sites the roof area is approximately 42 percent of the site area while for condominium sites the values is approximately 10 percent.





LEGEND:

- Subcatchment
- 600 Subcatchment ID

Watersheds

- Rouge River
- Highland Creek
- Water Front
- Study Area

0.5 0 0.5 1 1.5 2 Kilometers

Aquafor Beech Limited

Source: City of Toronto, Wet Weather Flow Management Master Plan, Study Area 5 - Highland Creek Rouge River and Waterfront area

HSP-F Modelling of Green Roof

Markham Branch Highland Creek

Figure 1: Study Area

Table 1: EMC's for selected water quality parameters

Parameter	Units	EMCs		
		WWFMMP	Control Roof	Green Roof
TSS	mg/L	467	7.23	2.65
Nitrate/Nitrite	mg/L	1.16	0.53	0.11
Total Phosphours	mg/L	0.5	0.09	0.63
TKN	mg/L	1.06	0.65	1.48
Copper	ug/L	27	103.28	29.69
Lead	ug/L	16	5.46	5.33
Zinc	ug/L	242	11.43	9.07
Benzo(g,h,l)perylene	ng/L	239	76.79	20.07
E-coil	#/100L	1138	440.28	5350.47

Table 2: % of Roof top area for representative 8 sites

Landuse	Lot size (m2)	Roof top (m2)	% Roof top
Industrial 1	84522	22043	26%
Industrial 2	35548	13071	37%
Industrial 3	39595	17759	45%
Industrial 4	23394	8370	36%
Industrial 5	25039	11168	45%
Industrial 6	30711	18729	61%
		Average	**42%**
Apartment 1	16645	1810	11%
Apartment 2	16709	1450	9%
		Average	**10%**

The existing database was then assessed to define, based on the URFs provided in the WWFMMP, the percentage of land uses where flat roofs could be implemented. This data is summarized on a subwatershed basis in Table 3.

Once the above was complete the HSPF model was run for a number of different scenarios for a typical year (1991). The objective was to assess the hydrologic benefit assuming 25,50 and 100 percent implementation of the green roof technology for suitable land uses.

Prior to running the model a couple of adjustments had to be made. The percent roof area that was assumed in the WWFMMP study for the representative land uses was changed to reflect the values shown in Table 2. Furthermore, for a given roof area it was assumed that only 75 percent of the area would be available for implementing the green roof technology.

INITIAL FINDINGS

The initial findings assuming 100, 50 and 25 percent implementation are shown on the accompanying figures and tables and are summarized below.

Figure 2 shows the monthly and annual runoff volumes at the mouth of the Markham Branch. On an annual basis the flow volume reduces from 10,200,000 m^3 without green roofs to 9,570,000 m^3 with green roofs assuming 100 percent implementation. This represents approximately a 4 percent reduction in runoff volume.

Figure 3 illustrates the hydrograph at the mouth of the Markham Branch for the year 1991. Table 4 summarizes the date, precipitation volume and peak flows (with and without implementation of the green roof technology) for the six largest events. The results show peak flow reductions of approximately 20%, 12% and 6% for 100%, 50% and 25% implementation of green roof technology respectively.

Only a general assessment of the benefit of implementing green roofs on water quality conditions was carried out for the following reasons.

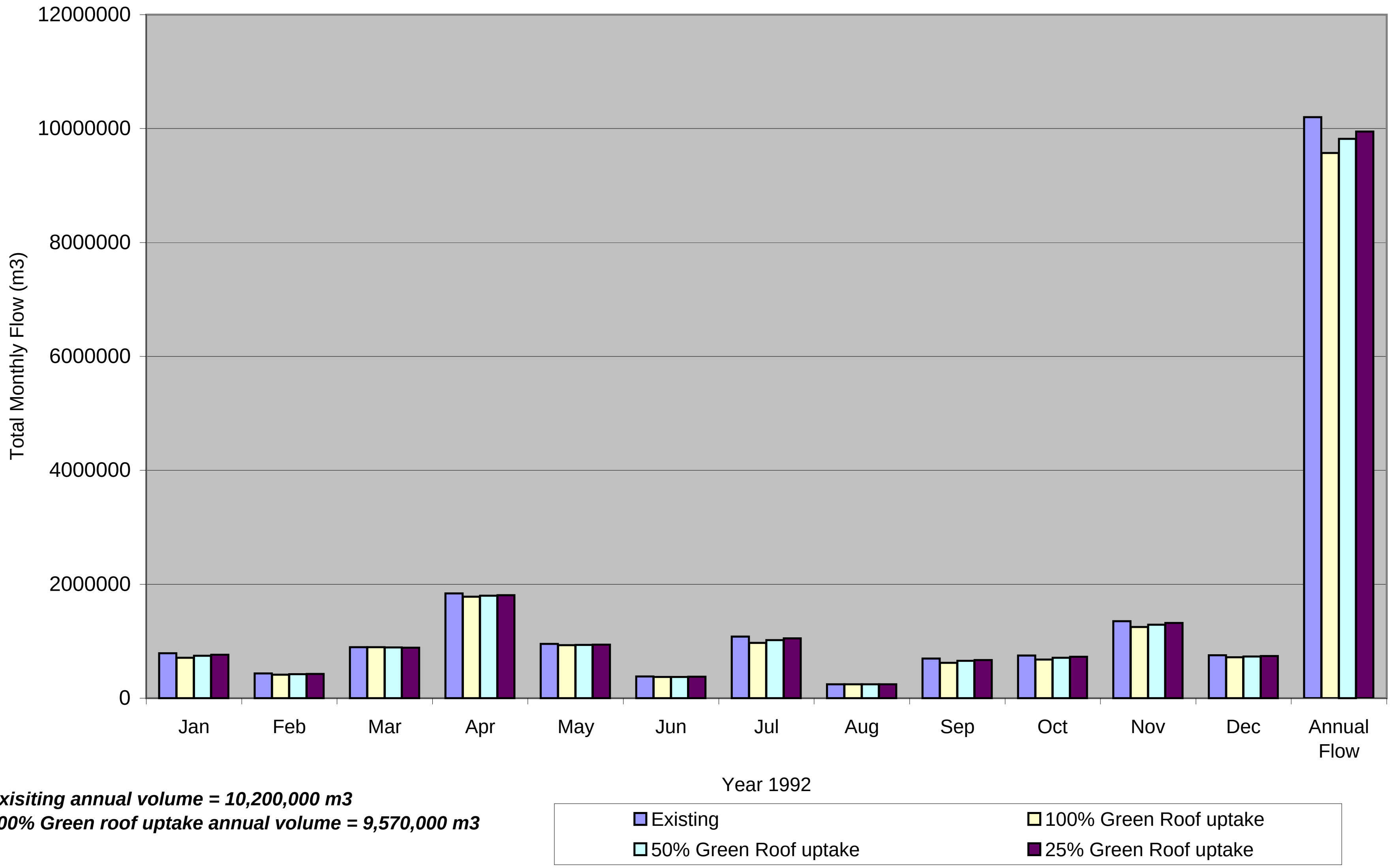
- The data, as shown in Table 1, shows mixed results if green roof technologies are implemented. While significant reductions in some parameters do occur; for four of the nine parameters there is no change or an increase in concentrations.

- Comparison of the EMC values shown in Table 1 shows that the EMC's for the entire site significantly exceed those for the control roof (which represents ambient air water quality) and the effluent conditions for the green roof for many parameters. Therefore, even if significant reductions in concentrations did occur as a result of implementing the green roof technology there would be nominal improvement in the water quality levels within the receiving watercourses.

Table 3: Flat Roof area simulated in Markham Branch HSP-F model

Catchment	Subcatchment area	Landuse with Flat Roof	WWF - Flat Roof area
300	429.6	193.7	57.2
301	369.5	180.8	54.3
302	308.5	147.2	45.6
303	280.2	91.6	31
304	367.7	88.3	19.4
305	151.9	8.9	0.9
306	217	8.7	0.8
Total	**2124.4**	**719.2**	**209.2**

Figure 2: Annual and Monthly runoff volume



Exisiting annual volume = 10,200,000 m3
100% Green roof uptake annual volume = 9,570,000 m3

Figure 3 - Annual Hydrograph - Mouth of Markham Branch - 1992

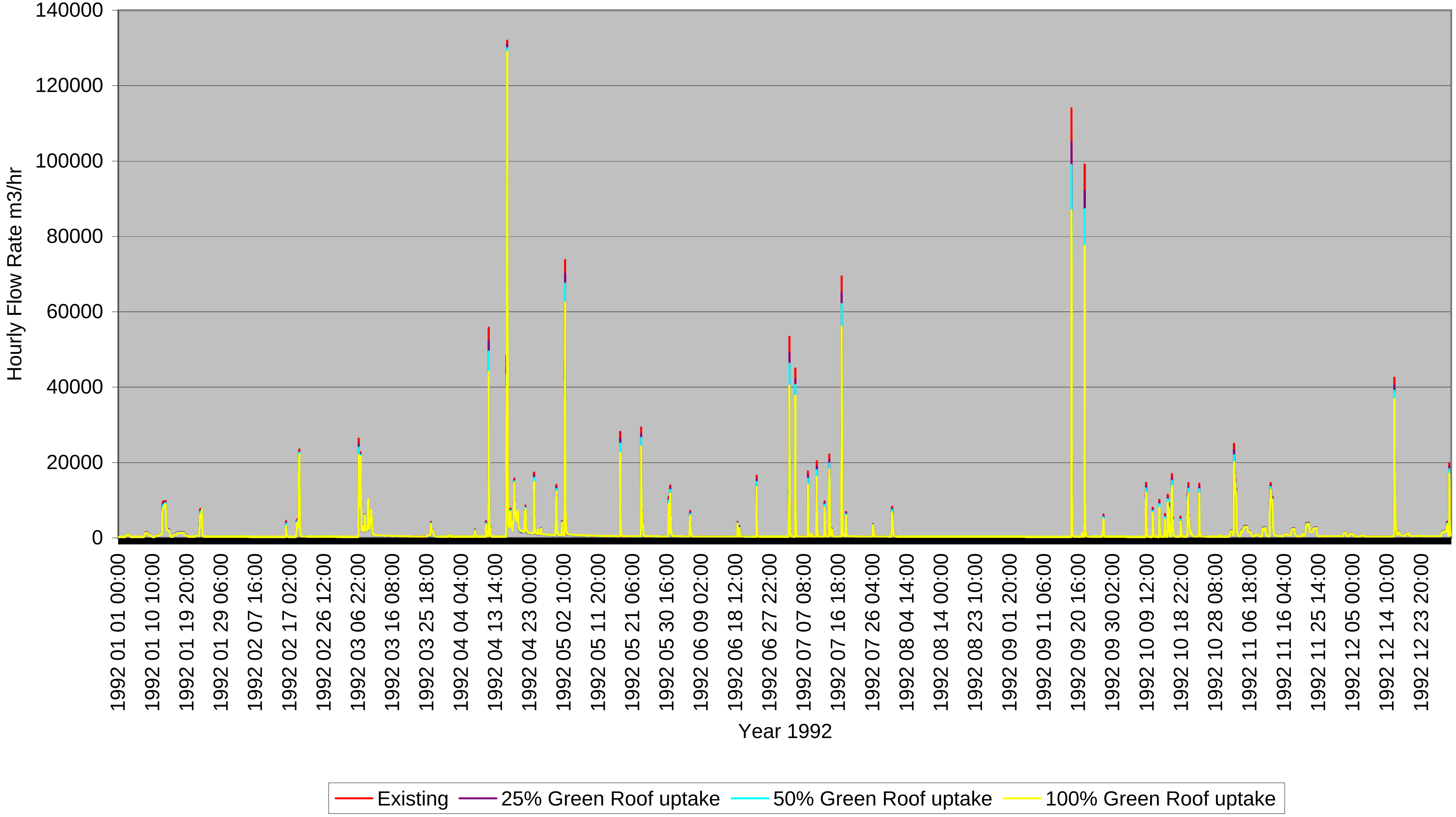
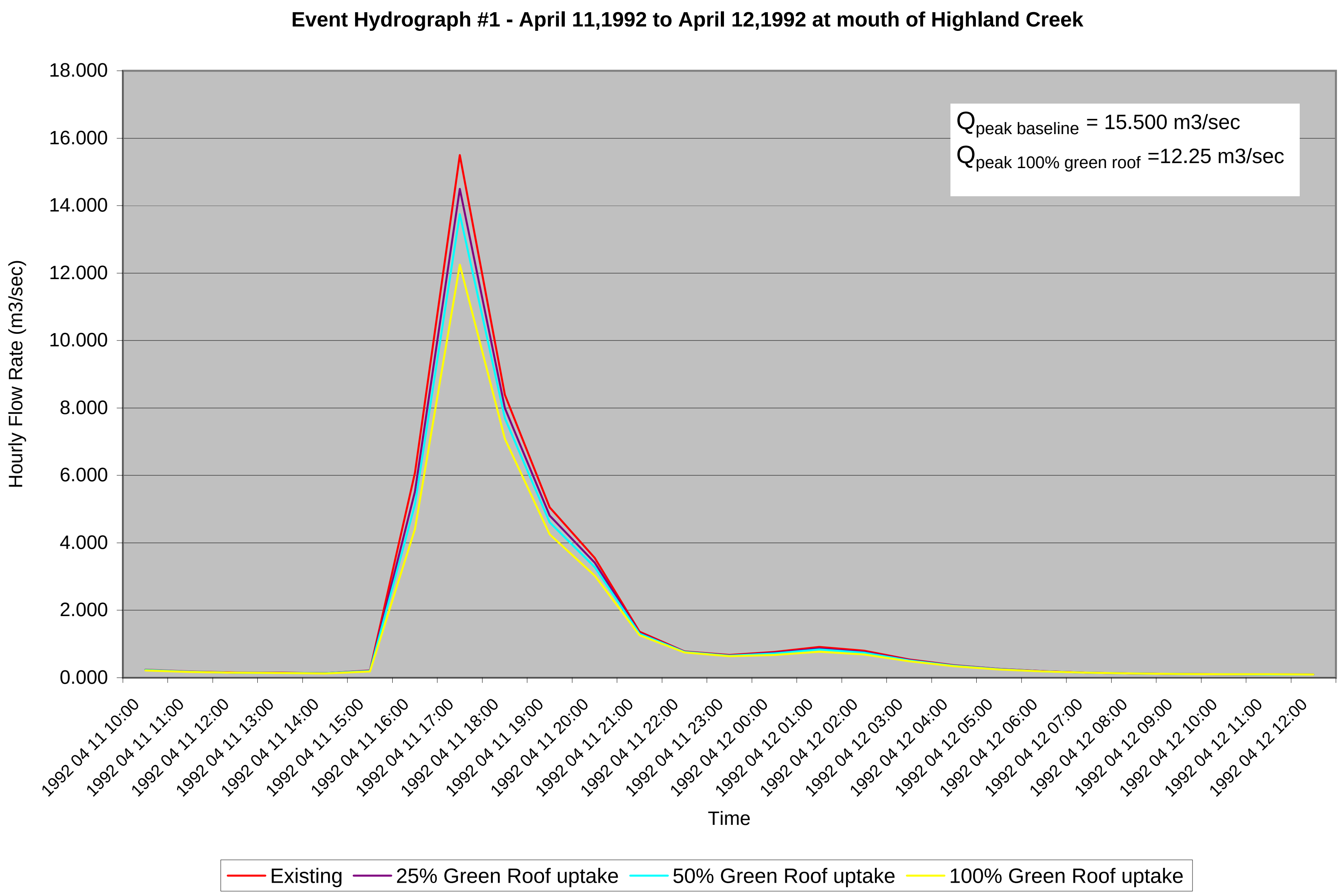
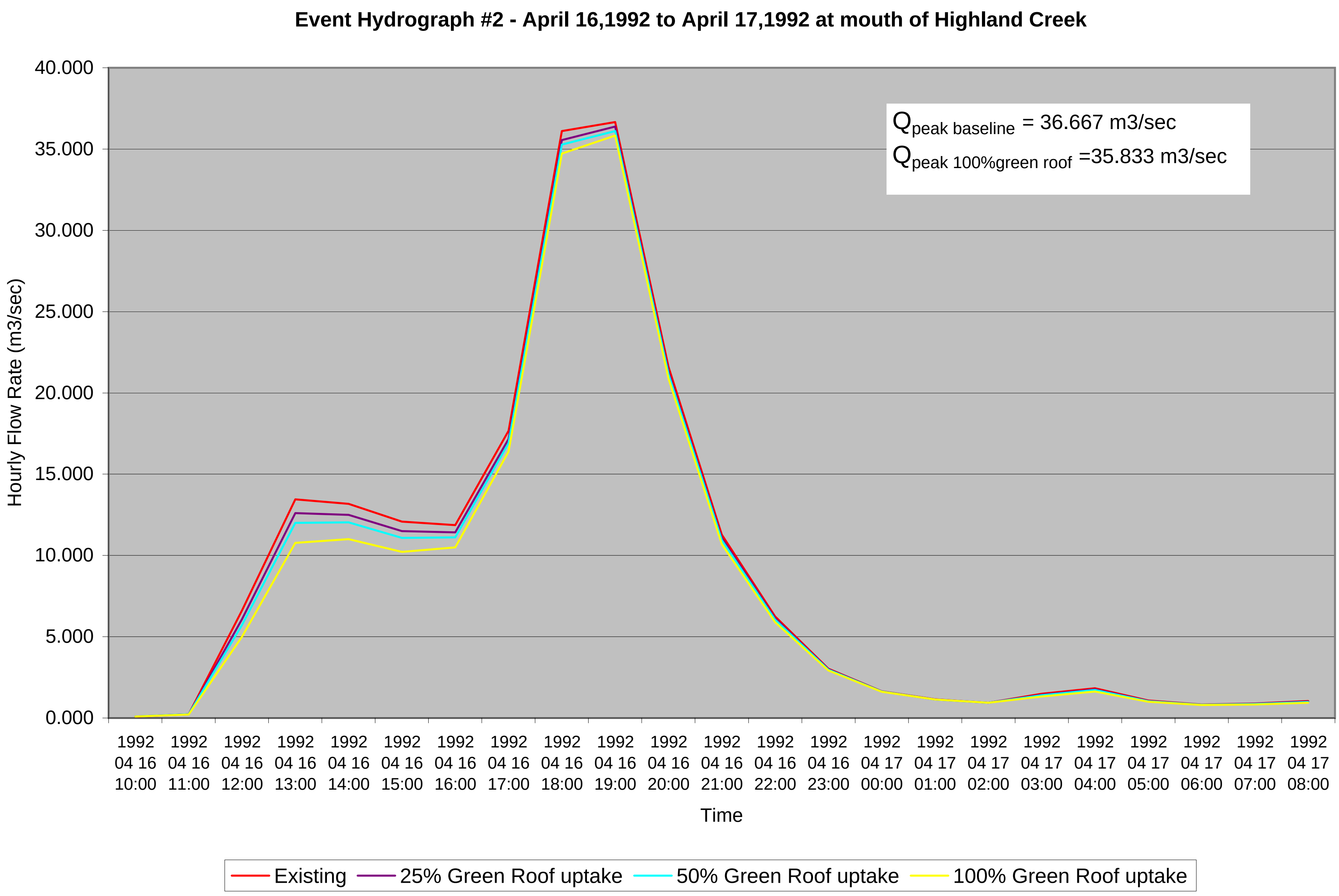
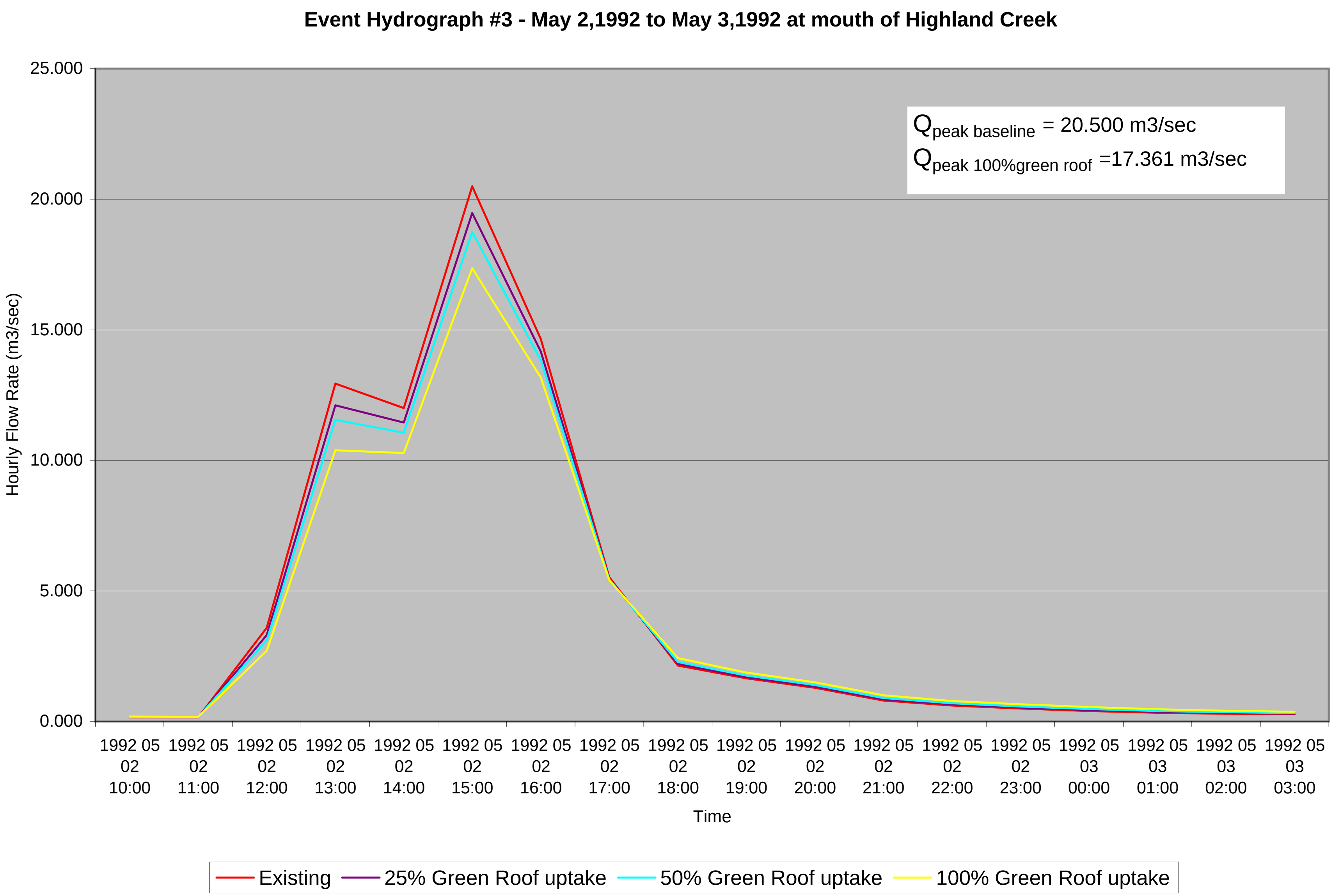


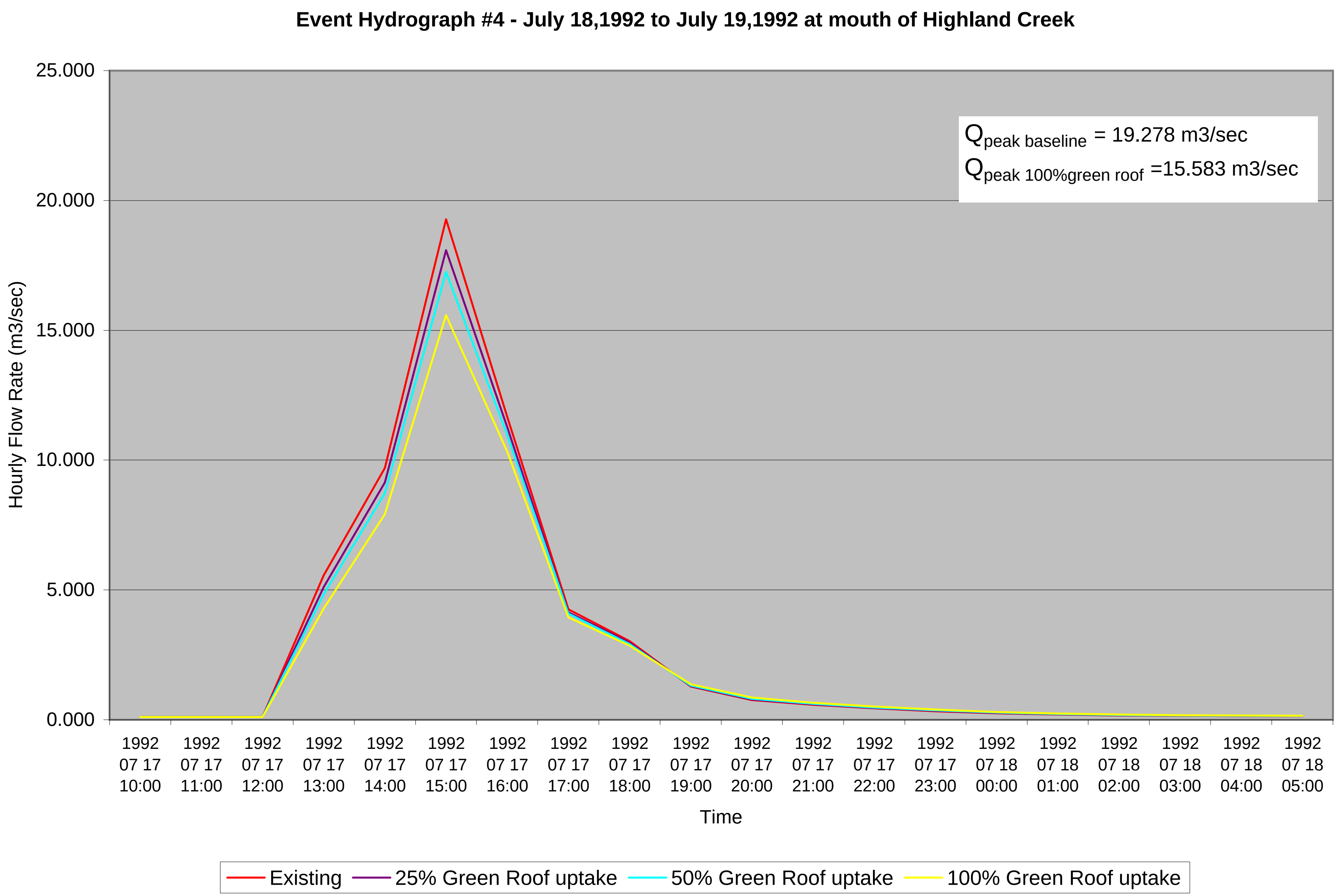
Table 4: Summary of Precipitation volume and Peak Flow Rates at the Mouth of Highland Creek

Date	Precipitation Volume (mm)	Peak Flow No Green Roof (m3/sec)	Peak Flow 100% Implementation (m3/sec)	% Reduction	Peak Flow 50% Implementation (m3/sec)	% Reduction	Peak Flow 25% Implementation (m3/sec)	% Reduction
April 11-12, 1992	25.10	15.50	12.25	21%	13.75	11%	14.50	6%
April 16-17, 1992	45.70	36.67	35.83	2%	36.11	2%	36.39	1%
May 2-3, 1992	27.90	20.50	17.36	15%	18.75	9%	19.47	5%
July 16-17, 1992	24.80	19.28	15.58	19%	16.00	17%	18.08	6%
September 18-19,1992	27.70	31.67	24.13	24%	27.50	13%	29.17	8%
September 21-22,1992	24.20	27.53	21.56	22%	24.25	12%	25.61	7%


Event Hydrograph #1 - April 11,1992 to April 12,1992 at mouth of Highland Creek
$Q_{\text{peak baseline}}$ = 15.500 m3/sec
$Q_{\text{peak 100\% green roof}}$ =12.25 m3/sec
Hourly Flow Rate (m3/sec)
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
1992 04 11 10:00
1992 04 11 11:00
1992 04 11 12:00
1992 04 11 13:00
1992 04 11 14:00
1992 04 11 15:00
1992 04 11 16:00
1992 04 11 17:00
1992 04 11 18:00
1992 04 11 19:00
1992 04 11 20:00
1992 04 11 21:00
1992 04 11 22:00
1992 04 11 23:00
1992 04 12 00:00
1992 04 12 01:00
1992 04 12 02:00
1992 04 12 03:00
1992 04 12 04:00
1992 04 12 05:00
1992 04 12 06:00
1992 04 12 07:00
1992 04 12 08:00
1992 04 12 09:00
1992 04 12 10:00
1992 04 12 11:00
1992 04 12 12:00
Time
Existing
25% Green Roof uptake
50% Green Roof uptake
100% Green Roof uptake

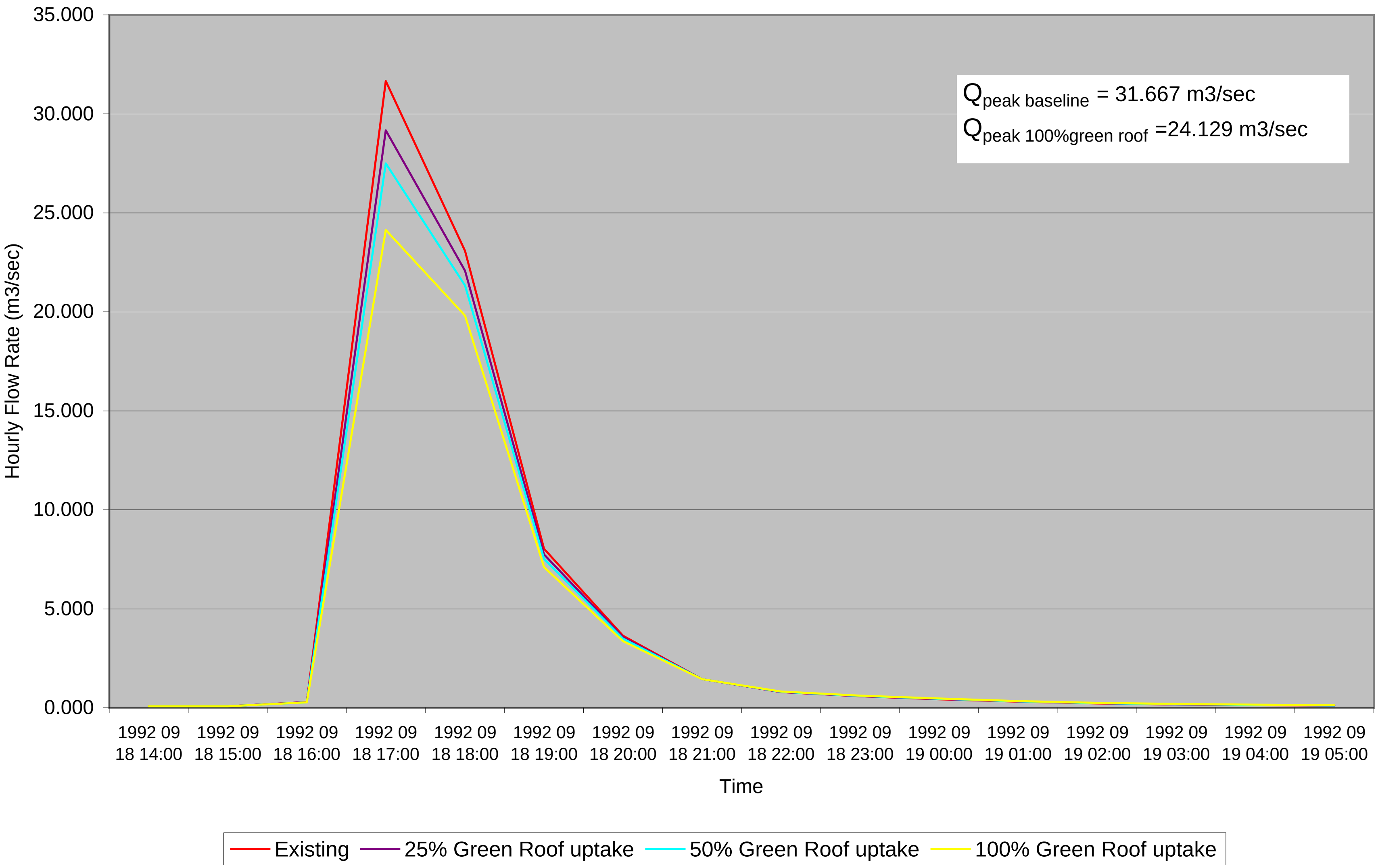

Event Hydrograph #2 - April 16,1992 to April 17,1992 at mouth of Highland Creek
Q peak baseline = 36.667 m3/sec
Q peak 100%green roof =35.833 m3/sec
Hourly Flow Rate (m3/sec)
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
1992 04 16 10:00
1992 04 16 11:00
1992 04 16 12:00
1992 04 16 13:00
1992 04 16 14:00
1992 04 16 15:00
1992 04 16 16:00
1992 04 16 17:00
1992 04 16 18:00
1992 04 16 19:00
1992 04 16 20:00
1992 04 16 21:00
1992 04 16 22:00
1992 04 16 23:00
1992 04 17 00:00
1992 04 17 01:00
1992 04 17 02:00
1992 04 17 03:00
1992 04 17 04:00
1992 04 17 05:00
1992 04 17 06:00
1992 04 17 07:00
1992 04 17 08:00
Time
Existing
25% Green Roof uptake
50% Green Roof uptake
100% Green Roof uptake

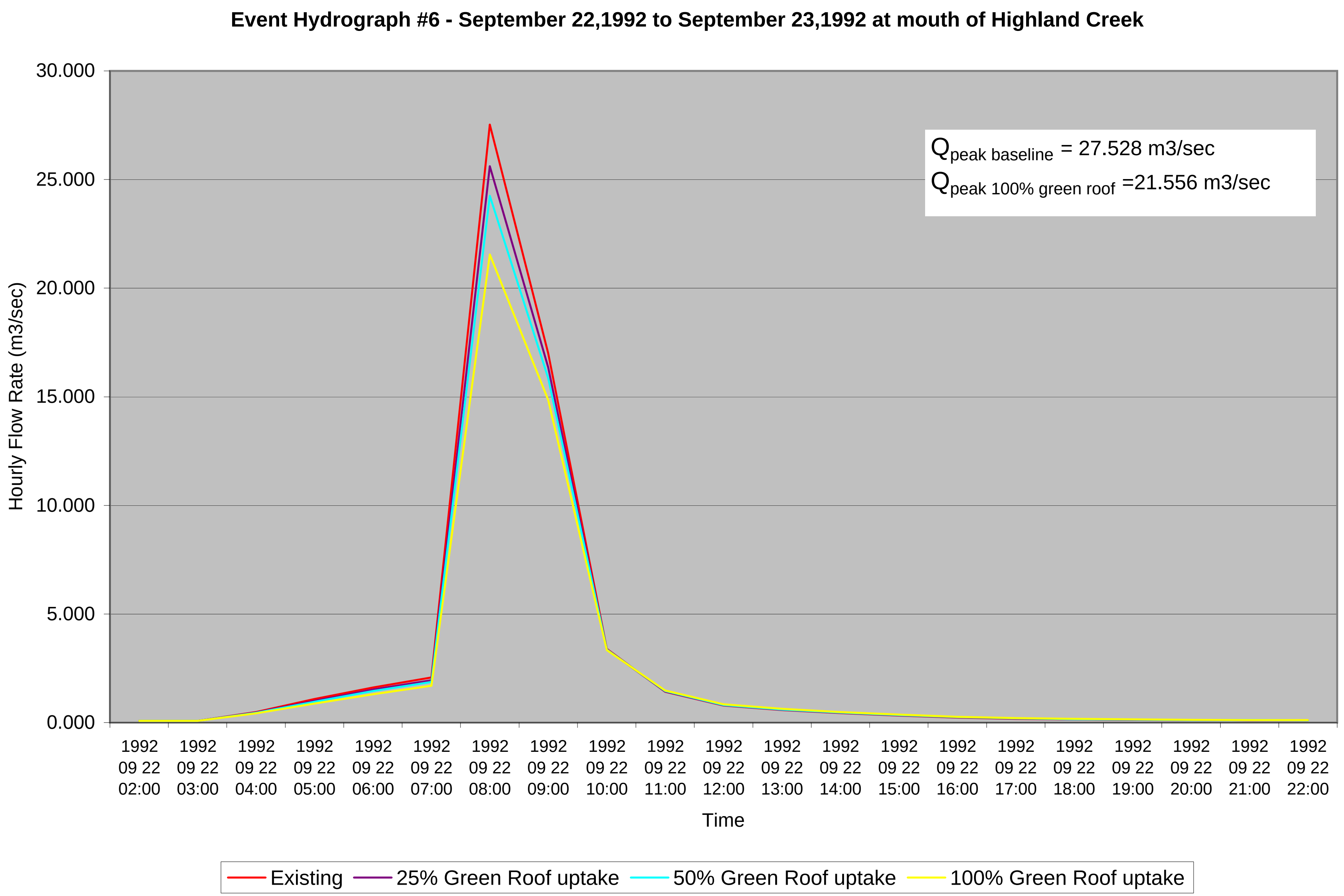

Event Hydrograph #3 - May 2,1992 to May 3,1992 at mouth of Highland Creek
$Q_{peak\ baseline}$ = 20.500 m3/sec
$Q_{peak\ 100\%green\ roof}$ =17.361 m3/sec
Hourly Flow Rate (m3/sec)
25.000
20.000
15.000
10.000
5.000
0.000
1992 05 02 10:00
1992 05 02 11:00
1992 05 02 12:00
1992 05 02 13:00
1992 05 02 14:00
1992 05 02 15:00
1992 05 02 16:00
1992 05 02 17:00
1992 05 02 18:00
1992 05 02 19:00
1992 05 02 20:00
1992 05 02 21:00
1992 05 02 22:00
1992 05 02 23:00
1992 05 03 00:00
1992 05 03 01:00
1992 05 03 02:00
1992 05 03 03:00
Time
Existing
25% Green Roof uptake
50% Green Roof uptake
100% Green Roof uptake



Event Hydrograph #4 - July 18,1992 to July 19,1992 at mouth of Highland Creek
$Q_{peak\ baseline}$ = 19.278 m3/sec
$Q_{peak\ 100\%green\ roof}$ =15.583 m3/sec
Hourly Flow Rate (m3/sec)
25.000
20.000
15.000
10.000
5.000
0.000
1992 07 17 10:00
1992 07 17 11:00
1992 07 17 12:00
1992 07 17 13:00
1992 07 17 14:00
1992 07 17 15:00
1992 07 17 16:00
1992 07 17 17:00
1992 07 17 18:00
1992 07 17 19:00
1992 07 17 20:00
1992 07 17 21:00
1992 07 17 22:00
1992 07 17 23:00
1992 07 18 00:00
1992 07 18 01:00
1992 07 18 02:00
1992 07 18 03:00
1992 07 18 04:00
1992 07 18 05:00
Time
Existing
25% Green Roof uptake
50% Green Roof uptake
100% Green Roof uptake

Event Hydrograph #5 - September 18,1992 to September 19,1992 at mouth of Highland Creek





Event Hydrograph #6 - September 22,1992 to September 23,1992 at mouth of Highland Creek
Hourly Flow Rate (m3/sec)
30.000
25.000
20.000
15.000
10.000
5.000
0.000
1992 09 22 02:00
1992 09 22 03:00
1992 09 22 04:00
1992 09 22 05:00
1992 09 22 06:00
1992 09 22 07:00
1992 09 22 08:00
1992 09 22 09:00
1992 09 22 10:00
1992 09 22 11:00
1992 09 22 12:00
1992 09 22 13:00
1992 09 22 14:00
1992 09 22 15:00
1992 09 22 16:00
1992 09 22 17:00
1992 09 22 18:00
1992 09 22 19:00
1992 09 22 20:00
1992 09 22 21:00
1992 09 22 22:00
Time
$Q_{peak\ baseline}$ = 27.528 m3/sec
$Q_{peak\ 100\%\ green\ roof}$ =21.556 m3/sec
Existing
25% Green Roof uptake
50% Green Roof uptake
100% Green Roof uptake

APPENDIX C

WATER QUALITY RESULTS FOR SUBCATCHMENTS

AND

GREEN ROOF EMCs CACULATIONS

Change in Loadings and Concentrations at the mouth of five different subwatershed in Highland Creek as a Result of 100 percent Implementation of Green Roofs for Suitable Land Uses

Subwatershed - Dorset Park Branch

Parameter	Loading		Percent	Concentrations		Percent
	Baseline	100% implemention	Difference	Baseline	100% implemention	Difference
Total Suspended Solid	kg 2207910	kg 2036210	-8%	mg/L 330.13	mg/L 321.63	-3%
Nitrate/Nitrite	kg 8357	kg 7753	-8%	mg/L 1.25	mg/L 1.22	-2%
Total Phosphorus	kg 2075.9	kg 2396	13%	mg/L 0.31	mg/L 0.38	18%
Total Kjedahl Nitrogen	kg 7408.9	kg 7975.5	7%	mg/L 1.11	mg/L 1.26	12%
Lead	kg 333.3	kg 313.6	-6%	mg/L 0.05	mg/L 0.05	0%
Zinc	kg 834.8	kg 741.1	-13%	mg/L 0.12	mg/L 0.12	0%
Benzo(g,h,l)perylene	g 805.2	g 923.4	13%	ug/L 0.14	ug/L 0.13	-8%
E-coli	10^11# 8388.2	10^11# 8371.3	0%	#/100ml 125.42	#/100ml 132.23	5%

Subwatershed - Bendale Branch

Parameter	Loading		Percent	Concentrations		Percent
	Baseline	100% implemention	Difference	Baseline	100% implemention	Difference
Total Suspended Solid	kg 3744440	kg 3557700	-5%	mg/L 311.31	mg/L 305.99	-2%
Nitrate/Nitrite	kg 15702	kg 15106	-4%	mg/L 1.31	mg/L 1.3	-1%
Total Phosphorus	kg 3444.9	kg 3814.7	10%	mg/L 0.29	mg/L 0.33	12%
Total Kjedahl Nitrogen	kg 14162	kg 14794	4%	mg/L 1.18	mg/L 1.27	7%
Lead	kg 578.3	kg 558.3	-4%	mg/L 0.05	mg/L 0.05	0%
Zinc	kg 1226.7	kg 1150.7	-7%	mg/L 0.1	mg/L 0.1	0%
Benzo(g,h,l)perylene	g 1466.5	g 1348.6	-9%	ug/L 0.12	ug/L 0.12	0%
E-coli	10^11# 18437	10^11# 18445.6	0%	#/100ml 153.36	#/100ml 158.57	3%

Subwatershed - Markham Branch

Parameter	Loading		Percent	Concentrations		Percent
	Baseline	100% implemention	Difference	Baseline	100% implemention	Difference
Total Suspended Solid	kg 3255160	kg 3058760	-6%	mg/L 314.93	mg/L 309.97	-2%
Nitrate/Nitrite	kg 12739	kg 12070	-6%	mg/L 1.23	mg/L 1.22	-1%
Total Phosphorus	kg 2974.8	kg 3444.9	14%	mg/L 0.29	mg/L 0.35	17%
Total Kjedahl Nitrogen	kg 11285	kg 12193	7%	mg/L 1.09	mg/L 1.24	12%
Lead	kg 492	kg 470.2	-5%	mg/L 0.05	mg/L 0.05	0%
Zinc	kg 1171.6	kg 1096.8	-7%	mg/L 0.11	mg/L 0.11	0%
Benzo(g,h,l)perylene	g 1300.9	g 1156.7	-12%	ug/L 0.13	ug/L 0.12	-8%
E-coli	10^11# 12746.3	10^11# 12727.2	0%	#/100ml 123.13	#/100ml 129.17	5%

Change in Loadings and Concentrations at the mouth of five different subwatershed in Highland Creek as a Result of 100 percent Implementation of Green Roofs for Suitable Land Uses

Subwatershed - Malven Branch

Parameter	Loading		Percent	Concentrations		Percent
	Baseline	100% implemention	Difference	Baseline	100% implemention	Difference
Total Suspended Solid	kg 2375790	kg 2173360	-9%	mg/L 333.73	mg/L 328.3	-2%
Nitrate/Nitrite	kg 8455	kg 7658	-10%	mg/L 1.19	mg/L 1.16	-3%
Total Phosphorus	kg 2738.5	kg 2295.7	-19%	mg/L 0.32	mg/L 0.41	22%
Total Kjedahl Nitrogen	kg 7350.1	kg 8204.8	10%	mg/L 1.03	mg/L 1.24	17%
Lead	kg 348.9	kg 325.2	-7%	mg/L 0.05	mg/L 0.05	0%
Zinc	kg 1017.4	kg 912.3	-12%	mg/L 0.14	mg/L 0.14	0%
Benzo(g,h,l)perylene	g 1042.4	g 870.6	-20%	ug/L 0.15	ug/L 0.13	-15%
E-coli	10^11# 5777.6	10^11# 5772.5	0%	#/100ml 81.09	#/100ml 87.27	7%

Subwatershed - Centenial Branch

Parameter	Loading		Percent	Concentrations		Percent
	Baseline	100% implemention	Difference	Baseline	100% implemention	Difference
Total Suspended Solid	kg 503970	kg 494510	-2%	mg/L 218.06	mg/L 215.86	-1%
Nitrate/Nitrite	kg 8455	kg 7658	-10%	mg/L 1.19	mg/L 1.16	-3%
Total Phosphorus	kg 385.2	kg 403.3	4%	mg/L 0.17	mg/L 0.18	6%
Total Kjedahl Nitrogen	kg 2277	kg 2327.2	2%	mg/L 0.99	mg/L 1.02	3%
Lead	kg 71.1	kg 70.9	0%	mg/L 0.03	mg/L 0.03	0%
Zinc	kg 117.9	kg 116.8	-1%	mg/L 0.05	mg/L 0.05	0%
Benzo(g,h,l)perylene	g 139.9	g 142.8	2%	ug/L 0.06	ug/L 0.06	0%
E-coli	10^11# 60278.5	10^11# 60270	0%	#/100ml 116.44	#/100ml 117.84	1%

Examples of Green Roof EMCs Caculation for Industrial landuses

Equation

Since

$$EMC_{WWFMMP} = EMC_{Non\text{-}Roof\ Area} * (1\text{-}\%\ of\ Roof\ Area) + EMC_{Control\ Roof\ Area} * \%\ of\ Roof\ Area$$

Therefore, by subituted the $EMC_{control\ Roof\ Area}$ by $EMC_{Green\ Roof\ Area}$
the $EMC_{WWFMMP\text{-}Green\ Roof}$ could be caculated

$$\boxed{EMC_{WWFMMP\text{-}Green\ Roof} = EMC_{Non\text{-}Roof\ Area} * (1\text{-}\%\ of\ Roof\ Area) + EMC_{Green\ Roof\ Area} * \%\ of\ Roof}$$

Example, The $EMC_{WWFMMP\text{-}Green\ Roof}$ of Total Suspended Solid for Industraial Landuse

1 st Step - Determine $EMC_{Non\text{-}Roof\ Area}$

$$EMC_{WWFMMP} = EMC_{Non\text{-}Roof\ Area} * (1\text{-}\%\ of\ Roof\ Area) + EMC_{Control\ Roof\ Area} * \%\ of\ Roof\ Area$$

$$467mg/L = EMC_{Non\text{-}Roof\ Area} * (1 - 42\%) + 6.2\ mg/L * 42\%$$

$$EMC_{Non\text{-}Roof\ Area} = \{467mg/L - (6.2mg/L * 42\%)\}/ (1\text{-}42\%) = 800.6mg/L$$

2 nd Step - Determint $EMC_{WWFMMP\text{-}Green\ Roof\ Area}$ by Subituted the $EMC_{Green\text{-}Roof\ Area}$ into the Equation

$$EMC_{WWFMMP\text{-}Green\ Roof} = EMC_{Non\text{-}Roof\ Area} * (1\text{-}\%\ of\ Roof\ Area) + EMC_{Green\ Roof\ Area} * \%\ of\ Roof\ Area$$

$$EMC_{WWFMMP\text{-}Green\ Roof} = 800.6mg/L * (1 - 42\%) + 2.2mg/L * 42\% = 465.3mg/L$$

Resutls

	EMC_{WWFMMP}	$EMC_{Control\ Roof}$	$EMC_{Green\ Roof}$	$EMC_{Non\text{-}Roof\ Area}$	$EMC_{WWFMMP\text{-}Green\ Roof}$
TSS	467	6.3	2.2	800.6103448	465.278
Nox	1.16	0.52	0.12	1.623448276	0.992
TP	0.5	0.078	0.577	0.805586207	0.70958
TKN	1.06	0.711	1.61	1.312724138	1.43758
Cu	27	111.1	42.9	-33.9	-1.644
Pb	16	3.8	4.8	24.83448276	16.42
Zn	242	10.8	8.2	409.4206897	240.908
Ben	239	68.4	11.8	362.537931	215.228
E.coli	1138	549	661	1564.517241	1185.04