City of Winnipeg
Water and Waste Department

Combined Sewer Overflow Management Study

PHASE 2 Technical Memorandum No. 1

PROBLEM DEFINITION

Internal Document by:

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In Association With:

Gore & Storrie Limited and EMA Services Inc.

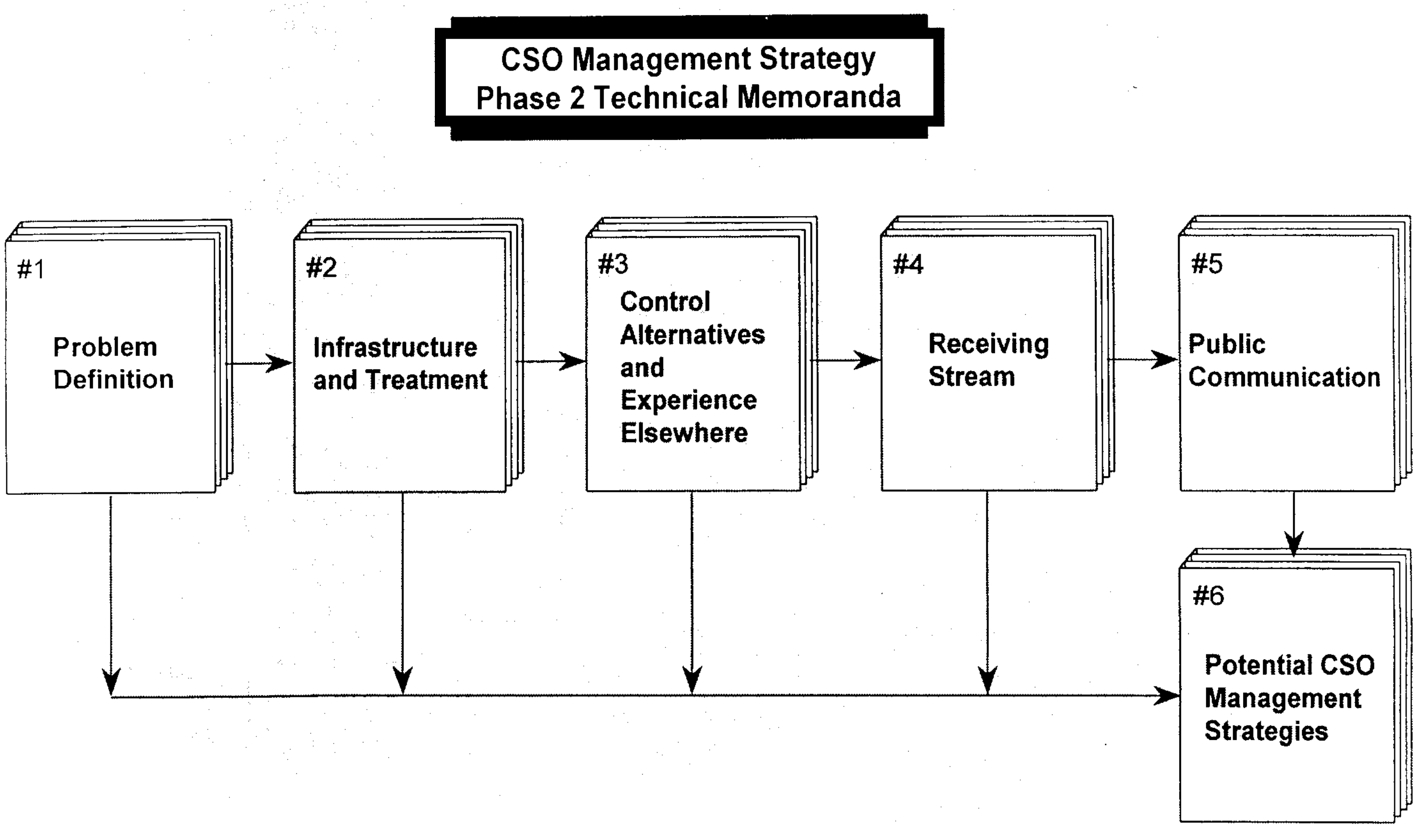
August 1995

August 29, 1995 8:41am

PREAMBLE

This Technical Memorandum (TM) is one of a series of TM's intended for internal discussion. It is not intended as a report representing the policy or direction of the City of Winnipeg.

This particular TM is part of a group of Phase 2 reports as shown in the schematic.



Each of the Phase 2 TMs draws on information developed in the prior Phase 1 TMs. In addition, the Phase 2 TMs document information and study analyses sequentially. Ideally, therefore, the TMs should be read in the sequence shown.

September 1, 1995 10:32am

ACKNOWLEDGEMENTS

The Study Team acknowledges, with sincere appreciation, the contribution of many individuals and agencies consulted in the course of Phase 2 of the CSO Management Study. The Study Team especially acknowledges the assistance of the City of Winnipeg Project Management Committee and the Advisory Committee.

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1.0 INTRODUCTION

1.1 GENERAL

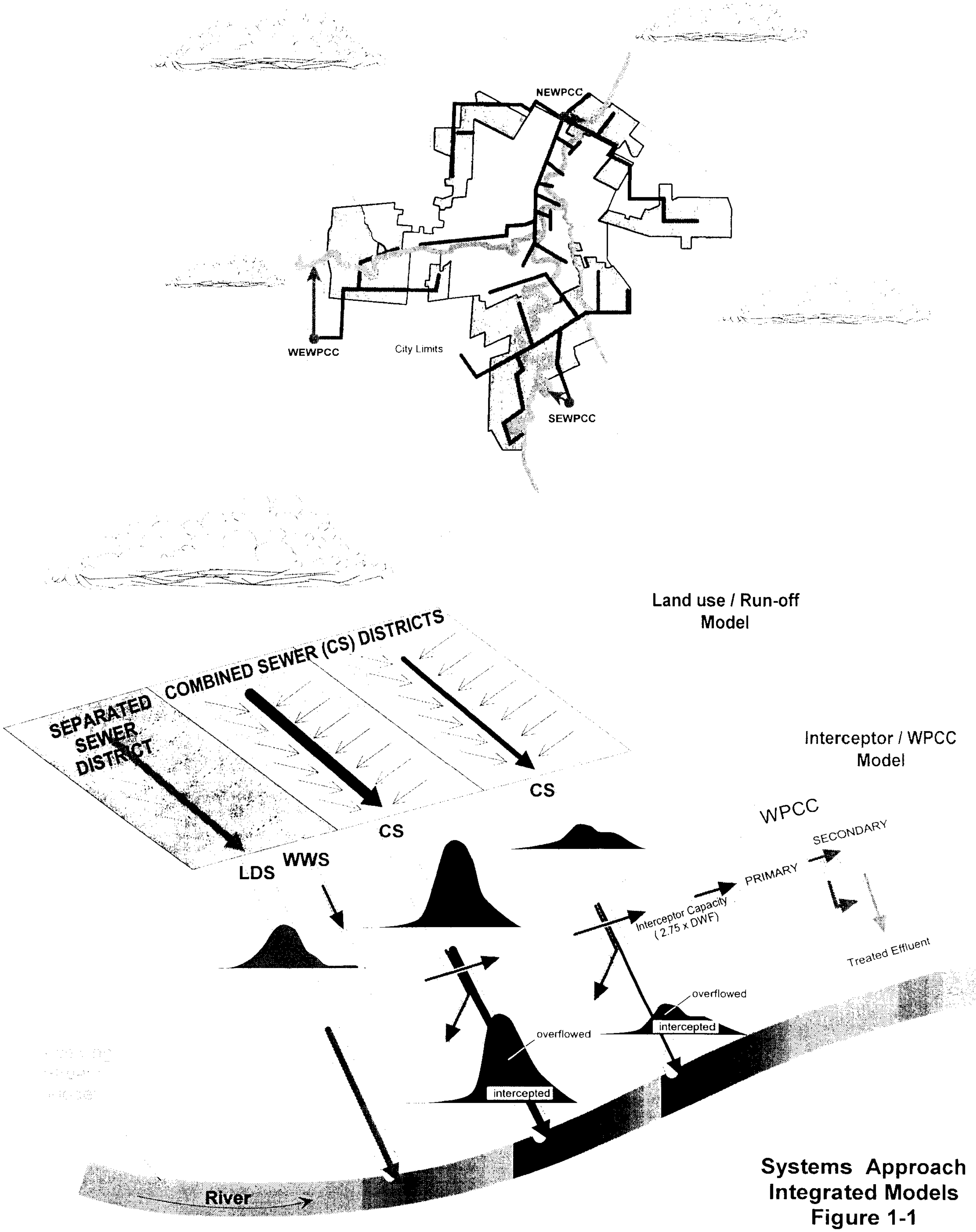
A series of technical memoranda (TMs) have been prepared for each major workstream to document and present the approaches, interactions, and key findings associated with CSO Phase 2 activities. The results from each component system modelled within the systems approach of integrated models flow from one model to the next as shown in Figure 1-1.

While combined sewer overflows (CSOs) are the focus of this study, their influence on receiving stream water quality must be considered in the context of other discharge sources to the river such as land drainage sewers and sanitary sewers.

This Technical Memorandum (TM) will focus on the methods applied in Phase 2 to estimate the representative wet weather flow (WWF) loadings (flow and quality) from combined sewer (CS) and land drainage sewer (LDS) districts to the local rivers in response to rainfall events. Phase 1 TM identified the known information on these loadings. This perspective was updated through the use of additional data and extensive analysis done in Phase 2.

This Phase 2 TM will:

- discuss the main issues associated with combined sewer overflows (CSOs);
- describe the selection of the runoff model;
- present the technical approach used to develop a calibrated computer-based model to simulate WWF discharges to the rivers from CSOs, LDS, and sanitary sewer overflows (SSOs);
- review calibration and verification to the specific Winnipeg conditions (with the use of Winnipeg rainfall data and monitored outfall flow and quality data on selected districts);
- extrapolate the calibrated model to a regional runoff model that estimates runoff hydrographs of flow and quality for CSO, LDS, and SSO in response to rainfall events; and
- run 30 years of rainfall history to generate the runoff hydrographs and quality data needed by the control alternatives modelling for estimation of loadings to the rivers.



Systems Approach
Integrated Models
Figure 1-1

1.2 ISSUES

The Manitoba Surface Water Quality Objectives (MSWQO) define water quality limits which are intended to ensure a healthy aquatic environment and protect beneficial water uses. The MSWQO describe in their General Requirements, conditions that should be avoided such as discharge of floatable material, sewage-related material, etc. Further, the Clean Environment Commission (CEC) has recommended, and Manitoba Environment has accepted these recommendations, that river uses to be protected for the local rivers shall be as shown in Table 1-1. The main water quality issue identified by the CEC was fecal coliform levels in the rivers due to urban discharges.

Receiving stream issues were reviewed at the Phase 1 Workshop in order to identify the main issues for planning level assessment in Phase 2. The results are summarized in Table 1-2. A series of working sessions were held during Phase 2 of the CSO study to assist in defining the importance of CSO-related issues for consideration in evaluation of control alternatives. The focus was to identify core, associated and motivating issues. These considerations were used to help shape the process of model development and simulations, and to establish a framework for benefits assessment.

Several parameters were considered in the characterization of CSO issues. These were:

- fecal coliforms (microbiological/health);
- sediments (aquatic life/benthics);
- dissolved oxygen (BOD);
- nutrients (nitrification - Lake Winnipeg and rivers);
- ammonia;
- mixing zones;
- persistent toxic substances (metals, pesticides, and so on);
- aesthetics; and
- basement flooding relief.

In Phase 1, specifically the Technical Memorandum (TM) No. 4 (Receiving Stream), water quality issues relating to CSOs were reviewed with due consideration for the Manitoba

TABLE 1-1

CEC RECOMMENDATIONS FOR RIVER USE PROTECTION

RIVER USE CLASSIFICATION	RED RIVER	ASSINIBOINE RIVER
Raw water for domestic consumption	√	√
Aquatic life and wildlife	√	√
Industrial Consumption	√	√
Agriculture (Irrigation)	√	√
Recreation		
a) primary	√	
b) secondary	√	√

	Issue				Monitoring		Modeling	
	Potential CSO Issue	CSO Elsewhere	Winnipeg CSO Issue		Winnipeg CSO Study		Winnipeg CSO Study	
Parameter	⇓	⇓	⇓	Comments	⇓	Comments	⇓	Comments
Hydraulic							●	*Hydrodynamics*
DO - BOD	●	O	O		●	*Confirmation Information*	O	
Nutrients	●	⊙		*Unlikely as Winnipeg Issue*		*Adequate*		*Loading Perspective*
Ammonia	●	O	O	*Unlikely as Winnipeg Issue*		*Separate Study*		*Loading Perspective*
Fecal Coliforms	●	●	●			*Adequate*	●	*Dynamic*
Mixing Zone	●	O				*Some Information Available*	O	*If Required as Detail*
Toxic Substances	●	●	?		O	*Some Information Available*	●	*Overflow volume as proxy*
Sedimentation	●	O	O		O	*Possibly, if Fisheries Issue*		
Aquatic Health	●	●	O		⊙	*Benthic Studies, More ?*		
Aesthetics	●	●	●		?	*Some Limited Information*	●	*Overflow volume as proxy*

● - HIGH
⊙ - MEDIUM
O - LOW
? - UNCERTAIN

Table 1-2
Receiving Stream

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Surface Water Quality Objectives (MSWQO) and the manner in which the Clean Environment Commission (CEC) considered that these discharges should be studied. This review of water quality issues was repeated in Phase 2, which confirmed that the discharge of CSOs in Winnipeg are particularly relevant to surface water quality for the following issues:

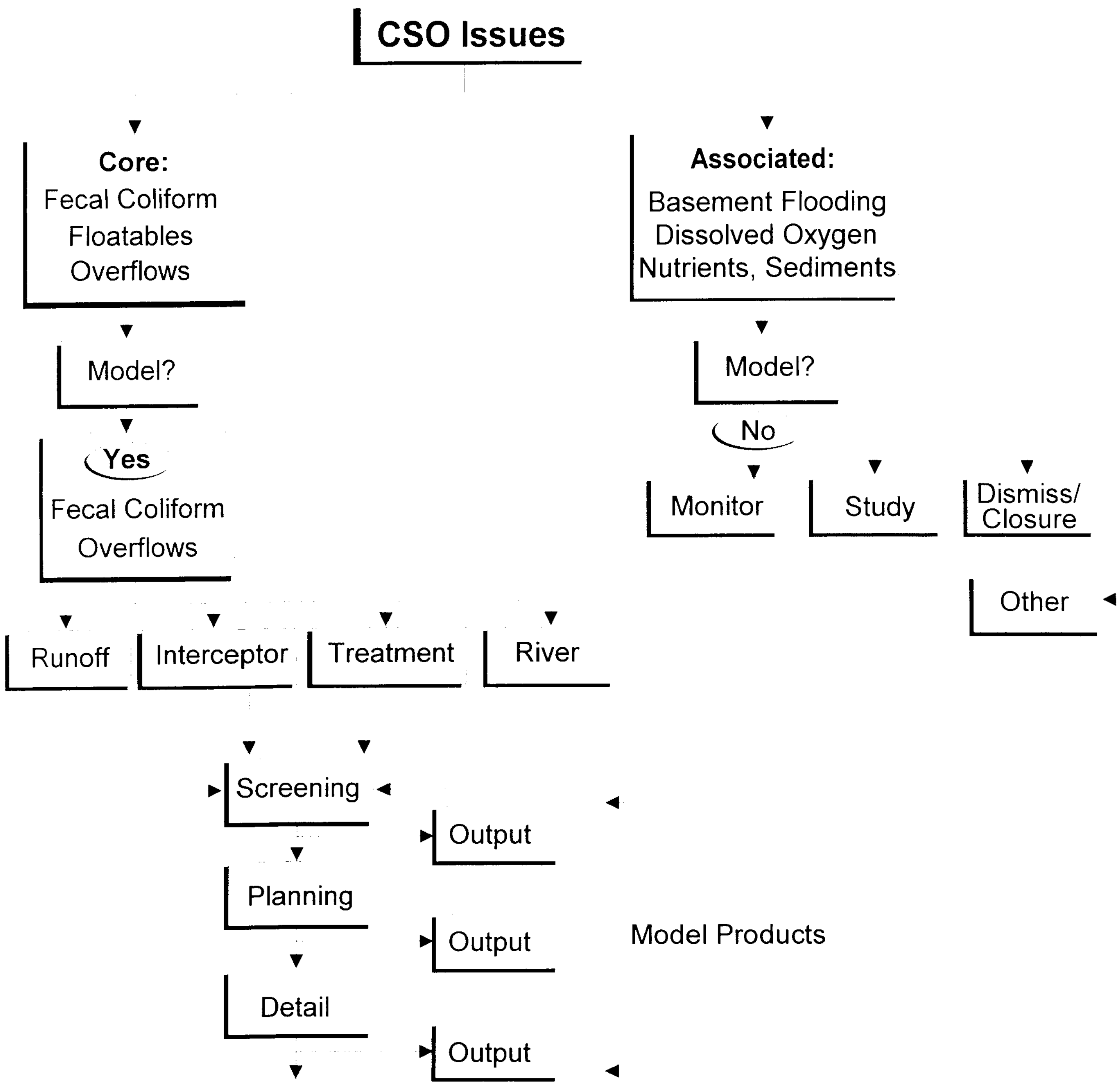
- **Aesthetics** - the river should be free from constituents attributable to sewage (e.g., floatables, scum, grease). The numerous outfalls in Winnipeg (CSO, LDS and sanitary sewage) represent a pollution control issue in this regard.

- **Microbiological Quality** - the microbiological quality of the Red and Assiniboine Rivers as measured by the indicator organism fecal coliforms exceeds the MSWQO, chiefly because of discharges from the City's water pollution control centres (WPCCs) during dry weather conditions and CSOs during wet weather conditions.

- **Dissolved Oxygen (DO)** - CSOs are a potential concern with regard to oxygen resources in the rivers, as they represent a oxygen demand on the rivers. However, actual monitoring of DO levels in the rivers both prior to the CEC river hearings and after have indicated that CSOs do not significantly affected DO levels in the rivers.

The core CSO issues were considered to be bacteriological (fecal coliforms), floatables, and overflows (number, frequency and duration). Associated CSO issues were considered to be basement flooding, dissolved oxygen concentrations, nutrient loadings, and sedimentation/benthic considerations. Motivating issues related to a river use in terms of primary and secondary recreation, irrigation, aesthetics, and regulatory policy. Improved compliance with the MSWQO was considered a measure in benefit assessment for ranking and categorizing possible control alternative strategies. Categorizing of CSO related issues for modelling considerations is illustrated in Figure 1-2.

The main issues associated with dry and wet weather loadings were reviewed in Phase 2 at a Working Session #1 held on September 27/28, 1994. An agenda for this session is provided in Appendix 1-A. Discussion of system requirements, provisions for model setup and development of models was also undertaken at this Working Session. This process helped



Categorizing CSO Issues
Figure 1-2

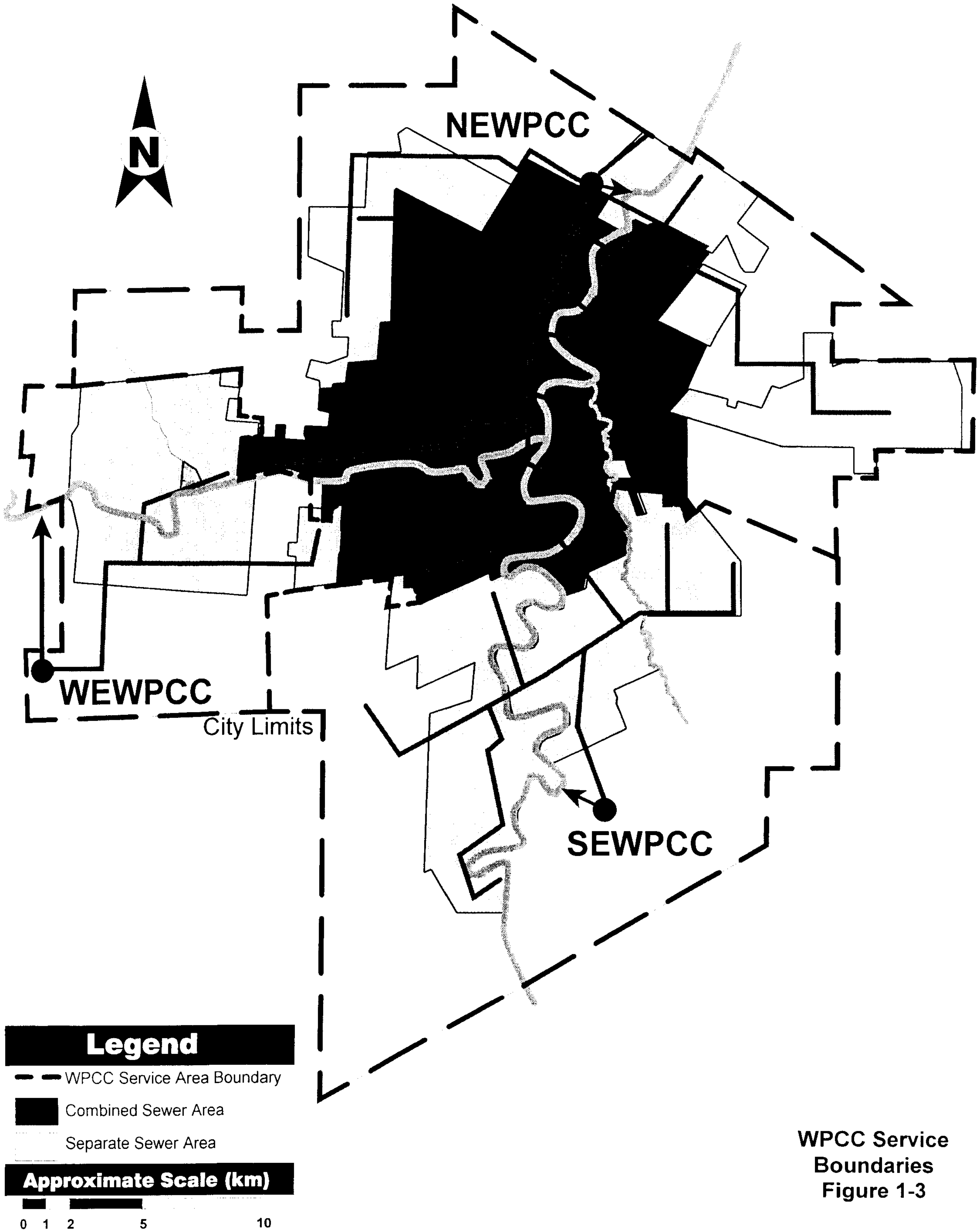
define the water quality parameters of interest and identify the appropriate models for subsequent modelling efforts.

Phase 2 Working Session #1 confirmed that the core water quality issues related to the CSO management study were the number and volume of overflows, fecal coliforms, and aesthetics (floatable material). These issues related directly to the recreational use and aesthetic enjoyment of the rivers. It was recognized that basement flooding has been, and continues to be, an associated issue with hydraulic conveyance limitations of the combined sewer system. Seasonal considerations were identified as an important aspect in the assessment of control technologies for CSO or other WWF discharge sources. The recreational season of the rivers as defined in the MSWQO (Williamson 1988) is usually restricted from May 1 to September 30 of the same year.

Accordingly, water quality issues associated with CSOs in Winnipeg relate mainly to aesthetic considerations and microbiological quality. The main focus of the review of CSO control options in this TM will relate primarily to these water quality issues.

1.3 EXISTING INFRASTRUCTURE

Current City of Winnipeg infrastructure consists of approximately 2,200 km of combined and sanitary sewers conveying wastewater to three pollution control centres (NEWPCC, SEWPCC, and WEWPCC) (Figure 1-3). The NEWPCC is the largest of the three plants, having an existing service area of 16,200 ha, and accepting about 70% of the wastewater generated within Winnipeg. The SEWPCC is the second largest of the three regional treatment plants and has an existing service area of 7,700 ha. This plant treats about 20% of the city-wide wastewater flow at present. The WEWPCC is the smallest of the three plants, having an existing service area of about 3,900 ha while treating only about 10% of the city-wide wastewater flow. The NEWPCC and SEWPCC plants are located on the Red River while the WEWPCC is located on the Assiniboine River. The historic and projected average dry weather flows (ADWF) and average annual flows (AAF) from the three WPCCs are given in Table 1-3.



WPCC Service Boundaries
Figure 1-3

TABLE 1-3

HISTORIC AND PROJECTED TREATMENT PLANT DISCHARGES

TREATMENT PLANT	TREATED EFFLUENT DISCHARGES (ML/d)					
	1989		2011[a]		2040	
	ADWF	AAF	ADWF	AAF	ADWF	AAF
NEWPCC	216	250	311	365	344[b]	396[c]
SEWPCC	48	54	87	97	140[d]	157[e]
WEWPCC	30	32	33	36	49[f]	58[f]

a) From Wardrop/Tetr*ES* 1991 Red and Assiniboine SWQO
b) Based on estimate of PDWF used in QUAL2E modelling for the Pembina Valley Water Cooperative Intervenor Submission
c) Assumes a multiplier of 1.16 to estimate AAF
d) Extrapolated projection from flow estimates contained in the SEWPCC Expansion Stage I Evaluation Study (Draft Report, 1993)
e) Assumes a multiplier of 1.12 to estimate AAF
f) From RCPL 1990 WEWPCC FDR

1.3.1 Water Quality Issues

The core issues associated with receiving stream water quality and their effect on beneficial river uses are microbiological (fecal coliforms) and aesthetic-related (floatables). Concern has been expressed in the past about recreational uses of the Red and Assiniboine Rivers and potential health risks associated with elevated fecal coliform levels. Coliform levels in the rivers typically exceed the Manitoba coliform objectives for primary and secondary recreation. A component of this study is to evaluate the significance of CSO management strategies in reducing fecal coliform densities in the rivers. Accordingly, it was deemed essential that the selected models must be capable of producing coliform loadings from the major sources and simulating receiving stream response. Urban land-use runoff modelling was used to estimate the runoff hydrographs from CS and LDS districts in response to specific rainfall events. Event mean concentrations (EMC) of fecal coliforms for major sources were estimated from available monitored water quality data. EMCs were subsequently applied to the runoff hydrographs in control alternative modelling efforts to generate the necessary loading files to be used in the receiving stream modelling, which simulate the response of the receiving stream to pollutant loads.

Recreational use of the river system (both on the rivers and along the rivers) has also created a concern for maintaining aesthetic standards related to water quality. The control of floatables (floating debris) has been viewed by many as a critical step to achieving satisfactory aesthetic value of the river system for individuals who utilize the river for recreational purposes. CSOs and LDSs are known to carry sewage-related material (CSOs) and street litter (CSOs and LDSs). The concept of modelling sewage and street-based debris was reviewed. However, based upon review of experience elsewhere, it was determined to be impractical to model the discharge and river transport of such material. It was concluded that the overflow volume (i.e., a function of the WWF hydrograph) could be used as a cursory estimate of floatable discharges to the rivers for possible capture by various control technologies.

The water quality issue of dissolved oxygen (DO) and its possible degradation from WWF loadings was reviewed. The available data indicates strongly that DO levels are only modestly affected by WWF as discussed in Phase 1 TM #4 - Receiving Stream. It was suggested that additional monitoring be undertaken downstream of the NEWPCC in a stretch of river considered to be most susceptible to possible DO degradation. This monitoring is expected to confirm that WWF impacts do not unacceptably suppress DO resources in the Red River. Results of this monitoring would also help define the need to model the DO dynamics of the rivers. It was deemed prudent that the receiving stream model be capable of modelling continuous DO dynamics and accepting runoff BOD loadings.

Receiving stream water quality impacts in response to sediments and toxic substances were considered to be important but secondary issues. It was decided that suspended solids be used as a surrogate to toxic substances in the estimation of possible mass loadings to the rivers in response to rainfall events. Suspended solids could later be fractionated to determine the composition of material comprising settable material. The amount of settleable solids removed by various control technologies could be used to express percent removed and a measure of improvement. Accordingly, it was considered that the WWF hydrographs, combined with event mean concentrations of suspended sediments, would be adequate for addressing possible concerns related to these water quality issues.

1.3.2 Associated WWF Issue

The City of Winnipeg has historically experienced its most significant basement flooding in combined sewer areas. Unseasonably high rains in 1993 exacerbated this problem and resulted in residential property damages which were among the highest on record. The Study Team recognized from the onset of this study that basement flooding control strategies must be considered in conjunction with CSO Management options. The City has implemented an ongoing relief program to improve the conveyance of wet weather to a 1 in 5 or 10 year return frequency level of protection to reduce basement flooding frequency. The improvement of conveyance capacity relieves the threat of basement flooding but delivers more combined sewage to the point of interception or by-pass, and, all other systems remaining unchanged, will result in greater rate of CSO to the City's rivers. Where basement flooding relief programs are currently underway in the City of Winnipeg, CSO control alternatives should be evaluated on the basis that basement flooding relief should not compromise future CSO control strategies.

1.3.3 Seasonal Conditions

The MSWQO defines the season for primary recreation as being from May 1 to September 30 of the same year. The main issue associated with dry and wet weather discharges relates to protection of the use of rivers for primary and secondary recreation, i.e., fecal coliform control. The MSWQO also suggests limits for fecal coliform to protect the use of the rivers for greenhouse and field crop irrigation. There is limited use of the rivers for this purpose within and downstream of the urban limits of Winnipeg. None of this use is year-round as was found in an irrigation survey conducted in preparation for Stage 2 of the CEC hearings (Tetr*ES* 1992). Therefore, the extent for compliance with the fecal coliform objectives is considered to be limited to the recreation season in these analyses.

The urban runoff modelling used to simulate present conditions and potential controls considered this May 1 to September 30 "compliance season". Runoff modelling used Atmospheric Environment Services (AES) data at the Winnipeg International Airport for the "compliance season" period from 1960 to 1992.

2.0 MODELLING APPROACH

The objective was to develop adequate information from systems modelling to assess the existing conditions and to be able to evaluate, on a screening basis, the effects of an array of potential WWF control options. Phase 2 models are intended to serve in the category of screening or planning level models.

2.1 INTEGRATED SYSTEM OF MODELS

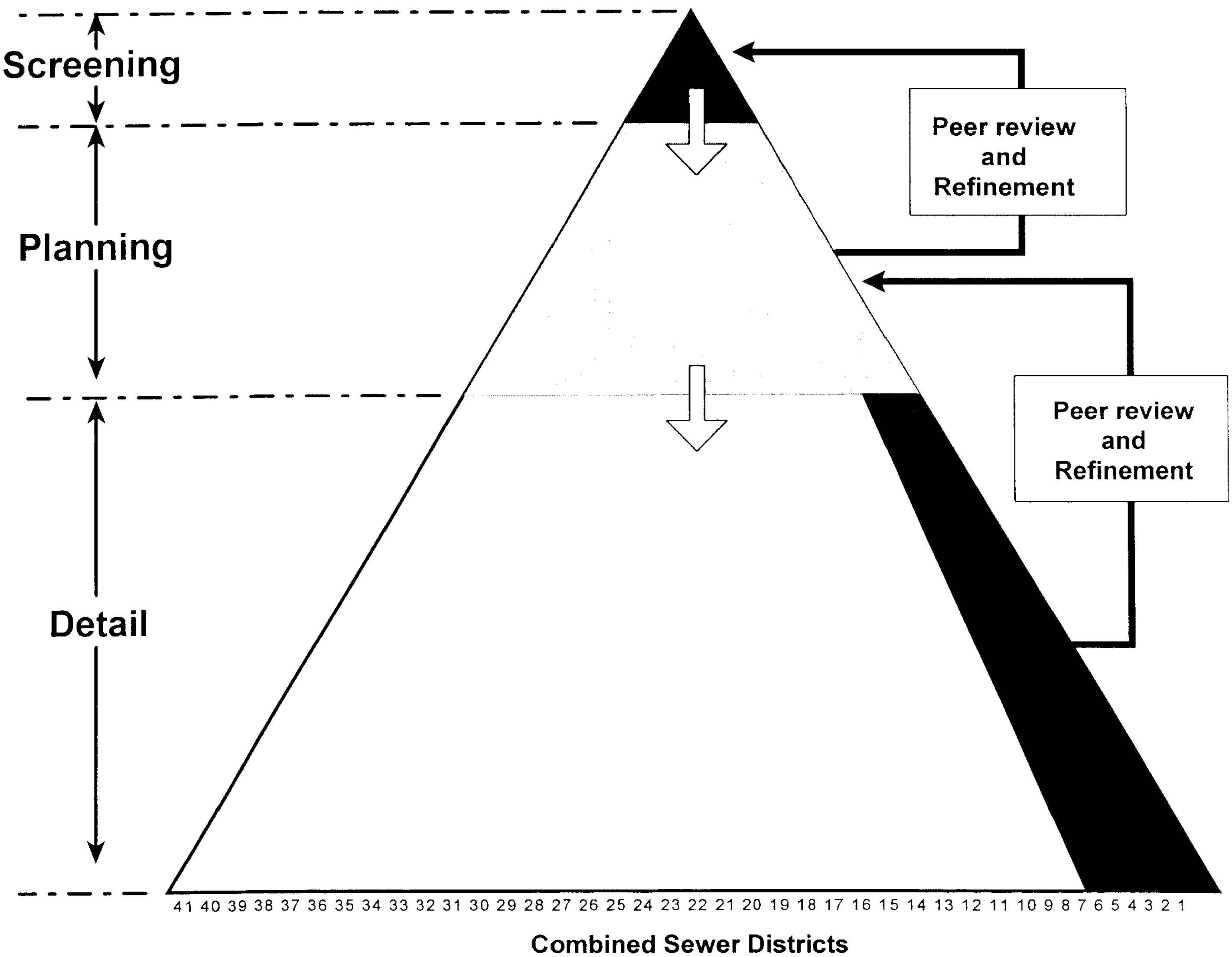
The modelling approach used in this study utilized a series of models and system components to comprise an integrated system of models. The four main components of the integrated system of models are: Urban Runoff Modelling, Control Alternatives, Interceptor/WPCC and Receiving Stream Modelling, as previously shown in Figure 1-1. In Phase 1, an "hierarchial" approach to the modelling was developed, as shown in Figure 2-1, which employed the following principles:

- apply numerical models to mathematically describe a physical system;
- progressively increase modelling detail to improve accuracy of predictions via:
  - screening level modelling
  - planning level modelling
  - detailed numerical design
  - operation Real Time Control (RTC)
- perform sensitivity analyses at each modelling level, determine significance of parameters modelled and their influence on results
  - calibrate/verify
  - use results to help focus next level of modelling
  - peer review
  - feedback/refinement of previous model.

This section will discuss the simulation of urban runoff for existing and potential future conditions. A schematic of the approach to urban runoff modelling is shown in Figure 2-2.

2.1.1 Urban Runoff Modelling

Urban runoff modelling is critical to the tasks of characterizing loadings to the river system resulting from combined sewer districts, land drainage sewers, and sanitary sewer districts. The urban runoff modelling effort considered actual periods of rainfall across the Winnipeg service areas and generated runoff hydrographs at points of interception for combined sewers or at the points of discharge to the rivers from land drainage. Areas of the City were modelled on a district by district basis utilizing historical rain records. Following calibration and verification, output data in the Runoff Modelling phase were compiled in a database and post-processed as input data files for Control modelling. Additional detail regarding the Runoff Modelling Approach is provided in Section 3.0.



Hierarchy of Models in Technical Framework
Figure 2-1

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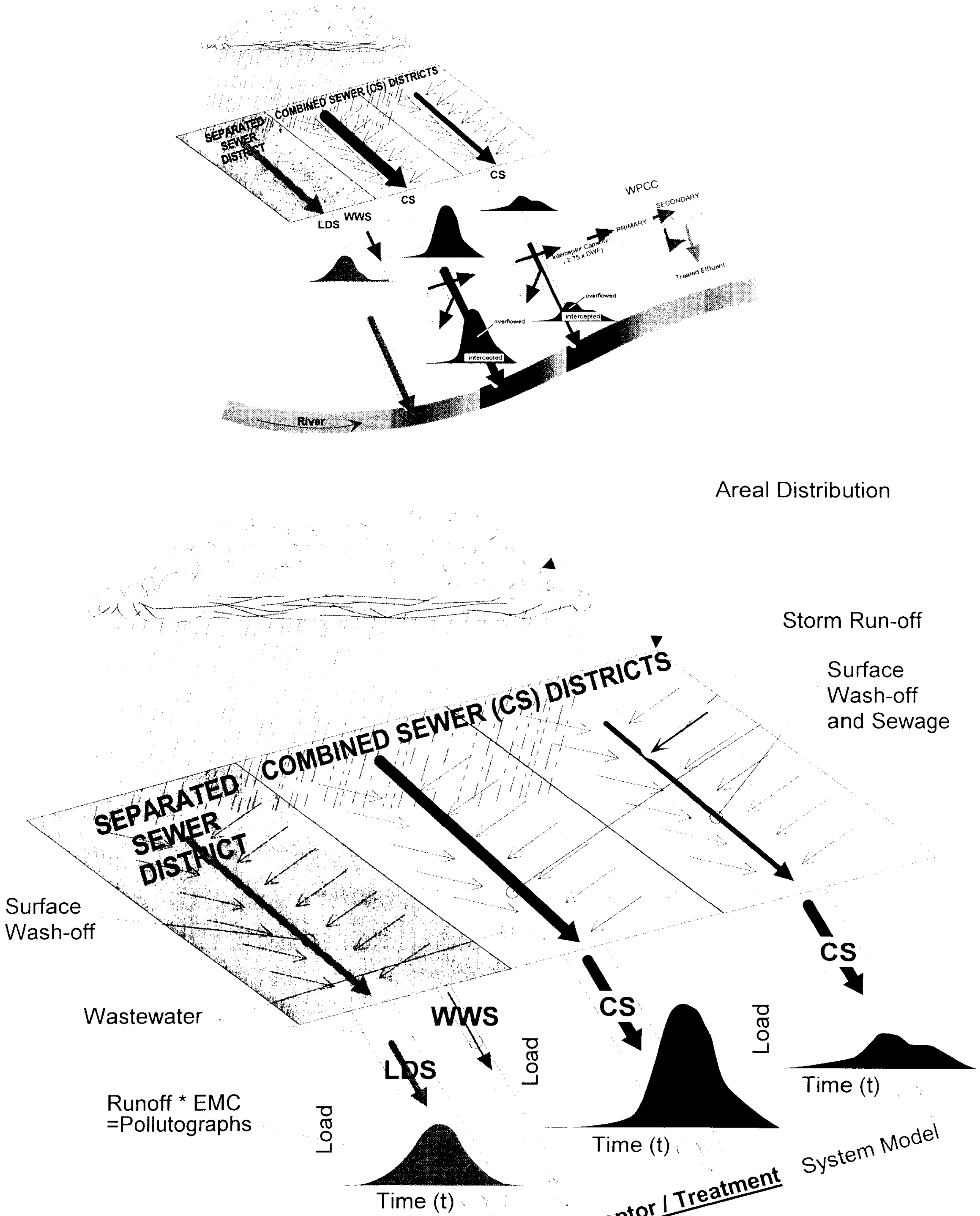


Schematic Description
Urban Runoff Model
Figure 2-2

2.2 PROCESSING OF DATA

An often necessary but time-consuming aspect of computer modelling is the preparation of raw data into an input file format consistent with the model requirements and interpretation of output. Due to limitations inherent in some computer models, it was necessary to develop custom interfaces, scripts and macros to pre- and post-process input and output data.

The processing of City-monitored rainfall data, monitored discharge flows and quality, and sewer district surface land use data required significantly greater effort than originally estimated. This was in part due to the sheer volume and assembly of data, its critical review to test its integrity, and despairingly different formats (digital and analog). The processing of output data for single event and continuous simulations, and its comparison to monitored conditions is a key aspect of calibration and assessment of results. Massive strings of output data required special processing to compile and parse the data into a format that could be viewed directly or plotted to make meaningful sense of the results. Accordingly, special hardware was purchased and employed to facilitate the processing and storage of massive amounts of input data required and generated by the urban runoff model.

The following subsection will discuss the details associated with the pre- and post-processing of data associated with runoff modelling.

2.2.1 Rainfall

District-specific rainfall data was provided by the City of Winnipeg in digital and analog formats. Data was collected from a network of fixed and portable rainfall telemetry gauges operated by City of Winnipeg Waterworks, Waste and Disposal Department staff. Data collected from the raingauge network was supplied in digital and analog formats. Information from both data formats required pre-processing into a 5 minute timestep format that could be accepted by the runoff model and later imported into a database or spreadsheet for analysis of results. Data was processed into a standard delimited file format that could be accepted by the runoff model. The runoff model is then capable of accepting this file and converting it into a binary format prior to use as input in the model.

2.2.2 Discharge Flow and Quality

The City of Winnipeg has an ongoing program for monitoring flow and quality data for selected sewer districts. Review of all flow records supplied by the City was necessary to assess the integrity of the data for subsequent analyses. Data records were provided in digital format for some monitoring stations and analog form (typed print-outs) for others. Monitored data which were not in digital form were entered into spreadsheets by data-entry personnel. Other data records which were expressed in english units required conversion to metric for standardization of units and calculations. Examples of monitored district data summaries generated for wet weather and dry weather flow are provided in Table 2-1 and Table 2-2, respectively.

Discharge flow data could not be accepted as an input into the runoff block of the modelling for comparison between monitored and modelled results. Flow data was processed in a standardized Lotus spreadsheet format to permit its use in model calibration and verification.

The data was reviewed and categorized in terms of source (e.g., CSO, LDS, WWS) and type of monitoring program (i.e., dry or wet weather). It was found that a substantial amount of the flow and quality data collected pertained specifically to combined sewer overflows. Some water quality information was available for land drainage discharges and dry weather flows. Unfortunately, data records did not always contain both flow and quality to estimate an EMC for locations and events monitored. This significantly reduced the sample size available to perform the necessary calculations to estimate EMC on a city-wide scale.

The time of water quality sampling and estimation of flows at a specific time were seldom synchronized. This required an additional step involving the interpolation of flow values to synchronize with quality samples. It was recommended that current and future monitoring programs collect and reduce the data such that a specific flow can be referenced to the time of water quality sampling.

WET WEATHER FLOWS

CSO District		Mager	Mager	Mager	Mager	Mager	Mager	Mager	Mager
Storm Date		Jun 12, 1989	Jun 29, 1989	July 5, 1989	July 12, 19	Aug 18,198	May 21, 1990	Jun 5, 1990	Jun 7, 1990
# Samples		24	8	9	6	14	3	7	24
BOD	(mg/l)	52.7	107.8	76	105.5	116.6	296.7	102.3	128.8
T. COLI.	10^5/100ml	N.A.	N.A.	N.A.	N.A.	N.A.	123	36	112
F. COLI	10^5/100ml	N.A.	N.A.	N.A.	N.A.	N.A.	62	30	43
pH		7.3	7.2	7.2	7.4	7.3	7	7.8	7.3
T.O.C.	(mg/l)	38	162	106	153	195	338	107	143
CHLORIDE	(mg/l)	23.2	54	51.5	34	31.8	52	109	141.6
AMMONIA	(mg/l)	1.9	2.3	2.4	1.6	2	14.2	5.3	8.3
NITRATE	(mg/l)	1.4	0.41	0.66	0.41	0.41	0.04	1.67	0.95
T.K.N.	(mg/l)	7	11	8.6	11.7	9.6	32	12.9	17.1
T. PHOS.	(mg/l)	1.4	2.4	1.8	2.3	1.8	6.3	2.2	3.5
T. SOLIDS	(mg/l)	400.4	975.3	600	808.3	838.7	1059	805.7	1172.8
SUS. SOLI	(mg/l)	164.2	635	360	467.3	552.4	696	176	557.5
CONDUCT.	(umho)	349.6	436	591	675	247.1	583	971.4	1062.5
SULFATE	(mg/l)	24.9	45	37	45	25.2	37.3	120.4	106.7
CADMIUM	(mg/l)	0.006	0.005	0.015	0.015	0.005	N.A.	N.A.	N.A.
CHROMIU	(mg/l)	0.03	0.03	0.03	0.03	0.03	N.A.	N.A.	N.A.
COPPER	(mg/l)	0.092	0.18	0.13	0.24	0.27	N.A.	N.A.	N.A.
NICKEL	(mg/l)	0.042	0.031	0.03	0.032	0.03	N.A.	N.A.	N.A.
LEAD	(mg/l)	0.05	0.16	0.09	0.11	0.12	N.A.	N.A.	N.A.
ZINC	(mg/l)	0.14	0.35	0.2	0.33	0.44	N.A.	N.A.	N.A.
TURB	(ntu)	50	150	106	144	134	N.A.	44	188
FLOW DAT	Yes?/No?	Y	Y	Y	Y	Y	Y	Y	Y

WET WEATHER FLOWS

CSO District		Baltimore	Baltimore	Baltimore	Colony
Storm Date		June 7, 1990	June 8, 1990	June 20, 1990	June 7, 1990
# Samples		8	11	9	6
BOD	(mg/l)	96.6	34.5	61.1	78.2
T. COLI.	10^5/100ml	32	36	72	17
F. COLI	10^5/100ml	16	12	29	8
pH		6.9	7.4	6.8	7.7
T.O.C.	(mg/l)	114.1	50.6	97.1	166
CHLORIDE	(mg/l)	140.6	59	69.8	34.8
AMMONIA	(mg/l)	2.7	2.3	4.2	2.8
NITRATE	(mg/l)	0.73	1.47	0.3	1.19
T.K.N.	(mg/l)	9.2	7.1	9.6	11
T. PHOS.	(mg/l)	2.2	0.91	2	2.9
T. SOLIDS	(mg/l)	844.3	515	638.4	1379.7
SUS. SOLI	(mg/l)	537.7	126.4	171.5	748.7
CONDUCT.	(umho)	607.1	760	1072.2	2100
SULFATE	(mg/l)	55	70.6	107.2	100
CADMIUM	(mg/l)	N.A.	N.A.	N.A.	N.A.
CHROMIU	(mg/l)	N.A.	N.A.	N.A.	N.A.
COPPER	(mg/l)	N.A.	N.A.	N.A.	N.A.
NICKEL	(mg/l)	N.A.	N.A.	N.A.	N.A.
LEAD	(mg/l)	N.A.	N.A.	N.A.	N.A.
ZINC	(mg/l)	N.A.	N.A.	N.A.	N.A.
TURB	(ntu)	170.7	42.5	66.1	247.7
FLOW DAT	Yes?/No?	Y	Y	Y	Y

Table 2-1

DRY WEATHER FLOWS

CSO District		Mager	Baltimore	Baltimore	Baltimore	Colony	Hawthorne	Hawthorne	Hawthorne	Linden	Linden	Linden
Storm Date		May 9, 1990	May 9, 1990	May 29, 1990	July 31, 19	May 9, 199	May 29,1990	July 13, 199	July 31, 1990	May 29,199	July 13, 1990	July 31, 1990
# Samples		3	3	3	3	3	3	3	3	3	3	3
BOD	(mg/l)	203.3	200	126.7	123.3	200	636.7	N.A.	285	500	87.3	163.3
T. COLI.	10^5/100ml	81	10	81	191	81	67	332	332	31	600	600
F. COLI	10^5/100ml	67	10	73	43	81	39	320	320	26	337.7	337.7
pH		7.3	7.2	6.9	7.1	7.5	6.9	7	7.5	6.9	7.3	7.3
T.O.C.	(mg/l)	197.3	168.7	108	N.A.	156.7	1203.7	N.A.	N.A.	1049.3	94.3	N.A
CHLORIDE	(mg/l)	54	43.7	30	646.7	50.3	52.3	N.A.	49.3	30	N.A.	32.3
AMMONIA	(mg/l)	28.5	27.3	16.5	20.5	23.8	35	24.2	31	27.2	22.3	25
NITRATE	(mg/l)	0.04	0.04	0.05	0.05	0.19	0.13	0.2	0.04	0.07	0.13	0.04
T.K.N.	(mg/l)	39.3	N.A.	29	25.7	40	68.7	37.7	51.7	72.7	33	35
T. PHOS.	(mg/l)	5.9	N.A.	5.4	5.7	6.9	10.3	4.8	8	9.8	5.4	6.2
T. SOLIDS	(mg/l)	645.3	666	1450.7	1758.7	504	4403.3	795.3	1204.7	4422	520.7	421.3
SUS. SOLI	(mg/l)	250.7	218	180	356	168.7	1237.7	N.A.	1064	3069	N.A.	530.7
CONDUCT.	(umho)	766.7	733.3	3433.3	2766.7	700	1466.7	666.7	633.3	583.3	1066.7	466.7
SULFATE	(mg/l)	33.3	32	262.3	N.A.	44	79.3	N.A.	N.A.	20	N.A	N.A.
CADMIUM	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CHROMIU	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
COPPER	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
NICKEL	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A	N.A.	N.A.	N.A.	N.A.
LEAD	(mg/l)	N.A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A	N.A.
ZINC	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A
TURB	(ntu)	183.3	103.3	55	45	73.3	2733.3	78.3	253.3	1440	45	88.3
FLOW DAT	Yes?/No?	N	N	N	N	N	N	N	N	N	N	N

DRY WEATHER FLOWS

CSO District		Alexander	Alexander	Alexander	Dumoulin	Dumoulin	Dumoulin	Moorgate	Moorgate	Moorgate	Strathmillan	Strathmillan	Strathmillan
Storm Date		Aug 2, 1990	Aug 9, 1990	Aug 13, 1990	Aug 2, 199	Aug 9, 1990	Aug 13, 1990	Aug 2, 1990	Aug 9, 1990	Aug 13,199	Aug 2, 1990	Aug 9, 1990	Aug 13, 1990
# Samples		1	3	3	1	3	3	1	3	3	1	3	3
BOD	(mg/l)	150	N.A.	493.3	180	N.A.	160	180	N.A.	230	370	N.A	290
T. COLI.	10^5/100ml	460	60	169	460	119	36	460	240	191	150	387	264
F. COLI	10^5/100ml	93	44	88	43	102	25	460	240	109	150	240	109
pH		7.1	6.5	5.3	7.4	7.6	7.6	7.2	7.3	7.6	6.9	7.4	7.8
T.O.C.	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A	N.A.
CHLORIDE	(mg/l)	107	377.3	1250	31	86	49.7	65	81.7	57.3	30	42	39
AMMONIA	(mg/l)	10.5	15.3	14.8	19.5	19.3	15.7	23.5	26.5	23.5	30	29.2	25
NITRATE	(mg/l)	0.28	0.13	0.19	0.04	0.06	0.12	0.1	0.05	0.07	0.04	0.07	0.13
T.K.N.	(mg/l)	20	31	31.3	29	27	23.3	32	34.7	33.7	49	46.7	37.7
T. PHOS.	(mg/l)	3.1	6.1	8.5	3.8	5.9	3.9	5.8	6.1	5.6	18	12.1	6.5
T. SOLIDS	(mg/l)	400	2185.3	3712	1182	438	987.3	158	788	1018	790	795.3	1018.7
SUS. SOLI	(mg/l)	N.A.	354.7	424	N.A.	68.7	137.3	N.A.	193.3	176	N.A.	337.3	256
CONDUCT.	(umho)	600	1900	3833.3	350	416.7	533.3	550	516.7	550	450	500	550
SULFATE	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A	N.A.	N.A.	N.A
CADMIUM	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A
CHROMIU	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A
COPPER	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
NICKEL	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
LEAD	(mg/l)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
ZINC	(mg/l)	N.A.	N.A	N.A.	N.A.	N.A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
TURB	(ntu)	60	111.7	81.7	60	39	55	60	75	86.7	270	106.7	136.7
FLOW DAT	Yes?/No?	N	N	N	N	N	N	N	N	N	N	N	N

Table 2-2

2.2.3 District Characteristics

A review was conducted to gather the available information on land-use characteristics needed for urban runoff modelling. Physical characteristics such as total and tributary areas, percent impervious area, slope, depression storage and sectorial composition (e.g., residential, commercial, industrial) were documented and compiled for later use in runoff modelling. Information in reports and studies was manually entered into spreadsheets to estimate the overall district characteristics (i.e., a single weighted value).

The 1986 Basement Flooding Report (City of Winnipeg 1986) and computer SWMM files were processed and supplemented by more recent information or reports. The 1986 Basement Flooding Report did not contain a summary of the combined sewer district information needed for urban runoff modelling in either paper or SWMM file formats. Accordingly, available SWMM files were first processed to extract the detailed subcatchment data for each district and reduced to single representative values for each of the model parameters. Secondly, detailed subcatchment information as contained on district maps, and not available in SWMM files were tabulated, entered into a spreadsheet and reduced to single representative values. This undertaking proved to be a large data management task and required careful interpretation of the data to ensure that the most current and representative district characteristics were used in runoff modelling.

Due to limited studies on relatively current separate sewer districts, actual land-use characteristics such as percent impervious, slope, depression storage and sectorial composition were not available for all separate sewer districts. It was assumed that separate sewer districts would have more green space and better land drainage than older and more established combined sewer districts. It was also assumed that the total area of each separate sewer district was representative of the tributary area for land drainage systems. Other area-wide characteristics from combined sewer areas such as slope and depression storage were considered to be adequate to estimate runoff from separate sewered areas.

2.2.4 Model Outputs

Continuous and discrete event urban runoff simulation for all combined and separate sewer systems generates numerous large files that need to be stored and processed to interpret results.

Single event storms were discrete events used in the calibration exercise for several districts. Rainfall was accumulated into 5-minute time periods to accurately describe monitored rainfall events. Model results were printed to an output file at 5-minute time steps for accurate representation of predicted peak, shape and volume of runoff. This required the importing and parsing of large output files into a spreadsheet, along with corresponding rainfall events to assess results. This was a very large data management and calibration task. Model results and monitored data were plotted simultaneously to visually assess the goodness of fit and sensitivity of model predictions to adjustment in model parameters. Spreadsheets and associated macros were custom developed to perform data-parsing and data-plotting used in the calibration. These specialized tools were essential to rapidly assess model parameters in calibration to monitored conditions for each rainfall among the selected combined sewer districts.

Continuous simulation required continuous rainfall records, as monitored by AES at the Winnipeg International Airport, for all combined and separate sewer districts. Rainfall records used in the simulation were from 1960 to 1993 for the recreation season (May 1 to September 30). Runoff files for each year and associated district (44 combined sewer and 54 separate sewer) were processed to convert the model output file from a binary format to an ASCII format so that it could be imported and compiled into a database for subsequent analysis and systems modelling (i.e., controls and receiving stream) as required.

The post-processing of model results for calibration, assessment of results, and use in subsequent modelling exercises was an enormous but essential data management exercise. Special interfaces, script files and macros were custom developed to accelerate the processing and analysis of data.

2.3 CHARACTERISTICS OF DISCHARGES TO RIVERS

It was necessary to characterize quantities of discharge originating from dry and wet weather sources and to apply representative quality concentrations in order to estimate loadings to the rivers and predict water quality responses. The simulation of dry and wet weather loadings for various water quality constituents (e.g., microbiological, nutrients, toxic substances, ...) is a very inexact science due to the high degree of variability of concentrations of pollutants in the sources.

The hydraulic discharges from individual sources can be described and quantified with satisfactory accuracy from urban runoff models. Runoff can be more accurately quantified because the conveyance system's physical characteristics are well-established and monitored rainfall can be events used to generate the necessary inflows, to replicate monitored hydraulic behaviour of the sewer system. Unfortunately, quality parameters cannot be simulated to the same degree of accuracy due to the inherent variability of concentrations in the origin of pollutants. The quantity of organisms or matter in wastewater and urban runoff is strongly influenced by factors that cannot be easily controlled. Specifically, the rate of build-up and wash-off of surface pollutants are a function of a number of variables that cannot be predicted to a sufficient degree of accuracy for detailed modelling purposes. Similarly, the composition of wastewater is dependent upon discharges from a large number and wide variety of sectors (domestic, commercial, industrial, institutional, ...). Accordingly, the concentrations can vary significantly in terms of quality and proportion due to the unique activities associated with each sector. For this reason, it was necessary to establish a statistical estimation of the quality of the discharges in terms of an event mean concentration (EMC) to represent the concentrations of water quality constituents in discharges to the rivers. These EMCs can then be subsequently applied to dry and wet weather flow hydrographs to estimate loadings to the rivers for particular contaminants.

2.3.1 Available Data

The City of Winnipeg has monitored both flow and quality for several discharge locations and developed a substantial database on loadings to the rivers. The locations monitored include:

• Ash CS District	1974
• Alexander CS District	1990, 91, 92
• Baltimore CS District	1989, 90
• Boyle CS District	1992
• Colony CS District	1990
• Clifton CS District	1992
• Crane LDS	1990, 91, 94
• Despin CS District	1992, 93
• Dumoulin CS District	1990, 91
• Hawthorne CS District	1990
• King Edward SRB	1990
• Linden CS District	1990
• Mager CS District	1989, 1990
• Mission CS District	1974
• Marion CS District	1992
• Mooregate CS District	1990, 91
• Munro CS District	1978
• Polson CS District	1978
• Strathmillan CS District	1990, 91
• St. Johns CS District	1978
• Syndicate CS District	1993, 94
• Tylehurst CS District	1994

The City also monitors inflow regularly at the three WPCCs, along with the effluent water quality, however the data on fecal coliform densities is limited.

Sampling data prior to 1989 was not available in a format that could be readily transformed into numerical data useful in subsequent calculations. This was not a major concern since the vast majority of data is from 1989 on. Table 2-3 lists CS District monitored data for eight districts since 1989. The table indicates that not all monitored locations contain flow and quality for each event. Accordingly, this significantly reduced the sample size that could be used to estimate event mean concentrations (EMCs).

Combined Sewer Overflows

District / Station	Date	Program	# Samples	BOD	FC	TS	SS	Metals	Flow
Alexander	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	06/07/91	WWF	24	N	Y	N	N	Y	Y
	06/25/91	WWF	48	N	Y	N	N	Y	Y
Baltimore	03/28/90	SRO	13	Y	Y	N	Y	Y	Y
	03/29/90	SRO	18	Y	Y	N	Y	Y	Y
	06/07/90	WWF	8	Y	Y	Y	Y	N	Y
	06/08/90	WWF	11	Y	Y	Y	Y	N	Y
	06/20/90	WWF	9	Y	Y	Y	Y	N	Y
Boyle Pump	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	06/16/92	CSO	2	Y	Y	Y	Y	N	Y
	07/19/92	CSO	2	Y	Y	Y	Y	N	Y
	07/02/92	CSO	23	Y	N	N	N	N	Y
	07/03/92	CSO	18	Y	N	Y	Y	N	Y
	07/07/92	CSO	4	Y	N	Y	Y	N	Y
	07/08/92	CSO	22	Y	N	Y	Y	N	Y
	07/14/92	CSO	16	Y	Y	Y	Y	N	Y
	07/27/92	CSO	4	Y	Y	Y	Y	N	Y
	08/22/92	CSO	23	N	N	Y	Y	N	Y
Clifton	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	06/16/92	CSO	24	Y	Y	Y	Y	N	Y
	06/17/92	CSO	18	Y	Y	Y	Y	N	Y
	06/24/92	CSO	24	Y	N	Y	Y	N	Y
	07/02/92	CSO	17	Y	N	Y	Y	N	Y
	07/07/92	CSO	24	Y	N	Y	Y	N	Y
	08/22/92	CSO	22	N	N	Y	Y	N	Y
Colony									
	06/07/90	WWF	6	Y	Y	Y	Y	N	Y
	06/08/90	WWF	10	Y	Y	Y	Y	N	Y
	06/20/90	WWF	35	Y	Y	Y	Y	N	Y
Galt Fl. Sta.	06/16/92	CSO	12	Y	Y	Y	Y	N	Y
	06/17/92	CSO	11	Y	Y	Y	Y	N	Y
	06/22/92	CSO	13	Y	Y	Y	Y	N	Y
	06/24/92	CSO	24	Y	N	Y	Y	N	Y
	07/01/92	CSO	12	Y	Y	Y	Y	N	Y
	07/02/92	CSO	14	Y	N	Y	Y	N	Y
	07/03/92	CSO	13	Y	N	Y	Y	N	Y
	07/14/92	CSO	8	Y	Y	Y	Y	N	Y
	07/27/92	CSO	10	Y	Y	Y	Y	N	Y
	08/22/92	CSO	16	N	N	Y	Y	N	Y
	09/05/92	CSO	24	N	N	Y	Y	N	Y
Mager	06/12/89	WWF	24	Y	N	Y	Y	Y	Y
	06/29/89	WWF	8	Y	N	Y	Y	Y	Y
	07/05/89	WWF	9	Y	N	Y	Y	Y	Y
	07/12/89	WWF	6	Y	N	Y	Y	Y	Y
	08/18/89	WWF	14	Y	N	Y	Y	Y	Y
	06/05/90	WWF	7	Y	Y	Y	Y	N	Y
	06/07/90	WWF	24	Y	Y	Y	Y	N	Y
	06/08/90	WWF	12	Y	Y	Y	Y	N	Y
Strathmillan	05/31/91	WWF	12	N	Y	N	N	Y	Y
	06/01/91	WWF	10	N	Y	N	N	Y	Y
	06/07/91	WWF	9	N	Y	N	N	Y	Y
	06/13/91	WWF	11	N	Y	N	N	Y	Y
	06/25/91	WWF	24	N	Y	N	N	Y	Y

Table 2-3

2.3.2 Event Mean concentrations (EMCs)

It has been found that EMCs, i.e., the storm event load or mass divided by the storm event runoff volume are remarkably log-normal in distribution, not only for CSOs, but also for stormwater runoff, rural runoff and treatment plant effluent (WEF Manual of Practice FD-17, 1994). The Nationwide Urban Runoff Program (NURP), reported in the results of test data from about 2,300 separate storm events on 81 sites in 22 different sites. These data showed, based on extensive statistical analysis, that EMCs were essentially uncorrelated with runoff volume (NURP 1983). These data analyses were based on a range of water quality parameters (metals, nutrients, solids). While fecal coliform were not in this group, there is little reason to believe this parameter would exhibit different characteristics.

The finding of no significant linear correlation between EMCs and runoff volumes is important in that it means that it is not likely that the size of storms for different monitored events will have biased the EMCs. Further, it indicates that refinement of methods to account for precipitation and runoff characteristics, antecedent conditions etc. are not warranted, particularly for planning level studies.

The concept of EMCs has been issued in many other CSO studies (e.g., Hamilton, Ontario, Chattanooga, Tennessee) and was considered appropriate for application in the Winnipeg studies.

2.3.3 EMC (COMBINED SEWER OVERFLOWS)

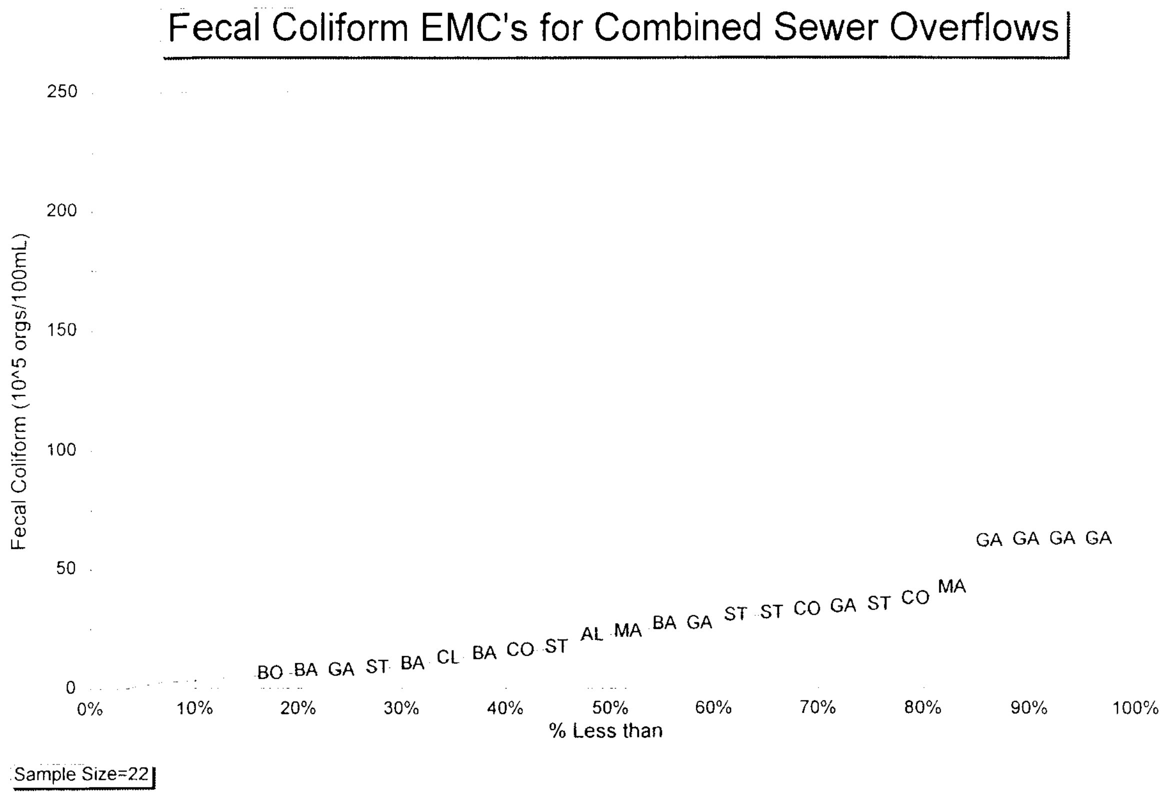
The CS districts monitored were previously reviewed in Phase 1 to assess the land use composition by sector; i.e. fraction of residential, commercial/institutional, and industrial areas. It was recognized that a primarily commercial combined sewer (CS) needed to be monitored to include adequate representation of all land use sectors. It was recommended that Tylehurst CS district be monitored because its land use is predominantly commercial and would provide data required for adequate characterization of the major land use sectors in combined sewer areas. Tylehurst, along with Syndicate CS district, was monitored in 1994;

tabulation of monitored data can be found in Appendix 1-A. The monitored data is considered to be adequate.

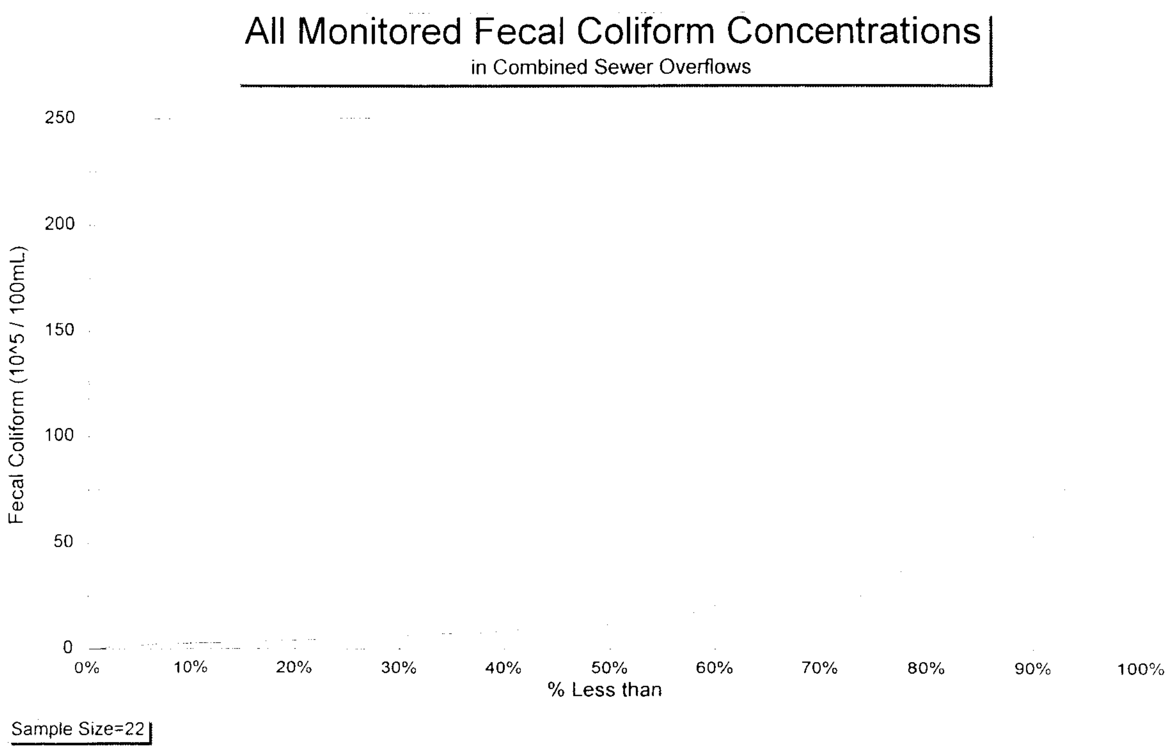
Estimating an event mean concentration (EMC) of a specific water quality parameter for a given rainfall event requires both flow and quality data. The data must be synchronized in order to estimate a flow weighted concentration. The estimated values exhibited a log-normal distribution and were considered to be statistically valid for planning level analyses. The following sections describe the approach used in the estimation of event mean concentrations and the corresponding values.

Rainfall induced flows were estimated by the City based on water level readings collected by Manning Dipper level indicators. Level indicators were configured such that waters overtopping the interception weirs would be recorded and activation of the water quality sampler would occur. Water levels were recorded in analog format (circular chart) on a continuous basis, while samples were collected on a predetermined time interval (i.e., every 10 or 15 minutes) for the duration of the overflow event. Water level readings were subsequently used to estimate the flow overtopping the weir at a specific time.

Due to equipment limitations, it was not always possible to collect both water levels (used to estimate flows) and water quality samples. All available quality data was independently analyzed to determine the range of values monitored and place subsequent calculations into perspective. It was important to review the monitored concentrations from each CSO location relative to each other to determine if certain CSO discharges exhibited significant fecal coliform concentrations. This analysis revealed that no statistically significant difference was exhibited at any of the monitored locations. A more detailed characterization in terms of land use to further describe combined sewer overflow quality was therefore not required. The results of the analysis are shown in Figure 2-3 and Figure 2-4. Event mean concentrations for each location monitored were assessed using a log-normal frequency distribution. The analysis indicated that the EMCs were evenly distributed and no one station exhibited consistently high or low values. A value of 2.4×10^6 fecal coliforms/100 mL and 650 mg/L for suspended solids in combined sewer overflows was selected using this method. These values were considered statistically representative values and adequate for planning level modelling of receiving stream impacts and benefits assessments of various control

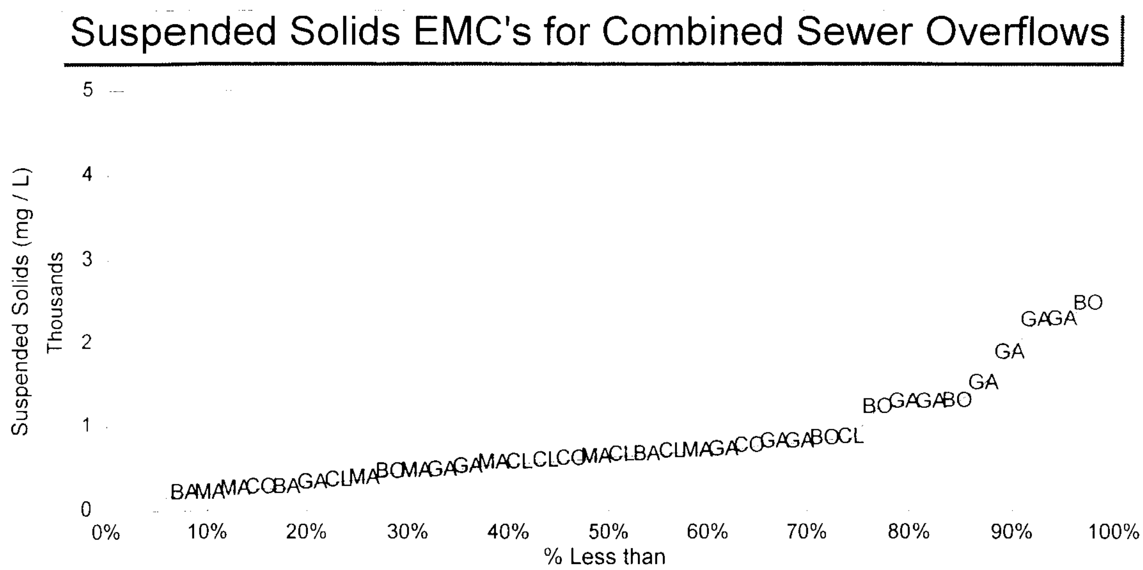


Fecal Coliform EMC's for Combined Sewer Overflows
Fecal Coliform (10^5 orgs/100mL)
250
200
150
100
50
0
BO BA GA ST BA CL BA CO ST AL MA BA GA ST ST CO GA ST CO MA GA GA GA GA
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Less than
Sample Size=22



All Monitored Fecal Coliform Concentrations
in Combined Sewer Overflows
Fecal Coliform (10^5 / 100mL)
250
200
150
100
50
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Less than
Sample Size=22

Figure 2-3


Suspended Solids EMC's for Combined Sewer Overflows
Suspended Solids (mg / L)
Thousands
5
4
3
2
1
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Less than

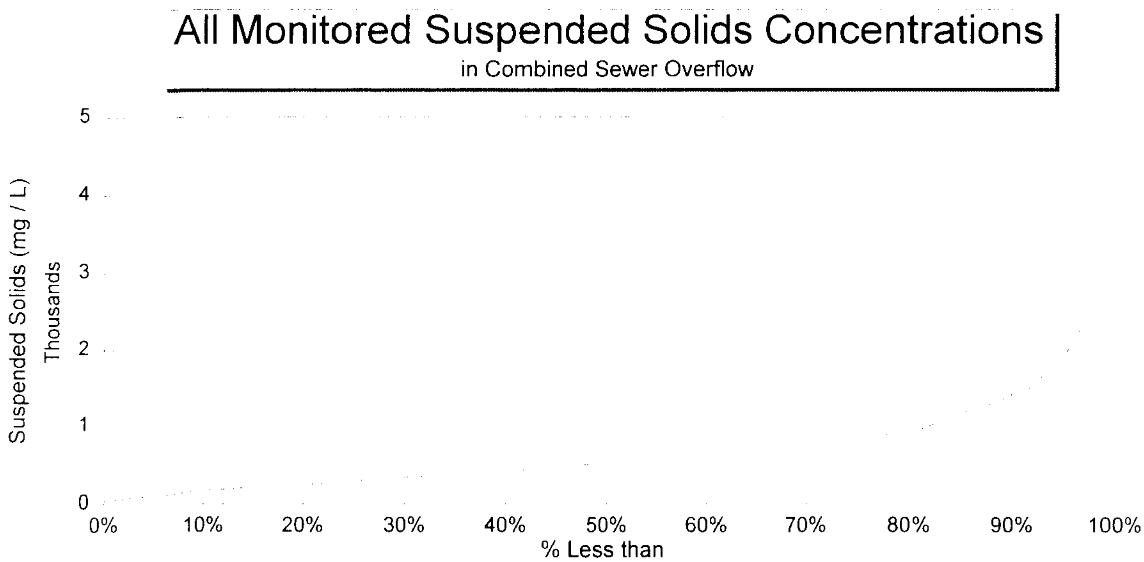

All Monitored Suspended Solids Concentrations
in Combined Sewer Overflow
Suspended Solids (mg / L)
Thousands
5
4
3
2
1
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Less than

Figure 2-4

alternatives. The full range, mean and standard deviation, based on a log-normal distribution, for fecal coliforms and suspended solids are listed in Table 2-4.

The estimation of EMC is illustrated in concept in Figure 2-5. For planning level analysis of receiving stream impacts, a representative concentration for discharges to the rivers needed to be established. To accomplish this task, a flow-weighted averaging of monitored concentrations was performed and used to approximate event mean concentrations for each location and overflow event where data was available. The weighting of monitored concentrations to flows provides a more accurate measure of total mass for the complete volume of discharge resulting from a specific rainfall event. Accordingly, total mass divided by overflow volume will yield an event mean concentration.

$$EMC = \Sigma Q_i C_i t_i / \Sigma Q_i t_i$$

where

EMC = Event mean concentration (mg/L)
Q_i = flow (m^3s) for a given time interval
C_i = concentration (mg/L) for a given time interval
t_i = time interval between samples (s)

The results are summarized in Table 2-4 for fecal coliforms, BOD, and suspended solids.

2.3.4 EMC (LAND DRAINAGE SEWERS)

There is limited local monitored data (flow or quality) on LDS discharges. It was recommended in Phase 1 that future monitoring be focussed on land drainage upstream and downstream of a storm retention basin (SRB) to gather data necessary to adequately characterize the quality of discharge from this source. Due to the planning requirement of selecting an accessible site and lead time necessary to install the monitoring equipment, it was not possible to gather quality data from such a location for these analyses. As an alternative, the Crane separate sewer land drainage outfall was monitored in 1994. This provided some important data to place the quality of discharges from land drainage systems into better perspective. Appendix 1-A contains a tabulation of monitored data. A monitoring site was established in the Transcona Lakes in 1995 to monitor the quality of stormwater upstream and downstream of a SRB.

EMC Summary Statistics for CSOs:

	Water Quality Parameter		
	Fecal Coliform (10^5 / 100 mL)	**BOD (mg / L)**	**Suspended Solids (mg / L)**
EMC's			
Number of Samples	28	36	38
Minimum Value	2.74	28.55	141.01
Maximum Value	62.08	243.19	2463.38
Average	27.32	108.78	844.67
Std Deviation	18.10	51.48	587.95

Table 2-4

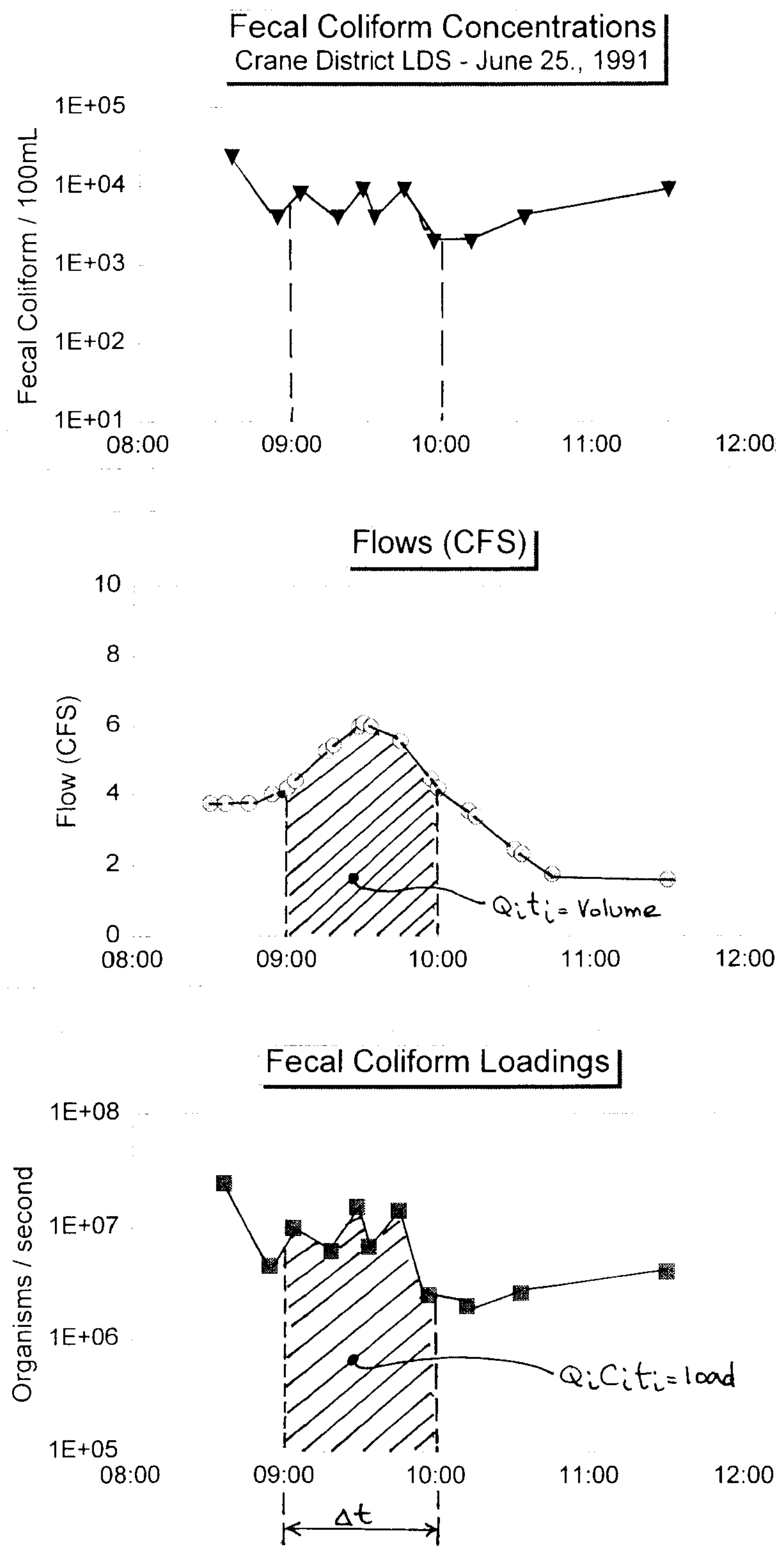

Fecal Coliform Concentrations
Crane District LDS - June 25., 1991
Fecal Coliform / 100mL
1E+05
1E+04
1E+03
1E+02
1E+01
08:00
09:00
10:00
11:00
12:00
Flows (CFS)
Flow (CFS)
10
8
6
4
2
0
08:00
09:00
10:00
11:00
12:00
$Q_i t_i$ = Volume
Fecal Coliform Loadings
Organisms / second
1E+08
1E+07
1E+06
1E+05
08:00
09:00
10:00
11:00
12:00
$Q_i C_i t_i$ = load
Δt

Figure 2-5

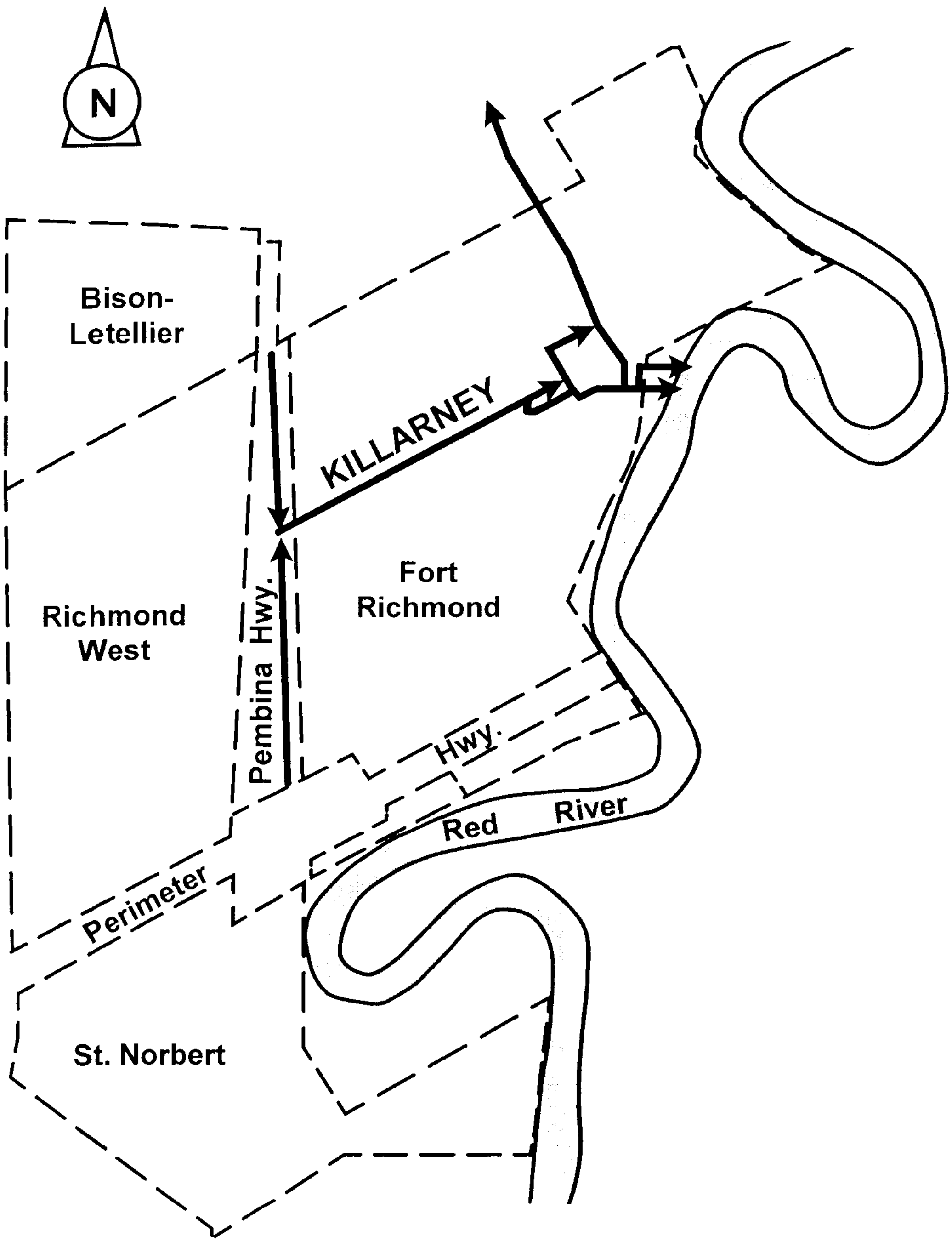
Available monitored data for land drainage discharges direct (Crane LDS) and through storm retention basins (SRB) (King Edward Retention basin), were assessed for both fecal coliforms and suspended solids to estimate a representative concentration. The limited data indicated that a value of 4×10^4 fecal coliforms/100 mL and 600 mg/L for suspended solids was typical for LDS direct discharges. For retention basin discharges, the values are approximately one-half of the LDS values. The values fall within the expected range for LDS discharges but require a larger sample size to more confidently categorize as representative city-wide concentrations.

2.3.5 EMC (SANITARY SEWER SYSTEM)

A more detailed review of the data gathered by the City of Winnipeg revealed that data gaps existed in the characterization of sanitary sewer overflows and treated effluent for fecal coliform densities.

A monitoring location was jointly established between the City and the CSO study team to characterize sanitary sewer overflows. The Killarney Avenue sanitary overflow, as shown on Figure 2-6, was selected because of its location on the south end wastewater interceptor system, and its function to alleviate surcharge levels in the interceptor by shedding excess flows directly to the Red River. Due to the high river flows in early 1995, the flow level and water quality monitoring station could not be installed until June 1995. Data is currently being gathered.

Sampling was performed during dry weather conditions in combined sewers to characterize the quality of wastewater flows. This information was used to place sanitary sewer overflow concentrations of fecal coliforms and suspended solids into representative ranges for local conditions. It was found that fecal coliform concentrations in raw sewage ranged from 4×10^6 to 400×10^6 organisms per 100 mL. This range was broader than previously reported in available data and literature. A value of 10×10^6 fecal coliforms/100 mL and 300 mg/L of suspended solids was considered to be representative of concentrations that would be observed in sanitary sewer overflows.



Killarney Sanitary Overflow

Figure 2-6

Kilrny
01_files

2.3.6 EMC (WPCC)

The concentration of fecal coliforms in treated effluents from the NEWPCC, SEWPCC, and WEWPCC used initially in Phase 1 analyses was based on values reported in the 1986 Disinfection Report (MacLaren 1986). Data on actual concentrations of fecal coliforms in treated effluent is sparse. Recent reports such as the UV Disinfection Study at the NEWPCC (Wardrop 1992) indicated that the fecal coliform concentration in the final effluent was substantially lower than previously measured. A comparison of discharge concentrations is shown in Table 2-5. A cursory analysis was performed using the full history bi-weekly monitored data upstream (Redwood Bridge) and downstream (North Perimeter Bridge) of the NEWPCC outfall to estimate the concentration of fecal coliforms in NEWPCC treated effluent discharge. It was found that the long-term geometric mean from the NEWPCC was in the order of 2×10^5 organisms per 100 mL. This is about half of the value previously used in the 1986 Disinfection Report (MacLaren 1986). Details of this cursory analysis are discussed in more detail in TM #2 and TM #4.

The density of fecal coliforms in the final effluent from the SEWPCC was found to agree well with previous studies. As such, a value of 2×10^5 was also considered representative for average dry weather flow discharges from the SEWPCC plant. The recent expansion and upgrades to the WEWPCC were considered to result in treated effluent quality similar to conventional secondary treatment (also recently upgraded and expanded) from the SEWPCC plant. Accordingly it was assumed that the WEWPCC would have similar effluent quality of 2×10^5 fecal coliforms per 100 mL. All three WPCCs were designed to produce treated effluent with a suspended solids concentration not to exceed 30 mg/L.

It was recommended that the City conduct regular monitoring of the final effluents from the 3 WPCCs on a weekly basis, along with secondary by-pass quality, to develop a database to characterize the density of fecal coliforms in the discharges for current plant conditions and operating practices. This activity is currently underway.

All three treatment plants are designed to provide full secondary treatment to flows not exceeding peak dry weather flows (PDWF) which are about 1.8 x ADWF. Flows up to PDWF were considered to have a fecal coliform concentration equal to ADWF of 2×10^5

TABLE 2-5

FECAL COLIFORM DENSITIES IN TREATMENT EFFLUENT

	DISINFECTION STUDY (MACLAREN 1986)	UV PILOT STUDY (WARDROP 1992)
NEWPCC	4×10^5	4.1×10^4
SEWPCC	2.5×10^5	2×10^5
WEWPCC	-	2×10^4

organisms/100 mL. Peak wet weather flows (PWWF) are about 3 x ADWF and only receive primary treatment. PWWF were assumed to have a quality similar to combined sewer overflow of 2.4 x 10^6 organisms/100 mL.

2.3.7 Summary of EMCs

The EMCs for the various discharges are summarized in Table 2-6.

3.0 URBAN RUNOFF

The urban runoff modelling effort was comprised of several key steps. Identification of modelling needs was necessary prior to the selection of a particular runoff model. Additionally, comparisons between AES monitored rainfall and City of Winnipeg monitored rainfall were required to determine the extent of areal variability in rainfall. Monitored data for overflow volume and quality was also assessed prior to running the runoff model. Once rain, flow and quality data had been processed and evaluated, the assembly of key district characteristics was undertaken and district data was entered into the runoff model for runoff simulation. Output derived from model runs was analyzed and model parameters were calibrated in an analysis phase which included repeated calibration and verification. Once satisfactory calibration was established, rainfall timestep sensitivity analyses were conducted prior to the eventual construction of the planning-level regional runoff model. Details associated with these activities are provided as Section 3.0 and illustrated schematically in Figure 3-1.

3.1 MODEL SELECTION

In Phase 1 a technical framework was established for the assessment of candidate models for use in the CSO study. Model characteristics which were deemed important to model selection and used to rank available models are listed below.

TABLE 2-6

SUMMARY OF REPRESENTATIVE FECAL COLIFORMS IN MAJOR CONCENTRATIONS

SOURCE	ORGANISMS/100 mL
WPCCs	
- DWF - PDWF - PWWF	200,000 200,000 2,400,000
LAND DRAINAGE	
- Direct - Ponds	40,000 20,000
CSO	**2,400,000**
SSO	**10,000,000**
INTERCEPTORS	
- CSO - SSO	2,400,000 10,000,000

Approach to Phase 2 RUNOFF Modelling

• Rainfall Data

- Review locations monitored (fixed and portable)
- Review data records (digital or analog)
- Review data format (time step, intensity)
- Review period of record (discrete - continuous)

• Monitored Overflow and Quality Data

- Identify locations with flow and quality (loading)
- Identify locations with flow only
- Perform calculation of Event Mean Concentrations

• Assess In-System Hydraulic Behavior

- Verify where monitored in system (U/S or D/S of O/F weir)
- Review assumptions used in hydraulic calculations of monitored O/F
- Gather information on interception capacity (pump rate)
- Estimate in-system DWF
- Compare number of O/F with rainfall history
- Compare FAST system with rainfall history

• Assemble Key District Characteristics

- Previous studies (flow and quality)
- Sewer district (CSO, LDS, LDS w/ Ponds)
- Sector classification
- Total and tributary areas (ha)
- Percent impervious
- Slope and width

• Acquire Model

- XP-SWMM

• Setup Districts

- Calibration set for CSO's
- Verification set for CSO's
- Tabulate available District characteristics on remainder

• Combine Information

- Match monitored O/F locations with rainfall files
- Partition into Calibration and Verification sets

• XP-SWMM Calibration of Selected Districts

- Run Selected Districts
- Use single event storms (5 min. time steps)
- Identify 5 monitored districts with range of O/F and rainfalls
- Determine if rainfall files can be readily used
- Digitize important rainfall events
- Input known district characteristics
- Document assumptions (depression storage and infiltration rates)
- Develop table of parameter values used in model
- Calibrate, adjust parameters until predicted agrees with monitored

• Assess Calibration Predictions

- Develop interactive spreadsheet (automate with macros)
- Calculate monitored and predicted O/F volumes and compare
- Compare peak O/F rate
- Assess goodness of fit
- Develop extrapolation table
- Compare with BFR Study

• Perform Sensitivity Analysis on Selected Districts

- Continuous simulation using 5 min. time step
- Use a Seleceted District for one season
- Compare number of overflows with FAST data
- Adjust model parameters to improve goodness of fit

• Develop Regional Models

- Extrapolation Table
- CSO, 43 Districts
- LDS and LDS w/Ponds, 90 Districts
- SSO, 90 Districts

• Indentify Monitoring Requirements

- Identify data gaps and new information required
- Select Districts for detailed monitoring
- Flow and Quality
- Portable rainfall gauge loacations
- Interceptor pump capacities
- DWF sewer gauging
- FAST alarm system

• Time Step Evaluation

- 5yr continuous simulation with 5 min. time steps
- Use a single district
- Post-process in automated spreadsheet
- Compare monitored with predicted (no. of O/F, peak, and volume)
- 5yr continuous simulation with 1 hour time steps
- Use a single district
- Post-process in automated spreadsheet
- Compare monitored with predicted (no. of O/F, peak, and volume)
- Adjust model parameters to improve goodness of fit
- Compare 5 min. and 1 hour predictions (no. of O/F, peak, and volume)
- Determine which time step is most appropriate for Regional model

Working Session

• Models Outputs

- Output files to INTERCEPTOR Model
- Output files to RIVER Model
- Output files to CONTROL Alternatives

Figure 3-1

- capability of simulating parameters related to dry and wet weather discharges (fecal coliform related);
- demonstrated reliability and applicability in other jurisdictions;
- demonstrated experience in local applications;
- well-documented and continuously upgraded;
- model must be of appropriate sophistication;
- model must not be difficult to implement, set-up/calibrate, and extend;
- ability to link with other models;
- model must be in the public domain (non-proprietary); and
- model must be cost-effective.

A matrix was developed to identify applicability of candidate models and their capabilities to modelling blocks in the CSO study. Figure 3-2 illustrates the ranking of models considered for the CSO study. Table 3-1 indicates the models selected and their intended applications. The Study Team concluded that XP-SWMM possessed the most desirable model characteristics for use in the CSO Study for runoff modelling and interceptor modelling. XP-SWMM was found to meet the above criteria and is based on the EPA SWMM model, which is in widespread use in addressing CSO management strategies. Additionally, the core SWMM model program is non-proprietary and with an "open architecture", allowing for customization of the software if required.

3.1.1 XP-SWMM

XP-SWMM is an extension of the stormwater management model, SWMM, which was originally developed in 1971. The acronym XP stands for expert and refers to a proprietary graphical interface developed by WP-software and packaged with the SWMM model. The model was developed under the sponsorship of the US EPA and a group of sub-consultants. The version of XP-SWMM used in this study is XP-SWMM Version 1.4 based on the US EPA SWMM Version 4. The unique features of XP-SWMM that were judged to be most beneficial to this study were:

Appropriate Levels of Model Sophistication and Ease of Use

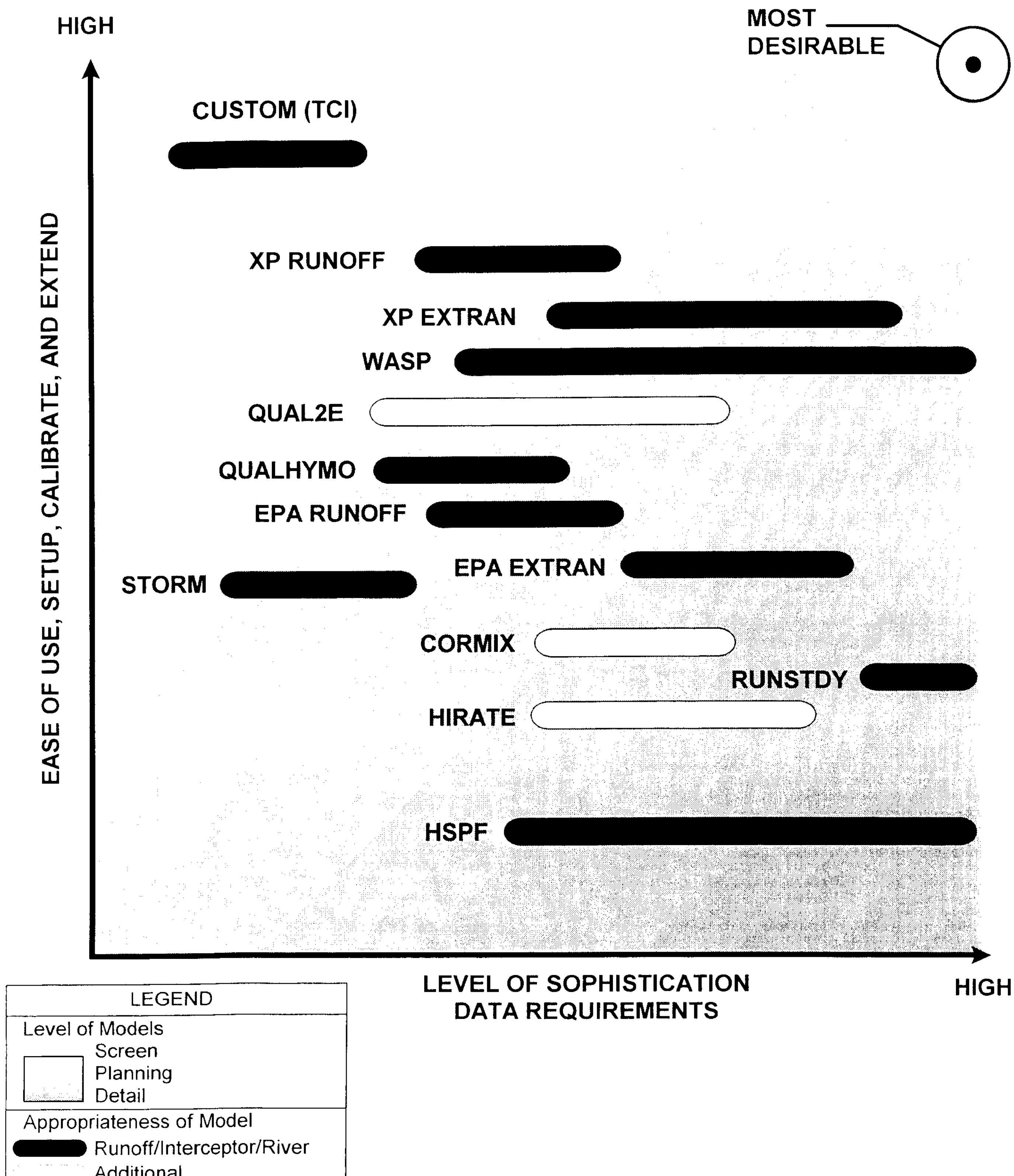


Figure 3-2

modlease
01_files

TABLE 3-1

APPLICATION OF MODELS

MODEL SYSTEM	SCREENING LEVEL (PHASE 2)	PLANNING LEVEL (PHASE 2 AND 3)	DETAIL LEVEL (PHASE 3 AND 4)
DISTRICT	• custom developed	• XP-SWMM) RUNOFF	• XP-SWMM - selected districts - TRANSPORT/EXTRAN
INTECEPTOR	• custom developed	• SWMM (EPA or XP) TRANSPORT	• SWMM (EPA or XP) EXTRAN
TREATMENT	custom developed	• XP-SWMM STORAGE/TREATMENT BLOCK	• HIRATE + XP-SWMM
RIVER	• custom developed	• WASP5	• WASP

- graphical interface to simplify and reduce the time required to enter data and define system description;
- ability to generate graphic outputs of model results for interpretation;
- ability to generate output files in a format that could be readily used by other EPA models or applications;
- can import input files used in earlier revisions of EPA SWMM;
- application to modelling interceptor hydraulics (Transport and XTRAN); and
- knowledgeable and available staff for support in application of the model.

The SWMM model simulates real storm events using rainfall data, other meteorological information and district-specific input data to predict model results such as quantity (outflow) and quality data.

Working Session #4 was held on January 26/27, 1995 and hosted the developer of XP-SWMM Dr. Robert E. Dickenson (key contributor to the development of SWMM). Dr. Dickenson's role at this Working Session was to critically review the application of XP-SWMM locally, to review modelling results, and to recommend improvement that would benefit the Winnipeg analyses.

3.1.2 Data Requirements

For planning-level runoff modelling, XP-SWMM data requirements can be classified into two categories; meteorological data and district catchment data. Meteorological data included single event and continuous rainfall records and pan evaporation rates. Required district data included tributary drainage area, percent impervious area, subcatchment width, pervious area storage, impervious area storage, percent zero detention on impervious areas, slope and Mannings "n". Table 3-2 summarizes the parameters required in the runoff model.

3.2 METEOROLOGICAL DATA

Meteorological data requirements in planning-level modelling were rainfall data and representative pan-evaporation rates.

TABLE 3-2

DATA REQUIREMENTS

Meteorological Data

• Rainfall Data
  - single event
  - continuous record
• Monthly Average Pan-Evaporation Rates

District Data

• tributary drainage area
• subcatchment width
• slope
• percent pervious and impervious area
• pervious and impervious storage
• Green-Ampts infiltration soil parameters
  - Average Capillary Suction
  - Saturated Hydraulic Conductivity
  - Initial Moisture Deficit

3.2.1 Rainfall

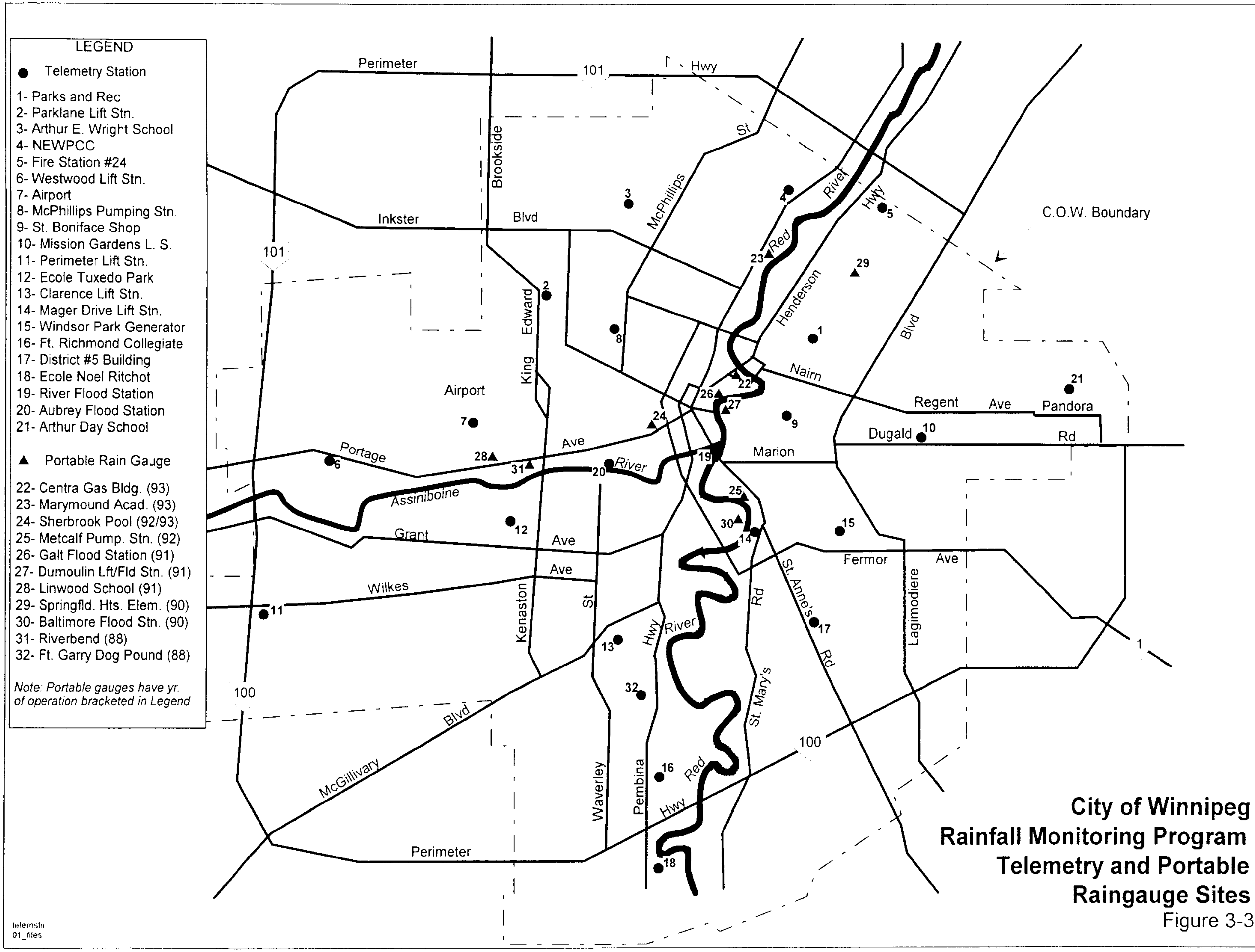
An extensive review of available rainfall data was required to determine the number of locations monitored, the format of data records (records were in digital or analog format), the timestep of the data, the period of record available for discrete and continuous rainfall, and the areal distribution of rainfall across Winnipeg.

Rainfall data was available from two sources: The City of Winnipeg's fixed and portable raingauge system and Environment Canada's Atmospheric Environment Services' (AES) Winnipeg International Airport monitoring station.

3.2.1.1 City of Winnipeg Raingauge System

According to available City records, the City of Winnipeg has operated and maintained its own rainfall monitoring program utilizing stationary telemetry and portable raingauge sites since 1978. The monitoring network currently consists of 21 permanently-located telemetry raingauge locations and 3 portable raingauges. An extensive effort was initiated by the City in 1987 to expand the number and location of fixed telemetry stations to more accurately define the temporal and spatial rainfall patterns across Winnipeg. The raingauge locations are dispersed approximately evenly throughout the city (Figure 3-3). Portable gauges were placed by the City in districts of interest to gather site-specific rainfall data relevant to relief studies being conducted for the City.

Rainfall data obtained from telemetry stations was given to the Study Team in digital format for use in XP-SWMM runoff modelling. The data was contained in separate files for each station and event, and not in a format that could readily be used by XP-SWMM. The data was selectively pre-processed for districts which had been monitored for combined sewer overflows. Portable raingauge data was provided in an analog format and was converted to digital file format prior to data processing. This was a very time-consuming task and required careful review of the analog tapes to properly reduce the data into a format that could be used by XP-SWMM.



City of Winnipeg
Rainfall Monitoring Program
Telemetry and Portable
Raingauge Sites
Figure 3-3

The City of Winnipeg rainfall data was used extensively for calibration exercises and the analysis of the areal distribution.

3.2.1.2 Winnipeg International Airport

Environment Canada's Atmospheric Environment Service (AES) continuously monitors meteorological conditions at the Winnipeg International Airport. The airport is located in the northwest quadrant of the City of Winnipeg in close proximity to the City's raingauge network shown in Figure 3-3. AES has rainfall measurements at the airport for a record of 30 years and is the only station where long-term, continuous rainfall measurements exist for the City. Rainfall is measured using a tipping bucket and graduated cylinder by trained professional staff. For this reason, rainfall data recorded at this location has been considered to be the most scrutinized and integral long-term data available for long-term runoff simulation. Tipping bucket measurements are recorded on a continuous basis and the time of each tip is discretely documented. Each tip represents 0.2 mm of rainfall.

AES publishes historic rainfall records in continuous hourly format and daily totals. It is possible to obtain rainfall history in 5-minute format, however data in the 5-minute format is voluminous and costly over a lengthy period of record. Tipping bucket data was historically recorded in analog format and manually discretized into accumulated hourly totals. The raw data exists in archives in Ottawa and can be reduced into 5-minute timesteps if requested. The cost to do so was found to be prohibitive and the need to do so uncertain. Special CSO monitoring programs were conducted in 1992 to characterize river water quality response to rainfall induced loadings to the receiving streams. Three specific monitoring campaigns were initiated based on the amount of rainfall (>10 mm) recorded at City of Winnipeg rainfall telemetry stations. A later comparison with AES rainfall as monitored at the Winnipeg International Airport revealed that two of the three events were not included in the AES hourly data. However, AES daily totals did reflect that rainfall events had occurred on these dates. An integrity check was performed comparing AES hourly and daily total formats. This analysis revealed that the hourly data was missing several events for several years, 1992 included. Table 3-3 compares the sum of rainfall for the recreation season (May to September inclusive) for both AES hourly and daily formats. The table indicates the years and amount

Table 3-3

Winnipeg Airport AES Records

Station	Year	Daily Summary	Hourly Summary	Missing Hours	Percent
5023222	1960	209.1	208.5		100%
5023222	1961	159.5	148.3		93%
5023222	1962	530.8	512.5	6	97%
5023222	1963	276.1	264.2		96%
5023222	1964	282.2	256.7		91%
5023222	1965	331.4	332		100%
5023222	1966	283.1	281.5		99%
5023222	1967	269.6	247.5		92%
5023222	1968	527.6	519.5	4	98%
5023222	1969	401.5	405	1	101%
5023222	1970	393.8	363	74	92%
5023222	1971	304.9	295.6		97%
5023222	1972	304.1	196.9	126	65%
5023222	1973	462.5	424.9		92%
5023222	1974	361.9	358.8	31	99%
5023222	1975	400.7	388.7	6	97%
5023222	1976	298.7	299.6		100%
5023222	1977	589.1	593.5		101%
5023222	1978	335.8	318	33	95%
5023222	1979	282.3	236.4	9	84%
5023222	1980	271.5	261.1	30	96%
5023222	1981	353.1	353.1		100%
5023222	1982	301.6	296.5	3	98%
5023222	1983	336.1	335.7		100%
5023222	1984	379.6	368.6	28	97%
5023222	1985	411.9	406.2		99%
5023222	1986	266.9	266.6		100%
5023222	1987	334	334.1		100%
5023222	1988	265.4	264.9		100%
5023222	1989	296.2	277.2	49	94%
5023222	1990	254.4	196.5	30	77%
5023222	1991	346.7	330.8		95%
5023222	1992	325.5	279.4	56	86%

of rainfall not included in the hourly format. The implications of the missed hourly rainfall in AES records will result in gaps of loadings to the receiving stream model. This condition was noted and discussed in TM #4 - Receiving Stream, in more detail, as part of the verification exercise.

3.2.1.3 Areal Distribution

Two rainfall data sets were available for use in the regional runoff modelling, City of Winnipeg and AES. The City of Winnipeg fixed and portable raingauge telemetry system records rainfall data for various locations within the city. Rainfall records for the updated and expanded telemetry network began collection in 1988. The integrity of the system and collected data improved substantially in subsequent years. The initial years (1988/89) contained gaps in data as a result of equipment failures and were resolved as encountered. The second data set, the AES Winnipeg Airport, consisted of data for a single location that had been collecting data for the past 30+ years. The City of Winnipeg database contained less years than the AES database but was better suited to assess areal distribution because of the telemetry network in place across the city.

It became necessary to understand the extent of influence that areal distribution of rainfall may have in planning-level runoff modelling.

<u>Continuous Record</u>

While there is significant areal variation for any given rainfall event, on average, any gauge is a reasonable proxy for long-term average conditions across the city. The AES station at the Winnipeg Airport was considered to be the best gauge to represent typical city-wide rainfall due to the long-term history of monitored rainfalls.

Comparisons were made between the AES Airport Station, and all available City of Winnipeg network gauges to analyze rainfall distribution. The analysis consisted of:

- calculating accumulated total rainfall per gauge station per rain event;

- running statistical analysis (mean, standard, % variation) for city-wide network and airport; and
- review and assessment of results, evaluation of significance of areal distribution.

It was found that areal distribution (temporal and spatial patterns) of rainfall was highly variable. However, it was found that discrete rainfall records at the Winnipeg Airport location, in the combined sewer districts, and city-wide compared quite favourably and would be adequate for planning-level runoff modelling. Figure 3-4 compares the daily totals of rainfall for these three areal considerations.

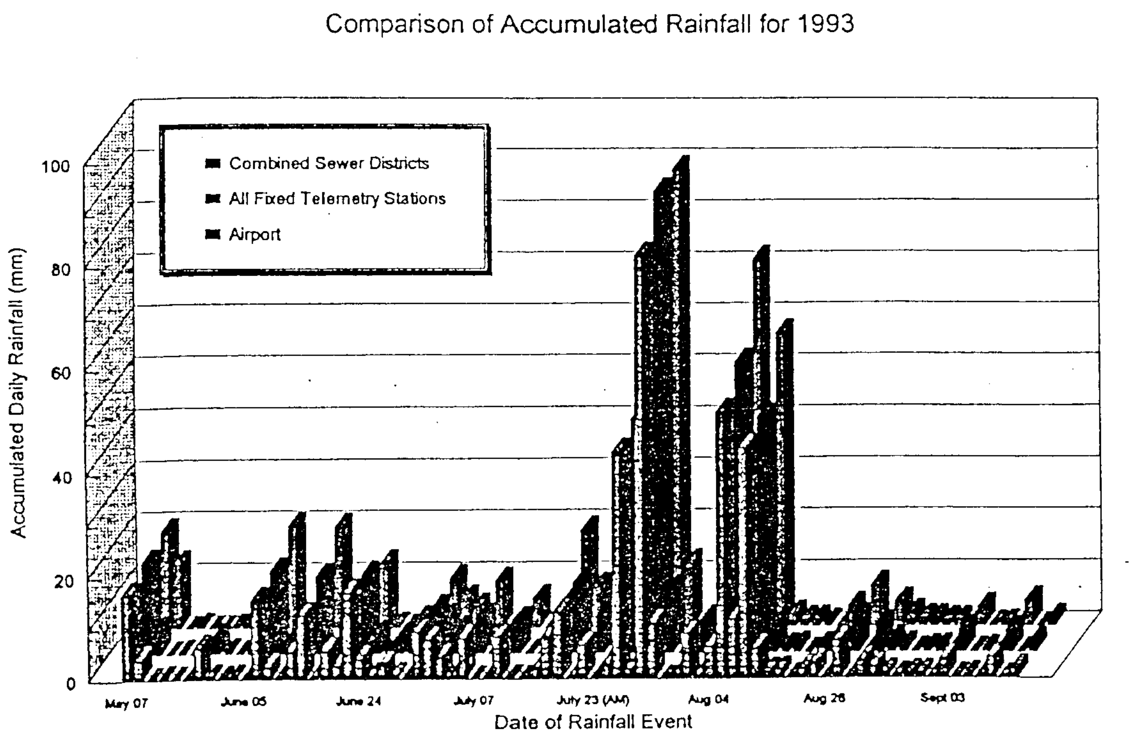
Analyses revealed that the rainfall data at the Winnipeg Airport station was a satisfactory representation of total rainfall that fell across the city. The long-term hourly AES rainfall data could confidently be used in long-term urban runoff simulation to estimate loadings to the rivers for planning level assessment of control alternatives.

Single Event Data

Single event rainfall records were used to calibrate the runoff model to monitored outflow data for combined sewer overflows. All available single event rainfall records were examined for integrity of data and corresponding monitored outflow data for application in the calibration exercise.

Seasonal Data

Seasonal rainfall records were extracted from continuous, year-round hourly AES Winnipeg Airport station rainfall records. The season of primary interest in this study is the recreation season which extends from May 1 to September 30. The recreation season is defined by Manitoba Environment to be the period in which primary recreation on the river system is possible. Primary recreation involves swimming, water skiing and other activities where full immersion in the water is likely to occur.


Comparison of Accumulated Rainfall for 1993
Combined Sewer Districts
All Fixed Telemetry Stations
Airport
Accumulated Daily Rainfall (mm)
100
80
60
40
20
0
May 07
June 05
June 24
July 07
July 23 (AM)
Aug 04
Aug 26
Sept 03
Date of Rainfall Event

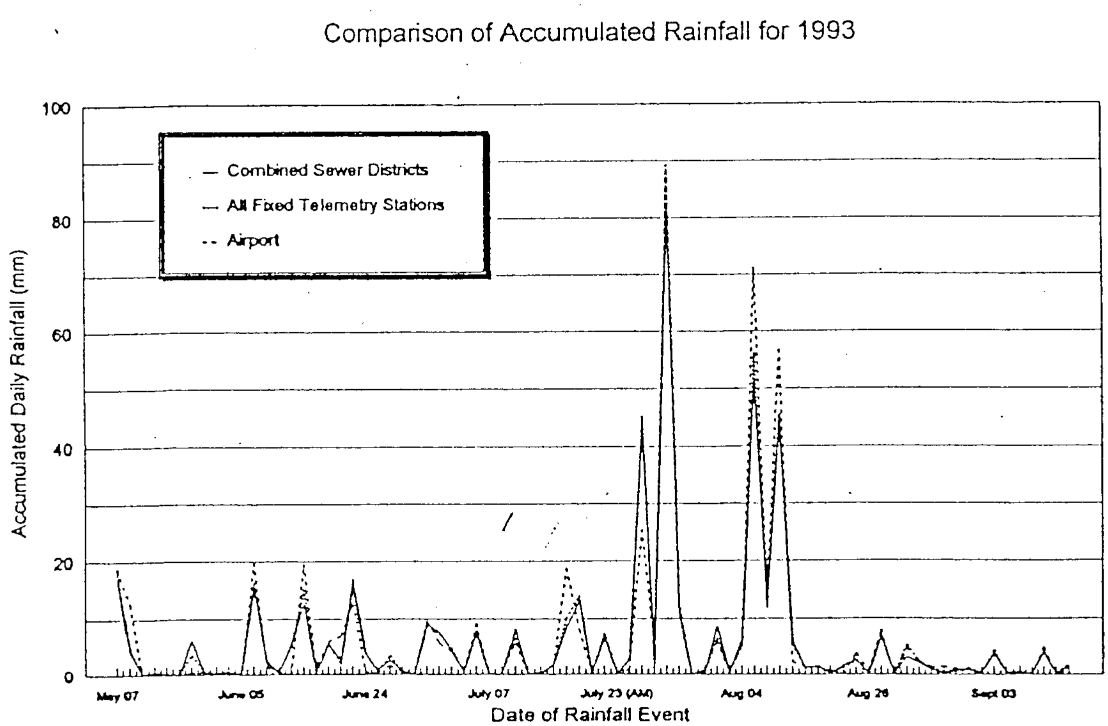

Comparison of Accumulated Rainfall for 1993
Combined Sewer Districts
All Fixed Telemetry Stations
Airport
Accumulated Daily Rainfall (mm)
100
80
60
40
20
0
May 07
June 05
June 24
July 07
July 23 (AM)
Aug 04
Aug 26
Sept 03
Date of Rainfall Event

Figure 3-4

Historical Record

Long-term historical rainfall records were obtained from Environment Canada's AES for the Winnipeg International Airport raingauge station. Processed hourly rainfall records were available in the standard AES format for the period spanning 1960 to 1993.

3.2.2 Pan Evaporation

Pan evaporation data is an important parameter used to approximate precipitation and soil moisture which is lost due to evaporation. The XP-SWMM model is designed to account for evaporation losses based on approximations derived from representative pan evaporation data. The evaporation loss is calculated by the model and subtracted from the runoff storage volume and soil moisture based on representative monthly pan evaporation rates. Representative monthly pan evaporation rates were obtained from AES and used as input in the model. Table 3-4 lists the monthly rates used in the analyses.

3.3 MONITORED OVERFLOW AND QUALITY DATA

The City of Winnipeg Waterworks and Waste Department has an ongoing program to monitor overflows and quality data for sewer districts selected on an annual basis. Typically, a sewer district is selected for monitoring prior to anticipated sewer relief projects or identified operational problems exist at the district's outfall location.

At present, 20 of the 44 CS districts have been monitored for outflow or quality. Monitored CS districts and year(s) of monitoring are listed in Section 2.3.1. Flow records for districts monitored from 1990 on were provided in digital format. Locations monitored in 1989 were available only in hard copy form and manually entered into the appropriate digital files.

Available flow records for monitored combined sewer districts were reviewed to determine which records could be confidently used in the calibration exercise.

TABLE 3-4

PAN EVAPORATION - REPRESENTATIVE MONTHLY EVAPORATION RATES FOR 1992

	MONTH	MM/DAY
1	January	0
2	February	0
3	March	2.6
4	April	5.2
5	May	5.2
6	June	8.2
7	July	6.8
8	August	7.5
9	September	7.1
10	October	5
11	November	2.5
12	December	0

3.4 IN-SYSTEM HYDRAULIC BEHAVIOUR

A number of steps were required to achieve an understanding of in-system hydraulic behaviour for each of the district's to be modelled. It was necessary to determine where flows were monitored in the system. Specifically, calibration procedures would differ if monitoring was done upstream or downstream of the overflow weir. It was learned that discharges monitored were flows that overtopped the interception weirs. This indicated that interception capacity for each overflow needed to be accounted for in the calibration of runoff. Accordingly, interception capacities (pump rates) were required for each modelled district to correctly account for intercepted volumes. In the absence of interception capacities, winter water consumption was multiplied by a factor of 3 to approximate the interception rate. The intercepted volume was removed from the XP-SWMM model's predicted runoff hydrograph to simulate the district's overflow accurately. These adjusted runoff hydrographs were then compared with monitored overflow hydrographs during the calibration procedure.

In-system dry weather flows (DWF) also required assessment. Some districts may produce overflows during dry weather conditions in response to additional flows to the sewer from such sources as groundwater-based air-conditioning systems or increased seasonal discharges from commercial or industrial processes.

Lastly, comparisons were made between the number of overflows to FAST alarm data versus rainfall history in order to obtain an understanding of the size of storm that causes a district to overflow and the frequency of such storms. This was used to place the results of continuous runoff simulation into perspective. It also was used to identify potential DWF and districts that may require further study or investigation.

3.5 KEY DISTRICT CHARACTERISTICS

Key district characteristics required by the XP-SWMM model included:

- catchment area;
- subcatchment width;

- percent impervious area;
- pervious and impervious area storage;
- Green-Ampts infiltration parameters;
- surface roughness (Mannings "n") coefficients; and
- average ground slope.

Some of this data was available from City of Winnipeg records, City of Winnipeg Engineering studies and consultant's reports for combined sewer districts. Unfortunately, information for separate sewer districts land drainage systems was limited and required approximation based upon combined sewer district characteristics.

Each sewer district in the city was classified as a combined or separated sewer district. Separated sewer districts are further classified based on whether they discharge directly to the rivers or through storm retention ponds and then to the rivers.

3.5.1 Single Catchment Approach

For a planning level analysis of urban runoff, it was necessary to determine the extent to which the number of subcatchments within a district could be reduced to adequately represent outflow hydrographs. A detailed, multi-subcatchment modelling effort is often required for a hydraulic assessment of sewer system conveyance of a district. Planning level analyses are interested in a broader understanding of system behaviour in terms of peak flows and runoff volumes.

A sensitivity analyses was conducted to assess the number of subcatchments required to adequately describe runoff in terms of peak, shape and volume. The sensitivity analysis revealed that differences between a single subcatchment and several subcatchment runoff hydrographs were small and compared favourably. Comparative flow plots were produced for outflows resulting from:

1) XP-SWMM - Single Catchment Area modelling;
2) Detailed, multi-subcatchment EPA modelling; and

3) Monitored outflow.

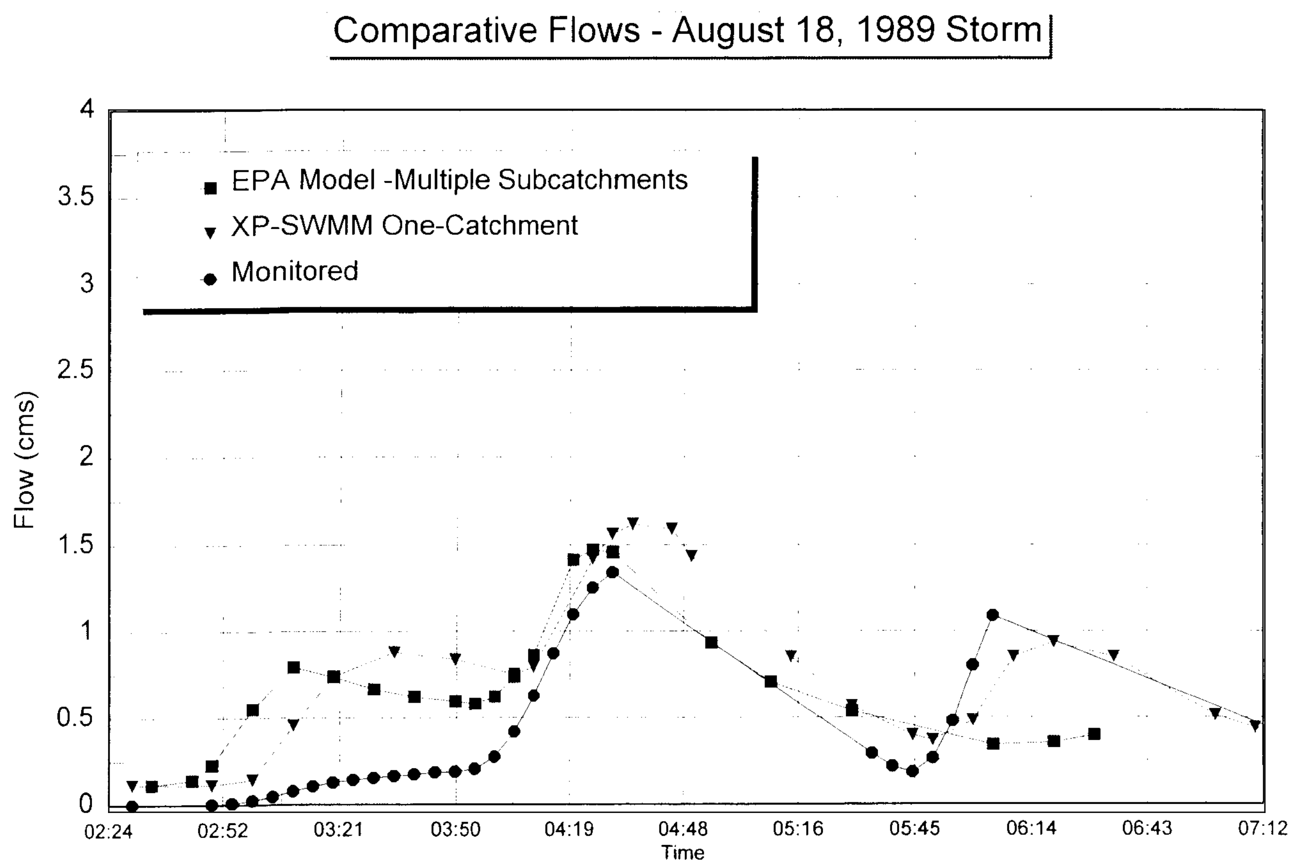
The predicted and monitored data plotted were for specific rainfall events. Figure 3-5 illustrates that peak flows, shape, and volumes can be accurately represented by a single subcatchment for each district. Working Session #4 (held on January 25/26, 1995) was used to review the results obtained from single subcatchment analyses. It was agreed that a single subcatchment could adequately describe the peak, shape and volume of runoff hydrographs for planning level analysis of control alternatives. The equivalent single subcatchment area approach was utilized for all districts in the subsequent XP-SWMM runoff modelling exercises.

3.5.2 Percent Impervious

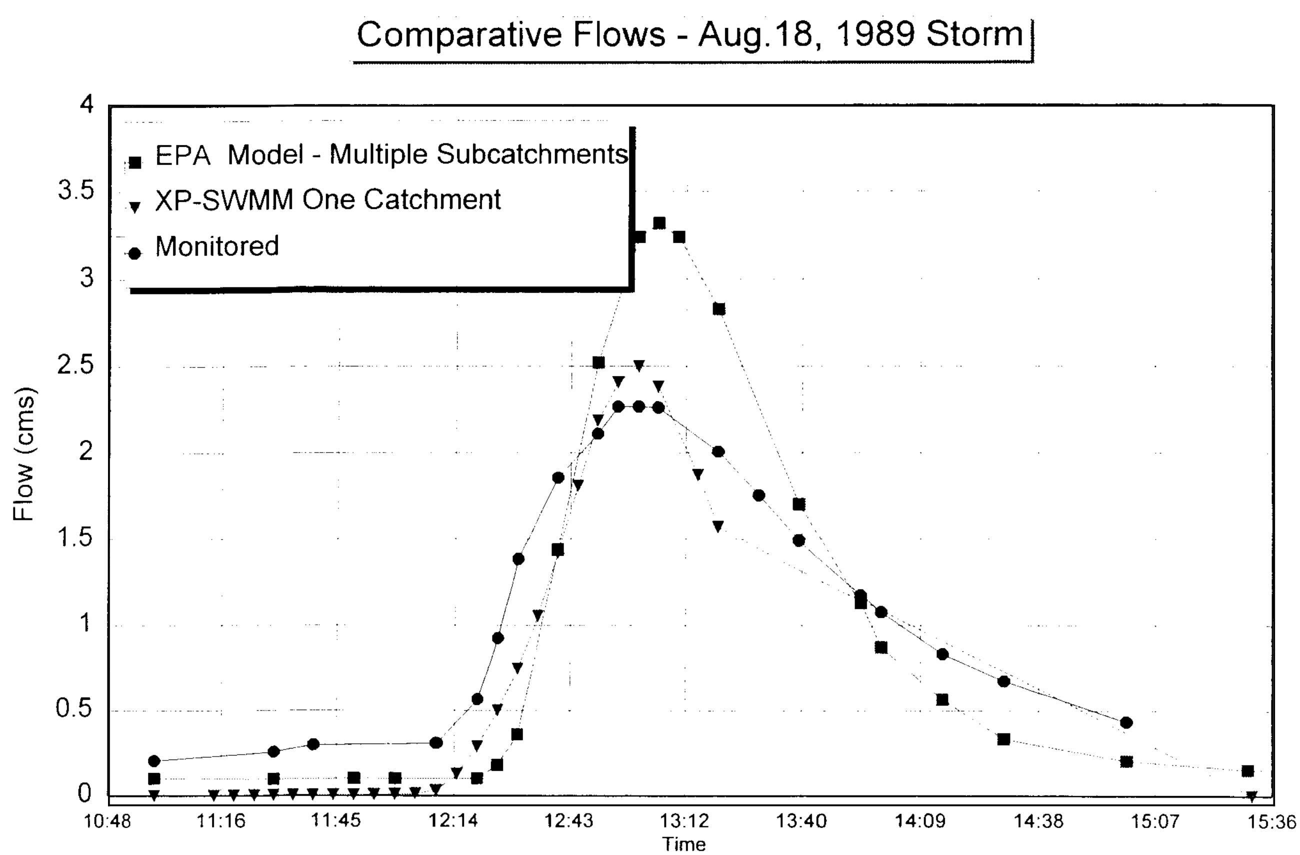
Percent impervious represents the portion of the catchment area which is not subject to infiltration. A portion of the impervious area is usually identified as having immediate runoff and contains no potential for depression storage.

Percent impervious values for CS districts were, where possible, derived from the 1986 Basement Flooding Relief Study model parameters (City of Winnipeg, Waterworks, Waste and Disposal Department, Basement Flooding Relief Study, 1986) and supplemented by more current and calibrated values from recent reports. In districts where district-specific consultant modelling reports were recently available, the new data was used in place of 1986 BFR data. The City of Winnipeg 1986 BFR Study was based upon Ferry Road characteristics which were extrapolated to other combined sewer districts. Detailed subcatchment data from reports or computer input files were aggregated into one representative overall value for each parameter. A list of CS districts and their corresponding percent impervious values is provided in Table 3-5 for combined sewer districts and Table 3-6 for land drainage districts.

Percent impervious values for land drainage districts were not available. Based on direction provided at Working Session #4, a percent impervious value between 25-30 percent for LDS was used. A sensitivity analysis was performed to assess the significance of the 25-30 percent range on predicted flows. A 25 percent value was found to produce similar results



Comparative Flows - August 18, 1989 Storm
EPA Model -Multiple Subcatchments
XP-SWMM One-Catchment
Monitored
Flow (cms)
4
3.5
3
2.5
2
1.5
1
0.5
0
02:24
02:52
03:21
03:50
04:19
04:48
05:16
05:45
06:14
06:43
07:12
Time



Comparative Flows - Aug.18, 1989 Storm
EPA Model - Multiple Subcatchments
XP-SWMM One Catchment
Monitored
Flow (cms)
4
3.5
3
2.5
2
1.5
1
0.5
0
10:48
11:16
11:45
12:14
12:43
13:12
13:40
14:09
14:38
15:07
15:36
Time

Figure 3-5

TABLE 3-5

COMBINED SEWER DISTRICTS: SURFACE CHARACTERISTICS

DISTRICT #	DISTRICT NAME	AREA (ha)	% IMP	WIDTH (m)	SLOPE	IMPERVIOUS STORAGE (mm)	PERVIOUS STORAGE (mm)	IMPERVIOUS "n"	PERVIOUS "n"	% ZERO DETENTION	AVG. CAPILLARY SUCTION (mm)	INITIAL MOISTURE DEFICIT	SAT. HYDRAULIC CONDUCTIVITY (mm/hr)
1.	Alexander	146	42	3449	0.007	1.78	4.67	0.015	0.25	50	177	.3	.004
2.	Armstrong	148	22	832	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
3.	Ash	823	33	3037	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
4.	Assiniboine	75	79	11666	0.004	1.78	4.67	0.015	0.25	50	177	.3	0.004
5.	Assiniboine Park	142	20	2000	0.004	1.78	4.67	0.015	0.25	50	177	.3	0.004
6.	Aubrey	390	35	620	0.004	1.78	4.67	0.015	0.25	50	177	.3	0.004
7.	Baltimore	211	21	961	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
8.	Bannatyne	206	30	1504	0.004	1.78	4.67	0.015	0.25	50	177	.3	0.004
9.	Boyle	25	33	4421	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
10.	Calrossie	10	25	2766	0.004	1.78	4.67	0.015	0.25	50	177	.3	.004
11.	Clifton	415	44	2119	0.004	1.67	4.67	0.015	0.25	50	177	.3	13.2
12.	Cockburn	233	26	1087	0.004	1.78	4.67	0.015	0.25	50	177	.3	0.004
13.	Colony	227	28	2002	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
14.	Cornish	127	23	181	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
15.	Despins	86	29	2737	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
16.	Doncaster	133	23	103	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
17.	Douglas Park	25	30	400	0.004	1.78	4.67	0.015	0.25	50	177	.3	0.004
18.	Dumoulin	64	22	1696	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
19.	Ferry Road	226	29	1680	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
20.	Hart	142	35	2966	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
21.	Hawthorne	219	27	1502	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
22.	Jefferson East	410	23	214	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004

DISTRICT #	DISTRICT NAME	AREA (ha)	% IMP	WIDTH (m)	SLOPE	IMPERVIOUS STORAGE (mm)	PERVIOUS STORAGE (mm)	IMPERVIOUS "n"	PERVIOUS "n"	% ZERO DETENTION	AVG. CAPILLARY SUCTION (mm)	INITIAL MOISTURE DEFICIT	SAT. HYDRAULIC CONDUCTIVITY (mm/hr)
23.	Jefferson West	567	23	1120	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
24.	Jessie	338	34	2609	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
25.	LaVerendrye	72	22	700	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
26.	Linden	149	23	1733	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
27.	Mager	260	23	935	0.0007	1.78	4.67	0.015	0.25	50	229	.24	0.004
28.	Marion	231	31	3301	0.004	3.73	4.0	0.014	0.03	60	4	.3	1
29.	Metcalfe	34	22	1952	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
30.	Mission	421	32	689	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
31.	Mooregate	157	22	400	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
32.	Munroe	375	23	8000	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
33.	Newton	56	23	2039	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
34.	Polson	238	36	1545	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
35.	River	108	27	2105	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
36.	Riverbend	189	34	1665	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
37.	Roland	178	42	4360	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
38.	Selkirk	259	25	788	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
39.	St. Johns	335	38	2781	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
40.	Strathmillan	69	14	160	0.007	1.78	4.67	0.015	0.25	50	229	.24	0.004
41.	Syndicate	79	23	2045	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
42.	Tuxedo	50	20	1631	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
43.	Tylehurst	185	41	2300	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
44.	Woodhaven	42	20	1527	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004

TABLE 3-6

LAND DRAINAGE DISTRICTS: SURFACE CHARACTERISTICS

DISTRICT #	DISTRICT NAME	AREA (ha)	% IMP	WIDTH (m)	SLOPE	IMPERVIOUS STORAGE (mm)	PERVIOUS STORAGE (mm)	IMPERVIOUS "n"	PERVIOUS "n"	% ZERO DETENTION	AVG. CAPILLARY SUCTION (mm)	INITIAL MOISTURE DEFICIT	SAT. HYDRAULIC CONDUCTIVITY (mm/hr)
45.	Doncaster Sep	167	25	3286	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
46.	Omands Creek (sum)	1239	25	1055	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
47.	Riverbend Sep	216	25	100	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
48.	Tuxedo Sep	395	25	844	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
49.	Charleswood C	63	25	2878	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
50.	Strathmillan Sep	89	25	775	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
51.	Sturgeon Creek (sum)	1046	25	3380	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
52.	Charleswood D	77	25	2778	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
53.	Parkdale 1	100	25	2831	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
54.	Charleswood	500	25	2242	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
55.	Parkdale 2	200	25	1744	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
56.	Charleswood G	223	25	2740	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
57.	Parkdale 3	200	25	1843	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
58.	Charleswood H1	42	25	3273	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
59.	Charleswood H2	125	25	1980	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
60.	Charleswood, RivWest 1	29	25	2733	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
61.	Charlewsood, RivWest 2	24	25	3131	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
62.	Parkdale 4	100	25	2765	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
63.	Kildare	1744	25	100	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
64.	Bunn's Creek-sum	870	25	4013	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
65.	West Kildonan J1	90	25	3108	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
66.	West Kildonan J2	40	25	1438	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
67.	Douglas	260	25	1684	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004

DISTRICT #	DISTRICT NAME	AREA (ha)	% IMP	WIDTH (m)	SLOPE	IMPERVIOUS STORAGE (mm)	PERVIOUS STORAGE (mm)	IMPERVIOUS "n"	PERVIOUS "n"	% ZERO DETENTION	AVG. CAPILLARY SUCTION (mm)	INITIAL MOISTURE DEFICIT	SAT. HYDRAULIC CONDUCTIVITY (mm/hr)
68.	West Kildonan J3	120	25	3211	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
69.	Hawthorne Sep	242	25	3495	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
70.	Newton Sep	1275	25	100	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
71.	Linden Sep	888	25	1314	0.0007	1.78	4.67	0.015	0.25	50	177	.24	0.004
72.	Seine Riv - sum	2154	25	4128	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
73.	Mager Sep 1	70	25	3272	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
74.	Mager Sep 2	40	25	3335	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
75.	Calrossie 1	120	25	100	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
76.	Calrossie 2	80	25	2685	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
77.	North St. Vital 1	73	25	2125	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
78.	Pulberry 1	36	25	3126	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
79.	Fort Garry 1	60	25	2572	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
80.	Fort Garry 2	60	25	2538	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
81.	Pulberry 2	90	25	2642	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
82.	North St. Vital 2	65	25	2717	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
83.	Fort Garry 3	120	25	1080	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
84.	Fort Garry 4	160	25	100	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
85.	North St. Vital 3	40	25	2015	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
86.	North St. Vital 4	73	25	2291	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
87.	Fort Garry 5	40	25	3335	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
88.	Fort Garry 6	100	25	2931	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
89.	Fort Garry 7	50	25	3225	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
90.	North St. Vital 5	114	25	1244	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
91.	South St. Vital	375	25	1208	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
92.	Fort Garry 8	70	25	2595	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004

Table 3-6 (cont'd)

DISTRICT #	DISTRICT NAME	AREA (ha)	% IMP	WIDTH (m)	SLOPE	IMPERVIOUS STORAGE (mm)	PERVIOUS STORAGE (mm)	IMPERVIOUS "n"	PERVIOUS "n"	% ZERO DETENTION	AVG. CAPILLARY SUCTION (mm)	INITIAL MOISTURE DEFICIT	SAT. HYDRAULIC CONDUCTIVITY (mm/hr)
93.	Fort Garry 9	80	25	2585	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
94.	Fort Garry 10	80	25	2407	0.007	1.78	4.67	0.015	0.25	50		.3	0.004
95.	Fort Garry 11	100	25	1478	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
96.	Fort Garry 12	30	25	2435	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
97.	Fort Garry land drainage 1	100	25	2498	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004
98.	Fort Garry 14	60	25	2705	0.007	1.78	4.67	0.015	0.25	50	177	.3	0.004

to that done in earlier studies (MacLaren 1979) and was adopted for use in subsequent modelling of urban runoff from separate sewered areas.

3.5.3 Subcatchment Width

Subcatchment width is a model parameter used to estimate overland flow length for a catchment area. A low value for catchment width will increase the overland flow path and result in longer overland flow times.

A secondary impact of catchment width is loss to infiltration in pervious areas and evaporation in both pervious and impervious areas. Correspondingly, a low value for catchment width will increase loss to infiltration and evaporation. According to Volume 1 of the XP-SWMM reference documentation, the subcatchment width is an important calibration parameter as it is "one of the few values which can significantly alter the hydrograph shape, rather than just runoff volume". Subcatchment width is expressed in metres and, in the case of an idealized rectangular catchment, subcatchment width represents the physical width of overland flow.

Subcatchment widths were calibrated for the 10 CS districts modelled prior to the regional model development. Widths were selected initially by using mean widths based on district area and shape. The value for subcatchment width then varied during the calibration process to achieve a reasonable match with monitored overflows.

3.5.4 Pervious Area Storage

The pervious area storage parameter is the average depth of storage available (in millimetres) over the pervious surface area in the catchment. Rainfall that is not stored is subject to both runoff and infiltration to the ground. After available storage has been exhausted from rainfall, excess flows are considered to runoff into the sewer system. Previous City of Winnipeg analyses (1986 BFR) used a value of 4.67 mm for pervious storage for all district analyses. The selected 10 CS districts were modelled and calibrated with a value of 4.67 mm for pervious storage. A value of 4.67 mm for pervious storage was assumed to be representative of all CS districts.

3.5.5 Impervious Area Storage

Impervious area storage is the average depth of storage available (in millimetres) over the impervious surface area. Rainfall that is not stored on impervious surfaces will immediately runoff, as no infiltration is considered to occur on impervious surfaces. In the runoff modelling analysis for the selected 10 CS districts, a range of 1.67 to 3.73 mm was used for impervious storage. It was found that a value of 1.78 was representative of the districts used in the calibration exercise. Some of these values were obtained from previous district design studies. The 1986 BFR Study used a value of 1.78 mm for impervious storage. It was found that this value remains valid for planning level analysis for this study.

3.5.6 Zero Detention

Zero detention is a model parameter used to estimate the percentage of impervious area which is incapable of storage (detains zero volume) and results in immediate runoff. This analysis adopted a default value of 50% zero detention. Results for the 10 districts used in the calibration exercise indicated that a value of 50% zero detention could be used to achieve a satisfactory match with monitored overflows.

3.5.7 Tributary Area

Tributary area is the portion of the total surface area that will contribute runoff into the district's piping network. Tributary area is normally less than a district's total service area. Portions of a district's surface area may drain directly into a natural or man-made surface channel and not contribute to the district's sewer system.

Net area values for combined sewer districts were derived from the 1986 BFR Study and other available sewer relief studies and reports. City of Winnipeg district area listings provided by Waterworks and Waste Department were used to fill in missing data for combined and separate sewered areas. District values for net area are listed in Table 3-5 and Table 3-6.

3.5.8 Surface Roughness

The Mannings "n" parameter is a measure of coefficient of roughness and the resistance to water flow. Mannings "n" values were derived from the 1986 BFR Study were 0.015 for impervious areas and 0.25 for pervious areas and were considered to be representative for this study. A low value of "n" is indicative of smoother surfaces, while a higher value is representative of rougher surfaces (such as grass).

3.5.9 Slope

The topography of the City of Winnipeg is extremely flat, with limited variations in slope except near rivers and streams. During the calibration of the set of 10 CS districts, district slopes were obtained from the 1986 BFR Study where available or from aggregated subcatchment areas and slopes in detailed district modelling reports. The slope in this calibration process ranged from 0.004 to 0.01. For the regional model, an intermediate slope of 0.007 was used for all districts in the analysis.

3.5.10 Infiltration Parameters

Working Session #4 hosted Dr. B. Dickenson, one of EPA SWMM's and XP-SWMM's developers, to critically assess model setup and results. It was strongly recommended that Green-Ampts infiltration be used instead of the Horton infiltration method for long-term continuous simulations. Dr. Dickenson recommended using Green-Ampts infiltration for the following reasons:

- Problems with infiltration "recovery" can occur with the Horton equation after rain events. Consequently, Horton is best used for single event modelling.

- Green-Ampts infiltration does not have difficulty "recovering" infiltration following a rain event, therefore Green-Ampts is better for continuous modelling.

- Green-Ampts uses physically-based parameters for soil in its equation. Values for these parameters have been documented by the United States Geological Survey (USGS) for a wide-range of soil types and is available in the US EPA PRZM model documentation, or directly if the local soil composition is known.

Three parameters are required by the XP-SWMM model for Green-Ampts infiltration equation are: average capillary suction; initial moisture deficit; and saturated hydraulic conductivity. Values used in XP-SWMM for average capillary suction and initial moisture deficit were based upon a clay soil type for the city. Values for saturated hydraulic conductivity based on the range for unweathered marine clay, as shown in Figure 3-6. Saturated Hydraulic Conductivity is essentially the ultimate rate of moisture movement through the soil in mm/hr.

3.6 CALIBRATION OF SELECTED DISTRICTS

Ten CS districts were selected and modelled for the purpose of determining calibrated model parameters for use in the regional model. The 10 districts represented a reasonable cross-section of CS districts in terms of district size, shape and land use characteristics. The locations, shapes and relative sizes of the districts are shown in Figure 3-7. Each selected district was required to have two or more monitored data sets available for both rainfall and outflow. This would allow the calibration of parameters to be set such that a range of monitored flows could be satisfactorily predicted. The ability to satisfactorily predict a range of monitored flows is fundamental to the credibility of model calibration. The 10 districts used in modelled calibration were:

- Alexander
- Baltimore
- Boyle
- Colony

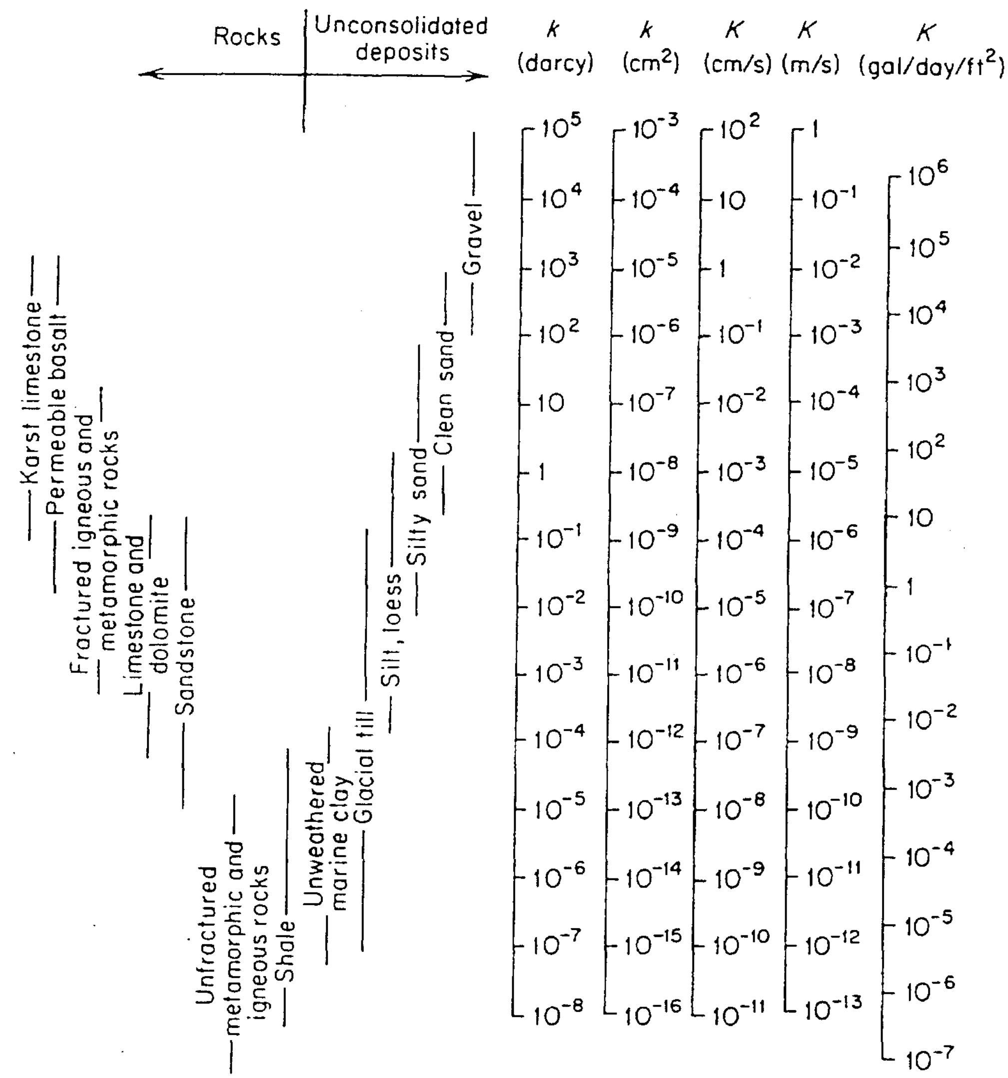
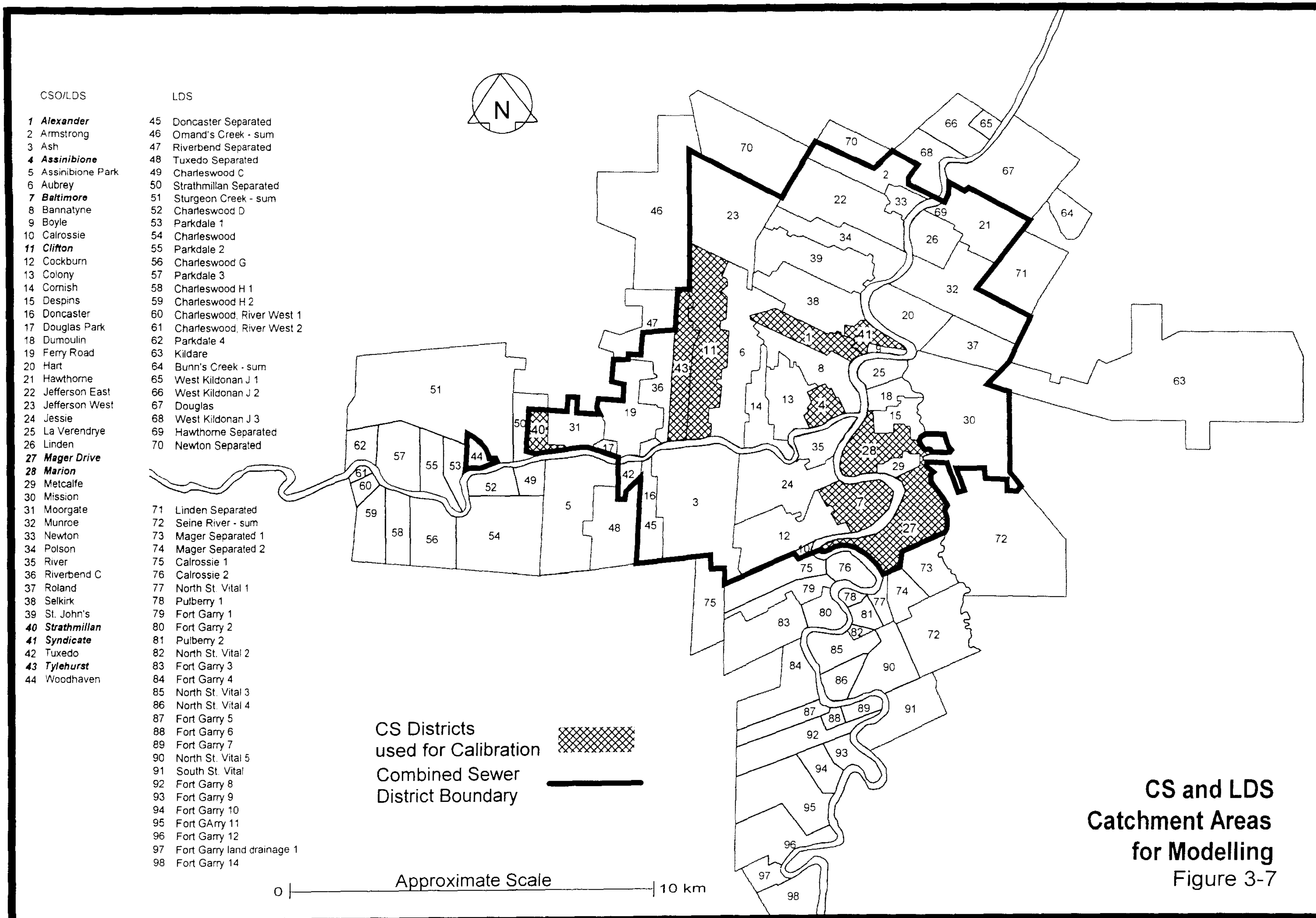


Figure 3-6

Range of Values of Hydraulic Conductivity and Permeability

Source: A.R. Freeze, Groundwater. 1979.



CS and LDS Catchment Areas for Modelling
Figure 3-7

sewrmap2

- Mager
- Marion
- Strathmillan
- Syndicate
- Tylehurst
- Clifton

The calibration process was based on the modelling of single event storms using rainfall data in 5-minute timesteps. For each of the 10 selected districts, an analysis was done to assess the prediction of overflow and corresponding monitored outfall data for a specific rainfall event. Once quality sets of rainfall event data and monitored outflow data were assembled for each district to be calibrated, the XP-SWMM model runs were completed and the calibration assessment process began.

3.6.1 Assessment of Calibration Predictions

After the first iteration of calibration was completed, an assessment of model predictions was performed. The large volumes of model output generated by XP-SWMM for 5-minute timesteps and printouts created a need for a spreadsheet macro routine to be developed for processing output data. The macro imported, parsed and performed various calculations on the output data to prepare it for comparison with monitored outflow data. Interception rates and dry weather flow were accounted for prior to calculating final outflow values for a comparison with monitored outflow data. The processed outflow from model predictions was plotted along with monitored outflow and monitored rainfall data to assess the goodness of fit. A summary table was also generated by the macro program to compare monitored and predicted outflow volumes and peak values.

Calibration parameters were adjusted, the model runs repeated, and output was re-processed utilizing the macro routines until a satisfactory match was achieved relative to monitored data. Model results were assessed for goodness of fit in terms of peak overflow rates, shape and overflow volumes.

3.6.2 XP-SWMM Calibration Parameters

Values for district parameters used in XP-SWMM were initially taken from the 1986 BFR Study as a starting point for the calibration exercise. Where available, this data was supplemented by newer, detailed SWMM-modelling done by other consultants for the City as part of sewer relief studies.

Several model parameters were known or assumed and were held constant during the calibration effort. These include:

- tributary area
- Mannings "n"
- percent zero detention
- pervious area storage
- average capillary suction
- initial moisture deficit

Model parameters which were adjusted are listed in their order of calibration adjustment:

- width of subcatchment;
- saturated hydraulic conductivity (varied within range for clay soils);
- impervious area storage;
- slope; and
- percent impervious.

The order of adjustment is important to note. The first parameter adjusted in calibration exercise was subcatchment width. This parameter is typically used to adjust hydrograph shape and volume because of its significant influence on runoff. Saturated hydraulic conductivity was the next calibration parameter that was adjusted to account for losses due to infiltration and varied within the range of 10^{-7} to 10^{-10} cm/s which is typical for clay soils as previously shown in Figure 3-6. Impervious area storage was the next parameter used in calibration and was adjusted if required to account for losses or fine tune the hydrograph shape. Slope and percent impervious values were adjusted modestly as a last step where necessary in the calibration process if all other attempts failed to achieve a satisfactory match with monitored date. Table 3-7 lists each district used in the calibration exercise and its corresponding calibrated model parameters.

3.7 CALIBRATION RESULTS

The intent of the calibration for selected districts and outflow hydrographs was to accurately simulate both small and large overflow events for the same model parameters. The calibration exercise often involved a critical review of rainfall data used in the runoff modelling. As discussed earlier, areal distribution is a significant factor in rainfall patterns and its influence on district runoff. It was necessary in most cases to use the nearest raingauge records for a specific rainfall event for estimation of runoff. As such, it can clearly be seen that model predictions are very sensitive to the rainfall records used in the model input. In some cases it was necessary to average monitored rainfall near other fixed raingauge locations to obtain a rainfall pattern that would coincide with monitored outflows.

A second important point associated with the temporal aspects of rainfall and monitored outflow is the synchronization of monitoring equipment. That is, the shape, peak, and volume of the predicted overflow would agree well with the monitored except for a discrete shift in time. In this case, model prediction was considered to be satisfactory and errors associated with equipment time synchronization. In some cases it was not possible to achieve a satisfactory agreement between monitored flows for small and large rainfalls. In this case it was deemed important to achieve a satisfactory match with small rainfall events and sacrifice some accuracy on larger rainfalls. CSO controls will have a greater benefit on smaller rainfall events because larger rainfall events would overwhelm the control device and result in degraded discharge quality. It would be impractical and prohibitively expensive to size CSO control facilities to capture/treat overflows from large rainfall events. Accordingly, accurate simulation of smaller rainfall events is more critical for CSO control than large rainfall events.

Results of model calibration were judged on the basis of predicted outputs to achieve a satisfactory agreement with monitored outflows in terms of peak, volume, and shape.

TABLE 3-7
COMPARISON OF TCI AND 1986 BFR STUDY MODEL PARAMETERS

DISTRICT	TRIBUTARY TCI VALUE AREA (Ha)	1986 BFR Net Area (H)	% IMPERVIOUS FROM RECENT REPORTS	1986 BFR % IMPERVIOUS	CALIBRATED WIDTH (m)	TCI VALUE SLOPE	1986 BFR SLOPE
Alexander	146	146	41.66	21.66	3000	0.01	0.004
Baltimore	211.44	211.44	20.75	20.75	700	0.01	0.004
Boyle	24.8	24.8	32.97	24.8	4000	0.01	0.004
Colony	226.9	226.9	28.44	28.44	1500	0.01	0.004
Mager	260	260	23.4	23.38	300	0.01	0.004
Marion	216.8	312.2	32.9	24.26	5000	0.01	0.004
Strathmillan	69.1	69.1	14	22.92	500	0.004	0.004
Syndicate	78.65	78.65	22.53	22.53	2000	0.004	0.004
Tylehurst	184.8	184.8	31.35	31.35	2300	0.004	0.004
Clifton	415	415	44.4	N/A	2000	0.004	0.004
Value used in calibration						0.007	

DISTRICT	TCI VALUE IMPERV "n"	1986 BFR IMPER "n"	TCI VALUE PERV "n"	1986 BFR PERV "n"	TCI VALUE IMP. STOR(m)	1986 BFR IMP.STOR(m)	TCI VALUE PERV STOR (mm)	1986 BFR PERV STOR (mm)	TCI VALUE ZERO DETN %
Alexander	0.015	0.015	0.25	0.25	0.5	1.78	4.67	4.67	50
Baltimore	0.015	0.015	0.25	0.25	1.78	1.78	4.67	4.67	50
Boyle	0.015	0.015	0.25	0.25	0.5	1.78	4.67	4.67	50
Colony	0.015	0.015	0.25	0.25	1.78	1.78	4.67	4.67	50
Mager	0.015	0.015	0.25	0.25	1.78	1.78	4.67	4.67	50
Marion	0.015	0.015	0.25	025	1	1.78	4.67	4.67	50
Strathmillan	0.015	0.015	0.25	0.25	1.78	1.78	4.67	4.67	50
Syndicate	0.015	0.015	0.25	0.25	1.78	1.78	4.67	4.67	50
Tylehurst	0.015	0.015	0.25	0.25	1.78	1.78	4.67	4.67	50
Clifton	0.015	0.015	0.25	0.25	1.57	1.78	4.67	4.67	50
Value used in calibration	0.015		0.25		1.78		4.67		50

Monitored and modelled overflow data were plotted along with rainfall for ease of comparison to judge goodness of fit. The vast majority of model predictions compared favourably with monitored data. The 10 CS districts used in the calibration represented a reasonable blend of district size, district shape, and district land use (residential, commercial, industrial). Each of the calibrated districts were modelled for a range of rainfall event intensities. The results from this effort indicated satisfactory calibration could be achieved using the district as a single catchment for planning purposes.

The results of four calibrated districts are presented and discussed in the following sections. A sample output file from the set of 10 calibrated districts model results is provided in Appendix 1-B.

Strathmillan CS District

The Strathmillan combined sewer (CS) district is a small, primarily residential CS district with a low percentage (about 14%) of impervious area. It's tributary area is approximately 69 ha in size. Model runs for this district were done for four rain events in June of 1991.

The model run for June 1, 1991 as shown in Figure 3-8 displays a good match between modelled and monitored overflow peak, volume, and shape. However the modelled results lag behind monitored flows by approximately one hour. The explanation for this situation may be a result of a combination of reasons. The three likely explanations are:

- rainfall data used for the modelling was obtained from the Tuxedo rain gauge, which is approximately 3 km east from Strathmillan district, because no gauged rainfall within the district was available;

- the monitoring equipment may not have been time synchronized; and

- the direction the rainfall tracked across the city (west to east).

From the rainfall plot, it appears that this rainfall is a high intensity, possibly localized event (each rainfall bar represents a 5-minute timestep). It appears that the delay in rain arriving at the monitored rainfall location is responsible for the lag in the modelled peak's occurrence.

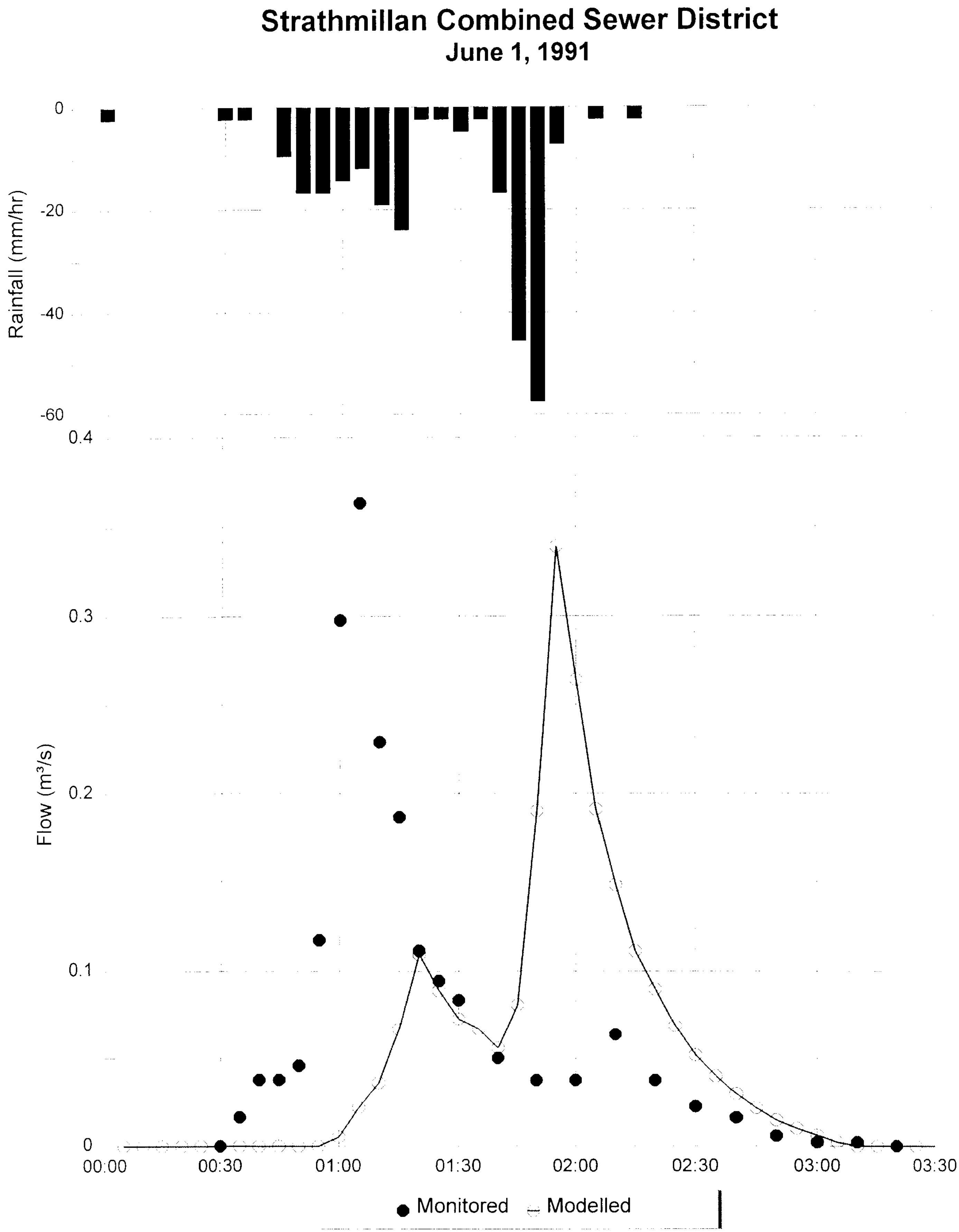

Strathmillan Combined Sewer District
June 1, 1991
Rainfall (mm/hr)
0
-20
-40
-60
Flow (m³/s)
0.4
0.3
0.2
0.1
0
00:00
00:30
01:00
01:30
02:00
02:30
03:00
03:30
Monitored
Modelled

Figure 3-8

The June 7,1991 model run as shown on Figure 3-9 is for a slightly more moderate rainfall event and displays exceptional agreement between modelled and monitored peak overflow, shape, and volumes. A slight lag between modelled and monitored outflow is evident and could be attributed to minor differences in equipment time synchronization or direction the rainfall tracked across the City outflows.

The June 13, 1991 Strathmillan model run as shown on Figure 3-10 is a modest rainfall and appears to be more evenly distributed. Peak outflow, volumes, and shape of the predicted output agree very favourably with monitored data.

The fourth model run for Strathmillan for June 25, 1991 as shown on Figure 3-11, compares well with the monitored data. Comparisons between modelled and monitored overflow hydrographs indicated a favourable degree of calibration for the range of monitored flows available. It was considered that Strathmillan was adequately calibrated to predict overflows to the Assiniboine River for continuous simulations for the duration of the recreation season.

Tylehurst CS District

Tylehurst is a narrow, long combined sewer (CS) district with primarily a industrial and commercial sector composition. It has a tributary area of about 184 ha of which approximately 41% is impervious. This district is primarily a commercial sector with Polo Park shopping mall, Winnipeg Stadium, Winnipeg Arena and several large apartment complexes located in the district. An important feature of the Tylehurst combined sewer district is Omands Creek which runs directly through the centre of the district and drains to the Assiniboine River. This natural surface channel has been extensively utilized for land drainage and can convey a significant amount of surface runoff. Many of the apartment blocks utilize groundwater for air conditioning and discharge into the sewer or Omands Creek. A separate sewer district, Brooklands, which is to the north of Tylehurst is approximately 320 ha in size and is primarily residential in sectorial composition. Brooklands discharges its wastewater in Tylehurst's combined sewer system. An analysis was done on winter 1992/93 water consumption to estimate dry weather flow from both districts. It was found that the water consumption was about equal for both districts at about 0.015 m^3/s (0.5 gal.s). A cursory analysis was performed to correlate the water to wastewater generation on a service-area

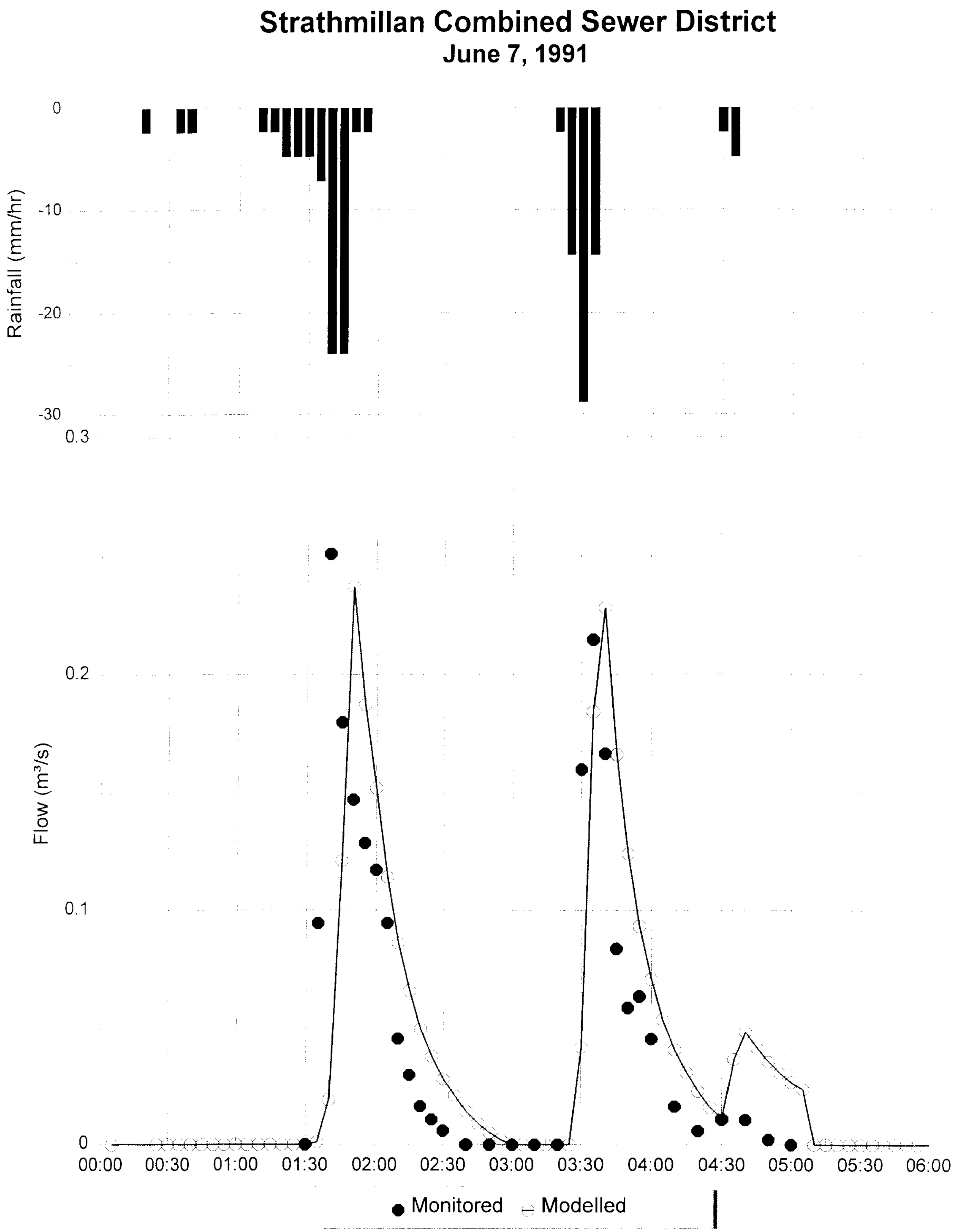

Strathmillan Combined Sewer District
June 7, 1991
Rainfall (mm/hr)
0
-10
-20
-30
Flow (m³/s)
0.3
0.2
0.1
0
00:00
00:30
01:00
01:30
02:00
02:30
03:00
03:30
04:00
04:30
05:00
05:30
06:00
Monitored
Modelled

Figure 3-9

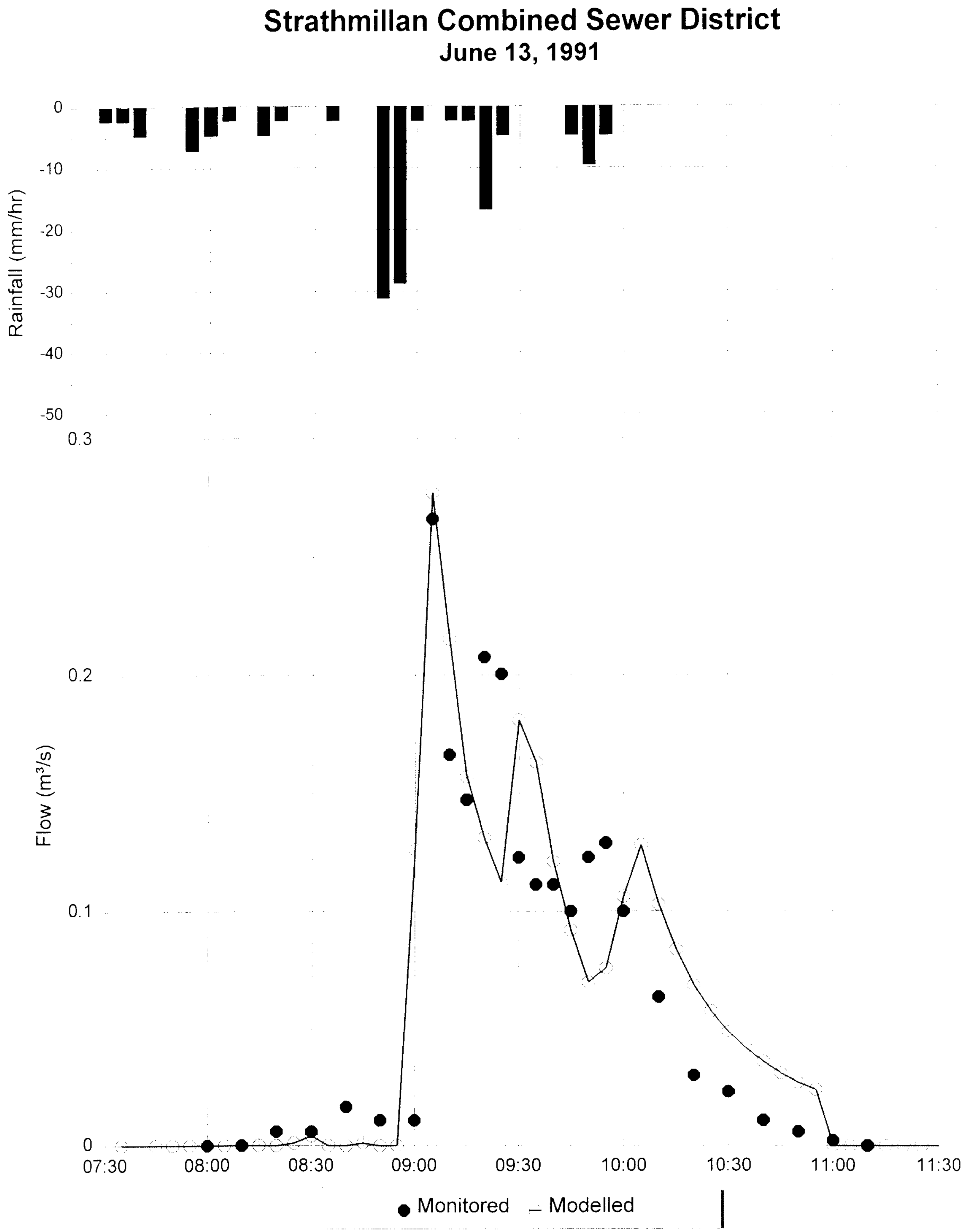

Strathmillan Combined Sewer District
June 13, 1991
Rainfall (mm/hr)
0
-10
-20
-30
-40
-50
Flow (m³/s)
0.3
0.2
0.1
0
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
Monitored
Modelled

Figure 3-10

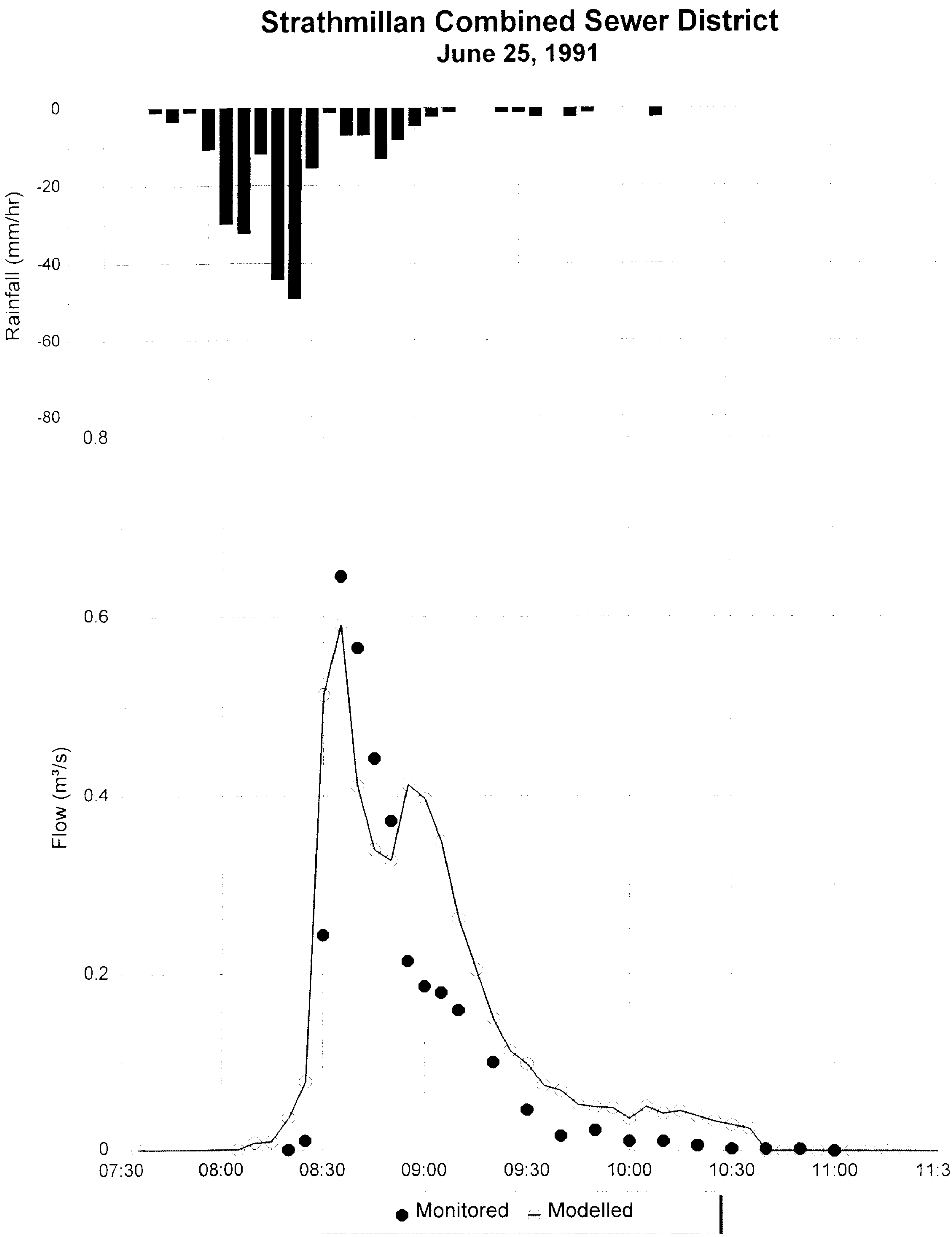

Strathmillan Combined Sewer District
June 25, 1991
Rainfall (mm/hr)
0
-20
-40
-60
-80
Flow (m³/s)
0.8
0.6
0.4
0.2
0
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
Monitored
Modelled

Figure 3-11

basis to the NEWPCC. It was found that, on average, dry weather flows arriving at the NEWPCC were 35% higher than water consumption. It was recognized that this value is variable and not necessarily specific to any district. However, for estimating purposes it provides a reasonable factor by which to scale up water consumption to predict wastewater flows. On this basis, distribution for both districts would be closer to 0.02 m^3/s. A recent monitoring program conducted by the City (August 1994) found that an ADWF ranged between 0.014 to 0.029 m^3/s for Brooklands and between 0.03 to 0.07 (average of 0.05) for Tylehurst indicating wastewater discharge and agreed favourably with estimated flows. As part of the monitoring conducted by the City, peak summer dry weather flows were also monitored and found to range between 0.050 and 0.11 m^3/s and represented the accumulated dry weather flows from both Brooklands and Tylehurst. The interception pumping capacity of Tylehurst is about 0.17 m^3/s. Based on the current configuration of the interception structure (i.e., offtake pipe and weir heights) the maximum interception rate to the pumps prior to overtopping the weir is about 0.27 m^3/s (UMA 1993). This indicates that conveyance to the interceptor is limited by pumping capacity, or about 0.17 m^3/s.

A review of the FAST alarm data indicated that Tylehurst may be experiencing a significant frequency of dry weather overflows. Pins (alarm level indicators) are set at specific elevations to indicate the surface level in the sewer system. These levels are recorded at a central computer located at McPhillips station and used to determine if operations crews need to be dispatched to a certain location to take appropriate remedial actions. Overflow alarms are set to indicate that a potential problem has arisen and allow sufficient lead time for operations crews to address the situation before an overflow occurs or causes basement flooding. In discussions with City representatives it was learned that Tylehurst and Cockburn stations experience a number of alarms indicating overflows may be occurring. These alarms typically occur during rainfall events and hot dry weather days. It is believed that the use of groundwater for cooling water in apartment building air conditioning systems and their discharge into the combined sewer system is largely responsible for dry weather overflows. This detail is discussed in more detail in TM #4 - Receiving Streams.

Tylehurst was found to have the widest range of monitored flows and rainfall. It was deemed to have a high degree of calibration and later used to assess the significance of rainfall timestep on the number and volume of overflows.

Figure 3-12 compares monitored and modelled overflows for Tylehurst in response to a light rainfall event which occurred on July 18, 1994. The modelled outflow hydrograph responds similarly to the monitored hydrograph in response to peak rainfall, the model predicts lower outflow volumes. Additionally, while the model predicts zero outflow between the rainfall peaks at approximately 1:00 and 7:30 a.m., the monitored data indicates overflow values at the outfall. It is believed that this volume of overflow is in part due to other inputs to the sewer than rain. Rainfall for the monitored overflow for this case was based on rainfall as recorded at the Winnipeg International Airport, approximately 3 km to the west. Tylehurst is known to experience dry weather overflows as documented by the FAST alarm system at times in response to surplus loadings to sewers, possibly from groundwater used in air-conditioning as documented by the FAST alarm system. Further monitoring and study of dry weather overflows at this district is recommended. The calibration indicates that the model will respond reasonably to small rainfall events and predict overflows.

For August 3, 1994 (Figure 3-13), a modest size, low duration storm event was found to have very favourable agreement between peak overflow values, shape, and volumes for monitored and modelled data. Rainfall was again based on gauged data at the Winnipeg International Airport. Peak response after maximum rainfall is virtually identical between monitored and modelled values and displays a high degree of calibration.

For August 11/12, 1994, (Figure 3-14), a medium-sized rainfall event was found to have peaks slightly higher than monitored peaks. However, runoff volumes are closely matched with very similar areas under each hydrograph. It is believed that more surface drainage may be conveyed to Omands Creek than originally estimated. Specifically the tributary area may be smaller than estimated, especially under higher rainfalls.

On July 3, 1994 (Figure 3-15) a significant rainfall was recorded at the Winnipeg International Airport and used in the modelling of runoff for Tylehurst. The modelled hydrograph shape is similar to the monitored hydrograph, however the modelled peak is significantly higher than the monitored value. Two major considerations for this overprediction are the rainfall used and the fact that more surface water may find its way to Omands Creek than estimated.

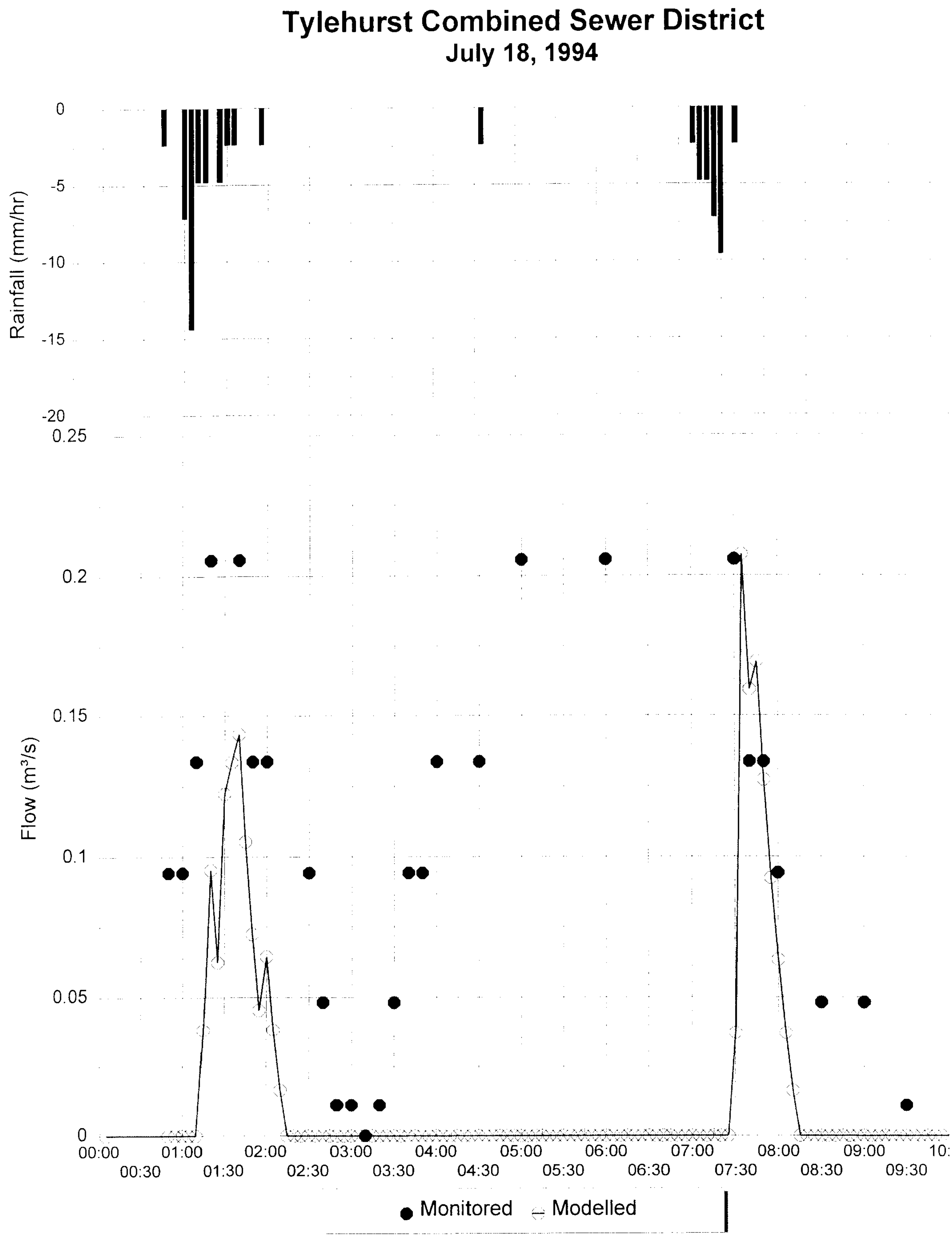
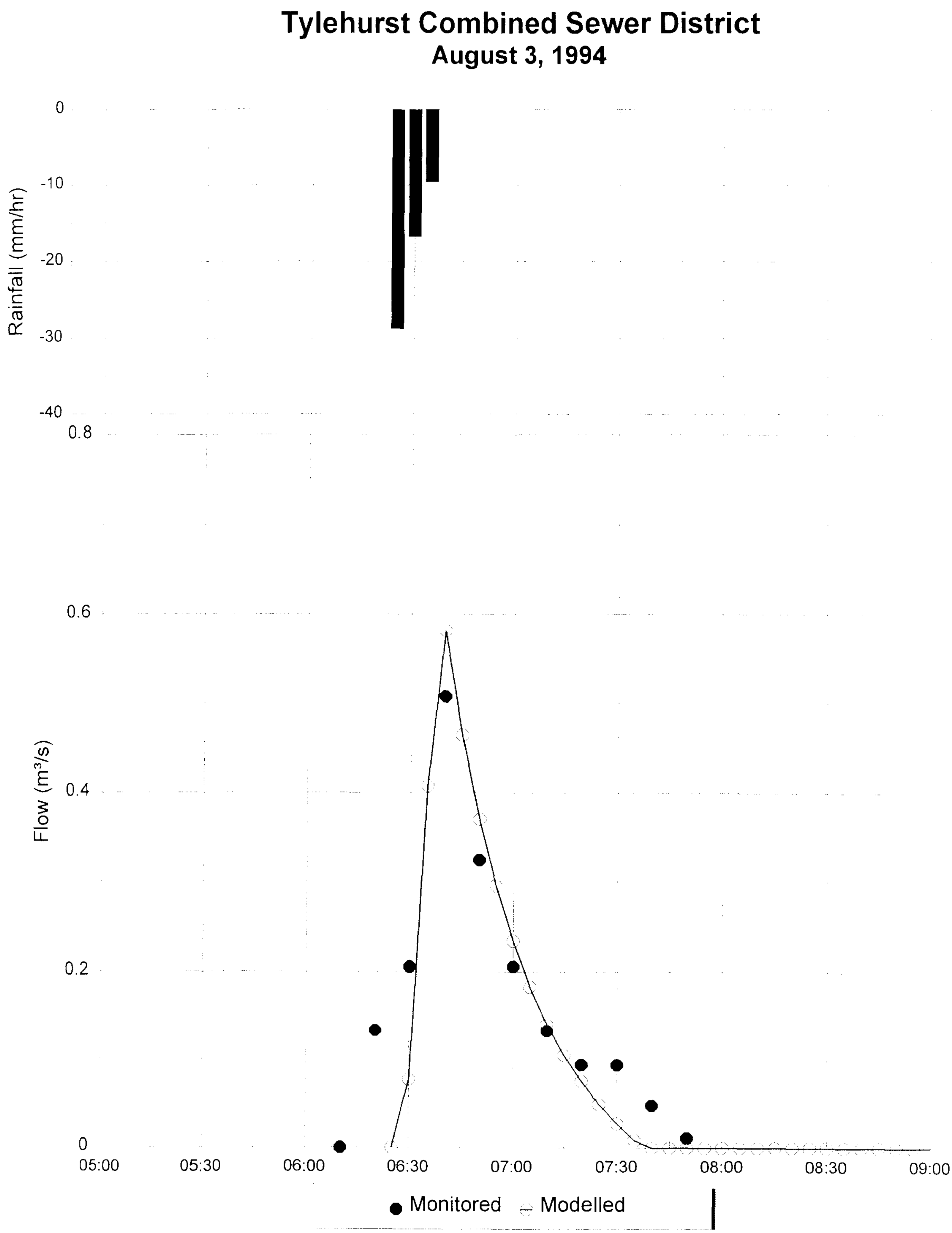

Tylehurst Combined Sewer District
July 18, 1994
Rainfall (mm/hr)
0
-5
-10
-15
-20
Flow (m³/s)
0.25
0.2
0.15
0.1
0.05
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
Monitored
Modelled

Figure 3-12



Tylehurst Combined Sewer District
August 3, 1994
Rainfall (mm/hr)
0
-10
-20
-30
-40
Flow (m³/s)
0.8
0.6
0.4
0.2
0
05:00
05:30
06:00
06:30
07:00
07:30
08:00
08:30
09:00
Monitored
Modelled

Figure 3-13

Tylehurst Combined Sewer District
August 11/12, 1994

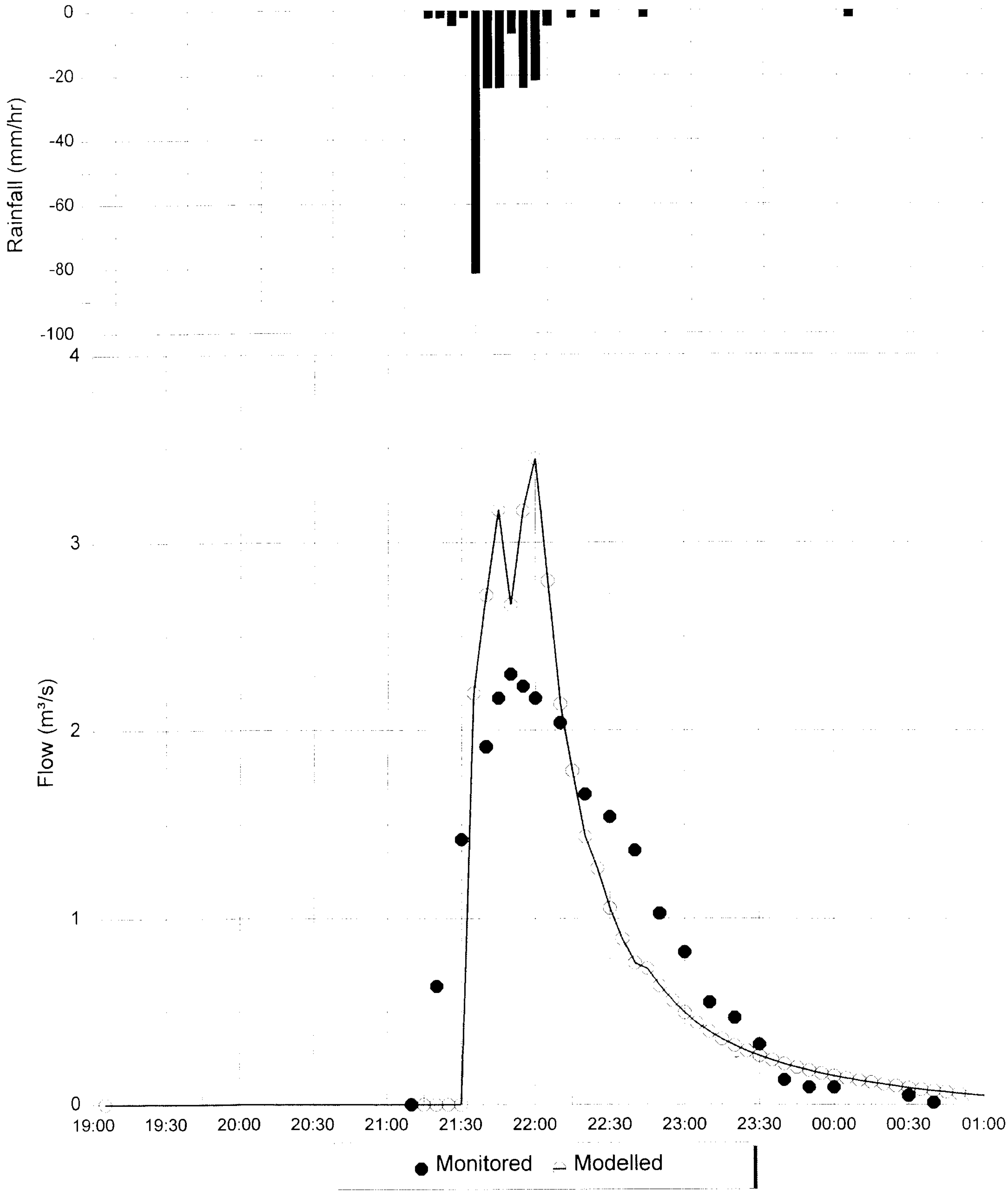


Figure 3-14

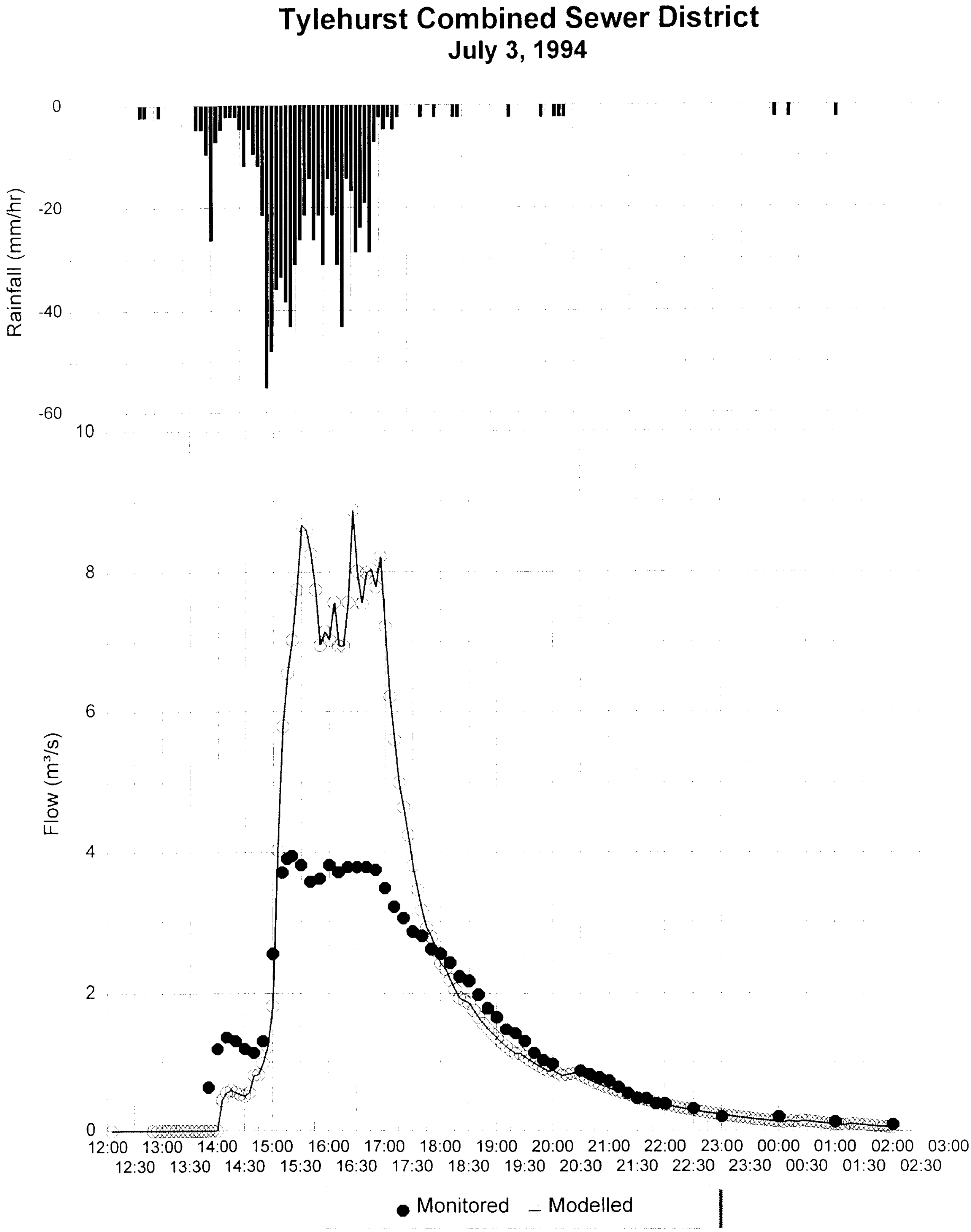

Tylehurst Combined Sewer District
July 3, 1994
Rainfall (mm/hr)
0
-20
-40
-60
Flow (m³/s)
10
8
6
4
2
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
00:30
01:30
02:30
Monitored
Modelled

Figure 3-15

Tylehurst was found to have the widest range of monitored outflows and was deemed sufficiently calibrated to assess the significance of rainfall timestep on the number and volume of overflows. As discussed earlier, it was deemed important to obtain sufficiently-accurate predictions at smaller overflows and sacrifice some accuracy at higher flows (if necessary) to evaluate the relative performances of various control technologies. It is believed that Omands Creek may receive a greater amount of surface runoff than originally estimated for higher rainfall events. This overprediction of flows from combined sewerage in this district will be balanced with less land drainage discharge for large rainfall events and result in a higher fecal coliform loading to the Assiniboine River. The capture and treatment of such large flows would require enormous facilities which would be cost and size prohibitive. Accordingly, the calibration of Tylehurst is adequate for planning level assessment of alternatives.

Boyle CS District

The Boyle CS district is a very small, 24.8 ha in area, and is located in the core of the downtown region. It is primarily an industrial area with 33% of its area being impervious.

The rainfall of July 3, 1992 as shown in Figure 3-16, as gauged at the River Station, was used in the runoff modelling and is a low intensity, long duration precipitation event. Favourable agreement between modelled and monitored outflow values was achieved for this rainfall event. It is noted that the outflow hydrographs predicted by the runoff model is responding explicitly to the monitored rainfall and somewhat overpredicts the second peak. The exact rainfall pattern is unknown but reasonably corresponds to monitored outflow for a small overflow event.

The July 8, 1992 rainfall event resulted in peak overflows similar to those predicted on July 3, 1992 but for a more intense and shorter duration as shown in Figure 3-17. Rainfall gauged at the River Station, which is approximately 2.5 km south of Boyle, was used in the runoff modelling. Modelled peak outflows matched monitored values for the first peak but underpredicted for the second peak. The model demonstrated a good, timely response to early rainfall but underpredicted in the second. Overall volumes for runoff are within reasonable agreement for planning level modelling.

Boyle Combined Sewer District
July 3, 1992

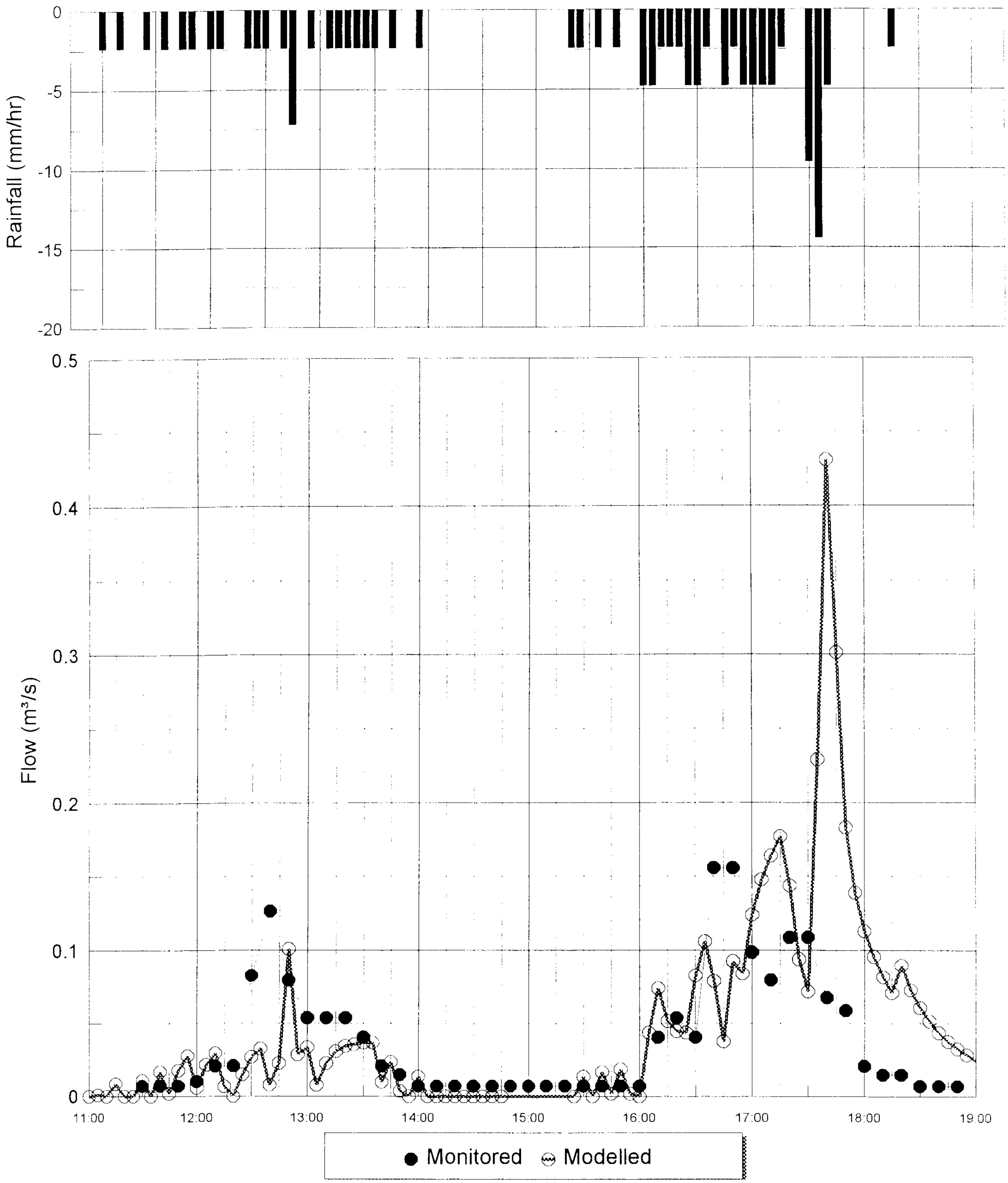


Figure 3-16

Boyle Combined Sewer District
July 8, 1992

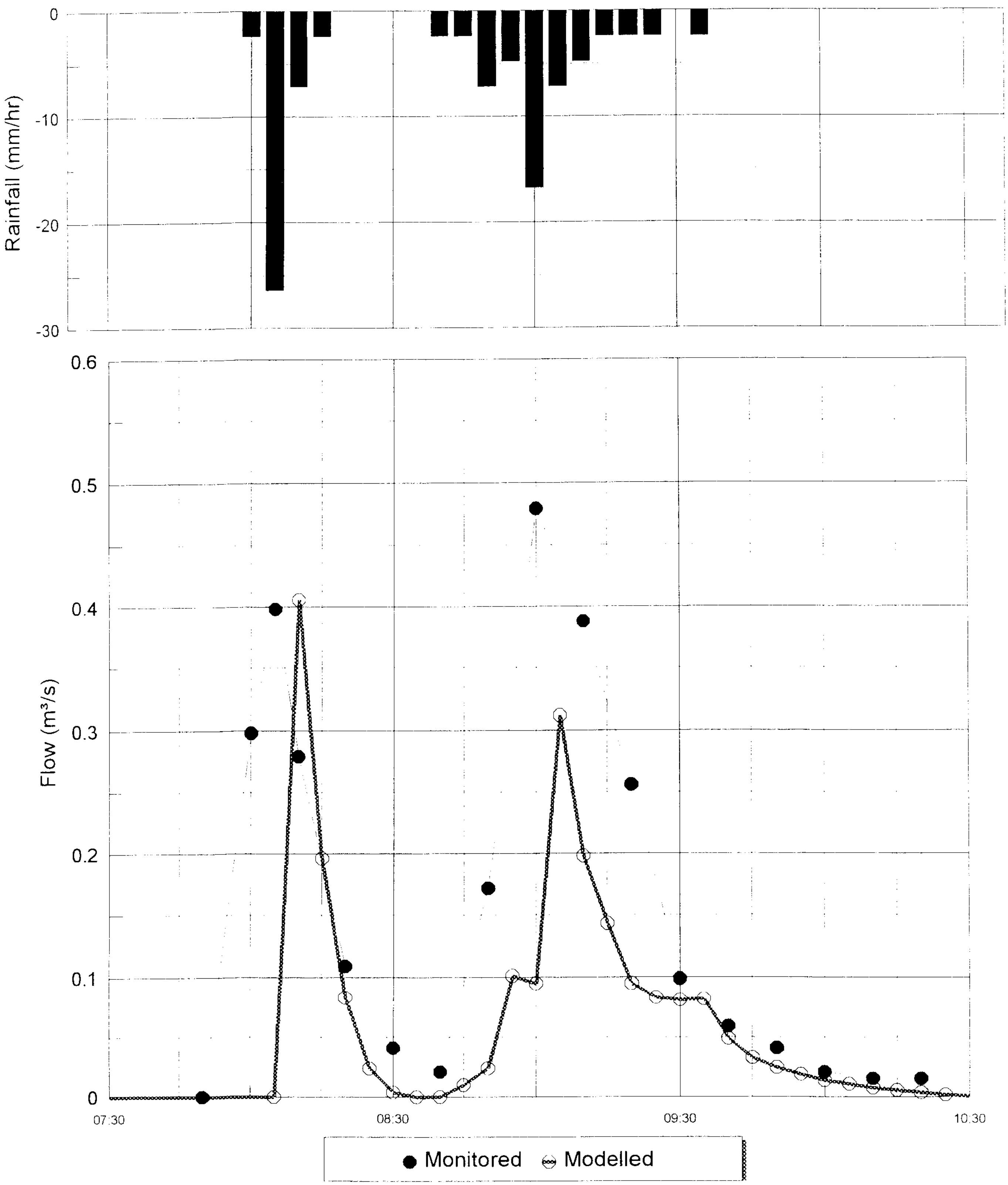


Figure 3-17

The August 22, 1992 rainfall event, as shown on Figure 3-18 was the average of rainfall as measured at the River and McPhillips rainfall telemetry stations. The McPhillips station is approximately 4 km to the west of Boyle. It was found that neither of these two stations would reasonably predict the monitored outflows but an averaging of the rainfall histories would provide a reasonable approximation. This clearly illustrates the significance of areal distribution of rainfall in single rainfall events and the sensitivity on runoff modelling predictions. With this understanding, it was found that the model overpredicted the first peak and accurately predicted the second peak. This indicated that the runoff model responded accurately to inputs and achieved a reasonable degree of calibration.

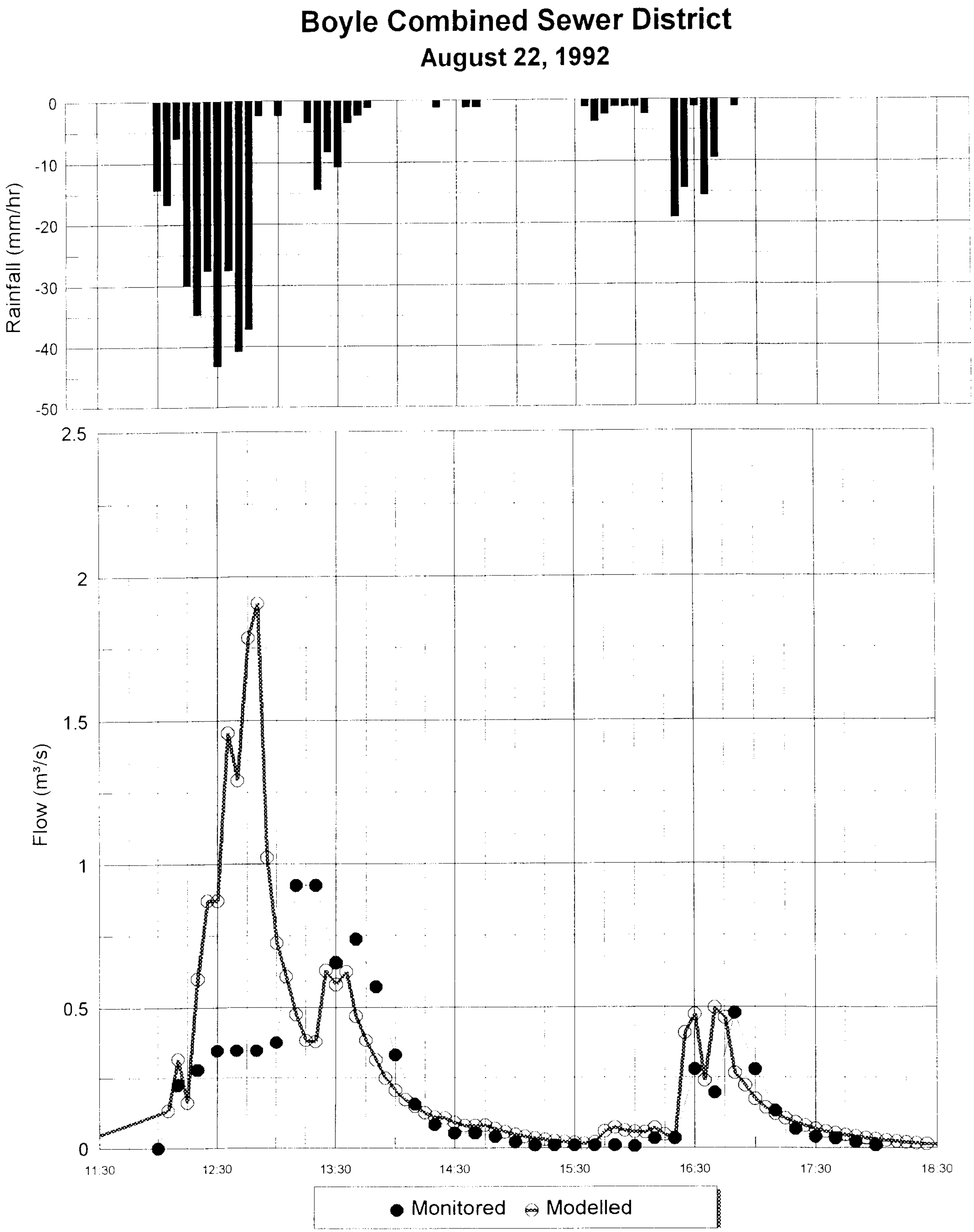
Mager CS District

The Mager CS district is a large sewer district with a service area of 781 ha and a tributary area of 260 ha. The district is primarily residential with approximately 23% of its area comprised of impervious surfaces. Mager CS district receives wastewater from Calrossie CS district, Cockburn CS district, and Baltimore CS district. Wastewater flows are pumped to Mager and are additive to the base DWF of the district itself.

For June 7, 1990 as shown in Figure 3-19, a brief, intense rainfall event was modelled with predicted flow values being larger than monitored values. Monitored rainfall was collected within the Mager district, at the telemetry station located in the northern portion of the district. It is possible that the monitored rainfall levels were not fully representative of the entire rainfall across Mager, resulting in monitored flows being somewhat less than predicted. The runoff model clearly responds accurately to the rainfall event and reasonably characterizes the shape, peak, and volume of the overflow.

For June 8, 1990 as shown in Figure 3-20, the modelled flow appears to display somewhat of a difference in response compared to that of monitored flow. Spatial variation of rainfall in the region is attributed to this difference. Peak outflow values and hydrograph areas are closely matched.

For June 12, 1989, as shown in Figure 3-21, the model prediction mimics the hydrograph shape of monitored data exceptionally well for a long-duration light-intensity rainfall. Again,



Boyle Combined Sewer District
August 22, 1992
Rainfall (mm/hr)
0
-10
-20
-30
-40
-50
Flow (m³/s)
2.5
2
1.5
1
0.5
0
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
Monitored
Modelled

Figure 3-18

Mager Combined Sewer District

June 7, 1990

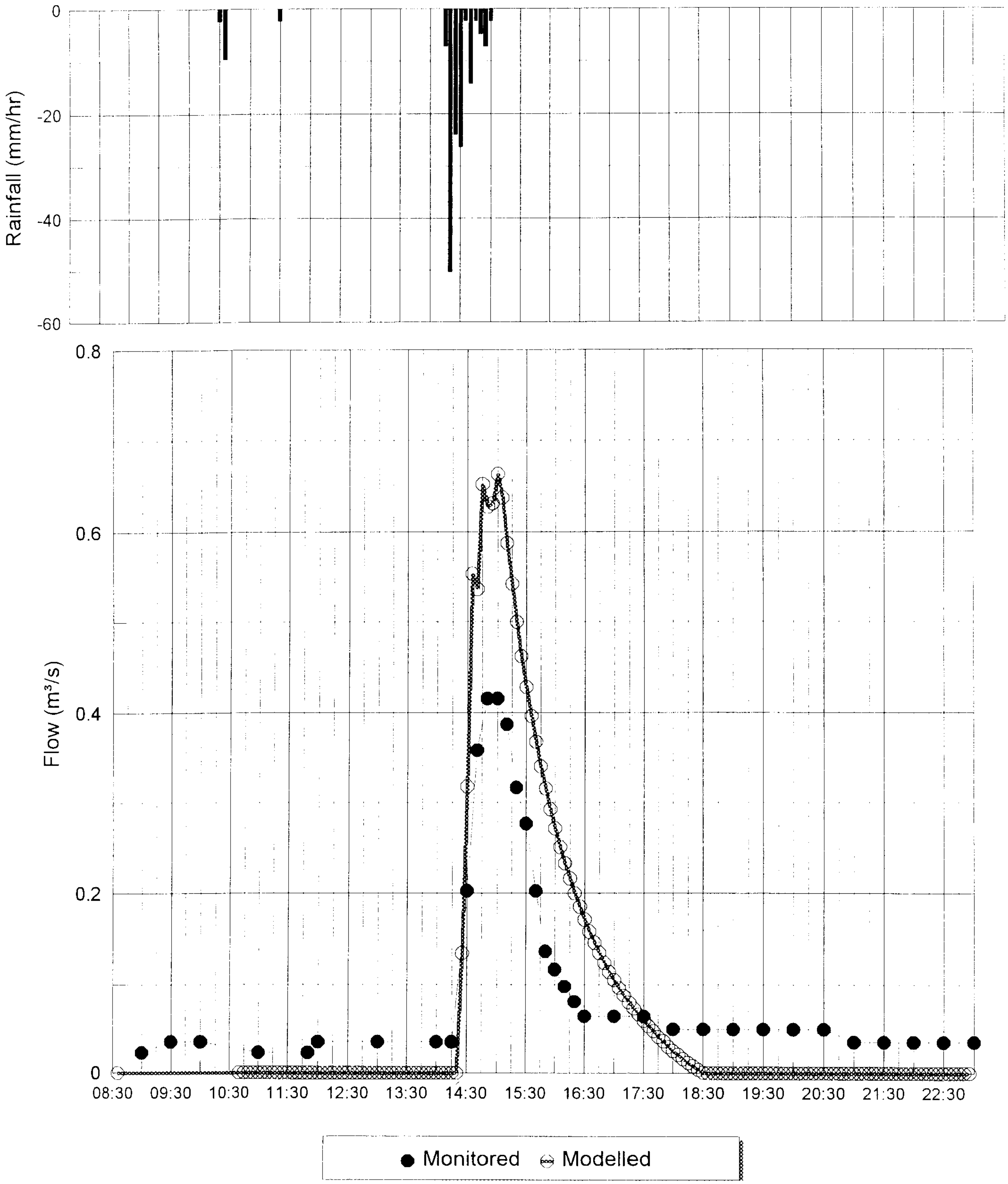


Figure 3-19

Mager Combined Sewer District

June 8, 1990

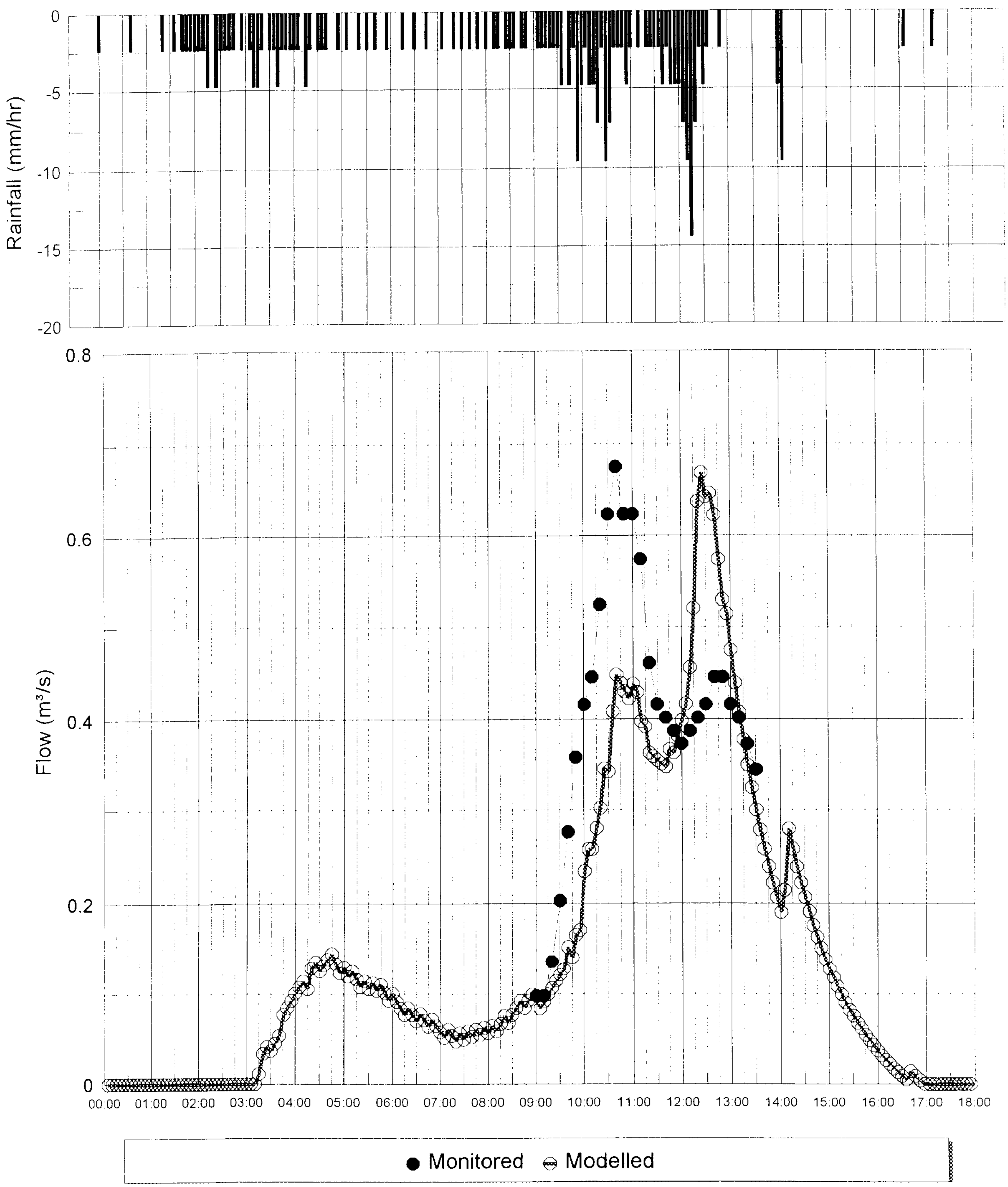
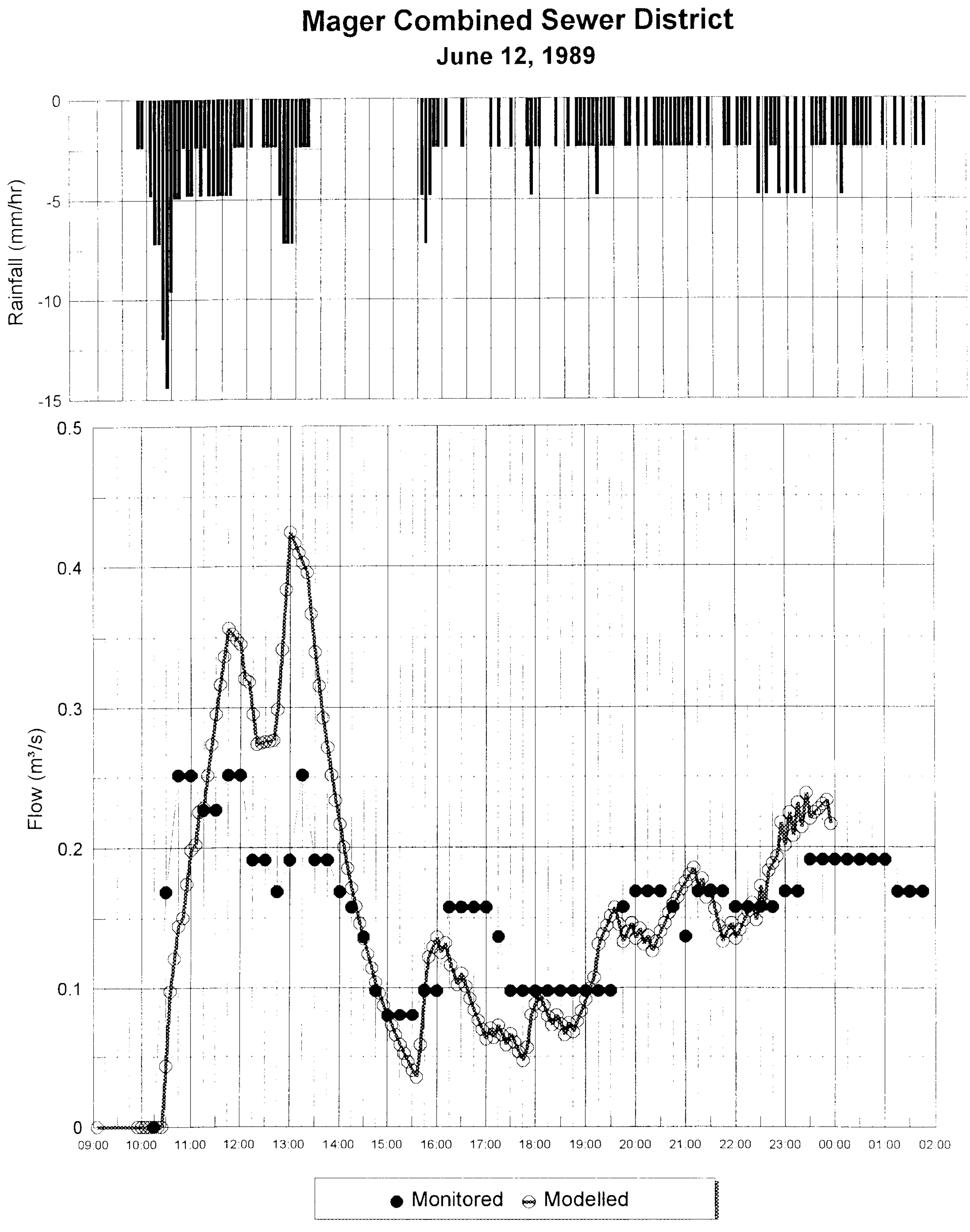


Figure 3-20



Mager Combined Sewer District
June 12, 1989
Rainfall (mm/hr)
0
-5
-10
-15
Flow (m³/s)
0.5
0.4
0.3
0.2
0.1
0
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
Monitored
Modelled

Figure 3-21

it is possible that the monitored rainfall was not completely representative of the rainfall which fell over the tributary area, resulting in a hydrograph peak somewhat different than expected for the gauged rainfall.

Overall, the calibration results display a high degree of calibration for a single district catchment for different size rainfalls and are sufficiently accurate for the purposes of planning-level modelling. Outflows predicted on a regional scale (using calibrated district parameters) will be processed and used as input to interceptor and receiving stream modelling. With planning-level outflow data, a screening assessment of CSO control alternatives will be possible. EMCs will be applied to the continuous outflow hydrographs to estimate loadings and assess receiving stream response for current conditions and those that might be observed for various control technologies. Once planning-level modelling is complete, detailed modelling will be done in Phase 3 to assess the effectiveness of the options which were identified as promising in the planning phase of the study.

3.8 TIMESTEP EVALUATION

Five-minute timestep values were used for detailed characterization of rainfalls in the model calibration exercises. Previous studies utilized hourly timesteps for planning level assessment of control alternatives. It was deemed important to assess the significance of timestep on the number and volume of overflows for continuous regional modelling. Five minute rainfall timesteps were used in the calibration process because they were available and provided an accurate representation of rainfall. Since available long-term rainfall records were in 1-hour timesteps, it was necessary to determine whether significant differences in runoff results would occur based upon the choice of timestep used in the modelling.

A 5-minute and 1-hour rainfall timestep analysis was completed by comparing predicted number of runoff events and volumes for continuous simulation of rain events for a calibrated district (Tylehurst). As illustrated in Table 3-8, the predicted runoff volume and runoff peaks for 5-minute and 1-hour rainfall timestep were found to be virtually the same based on a 4-hour time separation between overflow events. During this analysis, various separation time periods between overflow events was also assessed. The analyses found that the number

TABLE 3-8

TYLEHURST COMBINED SEWER DISTRICT
XP-SWMM CONTINUOUS SIMULATION OF RUNOFF (MAY TO OCTOBER)

ASSESSMENT OF TIMESTEP ON NUMBER OF OVERFLOWS AND VOLUME

				OVERFLOW VOLUME		
YEAR	NUMBER OF RAIN EVENTS	TIMESTEP	RUNOFF VOLUME (m^3)	3 x DWF (m^3)	6 x DWF (m^3)	9 x DWF (m^3)
1988	47	5 min	189,675	118,045	90,509	74,297
	47	1 hour	187,655	115,609	86,108	69,084
1989	31	5 min	121,695	67,360	45,924	33,111
	31	1 hour	122,014	68,264	47,357	34,238
1990	33	5 min	82,575	39,967	21,647	12,271
	33	1 hour	82,167	39,454	19,795	10,436
1991	47	5 min	209,708	128,917	94,672	77,244
	47	1 hour	214,674	133,029	96,760	79,336

of overflows could be strongly influenced by definition of separation time between overflow events. The maximum number of events would correspond to the number of rainfall events. It was found that a separation time of 4-hours or more would yield about the same number of overflow events for either 5-minute or 1-hour rainfall timesteps as shown in Table 3-9.

The analysis revealed that a 1-hour rainfall timestep for runoff modelling would accurately predict number and volume of overflows required for planning level assessment of alternatives. The adequacy of using a 1-hour timestep for rainfall would allow the availability of 30+ years of long-term data at the Winnipeg International Airport to be used in long-term continuous runoff simulation. A 4 to 6-hour time of separation was adopted to define an overflow event. The results for the 1-hour timestep for rainfall were reviewed at Working Session #5 held on April 5, 1995 and was deemed to be representative and satisfactory for screening of control technologies.

3.9 DEVELOPMENT OF THE REGIONAL MODEL

Following the process of calibrating selected districts to single and continuous events, the process of extrapolating results and developing the Regional Model was commenced. The Regional Model was constructed based upon a two-step process.

1. Formulation of a regression equation to predict subcatchment width, the key parameter used in calibration, based on quantifiable physical characteristics of the districts (i.e., impervious area, tributary drainage area, and length).

2. Use of the regression equation to extrapolate the results to combined sewer and land drainage districts.

Following completion of these two steps, the data required to model continuous rainfall and predict discharges to the Rivers for all the City's sewer districts was obtained. This data set constitutes the key information required to develop a Regional model.

TABLE 3-9

PART A - 4 HOURS BETWEEN OVERFLOW EVENTS

YEAR	TIMESTEP	NUMBER OF OVERFLOWS 3 x DWF	6 x DWF	9 x DWF
1988	5 min	24	17	14
	1 hour	24	16	13
1989	5 min	16	13	12
	1 hour	15	12	10
1990	5 min	13	15	9
	1 hour	12	13	6
1991	5 min	21	21	15
	1 hour	20	20	12

PART B - 8 HOURS BETWEEN OVERFLOW EVENTS

YEAR	TIMESTEP	NUMBER OF OVERFLOWS 3 x DWF	6 x DWF	9 x DWF
1988	5 min	21	14	13
	1 hour	20	14	11
1989	5 min	16	11	10
	1 hour	15	11	9
1990	5 min	13	11	9
	1 hour	12	8	5
1991	5 min	19	19	14
	1 hour	19	18	10

3.9.1 Regression Analysis

A regression analysis was performed on physical district characteristics from the 10 modelled and calibrated CS districts in order to predict catchment width values for use in the model. Catchment width was the primary parameter used to calibrate each of the 10 districts used in the calibration exercise and was therefore the key parameter to predict for other sewer districts. Three readily quantifiable physical characteristics were selected for use in the regression analysis to determine if a statistically significant relationship existed for predicting catchment widths.

The three parameters used in the regression analysis were:

1. Percent Impervious Area - the portion of district area which is impervious and experiences no water loss due to infiltration.

2. Tributary Area - the portion of the district's total area that drains surface runoff into the sewer system.

3. Length - the maximum longitudinal measurement of a district away from the rivers as approximated from district maps. The length, attempts to represent the street flow across subcatchments indicative of the district's shape.

Results of the regression analyses are shown in Table 3-10. The relationship for predicted catchment width based on tributary area, impervious area, and length yielded a very high R^2 value of 0.9, a 90% confidence level.

Figure 3-22 presents a plot of calibrated and predicted widths using the formulated regression equation based on quantifiable physical characteristics of each district. This plot demonstrates the range and the goodness of fit between predicted and calibrated values for catchment used. The analysis successfully resulted in a useful method to predict the key runoff parameter to estimate runoff in response to rainfall events.

Table 3-10
Regression Analysis

Prediction of Equivalent Widths for Regional Model

Percent Impervious Area (X1) and Tributary Area (X2) and True District Length (X3) to Modelled Width (Y)

$$Y=M1X1+M2X2+M3X3+C$$

M1=17479.1
M2=2.33
M3=-1.109
C=-1061.1
R^2=0.9

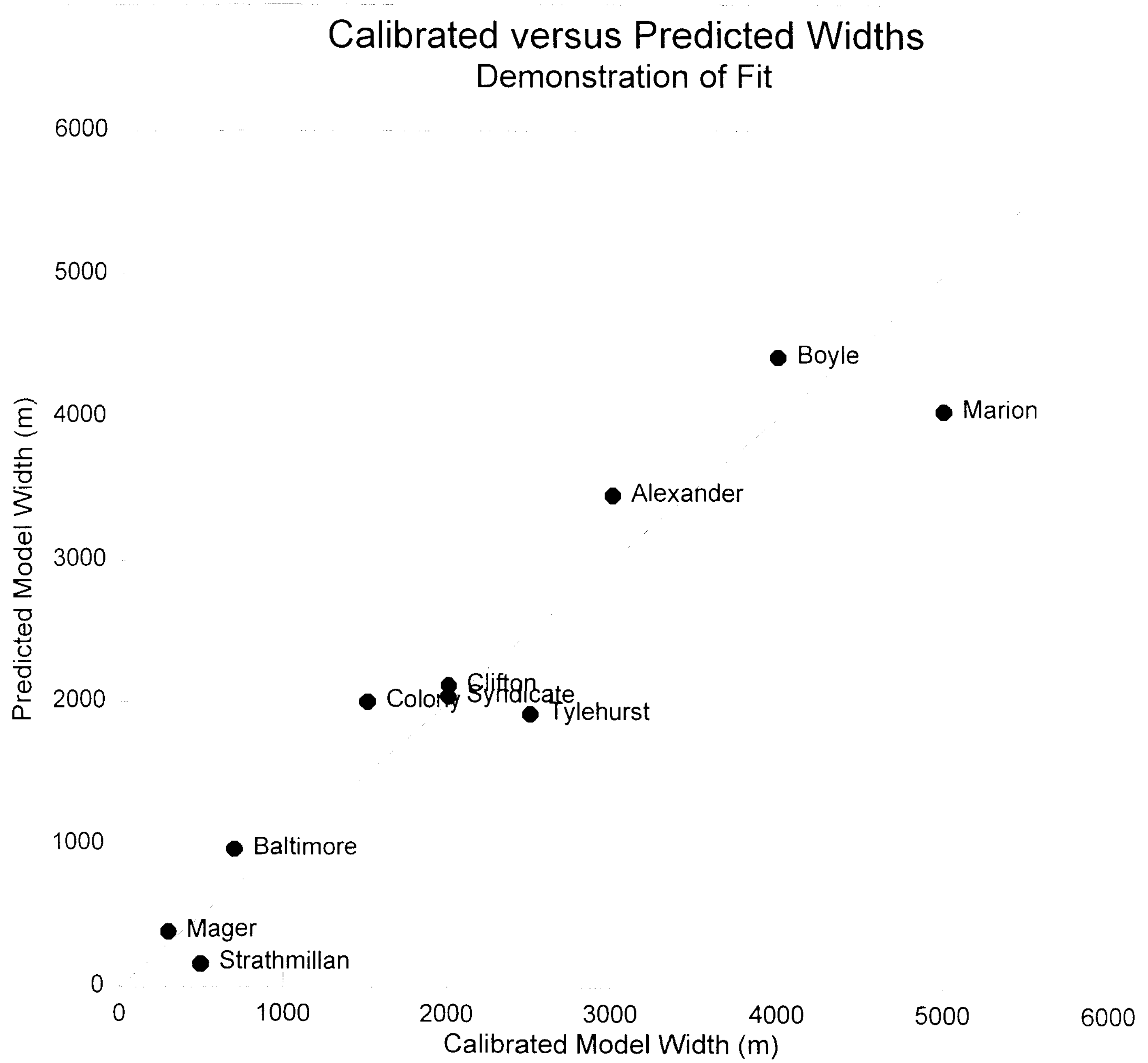

Calibrated versus Predicted Widths
Demonstration of Fit
Predicted Model Width (m)
6000
5000
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
Calibrated Model Width (m)
Boyle
Marion
Alexander
Clifton
Colony
Syndicate
Tylehurst
Baltimore
Mager
Strathmillan

Figure 3-22

Predicted catchment widths were calculated for all CSO and land drainage sewer (LDS) districts using the regression equation. The predicted subcatchment widths are tabulated along with the key physical district characteristics, in Table 3-11 and Table 3-12.

3.9.1.1 Area Wide Extrapolation - CS Districts

Based on the results of the 10 CS districts used in the calibration exercise, a relationship was established between tributary area, percent impervious and length to predict catchment width and used to interpolate or extrapolate results to the remaining 34 combined sewer districts. The regression equation allowed estimation of catchment width as a function of each district's percentage of impervious area, tributary drainage area, and district length. The results of the interpolation/extrapolation were summarized in Table 3-11. Once the subcatchment width was calculated for each district standardized values for slope, Mannings "n" values and infiltration parameters were input into each district's model set-up (as listed in Table 3-7). These standardized values were determined from the 10 district calibration effort and comparison with 1986 BFR Study reported values.

3.9.1.2 Area Wide Extrapolation - LDS Districts

The process of area-wide extrapolation for catchment widths for land drainage areas was based on the same regression equation derived from the calibration of 10 CS districts. Due to limited data on the percent impervious parameter for LDS districts it was necessary to approximate a value which would be representative of newer developments.

The Study Team discussed potential approximate values for LDS percent impervious area, and City representatives suggested using between 25-30% as the value for percent impervious. The modelling effort assumed 25% impervious for all LDS districts after sensitivity analyses demonstrated low sensitivity to model results for the 25-30% range for percent impervious. Values for remaining parameters were set as per the standardized values established in the calibration phase of the modelling. Table 3-12 presents the extrapolation table developed for LDS districts.

Table 3-11: Extrapolation Table - CSO Districts

District	(%/100) Impervious Area	Net Area (ha)	True Dist Length(m)	Predicted Modelled Width (m)
Alexander	0.42	146	2804	3449
Armstrong	0.22	148	2560	211
Ash	0.33	823	3231	3038
Assiniboine	0.79	75	1097	11666
Aubrey	0.35	390	4815	621
Baltimore	0.21	211	1890	961
Bannatyne	0.30	206	2865	1505
Boyle	0.33	25	305	4421
Calrossie	0.25	10	549	2766
Clifton	0.44	415	4999	2119
Cockburn	0.25	233	2530	1087
Colony	0.28	227	2195	2003
Cornish	0.23	127	2804	181
Despins	0.29	86	1341	2737
Doncaster	0.23	133	2926	103
Dumoulin	0.22	64	1158	1696
Ferry Road	0.29	226	2621	1681
Hart	0.35	142	2134	2967
Hawthorne	0.27	219	2377	1503
Jefferson E	0.23	410	3292	214
Jefferson W	0.23	567	2804	1120
Jessie	0.34	338	2804	2609
LaVarendrye	0.23	716	1219	700
Linden	0.23	149	1402	1733
Mager	0.23	260	2438	936
Marion	0.33	217	1036	4044
Metcalfe	0.22	34	792	1952
Mission	0.32	421	4267	689
Moorgate	0.22	157	1280	400
Munroe	0.23	375	3658	8000
Newton	0.23	56	975	2040
Polson	0.36	238	3840	1546
River	0.27	108	1646	2105
Riverbend	0.34	189	3231	1665
Roland	0.42	178	2134	4361
Selkirk	0.25	259	2743	787
Strathmillan	0.14	69	1250	160
St. Johns	0.38	335	3292	2782
Syndicate	0.23	79	914	2045
Tuxedo	0.20	50	792	1631
Tylehurst	0.52	132	4206	3618
Woodhaven	0.20	42	914	1528

Table 3-12: Extrapolation Table - LDS Districts

District	Impervious Area (percent/100)	Net Area (ha)	True Dist Length(m)	Predicted Modelled Width (m)
Doncaster Sep	0.25	167	370	3287
Omands Creek(sum)	0.25	1239	4630	1055
Riverbend Sep	0.25	216	3840	100
Tuxedo Sep	0.25	395	3050	844
Charleswood C	0.25	63	520	2878
Strathmillan Sep	0.25	89	2470	775
Sturgeon Creek (sum)	0.25	1046	2130	3380
Charleswood D	0.25	77	640	2778
Parkdale 1	0.25	100	640	2831
Charleswood	0.25	500	2010	2242
Parkdale 2	0.25	200	1830	1744
Charleswood G	0.25	223	980	2740
Parkdale 3	0.25	200	1740	1843
Charleswood H1	0.25	42	120	3273
Charleswood H2	0.25	125	1460	1980
Charleswood, RivWest 1	0.25	29	580	2733
Charleswood, RivWest 2	0.25	24	210	3131
Parkdale 4	0.25	100	700	2765
Kildare	0.25	1744	8140	100
Bunn's Creek- sum	0.25	870	1190	4013
West Kildonan J1	0.25	90	370	3108
West Kildonan J2	0.25	40	1770	1438
Douglas	0.25	260	2010	1684
West Kildonan J3	0.25	120	340	3211
Hawthorne Sep	0.25	242	340	3495
Newton Sep	0.25	1275	6460	100
Linden Sep	0.25	888	3660	1314
Seine Riv - sum	0.25	2154	3780	4128
Mager Sep 1	0.25	70	180	3272
Mager Sep 2	0.25	40	60	3335
Calrossie 1	0.25	120	3230	100
Calrossie 2	0.25	80	730	2685
North St. Vital 1	0.25	73	1220	2125
Pulberry 1	0.25	36	240	3126
Fort Garry 1	0.25	60	790	2572
Fort Garry 2	0.25	60	820	2538
Pulberry 2	0.25	90	790	2642
North St. Vital 2	0.25	65	670	2717
Fort Garry 3	0.25	120	2260	1080
Fort Garry 4	0.25	160	4940	100
North St. Vital 3	0.25	40	1250	2015
North St. Vital 4	0.25	73	1070	2291
Fort Garry 5	0.25	40	60	3335
Fort Garry 6	0.25	100	550	2931
Fort Garry 7	0.25	50	180	3225
North St. Vital 5	0.25	114	2100	1244
South St Vital	0.25	375	2680	1208
Fort Garry 8	0.25	70	790	2595
Fort Garry 9	0.25	80	820	2585
Fort Garry 10	0.25	80	980	2407
Fort Garry 11	0.25	100	1860	1478
Fort Garry 12	0.25	30	850	2435
Fort Garry land draing 1	0.25	100	940	2498
Fort Garry 14	0.25	60	670	2705

The predicted catchment widths and use of standardized parameter values (from a 10 district calibration) constituted the framework of values used to develop a Regional CSO and LDS District Runoff model.

4.0 MONITORING REQUIREMENTS

The City of Winnipeg has conducted many monitoring programs over the years and developed a substantial database on system behaviour and discharges. However, requirements remain for follow-up monitoring programs and studies to improve the characterization of discharge quality and hydraulic performance of the sewer infrastructure. While available monitoring data is adequate for Phase 2 planning level modelling, additional data requirements exist for detailed modelling associated with Phase 3 activities and assessments.

Areas where additional monitoring data would benefit ongoing analyses include:

- Combined Sewer Overflow districts;
- Land Drainage Sewer districts;
- Raw Sewage Concentrations (CSO, WPCCs);
- Sanitary Sewer Overflows;
- Dry Weather Flows - quality and quantity;
- Overflow Activation levels;
- Interception Capacities (both gravity and pumped); and
- District-specific parameters such as percent impervious.

4.1 COMBINED SEWER OVERFLOW DISTRICT MONITORING

At the time of this report, the City of Winnipeg's Waterworks, Waste and Disposal Department had monitored 20 CS districts for overflow quantity and quality. The districts and the year(s) of monitoring are listed in Section 2.3.1. In several CS sewer districts, monitored rainfall data flow and quality data existed but were not collected simultaneously, thereby reducing the number of districts and events that could be used in the model calibration process. In calibration, it was important to have flow and rainfall data corresponding chronologically to each other. To estimate event mean concentrations it is again necessary that both flow and quality data be collected simultaneously. Within the set of 20 monitored CS districts, 10 districts were identified to have correspondingly monitored flow and rainfall data. In the case of some districts, either flow or rainfall data was missing for particular events, rendering the event's data set incomplete and unsuitable for calibration.

Additional monitoring of CS districts would build upon the required flow and quality data-set required for calibration analyses in more detailed modelling and estimation of event mean concentration for loadings. In some previous CSO monitoring programs, flow and quality were not always monitored simultaneously. Future efforts should focus on monitoring flow and quality data simultaneously. Additional CSO monitoring could be optimized by monitoring CS districts based upon their land use characterizations. CS districts have been classified by the percentage of total district land use in terms of Residential, Industrial, and Commercial sectors (City of Winnipeg 1986). CS districts need to be re-evaluated according to the land-use composition to assess whether certain districts have changed substantially in their land-use and require follow-up monitoring; Mission CS in particular. Representative districts can be chosen from this revised list for additional monitoring of quality and flow data.

4.2 LAND DRAINAGE SEWER DISTRICTS

In response to City initiatives to address CSO management and basement flooding issues, the majority of monitoring efforts for flow and quality were focussed on CS districts. This situation creates a need for a better characterization of runoff in terms of quantity and quality from separated sewer areas.

While planning-level modelling affords approximations to be used for LDS runoff modelling, hydraulic monitoring data is necessary to calibrate storm runoff hydrographs. LDS monitoring for simultaneous flow and quality data is recommended for several districts, with district selection based upon land use characteristics. LDS districts selected for monitoring would be selected based on representative land-use classifications. Additional flow and level monitoring at as many as possible LDS outfalls will improve confidence in hydraulic calibration of runoff model parameters such as: runoff coefficient, percent impervious, and time of concentration.

The need exists for improved characterization of LDS discharge quality with respect to fecal coliforms from both direct discharges to the rivers and through a storm retention basin system. This data would be applied to estimating Event Mean Concentrations (EMC) and to place discharges from CSOs, LDSs and Winnipeg Pollution Control Centres (WPCCs) into perspective. The quality characteristics of retention pond outflows are not well defined within the current system. Sampling for flow and quality upstream and downstream of storm retention ponds is recommended to improve the quantification of pollutant loading resulting from direct discharges and discharges through SRBs.

4.3 QUALITY UNDER DRY WEATHER FLOW/WET WEATHER FLOW

A need exists for improved quantification of raw sewage levels from CSOs, SSOs and WPCC outfalls under conditions of DWF and WWF. Currently, the quantification of concentrations from these sources have come under question and need to be resolved to place loadings from the major sources into perspective. Current knowledge only allows identification of a range of values for concentrations of raw sewage in wet weather and dry weather flow. This range of values influences the discharge loading concentrations, so improved quantification of this range would result in improved accuracy in receiving stream loading, ranking of importance of discharge sources on water quality, and assessment of benefits resulting from various control alternatives.

At WPCCs, improved quantification of fecal coliform concentration entering and leaving the plants aids in assessing disinfection options. Recently (May 1995) the City began monitoring all 3 WPCCs for fecal coliform in inflow and outflow. Continuation of this monitoring is recommended, as data resulting from this effort is important for establishing representative loadings from treatment plants, potential disinfection benefits and building an historical database for future evaluations.

4.4 OVERFLOW ACTIVATION

The City records in-system water levels to assess hydraulic conditions using its "FAST Alarm" system. The FAST alarm system is set up in such a way that it indicates only the condition of a problem that is developing. Consequently, an alarm does not necessarily indicate an overflow has occurred, rather it may indicate that it requires attention to alleviate a potential problem. It is recommended that action be taken to understand how FAST alarm activation levels were set or should be set. Presently, information suggests that these activation levels may be set conservatively, resulting in possible over-estimation of overflow. Accordingly, more flow may be received by the WPCCs than currently realized. It may also be required for reporting purposes to the Environmental Management Division of the Province in the future to demonstrate the effectiveness of selected controls. As such, it is essential that current FAST alarm operation is well understood and documented to accurately characterize system behaviour.

4.5 PERCENT IMPERVIOUS AREAS

While the percent of impervious area in CS districts is known for some CS districts (from 1986 BFR Study, Consultant Reports), it is not well known for LDS and SS districts. In the regional planning-level modelling, the percent impervious values for LDS districts were set at one common value of 25% impervious. It is recommended that the City consider conducting an aerial photo and map analysis to estimate percent impervious area values on a city-wide basis to more accurately quantify remaining CS and LDS districts. This initiative would benefit all subsequent modelling efforts.

Appendix 1-A

CSO MANAGEMENT STUDY

PHASE 2: WORKING SESSION NO. 1

"TECHNICAL APPROACH"

AGENDA

Date:	September 27-28, 1994
Location:	Wardrop Engineering Inc. 386 Broadway - 4th Floor Winnipeg, Manitoba

Day 1: September 27, 1994

8:00 a.m. to 3:30 p.m., Wardrop 4th Floor (Large Boardroom)

COFFEE AND MUFFINS — ***8:00 to 8:30 a.m.***
- Introduction and settle in

SESSION OVERVIEW (G. REMPEL) — ***8:30 to 9:00 a.m.***
- Layout and format
- Modelling goals and objectives
- Products of session

BACKGROUND REVIEW (N. SZOKE/D. MORGAN) — ***9:00 to 10:00 a.m.***
- Phase 1 Technical Framework (Tech Memo #7)
- Phase 1 Workshop (Tech Memo #9)
- Evaluation measures used in Winnipeg (D. Morgan)

DEVELOPMENT OF EVALUATION CRITERIA — ***10:00 to 11:30 a.m.***
- Discussion of core and associated CSO issues (D. Morgan) - 15 minutes
- Establish Performance Measures, group discussion - 1 hr. 15 min.

REVIEW OF SELECTED MODELS (D. MORGAN) — ***11:30 to 12:15 p.m.***
- Assess model capabilities with evaluation criteria, group discussion

XP-SWMM SOFTWARE DEMO (R. REMPEL) — ***12:15 to 12:45 p.m.***
- Lunch

URBAN RUNOFF MODELLING ***12:45 to 2:15 p.m.***

- Winnipeg background information (N. Szoke) - ½ hr
- Technical considerations of model setup, group discussion - 1 hr

HIRATE (G. ZUKOVS) ***2:15 to 3:30 p.m.***

- Control alternatives model demo - 30 min.
- Technical considerations, group discussion - 45 min.

Move to Wardrop 4th floor Small Boardroom

DETAILED DISTRICTS MODELLING ***3:45 to 5:00 p.m.***

- City of Winnipeg Basement Flood Relief criteria (N. Szoke/G. Steiss) - ½ hr
- Technical considerations of model setup, group discussion - 45 min.

Day 2: **September 28, 1994**

8:00 a.m. to 3:30 p.m., Wardrop 4th Floor (Large Boardroom)

COFFEE AND MUFFINS ***8:00 a.m. to 8:30 p.m.***

INTERCEPTOR/TREATMENT MODELLING ***8:30 to 12:30 p.m.***

- Interceptor System background (G. Steiss) - 45 min.
- NEWPCC wet well levels and pumping protocols (D. Morgan) - 15 min.
- Review of 1994 field inspection program and Recommendations (G. Steiss) - 30 min.
- Technical considerations of model setup, group discussion - 2½ hr
- Lunch

RECEIVING STREAM MODEL (D. MORGAN) ***12:30 to 2:00 p.m.***

- Review of local conditions and monitoring data (D. Morgan) - ½ hr
- Technical considerations of model setup, group discussion - 1 hr

INTERNAL PROJECT MANAGEMENT MEETING
(G. REMPEL) ***2:00 to 3:30 p.m.***

- Resolve technical issues
- Task assignments

POST-WORKING SESSION (R. REMPEL/N. SZOKE)

- Preparation of Working Session Summary

CSO MANAGEMENT STUDY

PHASE 2: WORKING SESSION NO. 1

TIME SCHEDULE FOR PARTICIPANTS

<u>Specialist Consultants</u>

- D. Weatherbe - full time both days
- G. Zukovs - full time both days
- W. Clarke - full time both days

<u>Local Study Team Members</u>

- G. Rempel - part-time, Evaluation Criteria, Internal Meeting
- W. Dowhopoluk - part-time, Infrastructure
- D. Morgan - full time both days
- G. Steiss - full time both days
- N. Szoke - full time both days
- R. Rempel - full time both days

<u>City of Winnipeg Representatives</u>

- E. Sharp - full time both days
- M. Shkolny - part-time, Evaluation Criteria
- P. Lagassé (or B. Borlase) part-time, Evaluation Criteria
- others - part-time, indicate area of interest
- D. Wardrop - part-time, Evaluation Criteria, Urban Runoff

Full time	=	8
Part-time	=	5
TOTAL	=	<u>13</u>

1007.AGD

Combined Sewer Overflows

District / Station	Date	Program	# Samples	BOD	FC	TS	SS	Metals	Flow
✓ Alexander	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	06/07/91	WWF	24	N	Y	N	N	Y	Y
	06/25/91	WWF	48	N	Y	N	N	Y	Y
✓ Baltimore	03/28/90	SRO	13	Y	Y	N	Y	Y	Y
	03/29/90	SRO	18	Y	Y	N	Y	Y	Y
	06/07/90	WWF	8	Y	Y	Y	Y	N	Y
	06/08/90	WWF	11	Y	Y	Y	Y	N	Y
	06/20/90	WWF	9	Y	Y	Y	Y	N	Y
Boyle Pump	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	06/16/92	CSO	2	Y	Y	Y	Y	N	Y
	07/19/92	CSO	2	Y	Y	Y	Y	N	Y
	07/02/92	CSO	23	Y	N	N	N	N	Y
	07/03/92	CSO	18	Y	N	Y	Y	N	Y
	07/07/92	CSO	4	Y	N	Y	Y	N	Y
	07/08/92	CSO	22	Y	N	Y	Y	N	Y
	07/14/92	CSO	16	Y	Y	Y	Y	N	Y
	07/27/92	CSO	4	Y	Y	Y	Y	N	Y
	08/22/92	CSO	23	N	N	Y	Y	N	Y
Clifton	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	06/16/92	CSO	24	Y	Y	Y	Y	N	Y
	06/17/92	CSO	18	Y	Y	Y	Y	N	Y
	06/24/92	CSO	24	Y	N	Y	Y	N	Y
	07/02/92	CSO	17	Y	N	Y	Y	N	Y
	07/07/92	CSO	24	Y	N	Y	Y	N	Y
	08/22/92	CSO	22	N	N	Y	Y	N	Y
Colony									
	06/07/90	WWF	6	Y	Y	Y	Y	N	Y
	06/08/90	WWF	10	Y	Y	Y	Y	N	Y
	06/20/90	WWF	35	Y	Y	Y	Y	N	Y
Galt Fl. Sta.	06/16/92	CSO	12	Y	Y	Y	Y	N	Y
	06/17/92	CSO	11	Y	Y	Y	Y	N	Y
	06/22/92	CSO	13	Y	Y	Y	Y	N	Y
	06/24/92	CSO	24	Y	N	Y	Y	N	Y
	07/01/92	CSO	12	Y	Y	Y	Y	N	Y
	07/02/92	CSO	14	Y	N	Y	Y	N	Y
	07/03/92	CSO	13	Y	N	Y	Y	N	Y
	07/14/92	CSO	8	Y	Y	Y	Y	N	Y
	07/27/92	CSO	10	Y	Y	Y	Y	N	Y
	08/22/92	CSO	16	N	N	Y	Y	N	Y
	09/05/92	CSO	24	N	N	Y	Y	N	Y
Mager	06/12/89	WWF	24	Y	N	Y	Y	Y	Y
	06/29/89	WWF	8	Y	N	Y	Y	Y	Y
	07/05/89	WWF	9	Y	N	Y	Y	Y	Y
	07/12/89	WWF	6	Y	N	Y	Y	Y	Y
	08/18/89	WWF	14	Y	N	Y	Y	Y	Y
	06/05/90	WWF	7	Y	Y	Y	Y	N	Y
	06/07/90	WWF	24	Y	Y	Y	Y	N	Y
	06/08/90	WWF	12	Y	Y	Y	Y	N	Y
Strathmillan	05/31/91	WWF	12	N	Y	N	N	Y	Y
	06/01/91	WWF	10	N	Y	N	N	Y	Y
	06/07/91	WWF	9	N	Y	N	N	Y	Y
	06/13/91	WWF	11	N	Y	N	N	Y	Y
	06/25/91	WWF	24	N	Y	N	N	Y	Y

Dry Weather Flow

District / Station	Date	Program	# Samples	BOD	FC	TS	SS	Metals	Flow
Alexander	SUMMER	CSO Analysis (Telemetry) - Storm Data							
	08/02/90	DWF	1	Y	Y	Y	N	N	N
	09/08/90	DWF	3	N	Y	Y	Y	N	N
	08/13/91	DWF	3	N	Y	N	N	Y	N
	08/13/91	DWF	3	Y	Y	Y	Y	N	N
Baltimore									
	05/09/90	DWF	3	Y	Y	Y	Y	N	N
	05/29/90	DWF	3	Y	Y	Y	Y	N	N
	07/13/90	DWF	3	Y	Y	Y	Y	N	N
	07/31/90	DWF	3	Y	Y	Y	Y	N	N
Colony									
	05/09/90	DWF	3	Y	Y	Y	Y	N	N
Dumoulin									
	08/02/90	DWF	1	Y	Y	Y	N	N	N
	08/09/90	DWF	3	N	Y	Y	Y	N	N
	08/13/90	DWF	3	Y	Y	Y	Y	N	N
Hawthorne									
	05/29/90	DWF	3	Y	Y	Y	Y	N	N
	07/13/90	DWF	3	Y	Y	Y	Y	N	N
	07/31/90	DWF	6	Y	Y	Y	Y	N	N
Linden									
	05/29/90	DWF	3	Y	Y	Y	Y	N	N
	07/13/90	DWF	3	Y	Y	Y	N	N	N
Mager									
	05/05/90	DWF	3	Y	Y	Y	Y	N	N
Moorgate									
	08/02/90	DWF	1	Y	Y	Y	N	N	N
	08/09/90	DWF	3	N	Y	Y	Y	N	N
	08/13/90	DWF	3	Y	Y	Y	Y	N	N
Strathmillan									
	08/02/90	DWF	1	Y	Y	Y	N	N	N
	08/09/90	DWF	3	N	Y	Y	Y	N	N
	08/13/90	DWF	3	Y	Y	Y	Y	N	N
	08/31/91	DWF	3	N	Y	N	N	Y	N

Land Drainage Sewers

District / Station	Date	Program	# Samples	BOD	FC	TS	SS	Metals	Flow
Crane	07/03/90	LD	4	Y	Y	Y	Y	N	Y
	05/01/91	WWF	14	N	Y	N	N	Y	Y
	05/15/91	WWF	6	N	Y	N	N	Y	Y
	05/25/91	WWF	36	N	Y	N	N	Y	Y
	05/31/91	WWF	12	N	Y	N	N	Y	Y
	06/06/91	WWF	2	N	Y	N	N	Y	Y
	06/07/91	WWF	17	N	Y	N	N	Y	Y
	06/08/91	WWF	12	N	Y	N	N	Y	Y
	06/13/91	WWF	15	N	Y	N	N	Y	Y
King Ed.									
	08/17/90	SRR	3	Y	Y	Y	Y	N	N

C.O.W. Data recieved and in digital File format.......

Date	District	SWR , DWF,WWF,SRO, LD	# Samples
2/AUG/90	ALEXANDER	DWF	1
9/AUG/90	ALEXANDER	DWF	3
13/AUG/90	ALEXANDER	DWF	3
13/AUG/91	ALEXANDER	DWF	3
25/JUN/91 a.m.	ALEXANDER	WWF	24
25/JUN/91 p.m.	ALEXANDER	WWF	24
7/JUN/91	ALEXANDER	WWF	24
28/MAR/90	BALTIMORE	SRO	13
29/MAR/90	BALTIMORE	SRO	18
9/MAY/90	BALTIMORE	DWF	3
29/MAY/90	BALTIMORE	DWF	3
7/JUN/90	BALTIMORE	WWF	8
8/JUN/90	BALTIMORE	WWF	11
20/JUN/90	BALTIMORE	WWF	9
13/JUL/90	BALTIMORE	DWF	3
31/JUL/90	BALTIMORE	DWF	3
16/JUN/92	BOYLE PUMPING STATION	?	2
2/JUL/92	BOYLE PUMPING STATION	?	23
3/JUL/92	BOYLE PUMPING STATION	?	18
7/JUL/92	BOYLE PUMPING STATION	?	2
8/JUL/92	BOYLE PUMPING STATION	?	22
27/JUL/92	BOYLE PUMPING STATION	?	4
14/AUG/92	BOYLE PUMPING STATION	?	16
19/AUG/92	BOYLE PUMPING STATION	?	2
22/AUG/92	BOYLE PUMPING STATION	?	23
19-20/JUN/90	COLONY LIFT STATION	WWF	36
9/MAY/90	COLONY LIFT STATION	DWF	3
7/JUN/90	COLONY LIFT STATION	WWF	6
8/JUN/90	COLONY LIFT STATION	WWF	10
16/JUN/92	CLIFTON PUMPING STATION	?	24
17/JUN/92	CLIFTON PUMPING STATION	?	18
24/JUN/92	CLIFTON PUMPING STATION	?	24
2/JUL/92	CLIFTON PUMPING STATION	?	17
7/JUL/92	CLIFTON PUMPING STATION	?	24
14/JUL/92	CLIFTON PUMPING STATION	?	24
22/AUG/92	CLIFTON PUMPING STATION	?	22
3/JUL/90	CRANE GATE CHAMBER	LD	4
15/MAY/91	CRANE GATE CHAMBER	WWF	6
31/MAY/91 a.m.	CRANE GATE CHAMBER	WWF	2
31/MAY/91 p.m.	CRANE GATE CHAMBER	WWF	10
1/JUN/91	CRANE GATE CHAMBER	WWF	14
6/JUN/91	CRANE GATE CHAMBER	WWF	19
8/JUN/91	CRANE GATE CHAMBER	WWF	12
13/JUN/91	CRANE GATE CHAMBER	WWF	15
25/JUN/91 a.m.	CRANE GATE CHAMBER	WWF	11
25/JUN/91 p.m.	CRANE GATE CHAMBER	WWF	24
30/JUN/93	DESPINS LIFT/FLOOD STATION	?	24
9/JUL/93	DESPINS LIFT/FLOOD STATION	?	4
18/JUL/93	DESPINS LIFT/FLOOD STATION	?	11
22/JUL/93	DESPINS LIFT/FLOOD STATION	?	13
23/JUL/93	DESPINS LIFT/FLOOD STATION	?	12
27/JUL/93	DESPINS LIFT/FLOOD STATION	?	24
2/AUG/93	DESPINS LIFT/FLOOD STATION	?	14
8/AUG/93	DESPINS LIFT/FLOOD STATION	?	3
12/AUG/93	DESPINS LIFT/FLOOD STATION	?	24
2/AUG/90	DUMOULIN	DWF	1
9/AUG/90	DUMOULIN	DWF	3
13/AUG/90	DUMOULIN	DWF	3
13/AUG/91	DUMOULIN	DWF	3

29/MAY/90	HAWTHORNE	DWF	3
13/JUL/90	HAWTHORNE	DWF	3
31/JUL/90	HAWTHORNE	DWF	3
16/JUN/92	GALT FLOOD STATION	?	11
17/JUN/92	GALT FLOOD STATION	?	10
21/JUN/92	GALT FLOOD STATION	?	2
22/JUN/92	GALT FLOOD STATION	?	12
24/JUN/92	GALT FLOOD STATION	?	23
1/JUL/92	GALT FLOOD STATION	?	12
2/JUL/92	GALT FLOOD STATION	?	12
3/JUL/92	GALT FLOOD STATION	?	13
7/JUL/92	GALT FLOOD STATION	?	10
14/JUL/92	GALT FLOOD STATION	?	8
27/JUL/92	GALT FLOOD STATION	?	10
5/SEP/92	GALT FLOOD STATION	?	24
17/AUG/90	KING EDWARD & BURROWS	SWR	3
29/MAY/90	LINDEN	DWF	3
13/JUL/90	LINDEN	DWF	3
12/JUN/89	MAGER LIFT STATION	WWF	24
29/JUN/89	MAGER LIFT STATION	WWF	8
5JUL/89	MAGER LIFT STATION	WWF	9
12/JUL/89	MAGER LIFT STATION	WWF	6
18/AUG/89	MAGER LIFT STATION	WWF	14
9/MAY/90	MAGER LIFT STATION	DWF	3
21/MAY/90	MAGER LIFT STATION	WWF	3
5/JUN/90	MAGER LIFT STATION	WWF	7
7/JUN/90	MAGER LIFT STATION	WWF	24
8/JUN/90	MAGER LIFT STATION	WWF	12
24/SEP/92	MARION/DESPINS	?	9
1/OCT/92	MARION/DESPINS	?	3
30/JUN/93	MARION	?	11
1/JUL/93	MARION	?	24
9/JUL/93	MARION	?	6
17/JUL/93	MARION	?	5
18/JUL/93	MARION	?	4
22/JUL/93	MARION	?	24
24/JUL/93	MARION	?	24
2/AUG/93	MARION	?	7
2/AUG/90	MOORGATE	DWF	1
9/AUG/90	MOORGATE	DWF	3
13/AUG/90	MOORGATE	DWF	3
13/AUG/91	MOORGATE	DWF	3
2/AUG/90	STRATHMILLAN	DWF	1
9/AUG/90	STRATHMILLAN	DWF	3
13/AUG/90	STRATHMILLAN	DWF	3
31/MAY/91	STRATHMILLAN	WWF	12
1/JUN/91	STRATHMILLAN	WWF	10
7/JUN/91	STRATHMILLAN	WWF	9
13/JUN/91	STRATHMILLAN	WWF	11
25/JUN/91 a.m.	STRATHMILLAN	WWF	14
25/JUN/91 p.m.	STRATHMILLAN	WWF	10
13/AUG/91	STRATHMILLAN	DWF	3
1/JUL/93	SYNDICATE LIFT/FLOOD STATION	?	24
9/JUL/93	SYNDICATE LIFT/FLOOD STATION	?	24
2/AUG/93	SYNDICATE LIFT/FLOOD STATION	?	11
8/JUL/93	SYNDICATE LIFT/FLOOD STATION	?	12

Appendix 1-B

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ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ» º
    º          Storm Water Management Model          º
    º                 Version 1.30a                  º
    ÌÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
    Í¹ º                         Developed by        º
    ÌÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
    Í¹ º                    WP Software and XP
    Software            º
    º                                                º
    º               Based on the U.S. EPA            º
    º    Storm Water Management Model Version 4.3    º
    º                                                º
    º             Originally Developed by            º
    º              Metcalf & Eddy, Inc.              º
    º             University of Florida              º
    º           Camp Dresser & McKee Inc.            º
    º               September 1970                   º
    ÌÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
    Í¹ º  XP and WP Software       May 1994          º
    º     Data File Version --->     5.0             º
    ÌÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
    Í¹ º                 If problems occur in running
    this model          º
    º     please contact WP Software - Australia     º
    º                 or XP Software - U.S.A.        º
    º     Phone +61-6 253-1844  in Australia         º
    º     Fax # +61-6 253-1847  in Australia         º
    º     Phone (813)-888-6718  in U.S.A.            º
    º     Fax # (813)-885-4198  in U.S.A.            º

  ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼


ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
º         File names by SWMM Block          º
º          JIN  -> Input to a Block
º
º         JOUT  -> Output from a Block
º
ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
Í¼

   JIN for Block #     1 File #   20  C:\XPS\WORK\STRATHMI\RAIN\st250
  JOUT for Block #     1 File #    0  JOT.US
ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
º  Scratch file names for this simulation. º
º  Scratch files are used for all Blocks.  º
ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼

 NSCRAT #     1 File #    1  SCRT1.US
 NSCRAT #     2 File #    2  SCRT2.US
```

```
NSCRAT #     3 File #    3  SCRT3.US
NSCRAT #     4 File #   10  SCRT4.US
NSCRAT #     5 File #   11  SCRT5.US
NSCRAT #     6 File #   12  SCRT6.US
                            NSCRAT #     7 File #   13  SCRT7.US

ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
°    Parameter Values on the Tapes Common Block    °
ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼

 Number of Subcatchments in the Runoff Block (NW).... 1000  Number of
 1000 Runoff Water quality constituents (NRQ)............  5  Runoff
 5
 Number of Elements in the Transport Block (NET)..... 1000  Number of
 500 Number of Input Hydrographs in Transport (NTH)...... 1000  Numbe
 (NEE)........ 1000 Number of Groundwater Subcatchments in Runoff (NG
 all Blocks (NIE).. 1000 Number of Pumps in Extran (NEP)............
 (NEO)..................  500 Number of Tide Gates/Free Outfalls in E
 (NEW)........................  500 Number of Extran printout locatio
 elements in Extran (NTE).............  500 Number of Natural channel
 Storage junctions in Extran (NVSE)........  500
 Number of Time history data points in Extran(NTVAL).  100  Number of
 100 Number of Input Hydrographs in Extran (NEH)......... 1000  Numbe
 (NPS)...   10 Number of User defined conduits (NHW)..............
 (NECC)......   10 Number of Upstream elements in Transport (NTCC)...
 (NSTU)...........    2 Number of Values for R1 lines in Transport (N
 for (NNOD)........... 1000
#####################################################
# Entry made to the Runoff Block, last updated by #
  #     WP and XP Software during March, 1994.
                         #
#####################################################
                         #
 # "And wherever water goes, amoebae go along for
#
 #  the ride"                         Tom Robbins
#

#####################################################

                         #




 Snowmelt parameter - ISNOW.......................        0

 Number of rain gages - NRGAG.....................        0

 Quality is not simulated - KWALTY................        0
```

```
 Default evaporation rate used - IVAP............          0

 Hour of day at start of storm - NHR.............          7

 Minute of hour at start of storm - NMN..........

30

 Time TZERO at start of storm (hours)............

7.500
 Use Metric units for I/O - METRIC...............          1

  ===> Ft-sec units used in all internal computations

 Runoff input print control...                             0

 Runoff graph plot control....                             0

 Runoff output print control..                             2

     Limit number of groundwater convergence messages to     13122 (i

                              simulated)

 Month, day, year of start of storm is:                6/25/91

 Wet time step length (seconds).......                    300.

 Dry time step length (seconds).......                    300.

 Wet/Dry time step length (seconds)...                    300.

 Simulation length is......                               4.0 Hours
 Horton infiltration model being used
 Rate for   regeneration of infiltration = REGEN * DECAY
 Decay is read in for each subcatchment
 REGEN = .........................................     .01000
1

ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
                            »
 º   Processed Precipitation will be read on JIN(1)
º
ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
                            ¼

   ##############################
   #        Data Group F1       #
   # Evaporation Rate (mm/day)  #
   ##############################
```

```
JAN.  FEB.  MAR.  APR.  MAY   JUN.  JUL.  AUG.  SEP.  OCT.  NOV
DEC. ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ---
- ---3.00  3.00  3.00  3.00  3.00  3.00  3.00  3.00  3.00  3.00
3.00  3.00
************************************************
*          No Channel or Pipe Network          *
************************************************


ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
º           S U B C A T C H M E N T   D A T A        º
º Note that the labels for Infiltration refer to   º
º  either Horton, Green-Ampt or SCS parameters.
º
ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ
ͼ


Subcatchment          Channel    Zero        Width       Area    Percent
 No. - Name           or inlet  Detentn.      (m)        (hc)    Imperv.
 ÄÄÄÄÄÄÄÄÄÄÄÄÄ        ÄÄÄÄÄÄÄÄ  ÄÄÄÄÄÄÄÄ     ÄÄÄÄÄÄ      ÄÄÄÄÄ    ÄÄÄÄÄÄÄ
  1 1#1            1            50.00       500.00      69.10      14.00
Total Number of Subcatchments..                 1
Total Tributary Area (hectares).            69.10
Impervious Area (hectares)......             9.67
Pervious Area (hectares)........            59.43
Total Width (hectares)..........           500.00
Percent Imperviousness..........            14.00

1
**********************************************************
*     Arrangement of Subcatchments and Channel/Pipes     *
**********************************************************


    Inlet
1              No Tributary Channel/Pipes
               Tributary Subareas........ 1#1


************************************************************
                             *
* Hydrographs will be stored for the following   1 INLETS
*
************************************************************
                             *
1
```

```
**************************************************
*  Quality Simulation not included in this run *
**************************************************


      ***********************
      *    DATA GROUP M1    *
      ***********************
 TOTAL NUMBER OF PRINTED GUTTERS/INLETS...NPRNT..
1
    NUMBER OF TIME STEPS BETWEEN PRINTINGS..INTERV..
                             1

      ***********************
      *    DATA GROUP M3    *
      ***********************

       CHANNEL/INLET PRINT DATA GROUPS......1


*****************************************************
                          *
 *  Precipitation Interface File Summary
*
 *  Number of precipitation station....        1
*
*****************************************************
                          *

 Location Station Number
 -------- --------------
       1.             1


**************************************************
                        *
 * Summary of Quantity and Quality results for
*
 *           June       1991
*
**************************************************
                        *

   Day      Inlet            Rain         Flow
                              mm           mm
-----     -----           ----         ----     ---------
                          _
   25      1            19.00001       2.417
```

```
 Total      1            19.00001      2.417
 Year       1            19.00001      2.417
 ************************************************
 *      End of time step DO-loop in Runoff      *
 ************************************************

 Final Date (Mo/Day/Year)    =
6/25/91
 Total number of time steps =
  48
 Final Julian Date  =
91176
 Final time of day  =                                   41400.
seconds.
 Final time of day  =                                    11.50
hours.
 Final running time =                                  11.5000
hours.
    Final running time =                                    .4792
                          days.

 **************************************************
 *     Extrapolation Summary for Watersheds       *
 * # Steps ==> Total Number of Extrapolated Steps *
 * # Calls ==> Total Number of OVERLND Calls      *
 **************************************************

  Subcatch   # Steps   # Calls  Subcatch   # Steps   # Calls  Subcatch
  Calls --------   -------   -------  --------   -------   -------  --
  -------
 1#1               473       83
1
 **********************************************
 *       Continuity Check for Surface Water    *
 **********************************************
                                                                    M
                                                       cubic meters  T
 Total Precipitation (Rain plus Snow)                 1.312871E+04
 Total Infiltration                                   1.116689E+04
16.161
 Total Evaporation                                    1.661270E+02
 Surface Runoff from Watersheds                       1.670171E+03
 Total Water remaining in Surface Storage             1.366663E+02
 Infiltration over the Pervious Area...               1.116689E+04
                                  --------
 Infiltration + Evaporation +
 Surface Runoff + Snow removal +
 Water remaining in Surface Storage +
 Water remaining in Snow Cover.........               1.313985E+04
 Total Precipitation + Initial Storage.               1.312871E+04
```

```
 The error in continuity is calculated as
 ***************************************
 * Precipitation + Initial Snow Cover  *
       *      - Infiltration -
                    *
 *Evaporation - Snow removal -         *
 *Surface Runoff from Watersheds -     *
 *Water in Surface Storage -           *
 *Water remaining in Snow Cover        *
*-------------------------------------
                    *
 * Precipitation + Initial Snow Cover
*
***************************************
                    *
   Error..................................
                                       Percent
 *********************************************
 *       Continuity Check for Channel/Pipes   *
 *********************************************
                                                                      M
                                                                  over cubic mete
                                                                  Basin
 Initial Channel/Pipe Storage................               0.000000E+00
 Final Channel/Pipe Storage..................               0.000000E+00
 Surface Runoff from Watersheds..............               1.670171E+03
 Groundwater Subsurface Inflow...............               0.000000E+00
 Evaporation Loss from Channels..............               0.000000E+00
 Channel/Pipe/Inlet Outflow..................               1.670171E+03
 Initial Storage + Inflow....................               1.670171E+03
 Final Storage + Outflow.....................               1.670171E+03
 *******************************************
 * Final Storage + Outflow + Evaporation  - *
 * Watershed Runoff - Groundwater Inflow  -
                      *
 *     Initial Channel/Pipe Storage
*
 *     ----------------------------------
*
 *  Final Storage + Outflow  + Evaporation
*
*******************************************
                      *
 Error.......................................
1
                                                SUMMARY STATISTICS FOR SUBCATCHMENT
                                                ===================================

                                                                PERVIOUS AREA
AREA
```

SUBCATCH-MENT NO.	GUTTER OR INLET NO.	AREA (HA)	PERCENT IMPER.	TOTAL SIMULATED RAINFALL (MM)	TOTAL RUNOFF DEPTH (MM)	TOTAL LOSSES (MM)	PEAK REMAINIG DEPTH (MM)	RUNOFF (MM/HR)
1#1	1	69.10	14.0	482.6	.00	482.600	.000	

*** NOTE *** IMPERVIOUS AREA STATISTICS AGGREGATE IMPERVIOU

SUMMARY STATISTICS FOR CHANNEL

CHANNEL NUMBER	OF FULL COMPUTED FLOW (CMS)	FULL COMPUTED VELOCITY (M/S)	FULL COMPUTED DEPTH (M)	MAXIMUM OF INFLOW (CMS)	MAXIMUM OUTFLOW (CMS)	MAXIMUM OF DEPTH (M)	MA SURCHA VEL (M/
1				.6			

TOTAL NUMBER OF CHANNELS/PIPES = 1

*** NOTE *** THE MAXIMUM FLOWS AND DEPTHS ARE CALCULATED AT THE END

1

```
1.000 °ðððððððð°ðððððððð°ðððððððð°ðððððððð°ðððððððð°ððð
      o
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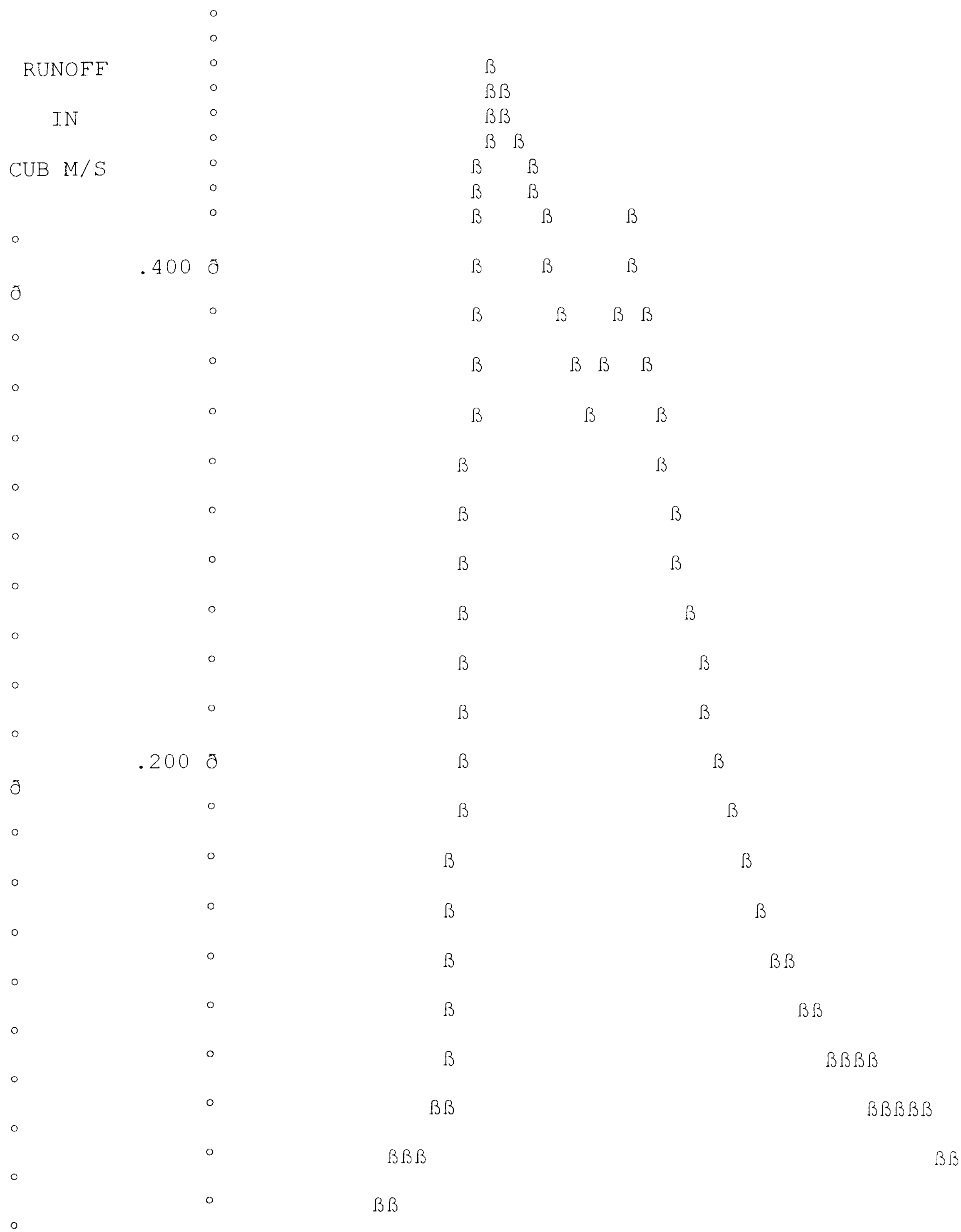
      o
 .800 ð
      o
      o
      o
      o
      o
      o
      o
      o
      o
 .600 ð
```


RUNOFF
IN
CUB M/S
.400
.200

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                          7.5        8.0        8.5        9.0        9.5       10.0

                             LOCATION NO. : FLOW SUM              TIME IN HOURS
                              SURFACE INLET HYDROGRAPH FLOW  SUMMATION FOR ALL INL
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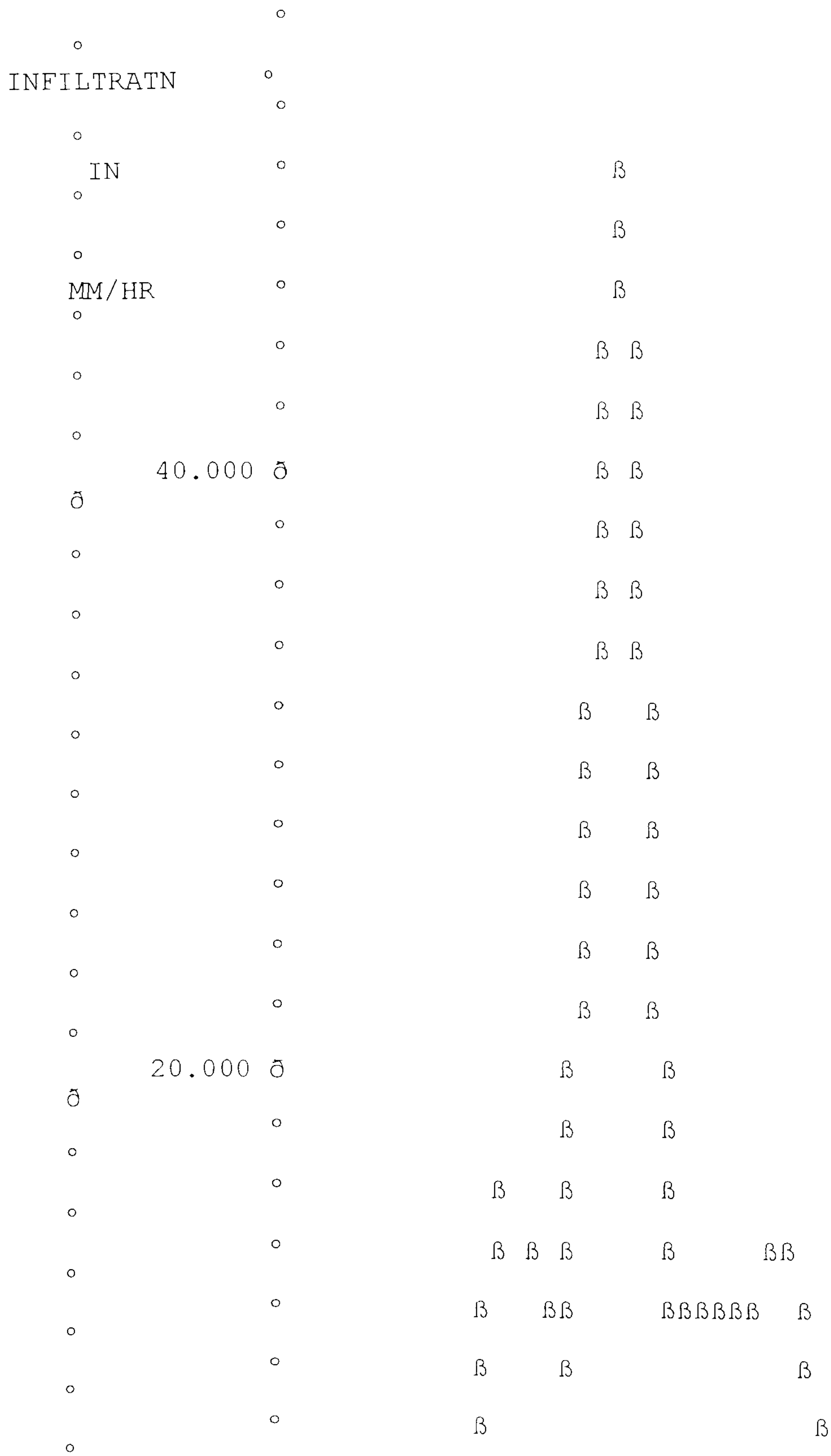
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IN
MM/HR
40.000
20.000

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                   7.5         8.0         8.5         9.0         9.5         10.0
                    LOCATION NO. : INFILTRA                 TIME IN HOURS
                     PLOT OF INFILTRATION RATE
1
 ************************************************
 *  Summary of quantity results (flow in cms) *
**************************************
                ********
```

Mo/Da/Yr	Hr:Min		Chan/Inlt Inflow 1 Cubic m/s
6/25/91	7	35	.000
6/25/91	8	5	.004
6/25/91	8	10	.031
6/25/91	8	15	.032
6/25/91	8	20	.059
6/25/91	8	25	.101
6/25/91	8	30	.536
6/25/91	8	35	.614
6/25/91	8	40	.435
6/25/91	8	45	.362
6/25/91	8	50	.350
6/25/91	8	55	.436
6/25/91	9	0	.420
6/25/91	9	5	.371
6/25/91	9	10	.285
6/25/91	9	15	.228
6/25/91	9	20	.174
6/25/91	9	25	.136
6/25/91	9	30	.121
6/25/91	9	35	.097
6/25/91	9	40	.091
6/25/91	9	45	.075
6/25/91	9	50	.072
6/25/91	9	55	.071
6/25/91	10	0	.059
6/25/91	10	5	.050
6/25/91	10	10	.042
6/25/91	10	15	.045
6/25/91	10	20	.039

```
    6/25/91  10  25        .033
    6/25/91  10  30        .029
    6/25/91  10  35        .025
    6/25/91  10  40        .022
    6/25/91  10  45        .020
    6/25/91  10  50        .017
    6/25/91  10  55        .015
    6/25/91  11   0        .014
    6/25/91  11   5        .012
    6/25/91  11  10        .011
    6/25/91  11  15        .010
    6/25/91  11  20        .009
    6/25/91  11  25        .008
    6/25/91  11  30        .007

  Flow wt'd means          .1159
  Flow wt'd std-devs       .1599
  Maximun value            .6141
  Minimum value            .0000
  Total loads           1.67E+03
                         Cubic-m
   ===> Runoff simulation ended
  normally.
   ===> SWMM Simulation ended normally.
   ===> Your input file was named : C:\XPS\WORK\STRATHMI\st250691.dat
              ===> Your output file was named: C:\XPS\WORK\STRATHMI\

ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
º       SWMM Simulation Date and Time Summary      º
ÓÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼
ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»
º Starting Date... March       18, 1995            º
º          TIME...          16:23: 8:60            º
º   Ending Date... March       18, 1995            º
º          Time...          16:23: 9:97            º
º  Elapsed time...                .017 minutes     º
º  Elapsed time...               1.000 seconds     º
ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼
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