Nottawasaga Valley Conservation Authority

Ministry of Natural Resources / Ministère des Richesses naturelles
Ontario

Environment Canada / Environnement Canada

Report

Watershed Hydrology Study for Nottawasaga, Pretty and Batteaux Rivers Black Ash, Silver and Sturgeon Creeks

Volume I — Technical Report

Canada/Ontario Flood Damage Reduction Program

May 1988
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May 3, 1988

Nottawasaga Valley Conservation Authority
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Attention: D. N. White
General Manager

Re: Watershed Hydrology Study for Nottawasaga, Pretty and Batteaux Rivers, Black Ash, Silver and Sturgeon Creeks

Dear Mr. White:

We are pleased to submit herewith our final report concerning the above-noted study.

The methodology and findings of our investigations are presented in the enclosed report (Volume I). Additional supporting documentation is presented separately in Volume II entitled "Technical Appendices".

We would like to express our sincere appreciation to all the members of the Project Committee for their co-operation and advice throughout the course of this study. All of which is respectfully submitted.

Yours very truly,
MacLAREN PLANSEARCH INC.

R. B. Wigle, P. Eng.
Project Manger

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ACKNOWLEDGEMENTS

This project was undertaken under the supervision of R.B. Wigle, P. Eng. who acted as Project Manager. The QUALHYMO modelling was conducted by M.D. Conetta, P. Eng. and assisted by P. Donahue. The DWOPER modelling was carried out by L.J.D. Alexander, P. Eng. Computer enhancements and meteorological data preparation were undertaken by G. Kearns, P. Eng. Dr. A.C. Rowney, Queen's University, served as technical advisor in as required basis.

The information presented in this report was derived with the kind cooperation and assistance of several individuals. Invaluable comments and direction were provided by the following members of the Canada-Ontario Flood Damage Reduction Program Project Committee:

- D.H. White, B.Sc., General Manager, Nottawasaga Valley Conservation Authority
- S. Moin, P. Eng., Environment Canada
- H. Sayeed, P. Eng., Ministry of Natural Resources, Central Region

The background data presented in this report was obtained from several sources including the Inland Water Directorate and the Atmospheric Environment Service of Environment Canada and the Ontario Ministry of the Environment.

We would like to express our gratitude to the Water Survey of Canada, Guelph for carrying out some of the streamflow measurements and training our staff. Finally, we would like to express our appreciation for the time and effort of all those who contributed to this project by way of information, discussions and otherwise.

1.0 INTRODUCTION

1.1 Objectives

In February 1986, the Nottawasaga Valley Conservation Authority initiated a comprehensive hydrologic study of the basins within the Authority's jurisdiction for the purpose of providing the flood magnitude on all watercourses for the 5, 10, 20, 50 and 100 year return periods and for the Regional Storm (Timmins Storm). Discharges were to be estimated on the Nottawasaga, Pretty and Batteaux Rivers and the Black Ash, Silver and Sturgeon Creeks and their tributaries under current and future urban land use conditions. Due to the large water storage capacity in the Minesing Swamp and the mild gradient of the Nottawasaga River between the Swamp and Georgian Bay, dynamic hydraulic routing procedures were to be employed to account for the attenuation effect on flood discharges.

Agricultural drainage within the Innnisfil Creek drainage catchment has reportedly contributed in recent years to the increase in the magnitude of flood peaks during the summer growing season. Hydrologic investigations were therefore, to address this concern and evaluate the hydraulic routing effect of municipal drains on larger storm flows that are experienced in Beeton Flats. Both existing and proposed drains were to be considered.

1.2 Description of the Drainage System (Ref. 4)

The Nottawasaga Basin is characterized by an extensive network of rivers and streams which collect surface run off and discharge into Georgian Bay (Figure 1.1).

The largest drainage system is the Nottawasaga River and its tributaries. It has a total length along its main channel of approximately 121 km. In the first 42 km, it flows north easterly, then swings north to follow a course near the eastern edge of the former Lake Algonquin. South of the

Minesing Swamp, the river enters the Simcoe Lowlands and meanders through the swamp northward to Jack's Lake. From there, the flow is towards the west for about 6 km following which a series of meanders lead in a straight course to the north-east through the sand dunes of Wasaga Beach to the river's outlet into Georgian Bay.

The Nottawasaga River has a total fall of 311 m from its source in the till moraines of Amaranth Township about 5 km south of the Town of Shelburne (elevation of 488 m) to the outlet into Georgian Bay (177 m). Its average gradient is 2.5 meters per km, varying considerably from a flat gradient of 0.11 meters per km near its mouth to a steep 19 meters per km in the upper reaches near Glen Cross.

The Nottawasaga River has five major tributaries; the Boyne River (243 square kilometers), the Mad River (466 square kilometers), the Pine River (347 square kilometers), all on the west side, and Innisfil Creek (464 square kilometers) and Willow Creek (308 square kilometers) on the east side. In addition, there are a number of streams that flow directly into Georgian Bay, the more prominent being Silver Creek (28.2 square kilometers), Black Ash Creek (40.5 square kilometers), the Pretty River (72.5 square kilometers), and the Batteaux River (66.5 square kilometers), in the northwest corner of the Authority's jurisdiction near Collingwood. These streams rise on the Niagara Escarpment and are characterized by extremely steep gradients in the upper reaches and mild slopes as they approach Georgian Bay.

One of the peculiarities of the area is the almost complete lack of natural lakes. There are only three of any consequences, Edward Lake, Little Lake and Marl Lake. Jack's Lake is known locally as a lake but is simply a swelling in the Nottawasaga River. The three lakes have surface areas of 28 ha, 253 ha, and 77 ha respectively.

There are a number of wetlands and marsh areas including Minesing Swamp in Vespra and Sunnidale Townships, Bear Creek source area in Barrie and the Townships of Essa and Vespra, Osprey Wetlands in Osprey Township, the Beeton Flats in Tecumseth Township and the Bailey Bog in Adjala and Tecumseth Townships. In total, all the wetlands cover some 6,475 ha in the Nottawasaga watershed.

1.3 Background Information

1.3.1 History of Flooding

High flows within watercourses draining the Nottawasaga River Basin are most commonly experienced during the spring months when the snowpack is dissipated by solar radiation and rainfall events. Long-term hydrometric records on the Nottawasaga River at Baxter indicate that in excess of forty-three percent of the annual runoff is gauged during the months of March and April while sixty percent is produced in the four month period between February and May. Climatological stations indicate a fairly uniform occurrence of precipitation across the watershed; however, during the winter season, the combined water equivalent of snowfall and rain within the lower portion of the basin near Georgian Bay exceeds the amounts in the central and upper zones by in excess of 100 mm (Ref. 4). Similar larger depths of precipitation occur on the Escarpment in the headwaters of the Pine, Mad and Boyne Rivers (Table 1.1) and persist as snowpack later into the spring due to the cooler temperatures.

Annual flow peaks are also observed most frequently in the spring months of March and April during the height of the freshet (Table 1.2). Nevertheless, flood discharges have occurred in all months except August and September. The second largest daily flow recorded on the Nottawasaga River at Baxter over the thirty-six year record period was caused by Hurricane Hazel (254 m^3/s; October 16, 1954).

NOTTAWASAGA RIVER BASIN: CLIMATOLOGY (Ref. 1, 6)

TABLE 1.1

LOCATION	WINTER DURATION			WINTER PRECIPITATION			SNOWPACK (Median Depth)		TEMPERATURE Mean Daily Maximum			TEMPERATURE Degree - Days		
	Mean First Date of	Mean Last Date of	Mean Length of Winter (days)	Rainfall (mm)	Snowfall (cm)	Total Water Equivalent (mm)	End of February (cm)	End of March (cm)	February °C-Days	March °C-Days	April °C-Days	February °C-Days	March °C-Days	April °C-Days
Barrie	Nov. 16	Apr. 05	141	159	275	408	30-40	<5	-3.1	2.0	10.3	5.3	29.4	153.7
✓Collingwood	Nov. 16	Apr. 05	141	133	254	348	30-40	<5	-2.5	2.3	10.3	8.3	38.2	175.5
Angus	Nov. 16	Apr. 05	141	103	280	311	30-40	<5	-2.3	2.7	11.5	5.2	35.3	171.9
Redickville	Nov. 10	Apr. 08	151	136	291	429	>40	>5	-4.4	0.1	8.8	2.5	20.9	139.8
Alliston	Nov. 18	Apr. 04	138	137	175	309	30	2	-2.7	2.1	11.6	-	-	-
Beeton	Nov. 18	Apr. 04	138	125	209	288	30	0	-2.3	2.8	11.4	5.1	38.0	183.2
Orangeville (MOE)	Nov. 17	Apr. 04	137	164	157	323	30	0	-3.3	1.6	10.0	5.3	33	159.2
Mount Forest	Nov. 09	Apr. 08	152	185	256	407	40	>5	-3.6	1.0	9.6	3.4	31.7	150.5

SEASONAL OCCURRENCE OF ANNUAL PEAK FLOWS

TABLE 1.2

GAUGE LOCATION	Drainage Area	Record Period	MAXIMUM MEAN DAILY FLOW		INSTANTANEOUS PEAK FLOWS		FREQUENCY OF OCCURRENCE OF ANNUAL PEAK INSTANTANEOUS FLOWS BY MONTH											
	(km^2)	(Years)	$m^3/s/(Date)$	$m^3/s/km^2$	m^3/s (Date)	$m^3/s/km^2$	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
Beeton Creek near Tottenham	86.0	1969-1984 (16 years)	17.0 (Mar. 5/79)	0.20	22.7 (Mar. 5/74)	0.26	1	3	7	5								
Bailey Creek near Beeton	207.0	1964-1978 (15 years)	49.8 (Mar. 5/74)	0.24	67.0([1]) Mar.5/74	-	1		3	9		1				1		
Boyne River at Earl Rowe Park	211.0	1969-1984 (16 years)	85.0 (Apr. 19/75)	0.40	122.0 (Apr. 19/75)	0.58		2	5	9								
Pine River near Everett	195.0	1969-1984 (16 years)	36.2 (Mar. 5/80)	0.19	53.0([1]) Mar.5/80	-		2	5	9								
Mad River near Glen Cairn	295.0	1964-1984 (21 years)	82.1 (Apr. 19/75)	0.28	129.0 (July 1/67)	0.44		1	7	10	1		1					1
Nottawasaga River near Baxter	1180.0([2])	1949-1984 (36 years)	267.0 (Apr. 13/51)	0.23	370.([1]) (Apr. 13/51)	0.31	1	3	14	15						1	1	1
Willow Creek above Little Lake	94.8	1973-1984 (12 years)	30.0 (Mar. 25/76)	0.32	35.3 (Mar. 21/80)	0.37		1	5	5								1
Willow Creek at Midhurst	127.0	1973-1984 (12 years)	19.9 (Mar. 15/77)	0.16	20.2 (Mar. 15/77)	0.16		1	7	4								

([1]) Instantaneous Flow Not Recorded; Estimated From Daily Record (Rep. No. 27)
([2]) Source of Information; Water Survey of Canada

Flooding has been of major concern throughout the history of the Nottawasaga Area (Ref. 3). Newspaper reports from the 1800's onwards describe floods within the basin with frequent regularity. Unfortunately, early accounts do not provide sufficient information regarding monetary values of flood damages, the amount of precipitation or streamflows. A historical summary of flood reports is presented in the Authority's Conservation Report (1973). Within rural areas, most flood damages have been in the form of crop losses, field erosion, loss of livestock and fences, silty deposits on the fields, contamination of wells and ponds, and the deterioration or destruction of roads and bridges.

The greatest damage resulting from a single flood occurred as a result of Hurricane Hazel in October 1954. Six lives were lost during this storm within the Authority's area and estimated losses corrected to 1987 prices were approximately $2,850,000.

Field inspections, interviews with local residents, as well as interpretation of aerial photographs during the preparation of the Authority's 1973 watershed report disclosed seasonal flooding along Bailey Creek, Batteaux River, Beeton Creek, Black Ash Creek, Lamont Creek, Innisfil Creek, Lisle Creek, Mad River, Nottawasaga River and Penville Creek. Lands around the perimeter of the Minesing Swamp are also subject to periodic flooding especially during the spring period. The extent of inundation has been documented for a typical high flow year (Ref. 3).

More recently, an inventory of flood damage centres was assembled (Ref. 4) as part of the Authority's water management plan. These are highlighted in the following points and noted in Figure 1.1:

Collingwood - Black Ash Creek

Significant areas along Black Ash Creek ~~has~~ have suffered damage during spring flood periods due to a combination of high flows and ice jams. During the summer, severe rainfall events have produced damaging flows.

Angus - Nottawasaga River and Pine River

The Village of Angus experiences significant flood damages at regular intervals of approximately five years.

Creemore - Mad River

The Village has developed in the flood plain of the Mad River. While flooding has not occurred in recent years the river rose to flood stage on February 22, 1937 in less than two hours. During this event, both the public school and continuation school were surrounded by water.

Avening - Mad River

The Hamlet of Avening immediately downstream of Creemore on the Mad River experiences flooding on a regular basis due to a combination of high flows and ice jams. About twenty-five residential dwellings are flooded to a minor degree, on a regular basis (1 in 5 years).

Wasaga Beach - Nottawasaga River

Within the Town of Wasaga Beach a considerable number of cottages and permanent residences have been established in low lying areas along the Nottawasaga River in the Oxbow area. Flooding can be caused by ice jams as well as high flows. The most recent occurrence was in the spring of 1981 when the blasting of ice jams was required as a relief measure.

Oro Township - Willow Creek

Oro Township has one minor flood damage centre along Highway No. 11 at Willow Creek. Frequent localized flooding is common at this location near the Second Line due to ice jams during spring runoff.

Sunnidale Township - Mad River

The lower reaches of the Mad River in the Township of Sunnidale has presented increasingly serious drainage and flooding problems to agricultural lands, township roads, and six residential dwellings. Continued erosion upstream on the Mad River has reportedly contributed to significant siltation of the lower reaches of the River upsteam of its confluence with the Nottawasaga River and the attendant loss of waterway conveyance capacity. This has caused a persistent problem throughout the spring and during high flow periods throughout the rest of the year. Portions of Sideroad 21 and Concession Road 11 were under water for more than 30 days in the spring of 1982 and during a number of days throughout the balance of the year.

Innisfil Township - Innisfil Creek

Flooding along Innisfil Creek due to rainfall events during the growing season between May 1 and November 1 causes considerable damage to agricultural crops.

1.3.2 Previous Hydrologic Studies

During the initial stages of the Hydrology Study, previous water resources reports on the Nottawasaga River basin were reviewed and pertinent information related to flood discharges and hydrologic parameters was abstracted. This data was subsequently used in establishing the basin hydrologic model and comparing the recurrence interval and Regional Storm flows with those established in earlier investigations. A synopsis of these reports together with a bibliography is presented in Appendix A of this report. The following points are considered relevant to this study.

i) watershed locations at which floodplain mapping is available from previous studies is shown in Figure 1-1

ii) hydrologic investigations have been completed for portions of the Conservation Authority's watershed noted in Table 1-3. When carried out in conjunction with floodplain mapping studies, design flows have been limited to Regional Storm discharges and with the exception of the Willow Creek and Black Ash studies, no calibration of hydrologic models has been undertaken

iii) hydrologic discretization of sub-basins during the current investigation took into account wherever possible the watershed units which have been used previously for flood plain mapping projects.

iv) earlier hydrologic investigations did not define the future land use on the basis of planning documents. It was, therefore, necessary to develop this information during the current study from Official Plans and amendments supplied by municipal offices. Existing land use inventories are not generally available from planning documents or previous hydrologic studies with sufficient definition to permit allocation to sub-basins used for hydrologic investigations. This information was assembled from aerial photography, Official Plans and Agricultural Land Use Systems maps.

TABLE 1.3

HYDROLOGICAL STUDIES WITHIN THE NOTTAWASAGA RIVER BASIN

Watercourse/Basin	Author/Title	Flows 5-Yr E	5-Yr F	10-Yr E	10-Yr F	25-Yr E	25-Yr F	50-Yr E	50-Yr F	100-Yr E	100-Yr F	Regional E	Regional F
Upper Nottawasaga River and Sheldon Creek	R.J. Burnside & Associates; Floodplain and Fill Line Mapping, Township of Mono, 1978	x		x		x		x		x		x	
Upper Nottawasaga River and Bailey Creek	Ainley and Associates Ltd.; Fill and Floodline Mapping of Adjala Twp., 1979												x
Beeton Creek	Triton Engineering Ltd. Beeton Floodline Mapping, 1973												x
Vespra Township-Nottawasaga River, Willow, Matheson, Marl and Bear Creeks	Ainley and Associates Ltd., Fill Line Mapping Township of Vespra, 1981												x
South Branch - Boyne River	Triton Engineering Services Ltd., Report on Hydrology for Channel Improvement Study on South Branch of the Boyne River, 1978	x		x		x		x		x			
Little Creek Town of Shelburne	Triton Engineering Associates Ltd.; Hydrological Analysis, Willow Creek, 1982	x		x		x		x		x		x	

Note: E = existing land use
F = future land use

TABLE 1.3 (Cont'd)

HYDROLOGICAL STUDIES WITHIN THE NOTTAWASAGA RIVER BASIN

Watercourse/Basin	Author/Title	Flows											
		5-Yr		10-Yr		25-Yr		50-Yr		100-Yr		Regional	
		E	F	E	F	E	F	E	F	E	F	E	F
Truax Creek (sub-catchments 600-603)	Cumming-Cockburn; A Floodplain Delineation Study for Truax Creek; 1985												x
Besley Drain Town of Shelburne	Marland Engineering Ltd.; Floodline Mapping for Besley Drain, Town of Shelburne												x
Pine River	The Lathem Group Ltd.; Flood Proofing Investigations, Angus Plaza, 1982									x	x		
Pine River	Crysler and Lathem Ltd.; Floodplain Study of Pine River near Angus, 1979												x
Willow Creek	Cumming-Cockburn & Associated Ltd.; Flood and Fill Line Mapping, Willow Creek, 1982	x		x		x		x		x		x	
Willow Creek	Cumming-Cockburn & Associates Ltd.; Hydrological Analysis, Willow Creek, 1982	x		x		x		x		x		x	

TABLE 1.3 (Cont'd)

HYDROLOGICAL STUDIES WITHIN THE NOTTAWASAGA RIVER BASIN

		Flows											
		5-Yr		10-Yr		25-Yr		50-Yr		100-Yr		Regional	
Watercourse/Basin	Author/Title	E	F	E	F	E	F	E	F	E	F	E	F
Lamont Creek (Town of Stayner)	Ainley and Associated Ltd.; Floodline Mapping Study, Lamont Creek, 1973												x
Lamont Creek	Cumming-Cockburn and Associates; King St. Flood Study; Town of Stayner, 1985	x		x		x		x		x		x	
* Black Ash Creek	Ainley and Associates Ltd.; Black Ash Creek Flood Control Study in the Town of Collingwood, 1983									x	x	x	x
Sturgeon Creek	Cumming-Cockburn and Associates; Beaver Brook Estates, Flood-plain Mapping Study, Sturgeon Creek									x	x		
Sturgeon Creek	Henderson, Paddon and Associates Ltd.; Mr. and Mrs. W. Plalte, Report on Hydrology and Hydraulics of Sturgeon Creek, 1985					x				x		x	
Upper Innisfil Creek	M.M. Dillon Limited; Fill Line and Floodplain Mapping Study; Innisfil Township, 1977												x

1.3.3 Sources of Information

A general description of the water resources of the Nottawasaga River together with an insight to the flood potential was obtained from watershed reports listed in the bibliography of this report. Records of streamflow and climatologic data for stations located within and adjacent to the Authority were provided by the Water Survey of Canada, the Ontario Ministry of the Environment and the Atmospheric Environment Service respectively.

Details of the physiographic characteristics of the study area that were required for the definition of the hydrologic model were assembled from a number of sources:

General

- The Physiography of Southern Ontario, Ontario Ministry of Natural Resources, 1984

Topographic Detail

- 1:50,000 national topographic information series maps
- 1:10,000 Ontario base maps (1984)
- flood plain maps (map coverage indicated in Figure 1.1)

Drainage Patterns

- 1:10,000 aerial photographs (1978)
- 1:30,000 Ontario base map aerial photographs (1983)

Soils

- Canada Department of Agriculture soil surveys of Simcoe and Dufferin Counties

Land use within the study area was identified to the degree required for hydrologic runoff computations. The definition of future urban land use was obtained from municipal plans and zoning by-laws (Table 1.4) while the real extent of current urban usage was interpreted from 1:30,000 aerial photographs. Agricultural cropping patterns and rural land cover was assembled from the Ontario Ministry of Agriculture and Food's agriculture land use systems series (1984). This information was considered valid for both the present and the future with the latter being applicable to those lands not affected by urban growth.

TABLE 1.4

FUTURE LAND USE: DATA SOURCES

	Municipality	Land Use Plan
Dufferin County	Township of Amaranth	1986 Official Plan
	Township of Melancthon	1986 Amendment #4 to Official Plan
	Township of Mono	1974 Official Plan, June 1986 Zoning By-law
	Township of Mulmur	1973 Official Plan; Amendment #5
Simcoe County	Township of Adjala	1986 Consolidated Official Plan
	Township of Essa	1985 Official Plan
	Township of Flos	1981 Amendment #7 to Official Plan
	Township of Innisfil	1981 Official Plan
	Township of Techumseth	1983 Amendment #4 to Official Plan
	Township of West Gwillimbury	1973 Official Plan, Amendment #3
	Township of Tosorontio	1972 Official Plan
	Township of Sunnidale	1985 Official Plan
	Township of Nottawasaga	1972 Official Plan
	Township of Vespra	1982 Official Plan
	Township of Medonte	1978 Official Plan
Grey County	Township of Collingwood	Official Plan of the Beaver Valley Planning Area
	Township of Osprey	1978 Official Plan of the Beaver Valley Planning Area
Cities, Towns and Villages	Town of Alliston	1975 Official Plan, Amendment #8
	Town of Collingwood	1986 Official Plan
	Town of Stayner	1980 Official Plan
	Town of Wasaga Beach	1984 Amendment #4 to Official Plan
	Village of Beeton	1980 Official Plan
	Village of Cookstown	1970 Official Plan
	Village of Creemore	1985 Amendment #2 to Official Plan
	Village of Tottenham	1984 Official Plan
	City of Barrie	1983 Official Plan

2.0 FIELD PROGRAMMES

2.1 Reconnaissance Surveys

At the onset of the Hydrologic Study, discussions were held with Authority staff in order to identify those drainage boundaries of the Nottawasaga basin which have not been well defined through topographic mapping. These headwater areas were examined on the 1:30,000 areal photographs to obtain a better appreciation of local drainage patterns and subsequently visited in the field during a reconnaissance survey. Final drainage boundaries depicted on Figure 1.1 reflect the height of land at these locations and the tributary drainage area of the Nottawasaga River system. Those sites requiring boundary definition during the study are summarized in Table 2.1.

In order to avoid discrepancies in drainage boundaries which may lead to errors in drainage planning, reference was made to annexation plan background studies for the City of Barrie (Ref. 26). Headwater areas of Bear Creek were defined in this manner.

2.2 Surveys of Waterway Cross-sections

2.2.1 Upper Nottawasaga River and Georgian Bay Tributaries

2.2.1.1 Selection of Cross-section Locations

During the field programme, surveys of waterway and floodplain cross-sections were completed for the Upper Nottawasaga River Basin and tributaries which discharge to the Lower Nottawasaga River and Georgian Bay. This information together with flow roughness estimates were required for hydrologic routing purposes when computing Basin flows with the digital model (QUALHYMO). Prior to implementing the field programme, the Nottawasaga watershed and catchments draining directly to Georgian Bay were discretized into sub-catchments representing uniform hydrologic characteristics (Figure

TABLE 2.1

DRAINAGE BOUNDARIES ESTABLISHED BY FIELD RECONNAISSANCE

HEADWATERS OF RIVER SYSTEM	DRAINAGE BASIN REFERENCE NO. (Figure 1-1)	LOCATION
Beeton Creek	200	South of Tottenham
Nottawasaga River	100, 102, 104	North of Orangeville
Boyne River	400	West of Shelburne
Pine River	500	North-West of Shelburne
Mad River	800, 801	West of Singhampton
Willow Creek	713	Craig Swamp
Willow Creek	707, 708, 709	South of Little Lake in City of Barrie
Bear Creek	600	City of Barrie
Innisfil Creek	300	North-East of Cookstown

2.1). Major watercourses which receive runoff from these sub-catchments and convey flows to Georgian Bay represent runoff from these sub-catchments and the Basin. Routing of flows through this network is required in order to accurately simulate peak flow attenuation processes and flow travel time. Stream and floodplain cross-sections form a basic input to the flow routing computations; therefore, field surveys of selected stream geometries were conducted to obtain representative conveyance sections.

The location of stream sections to be field surveyed was determined by initial inspection of available topographic maps and aerial photographs followed by a reconnaissance survey of the streams from road crossings. Stream reaches with relatively uniform cross-section and floodplain vegetation were delineated. It was determined that 30 field surveyed cross-sections would satisfy the foregoing hydrologic routing requirements. Location of sections is documented on Figure 2.1.

2.2.1.2 Field Surveys

Field surveys of waterway cross-sections within the subject stream reaches were carried out by a two-man crew (Messrs. L. Alexander and R. Malcolm) between July 7 and 11, 1986. Due to the low streamflows which were experienced at that time, it was possible to survey the stream bed bathymetry by fording the streams and measuring with a level, rod and tape. Elevations were recorded during this process with a level (Wild Nak O Serial No. 475095) which was located on the river bank quite close to the cross-section while horizontal distances were measured from an arbitrary reference point at some location within the section. No datum was established for the levels since the subsequent hydrologic routing did not require a geodetic reference. Waterway slopes were obtained from 1:50,000 NTIS maps.

The lateral extent of the surveyed cross-sections was established on a site-specific basis but primarily depended on the geometry of the cross-section and the difficulty of carrying a survey line through dense undergrowth. At each location, photographs were taken for documentation and for future reference when establishing the hydraulic roughness.

2.2.1.3 Presentation of Data

Survey information was documented for the Authority in the following format:

i) field survey book;

ii) the location of each cross-section together with the stream reach to which the section is applicable for routing purposes (Figure 2.1)

iii) waterway and floodplain cross-sections in a digital form. A hard copy is provided in Appendix B.

iv) cross-sectional plots for each section together with the Manning's 'n' used for the bed and overbank portions

v) photographs which document the vegetation and general setting of each section

Items i), iv) and v) were supplied to the Authority under separate cover.

2.2.1.4 Supplementary Information

During the subsequent hydrologic analysis of the Basins, it was found that the flow routing routines in the QUALHYMO model exceeded the flow travel time table at a few cross-sections under more extreme flooding conditions. This occurrence usually arose in stream reaches with wide flood plains in which the lateral inundation surpassed the distance that had been surveyed from the active waterway. The routing sections obtained in the field were supplemented with 1:10,000 OBM mapping in order to provide a fully defined section which will contain the flood discharge. Information on each section used in the hydrologic analysis can be obtained from the input files for the QUALHYMO model which was provided to the Authority as part of project documentation.

2.2.2 Minesing Swamp and Lower Nottawasaga River

2.2.2.1 Field Surveys

Surveys of the Nottawasaga River waterway cross-sections traversing the Minesing Swamp were carried out on July 15 to 17 and October 18, 1986. During July, the reach between Highway No. 90 and the confluence with the Willow Creek was completed while the lower portion of the Nottawasaga River within the swamp and Willow Creek were surveyed on October 18.

Reference water levels (geodetic datum) for the Nottawasaga River were recorded on each day of the July survey at the Highway No. 90 bridge in Angus, a Bailey bridge approximately 4.5 kilometres downstream, and at Edenvale near the outlet of the Minesing Swamp. Water elevations for the stream profile at intermediate locations within the swamp were estimated for each day of the survey by linear interpolation. Fourteen surveyed cross-sections (Fig. 2.2) of the Nottawasaga River were completed for the reach above the confluence with the Willow Creek. Section locations were first established from 1:50,000 topographic maps and modified as required during the field survey in order to provide representative cross-sections. Surveys were carried out using a survey tape and a sounding rod or chain for the waterway section and survey level (Wild Nak O serieal no. 475094) within the overbank section. Cross-sections were extended at least 50 metres from the edge of the stream. Due to the difficult access to the swamp and the numerous log jams encountered along the waterway, a canoe was used during the survey (Messrs. P. Donahue and C. Thomas) for transport.

During the bathymetric survey (October 15 to 18, 1986; Messrs. C. Thomas and G. Hebbert) of the Lower Nottawasaga River from the outlet at Nottawasaga Bay to the confluence with the Willow Creek and the foregoing Creek within the Minesing Swamp (Fig. 2.2), reference water levels were established on temporary staff gauges at the Wasaga Beach and Edenvale bridges and the crossings upstream and downstream of Jack's Lake. Nearby benchmarks were surveyed at the former two locations while a topographic elevation of the bridge decks was obtained at the Jack's Lake crossing. The elevations of the water profile at intermediate locations were interpreted linearly with chainage between these reference levels on the days of survey.

Thirty-three cross-sections (Fig. 2.2) were surveyed on the Lower Nottawasaga River below the Willow Creek confluence with a chart recording echo sounder (Furuno Model No. FE-600). Streambank surveys were carried out below Jack's Lake but were not possible above this point due to high waters which accompanied flood conditions. The topography of the floodplain was obtained from 1:10,000 Ontario base maps at these sections for modelling purposes. Doran Lake was sounded with a rod and chain due to the shallow water depths.

In the absence of as-built plans for the bridge-crossings at Jack's Lake and Doran Lake, field surveys of details required for hydraulic modelling were completed on October 28, 1986.

2.2.2.2 Presentation of Data

Survey information was documented for the Authority in the following format:

i) field survey book

ii) the location of each cross-section (Fig. 2.2)

iii) waterway and flood plain cross-sections in a digital form

iv) cross-sectional plots for each section

v) bridge dimensions and pictures

This information was forwarded to the Authority under separate cover.

2.3 Flow Monitoring

2.3.1 Upper Nottawasaga River Basin

2.3.1.1 General

There are several streamflow gauging stations within the Nottawasaga Valley Conservation Authority and the records at these hydrometric stations are useful for the calibration/validation of hydrologic models. However, some catchment areas within the NVCA have runoff characteristics that merit special attention when estimating the flood potential. Two such areas are the Innisfil Creek catchment area and the watercourses draining directly into Georgian Bay. The former catchment area has extensive municipal drains and the latter watercourses have steep channel gradients due to their proximity to the Niagara Escarpment.

In order to obtain high flow events for calibration/validation purposes, temporary manual flow gauging stations were established at a suitable location on Innisfil Creek and on Pretty River. The Pretty River was selected as being representative of the watercourses draining into Georgian Bay.

A temporary flow gauging station was also established on the upper Nottawasaga River during the study. Although a recording streamflow gauge exists at Baxter, it was felt that an additional upstream flow station on the Nottawasaga River near Alliston would provide streamflow data on a smaller catchment area for modelling purposes.

2.3.1.2 Field Monitoring Network

To obtain calibration/validation data for Innisfil Creek, Pretty River and Upper Nottawasaga River, continuous rainfall and streamflow data are required for high flow events. Based on modelling requirements, desirable flow monitoring locations for the above-noted catchment areas were initially identified from available mapping and areal photography. Similarly, two potential recording rainfall sites were identified to supplement the areal distribution provided by the existing recording rainfall network. One site was identified in the Cookstown area and the other in the Collingwood area.

Following the initial identification of potential sites, a field reconnaissance was undertaken to select appropriate sites for streamflow monitoring and rainfall observations. The following criteria was used for the selection of the streamflow sites:

- no backwater effect
- uniform channel section with non-erodible bed
- structure across the watercourse to conduct metering in safety
- easily accessible

Based on the above considerations, the following sites were selected for flow metering:

i) Innisfil Creek at the first culvert upstream of Highway 27, in the Cookstown area

ii) Pretty River at Highway 26 bridge, Collingwood

iii) Nottawasaga River at the second bridge downstream of Highway 50, south of Alliston

The locations of the above flow monitoring stations are shown in Figure 1.1. On June 25, 1986, staff gauges of three metre length were mounted on the downstream side of the concrete abutments at these locations to avoid backwater effects.

The following criteria was used for the site selection of the rainfall gauges:

- no vertical obstructions nearby to obstruct rainfall catch
- protection from potential vandalism
- availability of interested observer(s) to read the gauge(s)
- accessibility to hydro power

Two sites which met the foregoing criteria were located at 54 King St. N., Cookstown and 119 Minnesota St., Collingwood with the assistance of the Authority (Figure 2.1).

At each of the rainfall sites, a recording Tipping Bucket rain gauge was installed. Each recorder was connected to a hydro line and housed in a garage. A manual gauge was also installed near each Tipping Bucket rain gauge to compare the rainfall observations.

2.3.1.3 Training of Field Staff

The efficient and timely response required to monitor high flow events on small catchments dictates that field crews must be mobilized quickly. The assistance of the engineering firm, Reid and Associates Limited with offices in Barrie, was obtained to provide field crews on short notice to monitor high flow events.

In order to ensure that flow monitoring procedures were carried out to accepted standards, the Water Survey of Canada (WSC) personnel trained the field crews through class instruction and flow monitoring exercises at the Innisfil gauging station.

The rainfall observers were also instructed on the procedure to follow in reading the gauges and who to contact in case of a malfunction. The manual gauges were read twice daily at about 7:00 a.m. and 7:00 p.m.

2.3.1.4 Flow Monitoring Communication System

Although Reid and Associates were required to conduct the field monitoring, MacLaren Plansearch retained the responsiblity to advise the field crews of potential high flow events.

General weather reports were obtained by radio from the weather broadcast channel maintained by the Atmospheric Environment Service. However, for more specific information, arrangements were made to contact the Toronto Weather Office. Contact was initiated with the weather office to consult with the weather forecasters, obtain forecasted and observed rainfall amounts, and to obtain the path and aerial distribution of storms by the use of the weather radar.

The automated flow gauges on the Nottawasaga River at Baxter and the Pine River at Everett were also polled regularly by telephone. The information obtained from these flow gauges together with the recorded rainfall data provided an assessment of the soil moisture conditions within the NVCA. This information was useful in the assessment runoff from future rainfall amounts.

2.3.1.5 Flow Monitoring

The initial duration of the flow monitoring program was from July 2 to August 1, 1986. However, due to lack of high flow events during the above period, the flow monitoring program was extended until August 15, 1986.

Most of the rainfall events that occurred during the monitoring period were generated by thunderstorms. Unfortunately, thunderstorms are usually local in nature and their exact occurrence is difficult to forecast. This aspect made flow monitoring very difficult, because the exact rainfall amounts and the aerial distribution were often difficult to predict.

Although most of the rainfall amounts near the flow monitoring stations were generally small, one rainfall event did occur at Collingwood which provided significant rainfall. The event occurred early in the morning on July 26, 1986 and produced about 74 mm within a couple of hours. However,the thunderstorm was localized and was not brought to the attention of MacLaren Plansearch personnel by the weather office. Consequently, no flow monitoring of the Pretty River was undertaken. For the above event, the following rainfall amounts were recorded: Alliston, 20.6 mm; Cookstown, 23.6 mm; and Camp Borden, 22.0 mm. From the polling of the automated gauges on Pine River and Nottawasaga River at Baxter, the peaks generated from the above rainfall were small since fairly dry soil moisture conditions existed prior to this event.

Another major thunderstorm event occurred in the Cookstown area on August 15, 1986. The thunderstorm was part of the system that produced record rainfall in the Toronto area. Within the study area it produced the following rainfall amounts: Cookstown, 25 mm; Collingwood, 6 mm; Alliston, 11.8 mm; and Barrie, 0.0 mm. At Sharon, east of the NVCA, it produced 57.3 mm in less than one hour.

The Innisfil Creek catchment produced significant runoff from the above rainfall due to the wet antecedent soil moisture conditions. The water level at the gauging station rose about 0.75 metre. The field crew started to monitor the event starting about 21:00 hours on August 15 and finished about 16:00 hours on August 16. Since little warning was received regarding the severity of the thunderstorm and its path, there was some delay in mobilizing the field staff. Consequently, the rising limb of the flow hydrograph was not observed. The recorded hydrograph and rainfall are shown in Figure 3.5.

Daily rainfall totals recorded over the July 2 to August 15, 1986 observation period at the Collingwood and Cookstown manual gauges are presented in Table 2.2. Strip charts are also available. The continuous rainfall data was abstracted only for the August 15, 1986 event at Cookstown for the calibration of the Innisfil Creek hydrologic model.

2.3.2 Minesing Swamp and Lower Nottawasaga River

A flow and water level monitoring program was undertaken in conjunction with staff of the Conservation Authority and the Water Survey of Canada during the height of the spring freshet in 1987. The observed data was subsequently to be used for the calibration of hydraulic routing procedures on the Lower Nottawasaga River system.

Hourly stream flow information is available from permanent Water Survey of Canada gauging stations on the Nottawasaga River at Baxter, the Pine River at Everett, the Mad River near Glencairn, and the Willow River at Midhurst (Appendix L). Unfortunately, the spring data for the Pine River near Everett was not to be abstracted by the Ontario Ministry of the Environment for the Water Survey of Canada until December 1987 and was not available for the study. Further definition of inflows and discharges from the Minesing Swamp was provided by temporary stations which were established on the Nottawasaga River at the Highway No. 90 bridge in Angus and the Highway No. 26 bridge in Edenvale. River stage readings were taken within the lower Nottawasaga River at Edenvale and Wasaga Beach (Figure 1.1).

Overall coordination and organization of the field observations program was carried out by MacLaren Plansearch Inc.. Discharges emanating from the upper Nottawasaga River basin were remotely monitored by the consultant by accessing the Authority's telemark at the Baxter hydrometric station (Water Survey of Canada). At the same time, the Atmospheric Environment Service was contacted for forecasts of temperature (5 day) and rainfall (24 hours to 48 hours). Snowpack estimates for the watershed were available from snow-

TABLE 2.2

DAILY RAINFALL TOTAL RECORDED AT COLLINGWOOD AND AT COOKSTOWN

Date (1986)	Collingwood (mm)	Cookstown (mm)
July 2	-	2
3	-	-
4	5	Trace
5	1	1
6	-	-
7	-	-
8	-	-
9	-	Trace
10	-	-
11	-	-
12	Trace	Trace
13	19	8
14	Trace	-
15	-	-
16	-	-
17	9	7
18	2	11
19	-	2
20	-	-
21	-	-
22	-	-
23	-	-
24	-	-
25	-	-
26	74	23
27	-	-
28	2	-
29	Trace	-
30	1	-
Aug. 1	6	10
2	-	-
3	-	Trace
4	-	-
5	-	-
6	Trace	-
7	6	10
8	15	N/A
9	16	11
10	Trace	Trace
11	-	-
12	-	-
13	-	-
14	Trace	-
15	6	39

courses maintained by the Conservation Authority. When meteorological forecasts together with rising flows on the upper Nottawasaga River indicated the possibility of a significant spring flow event, a joint decision was made by the Authority and the consultant whether to assign a Water Survey of Canada field crew to the Nottawasaga River basin for flow monitoring duties. Flow monitoring was initiated by the consultant through a request for assistance which was directed to the Water Survey's office in Guelph.

Flow observations made by the Water Survey of Canada crew on the downstream side of the bridges at Highway No. 90 in Angus and Highway No. 26 at Edenvale between April 4 and 15, 1987 are presented on Table 2.3. Suspension measurements from the bridges were undertaken with Price current metres used to measure the velocity at the various metering panels. Discharges at Angus on intermediate days were synthesized during the subsequent dynamic routing investigations from continuous flow records which were available from the permanent stations on the Nottawasaga River at Baxter.

Water stages which were recorded on the lower Nottawasaga River by Authority staff over the freshet period are summarized in Table 2.4. The consultant had installed staff gauges at the Edenvale and Wasaga Beach bridges during the fall of 1986 in preparation for the spring monitoring program. In view of problems in observing levels at the old Highway No. 92 bridge in Wasaga Beach and concerns about the influence of lake elevations at this site, the Authority established a temporary staff gauge further upstream at the Schoonertown bridge and recorded water surface elevations throughout the high water period. These gauges were surveyed into the geodetic datum (G.S.C.) in order to relate observed water levels to computed flow profiles.

TABLE 2.3

WATER SURVEY OF CANADA FLOW OBSERVAIONS

Date	Location	River	Width (m)	Area (m^2)	M. Vel. (m/s)	M.G.H. (m)	Discharge (m^3/s)
Mar 08/87	Angus[1]	Nottawasaga	44.0	111	0.533	1.250	59.2
Apr 04/87	Angus	Nottawasaga	48.0	133	0.672	1.35	89.6
Apr 05/87	Angus	Nottawasaga	50.0	160	0.765	--	122.0
Apr 09/87	Angus	Nottawasaga	45.0	106	0.569	0.981	60.1
Apr 10/87	Angus	Nottawasaga	43.0	95.0	0.535	0.738	50.8
Apr 15/87	Angus	Nottawasaga	42.0	58.4	0.480	--	28.0
Apr 06/87	Edenvale[2]	Nottawasaga	85.5	219.0	0.310	--	67.9
Apr 09/87	Edenvale	Nottawasaga	80.0	247.0	0.514	3.180	127.0
Apr 10/87	Edenvale	Nottawasaga	80.0	254.0	0.508	3.13	125.0
Apr 15/87	Edenvale	Nottawasaga	80.0	199.0	0.485	2.500	96.5

(1) Dwoper Model Cross-section No. 1; Chainage 45,900 m

(2) Dwoper Model Cross-section No. 12; Chainage 29,910 m

TABLE 2.4

WATER ELEVATIONS: SPRING FRESHET 1987
STAFF GAUGE READINGS

1. Nottawasaga River at Edenvale (Hwy. 26 bridge, downstream face)

Date	Time	Geodetic Elevations (m)
April 07, 1987	18:34	182.505 (1)
April 08, 1987	7:19	182.630
	14:29	182.655
	18:45	182.655
April 09, 1987	7:33	182.680
	17:20	182.655
April 10, 1987	8:07	182.63
	16:41	182.58
April 11, 1987	14:30	182.505
April 12, 1987	13:51	182.380
April 13, 1987	9:36	182.280
April 15, 1987	8:00	181.980

2. Nottawasaga River at Wasaga Beach (Schoonertown bridge)

Date	Time	Geodetic Elevations (m)
April 07, 1987	20:12	177.467 (2)
April 08, 1987	6:57	177.427
	14:49	177.457
April 09, 1987	7:13	177.457
	17:42	177.467
April 10, 1987	7:50	177.457
	16:57	177.447
April 11, 1987	14:13	177.417
April 12, 1987	13:33	177.417
April 13, 1987	8:58	177.397 ("O" mark on staff gauge)
April 15, 1987	7:45	(readings discontiued - below "O" mark on staff gauge)

(1) Benchmark MTC 798122 Elev. 186.788 m.
Tablet in Concrete site on south side of Highway 26, 104.0 m west of concrete bridge over Nottawasaga River and 117.4 m south of centreline of Highway 26.

(2) Town of Wasaga Beach benchmark elev. 183.70 m.
Top of south west anchor bolt in light standard on Oxbow Park Road 149.64 m south of intersection of River Road West and Oxbow Park Road. Dwoper Model Cross-section No. 27; Chainage 5,607 m.

3.0 HYDROLOGIC INVESTIGATIONS

Within the Nottawasaga basin, recording hydrometric stations have been established and maintained by the Water Survey of Canada and the Ontario Ministry of the Environment to provide flow observations on the tributaries and main branch of the river. Historic flow records are an important source of frequency based information that provide an insight into the flow potential within the watersheds under the jurisdiction of the Conservation Authority.

Despite the density of the flow monitoring network, a requirement often arises to establish the flood hazard at intermediate ungauged locations. In these instances, existing development may be exposed to the flood hazard or urban growth may require an accurate assessment for planning purposes. Hydrologic models which simulate the runoff response of a basin to precipitation or snowmelt are increasingly used for this purpose especially when the record period for hydrometeorologic information also makes it possible to extend the database of flow records. Computations with the models consist of an accurate determination of the annual flood hydrograph from the hydrometeorologic data collected during the event and subsequent frequency analysis of the annual flow series to produce frequency based estimates of flood discharges.

In recent years, the effects of urban development and agricultural drainage on the timing and quantity of runoff has caused considerable concern to water resource planners and administrators. Depending on the increase in imperviousness and the degree of improvements made to local drainage systems, larger flood peaks can be produced which result in monetary damages to floodplain structures, agricultural lands and natural watercourses. Historical flow records will not provide estimates of the flood hazard arising from changes in basin response to inputs of precipitation or snowmelt. However, calibrated hydrologic models have demonstrated a capacity to accurately predict the future flood hazard especially when basin features related to drainage improvements are represented explicity in the simulation.

Hydrologic models of the Nottawasaga River basin and the smaller catchments of the Pretty and Batteaux Rivers plus the Black Ash, Silver and Sturgeon Creeks were established to provide frequency based estimates of flood magnitudes at numerous locations throughout the catchments and to quantify the effect of urbanization and agricultural drainage improvements. The flood standard which defines floodplain limits for regulatory purposes within the Nottawasaga Valley Conservation Authority continues to be the flood resulting from the Timmins storm (1961) event. These flood discharges were also calculated with the precipitation runoff model in order to provide a uniform hydrologic basis for flood profile computations.

3.1 Existing Database

3.1.1 Meteorological Records

The hydrologic model (QUALHYMO) used on the Nottawasaga Basin requires two input data time series: precipitation and temperature. The following sections outline the procedures used to develop the hourly precipitation and temperature databases.

3.1.1.1 Precipitation

Station Selection

The first step in selecting the precipitation stations to be used in this study was to obtain from the Atmospheric Environment Service, Environment Canada, a list of all stations within the rectangular areas bounded by latitudes 43°30' and 45°00' and longitudes 79°00' and 81°00'.

From this list, precipitation stations were selected based on their proximity to the Nottawasaga Basin, and the amount of data available at the station. All stations in and around the study area with a significant period of record were included. Table 3.1 lists the selected stations along with their time step and period of record. Data for all these locations (Figure 1.1) was obtained on magnetic tape from the Atmospheric Environment Service.

Data Preparation

Most of the precipitation data available within the Nottawasaga Basin is at a daily time step, while the hourly data is found outside or near the edge of the basin. To make full use of all data, and provide complete coverage of the study area, the following procedures were performed.

(a) The following eight daily stations with complete periods of records were selected as base stations:

Orangeville	Monticello
Glen Haffy	Mount Forest
Midhurst	Fergus
Maple	Essa

(b) A mathematical relationship was derived between each of the remaining daily stations and the eight base stations. This was done using multiple linear regression techniques.

(c) The missing data at each station were filled in using the relationships derived in (b). At this point, the daily precipitation database was complete at all stations for the period 1962 to the present.

TABLE 3.1

PRECIPITATION STATIONS

Location	AES Station Number	Period of Record
Daily Stations		
Alliston	6110216	1967-1974
	6110218	1973-1984
Beeton	6110667	1968-1971
	6110661	1962-1969
	6110663	1971-1984
Collingwood	6111793	1962-1974
Cookstown	6111859	1972-1984
Essa	6112340	1962-1984
Glen Haffy	6152833	1962-1984
Midhurst	6115099	1962-1983
Orangeville	6155790	1962-1984
Redickville	6146939	1962-1984
Shanty Bay	6117684	1973-1984
Shelburne	6147693	1981-1984
Thornbury	611HBEC	1968-1984
Wasaga Beach	6119294	1979-1981
Hourly Stations		
Barrie	6110557	1968-1984
Bolton	6150825	1978-1984
Fergus Shand Dam	6142400	1962-1984
Grand Valley	6142991	1975-1984
Maple	6154950	1962-1975
Mount Forest	6145503	1962-1984
Orillia	6115820	1965-1984

For example, (Appendix D), in order to obtain a complete record of daily precipitation at Collingwood from 1962 to present, the nearby meteorologic stations at Orangeville, Essa and Thornbury were selected and a multiple linear regression equation was established by standard statistical techniques.

Collingwood daily precipitation (preferred model) = Orangeville daily precipitation x 0.1264 + Essa daily precipitation x 0.4126 + Thornbury daily precipitation x 0.5933

Missing daily readings at Collingwood were infilled by application of the foregoing equation (preferred model). However, only Orangeville and Essa represent "bare stations" with complete records; therefore, for those days in which missing records occur at Thornbury, it was necessary to select "bare stations" further from Collingwood. A "secondary model" was established between Collingwood and Monticello, Orangeville, Midhurst and Essa by multiple linear regression techniques.

Collingwood daily precipitation (secondary model) = Orangeville daily precipitation x 0.1326 + Monticello daily precipitation x 0.1532 + Midhurst daily precipitation x 0.2667 + Essa daily precipitation x 0.5001

This secondary model was employed to estimate daily precipitation readings at Collingwood when corresponding daily readings were missing at Thornbury.

Data files of the recorded daily precipitation and the infilled records for each of the seventeen meteorologic stations were transferred to the Authority in digital format for future reference.

(d) The daily data were distributed into hourly amounts by using the closest hourly station as a guide. The percentage of the daily total occurring in each hour was set equal to that of the guide station.

If the closest hourly station had zero precipitation or missing data then the next closest hourly station was used. This substitution process was continued, if necessary, until all hourly stations had been examined. If there was still no suitable guide station, the daily total was divided into 24 equal amounts.

(e) Hourly precipitation data is not available during below zero (Celcius) temperatures at most AES stations due to gauge freeze-up. The Mount Forest station, however, provides six-hour data for the entire year. This six-hour data was divided into six equal hourly amounts and used in (d).

(f) The hourly data at each station was written to a computer disk file in the required format for the QUALHYMO model.

The final results of the above procedures was the establishment of an hourly precipitation database covering the whole of the Nottawasaga Basin from 1962 to the present.

3.1.1.2 Temperature

Temperature data at an hourly time step was available only at the Mount Forest station. This data was used for the whole study area. Any differences between the Mount Forest gauge and the conditions in a sub-basin were accounted for in the calibration of the snowmelt parameters.

3.1.2 Hydrometric Records

The location of the hydrometric stations within the NVCA are shown in Figure 1.1. The pertinent information related to each station is presented in Table 3.2.

Daily discharge data for all hydrometric stations was obtained for the period of record from the WSC. Hourly streamflow data was also obtained for Federal government stations from the WSC for the 1975-1984 period. These stations were: Willow Creek above Little Lake and at Midhurst; Mad River near Glencairn and Nottawasaga River at Baxter. Annual maximum instantaneous peak flows are also published by the WSC for each recording streamflow gauge over the entire record period.

Hourly streamflow for specific events during the 1975-1984 period were obtained from the Ontario Ministry of the Environment. These stations were: Pine River near Everett, Boyne River at Earl Rowe Park and Beeton Creek near Tottenham.

Hourly streamflow data for all stations is not available from early November to early March. The MOE data has several periods in the spring where hourly flow data was missing. The missing data in several cases restricted the events that could be selected for the calibration/validation of the QUALHYMO Model.

3.1.3 Snow Cover

The location of the snow courses within the NVCA are shown in Figure 1.1. The relevant information for each snow course is presented in Table 3.2.

The snow courses are operated by the NVCA and snow sampling is usually undertaken at the beginning and middle of each month during the winter/

TABLE 3.2

HYDROMETRIC STATIONS AND SNOWCOURSES

Ref. No.	Station	Agency	Station Type	Period of Record	DATA Precipitation	Temperature	Wind Speed	Streamflow	Snow Course
1	Barrie	AES	Recording	1968-Pres	X	X			
2	Mount Forest	AES	R	1962-Pres	X	X	X		
3	Alliston	AES	Manual	1968-Pres	X	X			
4	Cookstown	AES	M	1972-Pres	X	X			
5	Beeton	AES	M	1975-Pres	X	X			
6	Collingwood	AES	M	1960-1975	X	X			
7	Wasaga Beach	AES	M	1972-70 1978-81	X	X			
8	Shelburne	AES	M	1981-Pres	X	X			
9	Tottenham	AES	M	1971-79	X	X			
10	Orangeville OWRC	AES	M	1961-Pres	X	X			
11	Elora Res. Stn.	AES	R	1970-Pres	X	X	X		
12	Nottawasaga River near Baxter	WSC	MC RC	1944-65 1966-Pres				X	
13	Baily Creek near Beeton	WSC	RC	1963-78				X	
14	Beeton Creek near Tottenham	WSC	RC	1977-Pres				X	
15	Boyne River at East Rowe Park	WSC	RC	1969-75 1977-Pres				X	
16	Pine River near Everett	WSC	RC	1970-75 1978-Pres				X	
17	Mad River near Glencairn	WSC	RC	1967-Pres				X	
18	Willow Creek above Little Lake	WSC	RC	1973-Pres				X	
19	Willow Creek at Midhurst	WSC	RC	1973-Pres				X	
20	Colwell	MNR	M	1977-Pres					X
21	Edenvale	MNR	M	1971-Pres					X
22	Mono Centre	MNR	M	1971-Pres					X
23	Maple Valley	MNR	M	1977-Pres					X
24	Tottenham	MNR	M	1971-Pres					X

spring period. At each snow course snowpack depth and water equivalent information is measured.

The snowpack data was useful for comparison of observed and simulated snowpack water equivalent for the various calibration/validation events.

3.2 Hydrologic Model

3.2.1 Description of the QUALHYMO Model

After careful review of the Conservation Authority's water management program and the requirement for hydrologic information concerning magnitude and frequency of flood discharges, the model, QUALHYMO (Ref. 10, 11), was chosen to estimate peak flows throughout the Authority's watershed under existing and future land use conditions. QUALHYMO is a simple continuous water quantity and quality simulation model which was developed in 1983 at the University of Ottawa for the analysis of stormwater detention ponds. The model can be used as a general tool for simulating rainfall-runoff; however, it is most suited to planning level analysis of river basins where the land surface is developing from a rural or undeveloped state to an urban land use.

Several concepts in the QUALHYMO model have been retained from two earlier single event hydrologic models: HYMO (Ref. 12) which is a runoff model that has been tested and extensively used in Ontario for the hydrologic component of flood plain mapping studies and OTTHYMO (Ref. 13), which is gaining widespread acceptance in planning level studies of storm water management within urban areas.

Meteorologic input to the QUALHYMO model consists of hourly rainfall records or liquid input from snowmelt. During the winter period, precipitation is categorized as liquid or snow depending on air temperature relative to a specified threshold value at or near to 0° Centigrade. Snowpack accumulation and ablation is estimated by a temperature index equation.

In generating runoff from pervious land segments, the QUALHYMO model uses the U.S. Soil Conservation Service (Ref. 14) procedure to determine the excess moisture input to pervious areas. The soil moisture deficit of soils and the initial abstraction are updated by the model for each event to provide an accounting of initial moisture conditions. The initial abstraction is reduced by the antecedent precipitation over the preceding twenty-four hours and will recover to its user specified maximum in the absence of precipitation over the foregoing period of time. In the case of the soil moisture deficit, current values preceding an event are computed as a function of a variable Antecedent Precipitation Index which in turn is based on daily rainfall totals weighted by a recession coefficient with a system memory of approximately thirty days.

Runoff volume computations in impervious areas are carried out by reducing precipitation with an initial abstraction and subsequently applying a constant volumetric runoff coefficient. Inter-event updating of the initial abstraction is similar to the technique for pervious areas.

The QUALHYMO model calculates flow rates from flow volume by convolution of excess precipitation with two unit hydrograph shapes proposed by Nash (Ref. 15) and Williams (Ref. 16). Since runoff from pervious areas is convoluted separately from impervious areas, these can use either the same or different unit hydrograph shapes at the discretion of the modeller.

A kinematic approximation is used within QUALHYMO to route flows along river reaches. Hydraulics in the reach are represented either by a Manning flow equation or specified rating curve. Depth-flow velocity and depth-section area relationships for the channel are calculated by the model and used subsequently for flow routing purposes.

Calculation of base flow in the model is carried out with a single reservoir representing groundwater storage. A net inflow and outflow from the reservoir is calculated for each model time step with inflow taken as the difference between precipitation and runoff minus any losses to initial abstraction. Outflow is expressed as a function of a baseflow recession constant times the groundwater reservoir storage. Losses to deep groundwater storage are estimated as a constant proportion of the outflow from the groundwater storage reservoir and effectively reduce the contribution to baseflow.

3.2.2 Model Enhancements

In order to accommodate the flow travel and attenuation process within water courses of the Nottawasaga River basin, the kinematic approximation employed in the QUALHYMO model for streamflow routing was replaced by a hydrologic Muskingum method which incorporates the variable storage coefficient (VSC) (Ref. 12) method. The latter technique accounts for the variation in water surface slope and has been tested successfully on Ontario streams (Ref. 17).

A review of historical peak flow records in the Nottawasaga River basin indicates that annual peak events almost invariably occur during the spring freshet period. Many of the higher discharges involve a combination of snowmelt and rainfall. Based on findings of the snowmelt hydrology studies (Ref. 10) carried out for the Ontario Ministry of Natural Resources, the snowmelt model originally developed for the U.S. National Weather Service River Forecast System (Ref. 19) was added to the QUALHYMO model in order to improve computational accuracy during rainfall and snowmelt occurrences.

The NWS snowmelt model employs a temperature index procedure in which melt rates are proportional to the differences between the mean air temperature and a base temperature during periods without precipitation. A seasonal variation in the melt factor can be simulated to reflect the increase in solar radiation and the decrease in the albedo of a snow cover as the winter period progresses. During periods of precipitation a semi-empirical energy balance approach takes into account the net long wave radiation transfer to a snow cover, the latent heat transfer or sublimation of water vapour, sensible heat transfer due to the heat content of the air, and heat transfer to the snow cover which is caused by precipitation. Short wave radiation is considered zero during the occurrence of precipitation due to the presence of cloud cover. Meteorologic data required for computation is limited to air temperature and precipitation intensity during the snowmelt period.

Outflow of liquid water from the snowpack is differentiated from snowmelt in the NWS computational approach by a snowpack heat accounting technique, which indicates whether water will be in a liquid or solid phase. Liquid water is retained in the snowpack against gravity drainage and the portion which exceeds this capacity is transmitted as outflow after a time lag which represents routing of meltwater through the snowpack.

The runoff which occurs within small urban catchments is quite sensitive to short duration intensities. QUALHYMO was also modified to allow 15 minute duration rainfall amounts to be input to the model.

3.2.3 Watershed Application

The QUALHYMO model for the Nottawasaga Valley River Basin was developed from readily available sources of watershed information which provided the most recent documentation of land use, soils and topographic features. Field surveys were also carried out to supplement the mapping coverage of major watercourses and watershed boundaries. The collection, compilation and subsequent calibration exercises undertaken with this data supplied the model with the most representative basin definition.

3.2.3.1 Basin Delineation

The initial stages of the model's development involved the examination of the watershed boundaries for the study basins. Suspect boundary areas identified by the Authority and areas noted by MacLaren Plansearch were inspected thoroughly utilizing 1:10000 air photos and available mapping.

Verification of the delineation of the boundary in these areas was also carried out through site inspections by field crews. These investigations yielded only small changes to the defined boundaries as delineated by the Authority.

For modelling purposes, the natural drainage system within the study area was divided into nine (9) major sub-catchments which discharge to either the Nottawasaga River or directly to Nottawasaga Bay. Further discretization of the drainage area was undertaken to provide distributed estimates of flood discharges at numerous locations throughout the drainage system (Figure 2.1). A total of 191 hydrologic units or sub-catchments were defined to adequately simulate the hydrologic characteristics of the basin (Table 3.3). The following criteria were used for the delineation of the units:

- flow locations requested by the Authority
- sites of installed streamflow gauges
- sites of urban development
- sites of significant changes in hydrologic features
- areas of floodplain mapping studies
- major transportation crossings.

3.2.3.2 Hydrologic Soil Classification

Soil series and drainage conditions information obtained from Canada Department of Agriculture Soil Survey Reports was transferred to a 1:50,000 scale map for the study area. The Hydrologic Soil Group Designation (Ref. 14, 20) for the NVCA is shown in Figure 3.1. This classification contains the four following major soil groups which reflect the intake of water at the end of long duration storms occurring after prior wetting and opportunity for swelling, and without the protective affects of vegetation. Infiltration is the rate at which water enters the soil at the surface, and which is controlled at the surface, and the transmission rate is the rate at which the water moves in the soil and which is controlled by the soil horizons.

Group A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well- to excessively-drained sands or gravels. These soils have a high rate of water transmission.

Group B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

3.2.3.3 Land Use

The Nottawasaga Valley River Basin is primarily a rural agricultural basin with a scattering of urban centers. Notable exceptions are found within the Nottawasaga Bay Fringe, where recreational and seasonal development has occurred and further to the south near Angus within the military establishment at C.F.B. Borden. The Minesing Swamp, north of Angus, is a major wetland resource.

One of the requirements of the study was to investigate the impact of changing land use from the present condition to proposed future plans. To facilitate this requirement, a land use inventory for each hydrologic unit was undertaken for both existing and future conditions.

The principle source of land use information used for all rural or agricultural lands for the existing condition was the 1983 Ontario Ministry of Agriculture and Food (O.M.A.F.) Agricultural Land Use Systems mapping. These maps are available for all townships at a 1:50,000 scale. The major land use categories extracted from this source for hydrologic analysis are listed below.

- row crop
- small grains
- pasture or range
- woods
- swamp

The future land use designation for the agricultural lands was obtained by comparing the Official Plans for each township to the designations determined for the existing conditions. The Official Plans identify those lands that will be converted to urban development; however, they do not classify the type of agricultural practice for the rural lands. It was assumed that the existing non-urban lands not designated for development will retain existing agricultural crops in the future.

The urban areas, though small in comparison to the size of the basins, represent a significant portion of many of the individual sub-catchments. Their impact on the volume and rate of runoff can be significant on a local sub-watershed scale when imposed on the receiving streams. The identification of urban areas was first established through the examination of the Official Plans and Zoning By-laws for the towns and townships within the area. These documents also provided specific urban land use categories for the future condition. The urban land use categories and their associated

TABLE 3.3

HYDROLOGIC UNITS

Series	Watercourse/System	No. of Hydrologic Units
100	Nottawasaga River	43
200	Bailey and Beeton Creeks	16
300	Innisfil Creek	23
400	Boyne River	16
500	Pine River	17
600	Bear Creek	9
700	Willow and Marl Creeks	20
800	Mad River	19
900	Georgian Bay Inflows	28
	TOTAL	191

imperviousness which were adopted for hydrologic computations are listed below.

Urban Land Use Category	Percentage Impervious
Residential	35%
Commercial	75%
Institutional	70%
Industrial	70%

The above values represent average impervious conditions obtained from the Consultant's work for the Town of Vaughan (e.g. Town of Vaughan Design Criteria) and literature review (e.g. V.T. Chow, Handbook of Applied Hydrology, McGraw-Hill, 1964; Pg. 20-20) (Ref. 28).

The determination of existing conditions for the urban areas was undertaken through the use of existing land use mapping. In many instances this mapping had not been prepared by municipal planning departments. The 1:30,000 air photos (1983) and 1:10,000 mapping were employed in these cases to delineate the extent of the existing urban land use. It was assumed that the type of existing urban land use (Residential, Commercial, Institutional and Industrial) could be obtained from the Official Plan for the municipality.

Existing and future land use maps of the watersheds were provided to the Authority at a scale of 1:50,000.

3.2.3.4 Hydrologic Soil-cover Index

Land use and soil classification for each sub-watershed was compiled and the associated hydrologic soil-cover index for each land cover, and soil combination was assigned (Ref. 21). The representative index for each sub-watershed is presented in Appendix C.

Excess rainfall in pervious areas is calculated by the QUALHYMO model using the SCS relation:

$$Q = \frac{(P - ABSPER)*(P - ABSPER)}{(P - ABSPER + S^*)}$$

where;

Q = cumulative depth of runoff (mm)
P = cumulative depth of precipitation (mm)
ABSPER = initial abstraction (mm)
S* = loss parameter (mm)

In the QUALHYMO Model, S* and ABSPER are updated by the model on the basis of precipitation occurrence in order to provide an accounting of initial moisture conditions. In the case of S*, this is accomplished by expressing S* as a function of a variable Antecedent Precipitation Index, the API.

The API is determined from the following relation:

$$API_2 = APIK * API_1 + P_1$$

where:

APIK is a coefficient: 0.9 for daily time steps
P_1 is precipitation within time step 1, and the
API subscripts refer to conditions at the beginning of time step 1 and time step 2

The relationship that was found to be appropriate to relate S* and API is:

$$S^* = SMIN + (SMAX - SMIN)^* \exp(-SK^*API)$$

where:

SMIN and SMAX represent the range in S* and SK is a calibration parameter.

In order to apply the QUALHYMO model to the Nottawasaga River watershed, the following steps were taken:

i) Hydrologic soil-cover complexes (CN) were computed for each of the hydrologic soil group types and land covers in a watershed sub-catchment (hydrologic unit). A weighted average hydrologic soil-cover complex (CN) was calculated for the sub-catchment to correspond to the Soil Conservation Service Antecedent Moisture Condition I, II and III.

ii) The API sub-routine of the QUALHYMO model was used to analyze the hourly precipitation records between May and November for the Shelburne and Barrie precipitation stations over the 1963 to 1984 period and to calculate continuous API (Antecedent Precipitation Index) values at these two stations. It is noted that the hourly precipitation record at Shelburne was synthesized from daily records according to the procedure outlined in Section 3.1.1.1.

An API duration analysis of the two (Shelburne and Barrie) API sequences were carried out to determine the API values corresponding to the 15, 50 and 85 percent time of exceedance. It was established that for both stations the API values of 16.5 mm, 28.0 mm and 48.0 mm corresponded to the foregoing percentage exceedances respectively and therefore were applicable over the entire study area.

iii) an S* versus API curve was established for each sub-catchment. In order to obtain the general shape of this curve, the hydrologic soil-cover (CN) for each sub-catchment corresponding to the antecedent moisture conditions, I, II and III (point i) above) was converted to the equivalent S* loss parameter by the relationship following the Soil Conservation procedure (Ref. 14).

$$S^* = \frac{1000}{CN} - 10$$

Based on the experience of the author of the model, the foregoing S* magnitudes were plotted at the API values corresponding to the 15, 50 and 85 percent points. Values of SMIN and SMAX were subsequently established by graphical curve extension and Sk the, curve slope, was computed from the exponential equation relating this parameter to S*, SMIN and SMAX.

An example of the S* versus API relationship derived for the Boyne River catchment to Earl Rowe Park is shown in Figure 3.2. In this Figure an S* versus API relationship is derived for the A, B, C soil types and land use covers in addition to the aggregate value of S* for the total catchment area. The SK value derived in this case was 0.11.

3.2.3.5 Routing Reaches and Reservoirs

To simulate the routing characteristics of the basins the model includes 103 routing reaches and 2 routing reservoirs. The reach information was obtained from the survey of 30 representative channel cross-sections (Figure 2.2) in conjunction with overbank information supplemented from 1:10,000 mapping and 1:2,000 mapping from earlier flood plain mapping studies.

Two routing reservoirs were included to simulate the outflows from Little Lake on the Willow Creek system and Earl Rowe Dam on the Boyne River system.

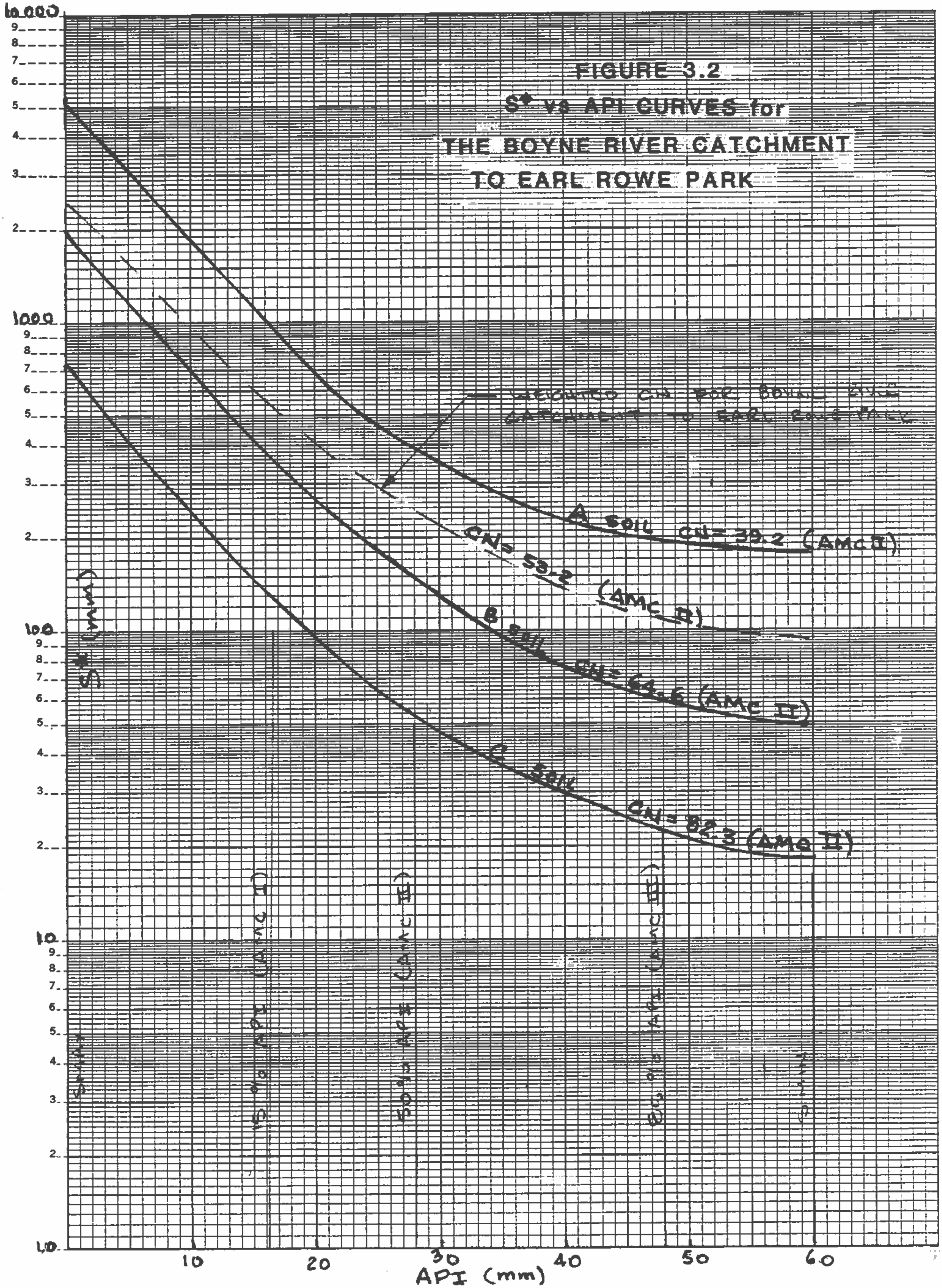


FIGURE 3.2

S* vs API CURVES for THE BOYNE RIVER CATCHMENT TO EARL ROWE PARK

Information for Earl Rowe Dam was obtained from the Ministry of Natural Resources, Central Region while similar information for Little Lake was provided by the Ministry of Natural Resources, Huronia District.

3.2.4 Model Calibration

3.2.4.1 General

As outlined in Section 3.1.2, hourly streamflow data for the 1975-1984 period was obtained from Water Survey of Canada and the Ontario Ministry of the Environment. It was found desirable to calibrate the QUALHYMO Model for catchment areas exhibiting a predominant type of hydrologic soils before applying the results to ungauged sub-catchments.

From the hydrologic soil cover complexes presented in Appendix C for the various A, B, and C soil types, Tables 3.4 was prepared. It is evident that Willow Creek exhibits predominantly B soil; Mad River, B-C soil; Pine River, A-B soil; Boyne River, A-B soil and Beeton Creek a mixture of A, B, C soils. From the above results, it was decided to calibrate the following catchment areas: Willow Creek above Little Lake, Mad River near Glencairn and Boyne River at Earl Rowe Park. These models were calibrated for specific summer and spring events during the 1980-1984 period. Additional calibration of the Nottawasaga River basin to Baxter and Beeton Creek at Tottenham and the Pine River to Everett was carried out subsequently for a summer event (July 1980) to check the model accuracy for mixed soil conditions.

Lumped models for the Mad River near Glencairn, Pine River near Everett, Nottawasaga River and Willow Creek above Little Lake are listed in Appendix E along with the appropriate precipitation station used as input to each lumped sub-model (Table 3.5).

The lumped model for the Nottawasaga River at Baxter gauge consisted of lumped sub-models for Beeton Creek, Bailey Creek, Upper Nottawasaga River, Innisfil Creek, Boyne River and local drainage areas. Channel routing was

TABLE 3.4

HYDROLOGIC SOIL COMPONENT FOR CATCHMENT AREA INDICATED

	Soil Group										
	A			B			C				
Catchment	Area (km^2)	%	CN	Area (km^2)	%	CN	Area (km^2)	%	CN	Total Area (km^2)	Weighted CN
Willow Creek above Little Lake	7.4	7.8	40.1	87.5	92.2	65.4	-	-	-	94.9	63.5
Mad River near Glencairn	31.3	10.3	39	171.9	56.7	63	99.9	33.0	72.4	303.1	64.0
Pine River near Everett	95.6	47.1	26.3	70.0	34.5	61.3	37.4	18.4	69.3	203.0	45.7
Boyne River at Earl Rowe Park	101.3	48.9	39.4	88.2	42.6	66	17.5	8.5	82.1	207.1	54.4
Beeton Creek near Beeton	18.3	26.4	45.3	31.2	45.1	62.2	19.7	28.5	69.0	69.2	59.6

Note: Antecedent Moisture Condition II used for CN value

TABLE 3.5

PRECIPITATION STATIONS USED IN QUALHYMO LUMPED MODELS

River System	Daily Precipitation Station	Hourly Precipitation Station	6 Hourly Precipitation Station
Willow Creek	Shanty Bay	Barrie Orillia Bolton Maple Grand Valley Mt. Forest Fergus	Mt. Forest
Mad River	Redickville	Grand Valley Mt. Forest Fergus Barrie Bolton Maple Orillia	Mt. Forest
Boyne River Pine River	Shelbourne	Grand Valley Mt. Forest Fergus Bolton Maple Barrie Orillia	Mt. Forest
Beeton/Bailey Creeks	Beeton	Bolton Barrie Maple Grand Valley Mt. Forest Fergus Orillia	Mt. Forest
Upper Nottawasaga River	Orangeville	Grand Valley Fergus Bolton Maple Mt. Forest Barrie Orillia	Mt. Forest

TABLE 3.5 (cont'd)

PRECIPITATION STATIONS USED IN QUALHYMO LUMPED MODELS

River System	Daily Precipitation Station	Hourly Precipitation Station	6 Hourly Precipitation Station
Innisfil Creek	Cookstown	Barrie Bolton Orillia Maple Grand Valley Mt. Forest Fergus	Mt. Forest
Mid-Nottawasaga River and Lower Boyne River	Alliston	Bolton Barrie Maple Grand River Mt. Forest Fergus Orillia	Mt. Forest

also included for each of the lumped models and an appropriate precipitation station was selected for precipitation input. The daily station selected for each lumped model and the corresponding hourly stations used to distribute precipitation is presented in Table 3.5.

As outlined in Section 3.2.3.1, a discretized QUALHYMO Model was set-up for all sub-catchment areas within the N.V.C.A. However, in order to establish initial model calibration parameters, a single lumped model was set-up for the Willow Creek, Mad River, Boyne River and Pine River catchment areas to their respective gauging stations. The primary purpose of this exercise was to adjust model parameters to obtain volume of runoff and peaks in close agreement to the observed.

For the Boyne River, the dam and reservoir upstream of the gauge was included in the modelling to account for its routing effect. The discharge characteristics for the dam and reservoir used in the model were obtained from MNR as noted in Section 3.2.3.5 while the stage - storage relationship for the reservoir was developed during the study. This information was provided to the Authority as part of the project files.

3.2.4.2 Lumped Models

3.2.4.2.1 General

Procedures outlined in Section 3.2.3.4 were used to estimate values of SMIN, SMAX and Sk for the lumped models of the Boyne, Pine and Mad Rivers and Willow Creek. The time to peak (tp) and recession constant (k) for each catchment area was computed using the William's empirical equations from the HYMO User Manual. Values of these parameters are given in Appendix H. The various parameters established are presented in Table 3.6. A plot of S*

TABLE 3.6

QUALHYMO PARAMETERS FOR CATCHMENT AREAS INDICATED

Catchment	Drainage Area (Km^2)	Time to Peak (TP) Hours	Recession Constant (K) Hours	Weighted CN	SMIN (mm)	SMAX (mm)	SK
Mad River near Glencairn	303.1	9.0	7.8	64	50	2000	0.11
Boyne River at Earl Rowe Park	207.1	13.4	12.2	54.4	95	2400	0.11
Willow Creek above Little Lake	94.9	7.4	10.5	63.5	50	2000	0.11
Pine River near Glencairn	203.0	12.7	9.6	45.7	111	3010	0.11
Beeton Creek near Tottenham	69.2	6.8	6.4	59.6	63	2085	0.11

versus API for the Mad River, Boyne River and Willow Creek catchments is presented in Figure 3.3.

The QUALHYMO model was run for the Willow Creek for a five month period during the summer of 1980 to calibrate the base flow parameters. Using hourly rainfall data, a plot of hourly simulated and observed flows was obtained for the five month period. Adjustments were made to the various base flow parameters until good agreement was obtained.

The final values used for the various parameters are presented below:

SLOSK1	(Base flow recession constant) = 0.000002 mm/sec/mm
SLOSK2	(Base flow reduction factor) = 0.2
BASMIN	(Minimum base flow rate) = 0 m^3/s

The parameter SLOSK1 is considered most important in controlling the base flow magnitudes.

The model was calibrated separately for summer and spring events because of the different conditions involved. These investigations are discussed in Sections 3.2.4.2.2 and 3.2.4.2.3 respectively.

3.2.4.2.2 Calibration of Summer Events

Daily streamflow data were used to computer plot continuous hydrographs from 1975-1984. These plots were screened to identify high flow summer events. The summer events selected for calibration between 1980 and 1984 are shown in Table 3.7 together with the recorded flows and rainfall amount.

For the July 28, 1980 high flow event, the rainfall amount of 6.8 mm recorded at Redickville does not appear consistent with rainfall amounts recorded at nearby stations. Therefore, the rainfall from this station was disregarded. In conducting the calibration for each of the above events,

TABLE 3.7

CALIBRATION/VALIDATION FOR SUMMER EVENTS

Watercourse	Peak Flow (m^3/s)			Observed Rainfall (mm)					
	Date of Peak	Observed	Simulated	Rainfall Duration	Colling-wood	Redick-ville	Shelburne	Barrie	Shanty Bay
Mad River Near Glencairn	28 July 1980	34.8	34.7	26-28 July 1980	41.3	6.8[1]	32.2	47.0	50.1
	15 June 1982	13.9	11.8	15-16 June 1982	47.7	37.8	29.2	33.3	36.2
	26 Sept. 1977	8.5	8.9	24-26 Sept. 1977	41.0	45.0	37.8	26.0	24.8
Willow Creek Above Little Lake	28 July 1980	23.9	23.8	26-28 July 1980	41.3	6.8[1]	32.2	47.0	50.1
	16 June 1982	9.8	9.6	15-16 June 1982	47.7	37.8	29.2	33.3	36.2
Boyne River at Earl Rowe Park	29 July 1980	28.9	26.8	26-28 July 1980	41.3	6.8[1]	32.2	47.0	50.1
Beeton Creek near Tottenham	29 July 1980	3.9	5.0	26-28 July 1980	41.3	6.8[1]	32.2	47.0	50.1
Pine River near Everett	29 July 1980	21.7	26.8	26-28 July 1980	41.3	6.8[1]	32.2	47.0	50.1
Nottawasaga River near Baxter	29 July 1980	66.7	96.6	26-28 July 1980	41.3	6.8[1]	32.2	47.0	50.1

[1] Anomaly in Rainfall Data - Not used for calibration

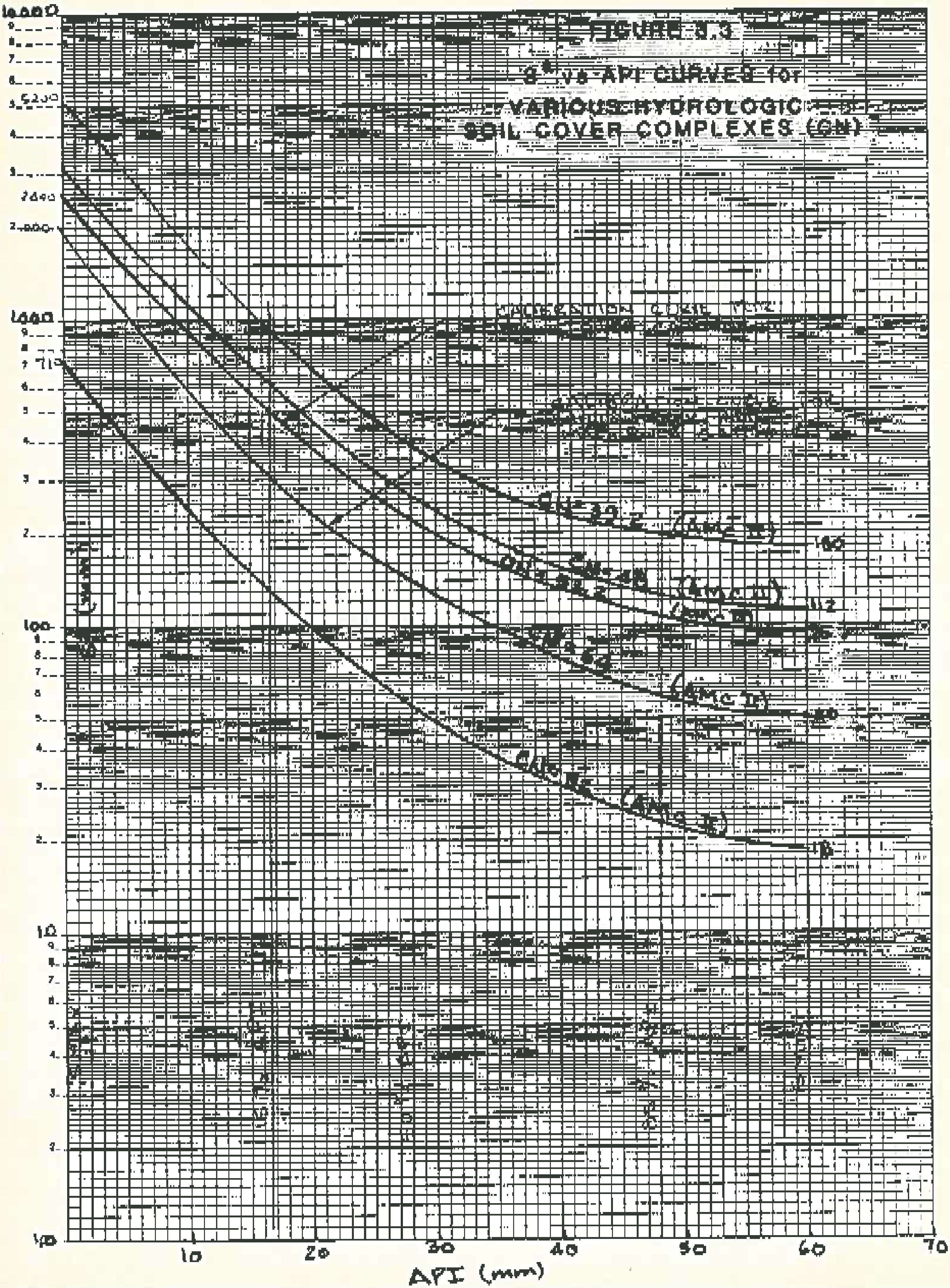


FIGURE 3.3
S* vs API CURVES for
VARIOUS HYDROLOGIC
SOIL COVER COMPLEXES (CN)
1000
100
10
1.0
10
20
30
40
50
60
70
API (mm)

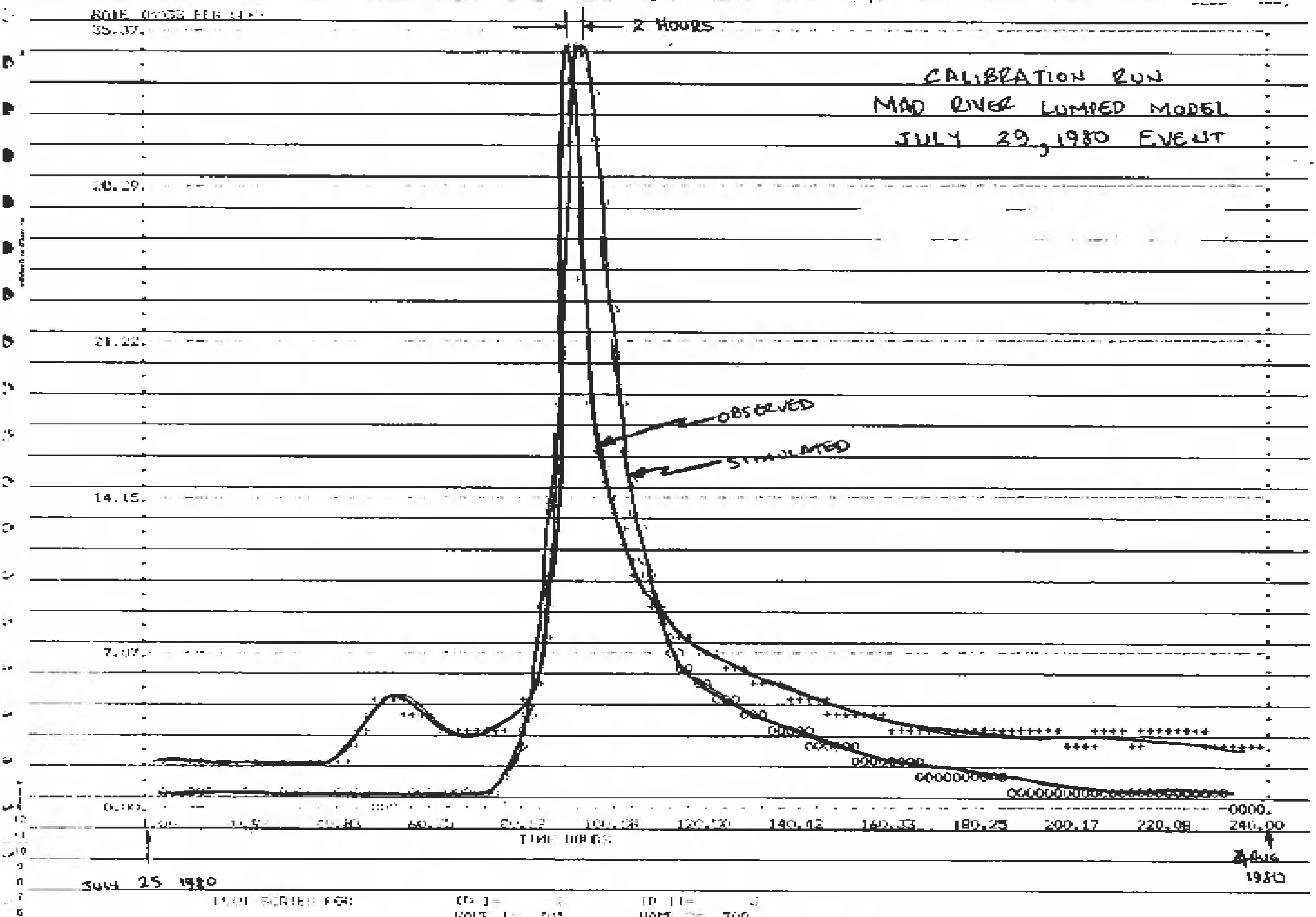
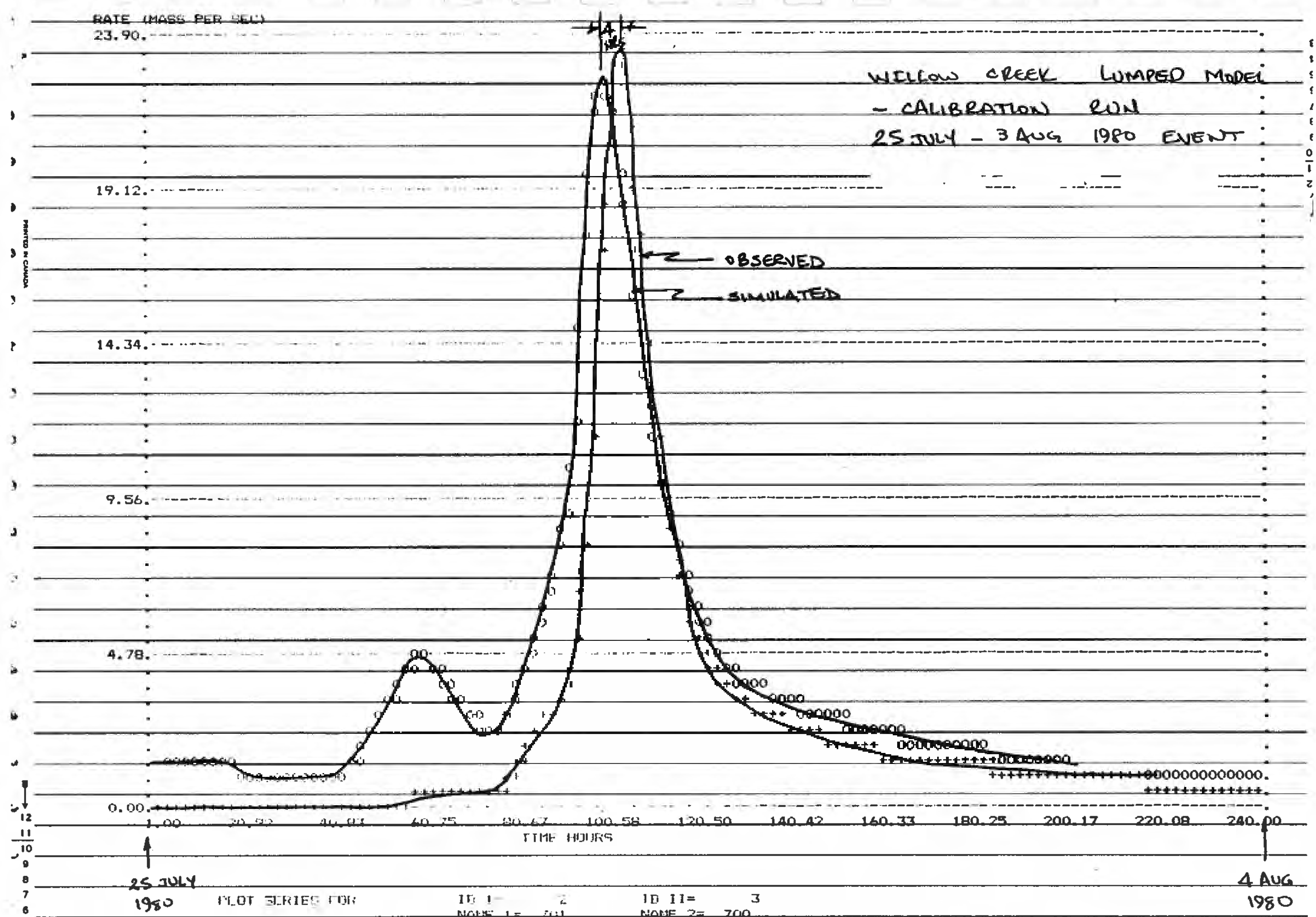

CALIBRATION RUN
MAD RIVER LUMPED MODEL
JULY 29, 1980 EVENT
2 HOURS
OBSERVED
SIMULATED
35.37
28.29
21.22
14.15
7.07
0.00
TIME HOURS
140.42
160.33
180.25
200.17
220.08
240.00
JULY 25 1980
4 AUG 1980

Fig. 3.4 (a)



RATE (MASS PER SEC)
23.90.
19.12.
14.34.
9.56.
4.78.
0.00.
1.00
40.83
60.75
100.58
120.50
140.42
160.33
180.25
200.17
220.08
240.00
TIME HOURS
WILLOW CREEK LUMPED MODEL
- CALIBRATION RUN
25 JULY - 3 AUG 1980 EVENT
OBSERVED
SIMULATED
25 JULY
1980
4 AUG
1980
PLOT SERIES FOR
ID II= 3
NAME 2= 700

Fig. 3.4 (c)

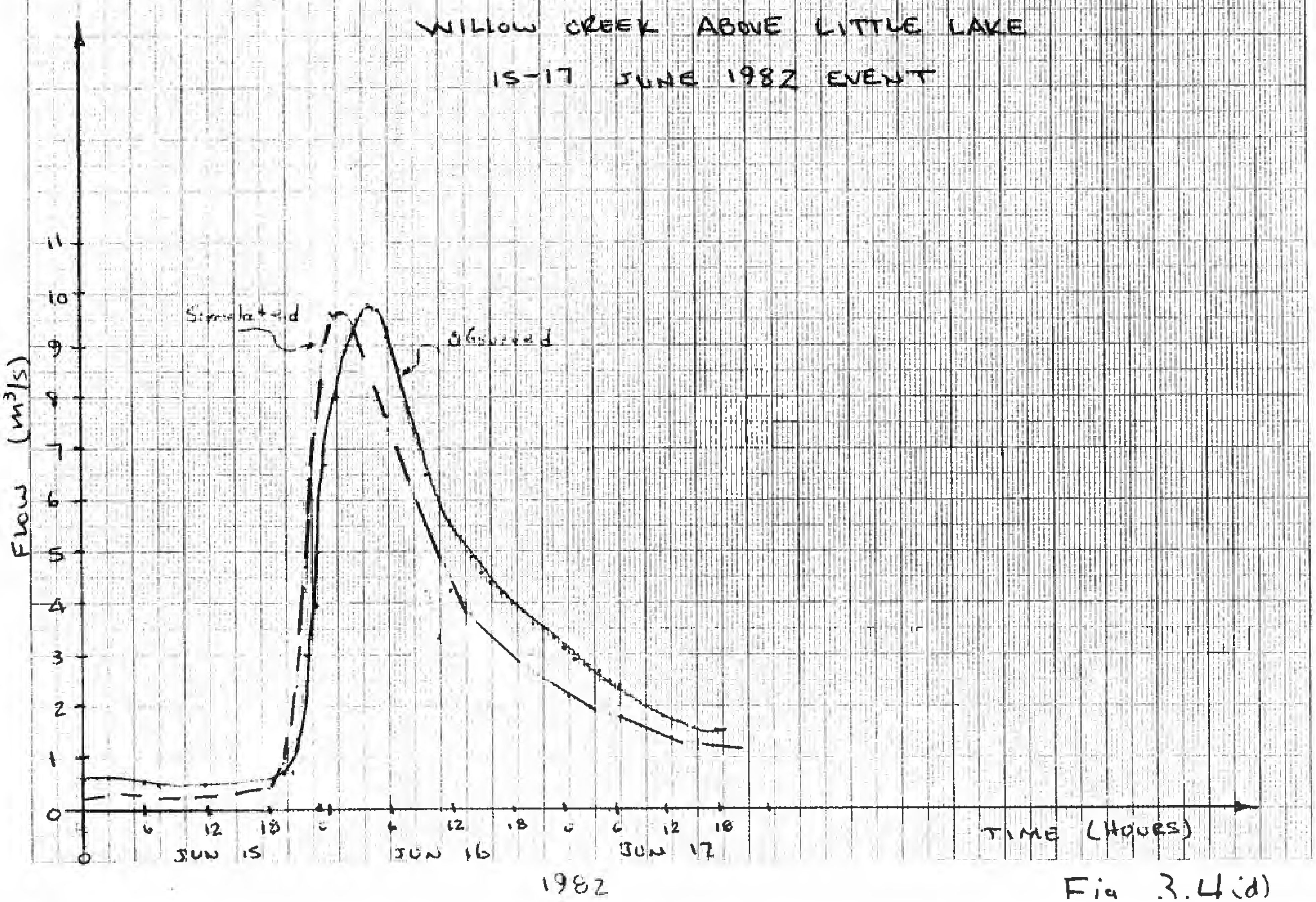

WILLOW CREEK ABOVE LITTLE LAKE
15-17 JUNE 1982 EVENT
Simulated
Observed
Flow (m³/s)
0
1
2
3
4
5
6
7
8
9
10
11
0
6
12
18
0
6
12
18
0
6
12
18
JUN 15
JUN 16
JUN 17
TIME (HOURS)
1982

Fig 3.4(d)

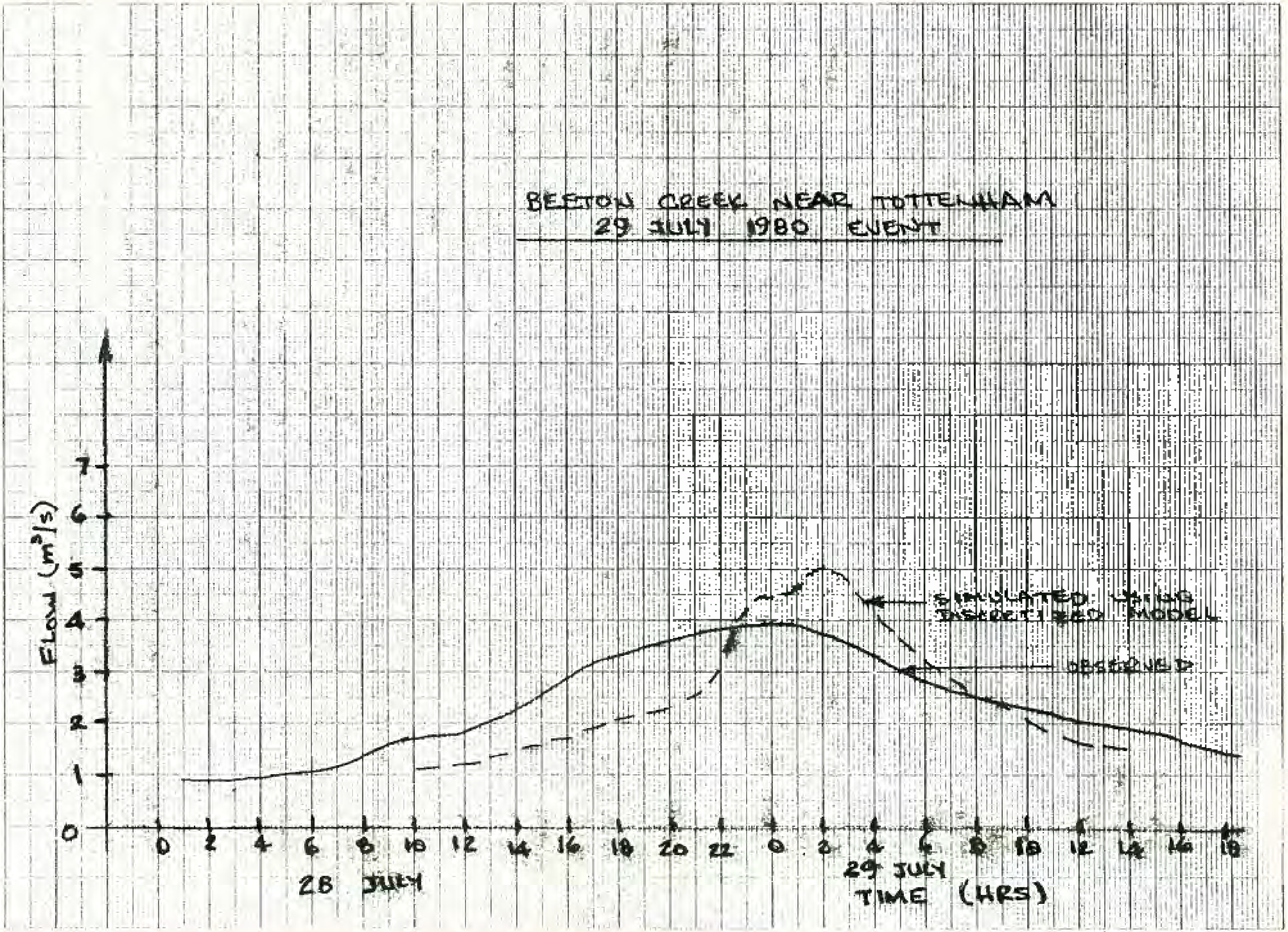

BEETON CREEK NEAR TOTTENHAM
29 JULY 1980 EVENT
SIMULATED USING DISCRETIZED MODEL
OBSERVED
Flow (m³/s)
0
1
2
3
4
5
6
7
0 2 4 6 8 10 12 14 16 18 20 22 0 2 4 6 8 10 12 14 16 18
28 JULY
29 JULY
TIME (HRS)

Fig. 3.4 (e)

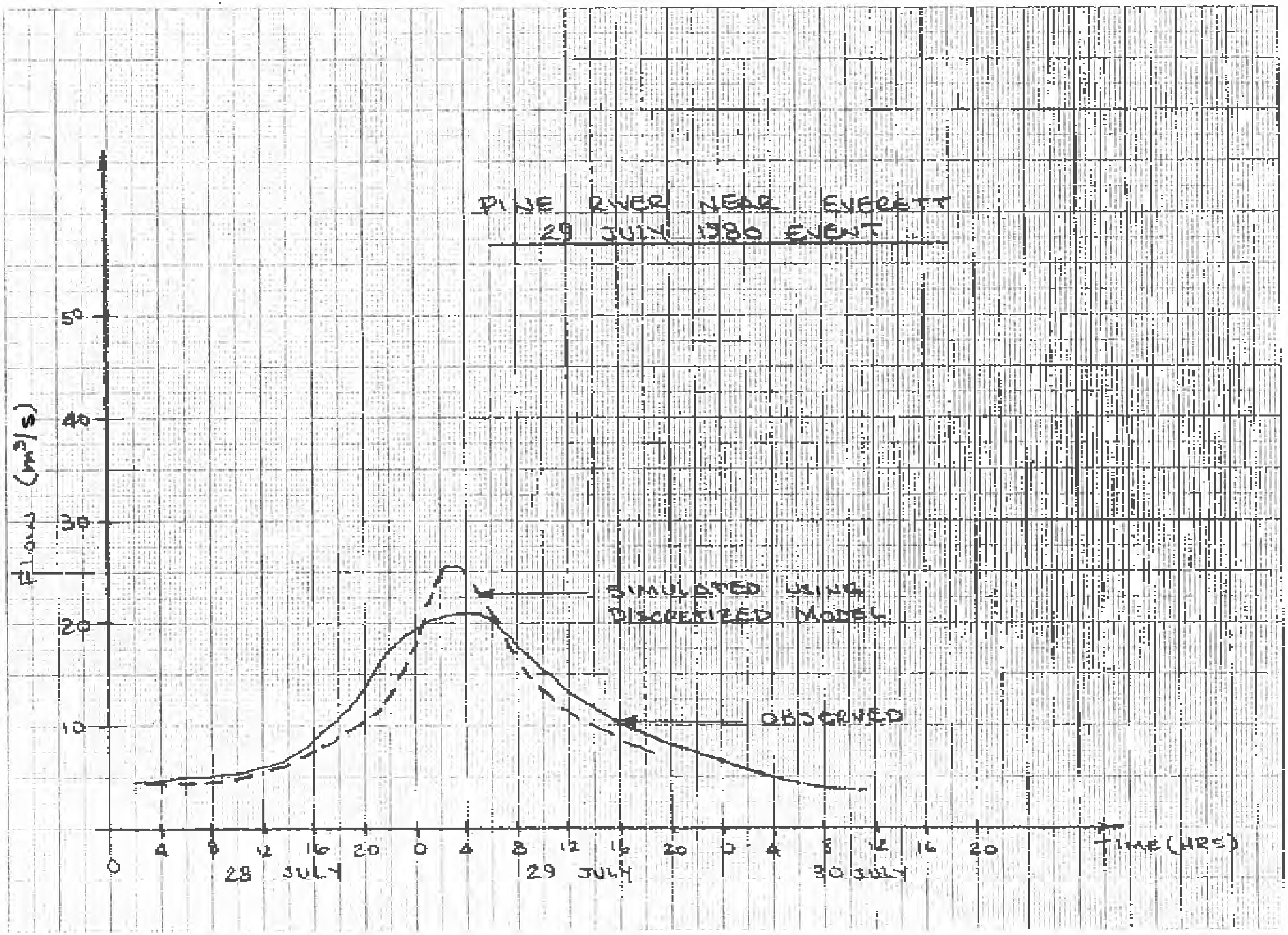

PINE RIVER NEAR EVERETT
29 JULY 1980 EVENT
SIMULATED USING
DISCRETIZED MODEL
OBSERVED
Flow (m³/s)
50
40
30
20
10
0
4
8
12
16
20
0
4
8
12
16
20
0
4
8
12
16
20
TIME (HRS)
28 JULY
29 JULY
30 JULY

Fig. 3.4(f)

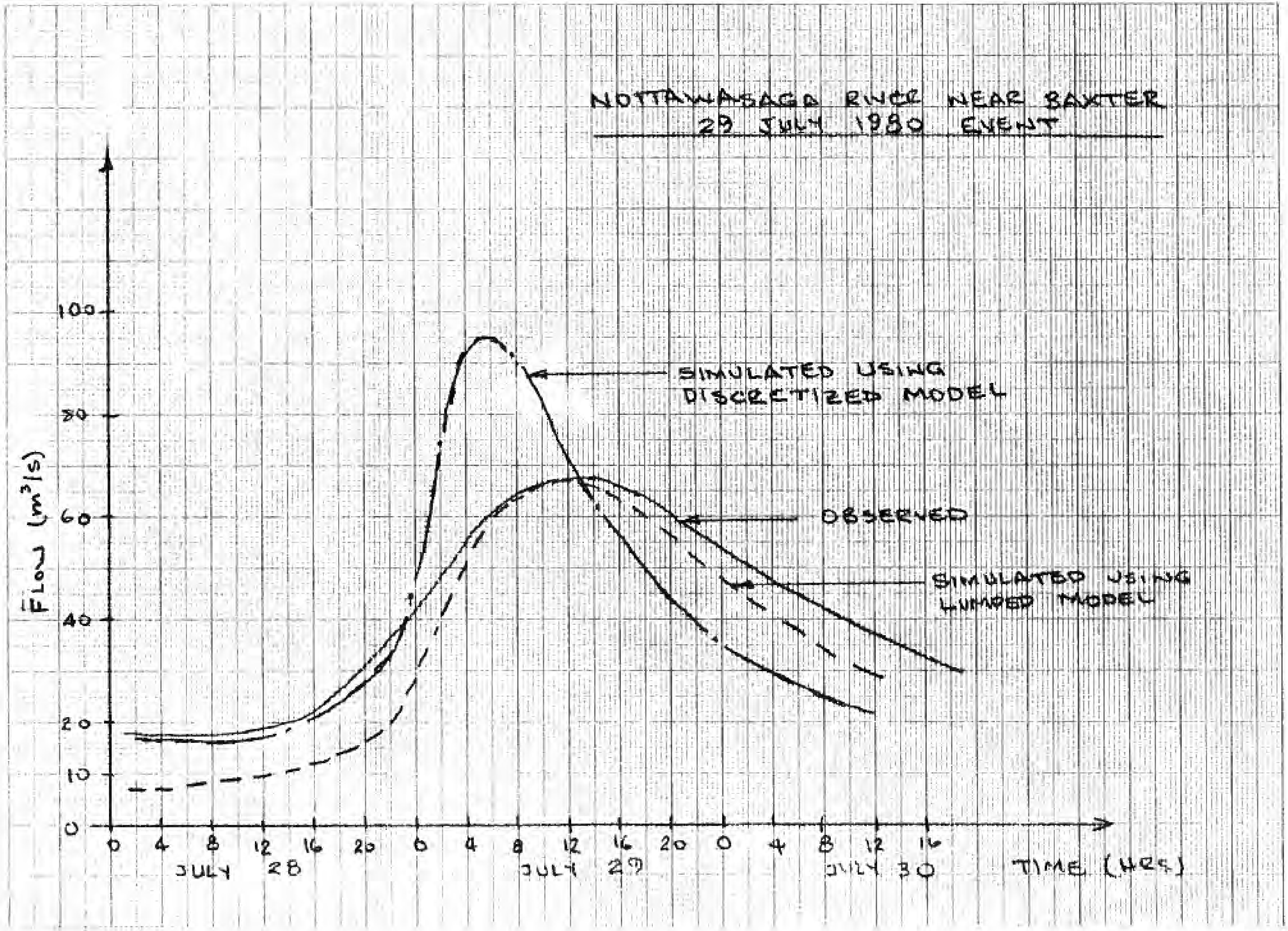

NOTTAWASAGA RIVER NEAR BAXTER
29 JULY 1980 EVENT
SIMULATED USING DISCRETIZED MODEL
OBSERVED
SIMULATED USING LUMPED MODEL
FLOW (m³/s)
0
10
20
40
60
80
100
0 4 8 12 16 20 0 4 8 12 16 20 0 4 8 12 16
JULY 28
JULY 29
JULY 30
TIME (HRS)

Fig. 3.4 (g)

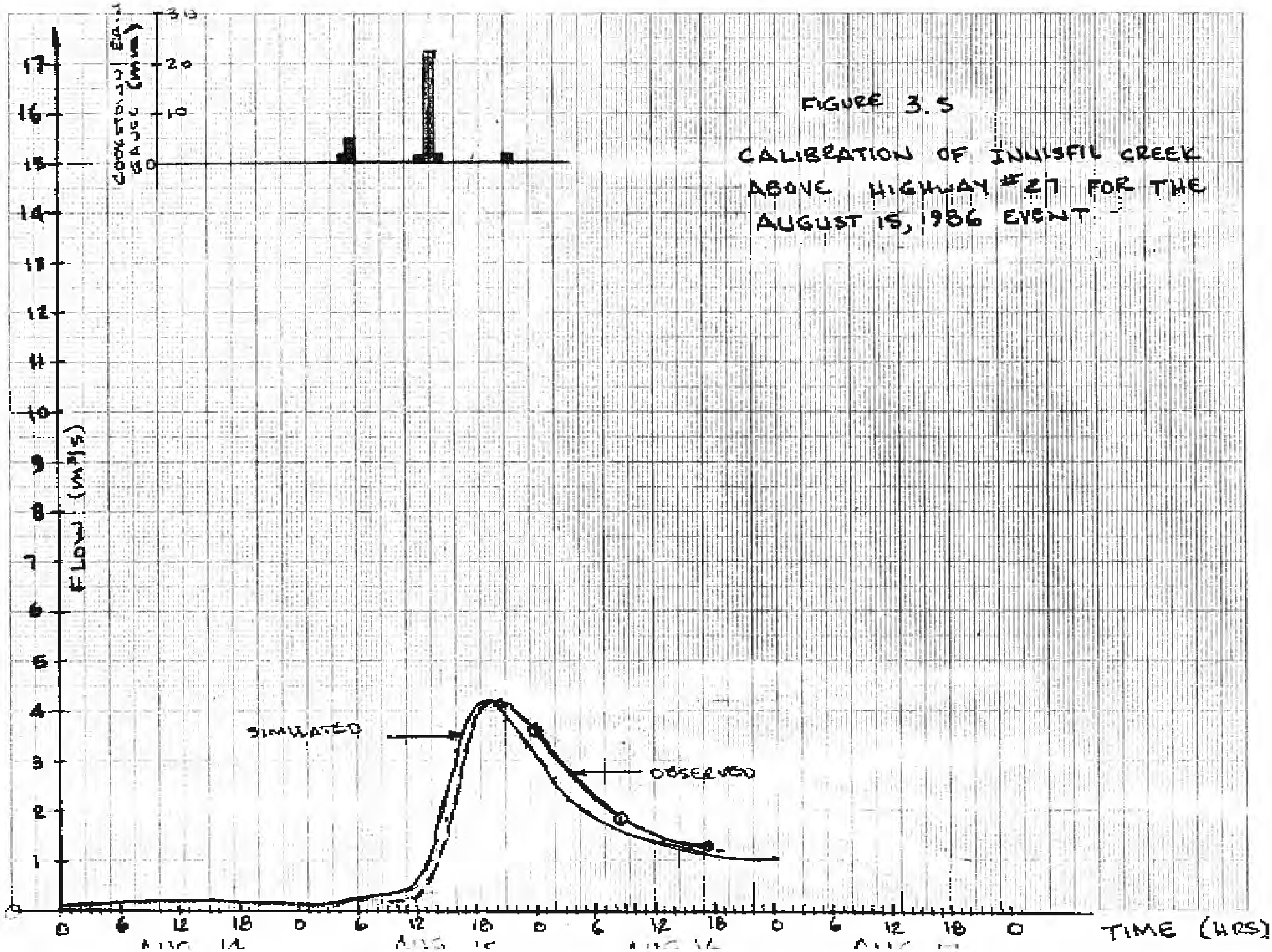


FIGURE 3.5
CALIBRATION OF INNISFIL CREEK
ABOVE HIGHWAY #27 FOR THE
AUGUST 15, 1986 EVENT
FLOW (M³/S)
TIME (HRS)
SIMULATED
OBSERVED
0
6
12
18
AUG 14
AUG 15
AUG 16
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

3.2.4.2.3 Calibration of Spring Events

The computer plots of daily streamflow for the 1975-1984 period were similarly screened to identify suitable calibration and validation events for the spring period. As indicated previously, suitable calibration events were selected from the 1980-1984 period and validation events from the 1975-1979 period. The calibration events selected are shown in Table 3.8. Some high flow events could not be selected because hourly streamflow data from November to early March was not available. The Boyne River gauge at Earl Rowe Park has missing hourly flow data for several events in late March and April.

The observed rainfall and snow course water equivalent data is also presented in Tables 3.8. The snow water equivalent is highly variable for the various snow courses; therefore, for modelling purposes it was not possible to accurately initialize snowpack water equivalent. To circumvent this problem, the modelling was started on November 1 and run through the winter period to about the end of April. In this manner the snowmelt model parameters could be more accurately calibrated.

In the calibration exercise, lack of actual hourly precipitation data provided serious problems. Although the AES provides hourly precipitation data for the winter period, the precipitation data usually consists of 24 equal values per day since the AES does not operate the recording precipitation gauges during the winter period. In some cases a thaw occurred accompanied by rainfall but actual rainfall distribution was not available. Where this occurred, the 24 equal values provided by the AES were redistributed using the 6-hour totals from the Mount Forest station. However, this also created some difficulty because of the distance of the Mount Forest station from the NVCA and the actual rainfall distribution within the 6-hour period was not known.

TABLE 3.8

SPRING CALIBRATION EVENTS

WATERCOURSE	PEAK FLOW (m³/s)				OBSERVED RAINFALL (mm)						OBSERVED SNOW WATER EQUIVALENT (mm)						SIMULATED
	Date	Observed (m³/sec)	Simulated	Type of Event	Date	Barrie	Shanty Bay	Allis-ton	Shel-burne	Redick-ville	Date	Eden-vale	Colwell	Totten-ham	Mono Centre	Maple Valley	Snow Water Equivalent (mm)
Mad River at Glencairn	21 Mar. 1980	74.4	75	Rainfall	20 Mar. 21 Mar.	16.8 14.4	19.2 21.6	18 13.6	14.4 16.8	0 45.6	01 Mar. 15 Mar. 01 Apr.	20 40 0	18 30 0	- - 0	35 46 0	35 - -	43.2 54 0
	31 Mar. 1982	90	102	Rainfall on Snowmelt	30 Mar. 31 Mar.	14.4 0	11.4 TR	13.0 0	24.0 0	0 26.4	15 Mar. 01 Apr. 15 Apr.	147 0 0	91 0 0	46 0 0	122 61 0	163 112 0	162 69 30
	04 Apr. 1984	37	37	Rainfall on Snowmelt	04 Apr. 05 Apr.	13.8 4.6	14.0 7.3	- -	9.6 3.0	0 24.9	15 Mar. 01 Apr.	46 0	43 0	20 0	33 0	71 0	53 24
Willow Creek above Little Lake	21 Mar. 1980	35.3	33.5	Rainfall	20 Mar. 21 Mar.	16.8 14.4	19.2 21.6	18 13.6	14.4 16.8	0 45.6	01 Mar. 15 Mar. 01 Apr.	20 40 0	18 30 0	- - 0	35 46 0	35 - -	102 112 13.6
	31 Mar. 1982	20	27.5	Rainfall on Snowmelt	30 Mar. 31 Mar.	14.4 0	11.4 TR	13.0 0	24.0 0	0 26.4	15 Mar. 01 Mar. 15 Apr.	147 0 0	91 0 0	46 0 0	122 61 0	163 112 0	210 110 43
Boyne River at Earl Rowe Park	05 Apr. 1984	17.5	19.5	Rainfall on Snowmelt	04 Apr. 05 Apr.	13.8 4.6	14.0 7.3	- -	9.6 3.0	0 24.9	15 Mar. 01 Apr.	46 0	43 0	20 0	33 0	71 0	36.8 12.1

In the calibration of the model, the precipitation data from the Redickville station was used for the Mad River. Similarly the Shelburne precipitation station was used for the Boyne River and the Shanty Bay precipitation station for Willow Creek.

As indicated previously, the NWS snowmelt routine requires several input parameters. The most important and most sensitive parameters are:

- MFMAX - Maximum non-rain melt factor
- MFMIN - Minimum non-rain melt factor
- UADJ - Mean wind function value during rain on snow periods
- SI - Areal water equivalent above which there is always complete areal snow cover (mm)

In the calibration of the model various ranges of parameter were used. (Ref. 19).

These are:

MFMAX	0.004 - 0.009
MFMIN	0.0018 - 0.0035
UADJ	0.017 - 0.057
SI	64 mm - 128 mm

The best overall results were obtained as indicated below:

MFMAX	0.005
MFMIN	0.0018
UADJ	0.057
SI	127 mm

For the Boyne River catchment it was found that the recession constant (K) computed by the Williams equations had to be reduced by 30% to 0.7 time the equation values. The presence of the reservoir within Earl Rowe Park upstream of the hydrometric station complicated the calibration procedure.

Plots of the observed and simulated hydrographs for each of the spring calibration events are presented in the Figures 3.6(a) to 3.6(f).

3.2.5 Model Validation

3.2.5.1 General

Events used over the summer and the spring period for the validation of the QUALHYMO model were selected from the computer plots of daily flows that were recorded over the 1975 to 1979 period. Hourly recorded discharges for the selected events thereafter formed a basis of comparison with simulated flows.

3.2.5.2 Lumped Models

Suitable validation events over the summer period were very sparse between 1975 and 1979. Only one event was found for the Mad River on September 26, 1977 (Table 3.7). Validation for the lumped catchment model for this event proved to be successful (Figure 3.7). A high flow event was also measured on the Boyne River at the Earl Rowe Park gauge; however, hourly streamflow records are not available and validation could not be carried out.

Validation events (Table 3.9) for the spring period were more numerous since annual peak flows usually occur during the freshet as a result of snowmelt, rainfall on saturated ground, or a combination of both. Plots (Figures 3.8(a) to 3.8(f)) of the observed and simulated hydrographs for each of the spring validation events indicate a close agreement with the exception of the March 25, 1976 event. The observed flow peaks on Willow Creek were checked against those measured at adjoining watersheds and were found not to reflect the general pattern of higher runoff during the initial event.

TABLE 3.9
SPRING VALIDATION EVENTS

WATERCOURSE	PEAK FLOW (m^3/s) Date	Observed	Simulated	Type of Event	OBSERVED RAINFALL (mm) Date	Barrie	Shanty Bay	Allis-ton	Shel-burne	Redick-ville	OBSERVED SNOW WATER EQUIVALENT (mm) Date	Eden-vale	Colwell	Totten-ham	Mono Centre	Maple Valley	SIMULATED Snow Water Equivalent (mm)
Mad River at Glencairn	21 Mar. 1976	102	88.5	Snowmelt	23 Mar. 24 Mar. 25 Mar.	0 2.4 0	0 0 0	0 2.4 0	0 0 0	0 0 0	15 Feb. 15 Mar. 01 Apr.	71 135 <------------	76 112 ------------	0 0 ASSUME 0	71 112 ------------	91 132 ------------>	133 114 3.4
	13 Mar. 1977	57.9	81.5	Rainfall on Snowmelt	12 Mar. 13 Mar.	18.1 -	18.5 -	20.1 -	16.3 -	19.1 -	14 Feb. 28 Feb. 15 Mar.	122 99 <------------	94 84 ------------	No Data Trace NO DATA	83.8 76.0 ------------	132 122 ------------>	134 132 25
Willow Creek above Little Lake	25 Mar. 1976	31.1	9.3[1]	Snowmelt	23 Mar. 24 Mar. 25 Mar.	0 2.4 0	0 0 0	0 2.4 0	0 0 0	0 0 0	15 Feb. 15 Mar.	71 135	76 112	0 0	71 112	91 132	150 142
	24 Mar. 1979	26.5	41.5	Rainfall on Snowmelt	23 Mar. 24 Mar.	4.0 14.0	4.2 13.8	4.4 14.8	- -	0 16.2	15 Mar. 01 Apr.	130 0	89 0	0 0	31 0	91 0	185 14.8
Boyne River at Earl Rowe Park	13 Mar. 1977	46.4	42.0	Rainfall on Snowmelt	12 Mar. 13 Mar.	18.1 -	18.5 -	20.1 -	16.1 -	19.1 -	14 Feb. 28 Feb. 15 Mar.	122 99 <------------	94 84 ------------	No Data Trace NO DATA	83.8 76.0 ------------	132 122 ------------>	87.2 90.7 10
	12 Apr. 1978	25.1	33.6	Rainfall on Snowmelt	10 Mar. 11 Mar.	6.7 10.0	7.8 9.6	7.4 4.2	10.8 6.5	0 22	15 Mar. 01 Apr. 15 Apr.	191 183 0	155 178 0	91 5 0	130 175 0	150 183 0	156.8 132.4 52.6

[1] Anomaly in Historical Streamflow Data

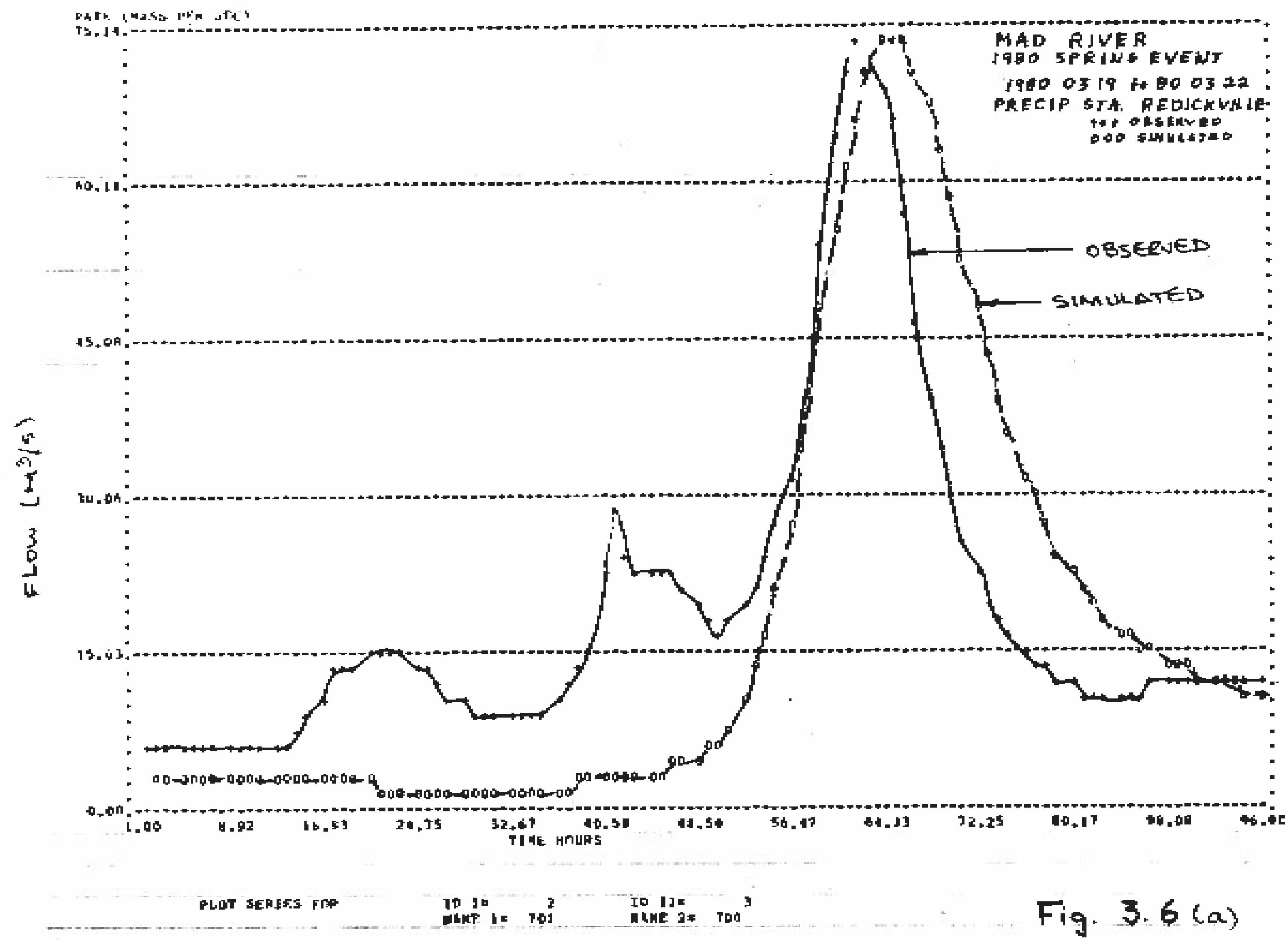

MAD RIVER
1980 SPRING EVENT
1980 03 19 to 80 03 22
OBSERVED
SIMULATED
FLOW (m3/s)
TIME HOURS
PLOT SERIES FOR

Fig. 3.6 (a)

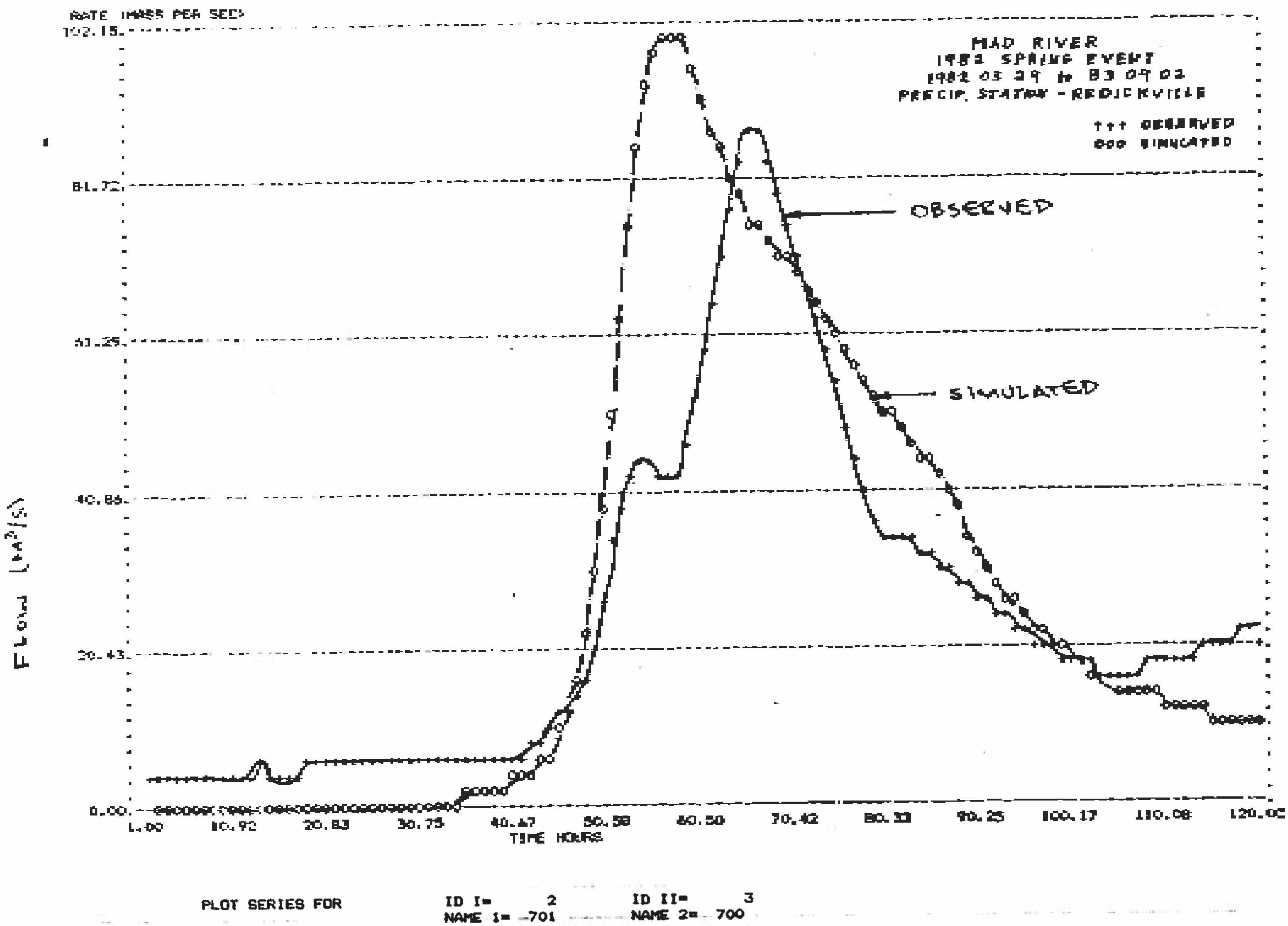

RATE (MASS PER SEC)
102.15
81.72
61.29
40.86
20.43
0.00
1.00
10.92
20.83
30.75
40.67
50.58
60.50
70.42
80.33
90.25
100.17
110.08
120.00
TIME HOURS
MAD RIVER
1982 SPRING EVENT
1982 03 29 to 83 09 02
PRECIP. STATION - REDICKVILLE
+++ OBSERVED
ooo SIMULATED
OBSERVED
SIMULATED
Flow (m³/s)
PLOT SERIES FOR
ID I= 2
NAME 1= 701
ID II= 3
NAME 2= 700

Fig 3.6 (b)

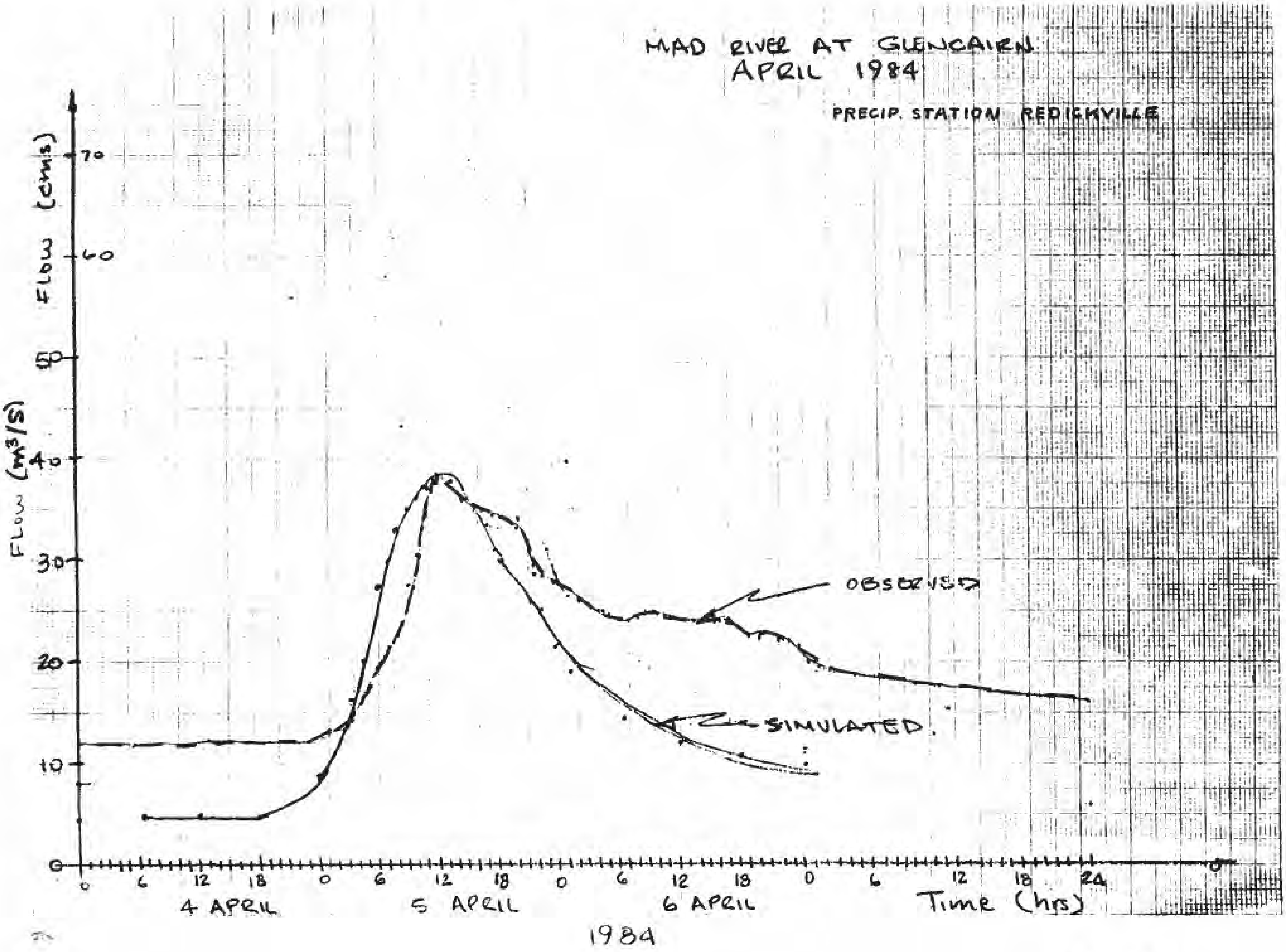

MAD RIVER AT GLENCAIRN
APRIL 1984
PRECIP. STATION REDICKVILLE
FLOW (cms)
FLOW (m³/S)
70
60
50
40
30
20
10
0
OBSERVED
SIMULATED
0
6
12
18
0
6
12
18
0
6
12
18
0
6
12
18
24
4 APRIL
5 APRIL
6 APRIL
Time (hrs)
1984

Fig 3.6 (c)

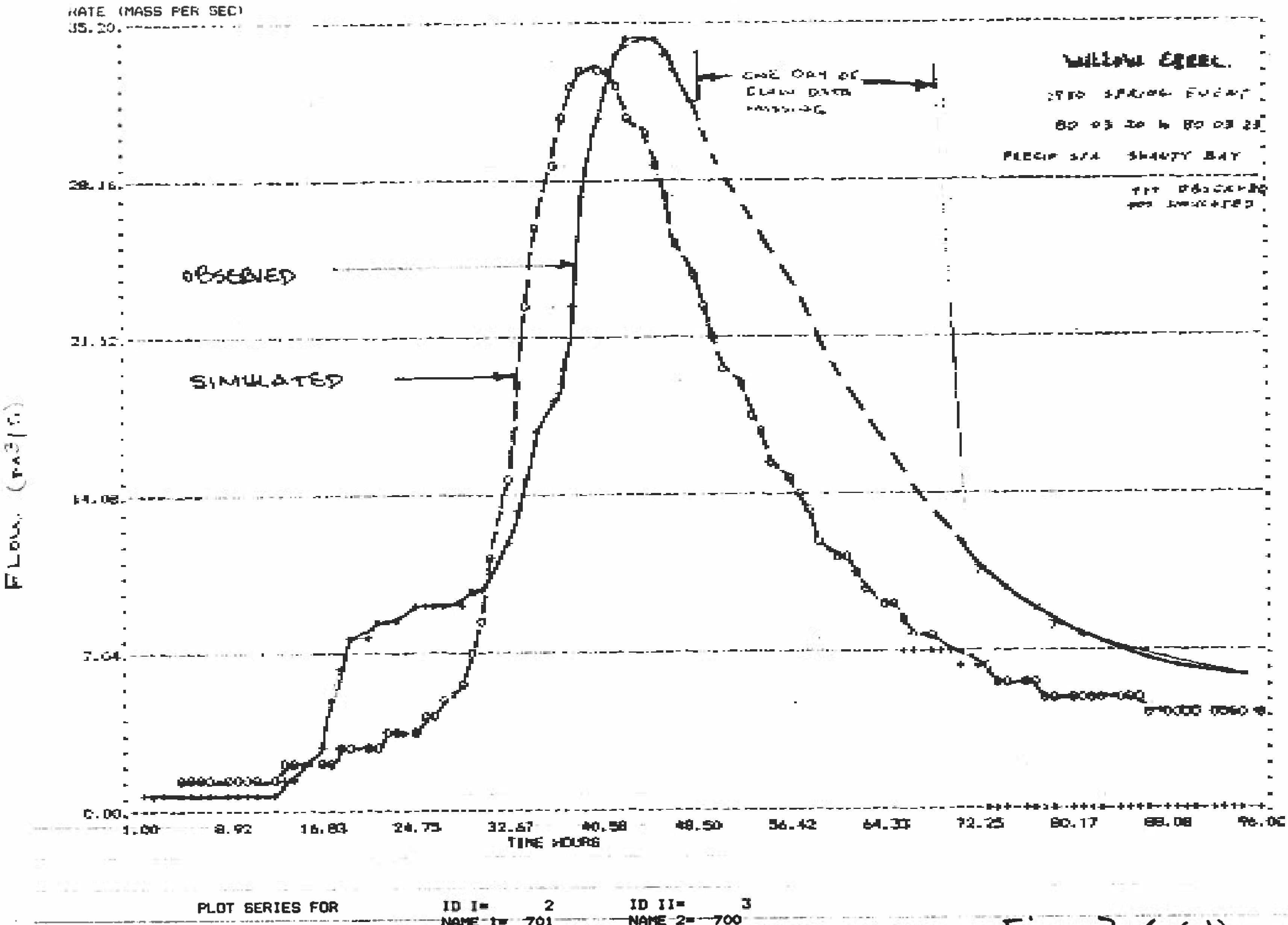

RATE (MASS PER SEC)
35.20
28.16
21.12
14.08
7.04
0.00
1.00
8.92
16.83
24.75
32.67
40.58
48.50
56.42
64.33
72.25
80.17
88.08
96.00
TIME HOURS
OBSERVED
SIMULATED
FLOW (m3/s)
PLOT SERIES FOR
ID I= 2
NAME 1= 701
ID II= 3
NAME 2= 700

Fig 3.6 (d)

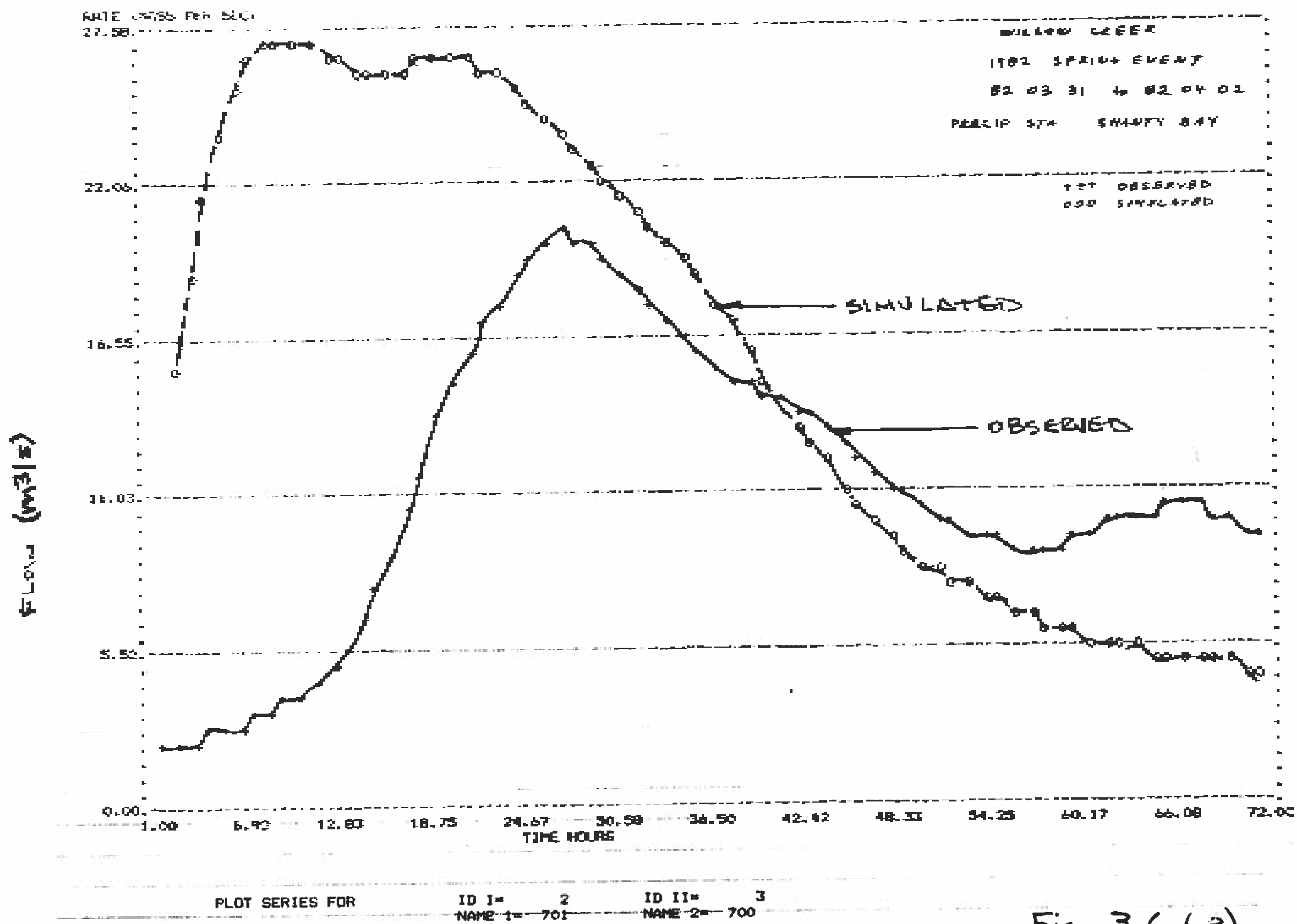

RATE (M3/S PER SEC)
27.58
22.06
16.55
11.03
5.52
0.00
1.00
6.92
12.83
18.75
24.67
30.58
36.50
42.42
48.33
54.25
60.17
66.08
72.00
TIME HOURS
+++ OBSERVED
ooo SIMULATED
SIMULATED
OBSERVED
FLOW (m3/s)
PLOT SERIES FOR
ID I= 2
NAME 1= 701
ID II= 3
NAME 2= 700

Fig 3.6 (2)

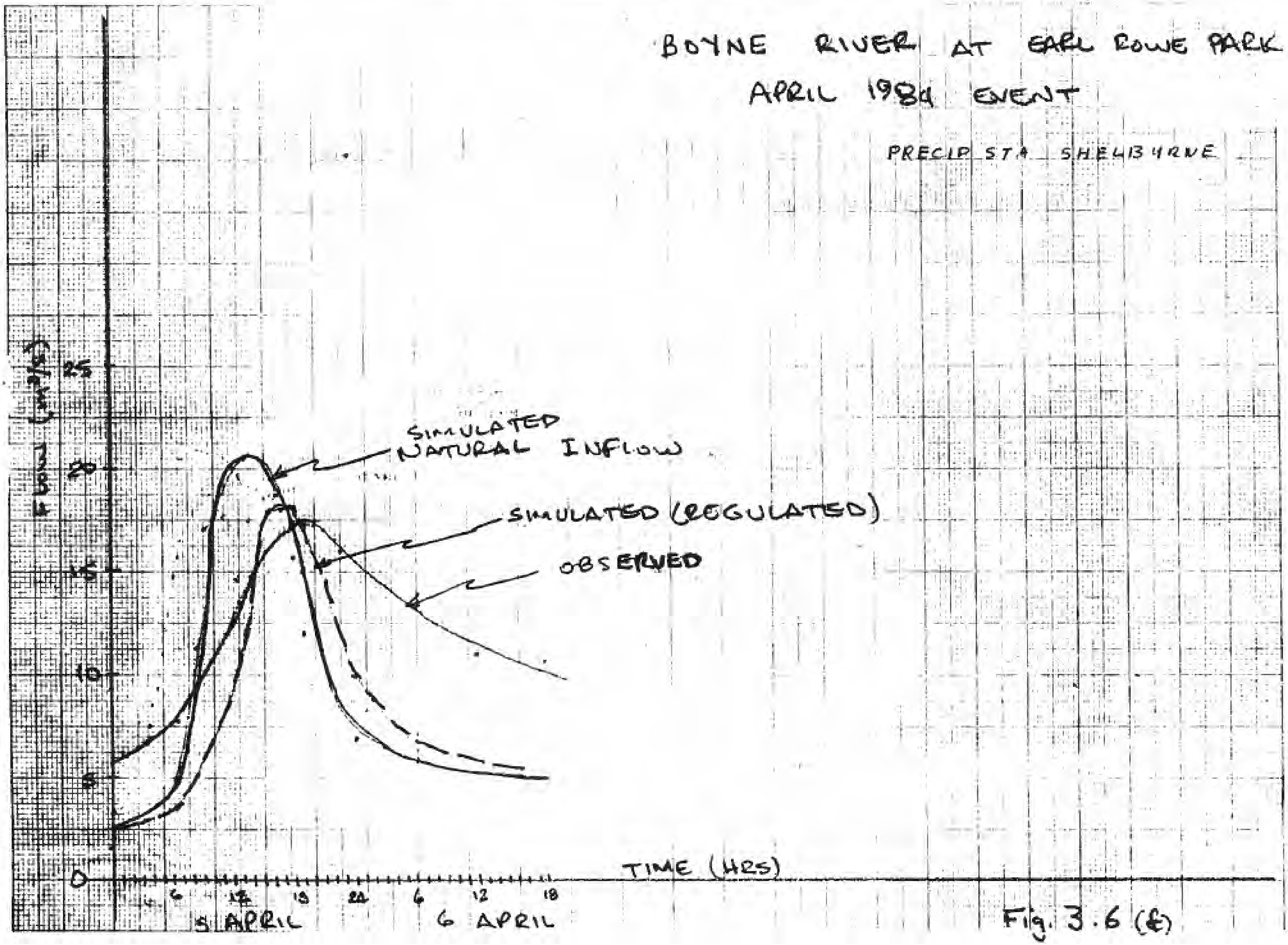

BOYNE RIVER AT EARL ROWE PARK
APRIL 1984 EVENT
PRECIP STA SHELBURNE
FLOW (m³/s)
25
20
15
10
5
0
SIMULATED NATURAL INFLOW
SIMULATED (REGULATED)
OBSERVED
TIME (HRS)
6
12
18
24
6
12
18
5 APRIL
6 APRIL

Fig. 3.6 (f)

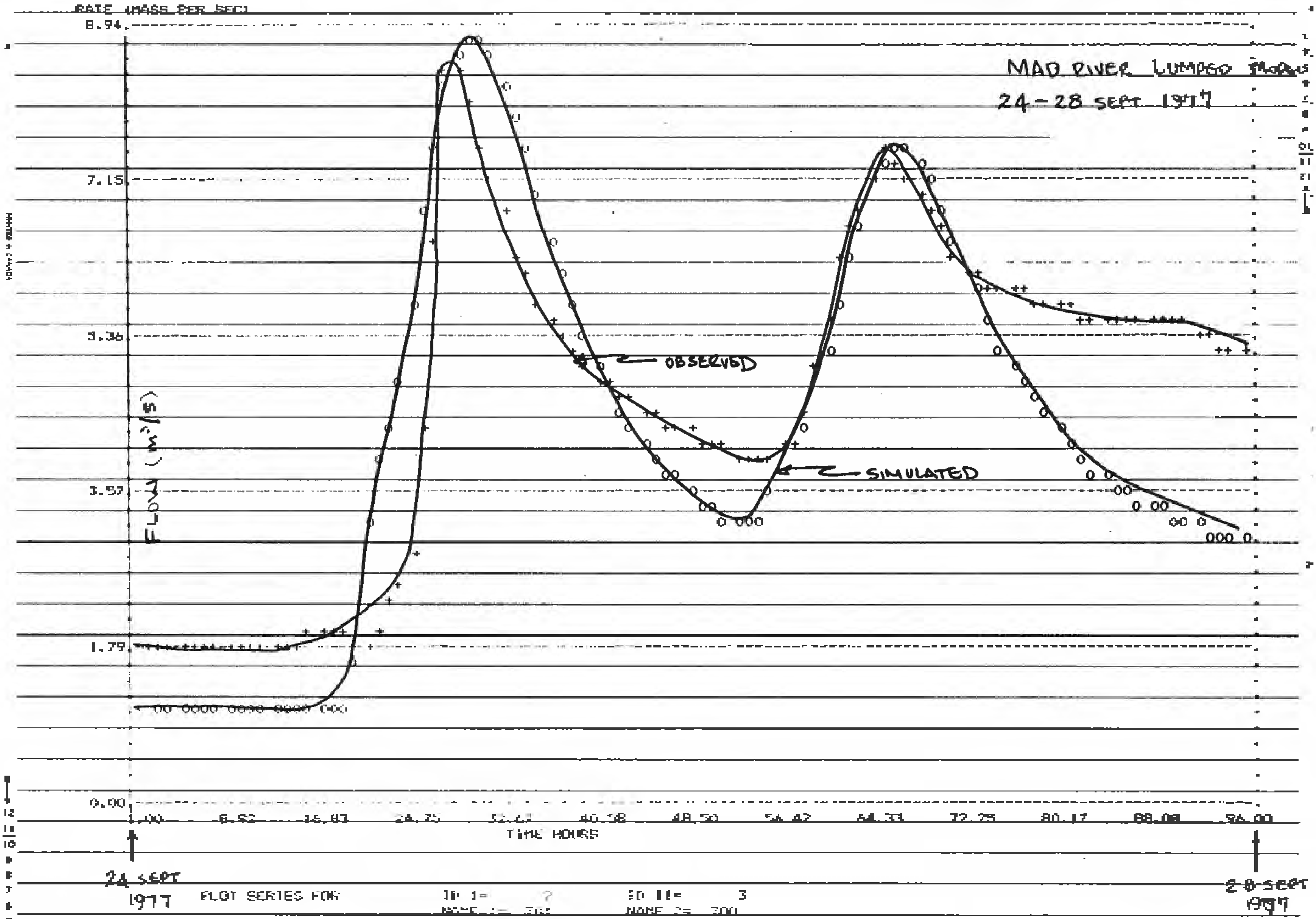

RATE (MASS PER SEC)
8.94
7.15
5.36
3.57
1.79
0.00
MAD RIVER LUMPSO
24 - 28 SEPT 1977
OBSERVED
SIMULATED
FLOW (m³/s)
1.00
8.92
16.83
24.75
32.67
40.58
48.50
56.42
64.33
72.25
80.17
88.08
96.00
TIME HOURS
24 SEPT 1977
28 SEPT 1977
PLOT SERIES FOR

Fig 3.7

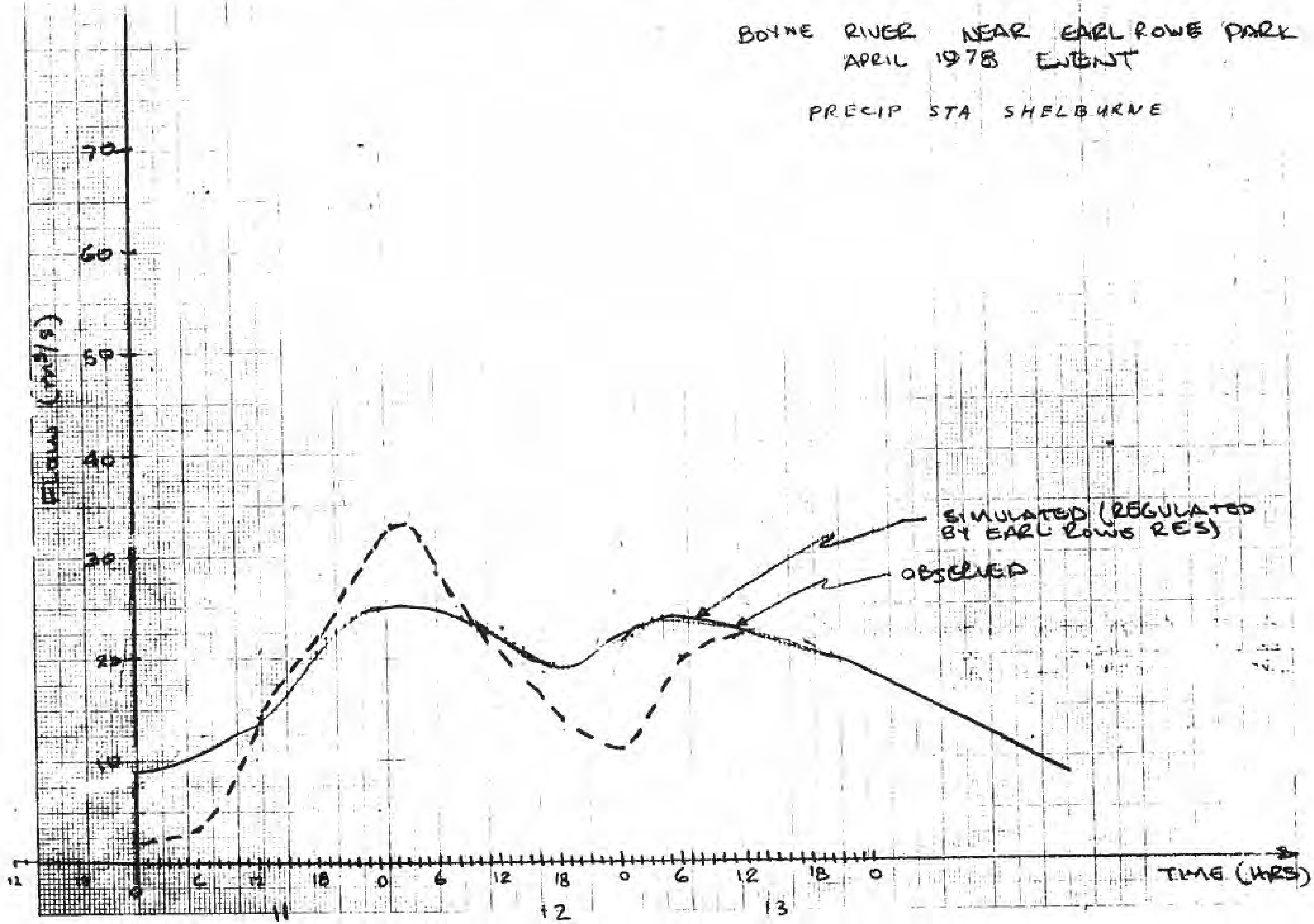

BOYNE RIVER NEAR EARL ROWE PARK
APRIL 1978 EVENT
PRECIP STA SHELBURNE
FLOW (m³/s)
70
60
50
40
30
20
10
SIMULATED (REGULATED BY EARL ROWE RES)
OBSERVED
TIME (HRS)
12 18 0 6 12 18 0 6 12 18 0 6 12 18 0
11
12
13

Fig 3.8 (a)

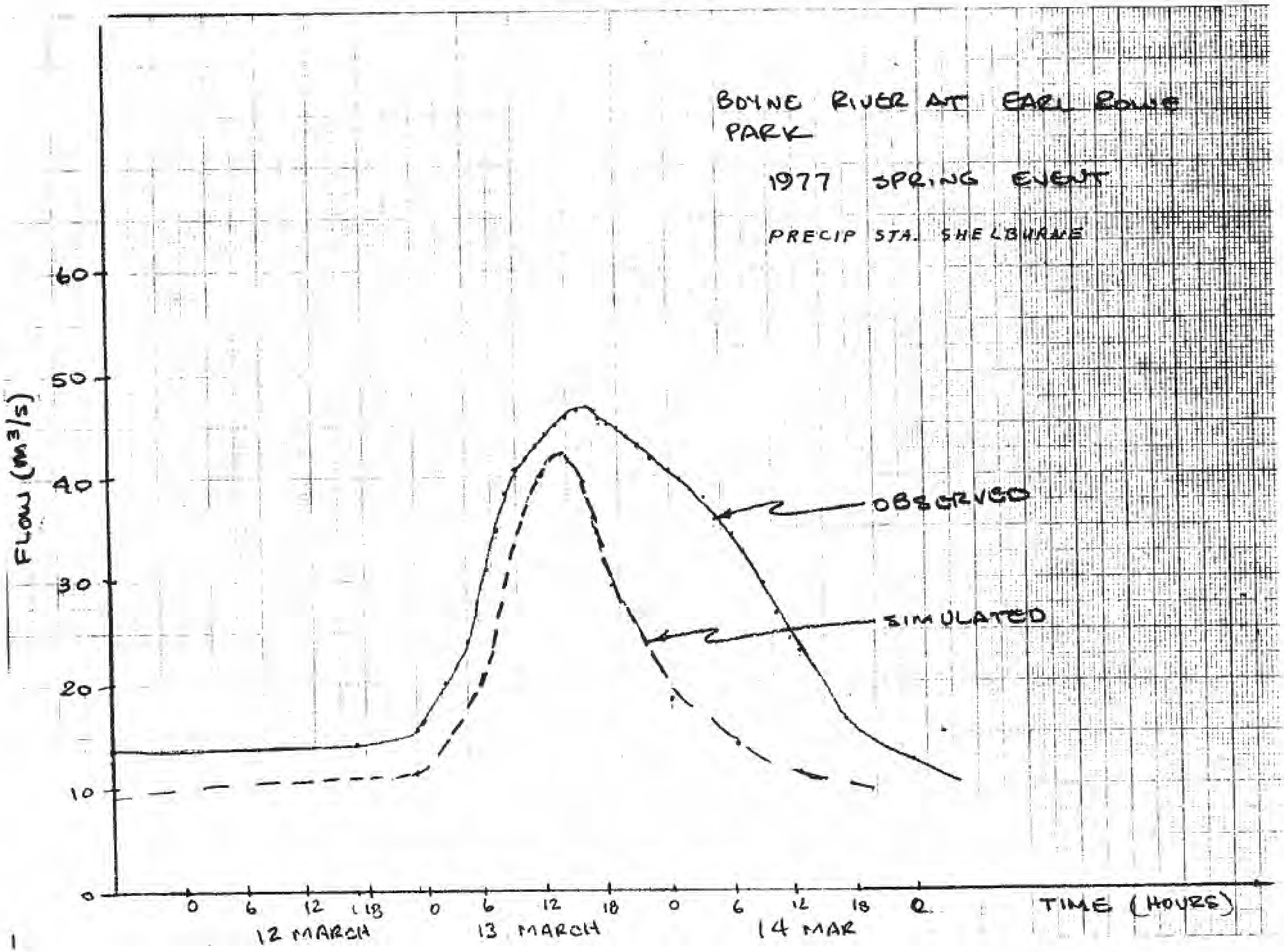

BOYNE RIVER AT EARL ROWE PARK
1977 SPRING EVENT
PRECIP STA. SHELBURNE
OBSERVED
SIMULATED
FLOW (m^3/s)
0
10
20
30
40
50
60
0 6 12 18
12 MARCH
0 6 12 18
13 MARCH
0 6 12 18 0
14 MAR
TIME (HOURS)

Fig 3.8 (b)

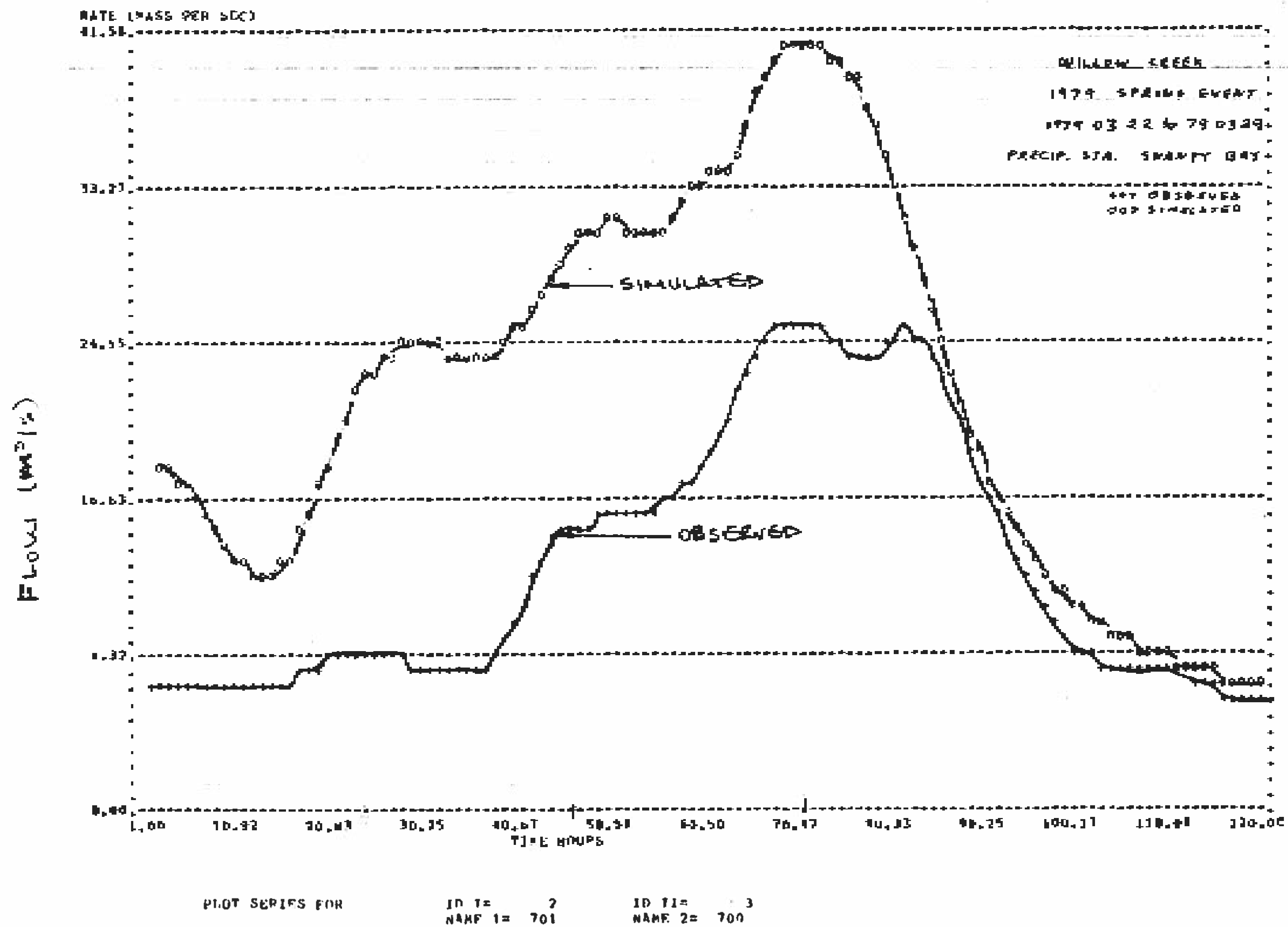

RATE (MASS PER SEC)
41.58
33.27
24.95
16.63
8.32
0.00
FLOW (m³/s)
WILLOW CREEK
1979 SPRING EVENT
PRECIP. STA.
SIMULATED
OBSERVED
1.00
10.92
20.83
30.75
40.67
50.58
60.50
70.42
80.33
90.25
100.17
110.08
120.00
TIME HOURS
PLOT SERIES FOR
ID T1= 2
NAME 1= 701
ID T1= 3
NAME 2= 700

Fig. 3.8 (c)

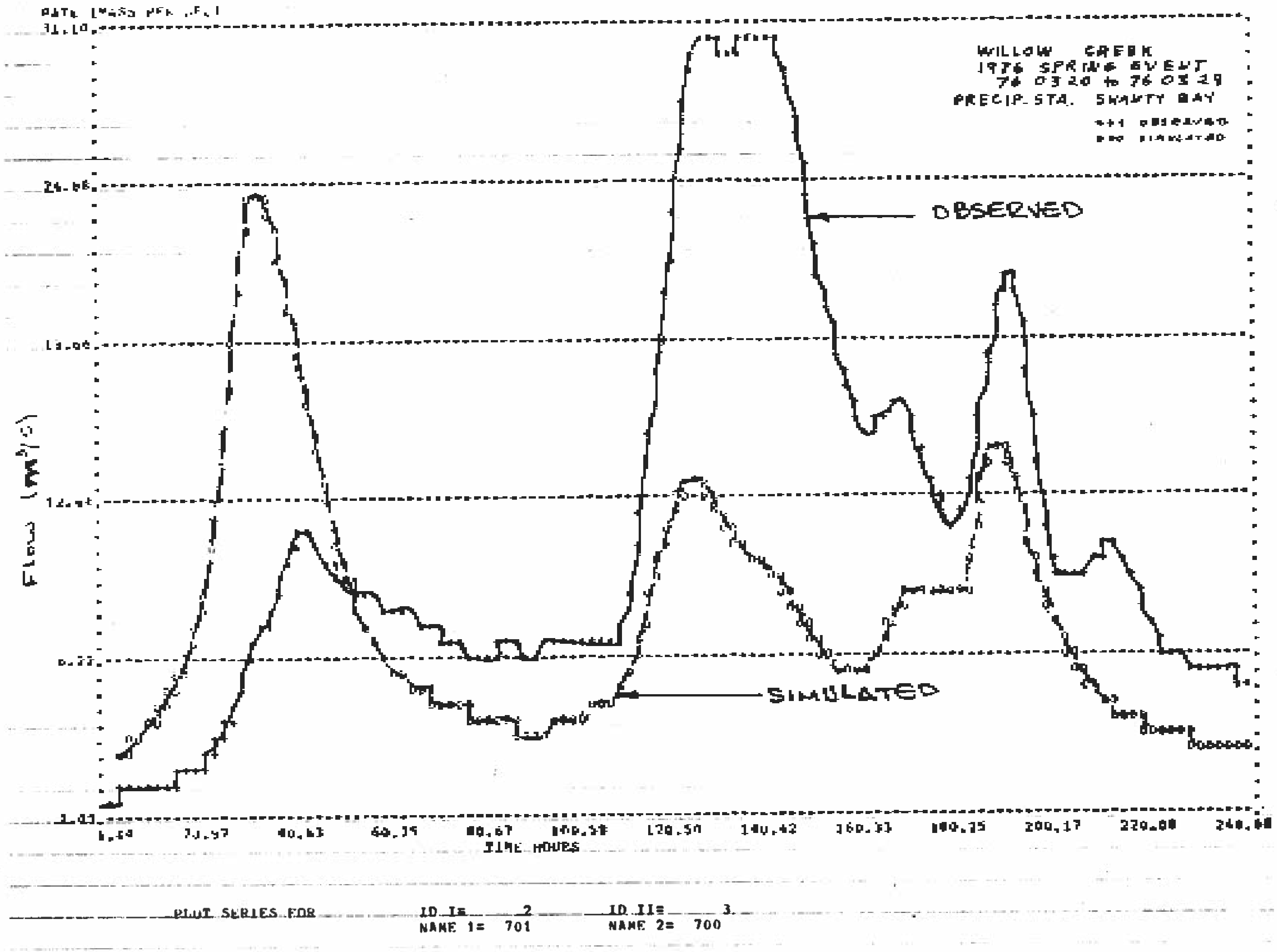

WILLOW CREEK
1976 SPRING EVENT
76 03 20 to 76 03 29
PRECIP. STA. SHANTY BAY
OBSERVED
SIMULATED
Flow (m³/s)
TIME HOURS
PLOT SERIES FOR ID I= 2 ID II= 3.
NAME 1= 701 NAME 2= 700

Fig. 3.8(d)

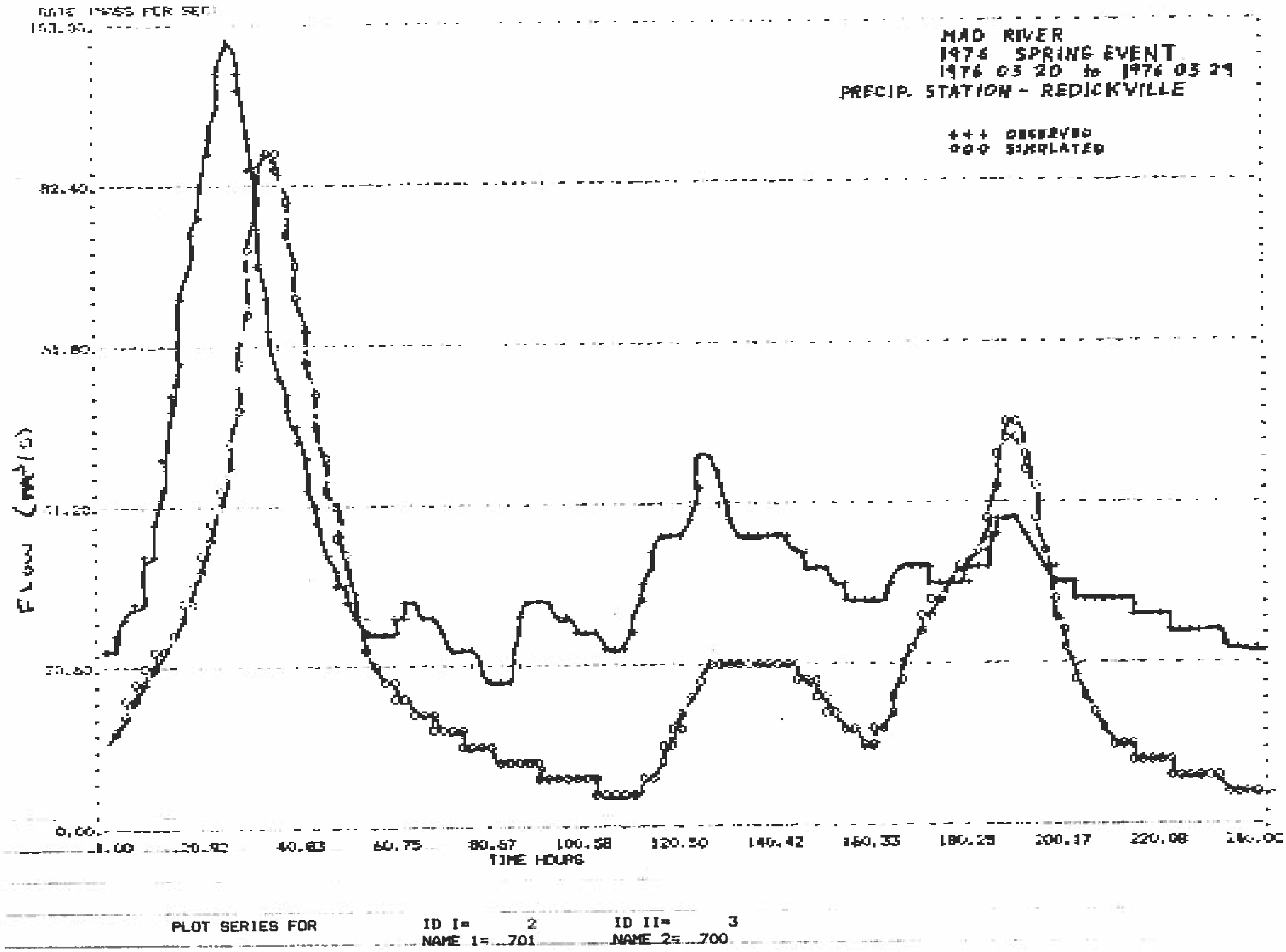
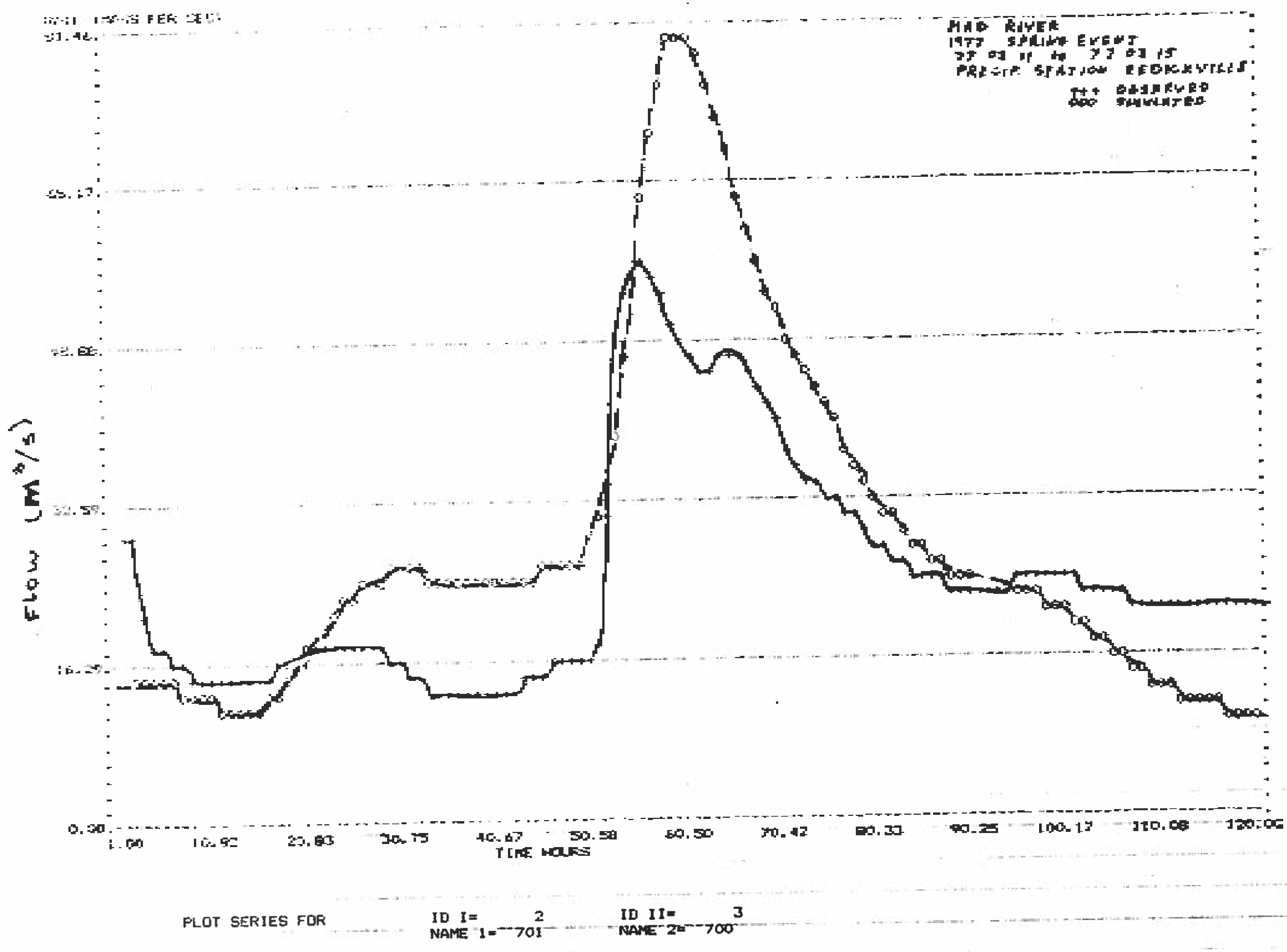

MAD RIVER
1976 SPRING EVENT
1976 03 20 to 1976 03 29
PRECIP. STATION - REDICKVILLE
+++ OBSERVED
ooo SIMULATED
Flow (m³/s)
82.40
0.00
40.83
60.75
80.67
100.58
120.50
140.42
160.33
180.25
200.17
220.08
TIME HOURS
PLOT SERIES FOR
ID I= 2
NAME 1= 701
ID II= 3
NAME 2= 700

Fig. 3.8(e)



MAD RIVER
1977 SPRING EVENT
PRECIP STATION EEDICKVILLE
+++ OBSERVED
ooo SIMULATED
Flow (M³/s)
81.46
65.17
48.88
32.59
16.29
0.00
1.00
10.92
20.83
30.75
40.67
50.58
60.50
70.42
80.33
90.25
100.17
110.08
120.00
TIME HOURS
PLOT SERIES FOR
ID I= 2
NAME 1= 701
ID II= 3
NAME 2= 700

Fig. 3.8 (f)

Since discussions with Water Survey of Canada indicated that the Willow Creek gauge above Little Lake is subject to backwater affects from the lake, this event was dismissed as an anomaly.

3.2.5.3 Discretized Model

The calibration/validation for the summer and spring events discussed in the previous sections was undertaken using lumped models. In order to confirm the above results, the discretized models for the Mad River, Boyne River, Pine River, Willow Creek and Nottawasaga River catchments were run for specific events.

Hydrologic model schematic for the Nottawasaga River and its tributaries and the Nottawasaga Bay watercourses are presented in Appendix K.

The results using the discretized models for some of the summer events are shown in Figure 3.9(a) to 3.9(c). For the spring and summer events, the comparison in peak flows is summarized in Table 3.10.

Since the lumped and discretized model produce similar results, this comparison provided a firm basis during the subsequent evaluation of frequency based design flows to use the lumped models for the simulation of the 22 years of historical flows and the discretized model to distribute the flow to tributary sub-catchments.

A further analysis of the sensitivity of flows with the time step used in the Variable Storage Coefficient routing was carried out (Table 3.10a) for the discretized model. Little variation in peak flow was noted for a shorter routing interval (15 minutes) than used in the model calibration and validation (one hour); therefore, the one hour time step was considered acceptable for application of the discretized model.

3.2.5.4 Historical Flood Peaks

As further validation of the QUALHYMO models, the annual peak flows were simulated for the 1963 to 1984 period and compared with observed discharges in a scatter diagram indicating individual events and by frequency analyses.

TABLE 3.10

Comparison of Results Using Lumped and

Discretized QUALHYMO Models

Catchment	Date	Observed Peak Flow (m^3/s)	Simulated Peak Flow: Lumped Model (m^3/s)	Simulated Peak Flow: Discretized Model (m^3/s)
Mad River near Glencairn	21 March 1980	74.4	75.0	78.2
Boyne River at Earl Rowe Park	13 March 1977	46.4	42.0	51.0
Willow Creek above Little Lake	21 March 1980	35.3	33.5	38.6
Beeton Creek near Tottenham	29 July 1980	3.9	4.4	5.0
Pine River near Everett	29 July 1980	21.7	15.7	19.2 [1]
Nottawasaga River near Baxter	29 July 1980	66.7	66.3	96.6

[1] Observed baseflow of 5.0 m^3/s was added to simulated peak flow of 14.2 m^3/s

TABLE 3.10a

SENSITIVITY TESTING OF ROUTING EFFECT USING 0.25 HOURS AND 1.0 HOUR TIME STEP FOR TIMMINS STORM

(All flows in m^3/s)

		0.25 HOUR TIME STEP		1.0 HOUR TIME STEP	
REACH NO.	FLOW POINT	PEAK FLOW	ROUTED PEAK FLOW	PEAK FLOW	ROUTED PEAK FLOW
	1070	1657.5	-	1648.0	-
44					
	1072	1682.8	1646.2	1674.3	1639.9
45	1074	1743.8	1682.5	1733.2	1672.7
46					
	1078	1844.6	1741.4	1827.2	1727.6
48					
	480	1867.9	1832.1	1851.5	1819.1
49					
			1844.9		1833.2

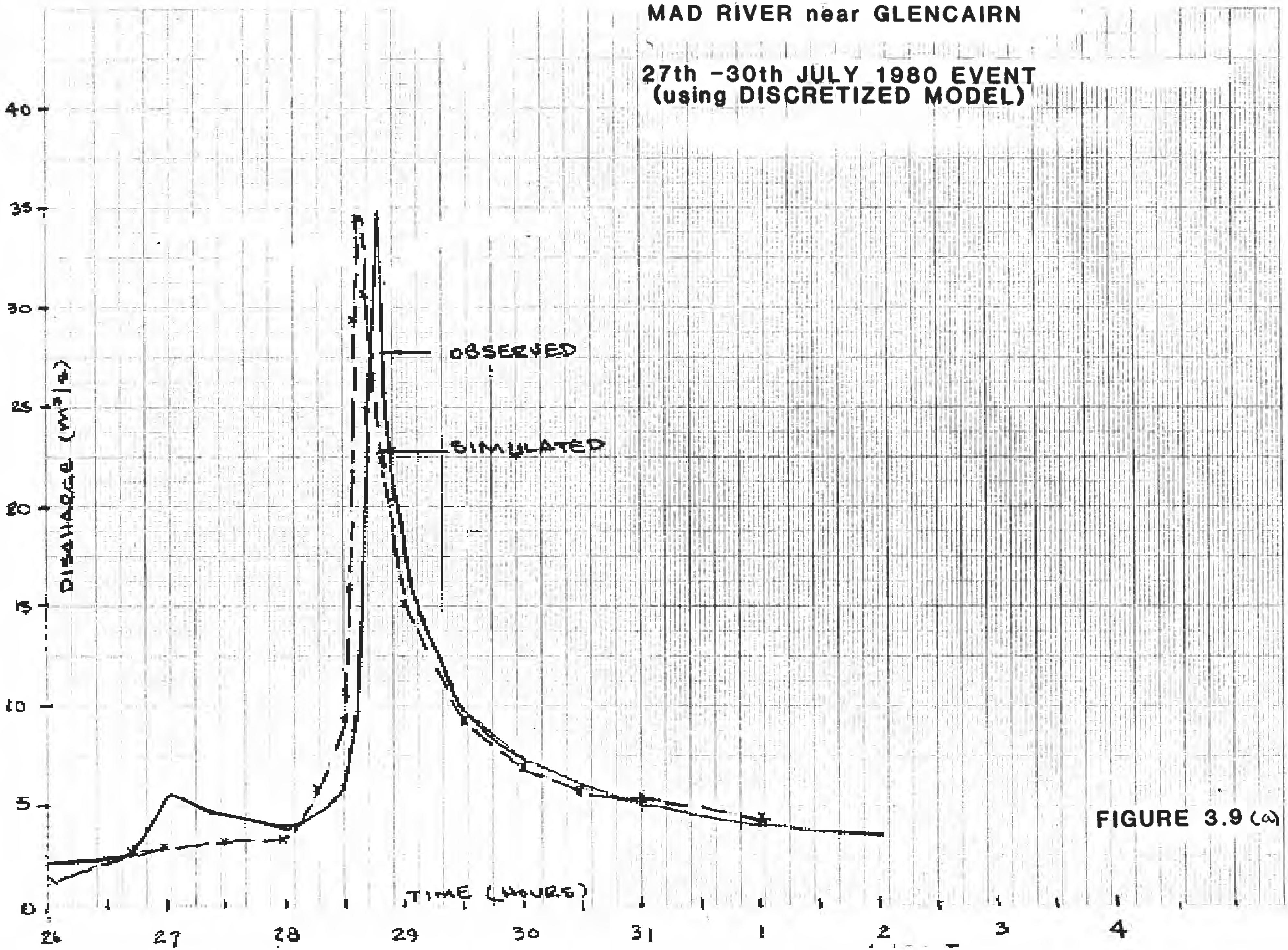
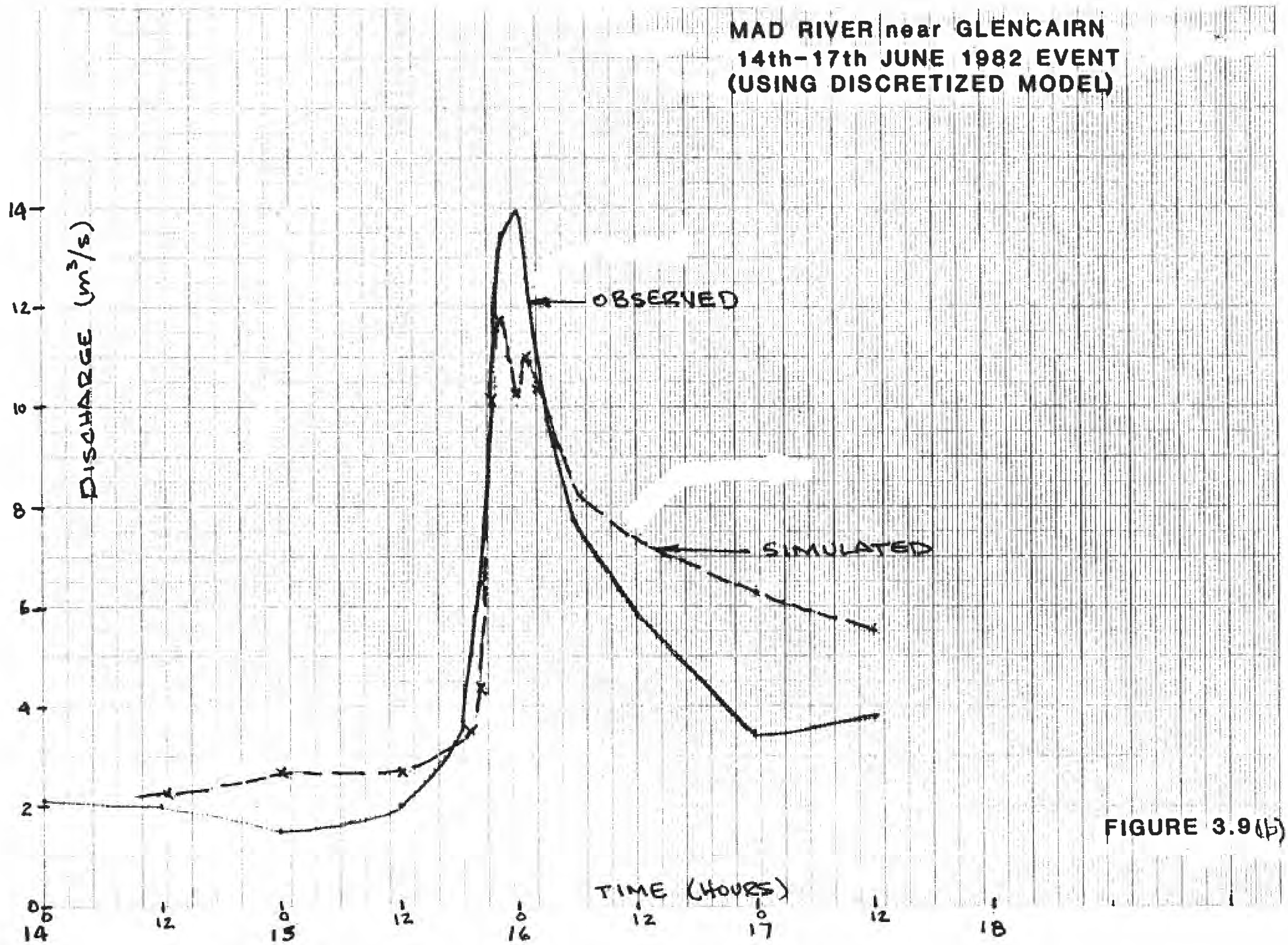

MAD RIVER near GLENCAIRN
27th -30th JULY 1980 EVENT
(using DISCRETIZED MODEL)
OBSERVED
SIMULATED
DISCHARGE (m³/s)
TIME (HOURS)
0
5
10
15
20
25
30
35
40
26
27
28
29
30
31
1
2
3
4

FIGURE 3.9 (a)



MAD RIVER near GLENCAIRN
14th-17th JUNE 1982 EVENT
(USING DISCRETIZED MODEL)
OBSERVED
SIMULATED
DISCHARGE (m³/s)
14
12
10
8
6
4
2
0
TIME (HOURS)
0
14
12
0
15
12
0
16
12
0
17
12
18

FIGURE 3.9(b)

WILLOW CREEK above LITTLE LAKE

27th-30th JULY 1980 EVENT
(USING DISCRETIZED MODEL)

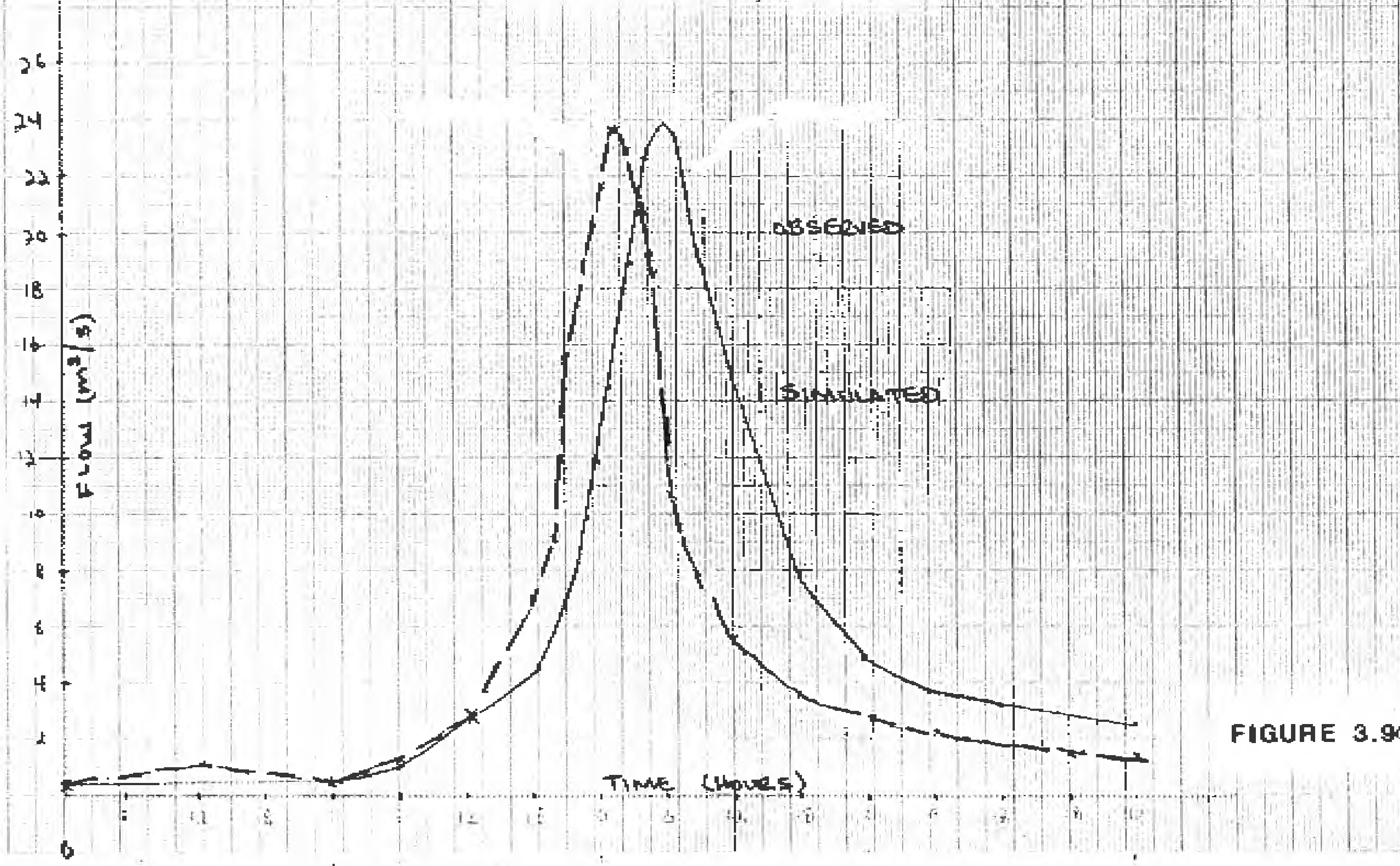


FIGURE 3.9(c)

Initial simulations produced notable discrepancies with recorded flows during a number of years for the Boyne River at Earl Rowe Park and Nottawasaga River at Baxter.

It was found that for most of the events the best overall results were obtained when the SI value was reduced to 64 mm (2.5") for these two sub-catchments. As a result of the above investigation, the following parameters were used:

i) All areas tributary to the Nottawasaga River near Baxter

SI = 64 mm (2.5")	MFMAX = 0.005
UADJ = 0.057	MFMIN = 0.0018

ii) Pine River, Mad River and Willow Creek

The same parameter values as above were used except SI was left at 127 mm (5").

Further analysis indicated that refinement in the value of some parameters was required to achieve a reasonable computation of spring flows during 1971, 1975, 1977, 1978 and 1982. These are described for each year in the following text.

The event that occurred on April 13, 1971, was primarily a snowmelt event but 5-10 mm of rainfall did fall over a two day period. It was found that in order to reduce the simulated peak at Baxter, the maximum melt factor (MFMAX) had to be increased to 0.009. Increasing the melt factor was felt to be a reasonable strategy since the event occurred in the middle of April. The above strategy produced reasonable results for most of the hydrometric stations except for the Mad River at Glencairn where the simulated peak was about five times the observed peak. The model seemed to accumulate more snowpack than was likely to exist in the Mad River catchment. However, there were no snow course data in the area in 1971 to check the simulated snowpack amounts. Increasing the minimum melt factor (MFMIN) to the upper limit of 0.0035 reduced the simulated peak to 113 m^3/s as compared with 37.9 m^3/s observed. As a result of the inconsistency encountered, the 1971 event for the Mad River was not plotted in the scatter diagram nor included in the frequency analysis.

The event that occurred on April 19-20, 1975, was primarily a rainfall event with 16.7 to 36.1 mm of rainfall recorded within the NVCA. Although the snowpack had disappeared by the first week in April, the model indicates that when the rainfall occurred there was still snow on the ground. In order to reduce the simulated peaks it was found necessary to reduce the snowmelt contributing to the peak. To achieve this, it was required to increase MFMIN to 0.0035 and MFMAX to 0.009. No change was made to the SI parameter.

The events that occurred in 1977, 1978 and 1982 were all primarily rainfall on snowmelt events. The 1977 event occurred in the second week in March, the 1978 event in middle of April and the 1982 event at the end of March. As was the case with the 1971 and 1975 events, adjustments to the melt factors were required for the 1977, 1978 and 1982 events. For the 1977 and 1978 events, MFMIN and MFMAX were increased to 0.0035 and 0.009, respectively. For the 1982 event the MFMIN was left at 0.0018 and the MFMAX was increased to 0.009. No changes to the SI parameters were required.

The scatter diagrams for the various hydrometric stations are presented in Figures 3.10(a) to 3.10(d).

As a further check on the accuracy of the QUALHYMO simulation of annual instantaneous peak flows, frequency analyses using the three parameter log normal and the Wakeby distributions were carried out by Environment Canada on behalf of the consultant using the following four conditions:

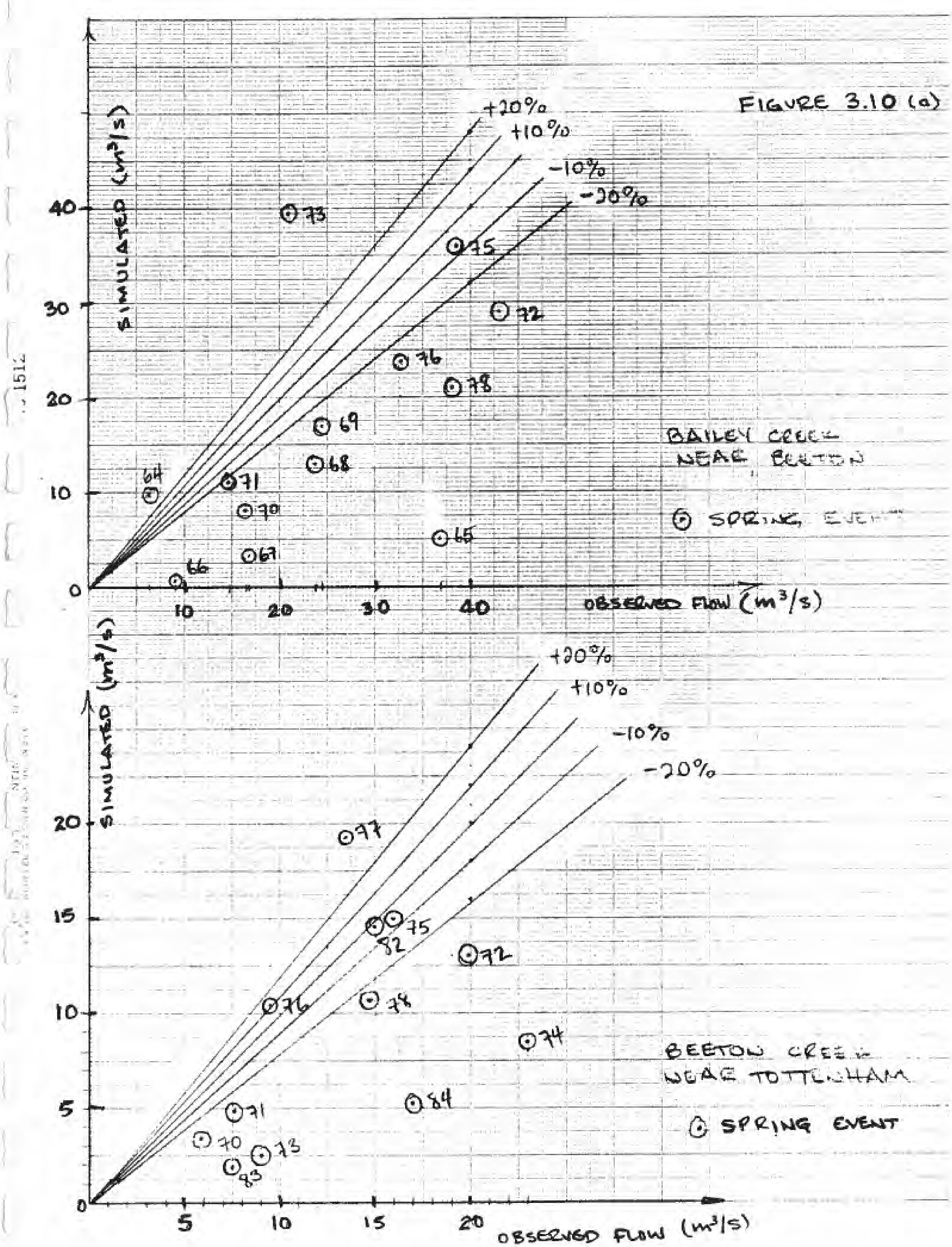


FIGURE 3.10 (a)
SIMULATED (m³/s)
+20%
+10%
-10%
-20%
73
75
72
76
78
69
68
64
71
70
65
67
66
OBSERVED FLOW (m³/s)
BAILEY CREEK NEAR BEETON
SPRING EVENT
SIMULATED (m³/s)
+20%
+10%
-10%
-20%
77
75
82
72
76
78
74
84
71
70
73
83
OBSERVED FLOW (m³/s)
BEETON CREEK NEAR TOTTENHAM
SPRING EVENT

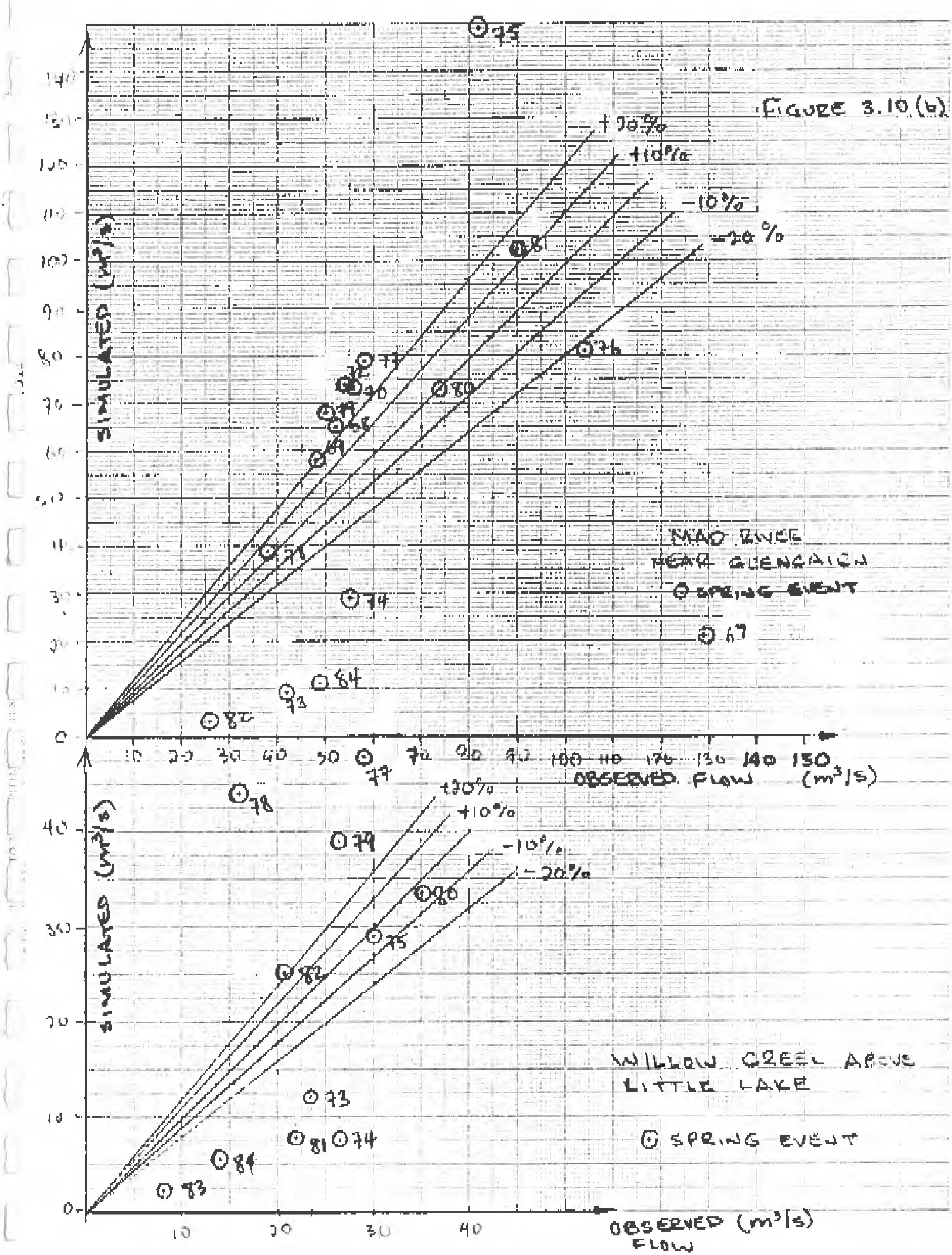


FIGURE 3.10 (b)
SIMULATED (m³/s)
OBSERVED FLOW (m³/s)
+20%
+10%
-10%
-20%
MAD RIVER NEAR GLENCAIRN
SPRING EVENT
WILLOW CREEK ABOVE LITTLE LAKE
SPRING EVENT
SIMULATED (m³/s)
OBSERVED (m³/s) FLOW

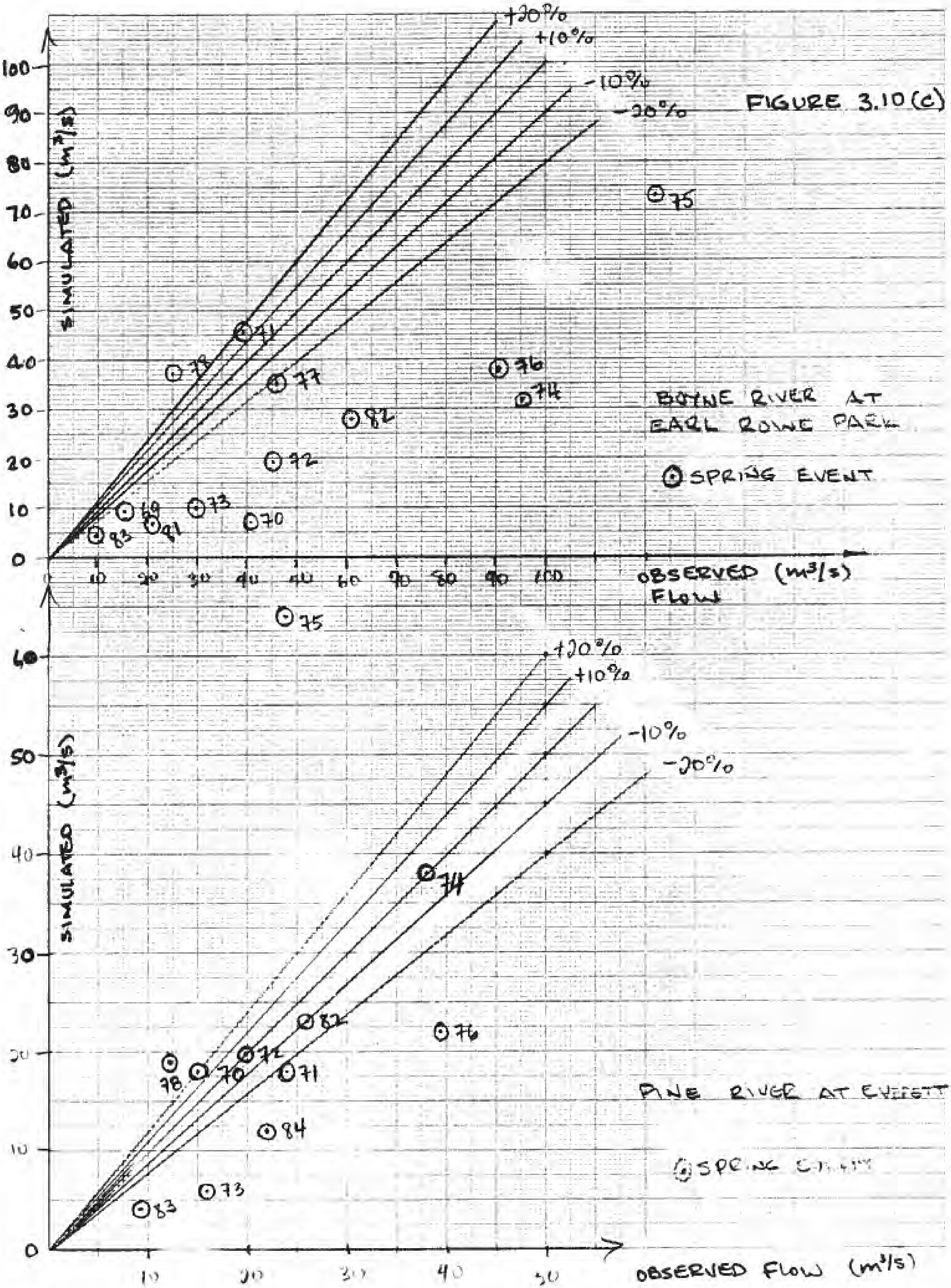
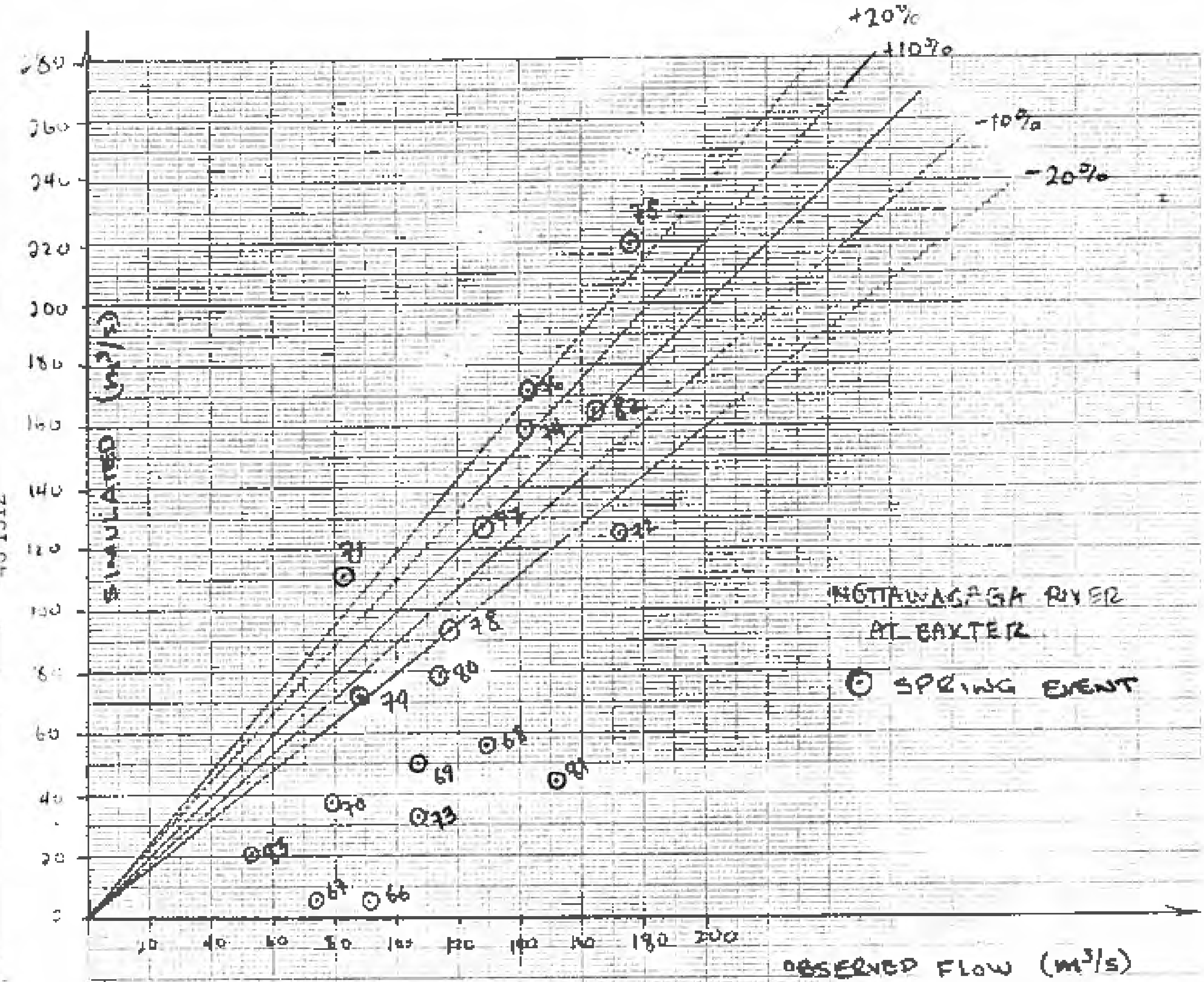


FIGURE 3.10 (c)
BOYNE RIVER AT EARL ROWE PARK
SPRING EVENT
SIMULATED (m³/s)
OBSERVED FLOW (m³/s)
+20%
+10%
-10%
-20%
PINE RIVER AT EVERETT
SIMULATED (m³/s)
OBSERVED FLOW (m³/s)



+20%
+10%
-10%
-20%
SIMULATED (m³/s)
NOTTAWASAGA RIVER
AT BAXTER
SPRING EVENT
OBSERVED FLOW (m³/s)

FIGURE 3.10 (d)

i) simulated annual peak flows for the 22 years from 1963 to 1984

ii) simulated annual peak flows from 1963 to 1984 for the same years in which observed annual peaks are available in iii)

iii) observed annual peak flows which are available from 1963 to 1984 if this duration is shorter than the record period

iv) observed annual peak flows for the period of record.

The direct comparison between simulated and observed frequency distributions was carried out between ii) and iii) with other sample periods used for further background information. Three parameter log normal frequency plots are provided in Appendix F while a comparison is given in Table 3.11. A further comparison between 100 year flow magnitudes which are computed from the QUALHYMO simulations, the observed record, and regional flood frequency analyses (Ref. 22, 23, 24) at hydrometric gauge locations is presented on Table 3.12. A similar comparison at three ungauged locations involving the frequency analysis of QUALHYMO annual peak simulations (Wakeby and three parameter lognormal distribution), and two Regional analyses is given in Table 3.13.

A sample of the values of the watershed parameters (B) (Ref. 12) which has been reported to vary from about 600 in steep terrain to 300 in very flat swampy country (Ref. 14) are presented in Table 3.14 and Appendix H.

3.2.5.5 Conclusions/Recommendations

The frequency plots and scatter diagrams in the previous figures represent the final results that can be achieved with calibrated parameters for soil moisture storage and snowmelt processes within the QUALHYMO Model. Substantial effort was spent in trying to obtain a reasonable agreement between the simulated and observed peaks. During this process, precipitation and

TABLE 3.11

SUMMARY OF SINGLE STATION FLOOD FREQUENCY ANALYSIS
(All Flows in m^3/s)

HYDROMETRIC STATIONS	D.A. (Km^2)	RETURN PERIOD	3 PARAMETER LOG NORMAL DISTRIBUTION: SIMULATED (1963-84) (1)	PARTIAL SIMUL. (2)	PARTIAL OBS. (3)	DOE (4)	WAKEBY DISTRIBUTION: SIMULATED (1963-84) (1)	PARTIAL SIMUL. (2)	PARTIAL OBS. (3)	DOE (4)
Beeton Creek near Tottenham	95	5	10	14	18	18	10.7	14.6	18.0	18.1
		20	20	22	28	28	17.5	20.0	21.9	25.8
		100	35	32	45	42	23.7	22.9	25.8	33.4
Bailey Creek near Beeton	207	5	25	26	35	39	27.0	27.5	36.7	37.7
		20	48	49	45	59	43.4	42.0	46.6	58.1
		100	83	83	55	84	57.2	52.4	51.1	84.4
Boyne River at Earl Rowe Park	211	5	31	48	78	70	31.8	50.0	79.2	69.0
		20	62	96	127	115	56.6	72.9	126.0	117.0
		100	112	172	190	176	84.0	92.0	172.0	175.0
Pine River near Everett	195	5	25	34	30	32	23.7	31.1	29.7	31.7
		20	45	58	42	49	42.1	55.9	42.6	48.4
		100	73	88	56	69	78.9	97.0	55.8	69.0
Mad River near Glencairn	295	5	78	91	82	75	83.3	89.9	78.7	71.2
		20	183	128	115	109	122.0	129.0	120.0	109.0
		100	377	163	155	149	146.0	159.0	176.0	167.0
Nottawasaga River near Baxter	1180	5	125	136	148	179	131.0	144.0	151.0	171.0
		20	212	224	177	264	201.0	211.0	187.0	268.0
		100	330	339	203	370	259.0	261.0	211.0	418.0
Willow Creek above Little Lake	95	5	26	335	30	30	27.3	41.5	29.1	29.8
		20	74	459	35	34	49.3	54.8	37.1	36.6
		100	184	605	39	37	73.9	60.1	46.6	45.1

(1) Simulated annual max. inst. discharges using QUALHYMO for 1963-1984 period.

(2)&(3) Simulated and observed flows for corresponding poeriods between 1963 and 1984 where observed max. inst. discharges exist.

(4) Flood frequency analysis conducted by Environment Canada for gauge record period.

TABLE 3.12

COMPARISON OF 1:100 YEAR PEAK FLOWS USING VARIOUS FLOOD FREQUENCY ANALYSIS

(All Flows in m^3/s)

HYDROMETRIC STATION	DRAINAGE AREA (Km^2)	SINGLE STATION (OBSERVED PEAKS)	SINGLE STATION (QUALHYMO PEAKS)	MULTIPLE REGRESSION (Ref. 24)	INDEX FLOOD (Ref. 23)	REGIONAL FLOOD FREQUENCY (Ref. 22)
Beeton Creek near Tottenham	95	42	35	38.5	36.1	70.6
Bailey Creek near Beeton	207	84	83	72.6	83.6	76.6
Boyne River at Earl Rowe Park	211	176	112	114	85.1	157.4
Pine River near Everett	195	69	73	76.5	79.0	149.5
Mad River near Glencairn	295	149	377	88.1	117.3	113.6
Nottawasaga River near Baxter	1180	370	330	298.1	441.0	294.3
Willow Creek above Little Lake	95	45	74	60.3	39.6	55.2

TABLE 3.13

SUMMARY OF 1:100 YEAR FLOWS FOR THREE UNGAUGED CATCHMENTS

(All Flows in m^3/s)

	DRAINAGE AREA (Km^2)	WAKEBY [1] DISTRIBUTION	THREE [1] PARAMETER LOG NORMAL DISTRIBUTION	MTC METHOD (Ref. 25)	INDEX FLOOD METHOD (Ref. 23)
Silver Creek at outlet	26.6	49.8	54.9	40.6	28
Spring Creek at outlet	15.3	25.4	25.9	22.9	20
Pretty River at outlet	77.0	90.1	117.0	76.2	70

[1] Annual peak flows between 1963 and 1984 simulated by QUALYHMO model.

TABLE 3.14

ESTIMATES OF B PARAMETER FOR VARIOUS SUB-CATCHMENTS

Watercourse	Sub-Catchment Number	Drainage Area (km²)	K/Tp	B Parameter
Innisfil Creek	300 + 302 311 312	40.87 24.1 12.65	1.1 1.1 1.7	298 298 210
Beeton Creek	200 + 201 202 205	23.44 10.15 16.49	0.88 1.70 1.80	360 210 201
Bailey Creek	208 211 212	24.74 25.63 18.74	1.00 1.10 1.25	322 322 270
Upper Nottawasaga	102 108 109	10.39 14.11 30.50	1.25 0.80 0.98	270 385 325
Sheldon Creek	113 + 114 115 117	36.82 14.20 34.42	0.75 0.85 1.20	410 368 278
Boyne River	400 401 406 409	30.49 15.21 38.21 26.07	1.15 1.30 1.10 0.85	288 261 298 368
Spring Creek	411 413	5.21 7.22	1.30 1.25	261 270
Pine River	500 + 501 502 506	74.90 29.28 21.83	0.70 1.05 0.90	430 310 351
Bear Creek	600 601 602	33.78 12.77 18.15	0.95 1.10 1.50	337 322 233
Truax Creek	603 604	10.15 10.95	0.90 1.45	351 239
Mad River	801 809 814 816	31.73 41.73 18.37 40.01	1.40 1.10 0.90 1.10	246 298 351 298

TABLE 3.14 (cont'd)

ESTIMATES OF B PARAMETER FOR VARIOUS SUB-CATCHMENTS

Watercourse	Sub-Catchment Number	Drainage Area (km²)	K/Tp	B Parameter
Silver ~~Spring~~ Creek	900	20.32	0.76	403
	901B	1.65	0.90	351
	901C	0.85	1.25	270
Willow Creek	700	16.15	0.90	351
	706	10.11	1.20	278
	707	14.24	1.25	270
	713 + 714	39.84	0.85	368
	712	23.63	1.05	310
	717	45.26	0.95	337

streamflow data were reviewed for discrepancies and various ranges of snowmelt parameters were tested to assess the model sensitivity.

Several reasons are cited as possible explanations for differences between simulated and observed flow peaks.

i) Lack of actual hourly rainfall data for some events during the spring. As indicated previously in some cases the 6-hourly precipitation data from Mt. Forest or distant hourly rainfall stations had to be used to distribute the daily precipitation into hourly data.

ii) Despite the reasonably dense network of meteorologic stations within the vicinity of the Nottawasaga River basin, the areal distribution of precipitation within catchments may introduce a source of error to the computations. During the calibration and validation investigation, point rainfall amounts from stations were selected as most representative of the tributary drainage area above a flow station.

iii) The API technique is used in the QUALHYMO Model under various spring snowmelt conditions under which very little model testing has been undertaken. The effect of frozen ground conditions upon runoff remains a subject of considerable hydrologic research. In addition, the practice of reducing the API during snow cover conditions is largely a matter of conjecture. While many of the larger observed flows were simulated quite well with this approach, a number of smaller runoff events were under-estimated possibly due to unrealistic antecedent moisture conditions based on a declining API. Baseflow magnitudes prior to spring events also often exceeded the predicted base flows especially when preceded by earlier runoff events. A more flexible recession coefficient defining baseflow contributions under these conditions may be a worthwhile addition to the QUALHYMO model.

iv) Most of the hydrometric stations within the NVCA have more than 14 years of historical records. In order to make use of this data, it is our recommendations that the NVCA use the available data for flood related studies. The QUALHYMO Model can be used to extend the record period at the various hydrometric stations for annual peak flows to 22 years and pro-rate these flows to upstream locations within the tributary catchment.

Based on the experience gained in simulating annual peak flows with the QUALHYMO model and the demonstrated transportability of model parameters, this simulation approach can be used with confidence on ungauged catchments tributary to the lower Nottawasaga River and watersheds draining directly to Nottawasaga Bay.

3.3 Design Flows

3.3.1 General

In the preceeding sections of the report, the QUALHYMO Model was calibrated and validated for both summer and spring events. The Model was subsequently used to generate 22 years (1963-1984) of flows using hourly precipitation and temperature data. From computer printouts, annual instantaneous peak flows were selected for the 22 years of simulated record at each of the existing hydrometric stations. Flood frequency analyses on the annual instantaneous peak flows were subsequently undertaken as discussed in Section 3.2.5.

The agreement between the observed and the simulated flood frequency curves with the same period of record is only marginal for most of the hydrometric stations. Possible explanation for differences between simulated and observed flow peaks are cited in Section 3.2.5.5; nevertheless, the number of spring flow peaks of small to intermediate magnitude which were underestimated by the QUALHYMO model is the underlying reason for the discrepancy between the frequency curves. The input data was also subjected to non-parametric testing and a number of low outliers were removed from the record; however, this did not alter the results of the frequency analysis.

Discussions were held with the Project Committee to resolve the discrepancy and develop a methodology to establish design flows. The procedure approved by the Committee is discussed in Section 3.3.2.

3.3.2 Present Watershed Flows

3.3.2.1 Methodology

The methodologies used to establish frequency based flows and to compute the Regional storm flows are discussed below.

3.3.2.1.1 Frequency Based Flows

From recommendations made in Section 3.2.5.5, Provincial Guidelines (Ref. 22) and direction given by the Project Committee, frequency based design flows (1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100 year) computed from the existing flow record at each hydrometric station are to be used when the length of record is equal to or greater than 20 years (Table 3.15). For the length of record between 10 years and 20 years, single station analysis is substantiated through comparison with regional frequency analysis. This process leads to the selection of the regression and index flood regional analysis (Ref. 23, 24) for the Beeton Creek and Pine River gauge (Table 3.15)

After frequency based flows were estimated at the existing hydrometric stations, these design flows are transferred to other watershed locations using the discretized QUALHYMO Model. Initially, it was considered using the ratio of simulated peak flows from QUALHYMO based on two historical high flow events. However, it was felt that the ratio would reflect the areal distribution of the selected historical events. In order to avoid this anomaly, it was felt more appropriate to select the point rainfall from a larger spring event that had only minimal snowmelt and to apply this

TABLE 3.15

DESIGN FLOWS AT EXISTING HYDROMETRIC STATIONS

(All Flows in m^3/s)

Hydrometric Station	Drainage Area (km^2)	Flood Frequency Method Selected	Return Period (Years)				
			5	10	20	50	100
Beeton Creek near Tottenham	95	Multiple Regression Analysis	19.5	23.7	28.1	34.0	38.5
Bailey Creek near Beeton	207	Single Station Analysis (3 PLN)[1]	39	49	59	73	84
Boyne River at Earl Rowe Park	211	Single Station Analysis (3 PLN)	70	92	115	149	176
Pine River near Everett	195	Index Flood Method	41.7	50.7	59.1	70.3	79.0
Mad River near Glencairn	295	Single Station Analysis (3 PLN)	75.0	92.0	109.0	131.0	149.0
Nottawasaga River near Baxter	1180	Single Station Analysis (3 PLN)	179	221	264	323	370
Willow Creek above Little Lake	95	Single Station Analysis (Wakeby Distribution)	29.8	33.1	36.6	41.3	45.1

1. 3 PLN - Three Parameter Lognormal Distribution

temporal distribution over the entire watershed which is tributary to the gauge sites. The Shelburne precipitation data for the March 1974 event was used for this purpose.

The total amount and the temporal distribution of rainfall at Shelburne were applied to each sub-catchment in the QUALHYMO model which is tributary to the hydrometric gauges on Willow Creek, Boyne River, Bailey Creek, Beeton Creek, Pine River, Mad River and Nottawasaga River at Baxter. The peak flows at each sub-catchment outlet and at the hydrometric stations were computed with the March 1974 event recorded at Shelburne applied evenly over the Nottawasaga basin with the QUALHYMO model. The ratios of simulated peak flows (watershed location to gauge site) were used to transfer the 1 in 5 to 1 in 100 year flows from the gauges to the watershed locations.

For example:

1. Upper Nottawasaga River, location <u>60</u> (Figure 3.11)

    a) QUALHYMO March 1974 peak flow: Location 60: 27.26 m^3/s
    : Nottawasaga River at Baxter: 210.72 m^3/s

    b) Return period flows Nottawasaga River at Baxter from analysis of flow record: 1 in 5 Year: 179 m^3/s (Table 3.15)
    1 in 100 Year: 370 m^3/s

    c) Return period flows at Location 60 (Upper Nottawasaga River)
    i) 1 in 5 Year: 23.2 m^3/s
    ii) 1 in 100 Year: 47.9 m^3/s

2. Boyne River, Location <u>350</u> (Figure 3.11)

    a) QUALHYMO March 1974 peak flow: Location 350: 20.62 m^3/s
    : Boyne River at Earl Rowe: 34.93 m^3/s

b) Return period flows Boyne River at Earl Rowe Park from single station analysis of flow record:

i) 1 in 5 Year: 70 m^3/s (Table 3.15)

ii) 1 in 100 Year: 176 m^3/s

c) Return period flows at Location 350 on Boyne River

i) 1 in 5 Year: 41.3 m^3/s

ii) 1 in 100 Year: 103.9 m^3/s

The foregoing procedure was employed to compute frequency based flows of watershed locations within the Willow Creek, Boyne River, Bailey Creek, Beeton Creek, Pine River, Mad River and Nottawasaga River at Baxter Watersheds.

Within the NVCA, there are several watercouses which flow directly into Georgian Bay or the Nottawasaga River below the Minesing Swamp. These catchments have not been gauged and therefore, no streamflow records are available. In order to estimate the frequency based flows it was necessary to simulate historical flows over 22 years using the QUALHYMO Model and the meteorologic database.

In the absence of streamflow data to calibrate/validate the QUALHYMO Model for these catchments, the same snowmelt parameters calibrated for Mad River and Pine River basins were used. These parameters are:

SI	= 127 mm (5")	MFMAX	= 0.005
UADJ	= 0.0057	MFMIN	= 0.0018

As outlined in Section 3.2.5.3, some adjustments to MFMAX and MFMIN were required for the spring events of 1971, 1975, 1977, 1978 and 1982. To be consistent with the MFMAX and MFMIN used for Mad and Pine River catchments for the various years noted above, the same parameters were also used in simulating the 22 years of streamflow data for the Georgian Bay catchments.

After 22 years of streamflow data were run with QUALHYMO, the annual maximum instantaneous peaks were abstracted. Flood frequency analyses (Wakeby distribution) were then conducted for various points along the watercourses using the Environment Canada CFA88 program to obtain the 1 in 5 year to 1 in 100 year flows.

3.3.2.1.2 Regional Storm

The Timmins Storm is the applicable Regional Storm for all drainage areas under the jurisdiction of the NVCA. This is the summer storm which produced 193 mm of rain in a 12-hour period over Timmins on September 1, 1961.

The calibrated/validated QUALHYMO Model was used to generate the Timmins Storm flows for all catchments. Rainfall was input in 1-hour intervals and the equivalent circular area method was used to make areal adjustment to the point rainfall. The equivalent circular area method accounts for the elongation of a basin by using the longest length of the watershed as the diameter.

The Ministry of Natural Resources requires that for the Timmins Storm, AMC II (average conditions) be used to establish antecedent soil moisture conditions on a watershed. However, since the QUALHYMO Model accounts for soil moisture conditions by the use of the API, it was felt that a more accurate indication of the soil moisture conditions prior to the Timmins Storm could be established. The daily rainfall recorded at the Timmins Airport for the months of July and August 1961 (prior to the Timmins Storm on September 1, 1961) was obtained. The rainfall was transposed to the Nottawasaga River basin and the API computed using the QUALHYMO Model. The API value established prior to the Timmins Storm was 27.0 mm. Subsequently this value was used in QUALHYMO to simulate the Timmins Storm flows.

3.3.2.2 Documentation of Flows

The design flows for the locations along the various watercourses are presented in Appendix G. The location of each flow point is shown in Figure 3.11.

The QUALHYMO Model was used to compute the Regional Storm flows as outlined in Section 3.3.2.1.2. The peak flows at points of interest along the various watercourses are presented in Appendix G.

3.3.2.3 Comparison with Previous Studies

Several hydrologic studies have been undertaken for various watercourses (Fig. 1.1) within the NVCA. A brief description of these studies is presented in Appendix A. To ensure consistency in design flows and to obtain confidence in the results obtained, the design flows developed in this study were compared with those from previous studies. A comparison of the design flows for the 1 in 100 year event and Regional Storm is presented in Table 3.16.

At most locations the 1 in 100 year and Regional Storm peak flows are in close agreement; however, discrepancies are apparent on the Sheldon Creek, the Nottawasaga River at Hockley, Truax Creek, Beeton Creek at Beeton and Innisfil Creek east of Cookstown. For the above-noted flow points, the peak flows established in previous studies are higher than the MacLaren study, except for Truax Creek. The flows on Sheldon Creek at Sheldon and the Nottawasaga River at Hockley appear excessively large. However it is emphasized that the hydrologic models applied in the present MacLaren Plansearch study were calibrated while earlier investigations did not perform this exercise. Therefore the design flows developed in this study are more accurate than those developed in earlier studies.

TABLE 3.16

COMPARISON OF 1:100 YEAR AND REGIONAL STORM PEAK FLOWS WITH PREVIOUS STUDIES WITHIN THE BASIN

Location	MacLaren Study			Author	Previous Study		
	Drainage Area (km^2)	Timmins Q(m^3/s)	1:100 Year Q (m^3/s)		Drainage Area (km^2)	Timmins Q(m^3/s)	1:100 Year Q (m^3/s)
Willow Creek above Little Lake	95.1	233.5	45.1	Cumming-Cockburn	90.4	241.0	45.2
Black Ash Creek at Outlet	29.1	125.9	51.5	Ainley	30.3	129.6	66.9 ~30% larger
Pine River at Outlet	335.9	220.0	101.4	MNR C.A.B	347.8	258.5	-
Lamont Creek at Stayner	26.9	124.5	56.8	Ainley	28.4	124.6	-
Spring Creek at Honda Plant	8.1	28.5	10.1	Giffels	12.2	43.0	20.18
Sheldon Creek at Sheldon	66.3	95.4	19.5	Burnside	59.6	261.0	185.4
Nottawasaga River at Hockley	175.9	164.2	44.7	Burnside	177.8	505.5	328.2
Sturgeon Creek	19.7	55.2	20.2	Cumming-Cockburn	21.02	60.7	14.4
Truax Creek	21.1	59.6	16.0	Cumming-Cockburn	17.0	35.2	-
Beeton Creek at Beeton	84.7	124.8	40.2	Triton	-([1])	180.9	-
Innisfil Creek East of Cookstown	65.4	121.0	26.1	Dillon	60.3	150.1	-

([1]) Same location as MacLaren flow point.

3.3.3 Future Watershed Flows

3.3.3.1 Methodology

Two separate discretized QUALHYMO Models were established for all the catchment areas within the NVCA: one model reflected present conditions while the other future conditions. The additional imperviousness due to future urbanization was simulated with the FRIMP parameter which is a fraction of impervious land. The methodology used to obtain estimates of future urbanization is outlined in Section 3.2.3.

The future Timmins Storm flows were simulated using the QUALHYMO Model set-up for future conditions. The methodology used to simulate these flows was the same as that outlined in Section 3.3.2.1.2 for Timmins Storm flows under present condition.

To establish future flows for the 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100 year events, it would be necessary to run the discretized QUALHYMO Model for 22 years. However, from the analysis of the Official Plans carried out in Section 3.2.3 for the urban areas, it was found that for most of the NVCA the increase in urbanization from present to future conditions is negligible. Approximately eleven (11) urban areas were identified where significant urbanization from a hydrologic point of view will take place. These are identified below:

- Boyne River at Shelburne and Alliston
- Spring Creek at Alliston
- Innisfil Creek at Cookstown
- Willow Creek near Barrie
- Bear Creek near Barrie
- Nottawasaga River at Glen Cross
- Lamont Creek at Stayner

- Black Ash Creek near Collingwood *
- Silver Creek near Collingwood
- Pretty River at Collingwood.

The discretized models for each of the above areas were separated from the main model. Downstream sub-catchment areas were included in each model to the point of a major confluence in order to assess the hydrologic impact of urbanization. Each sub-model was subsequently run for 22 years of historic events for both present and future conditions. Frequency analyses were then conducted at points of interest for both present and future conditions using the CFA88 program. At each point, the increase in flow from present to future conditions was determined for the various return periods (1 in 5 to 1 in 100 year). To obtain the future flows, the increase in flow was added to the corresponding return period flow established in Section 3.3.2.2 under existing conditions. An example of this procedure is provided in Appendix I.

A similar procedure was used for some of the other watercourses flowing into Georgian Bay and the local sub-catchments downstream of Minesing Swamp flowing directly into the Nottawasaga River.

3.3.3.2 Documentation of Flows

Using the methodology outlined in the previous section, the future flows for the Timmins Storm and 1 in 5 to 1 in 100 year events were determined. These flows are tabulated in Appendix G. The increase in future flows is small for both the Timmins Storm and the 1 in 5 to 1 in 100 year events.

3.3.4 Flow Estimation at Intermediate Locations

While the watercourses within the NVCA have been discretized into 191 sub-catchments for this study, it is recognized that the Conservation Authority may have future requirements to obtain design flows at other flow points. As indicated previously, design flows developed for this study are presented in Appendix G. The location of the flow points are cross-referenced to Figure 3.11. From a review of Figure 3.11, it can be seen that design flows may be required for (i) smaller headwater drainage basins than were modelled using QUALHYMO and (ii) along major waterways. This section of the report deals with the development of two methodologies to obtain design flows for headwater drainage areas and along major watercourses.

3.3.4.1 Headwater Drainage Areas

In consultation with the Project Committee, it was decided that the design flows for headwater drainage areas would be established by conducting linear regression analyses of peak flows versus drainage areas. The equation has the form of:

$$Q = CA^n$$

where:

Q is the peak discharge (m^3/s)

A is the drainage area (km^2)

and n and C are the slope of the line and intercept, respectively.

A computer program developed in-house was used to conduct linear regression analyses for the 1 in 5, 1 in 10, 1 in 20, 1 in 50, 1 in 100 year events and Timmins Storm. Regression analyses were conducted separately for the major watercourses to account for geographic and physiographic differences. Linear regression analyses were conducted for the following watercourses:

- Innisfil/Beeton/Bailey Creeks
- Upper Nottawasaga River (including Sheldon Creek)
- Boyne River
- Pine River
- Mad River
- Willow Creek
- Georgian Bay watercourses — BAC

The number of flows versus drainage area points used in the regression analyses ranged from seven to thirteen. The size of the drainage areas ranged from 1 km^2 to 134 km^2 and are documented in Table 3.17. Reference should be made to Appendix G for flow values. The result of the regression analyses for the above-noted watercourses are plotted in Figures 3.12(a) to 3.12(g) for the 1 in 20 and 1 in 100 year event and the Timmins Storm. From these figures, it can be seen that the slopes of the lines for each watercourse are similar for the 1 in 20, 1 in 100 year and Timmins Storm. This is also true for the 1 in 5, 1 in 10 and 1 in 50 year events.

A summary of the C and n parameters established from the linear regression analysis is presented in Table 3.18 for each watercourse. To compute the design flow at a point of interest for headwater drainage areas, the following procedure is recommended:

i) measure the drainage area to the point of interest using suitable mapping

ii) from Table 3.18, select the appropriate C and n values for the desired recurrence interval or Timmins Storm flows

iii) substitute the values obtained in (i) and (ii) above in $Q = CA^n$ to obtain design flow

TABLE 3.17

Headwater Basins Used in Regression Analysis for Watercourses Indicated

Watercourse	Ref. No.	Description	Drainage Area (km^2)
Innisfil Creek/ Beeton Creek/ Bailey Creek	302	Outlet of Basin 302 & 300	40.9
	240	Outlet of Basin 303	65.4
	311	Outlet of Basin 311	24.1
	316	Outlet of Basin 315 & 316	35
	290	Outlet of Basin 317	45.6
	314	Outlet of Basin 314	11.7
	1025	Confluence of Basins 314 & 317	57.3
	300	Outlet of Basin 318	60.4
	209	Outlet of Basin 209	27.7
	208	Outlet of Basin 208	24.7
	201	Outlet of Basin 201	23.4
	203	Outlet of Basin 203	11.3
	2100	Confluence of Basins 202 & 204	34.6
Mad River	800	Outlet of Basin 800	42.8
	670	Outlet of Basin 801	74.5
	804	Outlet of Basin 804	38.6
	710	Outlet of Basin 805	70.0
	810	Outlet of Basin 810	35.3
	720	Outlet of Basin 806	90.1
	814	Outlet of Basin 814	18.4
	790	Outlet of Basin 815	39.4
	680	Outlet of Basin 680	88.7

TABLE 3.17 (cont'd)

Headwater Basins Used in Regression Analysis for Watercourses Indicated

Watercourse	Ref. No.	Description	Drainage Area (km^2)
Upper Nottawasaga River	101	Outlet of Basin 101	27.2
	102	Outlet of Basin 102	10.4
	1001	Confluence of Basins 101 & 102	37.6
	114	Outlet of Basin 114	36.8
	1011	Confluence of Basins 114 & 116	51.0
	90	Outlet of Basin 116	66.3
	100	Outlet of Basin 117	100.7
Boyne River	400	Outlet of Basin 400	30.5
	401	Outlet of Basin 401	15.2
	1002	Confluence of Basins 400 & 401	45.7
	330	Outlet of Basin 402	57.4
	404	Outlet of Basin 404	21.1
	409	Outlet of Basin 409	26.1
	411	Outlet of Basin 411	5.21
Pine River	501	Outlet of Basin 501	74.9
	510	Outlet of Basin 502	104.2
	506	Outlet of Basin 506	21.8
	508	Outlet of Basin 508	29.6
	507	Outlet of Basin 507	35.2
	510	Outlet of Basin 502	8.5
	1101	Confluence of Basins 502 & 503	133.9

TABLE 3.17 (cont'd)

Headwater Basins Used in Regression Analysis for Watercourses Indicated

Watercourse	Ref. No.	Description	Drainage Area (km^2)
Georgian Bay Catchments	BAC 902	Outlet of Basin 902	11.1
	BAC 1510	Outlet of Basin 903	26.85
	Batteaux 909	Outlet of Basin 909	30.2
	Lamont 913	Outlet of Basin 913	26.9
	Warrington 915	Outlet of Basin 915	29.9
	Pretty 98	Outlet of Basin 906	43.4
	Silver 900	Outlet of Basin 900	20.3
	BAC 9012	Outlet of Basin 901B	1.65
	BAC 9013	Outlet of Basin 901C	0.85
Willow Creek	700	Outlet of Basin 700	16.1
	810	Outlet of Basin 702	25.2
	701	Outlet of Basin 701	27.3
	712	Outlet of Basin 712	23.6
	714	Outlet of Basin 714	39.8
	715	Outlet of Basin 715	20.5
	1400	Confluence of Basins 702 & 701	52.5

TABLE 3.18

SUMMARY OF LINEAR REGRESSION ANALYSIS PARAMETERS FOR HEADWATER DRAINAGE AREAS

WATERCOURSES	1 in 5 Year		1 in 10 Year		1 in 20 Year		1 in 50 Year		1 in 100 Year		Timmins	
	C	n	C	n	C	n	C	n	C	n	C	n
Innisfil/Beeton/Bailey Creeks	0.556	0.751	0.683	0.753	0.826	0.750	0.993	0.753	0.112	0.757	5.36	0.709
Upper Nottawasaga River	0.639	0.652	0.820	0.643	0.957	0.647	1.19	0.644	1.35	0.646	7.02	0.616
Boyne River	0.767	0.894	1.05	0.883	1.47	0.851	1.79	0.869	2.31	0.842	7.11	0.638
Pine River	0.228	1.00	0.289	0.999	0.332	0.999	0.396	0.998	0.443	0.999	0.928	1.00
Mad River	2.43	0.489	2.99	0.489	3.51	0.489	4.24	0.489	4.81	0.489	20.86	0.423
Willow Creek	0.553	0.880	0.624	0.880	0.698	0.878	0.789	0.878	0.879	0.872	3.21	0.959
Georgian Bay Inflows	1.58	0.817	2.02	0.808	2.51	0.790	3.37	0.749	3.99	0.729	9.33	0.754

Equation : $Q = CA^n$

where Q = peak discharge (m^3/s)

A = drainage area (Km^2)

c, n as given above

FIGURE 3.12 (a)

INNISFIL / BEETON/BAILEY CREEKS

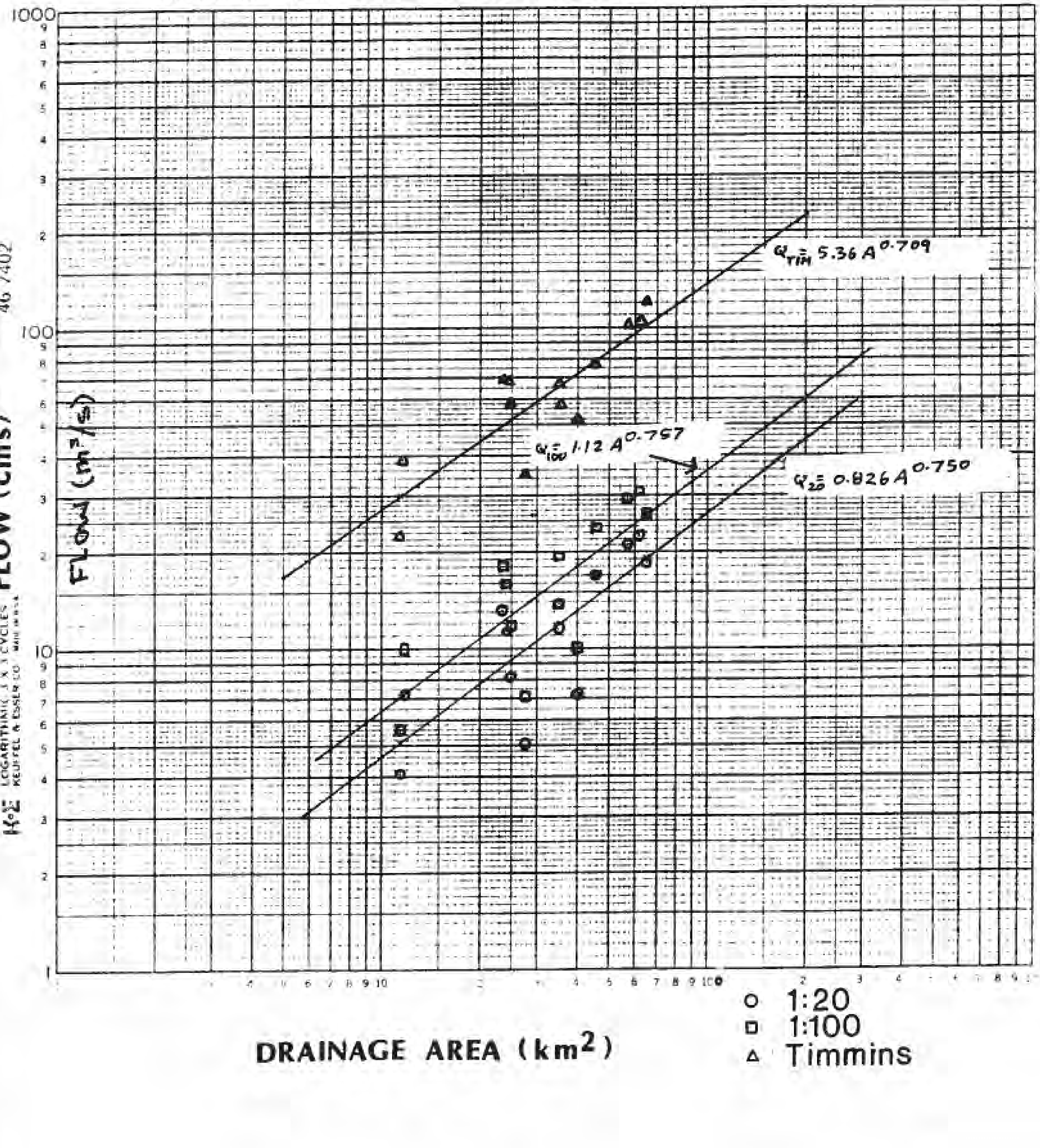


FIGURE 3.12(b)

UPPER NOTTAWASAGA

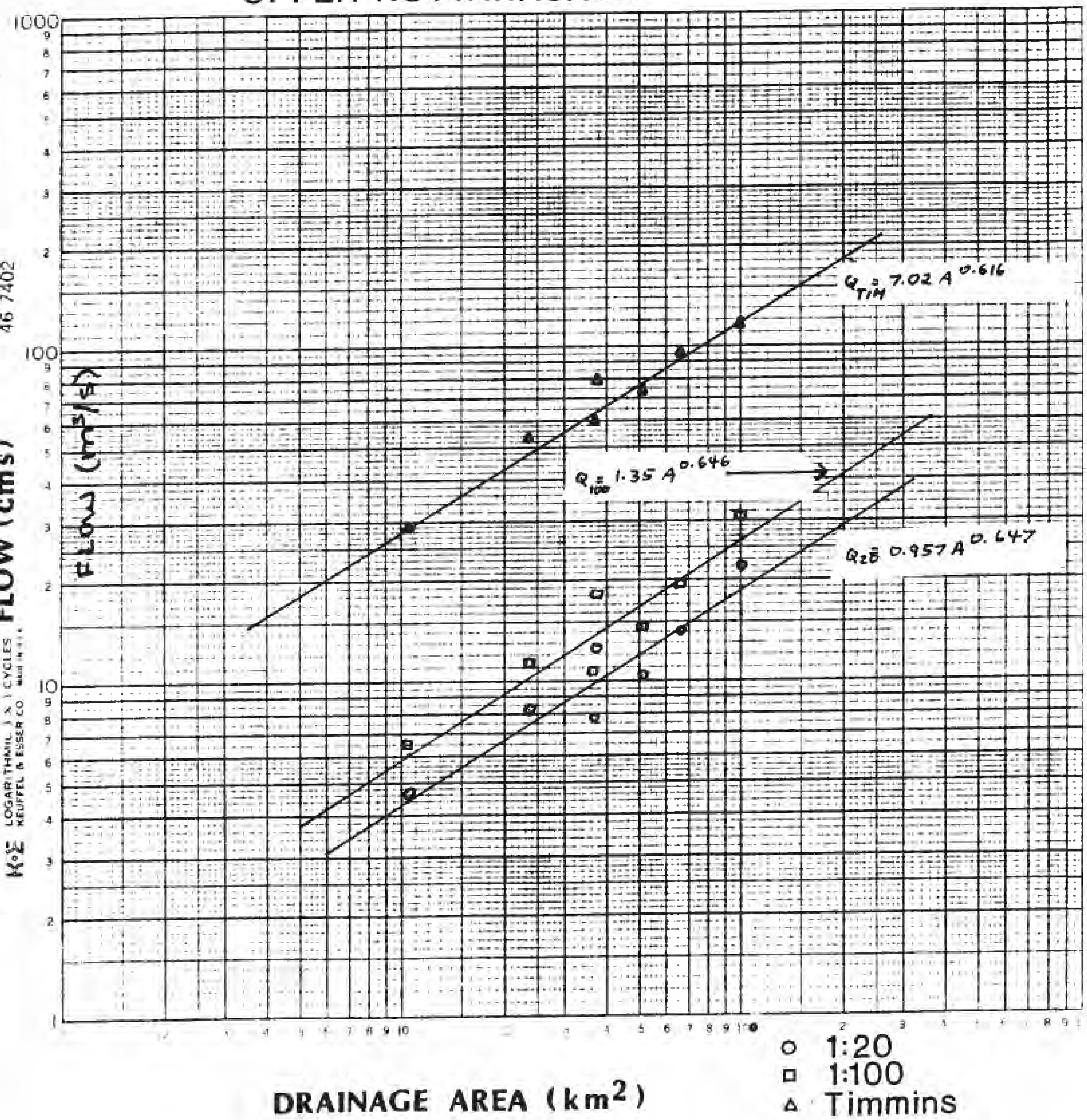
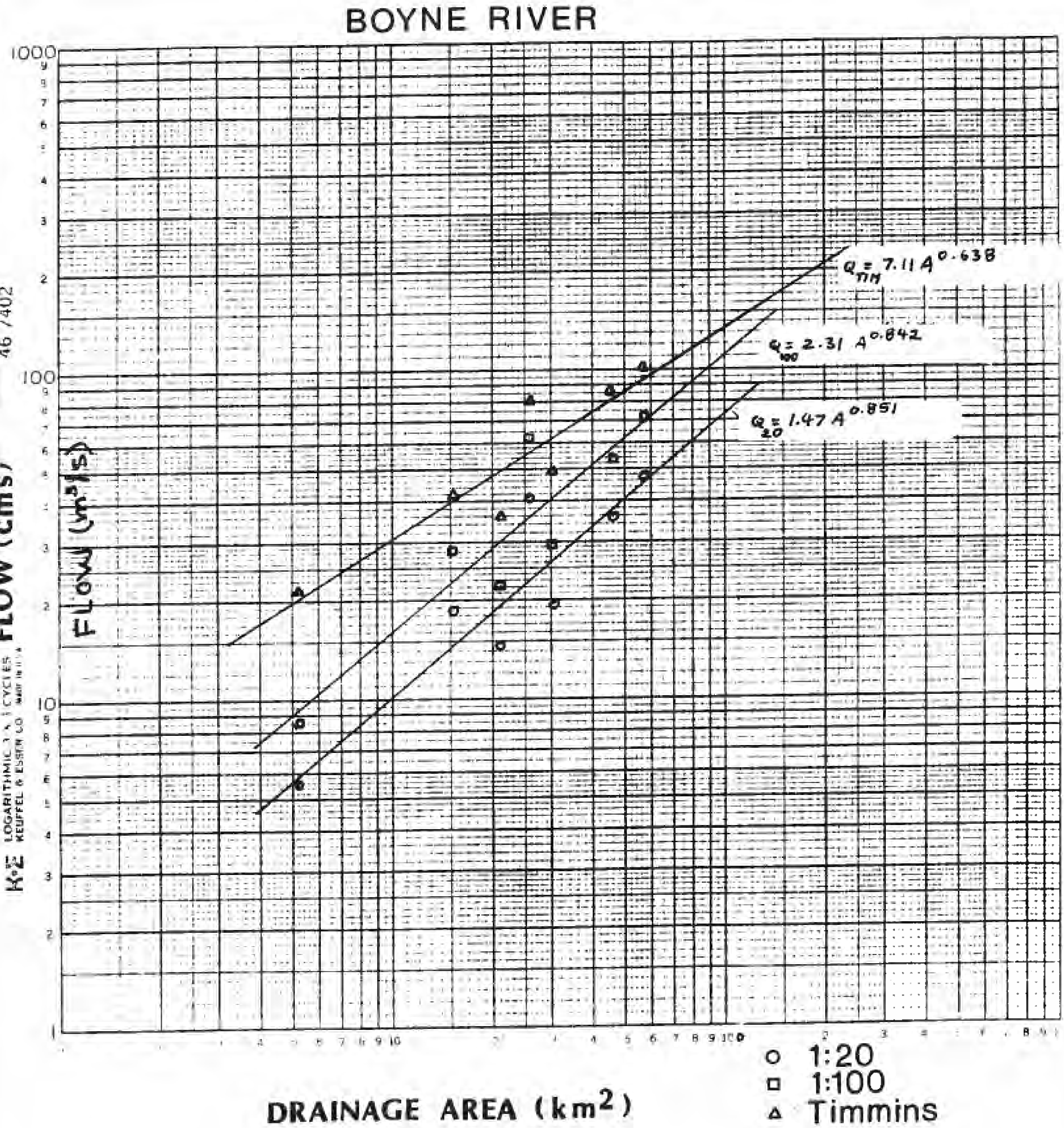


FIGURE 3.12 (c)



BOYNE RIVER
FLOW (cms)
FLOW (m³/s)
$Q_{TIM} = 7.11 A^{0.638}$
$Q_{100} = 2.31 A^{0.842}$
$Q_{20} = 1.47 A^{0.851}$
DRAINAGE AREA (km²)
○ 1:20
□ 1:100
△ Timmins
K·E LOGARITHMIC 3 X 3 CYCLES
KEUFFEL & ESSER CO.
46 7402

FIGURE 3.12(d)

PINE RIVER

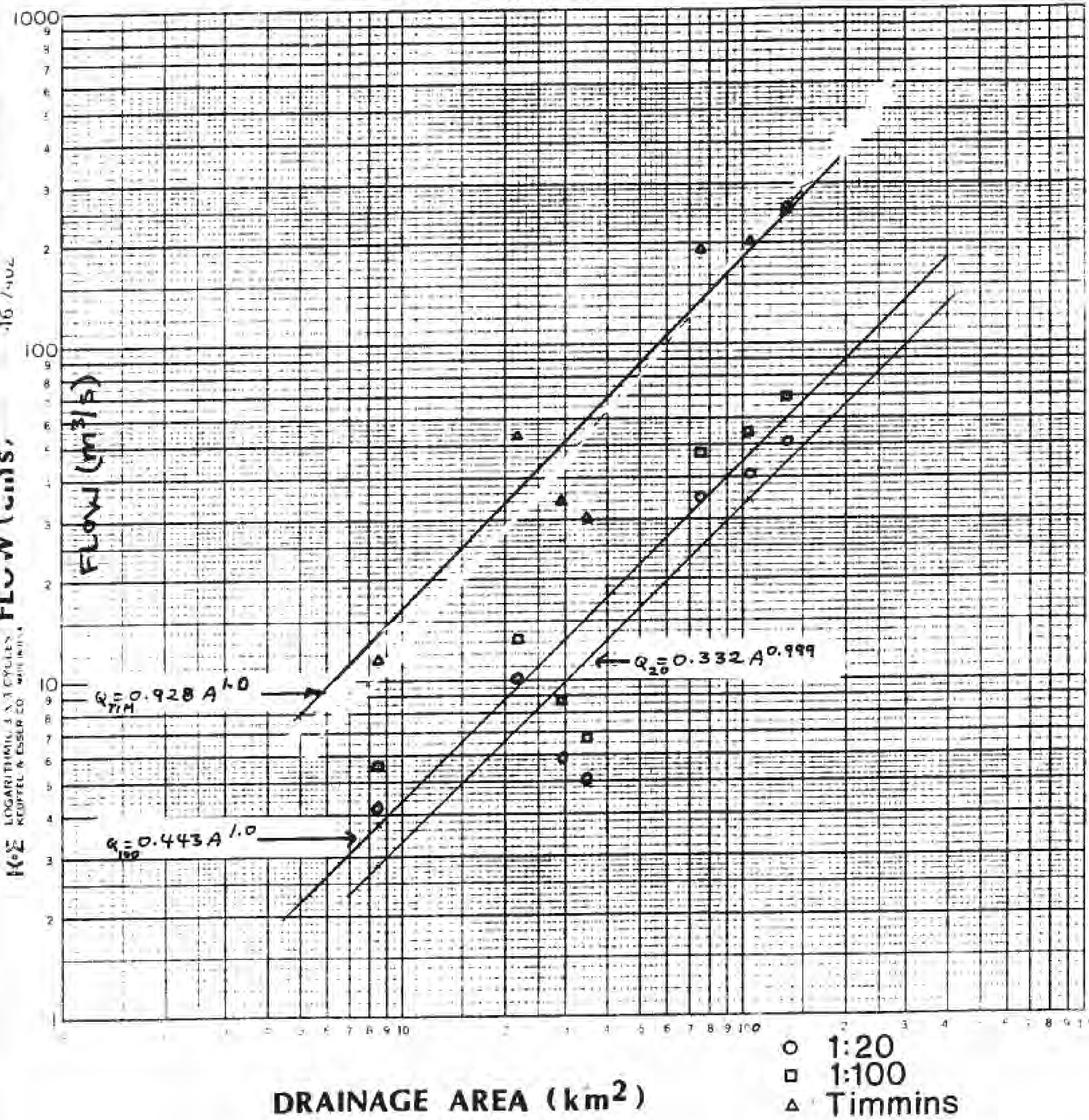


FIGURE 3.12 (e)

WILLOW CREEK

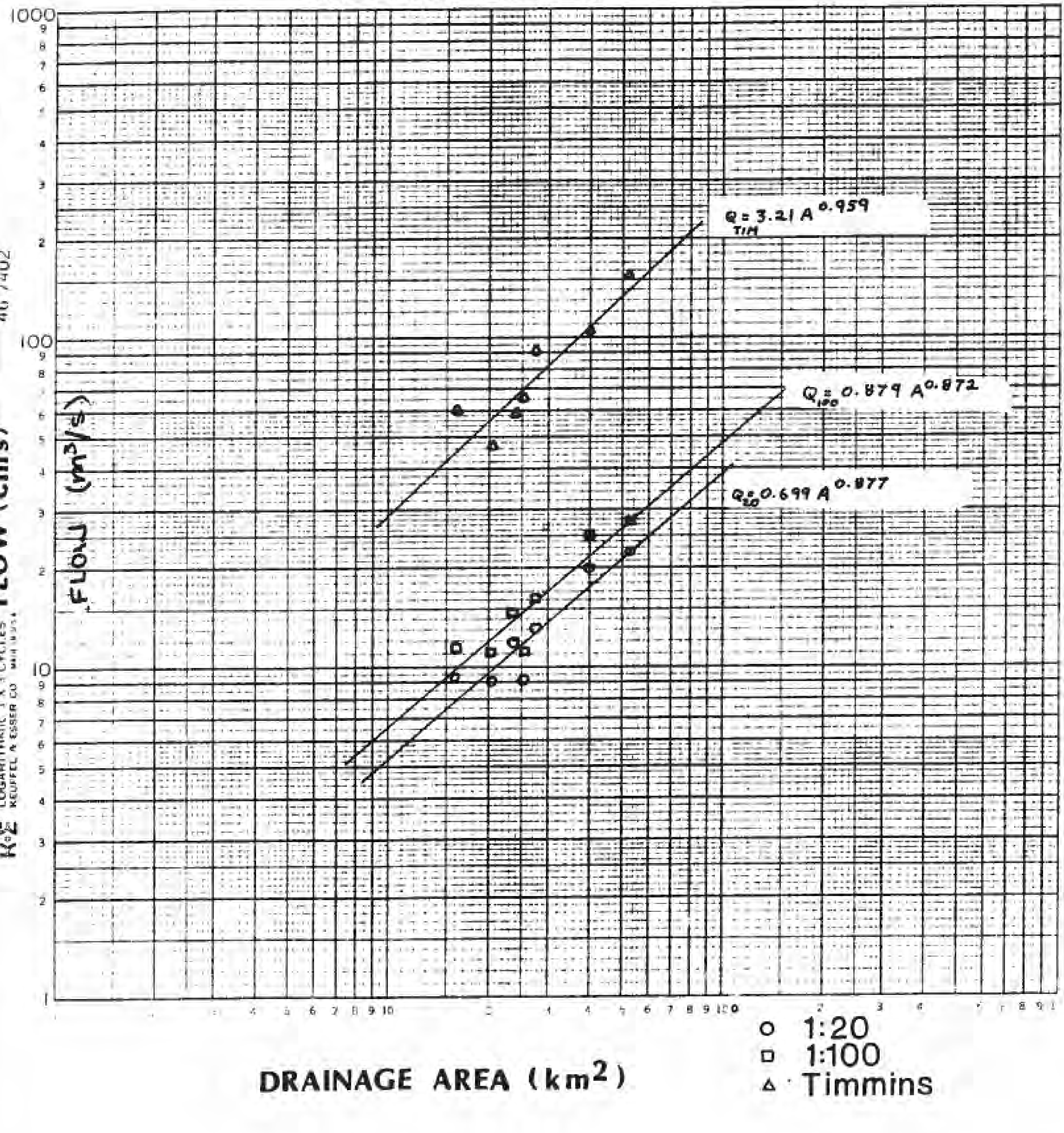


FIGURE 3.12 (f)

MAD RIVER

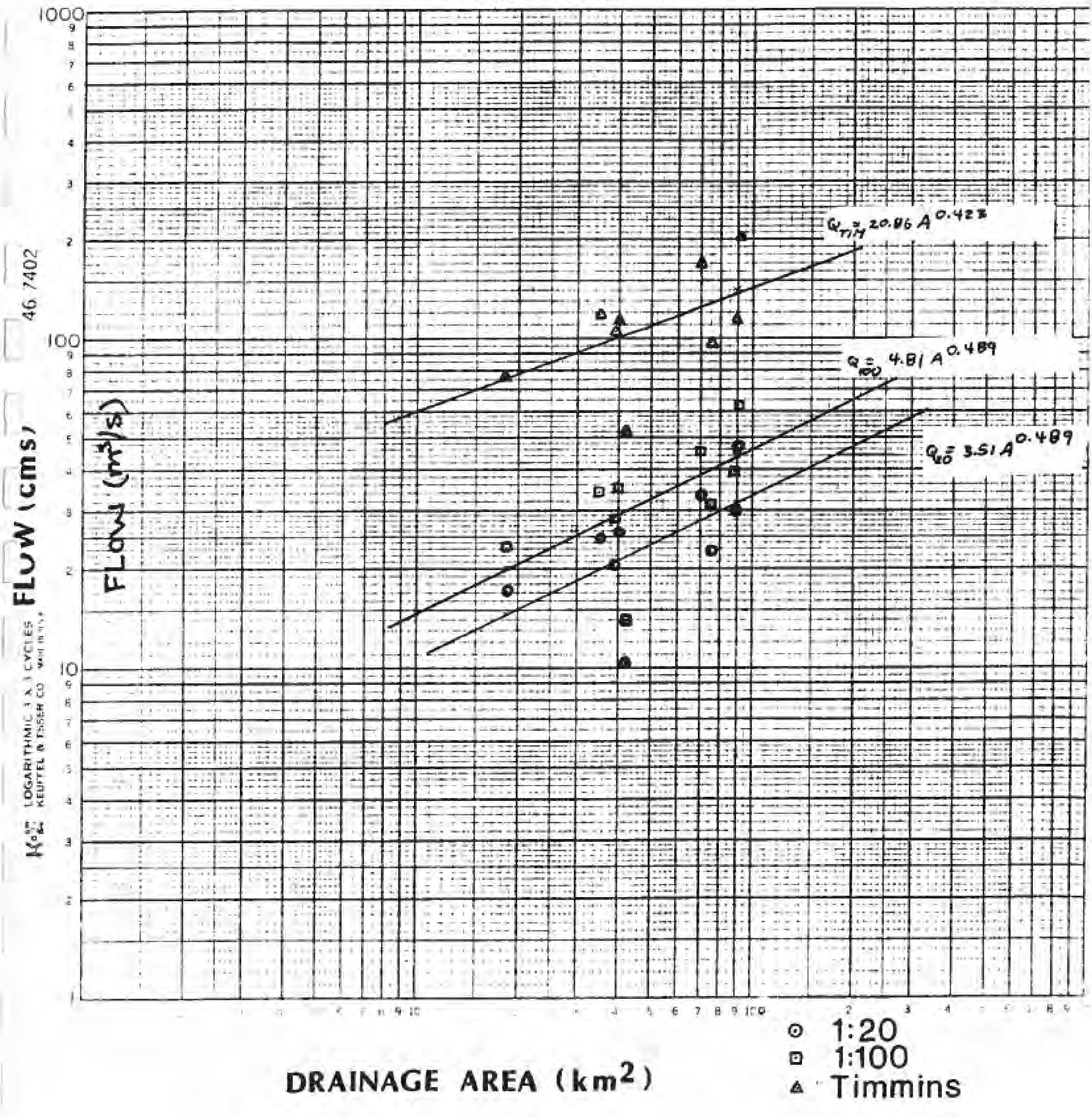
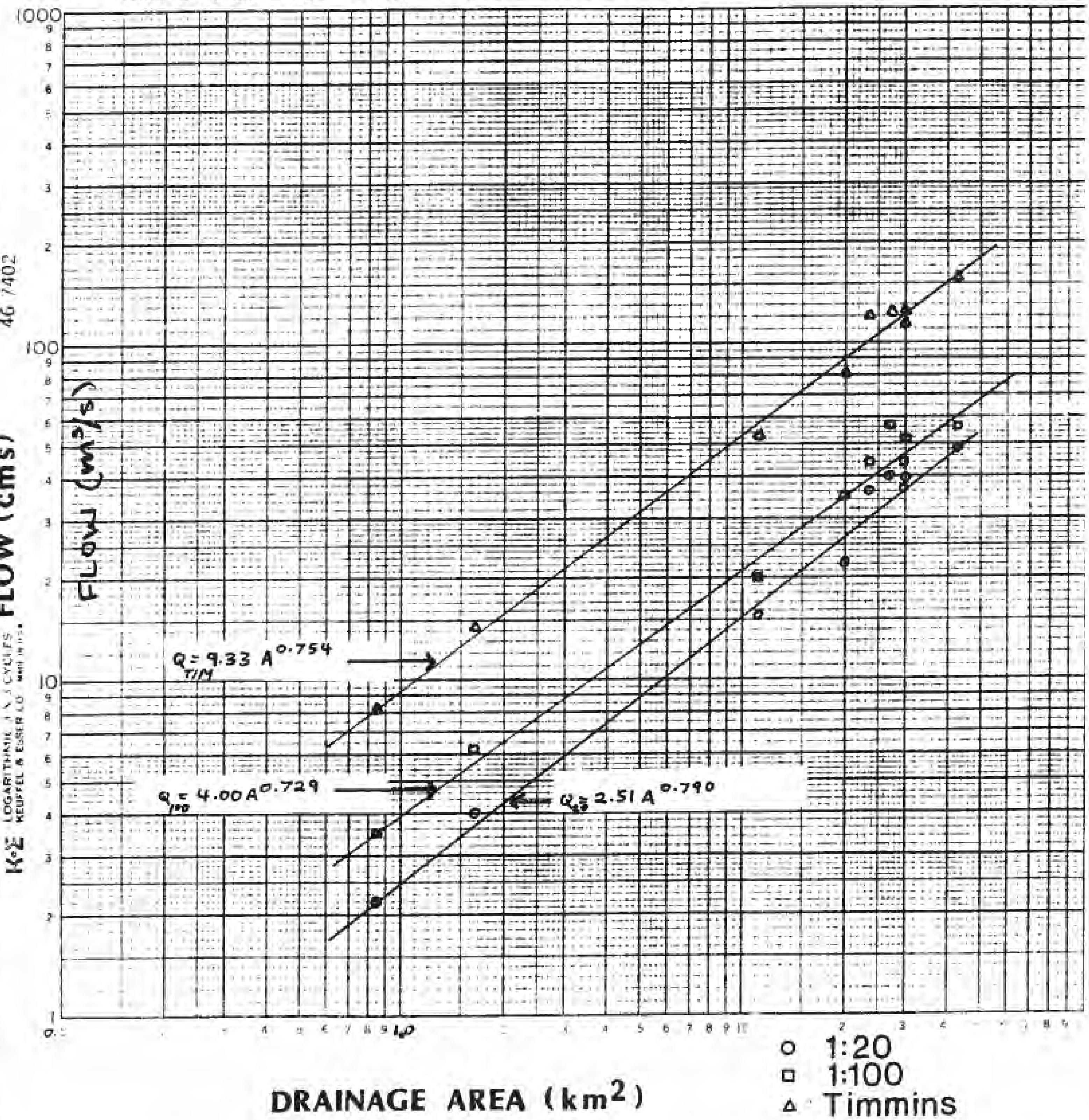


FIGURE 3.12(g)

GEORGIAN BAY CATCHMENTS



iv) repeat steps (ii) and (iii) for other recurrence interval flows or Timmins Storm flow

The above procedure is presented in flow chart format in Figure 3.12(h).

3.3.4.2 Major Waterways

Flow points along the major watercourses have been established at fairly close intervals as indicated in Figure 3.11. The change in flows from one flow point to the next point downstream is usually not very great. Therefore, to obtain design flows for intermediate points along the major watercourses, it is recommended that the flows be pro-rated linearly based on the incremental drainage area for those occasions where peak flows increase in a downstream direction. Careful attention must be taken when evaluating the tributary drainage at intermediate locations. Topographic maps are to be used to determine the portion of the incremental drainage area between flow points used in this study (Figure 3.11) which is tributary to the waterway upstream of the location of interest. Linear interpolation of flows based on stream length between flow points is not recommended as a computational procedure since the incremental drainage area may not be proportional to stream length. In those locations where design flows calculated at flow points decrease in the downstream direction, flow estimation at intermediate locations should be based on a linear interpolation of stream length between the flow points. Flow routing effects are considered of primary importance in attenuating peak flows in a downstream direction and this is most readily reflected in the stream length.

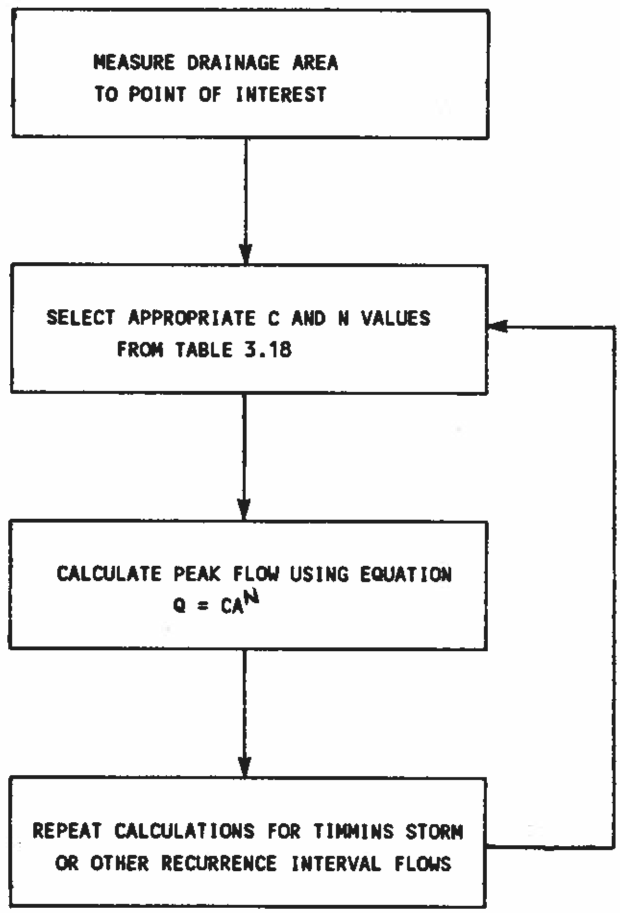
The above procedure is presented in flow chart format in Figure 3.12(i).

3.3.5 Flow Hydrographs

In order to establish design flows along the lower Nottawasaga River downstream of Minesing Swamp, it is necessary to carry out dynamic flow modell-

FIGURE 3.12 (h)

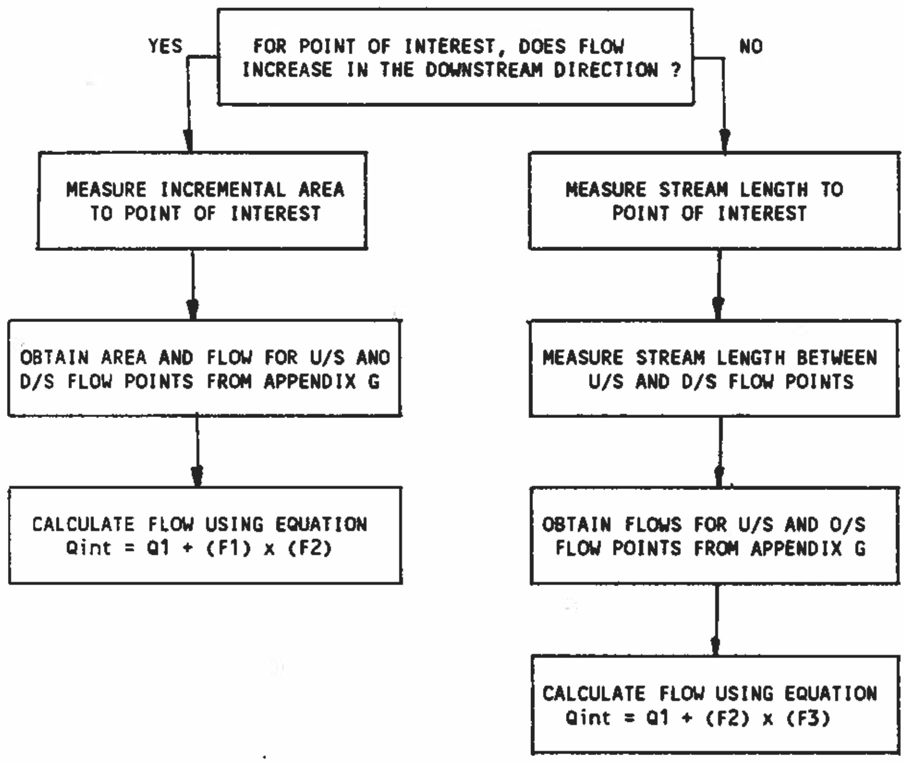
PROCEDURE TO CALCULATE FLOWS FOR HEADWATER DRAINAGE AREAS



WHERE : Q = PEAK DISCHARGE (M^3/S)
A = DRAINAGE AREA (KM^2)
N and C VALUES ARE AS PRESENTED IN TABLE 3.18

FIGURE 3.12 (i)

PROCEDURE TO CALCULATE INTERMEDIATE FLOWS FOR MAJOR WATERWAYS



WHERE : Qint = DESIRED FLOW AT POINT OF INTEREST (M^3/S)

Q1 = FLOW AT UPSTREAM FLOW POINT (M^3/S)

F1 = $\left(\frac{Aint - A1}{A2 - A1}\right)$ (AREA FACTOR)

Aint = TOTAL DRAINAGE AREA AT POINT OF INTEREST (KM^2) (TOTAL AREA AT UPSTREAM FLOW POINT PLUS INCREMENTAL AREA)

A1,A2 = TOTAL DRAINAGE AREAS (KM^2) AT UPSTREAM AND DOWNSTREAM FLOW POINTS, RESPECTIVELY

F2 = (Q2-Q1) (FLOW FACTOR)

Q1,Q2 = FLOW (M^3/S) AT UPSTREAM AND DOWNSTREAM FLOW POINTS RESPECTIVELY

F3 = (L1/L2) (LENGTH FACTOR)

L1 = STREAM LENGTH FROM UPSTREAM FLOW POINT TO POINT OF INTEREST (KM)

L2 = STREAM LENGTH FROM UPSTREAM FLOW POINT TO DOWNSTREAM FLOW POINT (KM) ing using the DWOPER Model. The model requires inflow hydrographs to Minesing Swamp and local inflow for the lower reaches of Nottawasaga River. Due to the storage attenuation effect of the Minesing Swamp on design flows within the lower Nottawasaga River, careful evaluation of inflow volumes to the Swamp was required. The methodology that will be used to develop flow hydrographs is discussed below.

3.3.5.1 Inflow to Minesing Swamp

The major source of flow contribution to Minesing Swamp is from the Nottawasaga River, Pine River, Mad River and Willow Creek. To ensure volumes contained within the design inflow hydrographs were in close agreement with historical observations, Environment Canada conducted volume frequency analyses based on historical flow records. The 7-day and 10-day maximum annual flows for the period of record were selected for Nottawasaga River near Baxter, Mad River near Glencairn, Pine River near Everett and Willow Creek above Little Lake. For each hydrometric station, the maximum annual 7-day and 10-day volumes were calculated. Subsequently frequency analyses were carried out for the 7-day and 10-day volumes for each hydrometric station.

The volumes calculated by Environment Canada for each recurrence interval (1 in 5 to 1 in 100 year) were pro-rated on a drainage area basis from each gauging station to the inflow to Minesing Swamp. The 7-day volumes were selected for flood analysis since this duration was felt to be representative of high flow events on the Nottawasaga River system.

Since the above-noted watercourses are gauged, it is possible to develop dimensionless hydrographs using flow records. For each of the hydrometric stations, the hourly flow data from 1976 to 1984 was screened. High flow spring events were selected and plotted on the same graph paper for each hydrometric station. The observed hydrographs were subsequently reduced to dimensionless hydrographs. From the plotted dimensionless hydrographs, a typical dimensionless hydrograph was drawn representing the "average" shape of the observed hydrographs for each gauging station. The design hydrographs for each watercourse at the inflow to Minesing Swamp were obtained by multiplying the ordinate of each dimensionless hydrograph by the 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100 year peak flows presented in Appendix G. Where discrepancies in volumes occurred, the ordinates of the design hydrographs were adjusted to agree with the volumes determined by Environment Canada.

Design inflow hydrographs to Minesing Swamp for Nottawasaga River, Pine River, Mad River and Willow Creek are shown in Appendix J.

The Timmins Storm flows under present and future conditions were generated using the QUALHYMO Model. The flow hydrographs are available at inflow points to Minesing Swamp for the four watercourses identified above. These inflow hydrographs were used as input to the DWOPER Model to establish the Timmins Storm flows downstream of the Swamp for both present and future conditions.

3.3.5.2 Lower Reaches of Nottawasaga River

The sub-catchments downstream of Minesing Swamp draining directly to the Nottawasaga River are not gauged. Consequently to develop local inflow hydrographs for these sub-catchments, it was necesesary to simulate the hydrographs based on historical precipitation input. This approach was similar to that used for the Georgian Bay sub-catchments described in Section 3.3.2.1.1.

Five spring high flow events were selected to develop a dimensionless hydrograph for each tributary or local sub-catchment. The same procedure outlined in Section 3.3.5.1 was used to obtain local inflow hydrographs for each sub-catchment/tributary shown in Figure 3.11. Design flow hydrographs at the outlet of some of the sub-catchments are shown in Appendix J.

The Timmins Storm flow hydrographs simulated using the QUALHYMO Model were used as input to the DWOPER Model.

3.4 Innisfil Creek Investigation

3.4.1 Agricultural Drainage Improvements

During the Nottawasaga River Hydrology Study, the effect of agricultural drainage improvements within the Innisfil Creek basin on downstream peak flows was investigated. Concern has been expressed in recent years that construction and upgrading of municipal drains in the Innisfil watershed has resulted in more frequent and more severe flood flows within the Nottawasaga River at Beeton Flats due to increased flow velocity in the waterway and reduced response time of the basin to rainfall. These flood prone lands adjacent to the confluence of the Nottawasaga River and Bailey Creek within Tecumseth Township are under active cultivation.

A proposed major municipal drain on Innisfil Creek and the Nottawasaga River reaching from 140 metres upstream of the Bailey Creek confluence to a point 2400 metres downstream of the Innisfil Creek and Nottawasaga River confluence was the subject of a second hydrological investigation.

An inventory of existing municipal drains in the Innisfil Creek basin was obtained from township maps (Tecumseth, Innisfil, and West Gwillimbury) prepared by the Ontario Ministry of Agriculture and Food and reviewed with the Project Committee. This information is documented in Figure 3.13. An examination of applications for agricultural drainage improvements under the

Drainage Act from the late 1970's to the present indicates that most projects are comprised of upgrading or cleaning of existing municipal drains.

The Contract drawings for the proposed Innisfil Creek and Nottawasaga River drainage works provided the channel dimensions for the investigation of this municipal drain.

Hydrologic investigations of agricultural drainage impacts during the study focussed on municipal drain improvements and was restricted to those drains on the major waterways consisting of Innisfil Creek, the lower reaches of Penville Creek, Bailey Creek, Cookstown Creek, and the Nottawasaga River. These stream reaches were represented in the watershed hydrologic model (QUALHYMO) and could be studied with respect to flow travel times and attenuation of flows due to routing and storage effects. The remaining municipal drains within the watersheds that are tributary to Beeton Flats were simulated indirectly in the hydrologic model by empirical runoff response relationships which are related to physiographic characteristics of the subwatersheds. For this reason, it was not possible to study the effect of improvements to the drains that are located on local watercourses; nevertheless, their effect on the flow magnitudes within the Beeton Flats area was considered small in relation to the major waterways.

For purposes of the investigation of improved drains tributary to Beeton Flats, field measurements of cross-sections on Innisfil Creek, Cookstown Creek, the lower reaches of Penville Creek and the Nottawasaga River (Figure 2.2) were left unaltered but the observed conveyance roughness was changed to reflect a system of well-maintained drains which have been cleaned and straightened. A Manning's "n" value of 0.02 was adopted for flow purposes.

During the examination of the flow impacts caused by the proposed Innisfil Creek and Nottawasaga River drainage works, the existing natural waterway was replaced in the flow routing computations by a representative channel cross-section. A Manning's "n" value of 0.02 was employed for the channelized reach.

3.4.2 Impacts on Flood Hydrology

In order to assess the effects of the foregoing municipal drain improvements on the peak flows within the Innisfil Creek at Beeton Flats, rainfall for two summer events (July 28, 1980 and August 15, 1986) were selected and used as input to the rainfall-runoff model of the watershed. These two events contain the largest summer rainfalls in recent years.

Hydrographs of these two events at Innisfil Creek, south of Cookstown and the confluence with Beeton Creek, are shown on Figures 3.14 and 3.15 for the 1986 and 1980 events respectively. A detailed summary of flows under the existing drain conditions and after cleaning is presented in Tables 3.19 and 3.20.

The analysis of the existing municipal drains on Innisfil Creek under existing conditions and after cleaning has indicated that resultant peak flows during two summer rainfall events increase only marginally with the increment never exceeding one or two percent, within the Beeton Flats waterway.

The areal definition of the August 15, 1986 rainfall event over the upper Nottawasaga River basin was not sufficient for hydrologic modelling purposes especially in view of the marked variation in local rainfall intensities that were experienced. The hydrologic investigation of the Innisfil Creek and Nottawasaga River drainage works therefore focussed on the July 28, 1980 event. The construction of the proposed municipal drain was found to increase the peak discharge for this event by less than one percent within the channelized reach (Table 3.21) and to marginally decrease the maximum downstream discharge due to slight changes in flow travel times.

Table 3.19

Depth of Flow

Innisfill Creek

Existing And Improved Municipal Drain Condition

Flow Point	X-Sect #	Existing Condition				Improved Conditions			
		1980		1986		1980		1986	
		Q (m^3/s)	depth (m)	Q (m^3/s)	depth (m)	Q (m^3/s)	depth (m)	Q (m^3/s)	depth (m)
302	11	3.16	0.80	1.09	0.53	3.16	0.72	1.09	0.49
250	11	10.44	1.25	5.73	0.84	10.55	1.14	5.93	0.81
260	11	10.90	1.28	5.81	0.97	11.16	1.16	6.07	0.90
270	11	6.78	0.68	2.95	0.52	6.78	0.63	2.95	0.46
280	11	19.42	1.55	9.43	1.12	19.84	1.38	9.72	1.02
300	6	10.23	1.24	4.83	0.97	10.23	1.16	4.83	0.89
310	11	32.78	2.16	15.48	1.57	32.91	1.98	15.71	1.47
140	5	6.47	0.72	1.18	0.33	6.53	0.65	1.22	0.31
200	0	13.25	0.92	2.95	0.47	13.32	0.92	3.00	0.47
1041	7	45.62	2.01	18.22	1.30	45.91	1.86	18.48	1.20
320	7	46.55	2.04	18.33	1.30	46.64	1.87	18.71	1.21

TABLE 3.20

PEAK FLOW: INNISFIL, BEETON, BAILEY CREEKS

EXISTING AND IMPROVED MUNICIPAL DRAIN CONDITION

DESIGN FLOWS:

REF. NO.	DESCRIPTION	TRIBUTARY AREA (km^2)	DISCHARGE (m^3/s) 1980 JULY EVENT EXISITING	PROPOSED	1986 AUGUST EVENT EXISTING	PROPOSED
INNISFIL						
302	Outlet of catchment 302 and 300	40.9	3.16	3.16	1.09	1.09
1020	Outlet of catchment 303	58.2	5.08	5.05	2.10	2.10
304	Outlet of catchment 304	7.2	0.99	0.99	0.61	0.61
1021	Confluence of Innisfil Creek at catchment 304	65.4	5.91	5.89	2.57	2.58
305	Outlet of catchment 305	14.6	2.15	2.15	1.35	1.35
240	Confluence of Innisfil Creek at catchment 305	80.0	7.81	7.81	3.79	3.81
250	Outlet of catchment 306	105.4	10.44	10.55	5.73	5.93
260	Outlet of catchment 310	112.7	10.90	11.16	5.81	6.07
311	Outlet of catchment 311	24.1	4.93	4.93	2.20	2.20
270	Outlet of catchment 312	36.8	6.78	6.78	2.95	2.95
1044	Confluence of catchment 312 and 310	149.5	17.68	17.87	8.64	8.87
280	Outlet of catchment 313	158.2	19.42	19.84	9.43	9.72

DESIGN FLOWS:

REF. NO.	DESCRIPTION	TRIBUTARY AREA (km^2)	DISCHARGE (m^3/s) 1980 JULY EVENT EXISITING	PROPOSED	1986 AUGUST EVENT EXISTING	PROPOSED
316	Confluence of catchment 315 and 316	35.0	6.27	6.27	2.68	2.68
290	Outlet of catchment 317	45.6	7.73	7.73	3.18	3.18
314	Outlet of catchment 314	11.7	3.01	3.01	2.77	2.77
1025	Confluence of catchment 314 and 317	57.3	9.67	9.67	4.56	4.56
300	Outlet of catchment 318	60.4	10.23	10.23	4.83	4.83
1045	Confluence of catchment 313 and 318	218.6	29.53	29.87	14.26	14.43
310	Outlet of catchment 321	249.9	32.78	32.91	15.48	15.71

DESIGN FLOWS:

REF. NO.	DESCRIPTION	TRIBUTARY AREA (km^2)	DISCHARGE (m^3/s) 1980 JULY EVENT EXISITING	PROPOSED	1986 AUGUST EVENT EXISTING	PROPOSED
BEETON/BAILEY CREEKS						
209	Outlet of catchment 209	27.7	1.14	1.14	0.28	0.28
208	Outlet of catchment 208	24.7	1.78	1.78	0.39	0.39
1028	Confluence of catchment 208 and 209	52.4	2.92	2.92	0.67	0.67
120	Outlet of catchment 210	54.9	3.17	3.17	0.71	0.71
130	Outlet of catchment 211	80.5	5.26	5.26	1.09	1.09
140	Outlet of catchment 212	99.2	6.47	6.53	1.19	1.22
213	Outlet of catchment 213	11.5	0.99	0.99	0.20	0.20
1032	Confluence of catchment 212 and 213	110.7	7.46	7.52	1.37	1.41
150	Outlet of catchment 214	113.9	7.56	7.60	1.36	1.40
201	Outlet of catchment 201	23.4	2.23	2.23	0.75	0.75
170	Outlet of catchment 202	33.6	2.85	2.85	0.89	0.89
203	Outlet of catchment 203	11.3	0.71	0.71	0.20	0.20
2100	Outlet of catchment 204	34.6	2.69	2.69	0.37	0.37
1035	Confluence of catchment 204 and 202	68.2	5.07	5.07	4.03	4.03
180	Outlet of catchment 205	84.7	5.32	5.32	2.69	2.69

DESIGN FLOWS:

REF. NO.	DESCRIPTION	TRIBUTARY AREA (km^2)	DISCHARGE (m^3/s) 1980 JULY EVENT EXISITING	PROPOSED	1986 AUGUST EVENT EXISTING	PROPOSED
BEETON/BAILEY/INNISFIL CREEKS						
190	Outlet of catchment 206	87.4	5.51	5.51	2.46	2.46
1039	Confluence of catchment 206 ANO 214	201.3	13.05	13.09	2.92	2.95
200	Outlet of Beeton and Bailey Creeks	204.8	13.25	13.32	2.95	2.10
1041	Confluence of Beeton and Innisfil Creeks	454.8	45.62	45.91	18.22	18.48
320	Outlet of Innisfil Creek	472.2	46.55	46.64	18.34	18.71

TABLE 3.21

PEAK FLOW IMPACT OF PROPOSED INNISFIL CREEK AND NOTTAWASAGA RIVER MUNICIPAL DRAIN

Flow Point	Description	Peak Flow Existing Waterway (m^3/s)	28 July 1980 event Proposed Municipal Drain (m^3/s)
320	Outlet of Innisfil Creek	46.7	46.8
1050	Downstream of confluence of Innisfil Creek and Nottawasaga River	68.4	68.5
220	Nottawasaga River upstream of Boyne River	69.8	69.6
1078	Nottawasaga River at Baxter	96.9	96.8
1252	Nottawasaga River at Angus (Highway 90)	125.1	124.8

Note: Channel dimensions

1. Upstream limit to confluence Innisfil Creek and Bailey Creek
   :Bottom width 6 metres
   Side slopes 2H:1V

2. Between confluences of Innisfil Creek with Bailey Creek and Nottawasaga River
   :Bottom width 12 metres
   Side slopes 2H:1V

3. Downstream of Innisfil Creek and Nottawasaga River confluence
   :Bottom width 15 metres
   Side slopes 2H:1V

INNISFIL CREEK

1986 AUGUST EVENT

MUNICIPAL DRAIN IMPROVEMENTS

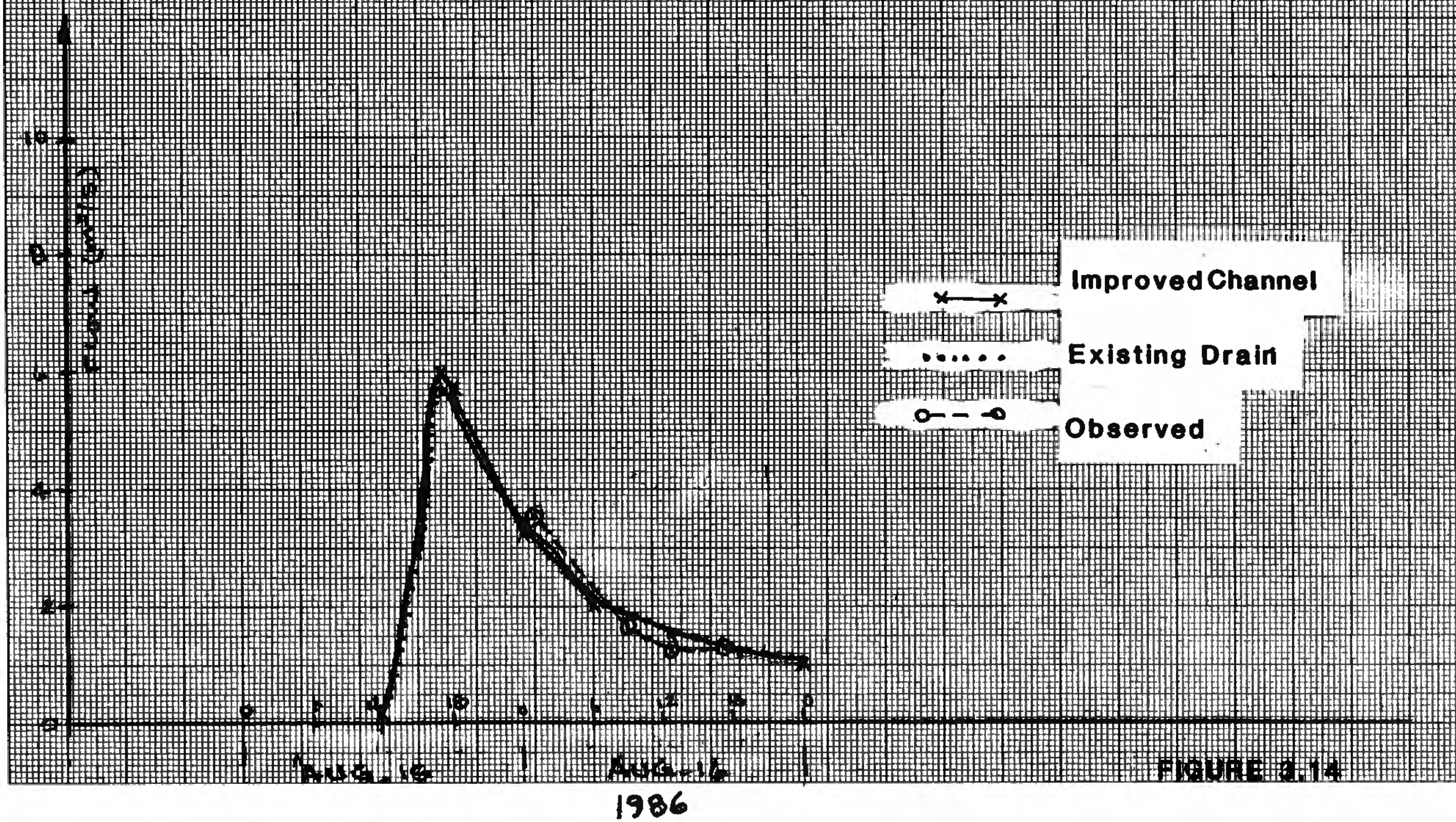


FIGURE 3.14

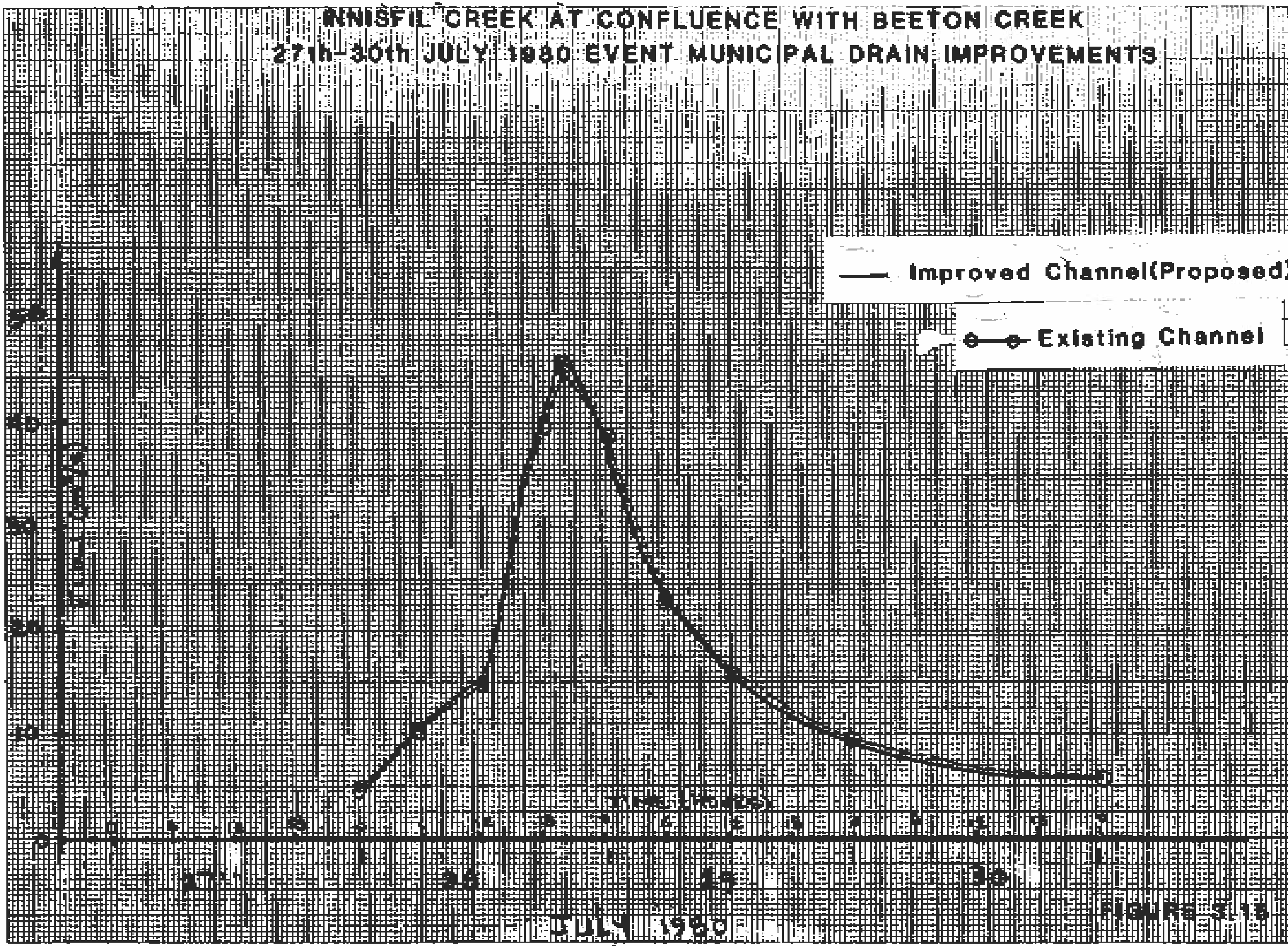

INNISFIL CREEK AT CONFLUENCE WITH BEETON CREEK
27th-30th JULY 1980 EVENT MUNICIPAL DRAIN IMPROVEMENTS
Improved Channel(Proposed)
Existing Channel
0
10
20
30
40
50
27
28
29
30
JULY 1980

FIGURE 3.15

4.0 DYNAMIC FLOW MODELLING

4.1 Introduction

The streamcourse of the Nottawasaga River between Angus and Edenvale is characterized by a large off-channel flood storage area called the Minesing Swamp. Downstream of Edenvale the stream channel is quite flat and contains a couple of small flood storage areas called Jack's Lake and Doran Lake. Due to the significant off-channel storage areas and the flat channel slopes it is not possible to determine flow routing effects using standard hydrologic routing techniques such as the lag and route and storage indication methods which do not account for flow continuity (i.e., off-channel storage effects)and the influence of backwater. Flow routing in the Lower Nottawasaga River system can only be reliably determined using unsteady, non-uniform flow modelling techniques which account for flow continuity and conservation of momentum.

The Dynamic Wave Operational Model (DWOPER) was selected for this purpose.

4.2 Description of Model

DWOPER is a dynamic wave routing model based on an implicit finite difference solution of the complete one-dimensional St. Venant equations for unsteady flow. The model was developed by the United States National Weather Service primarily for flood and day-to-day river forecasts.

The model is generalized for wide applicability to rivers of varying physical features such as irregular channel geometry, variable channel roughness, lateral inflows, flow diversions, off-channel storage, local head losses such as bridge contraction-expansion, lock and dam operations, and wind effects.

The model possesses a highly efficient automatic calibration feature for determining channel roughness factors based on observed hydrographs along the streamcourse.

Boundary conditions at the upstream and downstream limits of the model can be specified as either stage or discharge hydrographs. The downstream boundary conditions can also be specified by a known relationship between stage and discharge such as a rating curve.

DWOPER has the capability to model a dendritic river system consisting of the main channel and its tributaries. If only the main channel is of interest then tributary inflow can be specified as lateral inflows.

4.3 Geometric Properties of the Streamcourse

4.3.1 Cross-sections

A field survey of the streamcourse was conducted to obtain channel cross-sections at representative locations. The river channel between Highway No. 90 near Angus and the bridge at Edenvale was surveyed from July 15 to 17, 1987. The remainder of the channel downstream of Edenvale was surveyed from October 15 to 18, 1987. A total of fifty-two (52) cross-sections were surveyed.

Several of the surveyed cross-sections are very closely spaced and the inclusion of all of the measured sections in the DWOPER model would require extremely short simulation time steps with the associated high computer costs. Hence, only thirty-two (32) of the surveyed cross-sections were used in the DWOPER simulations. These were sufficient to represent the geometric properties of the streamcourses and their locations are shown in Figure 4.1.

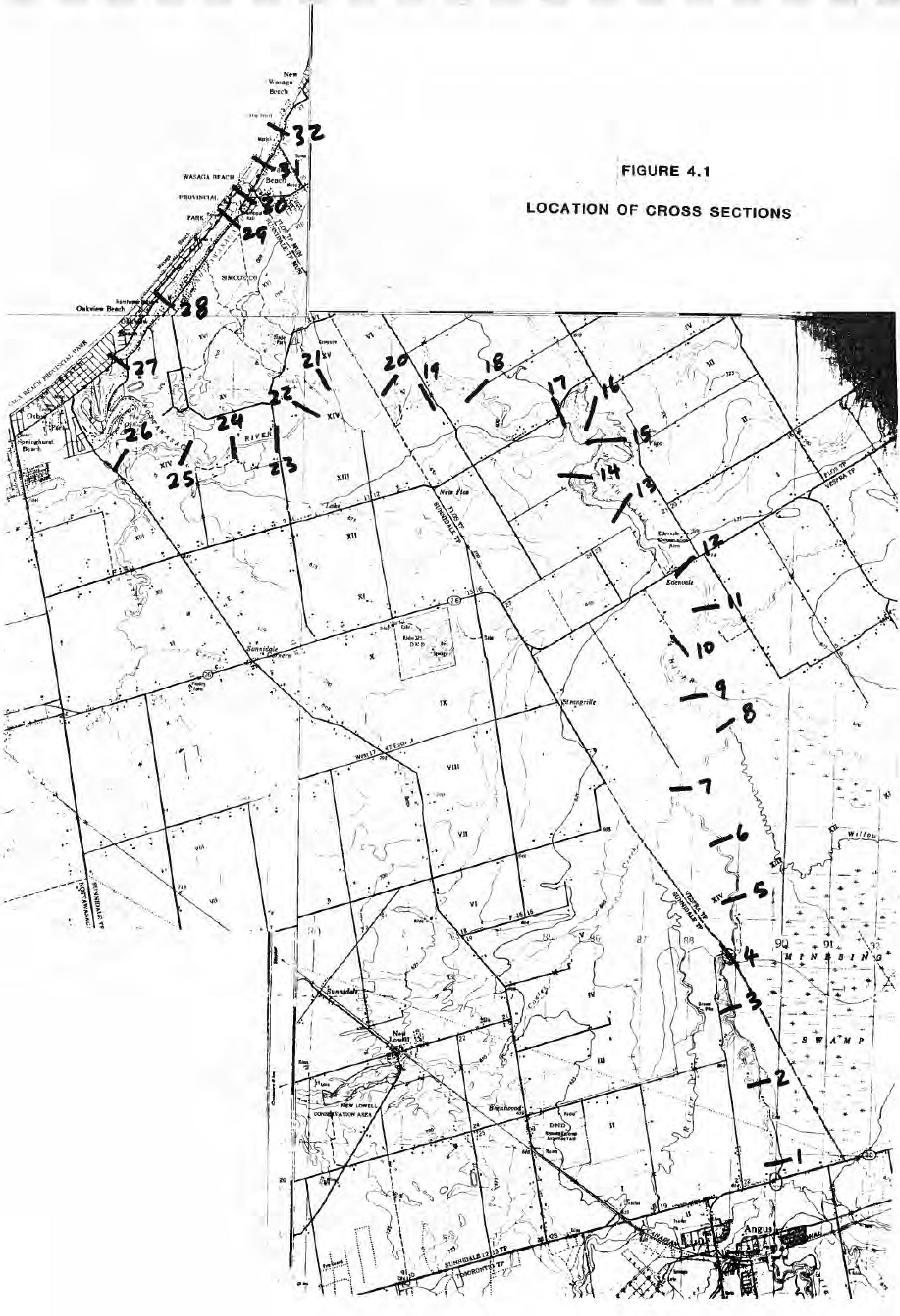
The spacing of the cross-sections is variable at an average distance of 1,500 m. The minimum and maximum cross-sectional spacings are 340 m and 5,843 m respectively. The thirty-two selected cross-sections were considered sufficient to adequately represent the stream geometry and avoid the need for extremely short time steps with the associated high computer costs.

TABLE 4.3 - **SUMMARY OF PEAK FLOW AND PEAK STAGE AT SELECTED LOCATIONS**

LOCATION	CROSS SECTION NUMBER	PEAK FLOW AND ASSOCIATED STAGE 5-YR	10 YR	20 YR	50 YR	100 YR	REGIONAL	PEAK STAGE AND ASSOCIATED FLOW 5-YR	10 YR	20 YR	50 YR	100 YR	REGIONAL	
Edenvale	012	161 183.46	180 183.73	201 184.00	224 184.28	247 184.49	243 185.05	159 183.46	178 183.73	199 184.00	223 184.28	244 184.49	237 185.07	flow (m^3/sec) stage (m)
Bridge D/S Doran Lake	D17	160 182.75	180 183.00	200 183.26	224 183.52	247 183.72	256 184.11	158 182.76	178 183.01	199 183.26	223 183.52	243 183.72	254 184.55	flow (m^3/sec) stage (m)
Bridge D/S Jack Lake	D23	158 182.13	178 182.36	199 182.58	223 182.81	242 182.98	340 183.98	158 182.13	178 182.36	199 182.58	223 182.81	242 182.98	330 184.01	flow (m^3/sec) stage (m)
Schooner-Town Bridge	D27	213 178.03	242 178.18	289 178.39	317 178.52	336 178.59	469 179.06	213 178.03	242 178.18	289 178.39	317 178.52	336 178.59	469 179.06	flow (m^3/sec) stage (m)
Wasaga Beach	D30	211 177.38	240 177.46	288 177.59	318 177.69	338 177.75	469 178.08	211 177.38	240 177.46	288 177.59	318 177.69	338 177.75	464 178.08	flow (m^3/sec) stage (m)

FIGURE 4.1

LOCATION OF CROSS SECTIONS



Based on the DWOPER cross-section numbering scheme, the cross-sections are numbered consecutively starting at the upstream end. A tabulation of cross-section numbers and the corresponding distances from the river mouth is given in Table 4.1. Cross-sectional plots are shown in Appendix M.

During the field survey (when the river was not in flood) the average top width of the channel was 35 m. The narrowest channel sections were at the upper and through the Minesing Swamp where the channel was approximately 20 m wide. The river was widest along the reach through Schoonertown and Wasaga Beach where it was approximately 100 m wide.

The average flow depth (at the thalaweg) was 3 m. The shallowest reach occurred through the Minesing Swamp where it was 1 to 2 m in depth and the deepest sections occurred along the reach between Edenvale and Jack's Lake where the flow depth is 4 to 6.5 m.

The average longitudinal channel slope is $25x10^{-5}$ through the Minesing Swamp. Except for a short steeper section just downstream of the confluence with Lamont and Warrington Creeks, the remainder of the streamcourse is relatively flat with an average slope of $36x10^{-6}$.

4.3.2 Off-channel Storage

The Minesing Swamp represents a significant dead water storage area which has a significant attenuating effect on flood peaks entering at Angus and at major tributaries such as Willow Creek and the Mad River. Due to the extent and heavily wooded nature of the swamp it was not possible to obtain the access required for a field survey. The cross-sectional properties of the swamp had to be abstracted from available topographic mapping. 1:10000 scale maps are available for the southern one-third of the swamp, however, only 1:50000 scale maps are available for the remainder. The topographic information from the 1:50000 scale maps were supplemented by spot elevations provided by the Ontario Ministry of Natural Resources Surveys and Mapping

TABLE 4.1

CROSS-SECTION DATA, LOWER NOTTAWASAGA RIVER

Cross-section No.	Distance from River Mouth (m)	Manning's Channel Roughness	
1	45,900	0.02	
2	44,400	0.02	
3	42,150	0.02	
4	40,900	0.035	Storage from Minesing Swamp (sections 1–8)
5	39,650	0.035	
6	38,150	0.035	
7	36,400	0.035	
8	34,650	0.035	
9	33,400	0.035	
10	31,900	0.035	
11	31,025	0.035	
12	29,910	0.035	
13	28,150	0.035	
14	26,900	0.035	
15	25,525	0.035	
16	24,650	0.035	Doran Lake
17	23,775	0.035	
18	21,400	0.035	
19	20,271	0.035	
20	19,275	0.035	
21	17,275	0.035	Jack's Lake
22	16,525	0.035	
23	15,650	0.035	
24	14,450	0.035	
25	13,400	0.035	
26	11,450	0.035	
27	5,607	0.02	
28	4,000	0.02	
29	1,750	0.02	
30	1,090	0.02	
31	750	0.02	
32	0	0.02	

Branch. The banks of the Nottawasaga River exhibit levee-like forms through the Minesing Swamp. Hence, channel conveyance is confined mostly between the banks and overbank areas are designated as off-channel storage areas. A conceptual sketch of the convergence and off-channel storage areas is shown in Figure 4.2.

Off-channel storage areas are specified at cross-sections 1 to 8 (inclusive). Storage areas (specified as top width vs. elevation) for cross-section 1 to 4 were obtained from 1:10000 scale maps whereas storage areas for cross-sections 5 to 8 were obtained from the 1:50000 scale maps.

Doran Lake and Jack's Lake are two small flood storage areas downstream of Edenvale. These are not expected to have a significant impact on the hydrologic routing but are, nevertheless, included at cross-sections 16 and 21 respectively.

4.4 Boundary Conditions

4.4.1 Upstream

The upstream boundary condition was specified as a discharge hydrograph at cross-section 1 located just downstream of the Highway No. 90 bridge near Angus.

In the case of the calibration run, this discharge hydrograph consisted of daily inflows observed during the spring of 1987. For the design flood simulations inflow hydrographs at the upstream boundary were obtained from hydrologic simulations of the watershed.

4.4.2 Downstream

The downstream boundary condition is the water surface elevation of Lake Huron. The observed water level during the simulation period was used for

CONCEPTUAL SKETCH OF CHANNEL CONVEYANCE AND OFF-CHANNEL STORAGE AREAS IN MINESING SWAMP

FIGURE 4.2

the calibration run and the long term average lake level during the spring months was used for the design flood simulations.

The downstream boundary condition turned out not to have a significant effect on the Lower Nottawasaga River since its influence was found to only extend approximately 6 km upstream of the river mouth (ie. to Schoonerstown).

4.4.3 Lateral Inflows

Inflow from major tributaries such as the Mad River and Willow Creek and runoff from subcatchment draining overland to the Nottawasaga River were specified as lateral inflow hydrographs at appropriate locations along the streamcourse. The inflow from the Mad River is specified at cross-section 7 and the inflow from Willow Creek is specified at cross-section 8.

4.5 Calibration

4.5.1 Objective

Although DWOPER is a physically based model, calibration is required to adjust model parameters such as the Manning's roughness coefficient. In this application the calibration exercise will also enable the refinement of the stage-storage volume relationship for the Minesing Swamp.

The calibration exercise concentrated on reproducing the lagging and attenuation effects of the Minesing Swamp on peak flood flows observed during the period of March 15 to April 15, 1987.

4.5.2 Calibration Data

Model calibration was based on daily steamflows recorded at Water Survey of Canada gauges at:

- the Nottwasaga River at Baxter (Station No. 02ED003)
- the Mad River near Glencairn (Station No. 02ED005)
- Willow Creek near Midhurst (Station No. 02ED010).

These flows were used to specify inflow hydrographs to the Lower Nottawasaga river system. Streamflow data from the Ontario Ministry of Natural Resources gauge on the Pine River were not available.

Additional data were obtained by Water Survey of Canada who measured flow rates in the Nottawasaga River at the Highway No. 90 bridge near Angus and at the Highway No. 26 bridge at Edenvale on April 6,9,10 and 15, 1987.

Water level data were obtained at Edenvale and at the Schoonertown bridge near the river mouth during the period of April 7-15, 1987 from staff gauges installed by the Consultant.

The upstream boundary of the DWOPER model is at the Highway No. 90 bridge near Angus. It was, therefore, necessary to adjust the flow record at Baxter to reflect the additional drainage area at the model limit and the flow contribution from the Pine River whose confluence with the Nottawasaga River is just upstream of the Highway No. 90 bridge. The daily flows at Baxter were compared with the flow measurements carried out by Water Survey of Canada at the Highway No. 90 bridge. It was determined that, on average,the Nottawasaga River flows at Highway No. 90 were 1.6 times the flows at Baxter. Hence, the upstream boundary flow hydrograph was obtained by multiplying the Baxter flow record by 1.6. The observed daily streamflow at the WSC gauges on the Mad River and Willow Creek were also adjusted to account for the additional drainage area between the gauge location and the confluences of the tributaries with the Nottawasaga River. Since measured flows at the confluences were not available, it was not possible to adjust the flows in a manner similar to that carried out for the Nottawasaga River. The tributary flows were simply prorated on a drainage area basis to account for additional drainage to the tributaries as well as local inflow to the Swamp.

The downstream boundary condition was specified as the water surface elevation of Lake Huron as recorded during the simulation period at the Environment Canada water level gauge at Collingwood. During the period of March 15 to April 15, 1987, the water level fluctuations of Lake Huron were minor varying from 177.03 M (GSC) to 177.07 M (GSC). Hence, the downstream boundary condition was specified as a constant water level of 177.05 M representing the mean water level during that period.

The inflow hydrographs used in the calibration exercise are presented in Table 4.2.

4.5.3 Bridge Losses

Head losses at six bridges along the stream channel were simulated by assigning appropriate head loss coefficients at the bridge locations. Based on procedures described in the Users Manual for the HEC-2 computer model, a head loss coefficient of 0.8 was assigned at bridge sections 12,17,19,23,27 and 30. This head loss coefficient represented the sum of contraction and expansion head loss coefficients of 0.3 and 0.5 respectively.

Since the dynamic wave simulation is primarily intended for flow routing, it was not necessary to utilize the internal boundary rating curve capability of the DWOPER.

4.5.4 Results

The dynamic wave modelling was carried out in order to properly account for flow routing effects through the Lower Nottawasaga River system. Accordingly, the calibration exercise concentrated on reproducing the lagging and attenuation of the peak flood flows.

The calibration was conducted by first adjusting the stage-storage relationship of the Minesing Swamp near the ground surface where the available

TABLE 4.2 CALIBRATION DATA
Daily Streamflows (m^3/s)

Date (1987)	Mad River near Glencairn	Mad River at[1] Confluence with Nottawasaga River	Willow Creek near Midhurst	Willow Creek[2] at Confluence with Nottawasaga River	Nottawasaga River at Baxter	Nottawasaga River[3] at Highway No. 90 bridge near Angus
March 15	4.1	6.4	1.8	4.7	21.2	33.9
" 16	3.6	5.6	1.7	4.5	17.5	28.0
" 17	3.7	5.8	1.6	4.2	15.5	24.8
" 18	3.7	5.8	1.6	4.2	16.2	25.9
" 19	4.3	6.7	1.6	4.2	18.3	29.3
" 20	4.6	7.2	1.7	4.5	21.4	34.2
" 21	5.1	8.0	2.0	5.3	23.6	37.8
" 22	5.9	9.2	2.4	6.3	27.2	43.5
" 23	7.7	12.0	3.4	8.9	33.5	53.6
" 24	9.7	15.1	4.6	12.1	35.2	56.3
" 25	12.6	19.7	6.2	16.3	34.5	55.2
" 26	16.3	25.4	7.4	19.5	38.7	61.9
" 27	14.1	22.0	8.0	21.0	29.0	62.4
" 28	12.7	19.8	7.3	19.2	26.0	41.6
" 29	11.9	18.6	6.5	17.1	21.1	33.8
" 30	19.5	30.0	6.1	16.0	19.9	31.8
" 31	14.8	23.1	6.5	17.1	21.1	33.8
April 1	13.1	20.4	6.0	15.8	32.8	52.5
" 2	12.5	19.5	5.5	14.5	30.9	49.4
" 3	11.4	17.8	5.1	13.4	30.3	48.5
" 4	10.5	16.4	4.8	12.6	29.6	89.6*
" 5	22.6	35.3	5.8	15.3	71.1	122.0*
" 6	29.1	45.4	7.7	20.3	106.0	169.6
" 7	21.3	33.2	7.0	18.4	71.9	115.0
" 8	16.6	25.9	5.8	15.3	56.0	89.6
" 9	14.9	23.2	5.0	13.2	39.3	60.1*
" 10	13.1	20.4	4.3	11.3	30.8	50.8*
" 11	11.8	18.4	3.7	9.7	22.0	35.2
" 12	11.0	17.2	3.2	8.4	17.7	28.3
" 13	10.0	15.6	2.8	7.4	17.8	28.5
" 14	-	-	2.4	6.3	17.0	27.2
" 15	-	-	2.2	5.8	18.0	28.0*

[1],[2], Prorated on a drainage area basis to include local inflow to Minesing Swamp plus the catchment area between the WSC gauge and confluence with the Nottawasaga River.
[3], Adjusted based on measured flows at Hwy. 90 bridge near Angus.
* Measured at Hyw. No. 90.

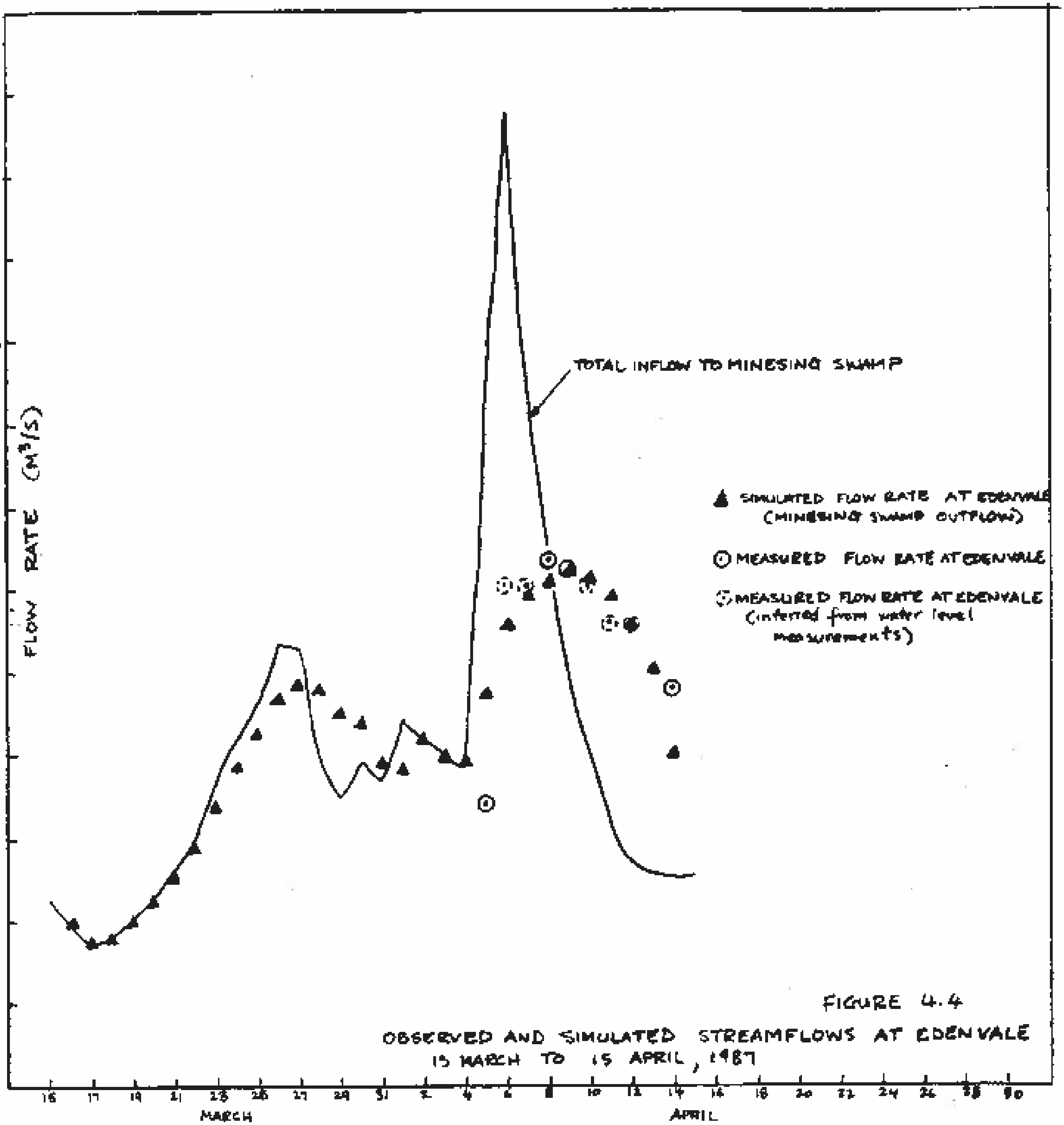


FIGURE 4.4

OBSERVED AND SIMULATED STREAMFLOWS AT EDENVALE
15 MARCH TO 15 APRIL, 1987

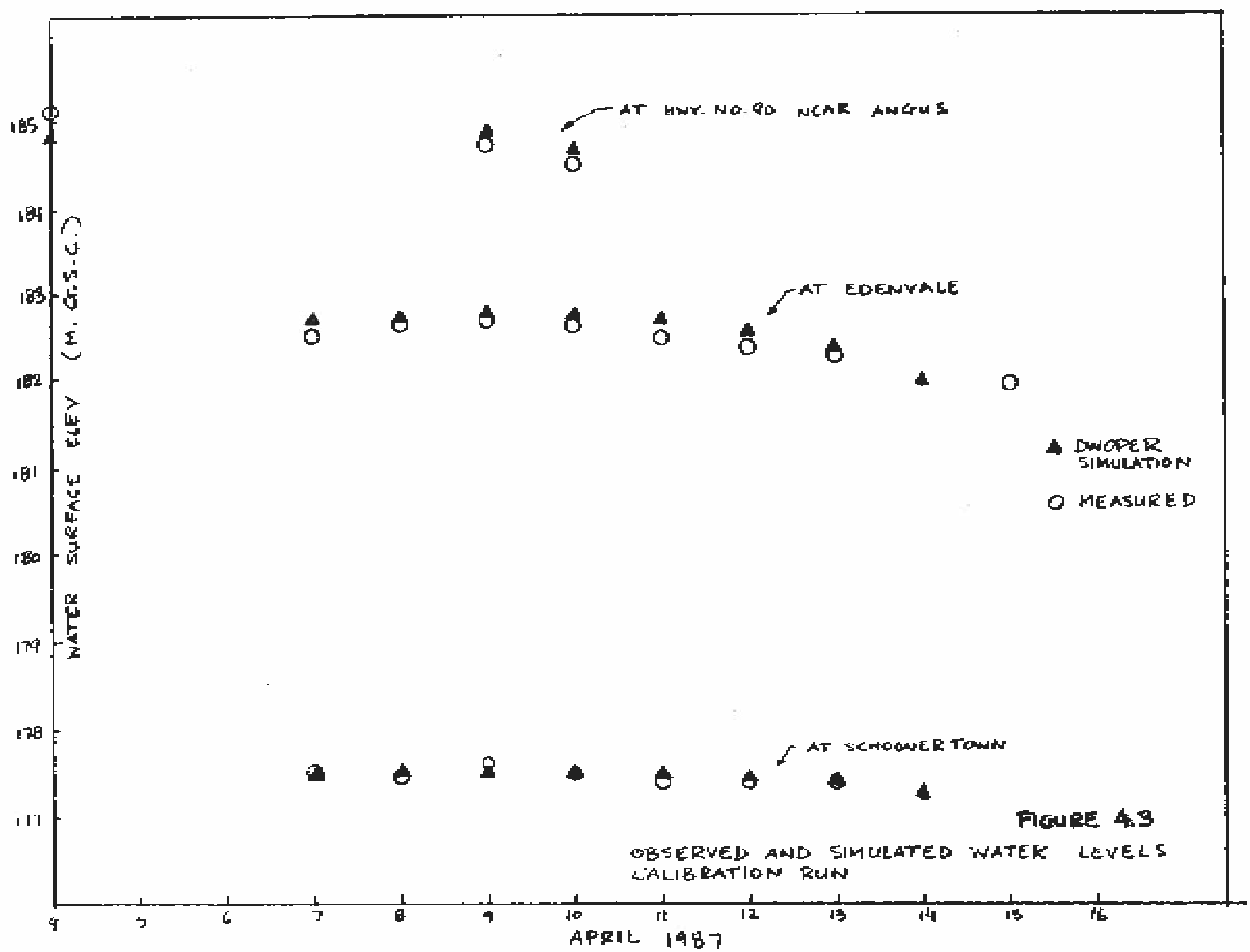


FIGURE 4.3

OBSERVED AND SIMULATED WATER LEVELS CALIBRATION RUN topographic information was the most uncertain. When reasonable agreement between observed and simulated peak flows were obtained (at Edenvale) the channel roughness coefficients were then adjusted to reproduce the water levels observed at Edenvale, Schoonertown and at the Hwy. No. 90 bridge. The reach from the Schoonertown bridge to the river mouth was found to have a Manning's roughness coefficient of 0.020, the reach from Schoonertown to the confluence with the Mad River was found to have a Manning's roughness coefficient of 0.035, and the remainder of the channel was found to have a Manning's roughness coefficient of 0.02 (refer to Table 4.1). The calibration simulations were conducted at time steps of 24 hours.

Observed and simulated discharge hydrographs at Edenvale representing the outflow from the Minesing Swamp are presented in Figure 4.3. The comparison of water levels is shown in Figure 4.4. There is excellent agreement with regard to both discharge and water levels, indicating that the dynamic wave model is capable of reliably simulating the lagging and routing effects of the Lower Nottawasaga River and Minesing Swamp.

4.6 Design Floods - Minesing Swamp and Lower Nottawasaga River

Peak design flows along the Lower Nottawasaga River were determined by specifying the appropriate inflow hydrographs to the calibrated DWOPER model. These inflows consist of the Nottawasaga River where it enters the Minesing Swamp(the upstream boundary condition for the model) and a number of lateral inflows representing tributaries and subcatchments contributing overland runoff directly to the streamcourse. A schematic representation of the DWOPER model is shown in Figure 4.5.

Design flows used in the simulations consist of the 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100 year return period flows and the Regional Flood. The design flow hydrographs comprising the inflows to the Minesing Swamp and the Lower Nottawasaga River were described in Section 3.3.5 and plots of the return period events are presented in Appendix J.

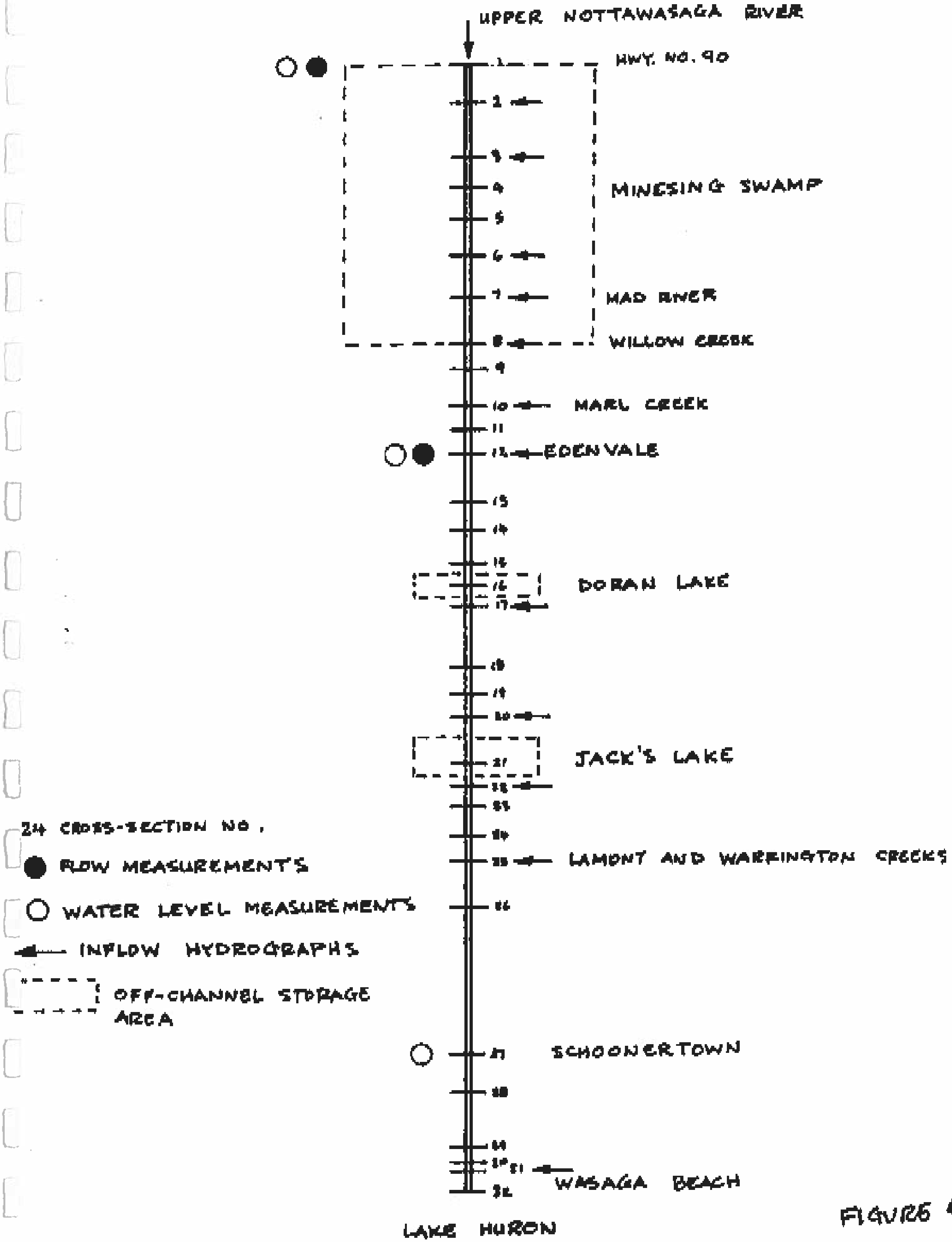


FIGURE 4.5

DWOPER SCHEMATIC

Peak flows corresponding to each of the design events obtained from the DWOPER simulations are presented in Appendix G for the Lower Nottawasaga.

Plots of the 1 in 100 year return period event and Regional Flood hydrographs are given in Figures 4.6 and 4.7 for following locations:

1. Highway No. 26 bridge near Edenvale (representing the outflow from the Minesing Swamp) (Reference No. D12).

2. The bridge just downstream of Doran Lake (Reference No. D17).

3. The bridge just downstream of Jack's Lake (Reference No. D23).

4. The Schoonertown bridge (Reference No. D27).

5. Highway No. 92 bridge at Wasaga Beach near the river mouth (Reference No. D30).

A summary of peak flows and peak stages are presented in Table 4.3 for these locations.

4.7 Discussion and Conclusions

4.7.1 Return Period Flows

The simulations showed that the Minesing Swamp provides significant peak flow attenuation during the design events. Considerable time lagging of the peak discharge was also observed. For example, the time to peak for the 1 in 100 year flood at Edenvale is approximately 130 hours compared to times to peak of 70 hours for the Nottawasaga River inflow at Highway No. 90 and 9 and 17 hours for Willow Creek and Mad River inflow hydrographs, respectively.

Downstream of the confluence with Lamont and Warrington Creeks, the effect of the local and tributary inflows become noticeable with the streamflow hydrographs exhibiting a "double peak" (see Figure 4.6) the first peak being

TABLE 4.3 - SUMMARY OF PEAK FLOW AND PEAK STAGE AT SELECTED LOCATIONS

LOCATION	CROSS SECTION NUMBER	PEAK FLOW AND ASSOCIATED STAGE						PEAK STAGE AND ASSOCIATED FLOW						
		5-YR	10 YR	20 YR	50 YR	100 YR	REGIONAL	5-YR	10 YR	20 YR	50 YR	100 YR	REGIONAL	
Edenvale	D12	161 183.46	180 183.73	201 184.00	224 184.28	247 184.49	243 185.05	159 183.46	178 183.73	199 184.00	223 184.28	244 184.49	237 185.07	flow (m^3/sec) stage (m)
Bridge D/S Doran Lake	D17	160 182.75	180 183.00	200 183.26	224 183.52	247 183.72	256 184.11	158 182.76	178 183.01	199 183.26	223 183.52	243 183.72	254 184.55	flow (m^3/sec) stage (m)
Bridge D/S Jack Lake	D23	158 182.13	178 182.36	199 182.58	223 182.81	242 182.98	340 183.98	158 182.13	178 182.36	199 182.58	223 182.81	242 182.98	330 184.01	flow (m^3/sec) stage (m)
Schooner-Town Bridge	D27	213 178.03	242 178.18	289 178.39	317 178.52	336 178.59	469 179.06	213 178.03	242 178.18	289 178.39	317 178.52	336 178.59	469 179.06	flow (m^3/sec) stage (m)
Wasaga Beach	D30	211 177.38	240 177.46	288 177.59	318 177.69	338 177.75	469 178.08	211 177.38	240 177.46	288 177.59	318 177.69	338 177.75	464 178.08	flow (m^3/sec) stage (m)

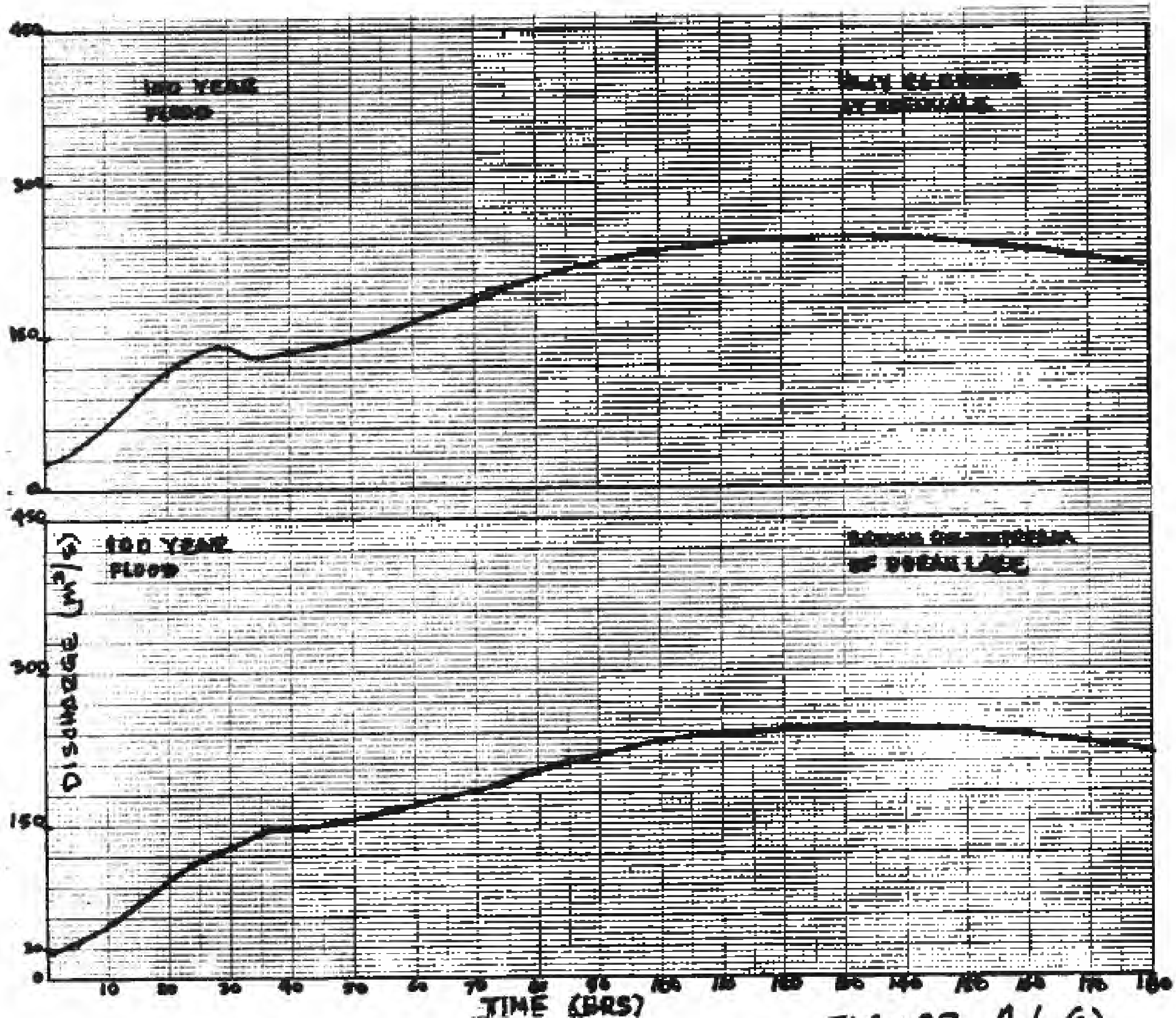


FIGURE 4.6 (a)

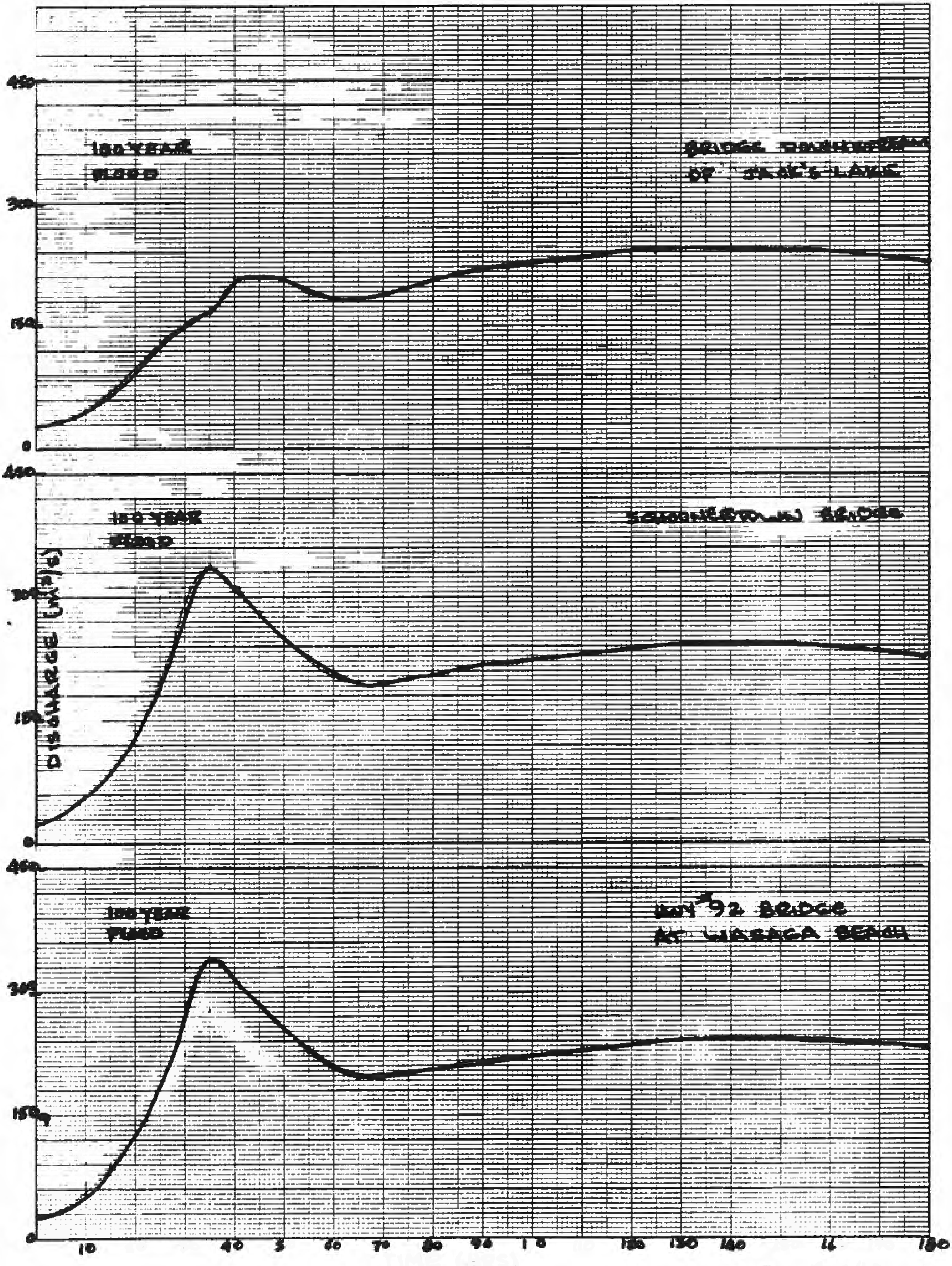

100 YEAR
FLOOD
100 YEAR
FLOOD
100 YEAR
FLOOD
HWY 92 BRIDGE
AT WASAGA BEACH
DISCHARGE (m³/s)
450
300
150
0
10
40
70
80
90
120
130
140
180
TIME (HRS)

FIGURE 4.6(b)

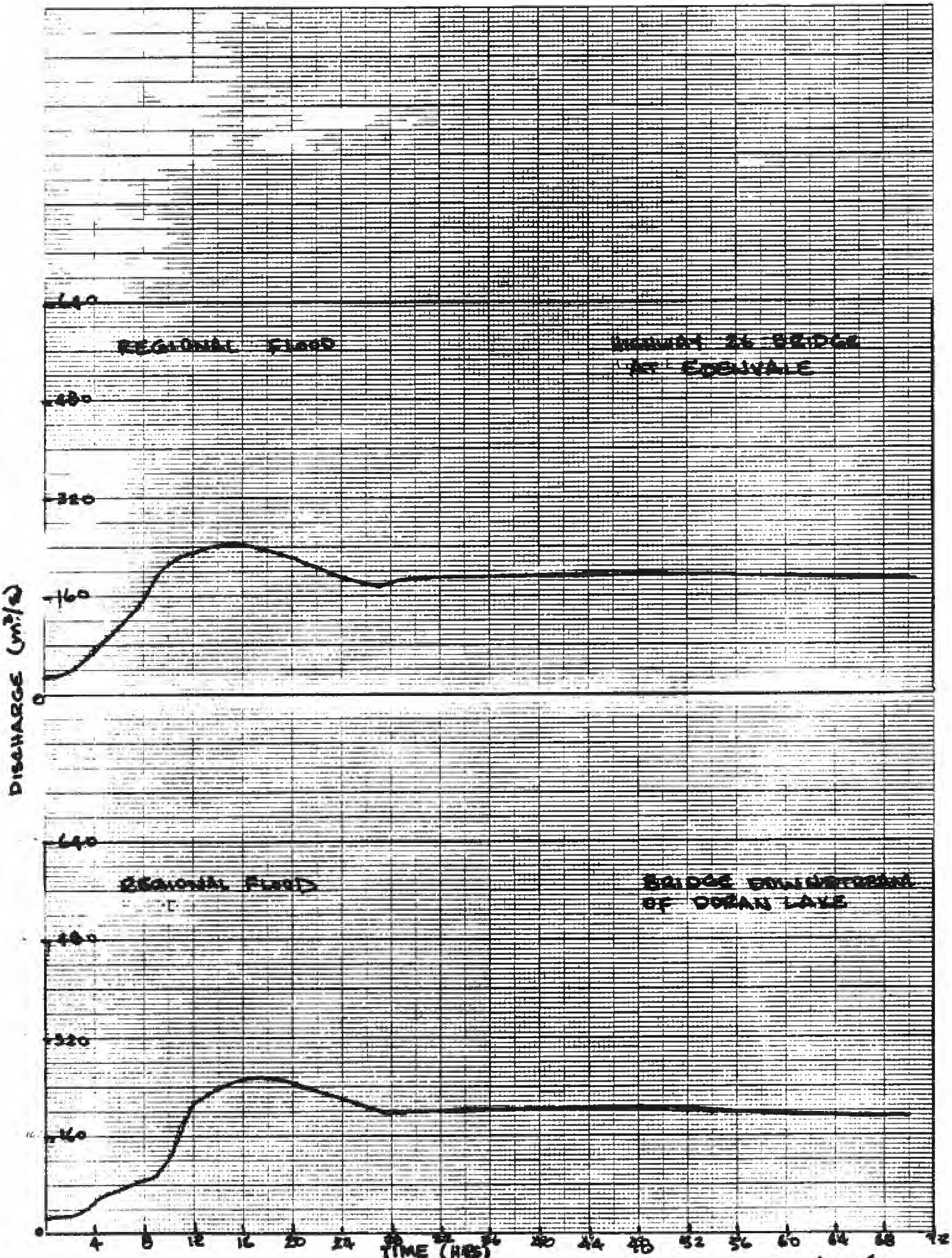
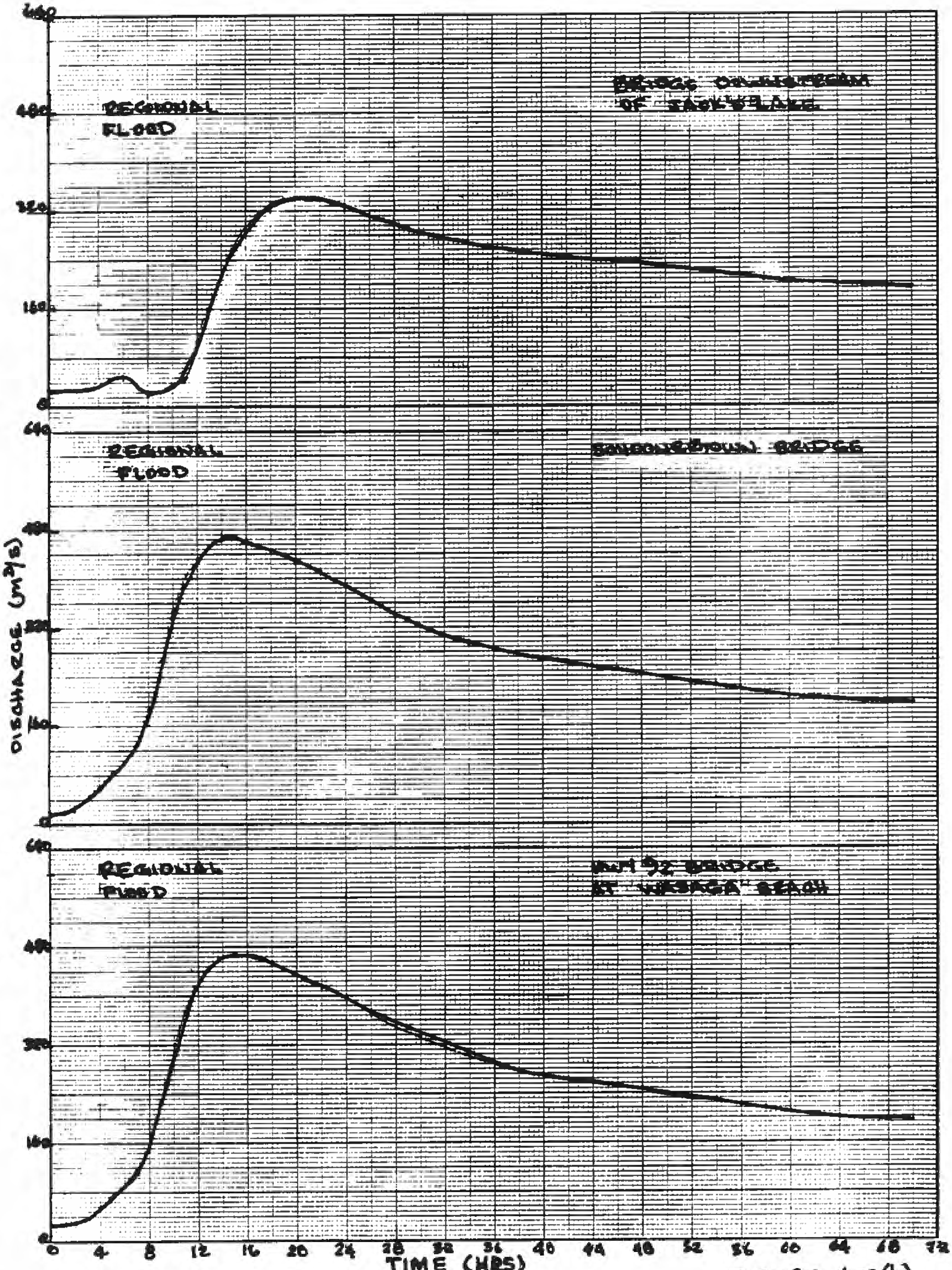

640
REGIONAL FLOOD
HIGHWAY 26 BRIDGE
AT EDENVALE
480
320
160
0
DISCHARGE (m³/s)
640
REGIONAL FLOOD
BRIDGE DOWNSTREAM
OF DORAN LAKE
480
320
160
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
TIME (HRS)

FIGURE 4.7 (a)



REGIONAL FLOOD
REGIONAL FLOOD
REGIONAL FLOOD
DISCHARGE (m³/s)
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72
TIME (HRS)

FIGURE 4.7(b)

due to local and tributary inflow and the second due to outflows from the Minesing Swamp. The highest flood levels, therefore occur at significantly different times along the streamcourse. Along the upper reach, from Edenvale to the confluence with Lamont and Warrington Creeks, the highest peak flow occurs at approximately 130 hours whereas the highest peak flow occurs at approximately 35 hours downstream of Lamont and Warrington Creeks.

Due to the significant difference in times to peak, consideration should be given to establishing flood levels using dynamic rather than steady flow water level simulations. This would require some refinement in the simulation of bridge losses as presently utilized in the model in order to improve its accuracy with regard to establishing flood elevations.

4.7.2 Regional Storm Flows

The results of the Regional Flood Simulation also indicated significant peak flow attenuation due to the Minesing Swamp. However, the times to peak along the Lower Nottawasaga only varies from 15 to 19 hours, and does not exhibit the "double peak" of the hydrographs for the return period floods. Hence, dynamic flow simulation techniques are not required to determine Regional Flood water surface elevations, and the usual steady state backwater analysis can be applied.

A mass balance calculation was carried out for the Regional Flood event to check the accuracy of the DWOPER simulations. For the period of simulations the difference between the total inflows to the model and outflows at the river mouth was found to agree with the change in channel storage within approximately one percent (1%).

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